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Learning adaptive management of Sierra Nevada forests: An integrated assessment

Sierra Nevada Adaptive Management Project

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Glossary of selected terms used in this report

We have defined the following terms used in the report as follows:

Collaborative Adaptive Management (CAM): The participatory process as implemented in SNAMP. CAM is a science-driven, stakeholder-based process for decision-making while dealing with the scientific unknowns inherent in many physical and biological systems. In the SNAMP process, adaptive management incorporates stakeholder participation to improve the amount and breadth of information for decision-making, create meaningful engagement and build mutual understanding, learning, and trust.

Fire Severity: A ranking of fire effects on the landscape from low to high, as described below.

Low severity fires generally stay low to the ground, clearing out underbrush, thin young trees, and forest floor biomass. Most leaves or needles remain on trees, even though some may be brown and the lower branches may be scorched. Low-severity fires are considered beneficial to maintaining a healthy forest by lessening the chance of future high severity wildfires.

Moderate severity fires burn into the forest canopy and consume the needles and leaves from many, but not all, trees. These fires also consume a portion of the forest ground cover. Since moderate severity fires typically leave the biggest and most vigorous trees alive, some forest canopy cover will remain.

High severity fires consume from half to all of the forest canopy and biomass on the forest floor. The ash from high severity fires offers little protection from rainfall and erosion, and under certain conditions, a water-repellent (or hydrophobic) layer is formed in the soil that decreases water infiltration and increases runoff and soil erosion, especially in the first rains following the fire.

"Neutral Third Party" role: University research and extension staff participated in SNAMP as a "third party" with the goal of providing independent or "neutral" information to the adaptive management process. This included scientific information and the facilitation and gathering of stakeholder input.

Strategically Placed Land Area Treatments or "SPLATs": Based on the theoretical demonstration that disconnected fuel treatment patches across a landscape can reduce the overall rate of fire spread and intensity. The Sierra Nevada Forest Plan Amendment calls for the strategic placement of SPLATs across the landscape to interrupt potential wildfire spread, reduce the extent and severity of these fires, and therefore improve the continuity and distribution of old forests across landscapes.

Chapter 1. INTRODUCTION

Overview

The Sierra Nevada Adaptive Management Project (SNAMP) is a joint forest management assessment by the University of California (UC), the University of Minnesota, the University of Wisconsin, state and federal agencies, and the public. SNAMP was created in response to uncertainty about forest fuels management in the Sierra Nevada and the controversy resulting from the United States Forest Service's 2004 Sierra Nevada Framework (USFS 2004) that established the current legal boundaries for management prescriptions in the Sierra Nevada national forests. Broadly, SNAMP was formed to learn how to apply adaptive management as required in the 2004 Framework, with an emphasis on engaging the public in a meaningful way. More specifically, SNAMP was designed to assess the efficacy of forest fuels management on potential fire behavior and the impacts of that management on three essential natural resources: forest ecosystem health, wildlife, and water, while incorporating participation by all interested stakeholders, including the public.

A key objective was to evaluate the impact of Strategically Placed Land Area Treatments (SPLATs; see Glossary), a forest fuel reduction treatment, with respect to four resource values:

- fire and forest ecosystem health,
- wildlife, focusing on the Pacific fisher (*Pekania* [*Martes*] *pennanti*) and the California spotted owl (*Strix occidentalis occidentalis*),
- water quantity and quality, and
- public participation.

Each response variable had an associated science team, and these teams were supported by a spatial analysis team. As a group, these teams were called the "UC Science Team" and comprised scientists from UC Berkeley, UC Merced, University of California Cooperative Extension, the University of Minnesota, and the University of Wisconsin. The UC Science Team functioned as an independent "neutral third party" (see Glossary) and implemented assessment methodologies that focused on specific response variables to:

1. make predictions,

2. analyze data and results,
3. provide feedback to the MOU Partner agencies, and
4. facilitate public participation and shared learning.

Sierra Nevada Adaptive Management Project's origins

The following chronology outlines a brief history of the events that led to creation of SNAMP:

2001 - The Sierra Nevada Forest Plan Amendment is released to supplement the primary, legal land and resource management plans for national forests in the Sierra Nevada and Modoc Plateau. Covered are the Humboldt-Toiyabe, Modoc, Lassen, Plumas, Tahoe, Eldorado, Stanislaus, Sierra, Inyo, and Sequoia National Forests and the Lake Tahoe Basin Management Unit. This document is known as the 2001 Sierra Nevada Framework and had its origins in work done to protect the California spotted owl through an ecologically based approach to assessing and managing landscapes on these national forests (USFS 2001).

2004 – The 2004 Sierra Nevada Forest Plan Amendment replaces the 2001 Framework in its entirety. This document is known as the 2004 Sierra Nevada Framework. It "adopts an integrated strategy for vegetation management that is aggressive enough to reduce the risk of wildfire to communities in the urban-wildland interface while modifying fire behavior over the broader landscape" (USFS 2004). This emphasis leads to significant controversies, including direct conflict among the State of California Resources Agency, the United States Fish and Wildlife Service, and the Forest Service. The 2004 Framework requires an adaptive management process but does not define this process.

2005 - The California Resources Agency, the Fish and Wildlife Service, the Forest Service Pacific Southwest Region, and the Forest Service Pacific Southwest Research Station sign a Memorandum of Understanding (MOU). Stipulated in this MOU is a request for the assistance of the University of California to serve as a "neutral third party" of experts to help develop an adaptive management plan. The UC Science Team and the MOU Partner agencies initiate the planning process to develop adaptive management.

2006 - The SNAMP workplan is drafted through an open, public process including shared academic peer review and public comments. Potential study areas are evaluated.

2007 – Study areas are selected. Implementation of the UC Science Team workplan begins with baseline data collection.

Goals of MOU Partner agencies

The Memorandum of Understanding entered into by the Forest Service Pacific Southwest Region, the Forest Service Pacific Southwest Research Station, the Fish and Wildlife Service, and the California Resources Agency in February 2005, laid out goals that the MOU Partner agencies wished to achieve (for MOU, see Appendix G). Their overarching goal was to "develop and apply a refined and active multiparty adaptive management and monitoring system consistent with the Sierra Nevada Forest Plan Amendment" and to achieve this goal through cooperation between the agencies and other stakeholders. The Partner agencies also stated individual and consensus goals.

The Forest Service stated its goals in the MOU as follows:

> The Forest Service is interested in building stakeholder understanding and trust in the implementation of the [2004 Framework]. The Forest Service and State recognize the value of using the University of California ("University") as a neutral third party with expertise in projects of this sort to assist in developing a process with the Forest Service and interested stakeholders to refine an active adaptive management and monitoring system. This refined adaptive management and monitoring process will inform and contribute to the improvement in implementation of land management practices, as prescribed, that will restore and protect valued natural resources and reduce the threats to them and communities at risk.

The Fish and Wildlife Service stated its goals in the MOU as follows:

> The Fish and Wildlife Service is interested in participating in the adaptive management process at both a technical and management level, in order to ensure that post-treatment and post-fire conditions offer multi-species habitat enhancement and the conservation of Federal threatened, endangered and candidate species. This process would include the development and review of individual project implementation monitoring and involve a feedback mechanism to ensure that appropriate changes are implemented when desired conditions and conservation goals are not being met at an individual project and landscape level.

The California Resources Agency stated its goals in the MOU as follows:

> The State is interested in increasing progress across the Sierra Nevada to reduce the risk of catastrophic wildfire to the communities, and associated destruction of wildlife habitat, water quality and adverse impacts on air quality in the region. The State is also interested in ensuring that the technical and management activities of the Forest Service, currently managing 11.5 million acres [~4.65 million hectares] in the Sierra Nevada on behalf of the public, are effectively achieving broadly agreed upon goals weighing wildlife habitat needs with reducing expected wildfire losses, and improving overall forest health and structure and protecting municipal water supplies on a watershed basis. This objective is best achieved by full engagement by the Forest Service in a collaborative adaptive management and monitoring process with interested federal, state, local stakeholders, government agencies, Native American Tribal representatives and the scientific community as full partners directed previously by Congress and consistent with the [Western Governors Association] 10-Year Comprehensive Strategy and Implementation Plan. This adaptive management approach can improve forest management practices on lands owned and managed by other entities, both public and private.

Finally, the MOU Partner agencies stated their consensus goals in the MOU as follows:

> There is mutual interest in understanding how various projects will look and function at the stand level as well as across larger landscapes. All Parties share the same general objective of balancing wildlife habitat needs and water quality considerations with reducing expected wildfire losses, and improving overall forest health and structure. A collaboratively developed and refined adaptive management strategy of annual monitoring, evaluation and accountability should inform management and interested stakeholders whether direction is being implemented as described, whether management practices are resulting in expected outcomes, and whether desired conditions are being met over appropriate timeframes. The adaptive management strategy should also offer a shared basis for designing and tracking changes or improvements at the stand and/or larger landscape levels. The refined [Sierra Nevada Forest Plan Amendment] adaptive management and monitoring process will be coordinated with other monitoring processes under the Healthy Forests Initiative, the Wildland Fire Leadership Council, the December 23, 2004 [National Forest Management Act] planning regulations, and other ongoing [Sierra Nevada Forest Plan Amendment] studies and research.

As part of SNAMP final products, the MOU Partner agencies will prepare a response to this final report that evaluates the UC Science Team assessment, the SNAMP collaborative process, and the extent to which SNAMP achieved their goals.

Sierra Nevada Adaptive Management Project framework and timeline

The overarching conceptual framework of SNAMP was that of a collaborative adaptive management process (see Glossary). Because the effects of any management activity, such as forest fuel treatments, are likely to be confounded by concurrent ecological and environmental changes, this confounding must be limited by the experimental design. The premise that collaborative adaptive management involves deliberate experimentation rather than a passive trial-and-error approach provided the first pillar of the SNAMP conceptual foundation. The second conceptual pillar was that collaborative adaptive management must be a participatory process that engages scientists, stakeholders, and managers in a long-term relationship grounded in shared learning about the ecosystem. The UC Science Team proposed that grounding collaborative processes in a common body of knowledge about the areas to be managed, and the unfolding of the assessment process, would support more effective science and inform decision-making and relationships among stakeholders and managers. The SNAMP collaborative adaptive management framework was predicated on the belief that this approach can provide for a shared understanding of the dynamic behavior of ecosystems and of the dramatic changes, both long- and short-term, that ecosystems have undergone.

SNAMP was born from a desire to try a different approach, one that diverged from the legacy of conflict, mistrust, and legal challenges. The UC Science Team was created as a neutral third party charged with developing information that could inform adaptive management in Sierra Nevada forests. To increase the likelihood that the SNAMP data and analyses would be useful to all participants, the UC Science Team had to establish from the beginning that all parties could trust SNAMP science and could also trust the UC Science Team's facilitation experts to act as neutral facilitators in the collaborative process. The UC Science Team decided early on that it had to make its activities and decisions as transparent as possible to everyone, agencies and public alike. This meant that the UC Science Team workplans, budgets, underlying assumptions and working hypotheses, methodologies, initial findings, data analyses, interpretations, and scientific disagreements all had to be detailed and discussed in public forums. SNAMP data were made publicly available to the extent possible (for the SNAMP Data Sharing Agreement, see snamp.cnr.berkeley.edu). As a neutral third party, the UC Science Team was also committed to objective communication to the best of its ability. The UC Science Team published a statement detailing its commitment to neutrality and outlining how it would maintain neutrality in SNAMP research (for the UC Science Team's Statement of Neutrality, see: snamp.cnr.berkeley.edu).

SNAMP was not structured to have the financial resources to statistically sample the variation in firesheds throughout the Sierra Nevada mixed conifer forest. The feasible alternative was to pick study areas that would represent the primary biogeographic gradient – latitude – by selecting one northern and one southern Sierra study area. SNAMP considered study areas that were broadly representative of northern and southern Sierra Nevada mixed conifer forest; areas that were outliers in any major characteristic were rejected. In 2007, the two SNAMP study areas were selected:

1) Last Chance, the northern study area, named after the Forest Service's Last Chance Project, was in the American River Ranger District of the Tahoe National Forest. The expanded California spotted owl study area included portions of the Eldorado National Forest. The northern study area contained Sierra Nevada mixed conifer forest with residual old-growth trees.

2) Sugar Pine, the southern study area, named after the Forest Service's Sugar Pine Project, was in the Bass Lake Ranger District of the Sierra National Forest. The forest was mixed conifer. The southern study area provided habitat for the Pacific fisher, and, as with the spotted owl team study area, the fisher study area encompassed more than just the Sugar Pine Project site.

The Forest Service's 2004 Sierra Nevada Forest Plan Amendment (USFS 2004) emphasized the need to adopt "an approach for modifying wildland fire behavior across broad landscapes through the strategic placement of area treatments." In the Supplemental Environmental Impact Statement (USFS 2004), these "broader landscapes" are referred to as firesheds. Consequently, SNAMP undertook to use the fireshed as the spatial scale for reporting SNAMP results and making management recommendations. Firesheds share the scalability of watersheds: large firesheds can be subdivided into smaller "catchment" sub-firesheds, which at the SNAMP study areas were between 3,500-10,000 acres (1,400-4,000 hectares). Each study area comprised a pair of firesheds, one in which a SPLAT treatment was implemented by the

Forest Service, the other serving as an untreated control. SNAMP analyses also employed a uniform time scale: immediate effects (0-5 years post-SPLAT treatment) and long-term effects (up to 30 years post-implementation, the estimated lifespan of a SPLAT treatment). Impacts were assessed both directly with seven years of field data and also with modelling, especially for longer term effects.

The original SNAMP workplan (see Appendix H) envisioned a rigorous "Before-After Control-Impact" (BACI) experimental design for the evaluated resources (see Chapter 3 for details). However, there were significant delays in implementing the SPLATs and a truncation of the original SNAMP timeline due to budget limitations, which diminished the value of the BACI design by weighting pre-treatment data over post-treatment data. The Fire and Forest Ecosystem Health Team and the Water Team were able to conduct modified BACI assessments. The wildlife teams could not employ a BACI experimental design, and instead, developed other study designs, including the use of datasets from related studies, to address the project's primary question of SPLAT impacts on resources (Note: the Pacific fisher BACI assessment will be completed at a later date by the Forest Service Pacific Southwest Research Station). In addition to addressing the primary question, the UC Science Team developed multiple new methods and analytic techniques and produced extensive datasets relative to each topical area, which are detailed in this final report and in the scientific journal articles listed in Appendix J.

An essential component of SNAMP was that the final product would include an integrated multi-resource assessment; that is, all the resources would be evaluated together as a unit. This integrated assessment provides a comparative framework that is the same for all the resources evaluated in the SNAMP project, allowing managers and other end-users to compare the impacts of SPLATs across resources.

The UC Science Team began pre-treatment data collection at both study areas in summer 2007, including pre-treatment lidar data flights flown in 2007 and 2008. During this period, the proposed Forest Service SPLAT treatments for the two sites proceeded through standard National Environmental Policy Act processes. Pre-treatment data collection continued for more years than had been initially anticipated because of delays in SPLAT implementation at both sites. The bulk of SPLAT implementation at the two sites took place in 2011 and 2012; the Forest Service was solely responsible for designing and implementing the SPLATs. Following SPLAT implementation, the UC Science Team collected 1-2 years' worth of post-treatment data in 2012 and 2013, including lidar data. In 2014-2015, the UC Science Team analyzed data and modelled outcomes, integrated team results, wrote the final report, and presented our findings and management recommendations to the MOU Partner agencies and interested stakeholders. The Participation Team will provide final outreach and feedback opportunities in 2015. See Figure 1-1 for the SNAMP timeline.

Content of the following chapters

Chapter 2 provides detailed information on the two SNAMP study areas, including a description of the study area selection process. **Chapter 3** compiles summaries from each individual team chapter intended to provide the background for the integrated assessment and management recommendations, including brief descriptions of each team's methodology and of those results most relevant to integration. **Chapter 4** provides the integrated assessment of the impacts of SPLATs on the SNAMP focal resources. **Chapter 5** comprises our integrated management recommendations. **Chapter 6** compiles the executive summaries from all the individual team chapters, including resource-specific findings and management recommendations.

The full individual team chapters are to be found as appendices to this report. The appendices also include a list of SNAMP publications.

References

USDA Forest Service (USFS). 2001. Sierra Nevada Forest Plan Amendment Environmental Impact Statement - Record of Decision.

USDA Forest Service (USFS). 2004. Sierra Nevada forest plan amendment: final supplemental environmental impact statement – Record of decision. R5-MB-046. [Vallejo, CA]: USFS, Pacific Southwest Region.

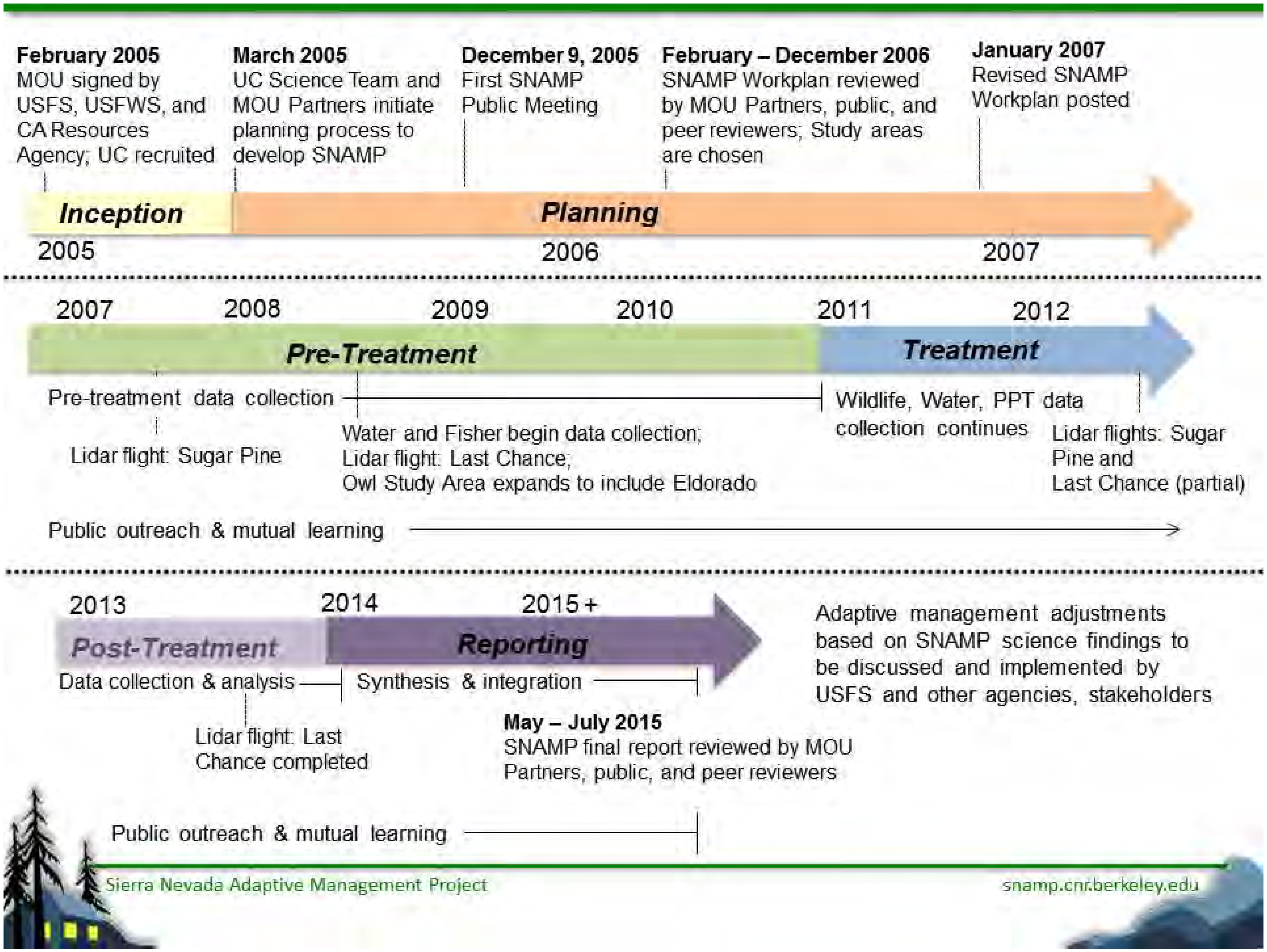

Figure 1-1: Sierra Nevada Adaptive Management Project (SNAMP) timeline, 2005-2015. MOU-Memorandum of Understanding; USFS-United States Forest Service; USFWS-United States Fish and Wildlife Service; UC-University of California; PPT-UC Science Team Participation Team.

Chapter 2. STUDY AREA SELECTION AND DESCRIPTION

Study area selection

To develop the foundation upon which an adaptive management model could be built by the Forest Service, the UC Science Team designed a monitoring approach that 1) used controls to isolate the impact of treatments (SPLATs); 2) evaluated effects on attributes of concern (e.g., fire, water, wildlife); and 3) provided a level of inference from the results sufficient to make decisions. The scale of the effort as described in the 2004 Sierra Nevada Forest Plan Amendment (USFS 2004) needed to consider "broad landscapes" called firesheds. In concept, firesheds are analogous to watersheds but are topographic units delineated based on the behavior of a problem fire – a fire that has the greatest negative potential impact given local topography, weather, and fire history. The size of firesheds can vary, but they need to be sufficiently large to assess the effectiveness of fuel treatments (Bahro et al. 2007).

There were approximately 10,577 mi^2 (4,084 km^2) of potential study area (westside mixed conifer forests) in the northern Sierra Nevada (Tahoe and El Dorado National Forests) available for sampling. In the Sierra and Sequoia National Forests, the combined mixed conifer forest type available for sampling covered 6,446 mi^2 (2,489 km^2). Among the many potential locations considered for the northern region, the Last Chance study area met the most selection criteria (8 of 11 criteria, Table 2-1); the Sugar Pine study area was best among the southern region (9 of 11 criteria, Table 2-1). Importantly, both areas fell within the range of structural and topographic variation present in the region and were therefore not outliers (Table 2-2). The two areas also represented a social-economic gradient in federal lands management. The northern study area, "Last Chance", near Foresthill, had a history of extractive use by the Forest Service. The southern study area, "Sugar Pine", near Oakhurst, abutted Yosemite National Park and had a somewhat contrasting federal management history (Figure 2-1).

Each study area comprised a pair of firesheds: one fireshed in which a SPLAT treatment project would be implemented by the Forest Service, the other fireshed receiving no treatment and thus providing an experimental control (Figures 2-2 and 2-3). Sugar Pine had a classic paired-fireshed approach: one fireshed was treated and the immediately adjacent fireshed served as a control. At Last Chance, the topography limited the availability of a classic control. The best control in terms of matching vegetation, soils, terrain, area, and management history was to use the two adjacent watersheds (one north and one south of the treatment fireshed) to represent the "control" fireshed. The two watersheds were not spatially connected, but they did meet the criterion for fireshed designation in that we expected similar wildfire behavior in the two watersheds.

The northern study area included the Last Chance Integrated Vegetation Management Project area in the American River Ranger District of the Tahoe National Forest in addition to portions of the Eldorado National Forest, in Placer and El Dorado counties (Figure 2-2; the Eldorado Study Area is part of the expanded Owl Study Area; see pages 28-29 and Appendix C for complete details). Both the Tahoe and the Eldorado National Forests, located in the north-central Sierra Nevada, supported diverse forest communities and a range of wildlife including the California spotted owl.

The southern study area included the Sugar Pine Adaptive Management Project area and was located in the Bass Lake Ranger District of the Sierra National Forest on the western slope of the south-central Sierra Nevada, almost completely in Madera County (Figure 2-3). The southern site provided a study area for the Pacific fisher, which, like the Owl Study Area, encompassed more than just the Sugar Pine site (see page 33 and Appendix D for complete details). The forests at the southern study area were mixed conifer forests with elements of old-growth forest structure.

Table 2-1: Criteria for study area selection and evaluation. Note criteria were unranked.

Criteria	Last Chance (northern)	Sugar Pine (southern)
Old forest habitat present for species at risk	Yes	Yes
Potential for recruiting large tree structure	Yes	Yes
Proximity to wildland urban interface	No	Yes
Adjacent to significant amounts of private land eligible for state grants	Yes	No
Large enough to support fireshed scale assessment	Yes	Yes
Representative of typical Sierran landscape (i.e., not an outlier)	Yes (see Table 2-2)	Yes (see Table 2-2)
Presence of perennial stream	Yes	Yes
Sufficient organizational capacity of National Forest to implement treatments	Yes	Yes
Presence of existing data/studies/infrastructure	Yes: Eldorado California spotted owl study	Yes: Kings River Study
History of land and resource management agencies involving community interest in forest management	Not determined	Not determined
Potential to influence desired forest conditions and monitor changes in those conditions	Yes	Yes
Costs of development and implementation of treatments	More remote; potentially more expensive	Yes; extensive infrastructure available

Table 2-2: Outlier analysis of chosen study areas relative to candidate locations in the northern Sierra Nevada (Tahoe and Eldorado National Forests) and the southern Sierra Nevada (Sierra and Sequoia National Forests). Results based on GIS data layers were provided by the USFS. For the quantitative variables (elevation, slope, and distance from urban areas), means are reported with standard deviations in parentheses. For categorical variables, the top two ranked categories are reported followed by their fractional importance in parentheses. Majority categories are reported for the candidate areas.

Region / **Study Area**	**Elevation** (ft)	**Slope** (°)	**Distance from urban area** (mi)	**Canopy cover class** (%) 1st Rank	2nd Rank	**Tree size distribution** (size class) 1st Rank	2nd Rank
Tahoe and Eldorado National Forests	4,956 (1,289)	5.5 (2.5)	13.3 (5.3)	>59 (0.40)	40-59 (0.30)	Small (0.44)	Medium (0.36)
Last Chance	5,241 (1,315)	6.7 (5.2)	16.8 (1.8)	Majority: 40-59		Majority: Medium	
Sierra and Sequoia National Forests	6,583 (1,020)	8.1 (3.3)	19.6 (8.0)	>59 (0.42)	40-59 (0.24)	Small (0.70)	Medium (0.17)
Sugar Pine	4,425 (820)	7.2 (2.9)	3.7 (2.0)	Majority: 40-59		Majority: Small	

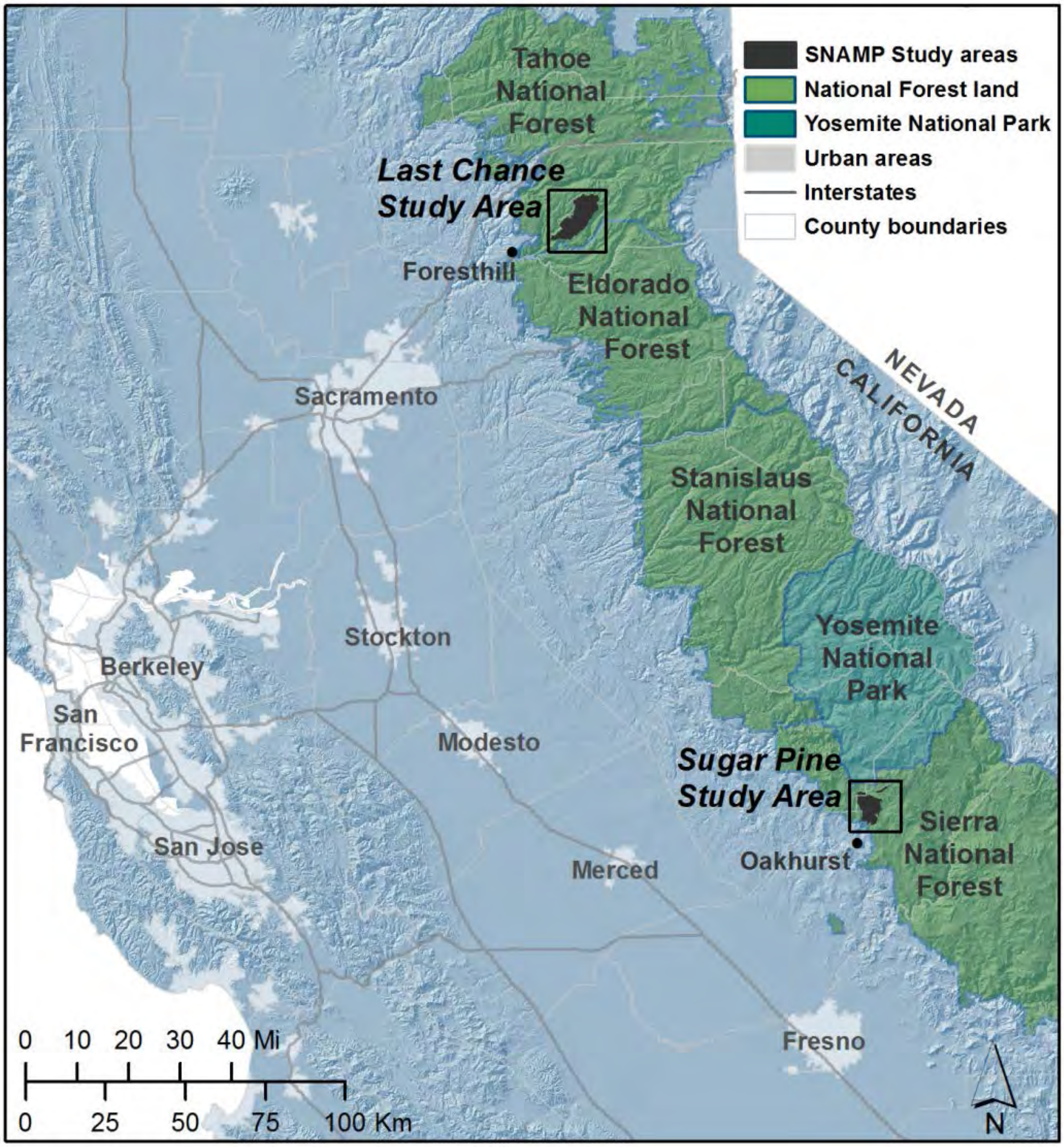

Figure 2-1: Sierra Nevada Adaptive Management Project study areas in the northern (Last Chance) and southern (Sugar Pine) Sierra Nevada, California.

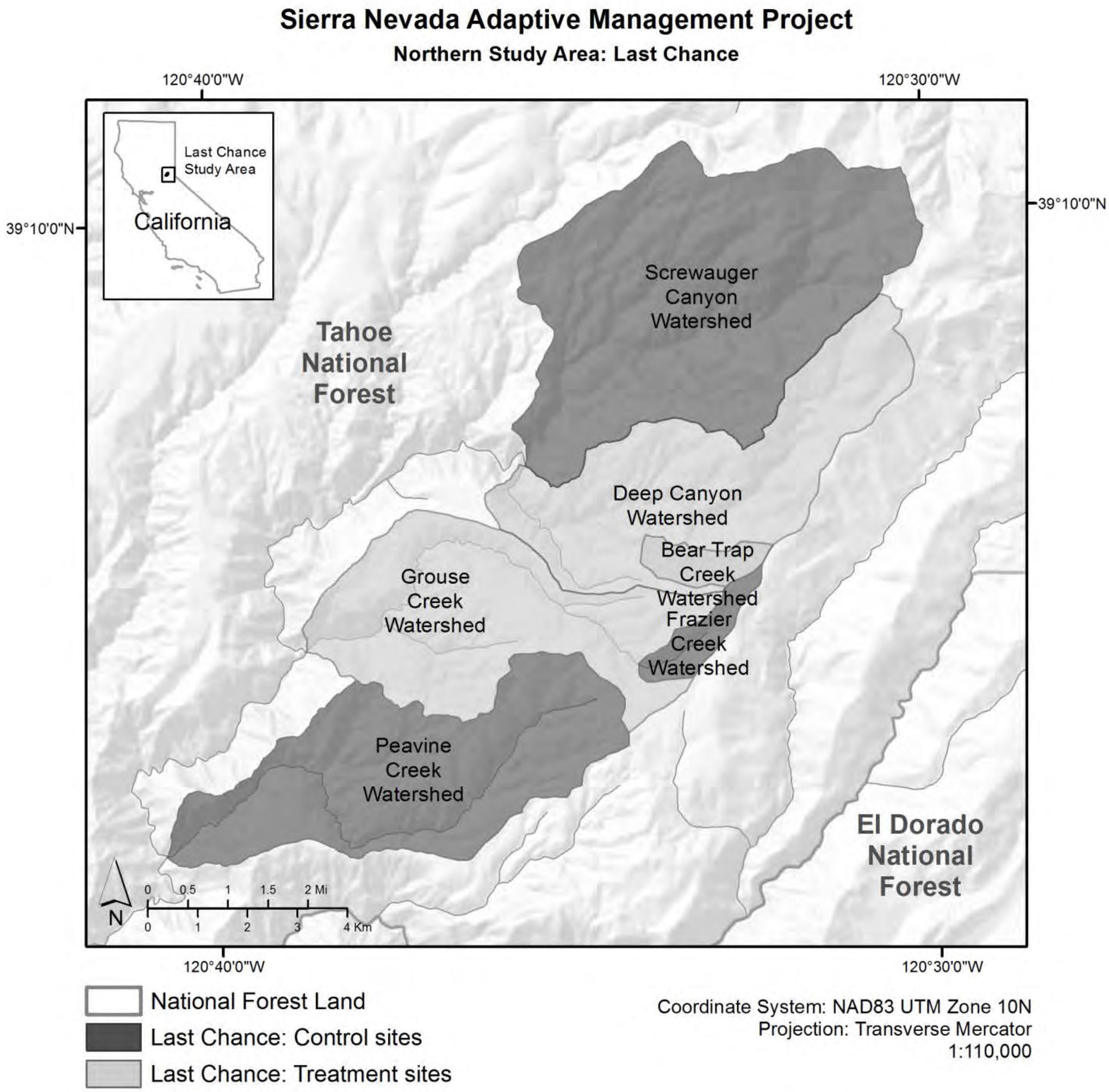

Figure 2-2: Control (dark grey) and treatment (light grey) sites at Last Chance, the Sierra Nevada Adaptive Management Project's northern study area in the Sierra Nevada, California. Bear Trap Creek and Frazier Creek were the headwater catchments evaluated by the Water Team.

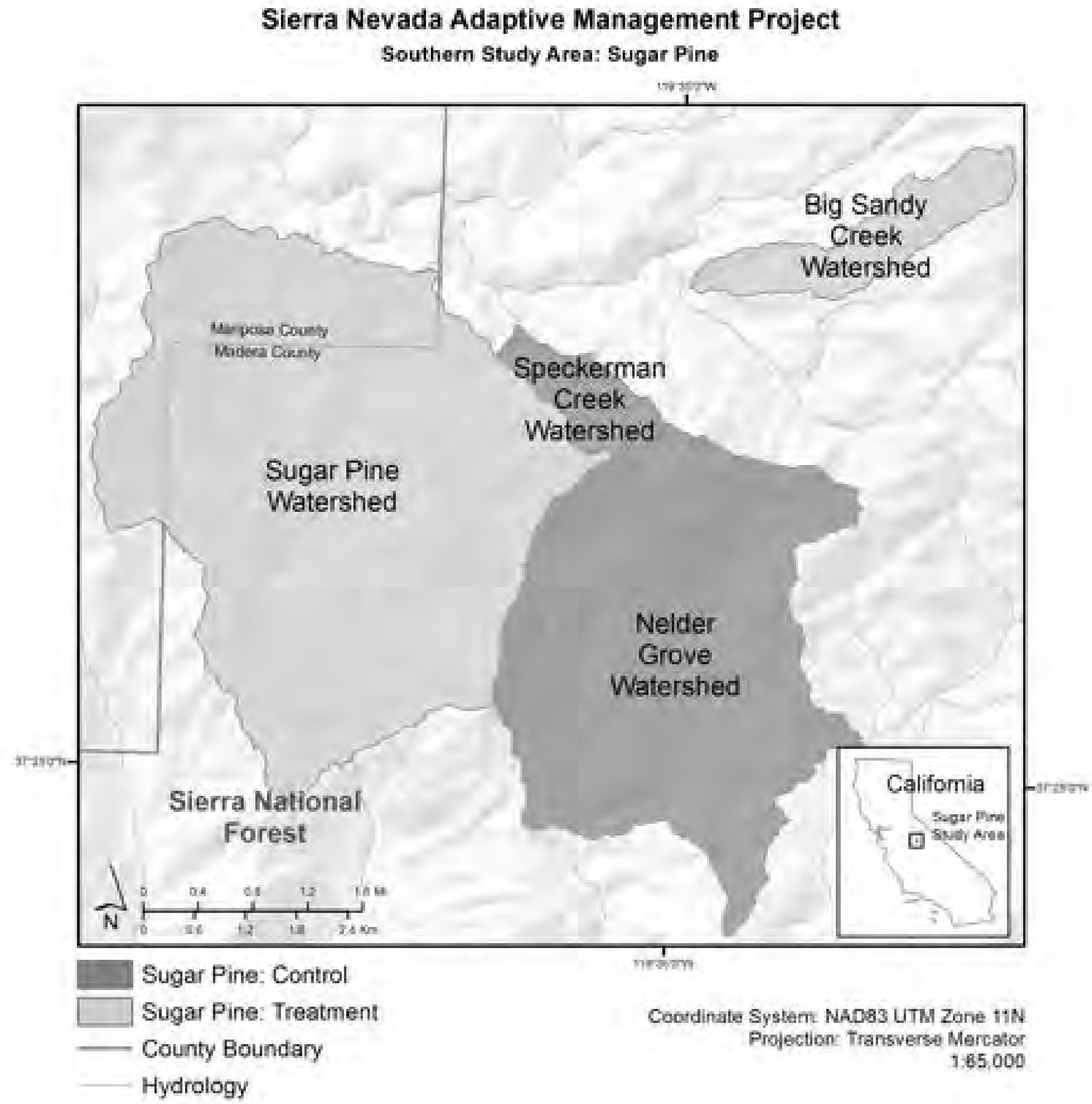

Figure 2-3: Control (dark grey) and treatment (light grey) sites at Sugar Pine, the Sierra Nevada Adaptive Management Project's southern study area in the Sierra Nevada, California. Big Sandy Creek and Speckerman Creek were the headwater catchments evaluated by the Water Team.

Study areas

Spatial, soils, and climatic characteristics

Last Chance, the northern study area, was defined by the boundaries of four adjoining watersheds (Figure 2-2). The treatment fireshed consisted of the two central watersheds: Deep Canyon and Grouse Creek. We used the two immediately adjacent watersheds as the control (Screwauger Canyon and Peavine Creek). The study area encompassed an area of 38.4 mi^2 (99.5 km^2), with elevation ranging from 2,625 ft (800 m) in the southwest to almost 7,218 ft (2,200 m) in the northeast portion of the study area (Table 2-3). Soils were moderately deep, well-drained Inceptisols with a gravely loam texture. The Crozier and Hurlbut soil series that were most common at Last Chance were derived from andesite and metasedimentary parent material (NRCS Web Soil Survey).

Table 2-3: Estimated perimeter and area of the Sierra Nevada Adaptive Management Project's Last Chance study area and its associated Owl Team study areas, Sierra Nevada, California.

Study area name	Treatment type	Perimeter (mi)	Area (mi^2)	Acres	Hectares
Screwauger Canyon watershed	Control	17.1	13.3	8,537	3,455
Deep Canyon watershed	Treatment	18.3	8.3	5,343	2,162
Grouse Creek watershed	Treatment	16.1	8.2	5,264	2,130
Peavine Creek watershed	Control	15.8	8.5	5,445	2,203
TOTAL LAST CHANCE CORE AREA		**67.3**	**38.4**	**24,589**	**9,951**
Hydrology study area (within Last Chance study area)					
Bear Trap Creek watershed	Treatment	4.1	0.7	426	172
Frazier Creek watershed	Control	4.6	0.7	457	185
Owl Team-related expanded study areas					
SNAMP Owl		39.2	95.6	61,183	24,760
Eldorado Study Area		69.6	220	140,800	56,980

Sugar Pine, the southern study area, was located in the southern end of the central Sierra Nevada, approximately 124 mi (200 km) south of Last Chance (Figure 2-3). Encompassing approximately 12.9 mi^2 (33.6 km^2), elevations at Sugar Pine ranged from 3,936 ft (1,200 m) in the southwest to 7,216 ft (2,200 m) in the northeast portion of the study area at Speckerman Mountain (Table 2-4). The deep, well-drained soils at Sugar Pine developed from weathered granodiorite. Holland family soils (Inceptisols) with a sandy loam texture were most common (NRCS Web Soil Survey).

Table 2-4: Estimated perimeter and area of the Sierra Nevada Adaptive Management Project's Sugar Pine study area and its associated Fisher Team study area, Sierra Nevada, California.

Study area name	Treatment type	Perimeter (mi)	Area (mi^2)	Acres	Hectares
Sugar Pine	Treatment	13.1	7.4	4,719	1,910
Nelder Grove	Control	14.5	5.5	3,549	1,436
TOTAL		27.6	12.9	8,268	3,346
Hydrology study area (Big Sandy is within the Forest Service's Fish Camp Project)					
Big Sandy	Treatment	6.1	0.9	592	240
Speckerman	Control	4.3	0.9	351	142
TOTAL		10.4	1.8	943	382
TOTAL SUGAR PINE CORE AREA		**38.0**	**14.8**	**9,211**	**3,727**
Fisher Team-related Forest Service projects adjacent to Sugar Pine					
Fish Camp Project		17.4	8.5	5,441	2,202
Cedar Valley Project		14.2	7.0	4,464	1,807

Climatic conditions during SNAMP's 7 years of data collection (2007-2013) were highly variable, with annual precipitation ranging 49.6 – 98.4 inches (125.5 – 250.0 centimeters) at Last Chance, and 23.2 – 72.4 inches (58.9 – 183.9 centimeters) at Sugar Pine (Figure 2-4). Annual values and years in this section refer to the water year, October to September (e.g., 2009 is the period October 2008 – September 2009). Precipitation during 2009-2010 was comparable to the long-term mean for most of the Sierra Nevada but substantially higher than average in 2011. Precipitation rates were below average for the remainder of the study period, resulting in drier than normal conditions in four of the seven years. Timing of precipitation during dry periods was variable, with some years having early season storms followed by dry winter months (2013), and some years exhibiting dry autumn periods followed by late winter storms (2012, 2007 in Sugar Pine). The Last Chance area received higher annual precipitation than Sugar Pine, consistent with the general trend of increased precipitation with higher latitudes in the Sierra Nevada for areas of similar elevation. Precipitation data for Last Chance and Sugar Pine were obtained from the Blue Canyon and Poison Ridge meteorological stations respectively, both operated by the U.S. Bureau of Reclamation.

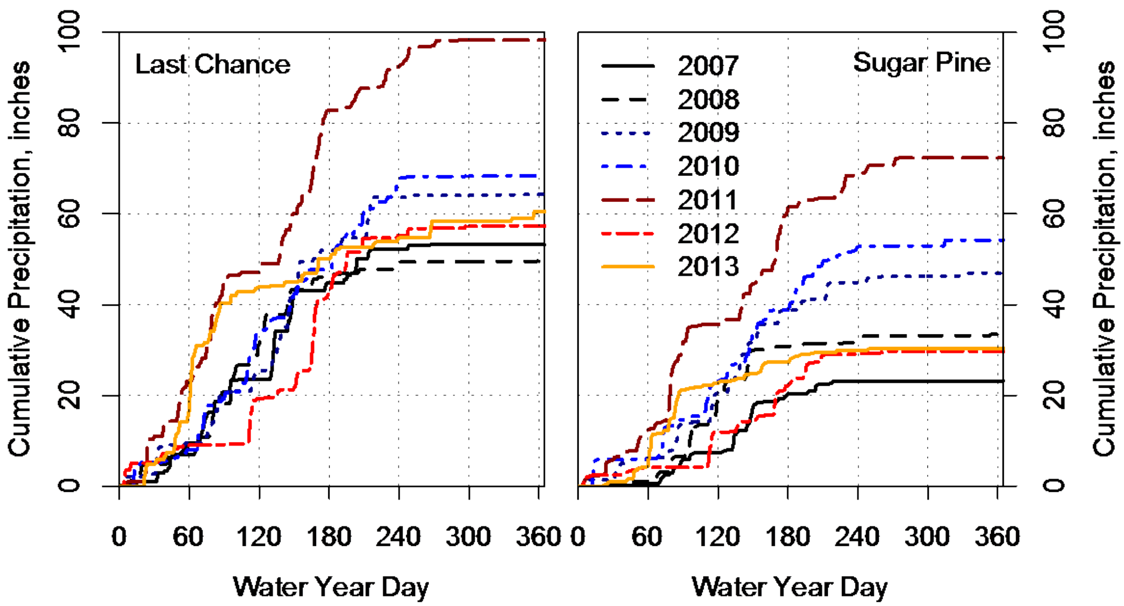

Figure 2-4: Cumulative water year precipitation rates at the Sierra Nevada Adaptive Management Project study areas, Last Chance and Sugar Pine, Sierra Nevada, California, during the study period (2007-2013). Precipitation data were obtained from the Blue Canyon (Last Chance) and Poison Ridge (Sugar Pine) meteorological stations, both operated by the U.S. Bureau of Reclamation.

Given the Mediterranean climate, strong seasonal signals of temperature and precipitation were present (Figure 2-5). Diurnal temperatures in the winter often fluctuated around the freezing point, with a December mean daily maximum/minimum temperature of 44.2°F/28.7°F (6.8°C/-1.8°C) for Last Chance and 43.4°F/22.8°F (6.3°C/-5.1°C) for Sugar Pine. Peak summer temperatures occurred during July, with a mean daily maximum/minimum temperature of 78.8°F/46.3°F (26.0°C/7.9°C) and 81.6°F/55.9°F (27.6°C/13.3°C) for Last Chance and Sugar Pine, respectively. Precipitation generally increased during October and November, leading to the majority of precipitation falling December through March before tapering off from April to June. The dry summer months yielded minimal rainfall. Inter-annual timing of precipitation was highly variable, with moisture totals during the month December ranging 0.3 - 21.9 inches (0.8 - 55.6 centimeters) at Last Chance and 0.0 - 19.5 inches (0.0 – 49.5 centimeters) at Sugar Pine.

Temperature data are from the Bear Trap and Big Sandy meteorological stations at Last Chance and Sugar Pine, respectively, which were more representative of mean fireshed elevation conditions than the higher elevation stations.

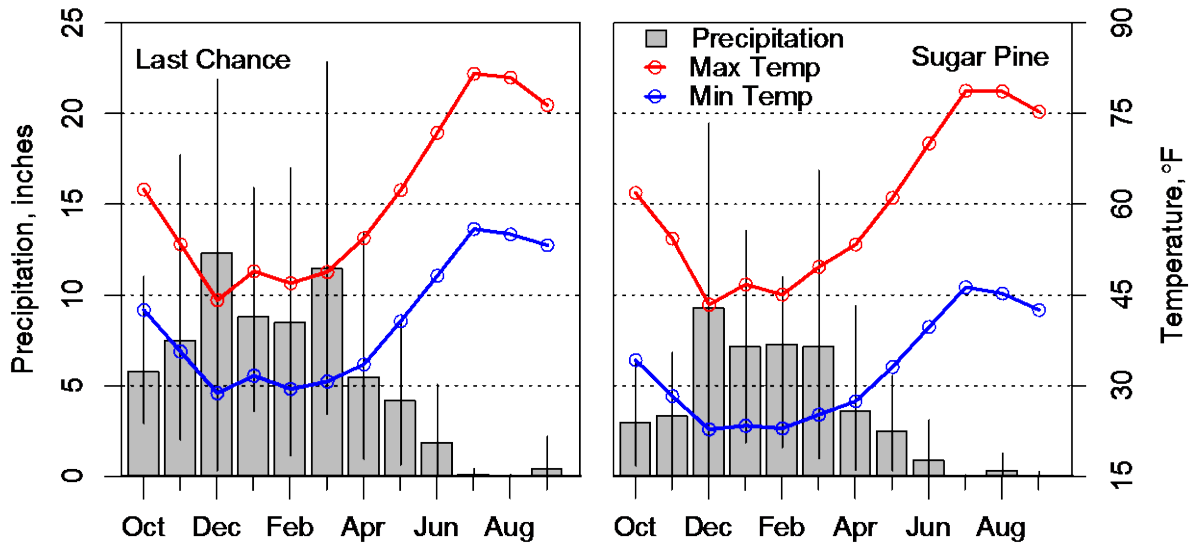

Figure 2-5: Seasonal patterns of precipitation and temperature observed during the Sierra Nevada Adaptive Management Project (2007-2013) in the northern (Last Chance) and southern (Sugar Pine) study areas, Sierra Nevada, California, representative of a Mediterranean climate. Vertical lines on the monthly precipitation bars indicate the range of observed conditions. Temperature lines connect monthly means of minimum and maximum daily temperatures.

Vegetation

To characterize stand structure and record changes in conditions resulting from treatments, the Fire and Forest Ecosystem Health Team established a system of forest inventory plots at Last Chance and Sugar Pine. From a random starting point, we established forest inventory plots at 1,640 ft (500 m) spacing across both study areas (Figure 2-6). This core grid resulted in 328 plots in Last Chance and 127 plots in Sugar Pine. In the small instrumented catchments used to measure hydrological responses, we increased the density of plots within our grid by reducing the spacing to 820 ft (250 m) or 410 ft (125 m). To better characterize fire effects, we increased plot density (820 ft spacing) in a recently burned area on Last Chance

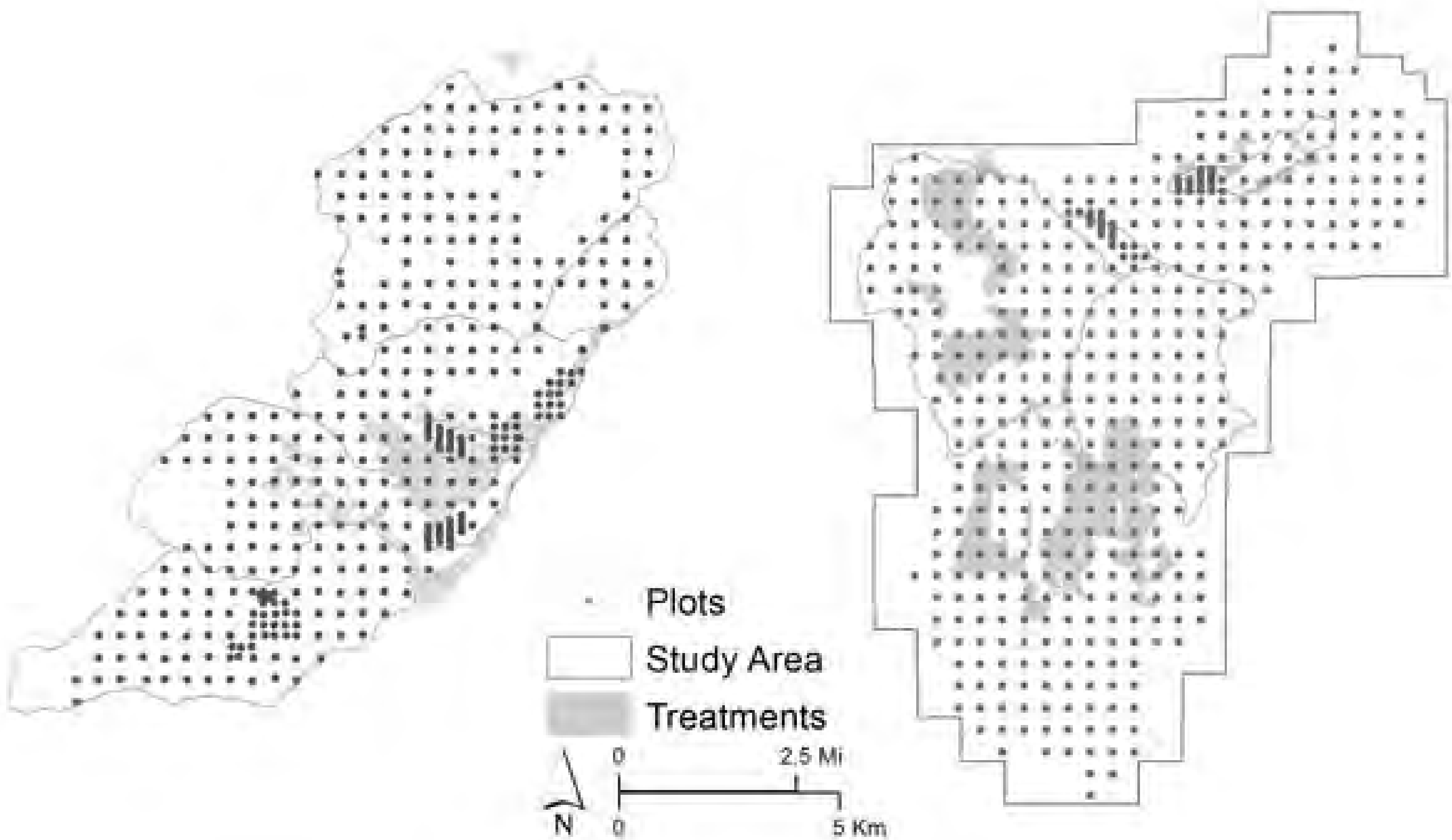

Figure 2-6: Forest inventory plots (black dots) and SPLAT locations (grey polygons) at (left) the northern site, Last Chance, and at (right) the southern site, Sugar Pine, in the Sierra Nevada Adaptive Management Project's two study areas, Sierra Nevada, California. Black lines (curved) show the fireshed boundaries, and the outer boundary is the Lidar footprint.

(Peavine fire) and extended the measurements to a site with recent fuel treatments just southwest of Sugar Pine (Cedar Valley). As a result we had 408 and 284 pre-treatment plots on Last Chance and Sugar Pine, respectively. Pre-treatment plot measurements were collected during the summers of 2007 and 2008. To maximize the time since treatment (2011-2012), we completed the post-treatment sampling in one field season – 2013.

Vegetation at Last Chance was dominated by a mature, mixed conifer forest (Table 2-5; Figure 2-7). White fir (*Abies concolor*) and Douglas-fir (*Pseudotsuga menziesii*) were the two most abundant species, but incense cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), and California black oak (*Quercus kelloggii*) were codominants at variable densities. Patches of montane chaparral dominated by manzanita (*Arctostaphylos* spp.) were interspersed throughout the study area.

Table 2-5: Extent and species composition of vegetation types at the Sierra Nevada Adaptive Management Project's Last Chance study area, Sierra Nevada, California.

Vegetation Class	Area %	ABCO[1]	ABMA	CADE	PILA	PIMO	PIPO	PSME	QUKE
		Relative Basal Area (%)							
Open True Fir	4	43	19	0	6	8	13	10	0
Pine Woodland	7	23	16	0	14	1	30	16	0
Mixed Conifer Woodland	12	34	3	6	13	0	22	18	2
Young Mixed Conifer Forest	19	24	2	8	19	0	24	20	3
Mature Mixed Conifer Forest	56	33	4	7	18	0	13	22	3
Low Shrub	1	(*Arctostaphylos* spp.)							
High Shrub	1	(*Arctostaphylos* spp.)							

[1]Species Codes: ABCO, white fir (*Abies concolor*); ABMA, California red fir (*A. magnifica*); CADE, incense-cedar (*Calocedrus decurrens*); PILA, sugar pine (*Pinus lambertiana*); PIMO, western white pine (*P. monticola*); PIPO, ponderosa pine (*P. ponderosa*); PSME, Douglas-fir (*Pseudotsuga menziesii*); QUKE, black oak (*Quercus kelloggii).*

Mature mixed conifer forest also dominated at Sugar Pine (Table 2-6; Figure 2-8), but species composition differed from Last Chance in that there was no Douglas-fir, and the Nelder Grove watershed contained a small grove of giant sequoia (*Sequoiadendron giganteum*). In addition to black oak and interior live oak (*Quercus wislizeni*), typical hardwood and shrub species included white alder (*Alnus rhombifolia*), Pacific dogwood (*Cornus nuttallii*), mountain whitethorn (*Ceanothus cordulatus*), deerbrush (*Ceanothus integerrimus*), and greenleaf manzanita (*Arctostaphylos patula*).

Table 2-6: Extent and species composition of vegetation types at the Sierra Nevada Adaptive Management Project's Sugar Pine study area, Sierra Nevada, California.

Vegetation Class	Area %	ABCO[1]	CADE	PILA	PIPO	QUKE	QUWI
		Relative Basal Area (%)					
Open Pine-Oak Woodland	3	2	0	15	48	33	0
Pine-Cedar Woodland	14	9	22	7	36	13	11
Mature Mixed Conifer Forest	57	26	29	8	17	9	7
Closed-canopy Mixed Conifer Forest	26	38	29	16	9	4	3

[1]Species Codes: ABCO, white fir (*Abies concolor*); CADE, incense-cedar (*Calocedrus decurrens*); PILA, sugar pine (*Pinus lambertiana*); PIPO, ponderosa pine (*P. ponderosa*); QUKE, black oak (*Quercus kelloggii*); QUWI, interior live oak (*Q. wislizeni).*

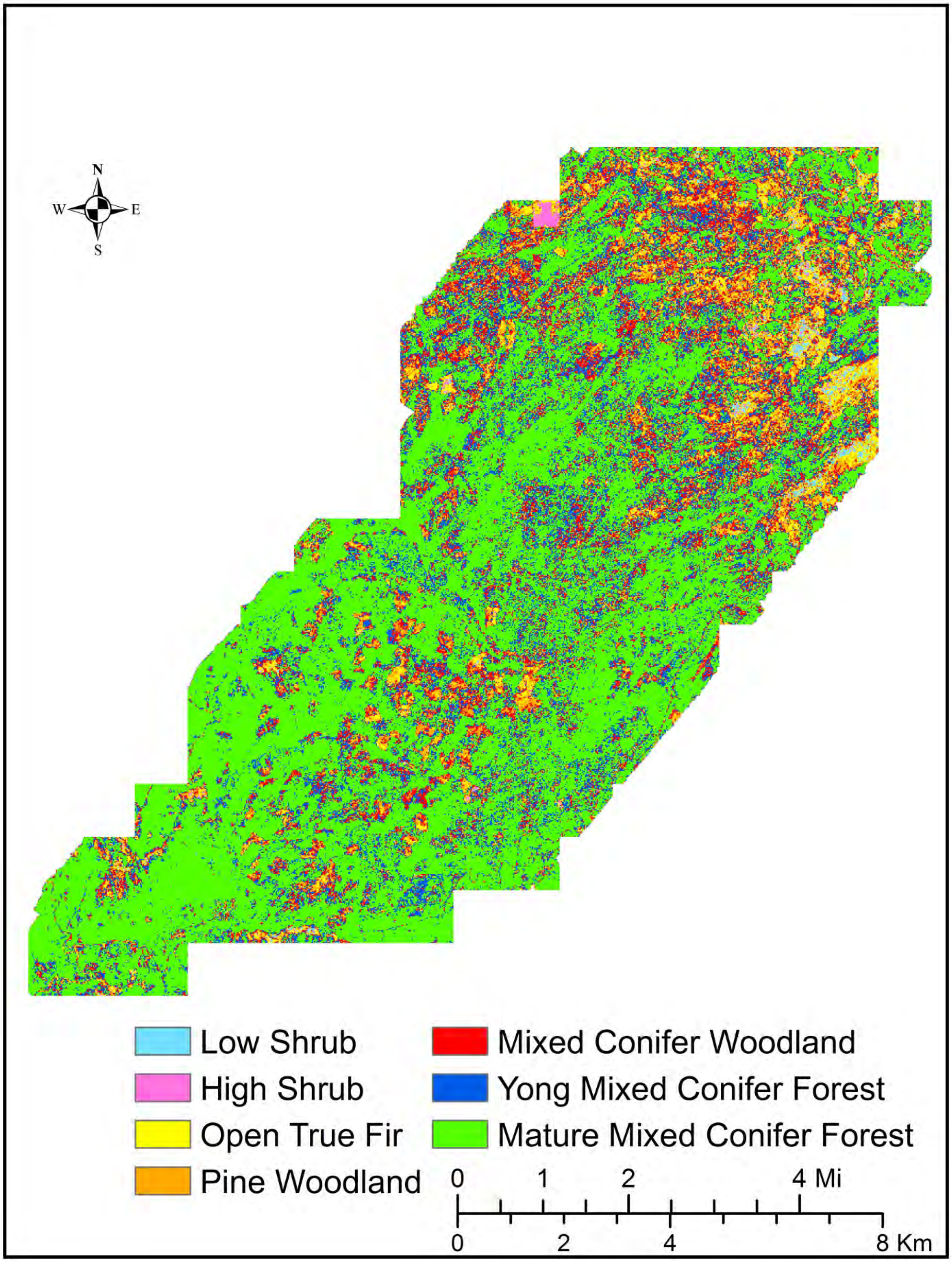

Figure 2-7: Vegetation map of the Last Chance study area, Sierra Nevada, California. Map includes the firesheds and surrounding regions captured by the Lidar imagery.

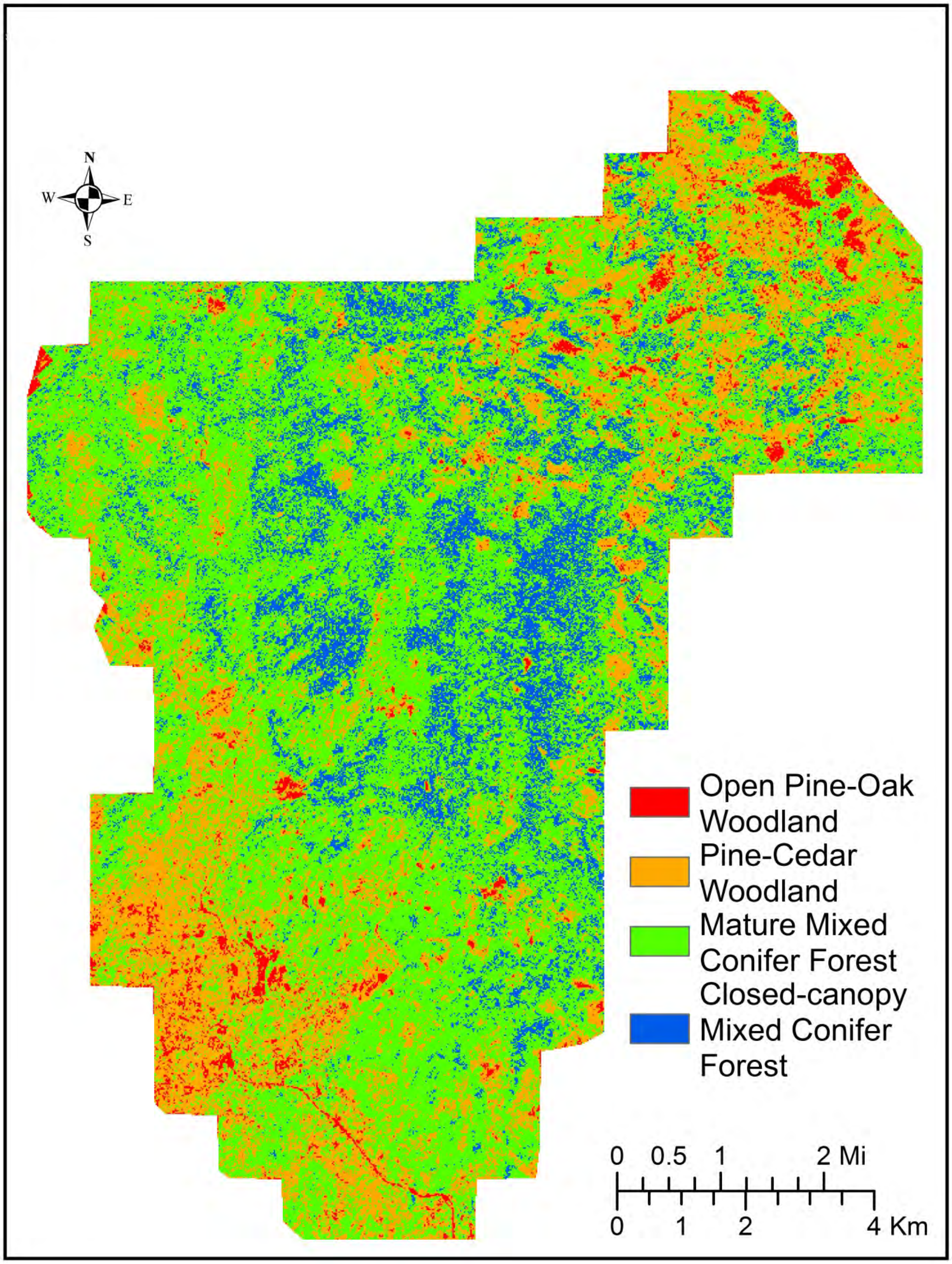

Figure 2-8: Vegetation map of the Sugar Pine study area, Sierra Nevada, California. Map includes the firesheds and surrounding regions captured by the Lidar imagery.

Forest structure varied between the two study areas. In general, the forests at Sugar Pine had more basal area and higher canopy cover (Table 2-7; Table 2-8). These differences reflected a combination of edaphic conditions as well as variation in fire history and timber management. Several small streams bisected both study areas, resulting in terrain that was moderately complex, though there were also a few areas of extreme slope and major dissecting features such as large rivers or steep ridges. This topographic complexity influenced variation in vegetation. However, the two study areas reflected the general condition of the mixed conifer forest in the Sierra Nevada. A century of fire suppression along with shifting policies regulating timber harvesting in the national forests has resulted in changes in species composition and forest structure. Compared to pre-settlement times, contemporary forests have a greater dominance of shade tolerant but fire sensitive species. In terms of structure, contemporary forests support higher surface fuel loads, greater tree density, and smaller average tree size (Collins et al. 2011, Taylor et al. 2014, McIntyre et al. 2015).

Table 2-7: Characteristics of forest structure at the Last Chance study area, Sierra Nevada, California.

Vegetation Class	Basal Area (ft^2/ac)[1]	Canopy Cover (%)	Lorey Height (ft)
Low Shrub	--	--	--
High Shrub	--	--	--
Open True Fir	17	9.2	33
Pine Woodland	49	21.8	43
Mixed Conifer Woodland	88	36.4	51
Young Mixed Conifer Forest	108	46.1	61
Mature Mixed Conifer Forest	210	61.5	86

[1] Mean values reported based on pre-treatment plot data.

Table 2-8: Characteristics of forest structure at the Sugar Pine study area, Sierra Nevada, California.

Vegetation Class	Basal Area (ft^2/ac)[1]	Canopy Cover (%)	Lorey Height (ft)
Open Pine-Oak Woodland	50	14.7	40
Pine-Cedar Woodland	86	38.1	58
Mature Mixed Conifer Forest	206	66.8	83
Closed-canopy Mixed Conifer Forest	296	74.6	106

[1] Mean values reported based on pre-treatment plot data.

Fire history

Fire history, inferred from fire scars recorded in tree rings, suggested a pre-Euro-American settlement fire regime that had predominantly frequent, low-severity fires occurring at regular intervals (Stephens and Collins 2004, Scholl and Taylor 2010). Based on fire scars collected in the study areas by the Fire and Forest Ecosystem Health Team, during this period the median fire return interval for Last Chance was 15.0 years and 11.0 years for Sugar Pine. Native American activity in the study areas was high before European settlement. The ancestral territory of the Nisenan Native American community is in the forests of north-central Sierra Nevada (Matson 1972). Up until 1901, the area that is now the town of Bass Lake (approximately 9 km from the Sugar Pine watershed) was a large, lush meadow used by the Chuckchansi and Mono tribes. Under traditional management, fire was used extensively to keep the forest open, encourage herbaceous growth for game animals, and produce vegetative growth conducive to basket weaving and arrow construction (Anderson 2005). The social context and forest history of the two study areas is discussed in greater detail below.

SPLAT implementation

The SPLATs implemented in the two study areas were typical of those placed in mixed conifer forests (Agee and Skinner 2005). In general, the prescriptions (Figure 2-6) allowed treatment of approximately 25-40% of the treatment watersheds (4,094 ac [1,657 ha]) by thinning (i.e., thinning from below or cable harvesting (Last Chance)), in some cases followed by mechanical/hand piling and burning. Mastication of shrubs and small trees (primarily within 20- to 30-year-old plantations at Last Chance) occurred on 1,037 ac (2.5-15%), and prescribed fire on 807 ac (4-5.6%). Because of operational delays, treatments were implemented over several years (2008–2012) and were modified at Sugar Pine to protect wildlife habitat. Within the Last Chance study area, the Peavine Fire (551 ac [223 ha]) burned in August 2008, prior to our pre-treatment sampling. Post-burn forest structure and fuels were measured, but we did not consider this a component of our fuel treatment network. Last Chance received SPLATs on 18.4% of its treatment fireshed while Sugar Pine received treatment on 29.3%.

Wildlife: California spotted owl study area (northern study area)

The SNAMP owl study had four areas, two of which were contiguous. The original SNAMP study area was the Last Chance study area (38.4 square miles [100 km^2]), consisting of core treatment and control firesheds (Figure 2-9: the "FFEH: Treatment" and "FFEH: Control" shaded polygons). To increase the sample size of owl locations, this core area was expanded by establishing a 1.5 mile (2.4 kilometer) "buffer area" (an additional 57 square miles [148 km^2]) that surrounded the main firesheds and incorporated several previously surveyed owl territories (Figure 2-9: "Owl: SNAMP Main Area" polygon). After the first year of field work (2007), the sample size of owls within this expanded area was deemed insufficient to assess the effects of SPLATs on owls. Therefore, the Owl Team proposed a further expansion of the SNAMP Owl study to incorporate additional areas from the Eldorado Spotted Owl Demographic Study where owls had been under long-term monitoring and where fuels treatment projects had been ongoing since that study's initiation (Seamans et al. 2001). These areas were the 137 square-mile (355 km^2) Eldorado Density Study Area (EDSA) and the 220 square-mile (570 km^2) Eldorado Regional Study Area (ERSA), located east of Georgetown in El Dorado and Placer counties, California (Figure 2-9: "Owl: Eldorado Study Area" polygon and multiple "Owl: Regional Areas" circles). Members of the Owl Team had established the EDSA in 1986 to assess population trends and monitor vital rates of the owl population. The ERSA was established in 1997 to increase the sample size of the EDSA and to allow assessment of owl dispersal; the ERSA consisted of individual or clusters of owl territories distributed over a much larger area than the EDSA. To maximize our sample size over space and time, we used historic data going back to 1993 from the EDSA and ERSA where many of the treatments were not specifically SPLATs. For example, fuel treatments on Forest Service land prior to 2004 did not follow the SPLAT guidelines delineated in the 2004 Sierra Nevada Framework, but their effects on forest structure were similar to SPLATs (i.e., similar retention guidelines for large trees, basal area, and canopy cover).

Throughout the remaining discussion, we refer to the original (smaller) SNAMP study area and its buffer as the "Last Chance Study Area" and any combination of data from the Eldorado Density and Regional Study Areas as the "Eldorado Study Area." When data were combined from all four study areas, we referred to this entire footprint as the "SNAMP Owl Study Area." All areas were typical of mid-elevation Sierra Nevada topography, with mountainous terrain bisected by steep river canyons. The Last Chance Study Area and Eldorado Density Study Areas were in close proximity (<3.5 miles [6 kilometers] distant); in some cases, boundaries of owl territories (based on nearest neighbor distances among owl locations) within the Eldorado Regional Study Area overlapped the Last Chance Study Area. Elevation ranged from 1,168 feet (356 meters) to 7,540 feet (2,298 meters). From 1990 to 2008, average annual precipitation was 46.5 inches (118.2 centimeters) at the Hell Hole Automated Weather Station, which was situated near both study areas at an elevation of 5,240 feet (1,597 meters). Most precipitation fell as snow at higher elevations, which often precluded access to the original SNAMP study area until well into the owls' annual breeding season. The Eldorado Study Area experienced a wide range of timber harvests on both public and private lands, as well as some wildfire, from 1986-2013 (see Appendix C for further details).

Vegetation on the SNAMP Owl Study Area was influenced by elevation, topography, soil, and natural and anthropogenic disturbance histories. These influences contributed to heterogeneity within the study area with respect to the distribution and composition of vegetation

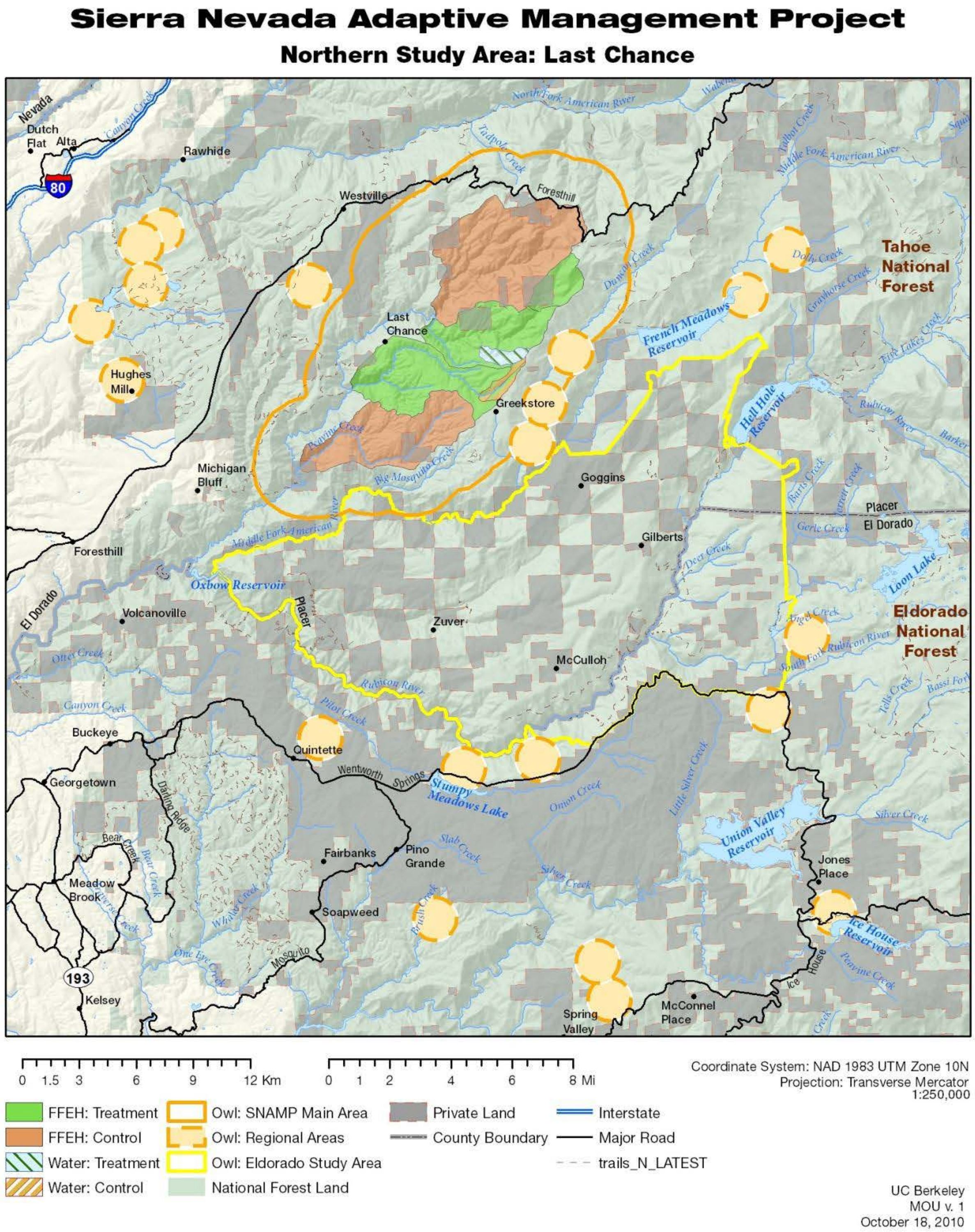

Figure 2-9: Map of the Owl Team study areas in the northern Sierra Nevada Adaptive Management Project study area, Sierra Nevada, California.

types. However, Sierran Mixed Conifer forest accounted for the majority of vegetation throughout all areas (Table 2-9) and was dominated by ponderosa pine and white fir. Other common tree species were sugar pine, California black oak, Douglas-fir, and incense cedar. Montane Hardwood and Montane Hardwood-Conifer made up approximately 14 and 7% of the areas respectively (Table 2-9). Montane Hardwood was dominated by various species of hardwood such as California black oak, tanoak (*Notholithocarpus densiflorus*), madrone (*Arbutus menziesii*), big leaf maple (*Acer macrophyllum*), and canyon live oak (*Quercus chrysolepis*). Montane Hardwood-Conifer was dominated by these same species in addition to conifers such as ponderosa pine, white fir, Douglas-fir, incense cedar, and sugar pine. Montane Hardwood-Conifer occurred either as mixed-species stands of hardwoods and conifers or as mosaics of patches of nearly pure hardwoods and conifers. Red Fir Forest made up a small proportion of vegetation in the area but was locally important because it supported several owl territories at higher elevations. This vegetation type was dominated by red fir (*Abies magnifica*) and lodgepole pine (*Pinus contorta*). Other vegetation types were locally important but collectively added relatively small proportions to the study area (Table 2-9).

Table 2-9: Proportion of vegetation types that constitute the Sierra Nevada Adaptive Management Project's Owl Study Area in the central Sierra Nevada, California; derived from the CALVEG GIS layer (USFS 1981). Classification follows California Wildlife Habitat Relationships Program (CWHR; Mayer and Laudenslayer 1988).

WHRTYPE	Description	% of Study Area
SMC	Sierran Mixed Conifer	57.89
MHW	Montane Hardwood	14.09
MHC	Montane Hardwood-Conifer	7.18
PPN	Ponderosa Pine	4.74
MCP	Montane Chaparral	4.47
WFR	White Fir	3.46
DFR	Douglas Fir	2.75
JPN	Jeffrey Pine	1.38
BAR	Barren [Rock/Soil/Sand/Snow]	0.88
AGS	Annual grasslands	0.73
PGS	Perennial grasslands	0.57
MCH	Mixed Chaparral	0.45
RFR	Red Fir	0.40
LAC	Lacustrine	0.27
MRI	Montane Riparian	0.11
CPC	Closed-Cone Pine-Cypress	0.08
URB	Urban	0.05
WTM	Wet meadow	0.04
BOP	Blue Oak-Foothill Pine	0.04
RIV	Riverine	0.01

Wildlife: Pacific fisher study area (southern study area)

The SNAMP fisher study area consisted of three nested landscapes: the SNAMP study area, the key watersheds, and the SNAMP Fisher study area. The original southern SNAMP study area, consisting of two control and two treatment firesheds (Sugar Pine, Nelder Grove, Speckerman, and Big Sandy firesheds) was considered too small to accurately assess both fisher population parameters and the impacts of fuel reduction efforts. To improve the Fisher Team's ability to assess treatment impacts, the study area was initially increased to include not only the SNAMP study area but also several surrounding Forest Service fuel reduction projects (i.e., the Fish Camp and Cedar Valley projects; Figure 2-10). This expanded study area, consisting of the Sugar Pine, Nelder Creek, White Chief Branch, and Rainier Creek watersheds, covered 49.4 square miles (128 km^2) and is hereafter referred to as the 'key watershed' area. This key watershed area defined the high-intensity, focal monitoring region for assessing the impacts of vegetation and fuel management on fishers.

However, as the project progressed, it quickly became evident that, due to the large movement capacity and space use of fishers, as well as their relatively low natural density, the key watershed area was still insufficient for assessing fisher population parameters. Therefore, additional less-intensive monitoring was conducted across a much larger area, including the non-wilderness region of the Bass Lake Ranger District as well as the southern portion of Yosemite National Park (Figure 2-10). This expanded study area, referred to as the SNAMP Fisher study area, covered approximately 502 square miles (1,300 km^2) between the Merced and San Joaquin Rivers (Figure 2-10), and incorporated both public and private land. Therefore, throughout the remaining discussion, we refer to the original four firesheds as the "SNAMP study area", the expanded area for assessing treatment impacts as the "key watershed area", and the larger study area for assessing fisher population dynamics as the "SNAMP Fisher study area".

The SNAMP Fisher study area incorporated landscapes between 3,280 feet (1,000 meters) and 7,875 feet (2,400 meters). This elevation gradient contained a mix of hardwoods (California bay (*Umbellularia californica*), canyon live oak, and California black oak), and a few conifers at lower elevations (ponderosa pine and incense cedar; California Wildlife Habitat Relationship [CWHR] system MHW, PPN, and MHC habitat types), a mix of multiple conifers (ponderosa pine, Jeffrey pine (*Pinus jeffreyi*), white fir, and incense cedar) and hardwoods (California black oak, white alder, and Pacific dogwood) between 4,265 feet (1,300 meters) and 6,070 feet (1,850 meters; CWHR habitat types SMC, MHC, PPN), and graded into red fir (CHWR habitat type RFR) above 6,235 feet (1,900 meters). Giant sequoia were present but primarily restricted to the Nelder Grove Historic Area within the Nelder Creek watershed. Common shrubs and tree-like shrubs included whiteleaf manzanita (*Arctostaphylos viscida*), greenleaf manzanita, mountain misery (*Chamaebatia foliolosa*), bush chinquapin (*Chrysolepis sempervirens*), mountain whitethorn, and snowberry (*Symphoricarpos mollis*).

Within the SNAMP Fisher study area, approximately 36,250 acres (14,670 hectares) of fuel and vegetation management occurred during the SNAMP fisher study (2007-2013; Figure 2-11). This included a variety of management actions ranging from site preparation for planting to mastication to prescribed fire. The dominant activities included: pre-commercial thinning (14,443 acres [5,845 hectares]), commercial thinning (10,400 acres [4,209 hectares]), mastication (6,284 acres [2,543 hectares]), and hazardous fuel reduction (4,599 acres [1,861 hectares]). Prescribed fire was conducted over 2,553 acres (1,033 hectares) at a range of intensities, and an additional 472 acres (191 hectares) burned in a wildfire in 2010. Within the key watershed area, approximately 6,902 aces (2,793 hectares) were treated for fuel reduction using a combination of mastication, pre-commercial and commercial thinning. This fell predominantly under three projects: Cedar Valley (1,604 acres [649 hectares], completed 2010), Fish Camp (890 acres [360 hectares], completed 2012), and Sugar Pine (5,790 acres [2,343 hectares], completed 2013).

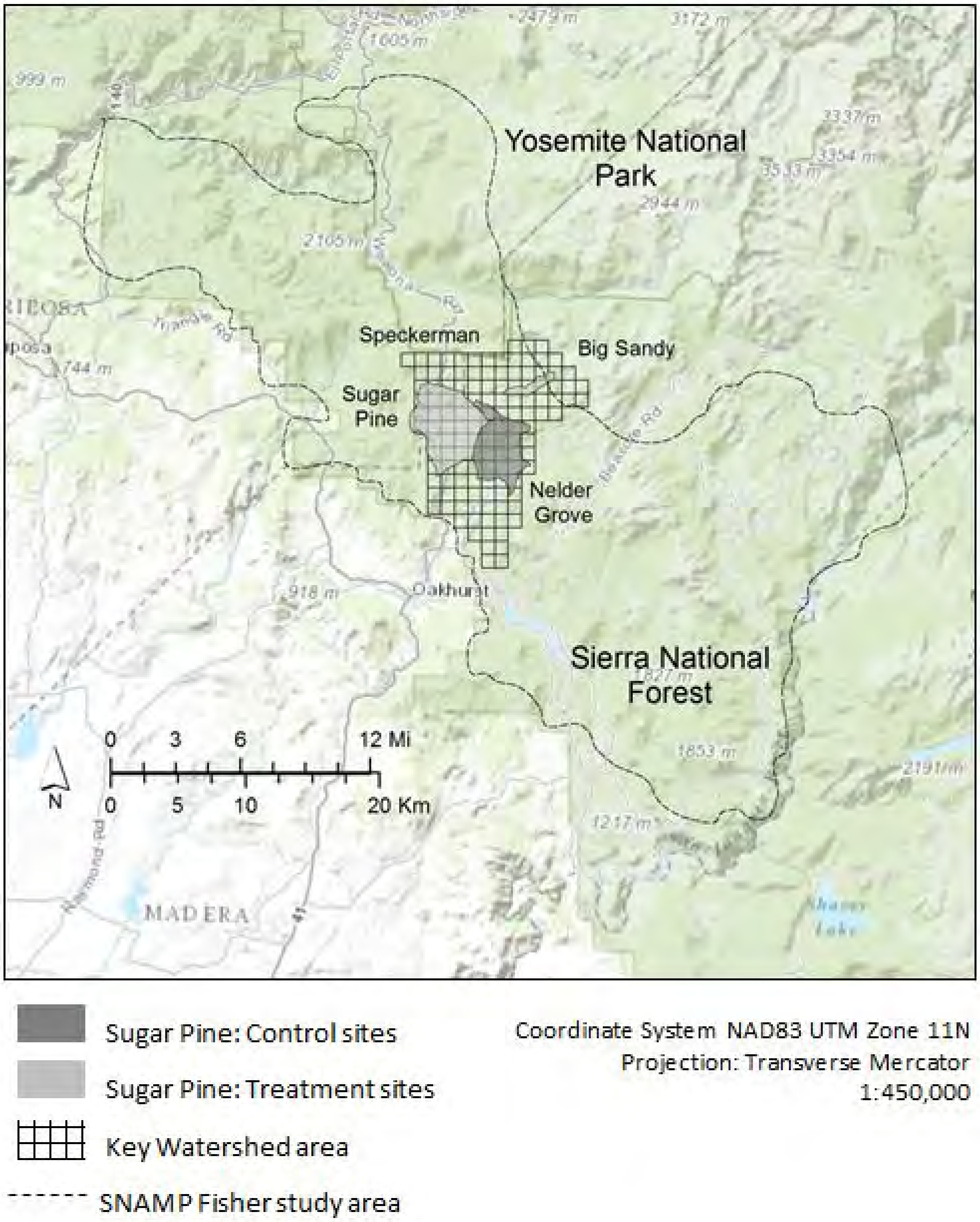

Figure 2-10: Map of the Sierra Nevada Adaptive Management Project (SNAMP) fisher study area, including the SNAMP study area firesheds and the key watershed area, in the Bass Lake Ranger District of the Sierra National Forest, California.

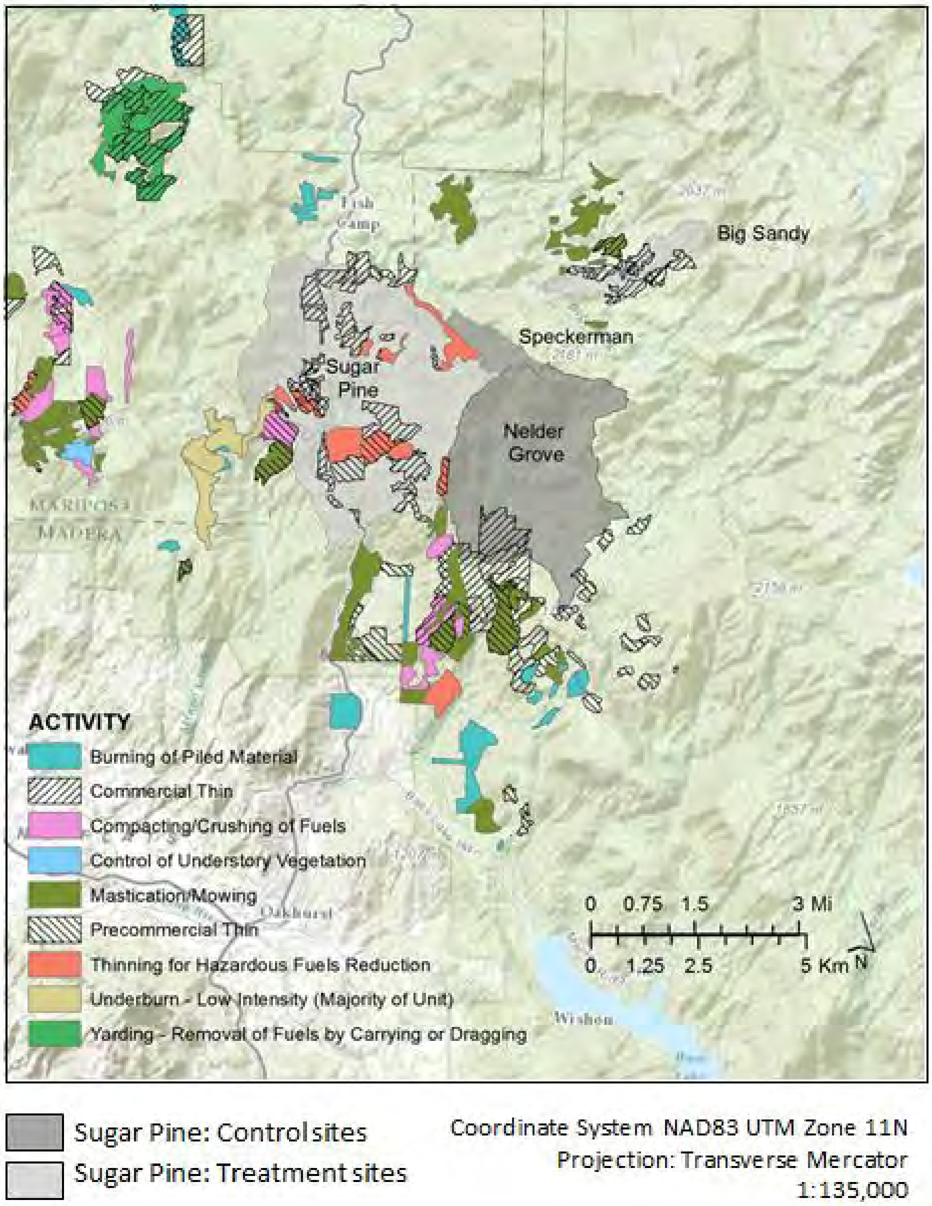

Figure 2-11: Fuel reduction treatments, 2007-2013, surrounding the southern Sierra Nevada Adaptive Management Project study firesheds in the southern Sierra Nevada, California.

Water study areas

Field sites for hydrologic monitoring were located at both Last Chance and Sugar Pine study areas (Figure 2-12). Multiple catchments in each study area were evaluated based on criteria such as slope, aspect, elevation, vegetation type, canopy closure, and tree size distribution. The goal was to identify catchments that had physiographic and vegetation conditions representative of the study area. Two headwater catchments were selected in each study site for intensive measurements based on comparable size, gradient, discharge, aspect, and vegetation cover for aquatic and terrestrial monitoring. Stream instrument clusters were installed along a relatively low-gradient reach near the outlet of each catchment where sediment scour and deposition was likely to occur (Table 2-10). One instrumentation cluster in each site was located in a treatment catchment subject to SPLATs, while the other was located in an undisturbed catchment as an experimental control.

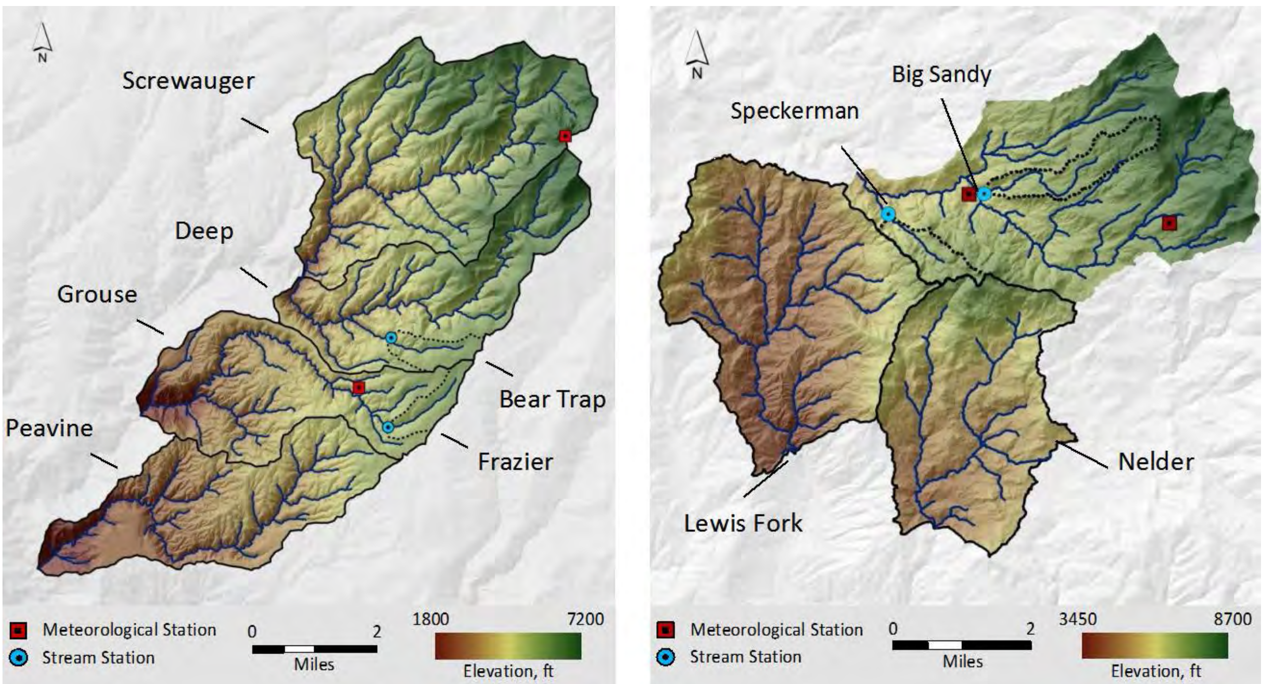

Figure 2-12: Location of monitoring stations within the Last Chance (left panel) and Sugar Pine (right panel) study areas, Sierra Nevada Adaptive Management Project, Sierra Nevada, California. The elevation-based map shows the fireshed catchment boundaries with a solid line and the headwater catchments with a dashed line.

In addition to the two stream instrument clusters, two meteorological stations were constructed in each study area. One station was located near the upper elevation of the headwater basins and another at an elevation similar to the stream monitoring locations (Table 2-10). Two additional clusters of instruments, at each stream and meteorological site, were located on a south-facing slope and a north-facing slope.

Table 2-10: Location of instrument nodes and watershed attributes measured at the Sugar Pine and Last Chance study areas of the Sierra Nevada Adaptive Management Project, Sierra Nevada, California.

Site	Instrument node	Area (miles^2)	Latitude (north)	Longitude (west)	Elevation (ft)
Last Chance	Bear Trap Creek	0.68	39.1067	120.5670	5,118
	Frazier Creek	0.65	39.0851	120.5689	5,266
	Duncan Peak Met	--	39.1546	120.5101	6,929
	Bear Trap Met	--	39.0945	120.5769	5,217
Sugar Pine	Speckerman Creek	0.63	37.4639	119.6051	5,640
	Big Sandy Creek	0.95	37.4684	119.5819	5,833
	Fresno Dome Met	--	37.4638	119.5362	7,139
	Big Sandy Met	--	37.4684	119.5856	5,758

The Frazier Creek and Bear Trap Creek watersheds were chosen for monitoring in the Last Chance study area. Both are located along Forest Route 44. Frazier Creek was approximately 6 miles (9.5 km) north of Forest Route 96 (Mosquito Ridge Road), and Bear Trap Creek is another 2.5 miles (4 km) north of Frazier Creek. The upper meteorological station at Last Chance, Duncan Peak, was approximately 0.6 miles (1 kilometer) west of Robinson Flat Campground along Forest Route 43. The lower meteorological station, Bear Trap, was situated between the stream sites approximately 1.5 miles (2.5 kilometers) from Frazier Creek along Forest Route 44. Although both Bear Trap and Frazier Creek were located in the treated fireshed, only Bear Trap had SPLATs implemented within the watershed. Frazier Creek was in a protected habitat area where treatments were excluded and therefore served as the control catchment.

Big Sandy Creek and Speckerman Creek watersheds were chosen for monitoring at Sugar Pine. From the junction between Jackson Road and CA-41, Speckerman Creek was approximately 3.5 miles (5.5 kilometers) east, while Big Sandy Creek was nearly 5.5 miles (9 kilometers) east. The upper meteorological station, Fresno Dome, was approximately 2 miles (3.25 kilometers) northeast of the Fresno Dome Campground along Sky Ranch Road (Forest Route 6S10). The lower meteorological station, Big Sandy, was located just west of the Big Sandy Campground. Speckerman Creek served as the control catchment, with Big Sandy being the treated catchment. Although the Big Sandy watershed was outside the Sugar Pine project, SPLATs were implemented there as part of the Fish Camp Project.

SNAMP study areas: social context

The forests of the Sierra Nevada from the period of Indigenous management through the present have changed because of human actions as well as environmental change and ecological processes. Each new wave of forest managers and forest residents works within the forest conditions and fire environment that they have inherited. But they also shape the forest at present and into the future, as the dynamic relationship between the people and the forests of the Sierra Nevada is ongoing. In this section, we highlight information about the socioeconomic settings of the study sites, using census data, archival research, and interviews with long-term residents.

Land tenure and population

Nearly 60 percent of land (11.5 million acres [~4.65 million hectares]) in the Sierra Nevada is public land managed primarily by the Forest Service and National Park Service, and most is spread across 11 national forests. SNAMP's northern study area, Last Chance, on the Tahoe National Forest, is in Placer County about 14 miles (22.5 km) from the town of Foresthill. Foresthill (Figure 2-13) was on a broad ridge between the North and Middle Forks of the American River. SNAMP's southern study area, Sugar Pine, on the Sierra National Forest, was in Madera County near the town of Oakhurst. Oakhurst is 14 miles (23 km) south of the entrance to Yosemite National Park, in the foothills of the Sierra Nevada, on the Fresno River. Both Oakhurst and Foresthill are unincorporated Gold Rush towns that have experienced rapid growth in the twentieth century (Figure 2-13), though population growth has slowed and even declined slightly since 2003. The populations concentrated in what the U.S. Census Bureau terms the "Census Designated Places" (CDP) of unincorporated Foresthill and Oakhurst remain under

3,000 people, but many more people live in the surrounding forests and woodlands, part of the "wildland urban interface" of the Sierran foothills.

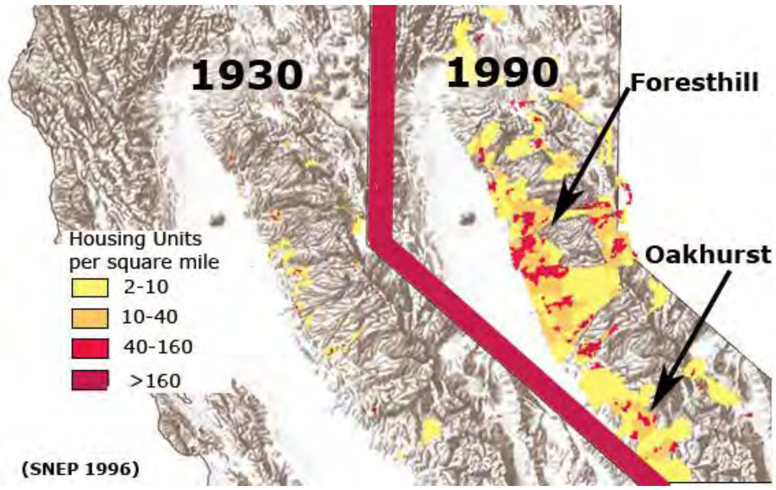

Figure 2-13: Increase in housing in the Sierra Nevada, 1930-1990 (adapted from *Sierra Nevada Ecosystem Project Report*, Volume II, Chapter 11 (1996) and Anthony Dunn Photography).

Exurban development is the dominant characteristic of these areas: houses are interspersed with forest in a "wildland urban interface" that is particularly challenging for fire-fighting and that puts a lot of private property at risk from forest fire (Figures 2-14 and 2-15).

Figure 2-14: A fire burning north of Oakhurst, California, August 18, 2014 (AP Photo/*The Fresno Bee*, Eric Paul Zamora)[1].

Figure 2-15: Foresthill is nestled among the trees (Photo by Chris English, Share Alike).

[1] http://www.foxnews.com/us/2014/08/19/authorities-tell-1500-people-to-leave-area-central-california-wildfire/

According to the 2010 census, compared to the population of the entire state, Foresthill and Oakhurst CDPs were less diverse than the state in general, although both had a higher proportion of Native Americans (Table 2-11). Residents were less likely to have completed a college degree or higher than the statewide average (Table 2-11). Reflecting Sierran in-migration, about a third more of the residents of the two communities were born outside California. Residents of these communities were more likely to use wood heat than other residents of the state, but there were no timber mills in either town, and in 2010, employment in timber, agriculture, fishing, hunting, mining and fisheries was virtually zero, while statewide it was 2%.

Comparing the two communities (Table 2-11), in 2010, Foresthill had a relatively high proportion of people in public administration, which may include those working for a natural resources agency like the Forest Service. In contrast, Oakhurst residents were more likely to be employed in construction and retail and in service industries in general, perhaps because of the proximity of Yosemite National Park (Figure 2-16). Oakhurst also had a higher proportion of residents over 62 than either Foresthill or the state (Table 2-11), and in both communities, the median age was more than 10 years older than that for the state.

Figure 2-16: Shopping Center in Oakhurst, California (Photo by Barry White, Share Alike).

Table 2-11: Comparison of selected demographics of Foresthill Census Designated-Place (CDP), Oakhurst CDP, and California in 2010 (USCB 2010).

Characteristic	Foresthill CDP	Oakhurst CDP	California
USDC Census Bureau: American community survey 2010			
Population size	1,483	2,829	37,253,956
Population density per square mile	125	472	239
% Native American/Alaska Native	3.8	4.6	1
% Hispanic or Latino of any race	6.5	16.7	37.6
% African American	0.9	1	7.2
% Asian or Pacific Islander	0.4	2	14.9
% over 16 unemployed	2.8	4.2	5.8
Median household income in $	59,091	37,813	60,883
Mean household income in $	71,715	44,299	83,483
% employed in "agriculture, forestry, fishing and hunting, and mining"	0	0	2.1
% employed in "educational services, health care, and social assistance"	28.9	14.8	20.1
% employed in public administration	22.3	4.4	4.6
% in retail trade	16.7	22.7	11
% in construction	2.7	10.9	7
% in any service job	13.5	28.8	17.4
% receiving food stamps	8	10	5
% with retirement income	15	27	15
% families living below the poverty line	12.7	13.7	10.2
% owner-occupied homes	65.1	56.4	55.9
Median home value in $	330,400	266,900	458,500
% using wood heat	33	33	2
Median age	45.7	48.4	35.2
% 62+ in age	10.2	18.1	11.4
% bachelor's degree or higher as highest degree	20	15	30
% born in different state	25.3	26	18.7

A Sierra Nevada Conservancy study of the overall Sierran region, including all or parts of 22 counties, reported in 2011 that the median age was 11 years older than that of California as a whole, and growing older faster (SNC 2011). The regional population was also growing more ethnically diverse but at a slower rate than the rest of California (Figure 2-17). The report mentioned that population and economic growth were highly variable within the region.

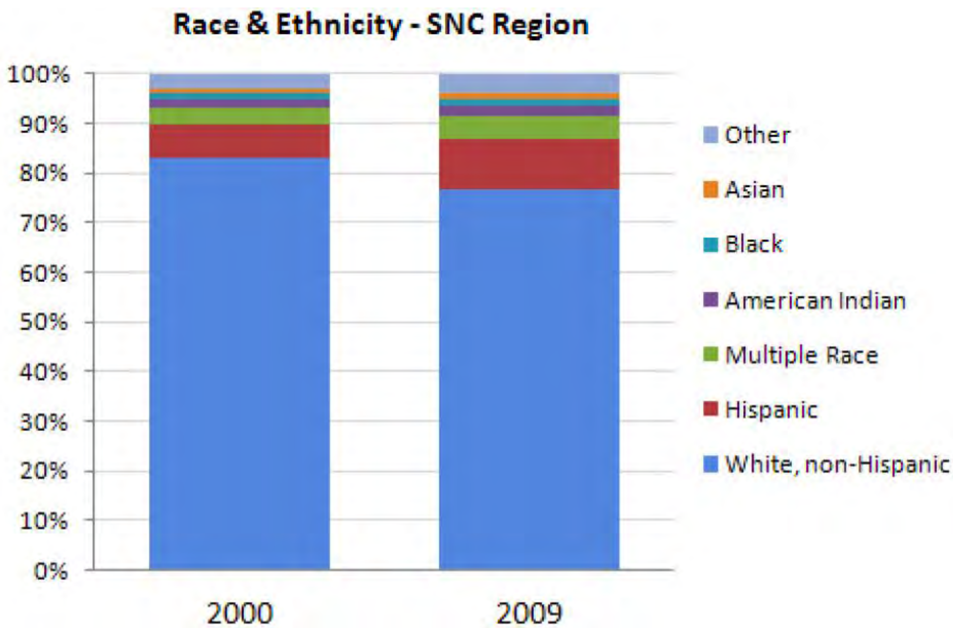

Figure 2-17: Racial and ethnic profile of the Sierra Nevada (SNC 2011).

Forest uses

Timber harvest is common in the areas surrounding the study areas, and livestock grazing is a long-time use, but in general, timber harvest (Figure 2-18) and grazing have declined since the 1980s in the national forests. In the Foresthill area, beargrass (*Xerophyllum tenax*) has a long history of being gathered by Native Americans for cultural uses, and a prescribed fire to maintain conditions for beargrass was conducted at Last Chance in 2011. Recreation within the SNAMP study areas is typical of that of Sierran conifer forest, including hiking, riding, jogging, biking, day picnics, the use of off-road vehicles, fishing, hunting, gold panning, mushroom collecting, snow shoeing, cross country skiing and snowmobile use. The Tevis Cup horse race and the annual Western States Endurance Run are near Last Chance, and these events have in the past drawn attention to logging activities in the area, causing the Forest Service to pay close attention to the scenic impacts of treatments near the race courses.

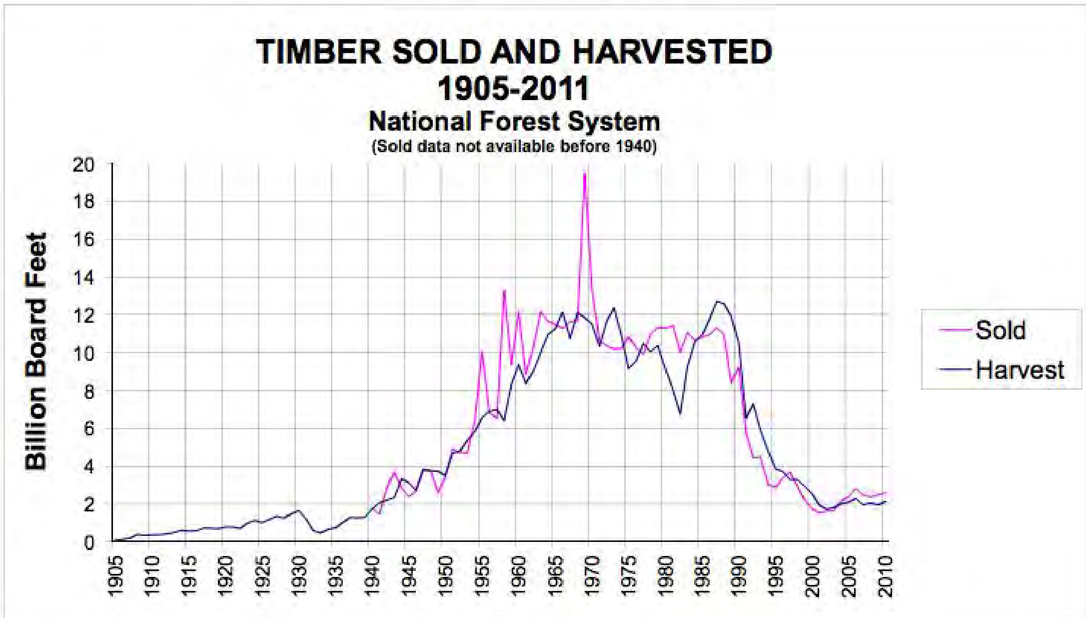

Figure 2-18: Timber sold from National Forests nationwide (USFS 1905-2011).

Foresthill was within and completely surrounded by an area designated in 2007 by the California Department of Forestry and Fire Protection (CalFire) as having the highest fire hazard severity rating based on fuels, terrain, weather, and other relevant factors, while Oakhurst was near such an area (Figure 2-19). Both study areas were within the highest fire severity rating zone.

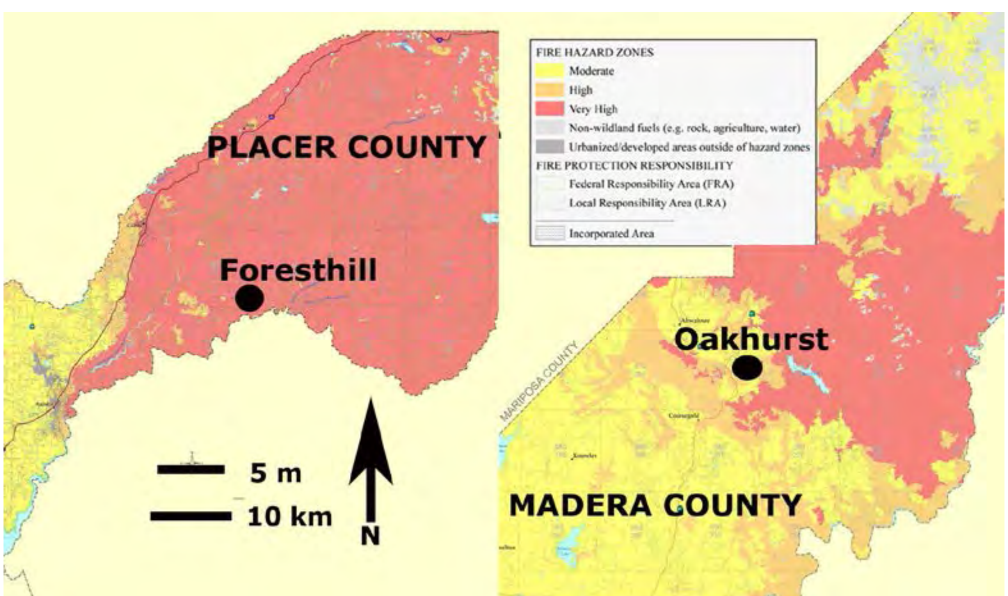

Figure 2-19: Fire hazard severity zones, all jurisdictions (Cal Fire 2007).

Demographic change in the study areas

Since the 1960s, the Sierra Nevada has experienced what has been referred to as a "second Gold Rush" (Walker and Fortmann 2003). Newcomers have been coming primarily from other parts of California, and they have been attracted by the landscape's amenity value—its scenic beauty, open spaces, and rural qualities—not its potential for production. As rural residential development has expanded to accommodate these migrants, the number of relatively small rural residential parcels in the region has increased. As a result of the population growth and demographic changes over the last five decades, parts of the Sierra Nevada region have become more exurban, with both urban and rural characteristics, but unlike suburbs, not on the edge of a major metropolitan area (Duane 2000).

The latest wave of migration to the region has already far exceeded the number of people who moved to the Sierra Nevada during the Gold Rush. From 1970 to 1990, the population of the Sierra Nevada increased by 130% from 273,000 in 1970 to 619,000 in 1990. Growth in the Sierra Nevada has been occurring much more rapidly than in the state as a whole, which had a rate of growth of 49% over the same period. The latest wave of in-migration has precipitated social/cultural, economic, and political changes, which has resulted in tensions between long-time residents and newer arrivals. It has also changed the social, cultural, and economic relationships between residents and Sierran ecosystems (Duane 2000).

Population growth in areas with high fire danger increases the costs and risks to people and property of extreme fires. The *San Francisco Chronicle* reported that between 1990 and 2000 the number of people living specifically in high fire danger areas in the Sierra increased by 16% (Fimrite 2007). At present, El Dorado, Nevada, and Placer counties lead the Sierra Nevada in number of houses being built in high fire-risk areas. The cost of defending these properties is high. Nationally, the Forest Service spends about $1.1 billion (in 2013 constant dollars) a year protecting homes that are adjacent to national forests. As the central Sierra region is one of the state's fastest growing regions, it seems unlikely that the trend will soon be reversed (Fimrite 2007).

Within the Sierra Nevada region, the Gold Country, which includes El Dorado, Nevada, and Placer counties, has been the epicenter of exurban population growth. According to the U.S. Census Bureau, the population of Placer County, where the Last Chance study site was located, grew from 77,306 in 1970 to 172,796 in 1990 to 371,694 in 2014 (USCB 1995; USCB 2015). With new residents, the economy of the Gold Country has diversified, and has come to rely on employment outside the region. In 2010, nearly 30% of employed workers in this region commuted to Sacramento County (USCB 2015). Although commodity extraction, recreation, and tourism remained important industries, the primary value of the landscape now comes from attracting residents.

The Mother Lode area, which includes Amador, Calaveras, Tuolumne, Mariposa, and Madera counties, showed similar patterns of growth and change, although not to the same extent as the Gold Country. According to the U.S. Census Bureau, the population of Madera County, in which the Sugar Pine study area was primarily located, grew from 41,519 in 1970 to 88,090 in 1990 to 154,548 in 2014, with about a fourth of those employed commuting to Fresno County (USCB 1995; USCB 2015). Mariposa County, where another part of the Sugar Pine study area was located, grew from 6,015 in 1970 to 17,682 in 2014 (USCB 1995; USCB 2015). A strong majority of those employed in Mariposa County worked within the County as of 2010 (USCB 2015). While many retirees have moved to the Gold Country, agricultural and other natural resource industries remain important to local economies. Growth in the Sierra Nevada foothills will likely continue; in 1993, the population in 2040 was projected to be 621,842 in Gold Country and 418,900 in the Mother Lode area (Duane 2000).

Perspectives of long term residents in the study areas

As part of the SNAMP assessment, the Participation Team conducted interviews in 2009 and 2010 with four long-term local community members to better understand the local perspective on the relationship between communities and the Forest Service, and the local experience of forest management, in the surroundings of the SNAMP study areas. The past experience of communities with forest management and with the Forest Service informed their views of SNAMP, outlook on working with the Forest Service, and potential response to forest treatments. Our conversations with these long time local community members are summarized here to highlight a few local perspectives that seem to have widespread resonance.

The interviewed residents had noticed increasing forest management controversy. Some felt that timber harvest had declined because of litigation. Discussing the Last Chance study area, one person described a particularly noteworthy conservation conflict focused on an area called Duncan Canyon in Placer County, where the controversy over old growth became so great that when the Forest Service brought the timber plan to the County Board of Supervisors, the Board chose the "no logging" alternative. This had never happened before and was the result of strong opposition to the plan by both environmentalists and hunters. In the opinion of at least one interviewee, the controversies over "fuels reduction" projects and salvage logging were the result of a 10-year struggle as the Forest Service moved away from a focus on timber harvest and more toward ecosystem management and management for multiple use. Another interviewee felt that recent new rule and policy changes created even more lawsuits, e.g., "planning regulations make it easy to sue".

Perceived Changes in the Forest Service Relationship with Communities

Interviewees noted that Forest Service budget reductions have had an impact on the areas around the SNAMP study areas. For example, historically, there were five ranger districts on the Sierra National Forest, but now there are only two. Interviewees commented that, "You get the impression that funding isn't great", as the Forest Service now has to do more with fewer people, and the facilities and roads are deteriorating.

In the opinion of interviewees, over time, local Forest Service districts have decreased their involvement with local communities. Relationships among the Forest Service, the cattlemen, and local communities were once strong, according to interviewees. They related that in the years after World War II, a Forest Service representative from the Sugar Pine area always went to the local Board of Supervisors meetings in Mariposa, would attend parades, and cooperated about summer camps, but currently, interviewees do not see Forest Service representatives participating in local community events. In the Last Chance area, it was noted that Forest Service personnel used to be part of the local population, but now the interviewee had the perception that very few Forest Service staff actually lived in Foresthill (the location of the Ranger District). In the past, local Forest Service personnel were part of volunteer fire departments and were part of the community, but this has changed. One interviewee felt that one big difference in the relationship between the Forest Service and the local community was that District Rangers used to have assistants to help them with the office work, which allowed the District Rangers to get out into the forest. Now, District Rangers spend too much time in the office and have much less assistance. As one interviewee related, “In 1966 when we first came, if the town siren went off, the Forest Service office emptied because they were all volunteer fire department, Lions Club, and Rotary Club members. Now, the local District Ranger doesn’t have time to do that; he has to wear so many hats. Now people say ‘what Forest Service in Mariposa?’” In discussing the Last Chance area, one interviewee said, “The Forest Service used to be in the forest. . . [It] seems [like] now everyone is behind a locked door. ... Supervisors’ offices had old maps and photos; [now it’s] harder to access something, but the internet makes some things easier.” The same interviewee also mentioned how most local people interacted with the Forest Service through their recreational interests, such as hunting and fishing, but now he saw younger people as less interested in the woods and wildlife so possibly Forest Service personnel have lost that connection to the local community as well.

Population and exurban growth

Interviewees had observed the shifts in local populations over time. They gave examples of how the influx of people into the vicinity of the study areas has affected local life. As several interviewees described, the make-up of Mariposa’s population began to change in the 1980s. Previously, the community had been mostly “loggers,” but after that time, there were more “city people.” As one person described, in the 1970s, “when this area was smaller, I used to see friends at the grocery store…[now]… the new people from LA, they …. don’t interact with the rest of the community.”

As Walker and Fortmann (2003) observed in Nevada County, many communities find themselves in an uneasy place because long-time residents and newcomers often have very different ways of valuing the landscape. Long-time residents will more likely have economic and cultural ties to natural resource-based production, while new migrants will typically value the landscape for its aesthetics and earn their livings in ways unconnected to resource extraction. By the early 1990s, these economic and cultural changes had worked their way into local politics as exurban migrants started to fill elected positions within county governments (Walker and Fortmann 2003). Interviewees also cited changes in the local officials as evidence of the population shifts that have taken place. For instance, as long ago as 1982, an incumbent sheriff lost to a newcomer from Los Angeles.

Wildfires and burning from a local perspective

Interviewees had experienced numerous fires and believed fires were getting worse. A fire near Last Chance burned an interviewee's family ranch and killed their animals. Some interviewees had experienced the challenges of attempting to restore fire as a management tool on the national forests. When one interviewee arrived in the Sugar Pine area in 1966 as a Forest Service employee, there had not been a controlled burn for a very long time. He went to the Cattlemen's Association to learn about controlled burning because the Association conducted burns on big ranches. In addition, he ordered 30 controlled burn documents and assigned one to each person on his team; they spent the whole winter studying. He conducted burns on the National Forest. "We'd take fire crews and use the guise of training" to do the brush control. He told of doing burns with the cowboys on the Sierra National Forest. In the early 1970s, the California Department of Forestry and Fire Protection (CalFire) attempted to re-burn the Harlow fire area. An interviewee talked about how they were able to get permission from the local cattlemen, but all the other ownerships in that area had become so splintered over time that they had to go house to house to get permissions. In the end, they were not able to convince all landowners and so the attempt failed. Even on the national forests, an interviewee who used to work for the Forest Service believed that only a portion of the amount of planned burning occurs each year due to air quality restrictions.

Interviewees noted that changes in both timber practices and prescribed burning had led to an increase in brushy material on the national forests. According to our interviewees, there was a noticeable difference between Forest Service land and Yosemite National Park where more burning had occurred. To our interviewees, the Forest Service land was so full of "dead branches, you can hardly walk through it". One interviewee related that in the 1970's, there were rancher complaints that the brush was so thick it was more and more difficult to find and manage the cattle.

One interviewee reported not want to cut a single tree when the interviewee moved to the Sugar Pine area but after a few years came to see the hazard and changed views. A Last Chance area interviewee observed the same pattern: he surmised that recent immigrants to the area wanted to protect all the vegetation while long-time residents were more aware of the fire hazard and more likely to want to open up the landscape and reduce fire hazard. However, another observed that possibly residents of larger towns like Oakhurst do not see the threat and therefore do not change their views. "As the population of Oakhurst increases, I think it is becoming more important that Forest Service get more involved with people because the chance of fire is so much higher now. So much more traffic into Yosemite, the more people, the threat is higher." It was also acknowledged that it was now harder to restore fire because of the massive amount of human encroachment into the forests, as one interview put it, "this is the fundamental dilemma in the Sierra."

Climate change and past management practices combined with a landscape dependent on fire have created a big challenge for forest management in the mountains of the Sierra Nevada (Figure 2-20). At the same time, natural resources agencies are learning how to interact with the public and are shifting to more open and transparent management. The Sierra Nevada's population and its land uses are also shifting, making the agency-public relationship more complicated and requiring the agencies to work even harder to reach out to those around them who may not have a history with forest lands and management. SNAMP was created to address both these situations by studying the impacts of forest fuels treatment projects and modeling a process that included the public in the scientific discovery.

Figure 2-20: Homesteader's cabin near Foresthill (Photo by Chris English, Share Alike).

References

Agee, J.K. and C.N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management 211: 83–96.

Anderson, K.M. 2005. Tending the wild: Native American knowledge and the management of California's natural resources. Berkeley, CA: University of California Press.

Bahro, B., K.H. Barber, J.W. Sherlock, and D.A. Yasuda. 2007. Stewardship and fireshed assessment: A process for designing a landscape fuel treatment strategy. Pages 41–54 in Proc. of conf. on Restoring Fire-adapted Ecosystems: 2005 National Silviculture Workshop. R.F. Powers (ed.). US For. Serv. Gen. Tech. Rep. PSWGTR-203.

Cal Fire. 2007. California Fire Hazard Severity Zone Map Update Project. Webpage available at: http://www.fire.ca.gov/fire_prevention/fire_prevention_wildland_zones_maps.php. Accessed July 3, 2014.

Collins, B.M., R.G. Everett, and S.L. Stephens. 2011. Impacts of fire exclusion and managed fire on forest structure in an old growth Sierra Nevada mixed-conifer forest. Ecosphere 2:51.

Cook, S.F. 1955. The epidemic of 1830-1833 in California and Oregon. University of California Publications in American Archaeology and Ethnology 43: 303-326.

Doak, S. and J. Kusel. 1996. Well-Being in Forest-Dependent Communities, Part II: A Social Assessment Focus. Pages 375-402 in: Sierra Nevada Ecosystem Project: Final Report to Congress, Vol II Assessments and Scientific Basis for Management Options. Davis, CA: University of California, Centers for Water and Wildland Resources.

Duane, T. 2000. Shaping the Sierra: Nature, Culture, and Conflict in the Changing West. Berkeley, CA: University of California Press.

Fimrite, P. 2007. Rural sprawl in the Sierra raises the risk of wildfires. San Francisco Chronicle, Tuesday, September 18, 2007, accessed online at www.sfgate.com.

Matson, R.G. 1972. Aspects of Nisenan ecology. Pages 39-44 in: Papers on Nisenan environment and subsistence. Center for Archaeological Research Publication 3. Davis, CA: University of California.

Mayer, K.E. and W.F. Laudenslayer, Jr. 1988. A guide to wildlife habitats of California. Sacramento, CA: California Department of Fish and Game.

McIntyre, P.J., J.H. Thorne, C.R. Dolanc, A.L. Flint, L.E. Flint, M. Kelly and D.D. Ackerly. 2015. Twentieth-century shifts in forest structure in California: Denser forests, smaller trees, and increased dominance of oaks. Proceedings of the National Academy of Sciences 112:1458–1463.

McKelvey, K.S., C.N. Skinner, C. Chang, D.C. Erman, S.J. Husari, D.J. Parsons, J.W. van Wagtendonk, and C.P. Weatherspoon. 1996. An overview of Fire in the Sierra Nevada. Pages 1033-1040 in: Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II, Assessments and Scientific Basis for Management Options. Davis, CA: University of California, Centers for Water and Wildland Resources.

NRCS Web Soil Survey. USDA Natural Resources Conservation Service online service available at: http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. Accessed June 2015.

Scholl, A.E. and A.H. Taylor. 2010. Fire regimes, forest change, and self-organization in an old-growth mixed-conifer forest, Yosemite National Park, USA. Ecological Applications 20: 362-380.

Seamans, M.E., R.J. Gutiérrez, C.A. Moen, and M.Z. Peery. 2001. Spotted owl demography in the central Sierra Nevada. Journal of Wildlife Management 65:425-431.

Skinner, C.N. and C. Chang. 1996. Fire Regimes, Past and Present. Pages 1041-1069 in: Sierra Nevada Ecosystem Project, Final Report to Congress, Vol. II, Assessments and Scientific

Basis for Management Options. Davis, CA: University of California, Centers for Water and Wildland Resources.

Sierra Nevada Conservancy (SNC). 2011. Demographic and Economic System Indicators Final Draft Report. Available at: http://www.sierranevada.ca.gov/our-board/board-meetings/sep2011/AIXSystemIndicatorsAttA.pdf. Accessed November 19, 2012.

Stephens, S.L. and B.M. Collins. 2004. Fire regimes of mixed conifer forests in the north-central Sierra Nevada at multiple spatial scales. Northwest Science 78(1): 12–23.

Taylor, A.H., A.M. Vandervlugt, R.S. Maxwell, R.M. Beaty, C. Airey, and C.N. Skinner. 2014. Changes in forest structure, fuels and potential fire behaviour since 1873 in the Lake Tahoe Basin, USA. Applied Vegetation Science 17:17-31.

USDA Forest Service (USFS). 1981. CALVEG: A Classification of California Vegetation. San Francisco, CA: Pacific Southwest Region, Regional Ecology Group. 168 pp.

USDA Forest Service (USFS). 2004. Sierra Nevada forest plan amendment: final supplemental environmental impact statement – Record of decision. R5-MB-046. [Vallejo, CA]: USFS, Pacific Southwest Region.

USDA Forest Service (USFS) FY 1905-2011 National Summary Cut and Sold Data and Graph. Webpage available at: ttps://docs.google.com/viewer?url=http%3A%2F%2Fwww.fs.fed.us%2Fforestmanagement%2Fdocuments%2Fsold-harvest%2Fdocuments%2F1905-2011_Natl_Summary_Graph.pdf. Accessed Nov. 27, 2012.

USDA Forest Service (USFS). 2012. Managing Sierra Nevada Forests. General Technical Report PSW-GTR-237.

USDC Census Bureau (USCB). 1995. Population of Counties by Decennial Census: 1900 to 1990. http://www.census.gov/population/cencounts/ca190090.txt Accessed 2006.

USDC Census Bureau (USCB). 2010. 2006-2010 American Community Survey 5-Year Estimates. Webpage available at: http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml. Accessed August 13, 2015.

USDC Census Bureau (USCB). 2012. Geographic Terms and Concepts – Place. Webpage available at: http://www.census.gov/geo/reference/gtc/gtc_place.html. Accessed July 3, 2014.

USDC Census Bureau (USCB). 2015. State and County QuickFacts. Webpage available at: http://www.census.gov/ Accessed August 13, 2015.

Walker, P. and L. Fortmann. 2003. Whose landscape? A political ecology of the 'exurban' Sierra. Cultural Geographies 10: 469-491.

Chapter 3. EXTENDED ABSTRACTS FOR INTEGRATION

Introduction

This chapter compiles from each team extended abstracts of their work for the SNAMP integrated assessment presented in the following two chapters. This chapter's purpose is to provide the background information upon which the integrated assessment and integrated management recommendations (chapters 4 and 5, respectively) were built. Each team's extended abstract includes an overview of the team's methodology, a summary of their results most relevant to the integrated assessment and management recommendations, and a description of their primary integration metrics.

General methodological approach

The SNAMP scientific assessment strategy was to use a Before-After Control-Impact (BACI) study design. As noted in Chapter 1, evidence for the effects of management activities, such as forest fuel treatments, is likely to be confounded by concurrent ecological and environmental changes; this confounding must be limited by the experimental design. A BACI study design helps to control for potential confounding factors and to isolate the ecosystem impacts related to forest management. The BACI design compensated for SNAMP's limited replication (only 2 sites) and for the non-random assignment of treatments by providing robust longitudinal controls (Stewart-Oaten et al. 1986).

BACI design defines two treatments, a control and an impact. As Stewart-Oaten and Bence (2001) described, the control site in a BACI design is not a true control but rather a measure of the existing natural variation in the ecosystem. The "before" measurements are crucial in that they provide a means to quantify the differences in ecosystem function between the control and impact sites that are not related to the management impact because these measurements occur before the imposition of any treatment. The "after" measurements serve to estimate the effect of the management treatment at the impact site based on the divergence between the control and impact sites.

Each of the two SNAMP study sites was subdivided into two firesheds. One fireshed received Strategically Placed Landscape Area Treatments (SPLATs) and was defined as the impact site (see Chapter 2 for details). The second fireshed served as the control. We defined the control as a comparable fireshed in terms of forest type, size, management history, fire history, and terrain features; the paired firesheds were also in close spatial proximity. In terms of management, permitted use in the control fireshed continued, but there was no major management intervention during the course of the study.

As noted in previous chapters, delays in SPLAT implementation at both study sites and the post-treatment timeline reduction limited the full deployment of a BACI design for SNAMP. The UC Science Team workplan originally envisioned 3-4 years of post-treatment assessment; the truncated timeline reduced this to 1-2 years of post-treatment assessment. The UC Science Team adapted to these study design constraints differently for each response variable, depending on the characteristics and situation relevant to the variable, as detailed below and in the individual team chapters (Appendices A-F).

Extended abstract for Fire

Introduction

The regional assessment of fire hazard and fuel loads in the 2004 Sierra Nevada Forest Plan Amendment identified modifying wildland fire behavior as a management priority (USFS 2004). The management direction outlined was to apply strategic fuel management at the landscape level. The defining characteristic of coordinated fuel reduction treatments (hereafter SPLATs) is that each treatment is part of a strategic pattern which slows and moderates a wildfire across the landscape. However, there are only a few spatially relevant, fully implemented landscape treatment projects in mixed conifer forests in the Sierra Nevada from which to evaluate and guide management decisions (Stephens et al. 2014). Our objectives were to evaluate the effects of SPLATs on landscape-level simulated wildland fire behavior, wildfire effects on forest structure, and projected forest dynamics. We analyzed fire behavior outputs and forest conditions under four scenarios: 1) with SPLATs and with fire; 2) without SPLATs and with fire; 3) with SPLATs and without fire; and 4) without SPLATs and without fire.

Methods

Using information from pre- and post-treatment forest inventory plot measurements, US Forest Service GIS treatment polygons, and the Lidar change detection maps we identified five distinct treatment types based on changes to forest structure and surface fuels (Table 3-1). These treatments alter forest conditions by removing and/or modifying surface, ladder, and crown fuels, thereby reducing the potential for extreme fire behavior.

Table 3-1: Cumulative acreage treated, in acres (percent of total area), by type for the treatment watersheds in both Sierra Nevada Adaptive Management Project study areas, Sierra Nevada, California.

Type	Last Chance	Sugar Pine
Mastication	348 (3.1)	217 (3.5)
Thinning	915 (8.3)	1298 (20.7)
Cable Logging	193 (1.7)	-
Thinning and Mastication	-	328 (5.2)
Prescribed Fire	577 (5.2)	-
Total	2033 (18.4)	1843 (29.3)

Our analytic approach was to simulate forest vegetation/fire interactions for all four scenarios, several decades into the future (Figure 3-1). This would permit an integrated product that the other SNAMP teams could use to evaluate the effectiveness of SPLATs on fire behavior and forest growth on their resource specific objectives. We used the ArcFuels platform to model: 1) forest stand dynamics with the Forest Vegetation Simulator (FVS), and 2) fire behavior with FARSITE and FlamMap. Fire behavior modeling was conducted assuming severe fire weather conditions (i.e., dry fuel moistures and moderate to high wind speeds), as these are the conditions associated with most large wildfires in the Sierra Nevada.

We developed topographic, fuels, and forest structure landscape map layers as required by the modeling programs using the SNAMP vegetation polygon map as the base layer for all pre- and post-treatment scenarios (Figure 3-1). We produced landscape flame length and fire type (i.e., surface fire, conditional crown fire, or active crown fire) maps at a 30-m resolution for each fire scenario. These were summarized to compare difference in fire behavior outputs at treatment and fireshed scales. To evaluate treatment and fire impacts on forest structure, we "grew" each stand for 30 years using forest growth simulations in FVS. Stand average flame lengths, based on FARSITE output, were used to simulate changes to forest structure through the Fire and Fuels Extension in FVS. Comparing current conditions and projected forest growth for all four scenarios allow for a full comparison of the impacts of SPLATs.

Results

Forest thinning was the most common treatment, followed by prescribed fire (Last Chance only) and mastication (Table 3-1). Generally, changes in forest structure varied with treatment type, primarily reducing surface and ladder fuels. For example, while prescribed fire reduced fine fuels there were only minimal changes in forest structure (e.g., 5% to 16% decrease in tree basal area and density, respectively), as opposed to mastication which augmented surface fuels, reduced shrub cover by an average of 39-47%, and modified basal area (ranging from 15% to -15%) and tree density (ranging from 21% to -70%) (Figure 3-2). The largest change was in thinning (Last Chance) and thinning followed by mastication (Sugar Pine only) units, with 41-57% reduction in basal area and 32-64% reduction in tree density.

To estimate potential offsite effects from treatments, we extracted FARSITE output pixel values within a 1,640 ft (500 m) buffer area outside treatment boundaries. Most treatments reduced both flame lengths (Figure 3-3) and fire type within the treated area as well as within the buffer area (Figure 3-4). Cable logging at Last Chance left activity fuels on site, which resulted in a slash-blowdown fuel model being assigned and consequently higher post-treatment flame lengths and crowning. Generally, there was a decrease in fire behavior from pre- to post-treatment conditions at the fireshed level (Table 3-2).

Overall conditional burn probability (CBP, for flame lengths greater than 6.6 ft [2 m]) was higher at Last Chance (Figure 3-5) compared to Sugar Pine (Figure 3-6) for the treatment fireshed. This is due, in part, to differences in forest structure; generally, Sugar Pine has higher basal area, lower density (Figure 3-2), and higher estimated canopy base heights. The effect of

SPLATs on CBP is evident at Year 0 (no fire scenario, blue bars in Figures 3-5 and 3-6), a 28% and 34% decrease at Last Chance and Sugar Pine, respectively. This difference wanes over time to only 2-4% by Year 30. Following essentially a zero CBP for either scenario immediately following simulated fire (red bars in Year 10), by Year 20 the recovery in CBP towards initial values (blue bars in Year 0) for the treatment scenario (light red bar) reached 67% at Last Chance and 96% at Sugar Pine. For the no treatment scenarios at Year 20 (stripe red bar) the recovery was slower, reaching 44% and 72% at Last Chance and Sugar Pine, respectively.

Table 3-2: Changes in fireshed-level fire behavior at both Sierra Nevada Adaptive Management Project study areas, Sierra Nevada, California. CBP, conditional burn probability for flame lengths > 6.6 ft (2 m).

	Control Fireshed			**Treatment Fireshed**		
Last Chance	**Pre**	**Post**	**Δ**	**Pre**	**Post**	**Δ**
Fraction of fireshed with flame lengths > 6.6 ft (2 m)	28.3	24.1	-4.2	32.9	22.5	-10.4
Fraction of fireshed with CBP > 0.1	54.3	40.5	-13.8	59.3	40	-19.3
Sugar Pine	**Pre**	**Post**	**Δ**	**Pre**	**Post**	**Δ**
Fraction of fireshed with flame lengths > 6.6 ft (2 m)	25	28.7	+3.7	29.3	25.3	-4
Fraction of fireshed with CBP > 0.1	67.3	54.3	-13	29	12.3	-16.7

Discussion

Several studies have simulated the effects of SPLATs on fire behavior in fire-frequent conifer forests. Here, we use a fully implemented treatment project, with a detailed inventory plot network, incorporating simulated wildfire effects to model fire behavior and forest growth. This and other empirical studies have demonstrated that SPLAT networks will reduce the risk and effects of uncharacteristically severe fire. This is consistent with SPLAT theory in that fire behavior is reduced not only in treated areas but also across the landscape, particularly on the leeside of treatments. Fuel treatments that targeted both ladder and surface fuels (e.g., thinning and prescribed fire at Last Chance, thinning followed by mastication at Sugar Pine) were the most effective at reducing simulated fire behavior.

Last Chance has an overall higher fire risk compared to Sugar Pine as indicated by the higher fireshed-level CBP, which is attributed to differences in forest structure--Sugar Pine has lower tree density and higher basal area and canopy base height-- and management history. Based on our simulations, fuel treatment scale and intensity should have the capacity to modify landscape fire behavior at both sites for two to three decades. Although we do not model it, maintenance treatments that would reduce surface fuels, namely prescribed fire, would probably extend treatment longevity across both landscapes. This is especially true considering most of the treatments focused on reducing ladder fuels, resulting in augmented surface fuels or a negligible change compared to pretreatment fuel conditions.

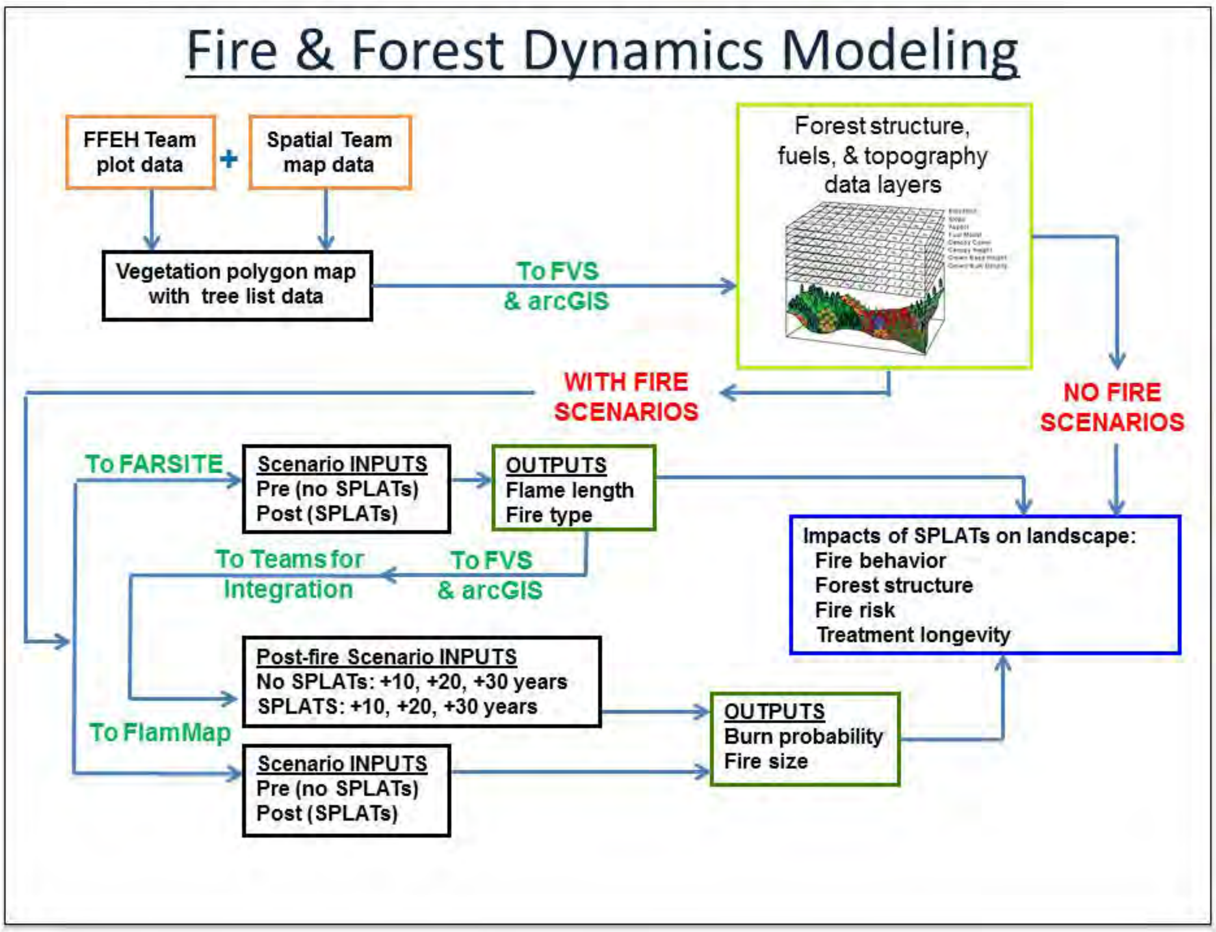

Figure 3-1: Flowchart of fire behavior and forest dynamics modeling used by the FFEH Team.

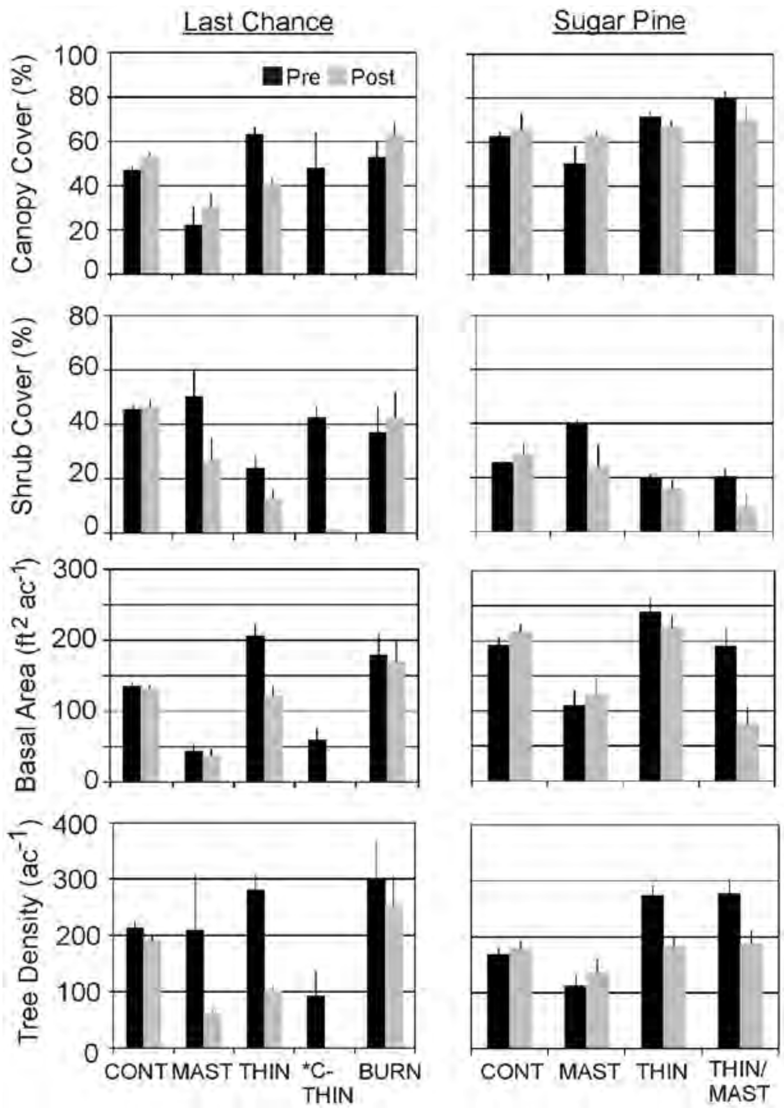

Figure 3-2: Changes in forest structure by treatment type at both Sierra Nevada Adaptive Management Project study areas, Sierra Nevada, California. Results based on pre- and post-treatment forest inventory plot measurements. Tree density and basal area are for trees with diameters > 2 in. CONT, control; MAST, mastication; THIN, thinning; C-THIN, cable logging; THIN/MAST, thinning followed by mastication; BURN, prescribed fire. *Only two plots were located in cable logging units and these had to be relocated for post-treatment measurements, prohibiting direct comparisons to pre-treatment measurements.

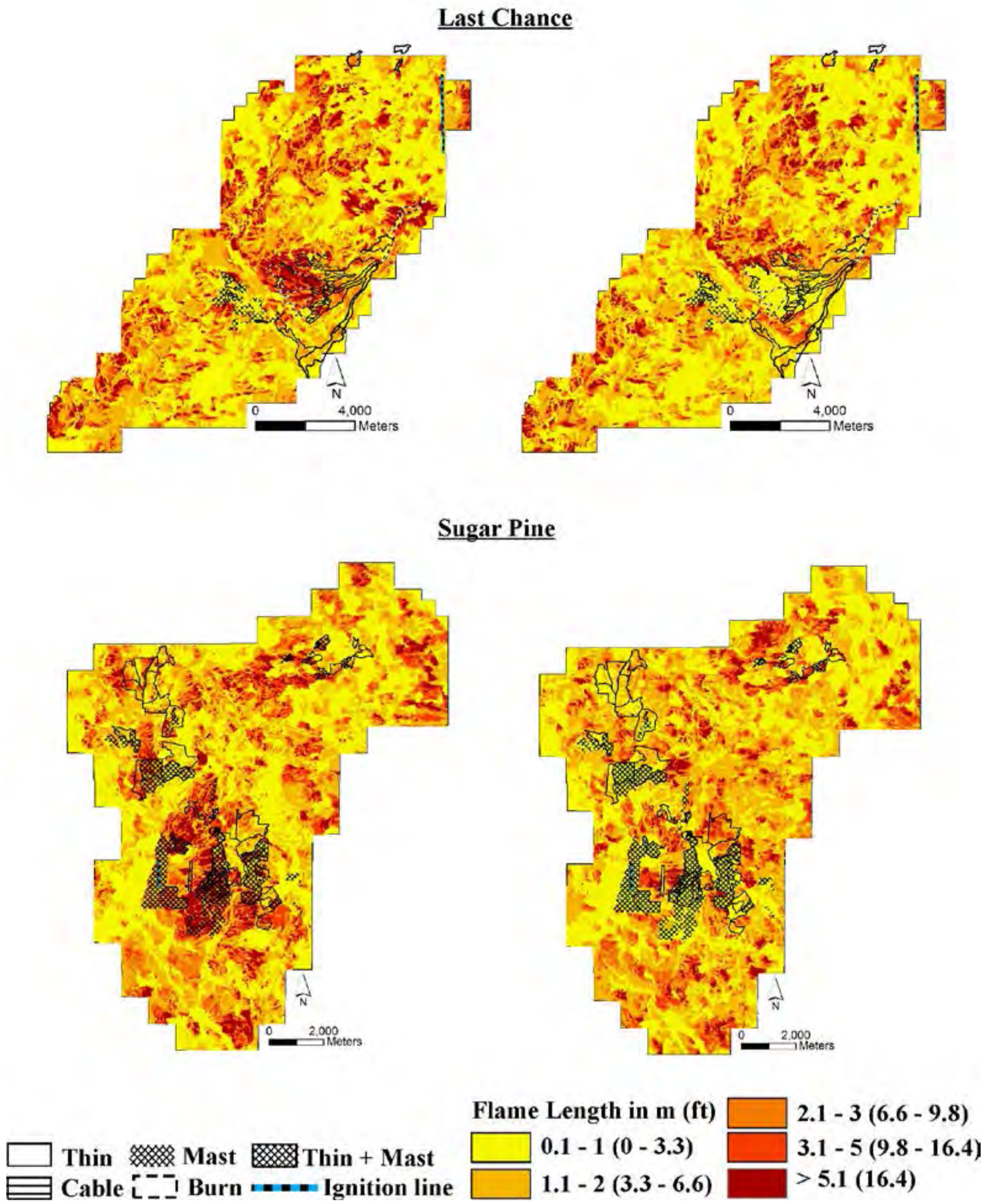

Figure 3-3: Simulated flame lengths for forest conditions pre-(left) and post-(right) implementation of SPLATs at both Sierra Nevada Adaptive Management Project study areas, Sierra Nevada, California. Results based on FARSITE fire growth simulations. Models were parameterized with plot-level tree lists and scaled to stand polygons using vegetation map. The simulated wildfire occurs immediately after pre- and post-treatment plot measurements. Thin, thinning; Mast, mastication; Thin+Mast, thinning followed by mastication; Cable, cable logging; Burn, prescribed fire.

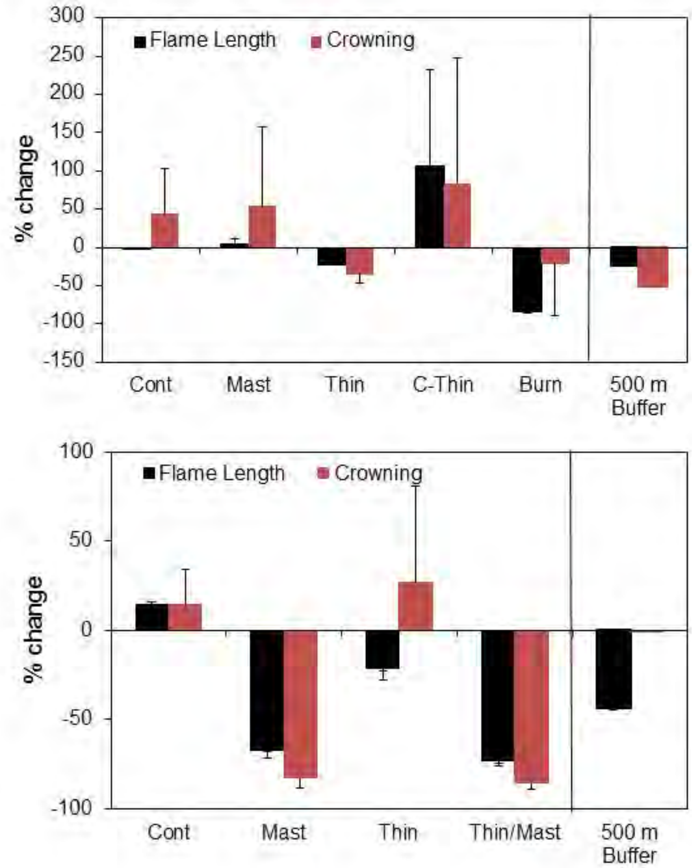

Figure 3-4: Changes in average flame length and proportion of the stand crowning by treatment type at Last Chance (top) and Sugar Pine (bottom) study areas, Sierra Nevada, California. Results based on comparisons of FARSITE pre- and post-treatment fire growth simulations. Cont, control; Mast, mastication; Thin, thinning; C-Thin, cable logging; Thin/Mast, thinning followed by mastication; Burn, prescribed fire.

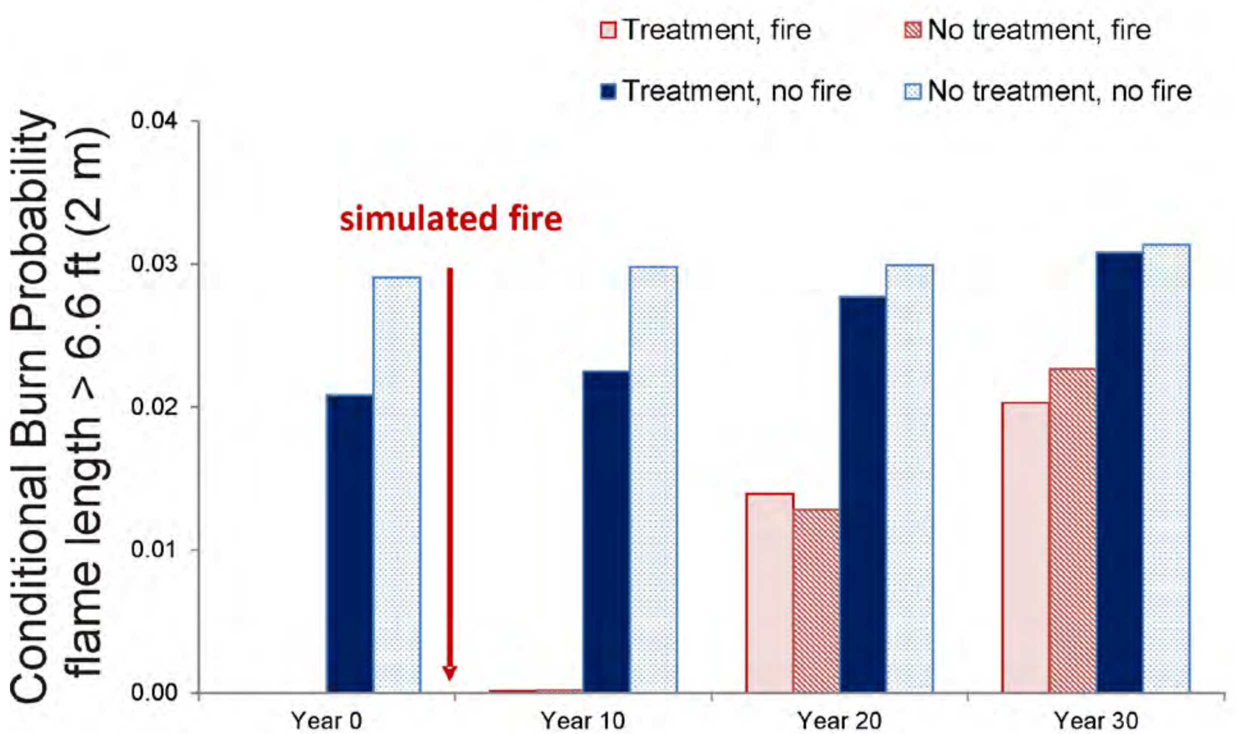

Figure 3-5: Changes in conditional burn probability by treatment and time at Last Chance study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using lidar and other spatial data. The simulated fire occurs immediately after Year 0 is measured. Results for the treated fireshed only.

Figure 3-6: Changes in conditional burn probability by treatment and time at Sugar Pine study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using lidar and other spatial data. The simulated fire occurs immediately after Year 0 is measured. Results for the treated fireshed only.

Extended abstract for Forest Ecosystem Health

Introduction

The 2004 Sierra Nevada Forest Plan Amendment (USFS 2004) included along with a strategy to modify wildland fire behavior the specific objective of improving tree vigor and overall forest health by reducing stand density. This concern over the health of the Sierran forests expressed by the federal land managers was shared by the state (FRAP 2003) as was the cause, namely increased competition in the more crowded stands. More recent evidence has linked rising tree morbidity and mortality in Sierran forests with worsening climatic water deficits (van Mantgem and Stephenson 2007), continued exposure to chronic air pollution (Panek et al. 2013), and greater susceptibility to beetle kill (Hicke et al. 2013).

In this context, forest health is narrowly defined in terms of tree demography, specifically the growth and mortality of canopy-sized individuals. While this definition recognizes the role of trees as the foundational organism in forest ecosystems (Ellison et al. 2005), it does not encompass the term's broad normative usage in a forest management context (Sulak and Huntsinger 2012). However forest health in all its complexity is difficult to quantify, but we can measure the performance of trees. Therefore our fundamental premise is that "healthy" trees are a necessary but not sufficient component of a "healthy" forest.

Of the suspected contributors to tree decline in the Sierra Nevada, tree density may be the most important factor that forest managers can affect, although species composition and tree arrangement are readily managed. In fact, a presumed co-benefit of fuel reduction strategies designed to modify fire behavior is the attendant reduction in competition associated with canopy thinning. The contention is that coordinating these treatments across the landscape not only would reduce the probability of high severity fire but also materially improve the health of the trees. Typically tree health is defined in terms of growth with a healthier tree expected to grow faster. The question we ask in regard to forest health is:

Do SPLATs improve the growth of trees at the scale of the fireshed?

Methods

Collectively we explored four scenarios: no fire and no SPLATs; fire and no SPLATs; no fire and SPLATs; fire and SPLATs. Initial parameters were defined using our field data with models extended for 30 years. In the fire scenarios, one explicit "severe" wildfire is modeled immediately after the field measurements (time = 0.1 yr). As noted above, we relied on tree growth metrics to measure health. For the fire scenario, we used the rate of return to pre-fire basal area to quantify forest health differences between treatment and no-treatment. However growth rate by itself is not ideal measure in the no-fire scenario because of its mutual dependence on individual traits (e.g., tree size, tree age) and community characteristics (e.g., tree density, soil fertility, moisture regime). Waring (1997) argued that a good index of forest health is the efficiency with which a stands grows. We defined this growth efficiency as the increment in stand basal area produced per unit leaf area. For all scenarios, we calculated fireshed-level changes in basal area and leaf area index. We used separate measures of forest health for the two fire scenarios: fractional basal area following fire and growth efficiency in the no-fire scenarios. Since the basal area response is on a relative scale, we express growth efficiency relative the maximum efficiency observed for the no-fire scenario.

Results

Based on stand-level classifications, 18.4% of the landscape was included in the SPLATs treatment at Last Chance. The most common treatment was canopy thinning (8% by area) which involved the removal of canopy trees as well as understory “ladder” fuels. Cable logging (1.79% by area) also removed canopy-sized trees. Thus in aggregate the treatments reduced tree density in approximately 12% of the fireshed. Mastication (3.1% by area) and prescribed burning (5.7% by area) accounted for the remaining treatment types. Both are more focused on modifying ground fuels and ladder trees than reducing canopy-tree density.

The implementation of SPLATs at Last Chance reduced tree basal area by 4.0% (Figure 3-7) and leaf area index by 8.8% (Figure 3-8). In the absence of simulated wildfire, these differences gradually increased through time. In contrast, the net loss of basal area and leaf area under the treated scenario was less when the fireshed was burned by wildfire (Figure 3-7, Figure 3-8). Thus the 4% decrease in basal area due to SPLATs reduced overall losses due to fire from 52% (no SPLATs) to only 34% (with SPLATs). Again these differences were maintained for the next 30 years (Figure 3-9). In absence of fire, there were small but consistent increases in growth efficiency associated with the SPLATs treatment (Figure 3-9). The gains in efficiency increased with time.

Based on stand-level classifications, 29.3% of the landscape was included in the SPLATs treatment at Sugar Pine. Most of the treatment involved thinning with or without mastication (25.8% by area). In aggregate, the treatments reduced tree density by 20% on the treated fireshed.

The implementation of SPLATs at Sugar Pine reduced tree basal area by 9.7% (Figure 3-10) and leaf area index by 6.9% (Figure 3-11). In the absence of fire, the treatment effects dissipated with time. By Year 30, treatment basal area was only 3.6% less than no treatment (Figure 3-10) and leaf area index was only 1.8% less (Figure 3-11). Again, more basal area was retained in the treated fireshed (66%) after simulated fire than in the untreated fireshed (59%). These differences continued to Year 30 (Figure 3-12). In the absence of fire, the treatment led to large gains in growth efficiency. For example, in Year 10, stands in the treated fireshed were adding more than twice the growth per unit of leaf area than the untreated stands (Figure 3-12).

Discussion

For both Last Chance and Sugar Pine, there were discernible gains in growth efficiency associated with SPLATs. In other words, leaves on trees in the treated fireshed fixed more carbon per capita than leaves in the untreated fireshed. Reductions in leaf efficiency are typically associated with resource scarcity (e.g., light, water, and/or nutrients) or stress (pest/pathogen attack; pollution). Thus higher efficiency implies greater access to resources and/or lower exposure to stress. Both situations support the contention of improved tree health and by extension forest health.

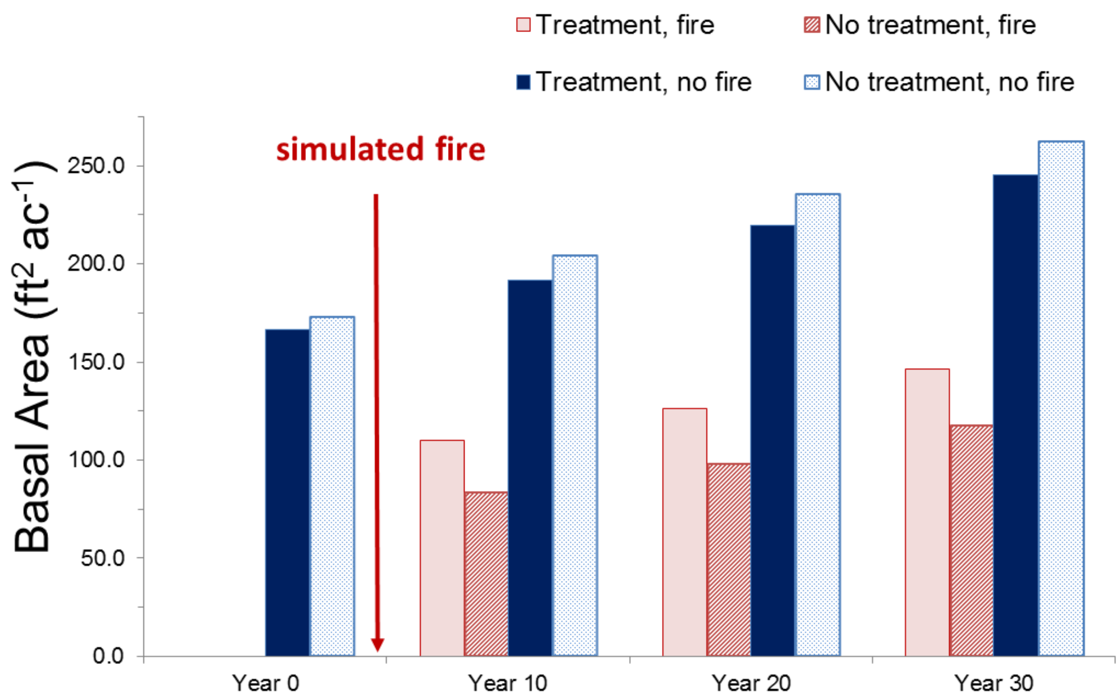

Figure 3-7: Changes in tree basal area by treatment and time at Last Chance study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

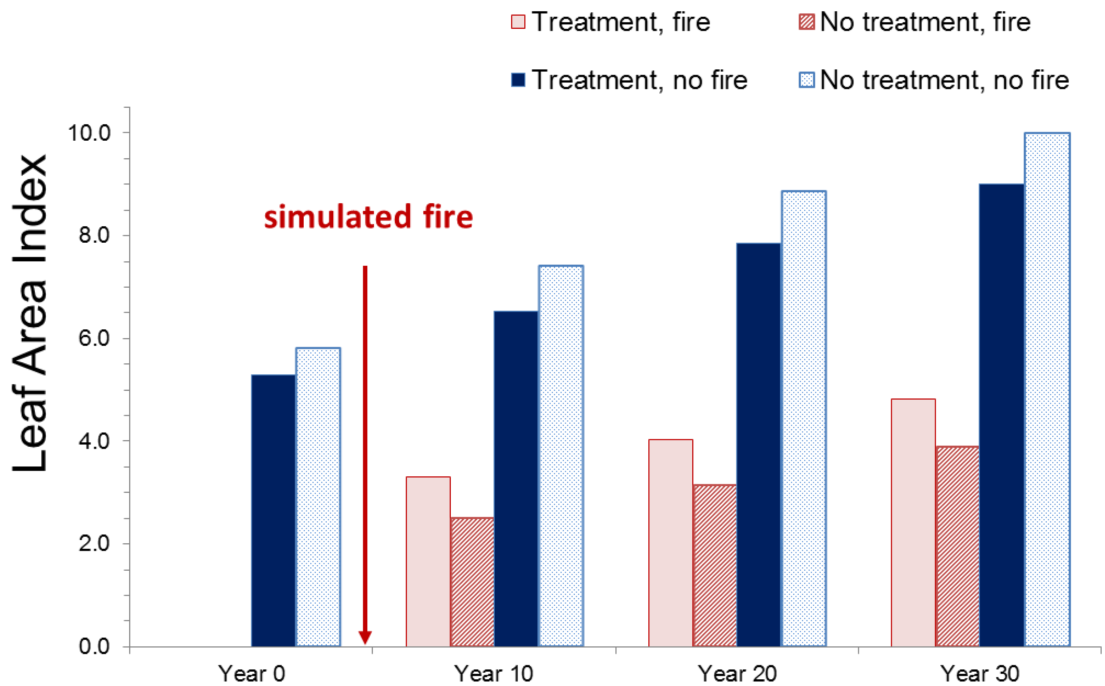

Figure 3-8: Changes in leaf area index by treatment and time at Last Chance study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

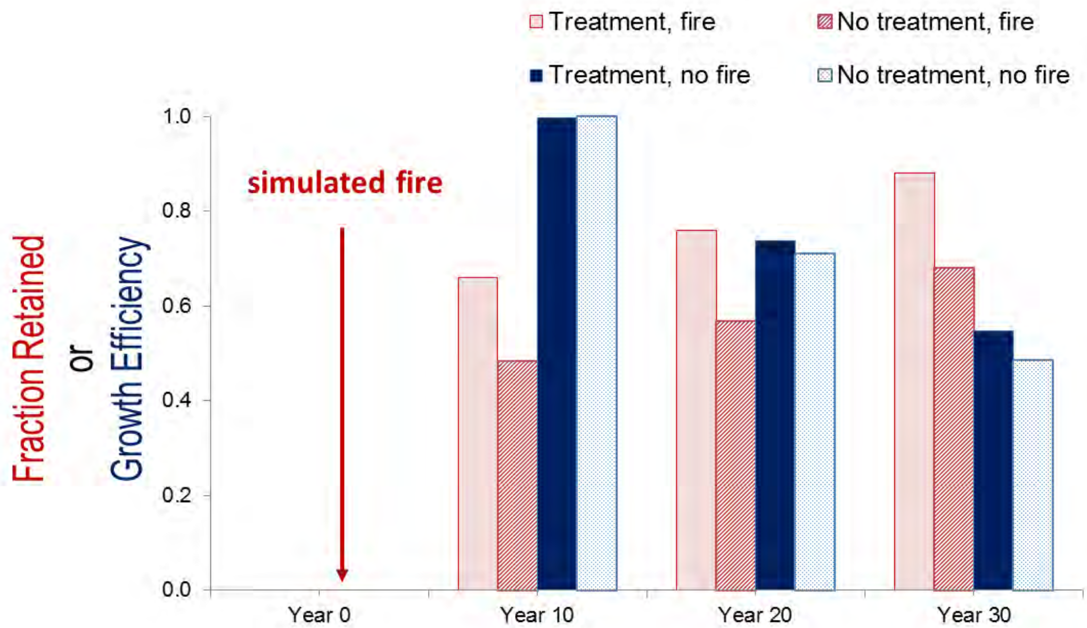

Figure 3-9: Trends in measures of forest health by treatment scenario at Last Chance study area, Sierra Nevada, California. For the fire scenarios, forest health is expressed as the fraction of the Year 0 basal area that is retained. For the no fire scenarios, forest health is expressed as the relative growth efficiency. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. Estimates based on changes that occurred during the interval. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

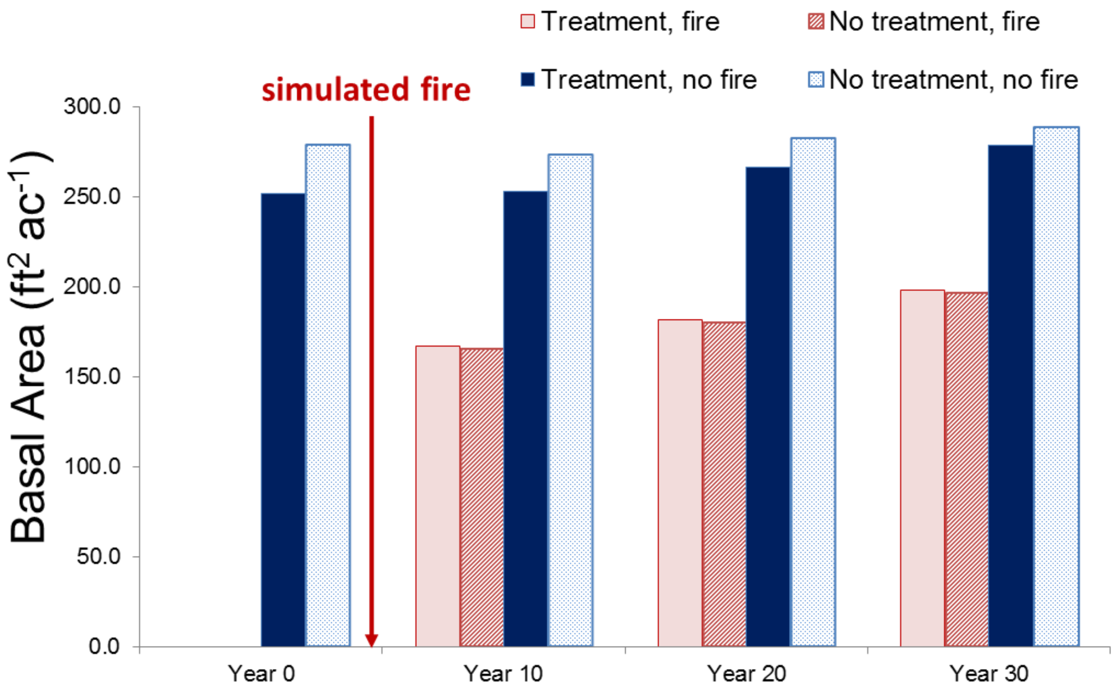

Figure 3-10: Changes in tree basal area by treatment and time at Sugar Pine study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

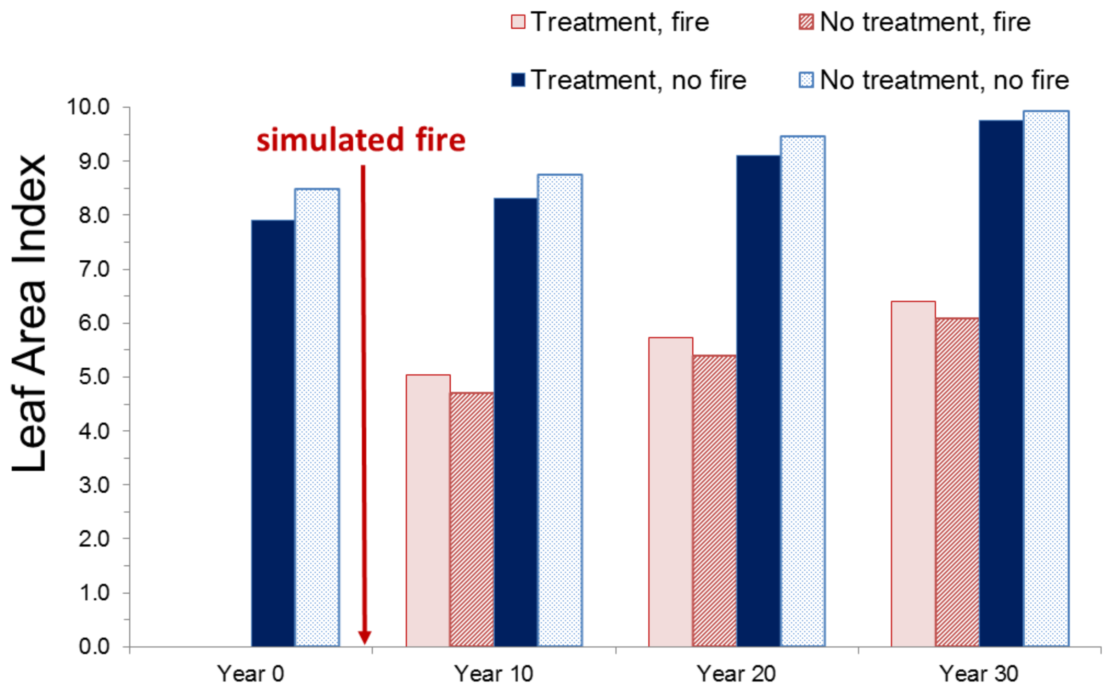

Figure 3-11: Changes in leaf area index by treatment and time at Sugar Pine study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

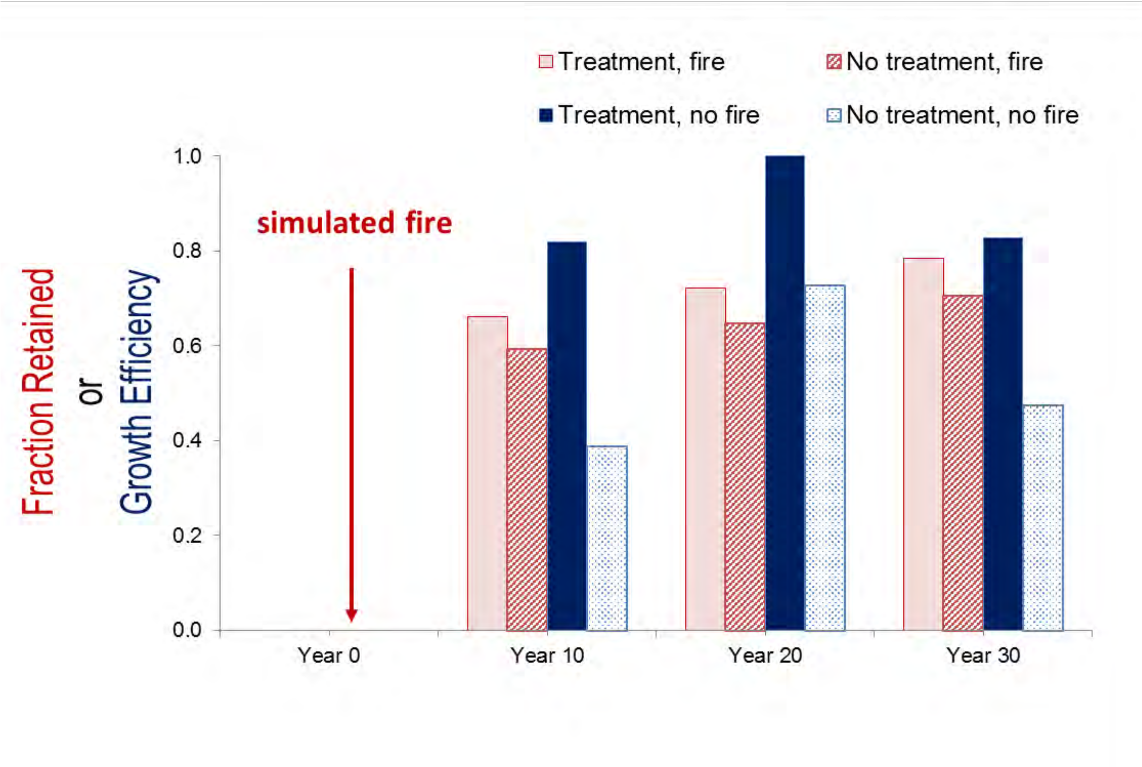

Figure 3-12: Trends in measures of forest health by treatment scenario at Sugar Pine study area, Sierra Nevada, California. For the fire scenarios, forest health is expressed as the fraction of the Year 0 basal area that is retained. For the no fire scenarios, forest health is expressed as the relative growth efficiency. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. Estimates based on changes that occurred during the interval. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

Extended abstract for Spatial Analysis

Introduction

The SNAMP Spatial Team was formed to provide support for the other SNAMP science teams through spatial data acquisition and analysis. The objectives of the SNAMP Spatial Team were: (1) to provide base spatial data; (2) to create quality and accurate mapped products of use to other SNAMP science teams; (3) to explore and develop novel algorithms and methods for Lidar data analysis; and (4) to contribute to science and technology outreach around mapping and Lidar analysis for SNAMP participants. The SNAMP Spatial Team has focused on the use of

Lidar – Light Detection and Ranging, an active remote sensing technology that has the ability to map forest structure.

Lidar data were collected for Sugar Pine (45.2 miles^2 [117 km^2]) in September 2007 (pre-treatment), and Nov 2012 (post-treatment); and for Last Chance (41.3 miles^2 [107 km^2]) on September 2008 (pre-treatment) and November 2012 and August 2013 (post-treatment). Field data were collected at each site according to an augmented protocol based on the FFEH plot method. From the Lidar data, field data, and aerial imagery (for some of the products), a range of map products were created, including: canopy height model, digital surface model and digital terrain model; topographic products (digital elevation model, slope, aspect); forest structure products (mean height, max height, diameter at breast height (DBH), height to Live canopy base (HTLCB), canopy cover, leaf area index (LAI), and map of individual trees); fire behavior modeling products (max canopy height, mean canopy height, canopy cover, canopy base height, canopy bulk density, basal area, shrub cover, shrub height, combined fuel loads, and fuel bed depth), as well as a map of individual trees, and a detailed vegetation map of each site.

Lidar data have been used successfully in the SNAMP project in a number of ways: to capture forest structure; to map individual trees in forests and critical wildlife habitat characteristics; to predict forest volume and biomass; to develop inputs for forest fire behavior modeling, and to map forest topography. The SNAMP Spatial Team also explored several avenues of scientific investigation with Lidar data that resulted in eleven peer-reviewed publications, listed in Appendix G. Our findings have been significant over a range of areas.

Technical developments from the SNAMP Spatial Team

In a comprehensive evaluation of interpolation methods, we found simple interpolation models are more efficient and faster in creating DEMs from Lidar data, but more complex interpolation models are more accurate, and slower (Guo et al. 2010 SNAMP Publication #4). The Lidar point cloud (as distinct from the canopy height model) can be mined to identify and map key ecological components of the forest. For example, we mapped individual trees with high accuracy in complex forests (Li et al. 2012 SNAMP Publication #6 and Jakubowski et al. 2013c SNAMP Publication #24), and downed logs on the forest floor (Blanchard et al. 2011

SNAMP Publication #7). We investigated the critical tradeoffs between Lidar density and accuracy and found that low-density Lidar data may be capable of estimating plot-level forest structure metrics reliably in some situations, but canopy cover, tree density and shrub cover were more sensitive to changes in pulse density (Jakubowski et al. 2013b SNAMP Publication #18).

Lidar data used to map wildlife habitat

Lidar can be used to map elements of the forest that are critical for wildlife species. We used our data to map large residual trees and canopy cover – two key elements of forests used by California spotted owl (*Strix occidentalis occidentalis*) for nesting habitat (Garcia-Feced et al. 2012 SNAMP Publication #5). Lidar also proved useful for characterizing the forest habitat conditions surrounding trees and snags used by the Pacific fisher (*Pekania pennanti*) for denning activity. Large trees and snags used by fishers as denning structures were associated with forested areas with relatively high canopy cover, large trees, and high levels of vertical structural diversity. Den structures were also located on steeper slopes, potentially associated with drainages with streams or access to water (Zhao, et al. 2012 SNAMP Publication #16).

Lidar products used in fire behavior modeling

Forest fire behavior models need a variety of spatial data layers to accurately predict forest fire behavior, including elevation, slope, aspect, canopy height, canopy cover, crown base height, crown bulk density, as well as a layer describing the types of fuel found in the forest (called the "fuel model"). These spatial data layers are not often developed using Lidar (light detection and ranging) data for this purpose (fire ecologists typically use field-sampled data), and so we explored the use of Lidar data to describe each of the forest-related variables. We found that stand structure metrics (canopy height, canopy cover, shrub cover, etc.) can be mapped with Lidar data, although the accuracy of the product decreases with canopy penetration. General fuel types, important for fire behavior modeling, were predicted well with Lidar, but specific fuel types were not predicted well with Lidar (Jakubowski et al. 2013a SNAMP Publication #13).

Use of Lidar for biomass estimation

Accurate estimation of forest AGB has become increasingly important for a wide range of end-users. Lidar data can be used to map biomass in forests. However, the availability of, and uncertainty in, allometric equations used to estimate tree volume influences the accuracy with which Lidar data can predict biomass volume (Zhao et al. 2012a SNAMP Publication #14). Many Lidar metrics, including those derived from individual tree mapping are useful in estimating biomass volume. We found that biomass can be accurately estimated with regression equations that include tree crown volume and that include an explicit understanding of the overlapping nature of tree crowns (Tao et al. 2014 SNAMP Publication #29). Satellite remote sensing has provided abundant observations to monitor forest coverage. Validation of coarse-resolution above ground biomass derived from satellite observations is difficult because of the scale mismatch between the footprints of satellite observations and field measurements. Lidar data when fused with course scale, fine temporal resolution imagery such as MODIS, can be used to estimate regional scale above ground forest biomass (Li et al. 2015 SNAMP Publication #37).

Management implications

Our work has several management implications. Lidar will continue to play an increasingly important role for forest managers interested in mapping forests at fine detail. Understanding the structure of forests – tree density, volume and height characteristics - is critical for management, fire prediction, biomass estimation, and wildlife assessment. Optical remote sensors such as Landsat, despite their synoptic and timely views, do not provide sufficiently detailed depictions of forest structure for all forest management needs. We provide management implications in four areas:

1. Lidar maps and products:

- Lidar data can produce a range of mapped product that in many cases more accurately map forest height, structure and species than optical imagery alone.
- Lidar software packages are not yet as easy to use as the typical desktop GIS software.
- There are known limitations with the use of discrete Lidar for forest mapping - in particular, smaller trees and understory are difficult to map reliably.
- Discrete Lidar can be used to map the extent of forest fuel treatments; treatment methods cannot be detected using discrete Lidar, but waveform Lidar might be alternative choice to map understory change.

2. Wildlife:

- Lidar is an effective tool for mapping important forest habitat variables – such as individual trees, tree sizes, and canopy cover - for sensitive species.
- Lidar will increasingly be used by wildlife managers, but there remain numerous technical and software barriers to widespread adoption. Efforts are still needed to link Lidar data, metrics and products to measures more commonly used by managers such as CWHR habitat classes.

3. Fire behavior modeling:

- Lidar data are not yet operationally included into common fire behavior models, and more work should be done to understand error and uncertainty produced by Lidar analysis.

4. Forest management:

- There is a trade-off between detail, coverage and cost with Lidar. The accurate identification and quantification of individual trees from discrete Lidar pulses typically requires high-density data. Standard plot-level metrics such as tree height, canopy cover, and some fuel measures can reliably be derived from less dense Lidar data.
- Standard Lidar products do not yet operationally meet the requirements of forest managers who need detailed measures of forest structure that include understanding of forest heterogeneity, and understanding of forest change. More work is needed to translate between the remote sensing community and the forest management community to ensure that Lidar products are useful to and used by forest managers.
- The fusion of hyperspectral imagery with Lidar data may be very useful to create detailed and accurate forest species maps.

The future of Lidar for forest applications will depend on a number of considerations. These include: 1) costs, which have been declining; 2) new developments to address limitations with discrete Lidar, such as the use of waveform data; 3) new analytical methods and more easy-to-use software to deal with increasing data sizes, particularly with regard to Lidar and optical imagery fusion; and 4) the ability to train forest managers and scientists in Lidar data workflow and appropriate software.

Extended abstract for California spotted owl

Introduction

The U.S. Forest Service (USFS) identified conservation of the California spotted owl (*Strix occidentalis occidentalis*) as a primary management objective in its 2004 Sierra Nevada Forest Plan Amendment, also known as the 2004 Sierra Nevada Framework (USFS 2004). Within the 2004 Framework, the USFS proposed SPLATs as a strategy for modifying wildland fire behavior and reducing the future risk of spotted owl habitat loss, while acknowledging that SPLATs could have negative, short-term effects on owl habitat. The agency further acknowledged that considerable uncertainty exists about the short- and long-term effects of SPLATs on spotted owls (and other old-forest species), and this uncertainty was one reason that the 2004 Framework proposed the use of an adaptive management approach. Therefore, we assessed the short- and long-term effects of SPLATs on spotted owl demography and habitat. We note, however, that SPLAT effects were confounded with other types of forest disturbance in our short-term analysis (see below).

Methods

To assess the short-term effects of SPLATS on spotted owls, we performed a retrospective analysis using 20 years of demographic data collected at 74 spotted owl territories that included the Last Chance Study Area (LCSA) and the nearby Eldorado Study Area (ESA). This approach deviated from our original plan to directly estimate the effects of SPLATs on spotted owls at Last Chance using a Before-After Control-Impact experimental design, similar to the approach used by some other SNAMP science teams. The revised approach was necessary because there were too few owls present on the LCSA. As a result, we needed to expand, both spatially and temporally, the retrospective analysis to achieve sufficient power to detect changes in owl demographic parameters (Popescu et al. 2012). The drawback to our revised approach was that we could no longer specifically estimate the effects of SPLATs on owls because many different types of timber harvest, as well as wildfire and forest succession, occurred within owl territories during our study period (1993-2012). Thus, we examined the effects of broader categories of forest change (light-, medium-, and high-intensity harvest, wildfire) on owls. The medium-intensity-harvest category contained SPLATs and other USFS treatments conducted prior to the adoption of SPLATs, as well as some harvests on private timberlands.

To assess the long-term effects of SPLATs on spotted owls, we used the fire-modeling and forest-growth results provided by the FFEH Team to perform a prospective analysis (30 years into the future) of the effects of SPLATs and wildfire on spotted owl habitat and demography within the LCSA only. This analysis represented our integration effort with the work conducted by the FFEH and Spatial teams, and we explored the same four scenarios as the other teams (no fire and no SPLATs; fire and no SPLATs; no fire and SPLATs; fire and SPLATs). To compare spotted owl habitat under the different scenarios for the entire LCSA, we developed a logistic regression equation that predicted the suitability of forest stands as owl nesting habitat using canopy-cover and large-tree measurements at nest stands and random locations on the ESA (Bond et al. 2004). To compare fitness (defined as population growth rate [λ]) and equilibrium occupancy (ψ_{Eq}) within the four owl territories on the LCSA, we used the modeled relationships from our 20-year retrospective analysis between the amount of high-canopy-cover forest (≥70% canopy cover, dominated by trees ≥12" [30.5 cm] diameter at breast height) within a territory and owl demographic rates (except for reproduction).

Results

In the retrospective analysis (i.e., short-term effects), correlations existed between owl demographic rates and several habitat variables, but life-stage simulation (sensitivity) analyses indicated that the amount of high-canopy-cover forest was the primary driver of population growth and equilibrium occupancy at the territory scale (Tempel et al. 2014a). Adult survival and territory colonization were relatively high, while territory extinction was relatively low, in territories that had greater amounts of high-canopy-cover forest. Reproductive success was negatively associated with the area of medium-intensity timber harvests within a territory, but was not strongly correlated with the amount of high-canopy-cover forest. In addition, our results suggested that the amount of edge between older forests and shrub/sapling vegetation may result in higher adult survival.

In the prospective analysis (i.e., long-term effects), we projected that SPLATs had a persistent, slightly negative effect on owl habitat and demographic rates for up to 30 years if simulated fire did not occur. After 30 years and no fire, the average habitat suitability (treated = 0.36; untreated = 0.37), mean λ (treated = 0. 850 ± 0. 008; untreated = 0.856 ± 0.005), and mean ψ_{Eq} (treated = 0.883 ± 0.037; untreated = 0.911 ± 0.023) were all greater under the "no treatment" scenario. In contrast, SPLATs had a persistent, positive effect throughout the 30-year period if simulated fire occurred. Thirty years after the simulated fires, the average habitat suitability (treated = 0.20; untreated = 0.17), mean λ (treated = 0.796 ± 0.009; untreated = 0.776 ± 0.008), and mean ψ_{Eq} (treated = 0.577 ± 0.053; untreated = 0.468 ± 0.042) were all greater under the treatment scenario. Although these differences appear modest, we note that small reductions in λ can translate into large population declines over longer time periods.

Discussion

In our retrospective analysis, we found that the amount of high-canopy-cover (≥70%) forest was the covariate most strongly correlated with spotted owl population growth rate and territory occupancy. Furthermore, more than 90% of medium-intensity harvests that occurred in high-canopy-cover forests reduced canopy cover to <70%, suggesting that SPLATs in such stands could have short-term, negative impacts on California spotted owl populations. High-canopy-cover forests declined by an average of 7.4% across territories during our study, suggesting that habitat loss could have contributed to declines in abundance and territory occupancy detected in previous studies of this population (Tempel and Gutiérrez 2013, Tempel et al. 2014b). Thus, we recommend that managers consider the existing amount and spatial distribution of high-canopy-cover forest before implementing SPLATs and that SPLATs be accompanied by a rigorous monitoring program within an adaptive management framework.

In our prospective analysis, we concluded that SPLATs may provide long-term benefits to spotted owls in the event of high-severity fire, but they may have negative effects on owls if fire does not occur. Thus, the net effect of SPLATs on spotted owls depends upon the true, but unknown, probability that high-severity fire effects will occur within individual owl territories. Other key remaining uncertainties include how much high-canopy-cover forest and how many large trees (structural attributes that have been shown to be consistent with high owl fitness) should remain on the landscape, under what conditions might wildfire benefit spotted owls, whether the projected impacts would be different at larger spatial scales that integrate multiple firesheds, and the reliability of simulating the effects of fuels treatments and fire on wildlife (i.e., we had no error estimates for the fire or forest-growth simulations). In conjunction with observed population declines in the last 20 years, we believe these uncertainties warrant an informed approach to landscape-fuels management that explicitly balances the seemingly conflicting goals of providing habitat for owls and reducing fire potential. Specifically, we recommend that the USFS continue its current policy that restricts timber harvest within spotted owl Protected Activity Centers (PACs), which contain ≈309 acres (≈125 ha) of the best habitat used by owls for nesting and roosting over long time periods (Berigan et al. 2012). Furthermore, designing and strategically placing SPLATs to limit the spread of high-severity fire into PACs could benefit owl populations.

Extended abstract for Pacific Fisher

Introduction

Fishers (*Pekania pennanti*) are a medium-sized mammalian carnivore with a pre-European distribution encompassing the boreal forest zone of Canada, the Great Lakes region and northeastern United States, a relatively limited portion of the Rocky Mountains in the United States, and mountainous areas of Washington, Oregon, and California (Powell 1993). The species is uncommon to rare in the western United States, and has been proposed by the US Fish and Wildlife Service for threatened status under the US Endangered Species Act. The California Department of Fish and Wildlife (CDFW) is currently reviewing the status of fishers in the state, with recommendations concerning listing to the Commission expected in 2015. The SNAMP Fisher Project was initiated by the UC Fisher Team in Fall 2007 in association with multiple other SNAMP programs designed to provide an independent evaluation of how vegetation management, prescribed by the 2004 Sierra Nevada Forest Plan Amendment (USFS 2004), affects fire risk, wildlife, forest health and water resources within the Sierra Nevada region. Specific objectives included 1) Determination of all key demographic parameters including age- and sex-specific survival, reproductive rates, and fecundity, and metrics on dispersal and movements. 2) Identify population limiting factors based on cause-specific mortality due to predation, disease, and human-linked factors such as roadkill on local highways. 3) Evaluate the effects of vegetation management on occupancy, survival, and fecundity.

Methods

The SNAMP Fisher Project study area is at the northern edge of the southern distribution of fishers in California, encompassing the area bounded by the Merced River in the north and the San Joaquin River in the south. Administratively, the study area was within the Bass Lake Ranger District in the Sierra National Forest, but early in the study a radio-collared fisher dispersed north into Yosemite National Park, which effectively expanded the study to encompass the southern area of Yosemite National Park. The study area consisted of two regions, the overall monitoring area and the focal study area. The overall monitoring area encompassed approximately 502 miles^2 (1300 km^2) of a topographically complex landscape with elevations ranging from 2,487 ft to 8,701 ft (758 m to 2652 m), and included sufficient habitat such that 20 active animals could be monitored simultaneously. A smaller focal study area was located in the approximate center of the overall monitoring area, centered on the SNAMP Sugar Pine firesheds. In this area, more detailed information on fisher occupancy and habitat use was collected to reflect fisher response to habitat change.

A range of standard methods were used in the study to live-trap, radiocollar and monitor survival status of individual fishers. Monitoring was accomplished almost entirely by fixed-wing aerial radiotelemetry, supported by an “in house” aviation program developed for SNAMP Fisher and administered by the Forest Service. Ground-based radiotelemetry was used to monitor female fishers during denning seasons, and to recover carcasses of deceased fishers. Camera traps were systematically placed within the SNAMP Sugar Pine firesheds and elsewhere in the study near the center points of 0.39 miles^2 (1-km^2) grids to determine variation in occupancy rates related to habitat structure and management activities. Camera traps in the focal study area were surveyed for fisher activity in each year of the study, whereas those placed elsewhere in the overall monitoring area were not.

To evaluate the short-term impacts of SPLATs and associated management activities on fisher, we conducted a multi-year occupancy analysis of the focal study area. We developed local, patch-specific biophysical covariates for use in analytical models of occupancy. We calculated the mean elevation (*elev*) for each surveyed grid. Habitat covariates included the proportion forest (i.e., total tree) and hardwood cover (*denMD*) based on land-cover data derived from satellite imagery (CWHR CalVeg; USDA Forest Service 2012). We also generated three management-oriented covariates for each camera location, with the camera defining the center of a 0.39 $miles^2$ ($1\text{-}km^2$) grid cell. Using the USDA Forest Service FACTS (Forest Service Activity Tracking System) database, we identified all management activities that had occurred in the focal study area between 2002 and 2013, and summed the acreage impacted for each grid cell per year. We grouped management activities as extractive (removal of timber or large trees) and restorative (hazardous fuel management). For each cell, we calculated the percentage of the cell that had been impacted by either type of activity over the 5 years preceding the survey. So, for example, the restorative covariate for a particular grid cell in 2009 would be the percentage of that cell that was impacted by hazardous fuel management activities between 2004 and 2008. We also calculated the overall percentage of each cell impacted by fire, either wildfire or prescribed, in the 50 years prior to the survey year. These variables, management and biophysical, were used to develop an occupancy model reflecting fisher response to habitat change.

To determine the impacts of SPLATs on future fisher habitat availability, we selected two structural variables reflective of fisher habitat suitability: canopy cover and large tree density. The selection of these metrics was guided by field data from both SNAMP Fisher as well as a comparable USFS fisher research project in the High Sierra District of the Sierra National Forest, as well as habitat modelling efforts by the Conservation Biology Institute (CBI). CBI found that out of 10 forest structure variables, canopy cover > 60% and the density of trees > 10” diameter at breast height (dbh) were the two most significant contributors to characterizing fisher denning habitat. Additional field data have further identified 24” dbh as the lower threshold of tree size used by fishers for dens and resting sites. We therefore defined large trees as those with a greater than 24” dbh. Examination of tree lists in the vicinity of known dens sites identified a threshold of 15.4 large trees per acre.

We projected the impacts of SPLATs on these two structural variables using a combination of pre and post-treatment plot data and forest growth and disturbance models (FVS, FARSITE). Four scenarios were considered, similar to the efforts of the other SNAMP teams: treatment with fire, treatment without fire, no treatment with fire, and no treatment without fire. At 10 year time intervals, we quantified the acreage with canopy cover > 60% and large tree density of greater than 15.4 trees per acre. The amount of suitable habitat over time was defined as stands the number of acres that met both criteria.

Results

Between 2007 and 2013, 110 individual fishers were captured, radiocollared, and tracked via aerial telemetry. Surveys with camera traps were completed in 905 unique 1-km^2 grids throughout the overall study area, including 56 grids within the southern region of Yosemite National Park from a companion study funded by the California Department of Fish and Wildlife. Fishers were detected in 448 of the unique grids surveyed, which helped to identify that fishers in this part of the southern Sierra Nevada were most common between 4,500 ft and 6,500 ft elevation (1,372 m and 1,981 m elevation). Occupancy estimates for multi-year surveyed grids corrected for imperfect detection < 1.0 ranged from 0.62 to 0.80. Detection rates for fishers at camera trap stations were much higher in the fall, winter, and spring seasons compared to summer, likely due to availability of a more abundant and diverse prey base in summer compared to winter especially.

The mean number of den trees used per female per denning season was 2.4 (range 1 to 5). We identified 125 unique structures used as natal or maternal dens, including 54 black oak trees, 41 incense cedar trees, 19 white fir trees, 10 sugar pine or ponderosa pine trees, and one canyon oak. We discovered that repeat use of den trees was not uncommon; sixteen individual den trees were used more than once. Fifty-six percent of the trees used for denning in the SNAMP area were live trees (n = 70), whereas 44% (n = 55) were snags. Overall mean DBH of black oak denning structures was 29.3 in (74.4 cm), 45.5 in (115.6 cm) for incense cedar, 42.6 in (108.3) cm for white fir, and 43.8 in (111.2 cm) for pine species. The majority of denning structures used in the SNAMP Fisher study area (83%) were in the elevation range 4,500 ft (1,371 m) to 6,000 ft (1,829 m), and denning structures were typically embedded in areas of high canopy cover (mean = 72%). Shrub cover and aspect near den trees was variable, and most den trees had multiple large down trees/logs nearby, whereas concealment cover to the base of den trees averaged more than 45%.

Multi-season occupancy models failed to identify a relationship between the management covariates and colonization rates, the probability that an unoccupied cell will be occupied the following year. However extinction rates, the probability that a grid cell occupied in one year would be unoccupied the next, were strongly related to the restorative covariate (covariate importance of 98%). Fisher persistence, the likelihood of a cell being occupied given that it was occupied the previous year, was negatively associated with restorative actions; probability of persistence decreased by 27% as the proportion of the grid treated for cumulative restorative fuel reduction increased from 0 (occupancy = 0.89, 95% CI: 0.85, 0.92) to 1.0 (occupancy = 0.65, 95% CI: 0.46, 0.81).

Without simulated fire, we projected that SPLATs had a negative effect on fisher habitat availability, reducing the acreage meeting both threshold values (canopy cover > 60% and ≥ 15.4 large trees per acre) by 2,075 acres (839.7 ha). This difference quickly disappeared; after 10 years SPLATs resulted in 859 more acres (347.6 more ha) meeting both threshold conditions. By year 30, the difference between treated and unlimited scenarios was negligible. With simulated fire, SPLATs had a limited positive impact on fisher habitat availability, resulting in 1,043 more acres (422.1 more ha) of suitable habitat available after 10 years. This positive impact persisted through the modelling period, with 600 more acres (242.8 more ha) meeting both conditions after 30 years.

Discussion

Occupancy modelling indicated that fishers reduced their use of forest patches exposed to higher levels of restorative fuel reduction, i.e., persistence of occupancy declined with additional acreage treated for fire resiliency. However neither restorative nor extractive (i.e., commercial thinning) fuel reduction was related to either initial probability of occupancy or local extinction. This pattern is likely due to interaction of several factors. First, the overall spatial scale of treatments, both restorative and extractive, is relatively small compared to a fisher's home range. Second, evidence indicates that fishers simply shift their space use patterns to avoid small treated areas. And third, evidence indicates that the reduction of surface and ladder fuels may change the small mammal community, therefore limiting fisher prey availability. It is worth noting that even at very high levels of restorative fuel activities (100% of a grid cell treated), the occupancy rate in the Sugar Pine firesheds was predicted to be 65%, a high value given the rarity of fisher across California.

We found that SPLATs caused an immediate 6% reduction in potential fisher habitat. However, they also moderated the impact of fire, resulting in greater available fisher habitat within 30 years. In the absence of simulated fire, the amount of habitat steadily increased over time due to forest succession, and was actually slightly greater on the treated landscape in year 30 than in year 0. The net benefits of SPLATs for the Pacific fisher will depend upon the true, but unknown, probability that high-severity fire effects will occur on a given portion of the landscape. However, future probabilities for specific fire behaviors (e.g., crown-fire initiation) are difficult to estimate, and it is therefore difficult to quantify trade-offs associated with SPLATs in absolute terms (Finney 2005). We further note that the SPLATs that were implemented at Sugar Pine appeared to have relatively modest impacts on forest structure and simulated fire behavior, and that it may be necessary to evaluate additional SPLATs of different intensities over a larger scale to fully assess the effects of SPLATs on fisher habitat.

Extended abstract for Water Quantity

Introduction

Forest management in the Sierra Nevada has a direct impact on the processes driving hydrologic storage and fluxes in these mixed-conifer montane watersheds. Quantifying the effects of historical fire suppression, vegetation treatments for fuel reduction, and wildfire on hydrologic properties is essential for effective land and water resource management. The

California Water Plan (California DWR 2013) specifies the necessity to "implement on-the-ground projects to create empirical evidence needed to justify investment in the upper watersheds" and to "[d]evelop and implement sustainable resource management strategies including adaptive forest management practices, effective fuels reduction programs, and enhanced watershed protection practices". In the Sierra Nevada, winter and spring runoff from seasonal precipitation and snowmelt is a critical source of California water supply, accounting for more than half of the water used in hydropower operations, agricultural irrigation, and municipal water throughout the state (Kattelmann et al. 1983; Department of Water Resources 2009).

When forest vegetation is modified by fuel treatments, wildfire, or climate variability, the change in forest structure has an impact on the net snowpack energy driving snowmelt rates (Black et al. 1991; Essery et al. 2008; Pomeroy et al. 2009; Lawler and Link 2011). Concurrently, the change in vegetation density also has an impact on rate of water lost to the atmosphere through evapotranspiration (Zhang et al. 2001; Moore et al. 2004; Biederman et al. 2014; Brown et al. 2014). The forest structure and associated hydrologic processes have inherent spatial heterogeneity, which can be addressed using hydrologic models supported by high temporal-resolution observations and high spatial-resolution remote sensing data. The question we ask in regard to water quantity is:

Do SPLATs increase runoff at the scale of the fireshed?

Methods

For the purpose of this study, a spatially explicit hydro-ecological model, anchored in observed data, was used to maximize available spatial data and the ability to scale from small to large catchments. The Regional Hydro-Ecological Simulation System (RHESSys; Tague and Band 2004) has been used in research applications of forest and mountain hydrology over a range of geographical regions, including the Sierra Nevada (Christensen et al. 2008; Meyers et al. 2010). RHESSys was calibrated using headwater catchment observations of climate, snow, soil moisture, and stream discharge for the three pre-treatment years (2010-2012), which encompassed wet, average, and dry precipitation conditions. 5000 parameter sets were tested with each headwater model, of which 6 sets in Last Chance and 17 sets in Sugar Pine met the minimum calibration criteria. These four calibration criteria were Nash-Sutcliffe coefficient (NSe; Nash and Sutcliffe 1970) and log-NSe for daily stream discharge greater than 0.60, along with annual and August water yields within 20% of measured values. These requirements ensured good calibration of the seasonal wet and dry periods, along with storm peaks and annual discharge rates. The successful headwater calibrations were then transferred to the fireshed scale, based on geologic similarities between catchments, which has been used to link common hydrologic model parameters in RHESSys (Tague et al. 2013). The results presented here are mean values of all the successful calibration sets run over four years (2010-2013). Changes in forest structure for each scenario were determined by differences in Leaf Area Index (LAI), overstory canopy cover, and understory shrub cover.

Results

Implementation of SPLATs at Last Chance resulted in runoff increases of at least 12% for the initial 20 years, falling to 9.8% by Year 30, when compared to the no treatment scenario (Figure 3-13). Model scenarios included shrub cover, resulting in a LAI decrease of 8.0% due to SPLATs – slightly different from the Fire and Forest Ecosystem Health Team results (Figure 3-15). Vegetation growth following SPLATs showed the reduced biomass densities only lasted for about 10 years, also reducing runoff rates to pre-treatment levels. Including shrub cover, fire without SPLATs reduced vegetation by 49.8% while fire with SPLATs reduced vegetation by 38.1%, increasing respective runoff rates by 66.7% and 54.9%.

SPLAT implementation at Sugar Pine shows runoff increases of less than 3% compared to the no treatment scenario over 30 years (Figure 3-16). With the inclusion of the shrub vegetation layer, SPLATs resulted in a 7.5% decrease in Sugar Pine LAI (Figure 3-18), again slightly different from the Forest Ecosystem Health Team results. Vegetation growth following SPLATs again showed the reduced biomass densities only lasted for about 10 years. Differences in LAI and runoff were less than 3% and 1% respectively after 30 years. Including shrub cover, fire without SPLATs reduced vegetation by 42.5% while fire with SPLATs reduced vegetation by 39.5%, increasing respective runoff rates by 15.2% and 13.1%.

Discussion

Implementing SPLATs, both with and without wildfire, had a greater effect on runoff rates in Last Chance than in Sugar Pine. The difference in the two study area responses can largely be attributed to the differences in precipitation rates. Changes in vegetation at Sugar Pine had minimal effect on annual evapotranspiration (ET) rates, suggesting the forest is more water-limited than at Last Chance, where changes in ET were more closely linked to forest density. This response can be illustrated using the scenario of greatest vegetation change, wildfire without SPLATs, where a 42.5% reduction in Sugar Pine vegetation led to a 2.9% decrease in ET (Figure 3-17). Alternatively, the 49.8% reduction in Last Chance vegetation resulted in a 22.8% decrease in evapotranspiration (Figure 3-14). Although the high-intensity fires can result in greater vegetation reductions and lead to increased runoff, these results did not specifically address water quality issues related to these wildfires such as soil erosion into the stream channel, hydrophobic soils, and elevated snowmelt rates.

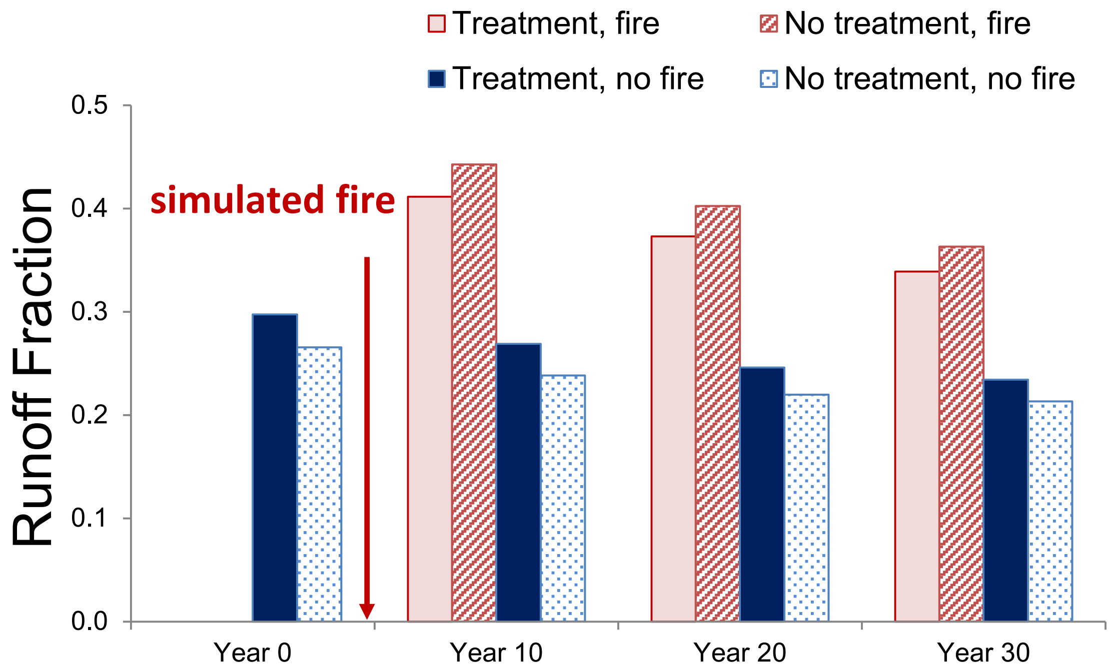

Figure 3-13: Changes in the runoff fraction of precipitation by treatment and time at Last Chance study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

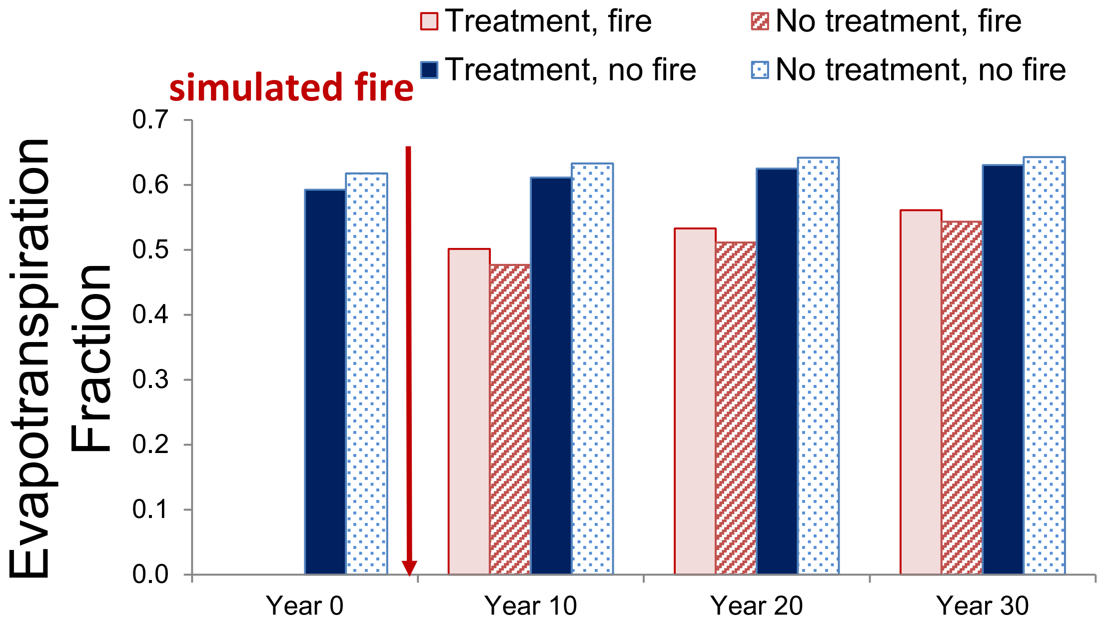

Figure 3-14: Changes in the evapotranspiration fraction of precipitation by treatment and time at Last Chance study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

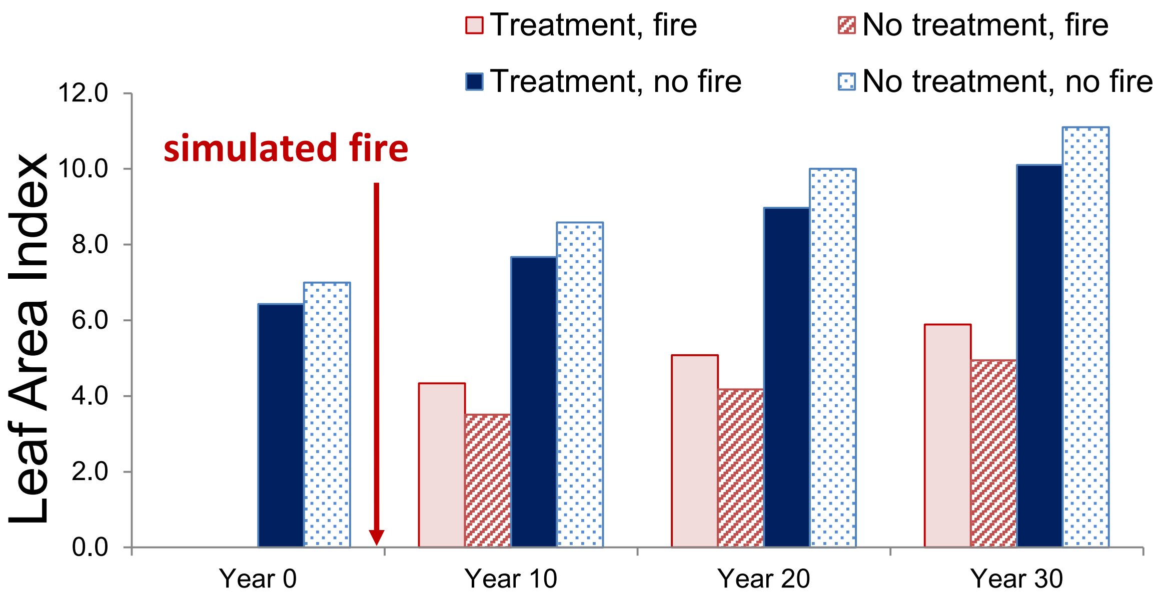

Figure 3-15: Changes in leaf area index by treatment and time at Last Chance study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

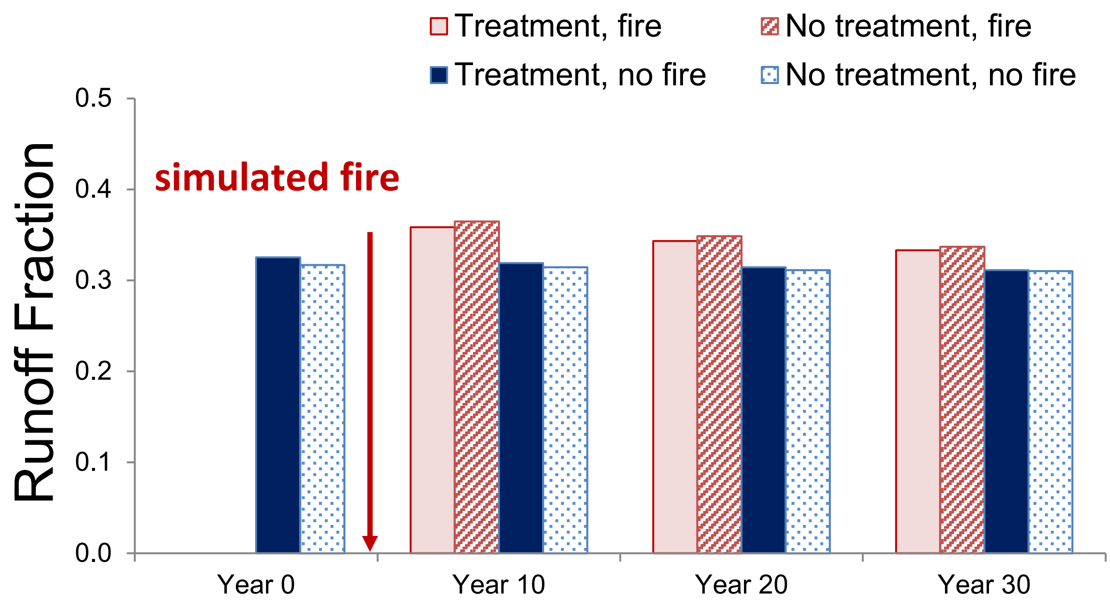

Figure 3-16: Changes in the runoff fraction of precipitation by treatment and time at Sugar Pine study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

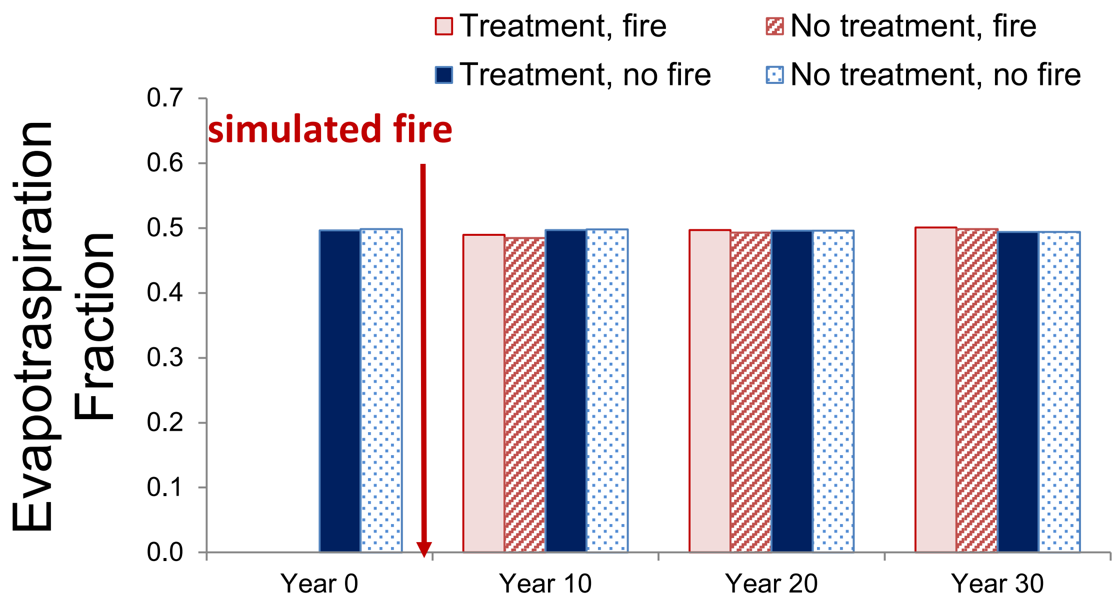

Figure 3-17: Changes in the evapotranspiration fraction of precipitation by treatment and time at Sugar Pine study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

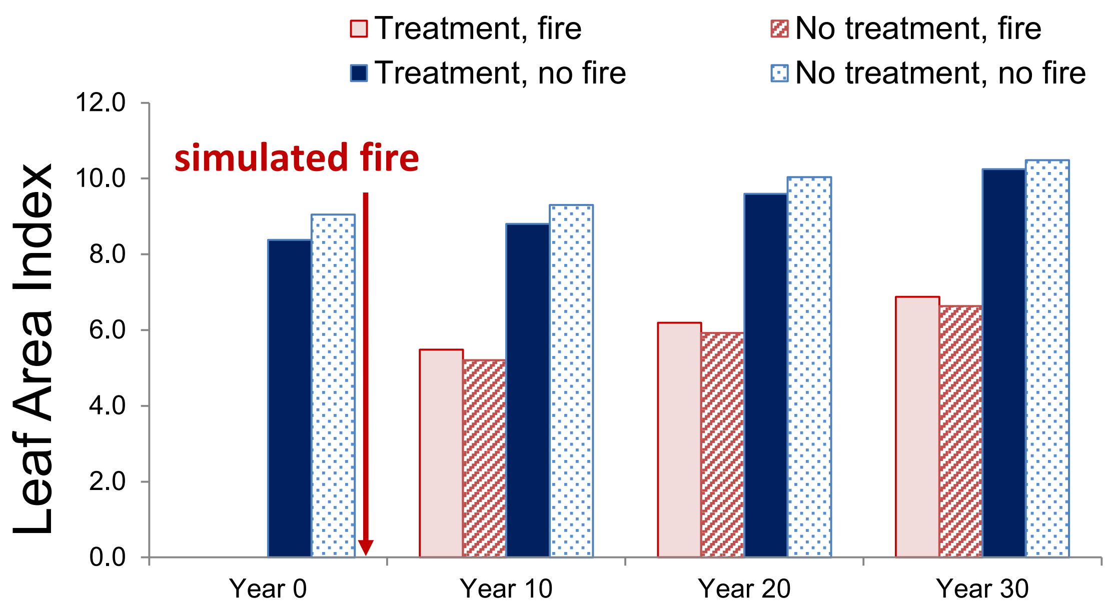

Figure 3-18: Changes in leaf area index by treatment and time at Sugar Pine study area, Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

Extended abstract for Participation

Introduction

The SNAMP integrated focal question can be restated for the Participation Team as:

> **How do SNAMP participants perceive the short term and long term responses of the studied resources to fuels treatments conducted by the Forest Service, and did SNAMP help shape these perceptions?**

Methods

Perceptions of participants were shaped in part by the ways resource specific information was shared with them. Two outreach workers based in the study communities made presentations about SNAMP to local civic clubs, conservation groups, local governments, resource groups and schools as well as hosting and organizing public/annual meetings, integration team (science) meetings, field trips and workshops featuring presentations by rest of the UC Science Team to promote shared understandings of the science. To engage a larger audience, the Participation Team also developed a SNAMP website, science briefs for published journal articles, newsletters, web digests, and webinars.

The Participation Team used information gathered up to the summer of 2014, prior to the final SNAMP results and report, to address the focal question. Only data from interviews and email surveys of SNAMP participants pertaining directly to perceptions of treatment outcomes, and about the role of SNAMP in shaping perceptions, were used in this analysis. Participation Team complete summary, methods, and detailed results are found in Appendix F.

Interviews with 26 SNAMP participants targeting those of a variety of backgrounds, affiliations and viewpoints were conducted between the end of 2013 and the start of 2014. These interviews informed the creation of the 2014 email survey that collected views from those on the SNAMP email distribution list (801 recipients). The email survey results include responses from 258 respondents (a 32% response rate). Combined these two sources of data provide a proportional view of the opinions and perspectives of SNAMP participants via the email survey as well as a descriptive, in depth view of those perceptions via the interview comments.

In both the email and interview surveys, stakeholders were asked for their opinions about how SNAMP fuels reduction treatments influenced the resources studied in SNAMP, including forest health, Pacific fisher, California spotted owl, and water quantity and quality. In some cases, for consistency between the interview and email survey interpretations, affiliations were used to differentiate respondents, breaking them into nine groups: UC Science Team, Forest Service, other state and federal agency participants, environmental NGOs (non-governmental organizations), forest products groups (both for and not for profit), local governments, Native American Tribe representatives, and unaffiliated (including fire safe council members, local citizens and other types of interested parties).

Results

Email survey and interview respondents felt that fuels treatments could impact fire behavior and that the forest health of the two study areas had improved after the treatments were implemented. There were also interviewee and email survey participant results suggesting that the fuels treatments might be too light to protect the landscape from severe fire and interviewees indicated that the studies may not be able to detect treatment impact due to study design limitations.

For treatment impacts on wildlife, email survey participants were divided into thirds with regard to their assessment of the short term impacts (a third felt fisher and owl habitat had improved, a third felt it had deteriorated and a third saw no impact in the short term), while there was more broad support for the idea that the treatments will benefit the species in the long term. The interviewees expressed concerns about short term negative impacts of the machines and structure changes and commonly mentioned that treatment effects might be obscured by other factors affecting the fisher, such as rodenticide, road kill and predation.

Email survey results and interview comments showed almost no support for a negative impact on water quality or quantity from the treatments in the short or long term. Interviewees described treatments that were too light to have an effect and that the study was likely to be too short to be able to detect an effect.

Overall, during the lifetime of the SNAMP project, most email survey respondents reported changes in their opinions during SNAMP. Just over half the email survey respondents felt that SNAMP influenced their opinions on forest health, water and impacts to the owl, but nearly three-quarters felt SNAMP affected their opinions about impacts to the fisher.

Comparing responses by the affiliation of the respondents (Science Team, Public, Forest Service, environmental NGO, etc.) showed no statistical differences in responses about the likely treatment impacts on the fisher and the owl; the majority of people in each group responded the same way. Most affiliation groups also had similar distributions of responses about the impacts on water quality and quantity, but the UC scientist responses differed. Science team members were more likely to report an opinion of no impact on water quality in the long term whereas local government participants were more likely to predict a positive impact on water quality in the long term. Forest products participants separated themselves from the group because they more often reported an opinion that, in the long term, forest health would not be improved—comments indicated that most felt that the treatments did not remove enough material to improve forest health over the long term.

The forest products email survey participants were also less likely to report they had learned or changed their opinions about any topic studied in SNAMP. Interviews revealed that forest products participants often referred to their own observations from working in the forest in preference to SNAMP information. The unaffiliated citizens who participated in the email survey frequently selected "I do not know enough to have an opinion" about the impacts of the treatments and this could be why they were also less likely to respond that they experienced a change in opinion from the influence of SNAMP. In contrast, the unaffiliated citizen interviewees did report learning from SNAMP.

Most interviewees who learned from SNAMP talked about learning about the forest management context, agency decision-making, and the ins and outs of fuels management, and emphasized that the field trips were very important for their learning. There was an incredible amount of learning mentioned about basic fisher biology and about owls and habitat use. Many interviewees talked about learning from the Water Team about the process of doing hydrological studies and the techniques and equipment required. The learning in SNAMP was novel for some and reaffirmed, confirmed and strengthened many participant opinions. Nevertheless, the completed SNAMP report is what many participants said they would eventually base their opinions on.

Learning was also fostered other ways. Interviewees reported that events that included face-to-face meetings with the UC Science Team were especially good venues for learning. Participants agreed strongly on post event evaluations that they learned something new at the integration science meetings, field trips, and subject matter workshops (these workshops went beyond SNAMP science and were aimed at applied management but were not always SNAMP sponsored). They appreciated the subject matter workshops for their hands-on activities and the field trips for the opportunity to visualize and discuss conceptual terms such as "resiliency" and "forest health" in tangible ways that cannot readily be done in other meetings.

Discussion

SNAMP's outreach program created an array of participation options to promote learning through in-person events and information sharing at a distance. Evaluation information showed that in-person events, most importantly field trips and subject matter workshops were best for science learning. Overall, results demonstrated public endorsement of the fuels treatments by participants, showed that participants learned from SNAMP, and revealed that most participants thought that long-term treatment impacts would be positive. For all SNAMP focal areas, some participants changed opinions and most learned from the project. This was the case most strongly with forest health, fire behavior and fisher.

A focus on learning dominated every aspect of the SNAMP process from the original title of the work plan ("Learning how to apply adaptive management…") to the final public meeting and creation of the final report. The extensive outreach effort allowed participants to learn from the scientists and change or support their opinions. Shared understandings evolved around the impacts of treatments on the studied resources, as well as around the underlying assumptions of the project: what constitutes forest health and adaptive management process itself (Sulak and Huntsinger 2012; Sulak et al 2015 and see Appendix F of this report). In terms of outreach approaches, while integration meetings, in which direct dialogue with managers and scientists were facilitated, were strongly appreciated, outreach field trips were the most popular and accessible to a broad audience.

References

Berigan, W.J., R.J. Gutiérrez, and D.J. Tempel. 2012. Evaluating the efficacy of protected habitat areas for the California spotted owl using long-term monitoring data. Journal of Forestry 110: 299–303.

Biederman, J., A. Harpold, D. Gochis, B. Ewers, D. Reed, S. Papuga, and P. Brooks. 2014. Increased evaporation following widespread tree mortality limits streamflow response. Water Resour. 50: 5395–5409, doi:10.1002/2013WR014994.

Black, T., J.-M. Chen, X. Lee, and R. Sagar. 1991. Characteristics of shortwave and longwave irrandiances under a Douglas-fir forest stand. Can. J. For. Res. 21: 1020–1028.

Blanchard, S., M. Jakubowski, and M. Kelly. 2011. Object-Based Image Analysis of Downed Logs in Disturbed Forested Landscapes using Lidar. Remote Sensing 3: 2420-2439.

Bond, M.L., M.E. Seamans, and R.J. Gutiérrez. 2004. Modeling nesting habitat selection of California spotted owls (*Strix occidentalis occidentalis*) in the central Sierra Nevada using standard forest inventory metrics. Forest Science 50: 773–780.

Brown, M.G. et al. 2014. Evapotranspiration and canopy characteristics of two lodgepole pine stands following mountain pine beetle attack. Hydrol. Process. 28(8): 3326–3340, doi:10.1002/hyp.9870.

California Department of Water Resources (DWR). 2013. California Water Plan Update 2013: Investing in Innovation & Infrastructure. Sacramento, CA.

Christensen, L., C.L. Tague, and J.S. Baron. 2008. Spatial patterns of simulated transpiration response to climate variability in a snow dominated mountain ecosystem. Hydrol. Process. 22(January): 3576– 3588, doi:10.1002/hyp.

Ellison, A.M., M.S. Bank, B.D. Clinton, E.A. Colburn, K. Elliott, C.R. Ford, D.R. Foster, B.D. Kloeppel, J.D. Knoepp, G.M. Lovett, J. Mohan, D.A. Orwig, N.L. Rodenhouse, W.V. Sobczak, K.A. Stinson, J.K. Stone, C.M. Swan, J. Thompson, B.V. Holle, and J.R. Webster. 2005. Loss of foundation species: Consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment 588 3:479-486.

Essery, R., J. Pomeroy, C. Ellis, and T. Link. 2008. Modelling longwave radiation to snow beneath forest canopies using hemispherical photography or linear regression. Hydrol. Process. 22: 2788–2800, doi:10.1002/hyp.6930.

Finney, M.A. 2005. The challenge of quantitative risk analysis for wildland fire. Forest Ecology and Management 211: 97-108.

FRAP. 2003. The Changing California: Forest and Range 2003 Assessment Summary. Fire and Resource Assessment Program. California Department of Forestry and Fire Protection. http://frap.fire.ca.gov/data/assessment2003/index.html.

Garcia-Feced, C., D. Tempel, and M. Kelly. 2011. LiDAR as a tool to characterize wildlife habitat: California spotted owl nesting habitat as an example. Journal of Forestry 108(8): 436-443.

Guo, Q., W. Li, H. Yu, and O. Alvarez. 2010. Effects of topographic variability and lidar sampling density on several DEM interpolation methods. Photogrammetric Engineering and Remote Sensing 76(6): 701–712.

Hicke, J.A., A.J.H. Meddens, C.D. Allen, C.A. Kolden. 2013. Carbon stocks of trees killed by bark beetles and wildfire in the western United States. Environmental Research Letters 8, 035032. doi: 10.1088/1748-9326/8/3/035032.

Jakubowski, M., Q. Guo, B. Collins, S. Stephens, and M. Kelly. 2013a. Predicting surface fuel models and fuel metrics using lidar and CIR imagery in a dense, mountainous forest. Photogrammetric Engineering and Remote Sensing 79(1): 37–49.

Jakubowski, M.K., Q. Guo, and M. Kelly. 2013b. Tradeoffs between lidar pulse density and forest measurement accuracy. Remote Sensing of Environment 130: 245–253.

Jakubowski, M.K., W. Li, Q. Guo and M. Kelly. 2013c. Delineating individual trees from lidar data: a comparison of vector- and raster-based segmentation approaches. Remote Sensing 5: 4163-4186.

Lawler, R.R. and T.E. Link. 2011. Quantification of incoming all-wave radiation in discontinuous forest canopies with application to snowmelt prediction. Hydrol. Process. 25: 3322-3331, doi:10.1002/hyp.8150.

Li, W., Q. Guo, M. Jakubowski, and M. Kelly. 2012. A new method for segmenting individual trees from the lidar point cloud. Photogrammetric Engineering and Remote Sensing 78(1): 75-84.

Li, L., Q. Guo, S. Tao, M. Kelly, and G. Xu. 2015. Lidar with multi-temporal MODIS provide a means to upscale predictions of forest biomass. ISPRS Journal of Photogrammetry and Remote Sensing 102: 198-208.

Meyers, E.M., B. Dobrowski, and C.L. Tague. 2010. Climate Change Impacts on Flood Frequency , Intensity , and Timing May Affect Trout Species in Sagehen Creek , California. Trans. Am. Fish. Soc., 1657–1664, doi:10.1577/T09-192.1.

Moore, G.W., B.J. Bond, J.A. Jones, N. Phillips, and F.C. Meinzer. 2004. Structural and compositional controls on transpiration in 40- and 450-year-old riparian forests in western Oregon, USA. Tree Physiol. 24(5): 481–91.

Nash, J.E. and J.V Sutcliffe. 1970. River flow forecasting through conceptual models part I --- A discussion of principles. J. Hydrol. 10(3): 282–290.

Panek, J., D. Saah, A. Esperanza, A. Bytnerowicz, W. Fraczek, and R. Cisneros. 2013. Ozone distribution in remote ecologically vulnerable terrain of the southern Sierra Nevada, CA. Environmental Pollution 182, 343-356.

Pomeroy, J., D. Marks, and T. Link. 2009. The impact of coniferous forest temperature on incoming longwave radiation to melting snow. Hydrol. 2525(May): 2513–2525, doi:10.1002/hyp.

Popescu, V.D., P. de Valpine, D. Tempel, and M.Z. Peery. 2012. Estimating population impacts via dynamic occupancy analysis of Before–After Control–Impact studies. Ecological Applications 22:1389–1404.

Powell, R.A. 1993. The fisher: life history, ecology, and behavior, 2nd ed. University of Minnesota Press, Minneapolis, Minnesota, USA.

Stephens, S.L., S.W. Bigelow, R.D. Burnett, B.M. Collins, C.V. Gallagher, J. Keane, D.A. Kelt, M.P. North, L.J. Roberts, P.A. Stine, D.H. Van Vuren. 2014. California spotted owl, songbird, and small mammal responses to landscape fuel treatments. Bioscience doi:10.1093/biosci/biu137.

Stewart-Oaten, A. and J.R. Bence. 2001. Temporal and spatial variation in environmental impact assessment. Ecological Monographs 71: 305-339.

Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "Pseudoreplication" in time? Ecology 67: 929-940.

Sulak, A. and L. Huntsinger. 2012. Perceptions of forest health among stakeholders in an adaptive management project in the Sierra Nevada of California. Journal of Forestry 110: 312-317.

Sulak, A., L. Huntsinger, and S. Kocher. 2015. The Sierra Nevada Adaptive Management Project: Cooperative Extension and University Researchers Collaborate. California Agriculture, in press (Planned for publication 69:1 March 2015).

Tague, C.L. and L.E. Band. 2004. RHESSys: Regional Hydro-Ecologic Simulation System—An Object-Oriented Approach to Spatially Distributed Modeling of Carbon, Water, and Nutrient Cycling. Earth Interact. 8(19): 1, doi:10.1175/1087-3562(2004)8<1:RRHSSO>2.0.CO;2.

Tague, C.L., J.S. Choate, and G. Grant. 2013. Parameterizing sub-surface drainage with geology to improve modeling streamflow responses to climate in data limited environments. Hydrol. Earth Syst. Sci. 17(1): 341–354, doi:10.5194/hess-17-341-2013.

Tao, S., Q. Guo; L. Li, B. Xue, M. Kelly, W. Li, G. Xu, and Y. Su. 2014. Airborne lidar-derived volume metrics for aboveground biomass estimation: a comparative assessment for conifer stands. Agricultural and Forest Meteorology 198-199: 24-32.

Tempel, D.J. and R.J. Gutiérrez. 2013. Relation between occupancy and abundance for a territorial species, the California spotted owl. Conservation Biology 27: 1087–1095.

Tempel, D.J., R.J. Gutiérrez, S.A. Whitmore, M.J. Reetz, R.E. Stoelting, W.J. Berigan, M.E. Seamans, and M.Z. Peery. 2014a. Effects of forest management on California spotted owls: implications for reducing wildfire risk in fire-prone forests. Ecological Applications 24:2089–2106.

Tempel, D.J., M.Z. Peery, and R.J. Gutiérrez. 2014b. Using integrated population models to improve conservation monitoring: California spotted owls as a case study. Ecological Modelling 289: 86–95.

USDA Forest Service (USFS). 2004. Sierra Nevada forest plan amendment: final supplemental environmental impact statement – Record of decision. R5-MB-046. [Vallejo, CA]: USFS, Pacific Southwest Region.

USDA Forest Service (USFS). 2012. CalVeg GIS website. http://www.fs.usda.gov/main/r5/landmanagement/gis.

van Mantgem, P.J. and N.L. Stephenson. 2007. Apparent climatically-induced increase of tree mortality rates in a temperate forest. Ecology Letters 10, 909-916.

Waring, R.H. 1983. Estimating forest growth and efficiency in relation to canopy leaf area. Advances in Ecological Research 13: 327-354.

Zhang, L., W.R. Dawes, and G.R. Walker. 2001. Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water Resour. 37(3): 701–708.

Zhao, F., Q. Guo, and M. Kelly. 2012. Allometric equation choice impacts lidar-based forest biomass estimates: a case study from the Sierra National Forest, CA. Agricultural and Forest Meteorology 165: 64– 72.

Zhao, F., R.A. Sweitzer, Q. Guo, and M. Kelly. 2012. Characterizing habitats associated with fisher den structures in southern Sierra Nevada forests using discrete return lidar. Forest Ecology and Management 280: 112–119.

Chapter 4. INTEGRATED RESOURCES ASSESSMENT

Introduction

Chapter Four addresses one of the primary goals of the Sierra Nevada Adaptive Management Project: an integrated assessment of the impact of SPLATs on forest resources. Appendices A-F describe in detail how the individual resources respond to the fuel treatments. Here we identify the key insight regarding each resource and present these insights in a quantitatively consistent context to evaluate the collective influence of SPLATs. This framework (Figure 4-1) considers both the immediate and long-term impacts of the fuels treatments. These impacts include: the effect of SPLATs on forest composition and structure in the treated area (which causes changes in habitat quality for example); and SPLATs-caused reduction in the hazard posed by a high severity fire.

To complete this assessment, each team selected a synoptic variable (also known as the integration metric) that best captured the resource's response to SPLATs, and the Participation Team contributed participant perspectives on the impact of treatments on those resources as well as the influence of SNAMP science on those perspectives from data collected over the course of SNAMP. The resource integration metrics were informed by the field data collected over the past 7 years and by results from multiple models used to assess post-treatment effects over 30 years. Response to either wildfire (modeled) or SPLATs (field data extended by modeling) were standardized to a baseline condition of the pre-treatment forest. This standardization helped ensure that the integration metrics were broadly comparable in terms of the magnitude of impact on the resource. We have presented results in a consistent graph style that includes four scenarios modeled over a 30 year period:

1) no SPLATs are implemented and no wildfire burns the fireshed (no treatment; no fire);
2) SPLATs are implemented and no wildfire burns the fireshed (treatment; no fire);
3) no SPLATs are implemented and a wildfire burns the fireshed immediately following Year 0 (no treatment; fire); and
4) SPLATs are implemented and a wildfire burns the fireshed immediately following Year 0 (treatment; fire).

Our hope is that these standardized integration metric graphs, presented together, will provide managers and stakeholders with the ability to compare SPLAT effects across resources.

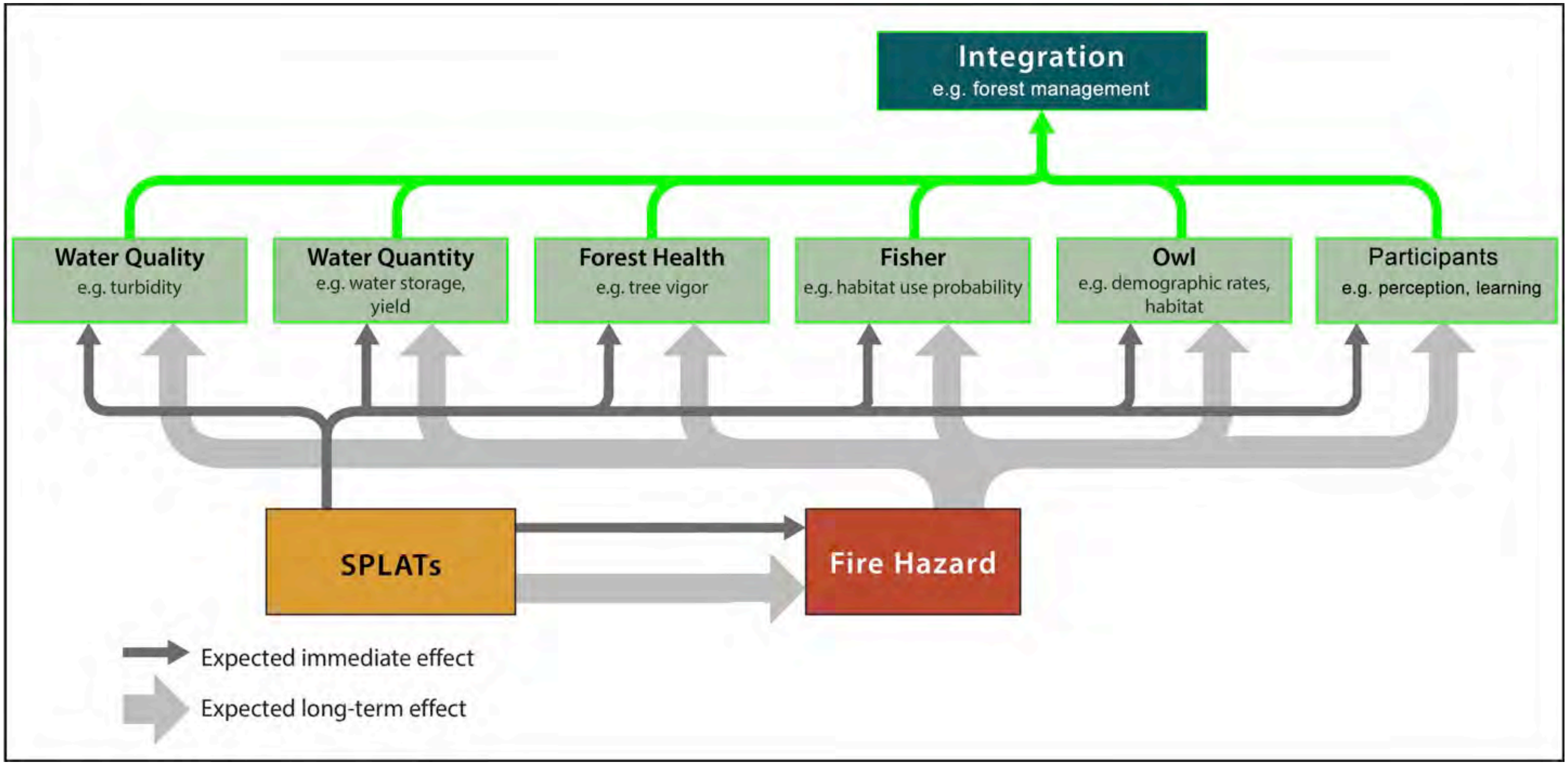

Figure 4-1: The SNAMP integration framework.

Methods

The integration framework required a common spatial and temporal scale. Given the policy directive to manage fire across the landscape, the spatial scale relevant to management was the fireshed. Thus, we combined results from remote sensing with field data to map the firesheds into specific polygons that captured variations in forest composition, canopy structure, and fuel loads across the landscape. Each polygon included the tree lists necessary to simulate forest growth with the Forest Vegetation Simulator (FVS) as well as the information needed to simulate wildfire behavior via FARSITE/FlamMap. The 30-year time frame fit with the expected predicted service life of SPLATs given the expected rate of vegetation recovery.

Because SPLATs are designed to modify the behavior of a "problem fire," we simulated wildfire occurring under severe conditions using dry fuel moisture and extreme (90^{th}-95^{th} percentile) fire weather parameters. In other words, the modeled fire burned at predominantly high intensity and would be difficult to suppress. The start of simulated fire (the ignition line in Figure 4-2) was based on the history of wildfire and determined by the location of the most recent problem fire at each study area.

Based on stand-level classifications, 18.4% of the landscape was included in the SPLAT treatments at Last Chance (Figure 4-2). The most common treatment was canopy thinning (8% by area) which involved the removal of canopy trees as well as understory "ladder" fuels. At Sugar Pine, 29.3% of the landscape was included in the SPLAT treatments. Most of the treatment involved thinning with or without mastication (25.8% by area). Overall the immediate impact of SPLATs was to reduce the flame lengths in the treated fireshed under the wildfire scenario (Figure 4-2) and to lower basal area under the no fire scenario (Figures 4-3 and 4-4).

In an attempt to reduce conflict over forest management in the Sierra Nevada, learning through adaptive management about this integration of the impacts of SPLATs by all participants was the foundational concept for the SNAMP project. To facilitate learning, the Participation Team conducted an extensive outreach program associated with the science conducted in SNAMP, consisting of a website, annual meetings, integration team (science) meetings, field trips, subject matter workshops featuring presentations by the UC Science Team and presentations to local study area groups to promote shared understandings of the science (see Appendix F). It was through these kinds of outreach that participants learned from SNAMP. To address this integrated assessment, the Participation Team used information gathered from people affiliated with SNAMP up to the summer of 2014, prior to the final SNAMP results and report. Only data from interviews (26 participants) and email surveys (258 participants, 32% response rate) of SNAMP participants pertaining directly to perceptions of treatment outcomes, and about the role of SNAMP in shaping perceptions, were used in this analysis. In some cases, affiliations were used to differentiate respondents, and we included the perspectives of UC Science Team members. Combined, these two sources of data gave us a proportional view of the opinions and perspectives of SNAMP participants via the email survey as well as a descriptive, in-depth view of those perceptions via the interview comments.

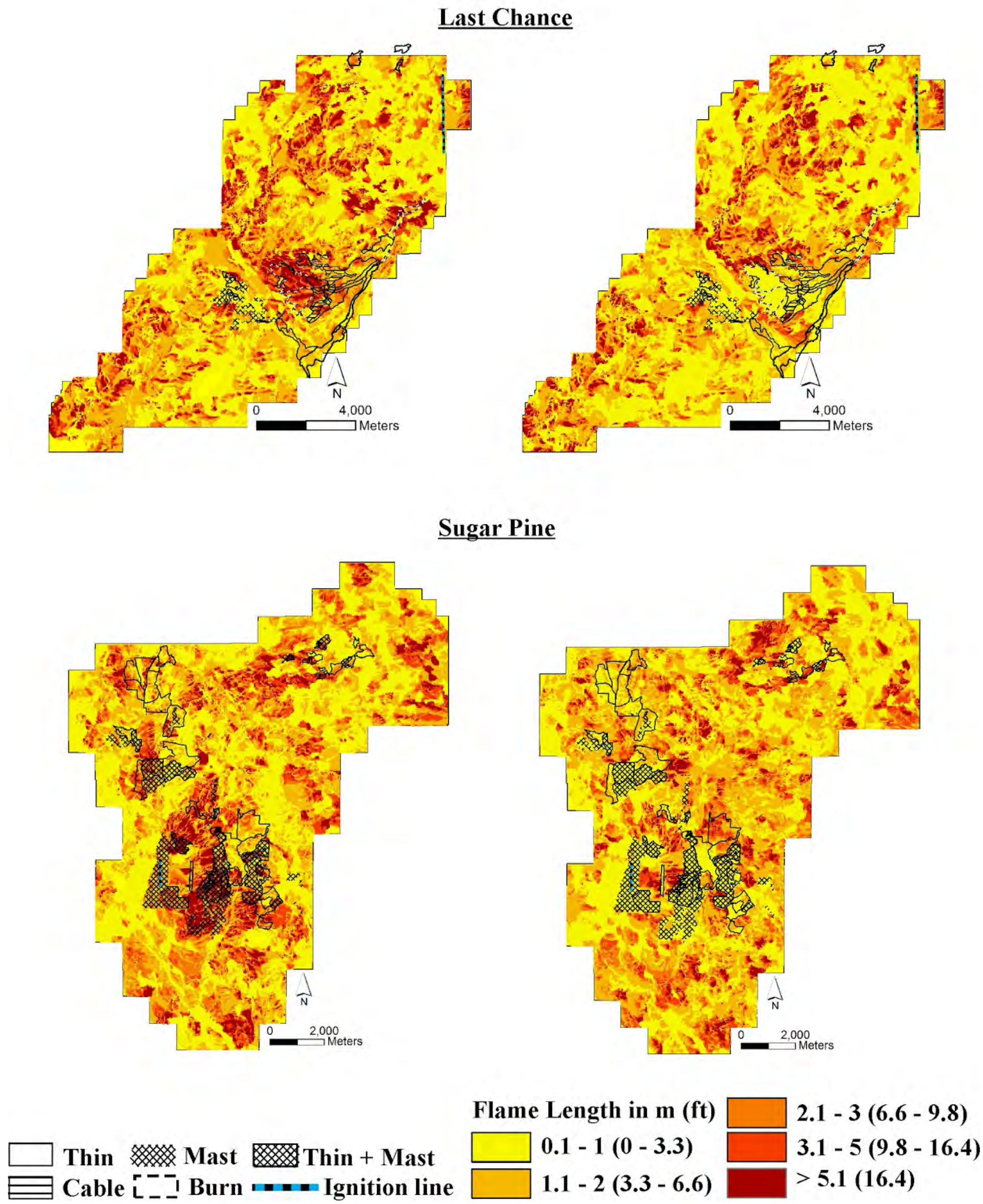

Figure 4-2: Simulated flame lengths for forest conditions pre-(left) and post-(right) implementation of SPLATs at both Sierra Nevada Adaptive Management Project study areas, Sierra Nevada, California. Results based on FARSITE fire growth simulations. Models were parameterized with plot-level tree lists and scaled to stand polygons using vegetation map. The simulated wildfire occurred immediately after pre- and post-treatment plot measurements as follows: Thin, thinning; Mast, mastication; Thin+Mast, thinning followed by mastication; Cable, cable logging; Burn, prescribed fire.

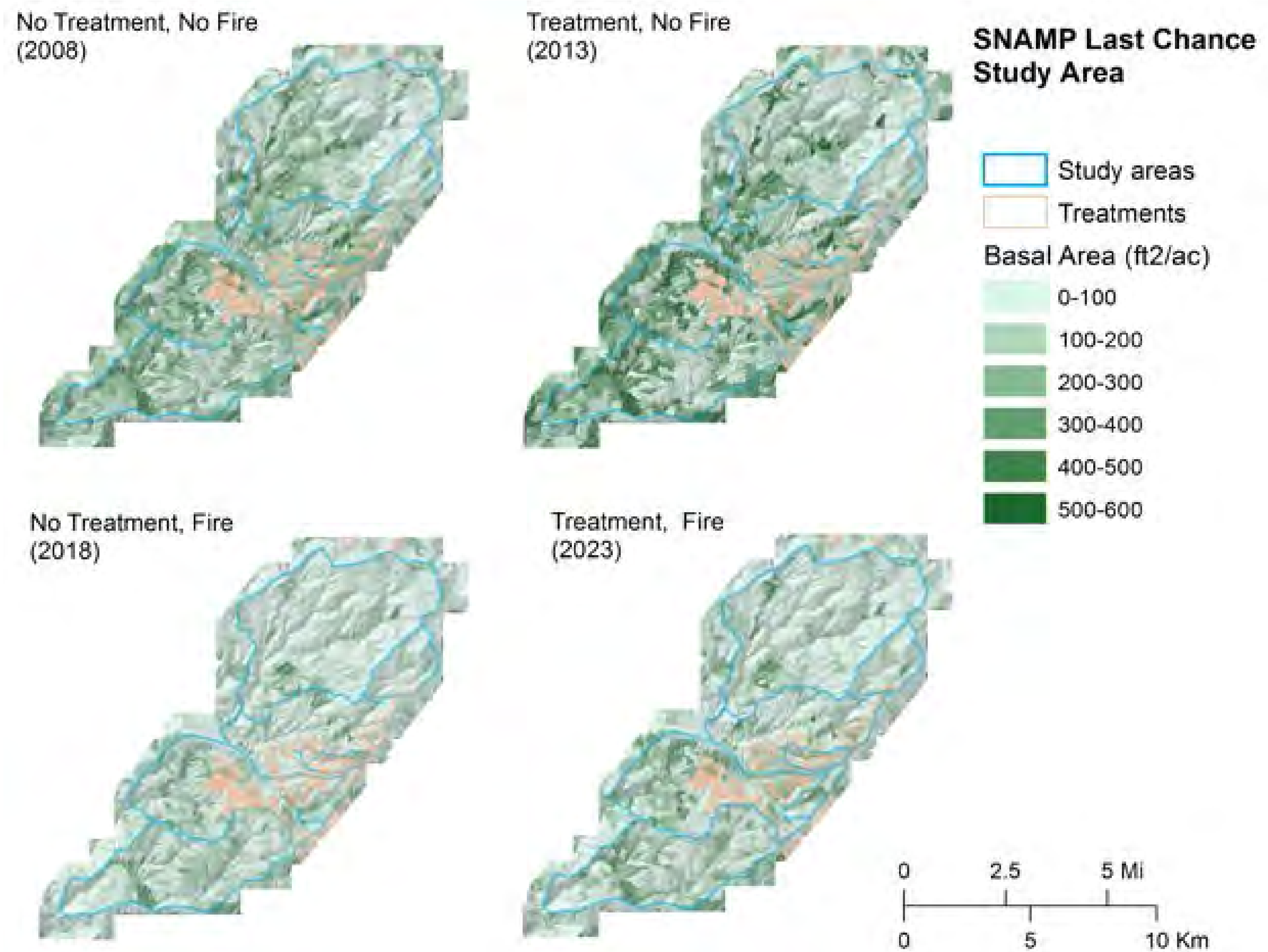

Figure 4-3: Basal area (in ft^2/acre) in 4 scenarios (no fire and no SPLATs; no fire and SPLATs; fire and no SPLATs; fire and SPLATs) at Last Chance, the Sierra Nevada Adaptive Management Project's northern study area in the Sierra Nevada, California.

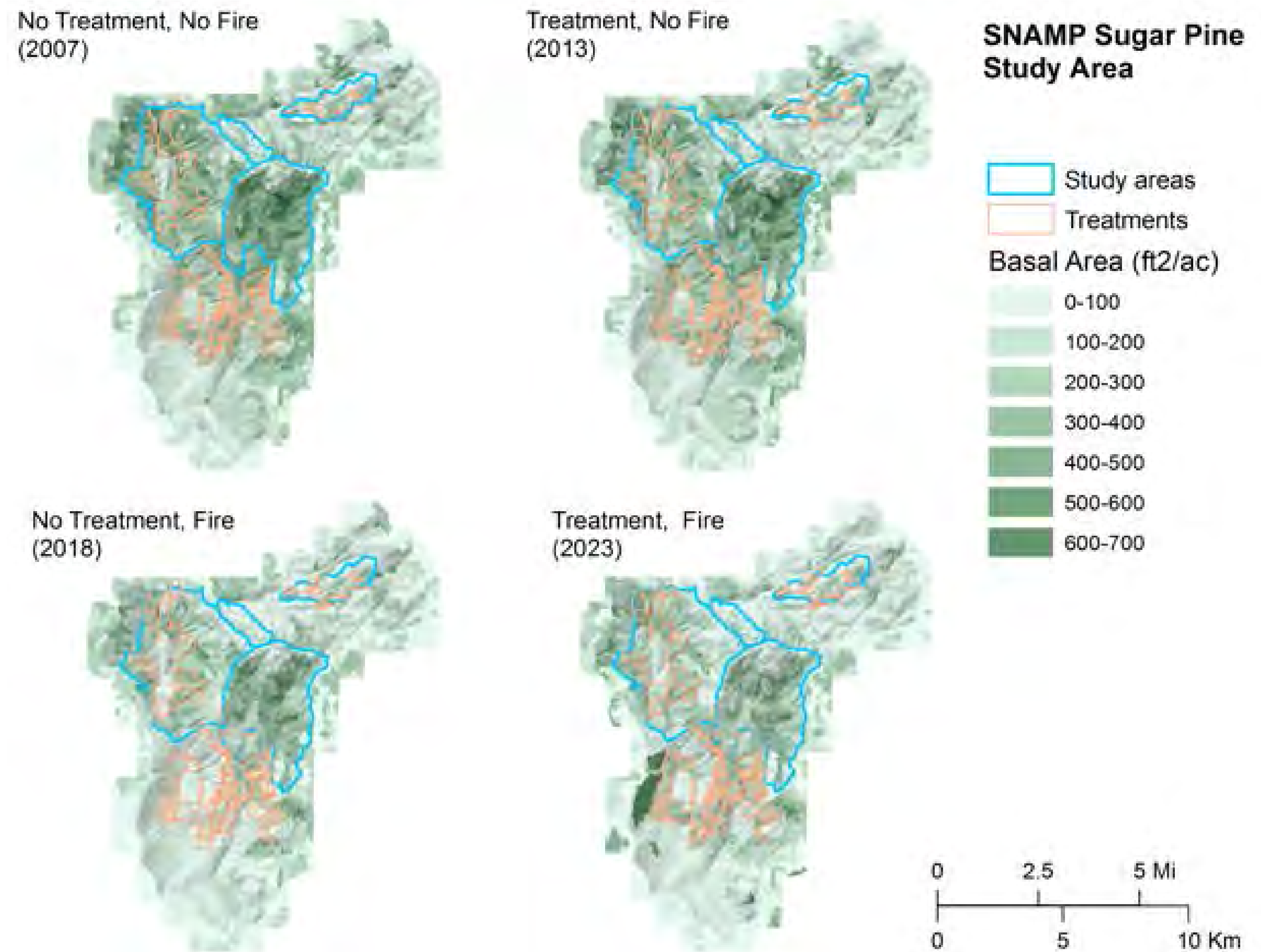

Figure 4-4: Basal area (in ft^2/acre) in 4 scenarios (no fire and no SPLATs; no fire and SPLATs; fire and no SPLATs; fire and SPLATs) at Sugar Pine, the Sierra Nevada Adaptive Management Project's southern study area in the Sierra Nevada, California**.**

Results

Fire behavior

The Fire and Forest Ecosystem Health (FFEH) Team used the fire modeling and forest-growth results to project changes in hazardous fire potential (the conditional burn probability for fire occurring with flame length > 6.6 ft) at both study areas 30 years into the future under four scenarios (no fire and no SPLATs; fire and no SPLATs; no fire and SPLATs; fire and SPLATs). We projected this change within the treated fireshed only. SPLATs had a persistent, slightly positive effect on hazardous fire potential for up to 30 years if simulated fire did not occur. This was evident at Year 0 (blue bars in Figures 4-5 and 4-9) where the conditional burn probability (CBP) for the treatment scenario was 28% and 34% lower at Last Chance and Sugar Pine, respectively, compared to the "no treatment" scenario. This difference waned over time to only a 2-4% difference by Year 30. In contrast, SPLATs had a persistent, positive effect throughout the 30-year period if simulated fire occurred. Following essentially a zero CBP for either scenario immediately following simulated fire (red bars in Year 10), by Year 20 the recovery in CBP towards initial values (blue bars in Year 0) for the treatment scenario (light red bar) reached 67% at Last Chance and 96% at Sugar Pine. For the no treatment scenarios at Year 20 (stripe red bar) the recovery was slower, reaching 44% and 72% at Last Chance and Sugar Pine, respectively. Thirty years after the simulated fires, the average CBP was lower under most of the treatment scenarios. Only with simulated fire at Sugar Pine were CBPs for the treatment scenarios equal. While the impact of SPLATs was lower at Sugar Pine, its overall CBP was also lower.

Although these differences appear modest, we note that reductions in CBP can translate into larger benefits over short time periods. This and other work has shown that SPLATs reduce CBP not only within treated areas but also in stands adjacent to treated areas. The identification of an explicit threshold for the amount of change in CBP for the treatment fireshed is subjective, but nevertheless a decline in hazardous fire potential following treatment will help to reduce the negative consequences of subsequent severe wildfires, resulting in more resilient forests in the long-term.

Forest ecosystem health

We relied on tree growth metrics to measure the forest health response to the four scenarios. For the fire scenario, we used the rate of return to pre-fire basal area to quantify forest health differences between treatment and no-treatment. However, growth rate by itself is not an ideal measure in the no-fire scenario because of its mutual dependence on individual traits (e.g., tree size, tree age) and community characteristics (e.g., tree density, soil fertility, moisture regime). Instead, we used the growth efficiency as the index of forest health, defined as the increment in stand basal area produced per unit leaf area. Because we relied on separate measures of forest health for the two fire scenarios -- fractional basal area following fire and growth efficiency in the no-fire scenarios – we reported the relative change in the indices to ease comparison.

The implementation of SPLATs at Last Chance reduced tree basal area (Figure 4-3). In contrast, the net loss of basal area was less when the fireshed was burned by wildfire (Figure 4-6). Thus, the decrease in basal area attributable to SPLATs reduced overall losses by fire from 52% (no SPLATs) to only 34% (with SPLATs). In the absence of fire, there were small but consistent increases in growth efficiency associated with SPLAT treatments and the gains in efficiency increased with time (Figure 4-6).

The implementation of SPLATs at Sugar Pine reduced tree basal area (Figure 4-4). As at Last Chance, more basal area was retained in the treated fireshed (66%) after simulated fire than in the untreated fireshed (59%). These differences continued to Year 30 (Figure 4-10). In the absence of fire, the treatment led to large gains in growth efficiency. For example, in Year 10, stands in the treated fireshed were adding more than twice the growth per unit of leaf area than the untreated stands (Figure 4-10).

At both study areas, there were discernible gains in fraction of basal area retained (fire scenario) and growth efficiency (no fire scenario) associated with SPLATs. These results supported the contention of improved tree health and by extension forest health. However, the magnitude of increase in growth efficiency related to SPLATs at Last Chance was minor. Thus, fuel treatments at Last Chance under the no-fire scenario most likely did not represent meaningful improvements in tree vigor. On the other hand, the higher efficiencies observed at Sugar Pine implied that the remaining trees have much greater access to resources and/or lower exposure to stress.

Participant perspectives on fire behavior and forest ecosystem health

Participants felt that the treatments improved forest health at both sites (81% and 77% of email survey participants felt the forest health at Sugar Pine and Last Chance, respectively, had improved after treatment in the short term) and would reduce wildfire intensity but that an extreme fire would overwhelm both sites' treatments because not enough material was removed. The SNAMP participants whose interests lay in forest products stood out for their critical view of the results of the treatments, with the following as an exemplar: "In my opinion in north and south sites, we aren't doing enough fuels reduction to make a difference if there is a wildfire."

Most of the affiliation subgroups in the email survey show a majority agreeing that their ideas about the impacts of forest fuel treatments on forest health have changed over the last 7 years, and that SNAMP did influence that change. However, the participants from the forest products industry did not agree that SNAMP had influenced their opinions about forest health, and unaffiliated citizens were split with about half agreeing and half disagreeing that SNAMP influenced their opinions.

Of those who answered "yes" to our interview question regarding opinion change with regard to fuels treatments and their impact on fire behavior, many felt their opinions changed only a little bit: "[SNAMP] helped me to be open to learning" or "I want to say yes but I am not sure how" and "No, not really, but probably just from conversations with [UC scientists] I am more confident that it is [going to have an effect] than I was before. Maybe a little." Most interviewees who learned from SNAMP talked about learning about the forest management context, decision-making and fuels management and emphasized that the field trips were very important for that learning. Over the course of the project, participant definitions of forest health grew closer together.

California spotted owl

The Owl Team used the fire-modeling and forest-growth results provided by the FFEH Team to project changes in California spotted owl habitat, territory fitness (population growth rate, λ), and territory equilibrium occupancy (ψ_{Eq}) at Last Chance 30 years into the future under the four integration scenarios (no fire and no SPLATs; fire and no SPLATs; no fire and SPLATs; fire and SPLATs). Territory fitness represented the population growth rate conferred on resident owls by habitat conditions within a territory, and territory equilibrium occupancy represented the long-term probability that a territory would be occupied by owls in any given year. We projected habitat change at two spatial scales—within the treated fireshed only and within the combined control and treated firesheds. We projected changes in territory fitness and territory occupancy within four owl territories that were located within both the control and treated firesheds. We estimated that the treated fireshed contained slightly more owl habitat than the combined control and treated firesheds at the beginning of the study, but we observed similar patterns in habitat change at both spatial scales over the 30-year period under each scenario (Figures 4-S1 and 4-S2).

We projected that SPLATs had a persistent, slightly negative effect on owl habitat and demographic rates for up to 30 years if simulated fire did not occur. After 30 years and no fire, the average habitat suitability (treated = 0.38; untreated = 0.40), mean λ (treated = 0. 850; untreated = 0.856), and mean ψ_{Eq} (treated = 0.883; untreated = 0.911) were all greater under the "no treatment" scenario (Figures 4-7, 4-S1, and 4-S3). In contrast, SPLATs had a persistent, positive effect throughout the 30-year period if simulated fire occurred. Thirty years after the simulated fires, the average habitat suitability (treated = 0.23; untreated = 0.17), mean λ (treated = 0.796; untreated = 0.776), and mean ψ_{Eq} (treated = 0.577; untreated = 0.468) were all greater under the treatment scenario (Figures 4-7, 4-S1, and 4-S3). Although these differences appear modest, we note that small reductions in λ can translate into large population declines over longer time periods. Thus, the net effect of SPLATs on spotted owls depended upon the true, but unknown, probability that high-severity fire effects will occur within individual owl territories. In addition, our retrospective analysis showed that both territory fitness and equilibrium occupancy had a non-linear relationship with the amount of high-canopy-cover (≥70%) forest within a territory (see Figures 4a and 5a in Appendix C), which was the product of underlying non-linear relationships between high-canopy-cover forest, survival, and territory colonization. The identification of an explicit threshold amount of high-canopy-cover forest to retain within owl territories will be subjective, but nevertheless a steep decline in owl demographic parameters will result as high-canopy-cover forest decreases within a territory.

Pacific fisher

The Fisher Team used the fire-modeling and forest growth results provided by the FFEH Team to project changes in Pacific fisher habitat availability over 30 years under the four integration scenarios (SPLATs and no SPLATs, with and without a simulated wildfire). Specifically, we projected the consequences of each scenario on the acreage of dense canopy cover (>60%) and on the acreage containing at least 15.4 large (dbh > 24 inches [61 cm]) trees per acre, as well as the acreage that met both conditions.

Without simulated fire, we projected that SPLATs had a negative effect on fisher habitat availability, reducing the acreage meeting both threshold values (canopy cover > 60% and ≥ 15.4 large trees per acre) by 2,075 acres (840 ha; Figure 4-11). This difference quickly disappeared; after 10 years, SPLATs resulted in 859 more acres (348 more ha) meeting both threshold conditions. By year 30, the difference between treated and untreated scenarios was negligible. With simulated fire, SPLATs had a limited positive impact on fisher habitat availability, resulting in 1,043 more acres (422 more ha) of suitable habitat available after 10 years. This positive impact persisted through the modelling period, with 600 more acres (243 more ha) meeting both conditions after 30 years. Overall, the effects of SPLATs on fisher habitat were limited, with a significantly greater difference in habitat availability projected to exist between burned and unburned scenarios.

Overall, the difference in habitat availability between burned and unburned landscapes appeared to be primarily driven by large tree density. On the Sugar Pine landscape, fisher habitat availability appeared to be limited by the presence of suitable numbers of large trees (Figure 4-S4). In the absence of simulated fire, SPLATs reduced the acreage meeting the large tree density criteria at Year 0 from 16,669 to 15,001 acres (6,746 to 6,071 ha). As with overall habitat availability, this effect reversed after 10 years and essentially disappeared by Year 30. With simulated fire, the acreage meeting the large tree density criteria was further reduced to 12,670 acres (5,127 ha) with SPLATs and 11,682 acres (4,728 ha) without. As with overall habitat availability, this positive effect of SPLATs on large tree density persisted throughout the 30 year modeling window. Comparatively, in the absence of fire, SPLATs reduced the acreage meeting the canopy cover criteria at Year 0 by 1,686 acres (682 ha; Figure 4-S5). This difference increased to 3,787 acres (1,533 ha) at Year 10, then declined to 728 acres (295 ha) by Year 30. With a simulated fire, SPLAT treatment resulted in 1,801 more acres (729 more ha) meeting the canopy cover criteria at Year 10, with the effect declining to 284 and 297 acres (115 and 120 ha) at Year 20 and Year 30, respectively.

Participant perspectives on wildlife

For both species, the email survey respondents were split into thirds regarding their opinions of the impact of the treatments in the short term – a third saw fisher and owl habitat as deteriorated, a third saw it as improved, and a third anticipated no change in the short term. A majority in all respondent subgroups agreed the impacts on fisher (73% of all email survey participants) and spotted owl (67% of all email survey participants) were likely to be positive in the long term. Interviewee comments were positive about impacts from reduced risk of fire. Interview comments also provided reasons behind the short term concerns: participants felt that both species would be impacted negatively by the implementation process of the treatments (machines, tree removal). Some commented that other issues (rodenticide, road kill, and predation) may have more of an impact on fisher than treatments:

> "...hopefully it will give it a chance at living. There is always going to be the issue of the rodenticides due to illegal pot farms, ...and also going to be ...people, cars and so forth but I think, by taking their habitat into consideration, and how the area is treated for fires and such, if a fire goes through it may save their habitat and the people's habitat around it." Environmental NGO.

> "I think it will give the owl a better chance of surviving in that their habitat would be significantly less damaged by anything but a very high intensity fire, or severe greater than 100-year intensity fire." Unaffiliated citizen.

Email survey participants changed their opinions about the treatment impacts on both wildlife species, and learned from SNAMP in ways that influenced their opinions except those who were associated with the forest products industry. Across all interviewees, positive reports of learning were strongest for the fisher portion of SNAMP. Fisher-related meetings were also the best attended integration meetings. Interviewees talked extensively about the impressive amount of learning that occurred in SNAMP about basic fisher biology. Based on what they learned in SNAMP, some interview participants felt they now know more about owl habitat use and so feel more comfortable with conclusions that are the opposite of their preconceived opinions:

> "...before I was in SNAMP I would have said yes, what one thinks of as an old growth-associated species [fisher] would be affected … probably negatively. Based on what I have learned as a participant in SNAMP I would now say that it's not clear – not sure there would be strong immediate effects." UC Science Team.

> "Before this it was a hypothesis more and now it is more "this should happen because I know [about the owl]" not just because "I think". Learning in SNAMP solidified my concerns and what needs to happen." Environmental NGO.

Water quantity

The Water Team used the fire-modeling and forest-growth results provided by the FFEH Team to project changes in runoff rates at both study areas 30 years into the future under the four integration scenarios (no fire and no SPLATs; fire and no SPLATs; no fire and SPLATs; fire and SPLATs). We projected this change within the treated fireshed only, using the overstory canopy cover, overstory Leaf Area Index (LAI), and understory shrub cover to represent changes in forest vegetation structure with the Regional Hydro-Ecological Simulation System (RHESSys).

The implementation of SPLATs at Last Chance increased runoff by 12%, rising from 0.266 to 0.298 as a fraction of precipitation (Figure 4-8). Vegetation re-growth following SPLATs reduced runoff rates similar to pre-treatment levels after 10 years, but given that vegetation growth was occurring in both scenarios over time, SPLATs maintained a 12% higher runoff for 20 years compared to the no SPLATs scenario, only falling to a difference of 9.8% by year 30. When the fireshed was burned by wildfire, the runoff fraction increased to 0.412 when SPLATs were present and to 0.443 without SPLATs, due to the greater reductions in vegetation. The effects of a wildfire without SPLATs resulted in a consistently higher runoff (7-8%) compared to a wildfire that burned with SPLATs for all the years simulated.

The implementation of SPLATs at Sugar Pine only increased runoff by 2.7%, rising from 0.317 to 0.325 as a fraction of precipitation (Figure 4-12). Vegetation re-growth following SPLATs also reduced runoff rates similar to pre-treatment levels after 10 years, but the small increase from SPLATs diminished over time, falling to 0.4% by year 30. When the fireshed was burned by wildfire, the runoff fraction increased to 0.358 when SPLATs were present and to 0.365 without SPLATs. The effects of a wildfire without SPLATs resulted in marginally higher runoff (1-2%) compared to a wildfire that burned with SPLATs for all the years simulated.

Implementing SPLATs, both with and without wildfire, had a greater effect on runoff rates in Last Chance than in Sugar Pine. The difference in the two study area responses can largely be attributed to the differences in precipitation rates. Changes in vegetation at Sugar Pine had minimal effect on annual evapotranspiration (ET) rates, suggesting the forest is more water-limited than at Last Chance, where changes in ET were more closely linked to forest density. This response can be illustrated using the scenario of greatest vegetation change, wildfire without SPLATs, where a 42.5% reduction in Sugar Pine vegetation led to a 2.9% decrease in ET. In contrast, the 49.8% reduction in Last Chance vegetation resulted in a 22.8% decrease in evapotranspiration. Although high-intensity fires can result in greater vegetation reductions and lead to increased runoff, these results did not specifically address water quality issues related to these wildfires such as soil erosion into the stream channel, hydrophobic soils, and elevated snowmelt rates.

Participant perspectives on water quantity and quality

Most email survey respondents felt that that the treatments would have positive or no effects on water quality and quantity, with long term impacts viewed the most positively (only 5% and 8% of email survey respondents thought there would be a negative impact on water quality and quantity respectively in the long term). The UC Science Team participants in the email survey were more likely than the other affiliation subgroups to report an opinion of no impact to water and the local government participants were more likely to predict a positive impact on water quality in the long term. Similarly some interviewees supported the likelihood of small to nonexistent treatment impacts on water because best management practices were used, the treatments were too light to have an effect, or the study was too short to be able to detect an effect. The interviewees also said the treatments would have a positive impact on water quality and quantity especially when compared to severe fire and thought that increased water yield was an advantage of treatment. Interviewees had varying ideas about the processes that would cause increased water yield:

> "...I think that it is more that the destructive effects of the fire would be reduced and that the actual treatments themselves, by themselves, will have relatively minimal effect on either quality or quantity…the long term treatment I don't think is going to be really probably measurable, particularly in terms of water quantity." Agency.

Email survey participant opinions of treatment impacts on water quality and quantity changed during SNAMP and just over half reported an influence of SNAMP on their opinions. The two subgroups that reported change less frequently were the forest products participants and unaffiliated citizen participants. Few interviewees felt that they had changed their opinions about the impact of forest treatments on water quality or quantity over the last 7 years but many did feel they learned from the project about water and their preconceived opinions were supported. Interviewees mentioned learning from SNAMP about water assessment techniques and equipment, learning about the interactions of leaf area index and water, or, like the other subjects, some participants knew little of the topic before SNAMP and so the learning in SNAMP was significant for them:

> "Found it fascinating, all the little monitors etc. Website, field trips and meetings [is where I] learned it. Especially from the field trip that I went on – I think I went on almost all hydrological team field trips." Unaffiliated citizen.

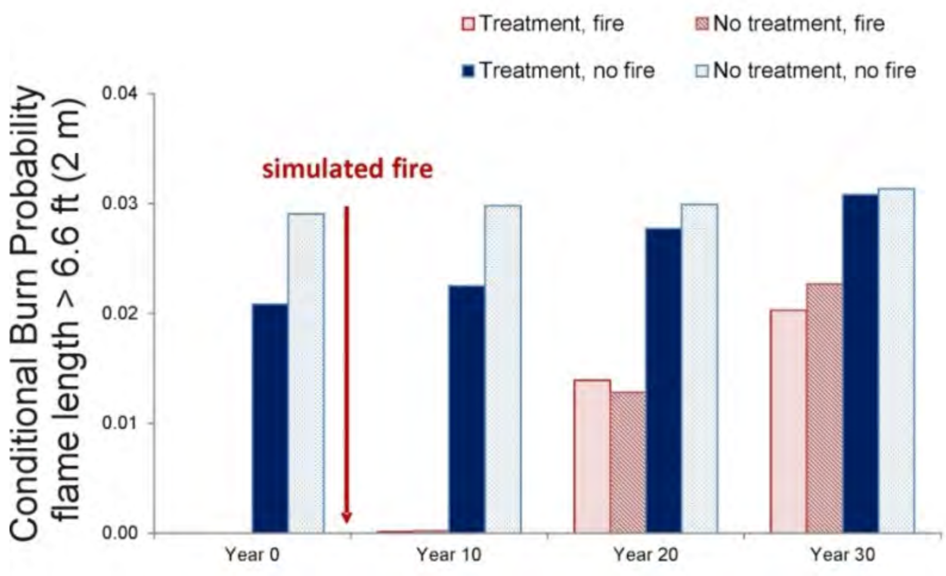

Figure 4-5: Changes in conditional burn probability by treatment and time at Last Chance, the Sierra Nevada Adaptive Management Project's northern study area in the Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using lidar and other spatial data. The simulated fire occurs immediately after Year 0 is measured. Results for the treated fireshed only.

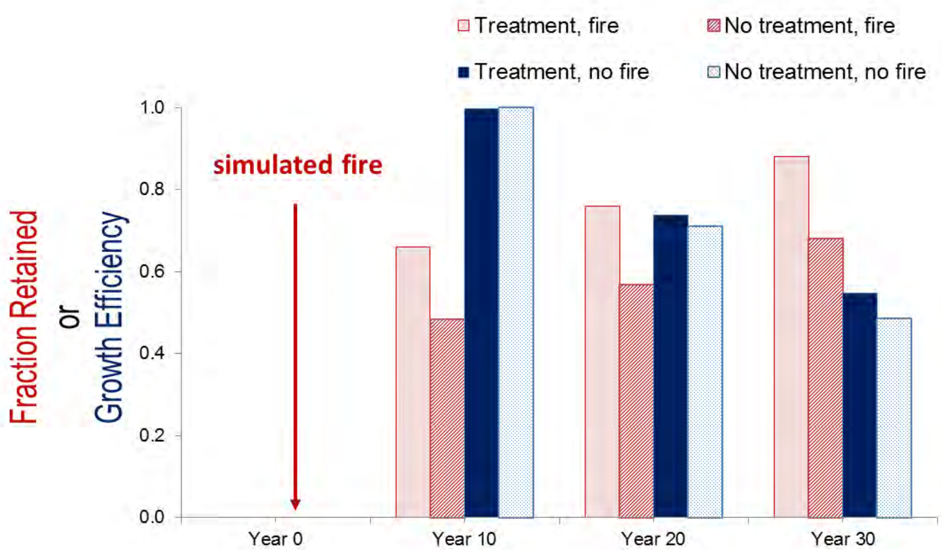

Figure 4-6: Trends in measures of forest health by treatment scenario at Last Chance, the Sierra Nevada Adaptive Management Project's northern study area in the Sierra Nevada, California. For the fire scenarios, forest health is expressed as the fraction of the Year 0 basal area that is retained. For the no fire scenarios, forest health is expressed as the relative growth efficiency. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. Estimates based on changes that occurred during the interval. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

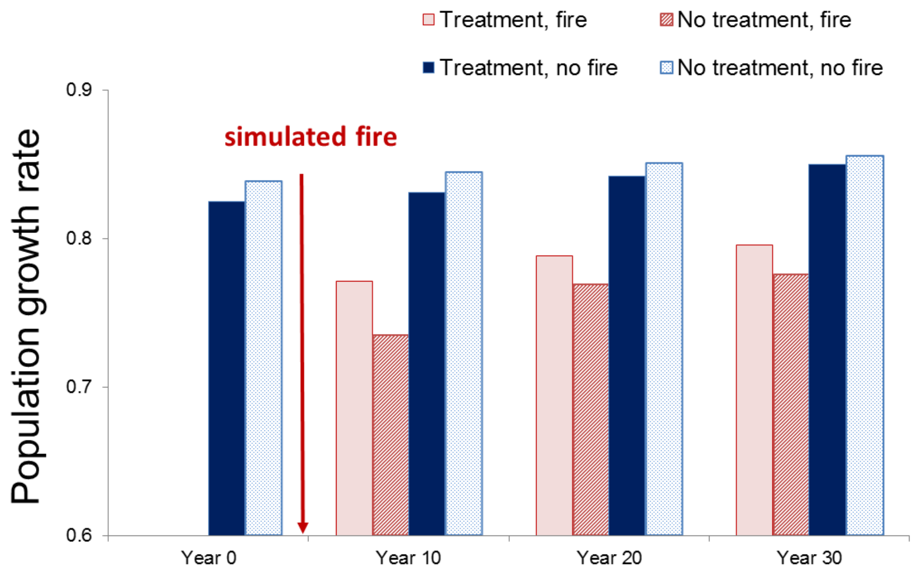

Figure 4-7: Changes in average California spotted owl territory fitness (population growth rate), by treatment and time at Last Chance, the Sierra Nevada Adaptive Management Project's northern study area in the Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for four California spotted owl territories located within both the control and treated firesheds.

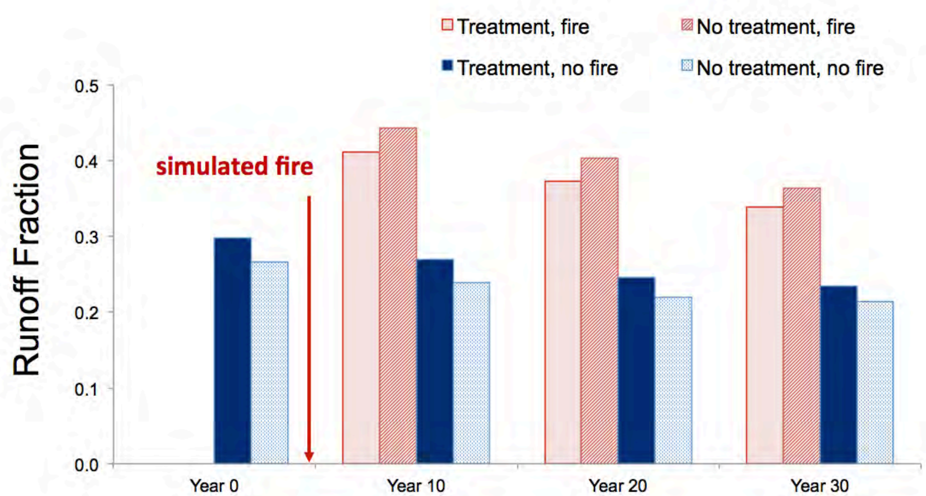

Figure 4-8: Changes in runoff as a fraction of precipitation by treatment and time at Last Chance, the Sierra Nevada Adaptive Management Project's northern study area in the Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using lidar and other spatial data. The simulated fire occurs immediately after Year 0 is measured. Results for the treated fireshed only.

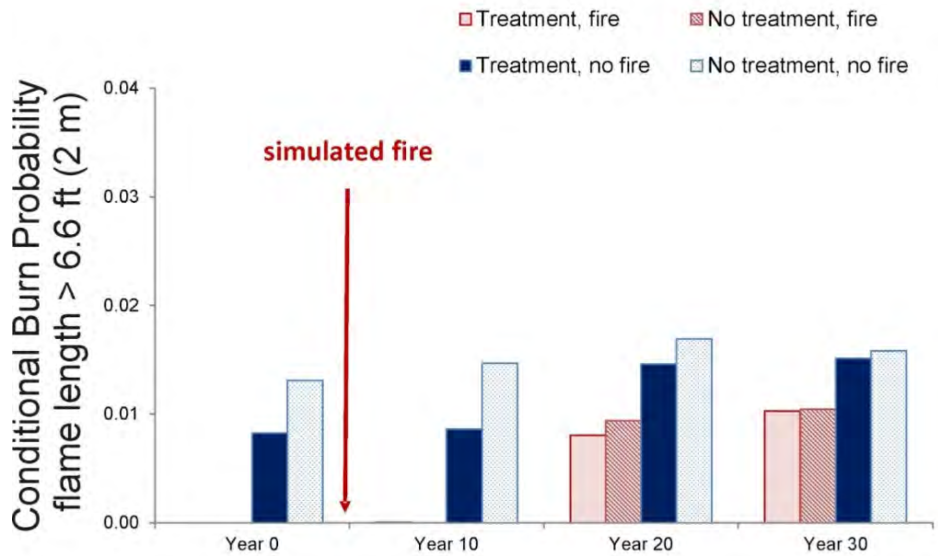

Figure 4-9: Changes in conditional burn probability by treatment and time at Sugar Pine, the Sierra Nevada Adaptive Management Project's southern study area in the Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using lidar and other spatial data. The simulated fire occurs immediately after Year 0 is measured. Results for the treated fireshed only.

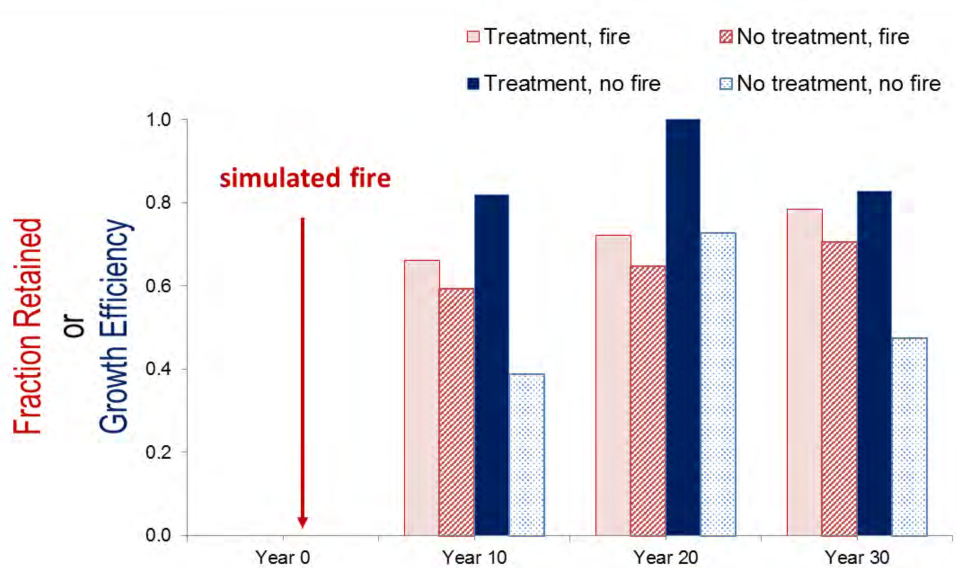

Figure 4-10: Trends in measures of forest health by treatment scenario at Sugar Pine, the Sierra Nevada Adaptive Management Project's southern study area in the Sierra Nevada, California. For the fire scenarios, forest health is expressed as the fraction of the Year 0 basal area that is retained. For the no fire scenarios, forest health is expressed as the relative growth efficiency. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. Estimates based on changes that occurred during the interval. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

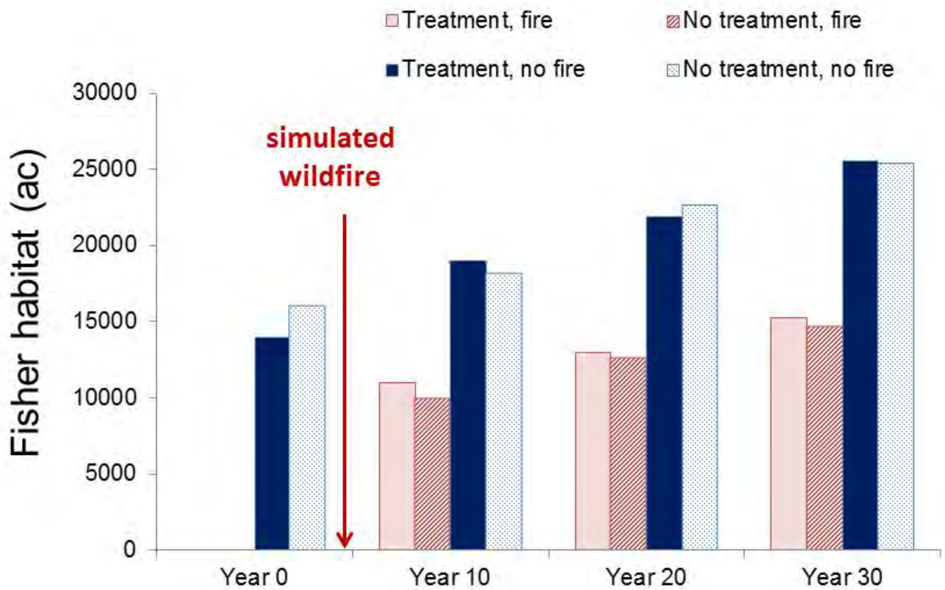

Figure 4-11: Changes in Pacific fisher habitat availability under four alternative scenarios at Sugar Pine, the Sierra Nevada Adaptive Management Project's southern study area in the Sierra Nevada, California. Models were parameterized using plot level data; pre-treatment data in the case of no treatment scenarios, and post-treatment data in the case of treatment scenarios. Forest recovery and succession was modeled using FVS, fire behavior was modeled using FARSITE.

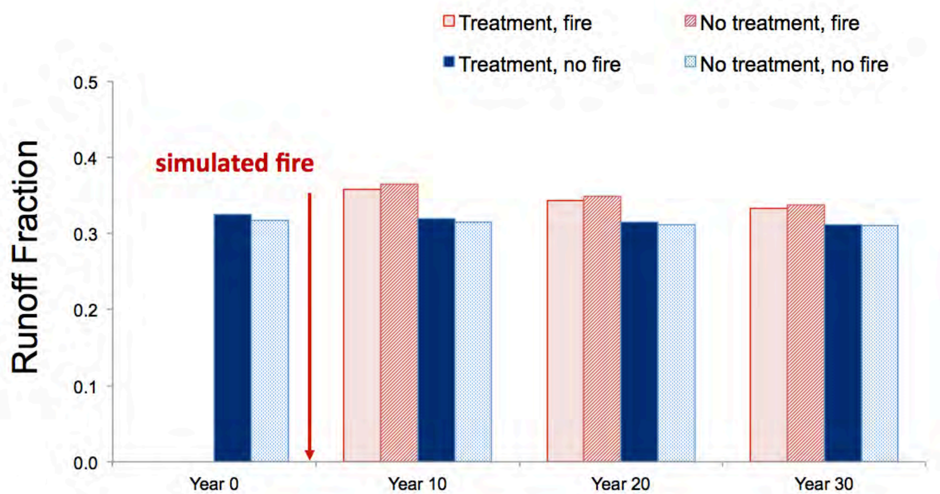

Figure 4-12: Changes in runoff as a fraction of precipitation by treatment and time at Sugar Pine, the Sierra Nevada Adaptive Management Project's southern study area in the Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using lidar and other spatial data. The simulated fire occurs immediately after Year 0 is measured. Results for the treated fireshed only.

Discussion

The integrated assessment makes explicit the trade-offs between reducing fire hazard and the habitat requirements of sensitive wildlife populations. Furthermore, it considers treatment impacts on water quality as well as the potential co-benefits in forest health and water yield. By intention, we have simplified complex responses. This simplification ignores model uncertainties. While we shared common spatial (e.g., vegetation map) and temporal data (e.g., results from simulations of scenarios), each team relied on resource-specific analytical approaches. Moreover, we simulated only one problem fire in addition to the production of conditional fire probability maps for each site. Many of the complexities are addressed in the detailed appendices written by each team. To repeat them here would defeat the purpose of providing a clear, comparative framework. Nevertheless, the limitations of this approach must be acknowledged. There are no error bars on the integration graphs despite the potential for propagation of errors from the upscaling and modeling. Also, we evaluated only four scenarios parameterized by measurements taken at two sites in the Sierra Nevada. Thus, conclusions drawn from the integrated assessment should reflect the origins of the analysis and its inherent uncertainty.

One value of SPLATs not considered in our scenarios is their contribution toward increasing fire suppression efficiency. Our simulations demonstrate that if a wildfire enters a SPLAT, it will change its behavior (Figure 4-2). Fire suppression crews can take advantage of this change. This could make it possible for a fire suppression crew to suppress a fire before it enters a spotted owl protected activity center (PAC) or other wildlife habitat feature. The SPLAT only has to change behavior enough for successful suppression in some cases.

The efficacy of SPLATs in modifying fire behavior reported here does not apply to fires like the King (2014; 97,717 acres burned), Rim (2013; 257,314 acres burned), and Moonlight (2007; 65,000 acres burned). These wildfires are outside of our modeling potential. They have plume impacts that no fire behavior model can duplicate. Not all fires will have behaviors such as these, but this does limit our modeling results to the high-severity category. The extreme fire behavior observed in these "mega-fires" can sometimes change wildlife habitat and forest mortality patterns at large spatial scales very rapidly (over 1-2 days in the case of the King Fire).

SPLAT installations or managed wildfire at larger spatial scales than used in SNAMP are probably the only way to reduce the chances for these events.

Best practices for learning and working together

Learning cannot occur without starting with a strong outreach effort based in transparency and inclusivity. Based on our experiences in SNAMP, we strongly suggest that organizations design a variety of participation events that accommodate diverse backgrounds and knowledge levels – overview large meetings, technical detailed smaller meetings, hands-on workshops, field trips, and webinars or conference calls as needed. Most importantly, organizations should conduct as many field trips as possible to draw the broadest audience of participants and clarify discussions in realities on the ground. But these events should also build in informal time at meetings, as it is important for people to network and always include question and answer sessions to allow participants to get to know what others think.

At the end of SNAMP, after almost all the outreach had been conducted but just before the final results of SNAMP were shared, our email survey and interview results showed that SNAMP participants were supportive of the Sugar Pine and Last Chance fuel treatments because respondents believe they increased forest health, decreased the risk of damage by wildfire (except in the case of extreme fires), may benefit wildlife in the long term, and would be unlikely to have a negative impact on water quality and quantity. The only affiliation subgroups in SNAMP that did not follow these trends in a few aspects were the forest products and unaffiliated citizen groups. The forest products participants often felt that the treatments did not go far enough to have significant impact and the unaffiliated email survey participants often selected "I do not know enough to have an opinion" about the impacts of the treatments and this could be why they were less likely to respond that they experienced a change in opinions and reported infrequently an influence of SNAMP on their opinions. In contrast, the unaffiliated citizen interviewees who focused on the owl and the water portions of SNAMP did report learning from SNAMP.

The convergence of opinions was similarly reflected in our analysis of definitions of adaptive management and forest health over the life of the project (see Appendix F). By 2014, interview and email participant definitions of forest health had coalesced around the theme of functioning ecological processes with species diversity as an important component. Similarly, interviewee descriptions of adaptive management centered on an experimental, science-based approach with monitoring components, and participants were commonly using terms like "cycles" and "loops" in their descriptions. Shared understandings and learning together are crucial for successful collaborations and help to reduce conflict, and we saw this evolution in SNAMP – more than 85% of 2014 email respondents agreed that there was an "increase in shared understandings" as a result of the UC role as a third party in the SNAMP process, though respondents were ambivalent about SNAMP's ultimate impact on reducing regional conflict over forest management (see Appendix F). SNAMP demonstrated a scientific, outreach and facilitation process that brought together people from disparate backgrounds, affiliations and viewpoints who, by the end, shared some common understandings about the process and the impacts of Sierra forest fuel treatments.

Future improvements and knowledge gaps

Larger spatial scale for wildlife

Both wildlife teams found a limited number of animals within the original study areas at Last Chance and Sugar Pine and thus had to expand their study areas to obtain sufficient sample sizes. For example, the Owl Team found only four spotted owl territories within the Last Chance study area. Both the owl and fisher have large home ranges relative to the spatial scale of a fireshed, and to understand how SPLATs may affect populations of these species (as opposed to individual animals or territories) will necessarily require study areas that incorporate multiple firesheds. Thus, we recommend that future studies to assess how SPLATs (or other management activities) affect the spotted owl and fisher should consider the use of much larger spatial scales (perhaps an order of magnitude or more) than either of the SNAMP study areas. We acknowledge that expanded study areas will result in the application of more treatments, which could have negative impacts on these two at-risk species, but accepting a greater level of risk will be a necessary cost if we wish to improve our ability to assess treatment effects on these species. Studies at larger spatial scales will necessarily entail greater financial costs, so we suggest occupancy-based studies that are less labor-intensive and relatively inexpensive when compared to mark-recapture or radiotelemetry studies, recognizing the limitations for information gathered in the former.

Use of spatial data

The UC Science Team used lidar spatial data as a key integrating method for the SNAMP project. We used the lidar data to create vegetation maps that displayed forest stands and identified the SPLAT treatment areas. These products were used in the fire behavior modeling process. Additionally, many other sophisticated applications of lidar data have been used to map forest attributes. For example, lidar data have been proven useful in mapping biomass, as well as critical forest habitat variables – such as individual trees, tree sizes, and canopy cover - for sensitive species.

Probability of fire on the landscape

Our goal in presenting the integration metric graphs is to provide managers and other end-users with the ability to compare SPLAT effects across resources and so inform their decision-making regarding deployment of SPLATs on the Sierra Nevada landscape. A crucial consideration is the probability of wildfire on the landscape. As demonstrated here, forest fuel treatments can have negative short-term impacts on a resource but positive long-term effects. Judging the potential future benefit against the short-term costs depends on knowing the likelihood of a wildfire. However, the science of predicting wildfire occurrence requires future research especially regarding how it impacts late seral forest habitat.

Climate sensitivity

The Sierra Nevada region typically has inter-decadal periods of wet and dry timespans that often occur in consecutive years. This seven-year project had two normal years of precipitation, one very wet year, and four years of drier than normal conditions. The range of annual climate was representative of long-term conditions in this area, but there was a dry year following the implementation of SPLATs, potentially masking any observed hydrologic changes that might have been measured in a normal or wet precipitation year. As this region is now in a fourth consecutive dry year, we suggest considering climate variability when planning future projects, keeping the range of possible conditions in mind when thinking about environmental responses and time needed for measuring baseline and experimental treatment effects.

Future climate conditions also need to be considered when planning forest or land management projects. In this project, we modeled wildfire and forest growth conditions for 30-years, during which temperatures are expected to increase. These elevated temperatures will have a direct impact on all aspects of this project. Reduced snowpack storage and increased forest evapotranspiration may result in lower stream water yield. Forest community structure and species composition are expected to migrate to higher elevations. Mixed-conifer forests will need to endure longer summer dry periods due to the earlier snowmelt, making them more susceptible to drought-stress, competition, and invasive pests. The number and extent of recent western US wildfires has also been shown to be increasing, with the extended dry season leading to higher risks of a fire ignition. Vegetation communities that become established post-fire may not be similar to the historical structure, adapting to the new climate conditions. For example, changes in overstory structure from wildfire may accelerate plant community shifts towards species from warmer regions through impacts on understory microclimate at small scales. Wildlife could potentially migrate with their habitat (e.g., move to higher elevations), and may also encounter new competition for space and resources as existing habitat becomes more suitable for other species. These forests are the source of a majority of California's surface water, so future concerns of reduced snowpack storage, increased wildfire risk, and changing forest composition will ultimately affect many of the stakeholders and public participants who have been involved in this project, including forest managers, operators of storage reservoirs and hydropower facilities, aquatic wildlife managers, and suppliers of municipal water.

Supplemental integrated metrics graphs

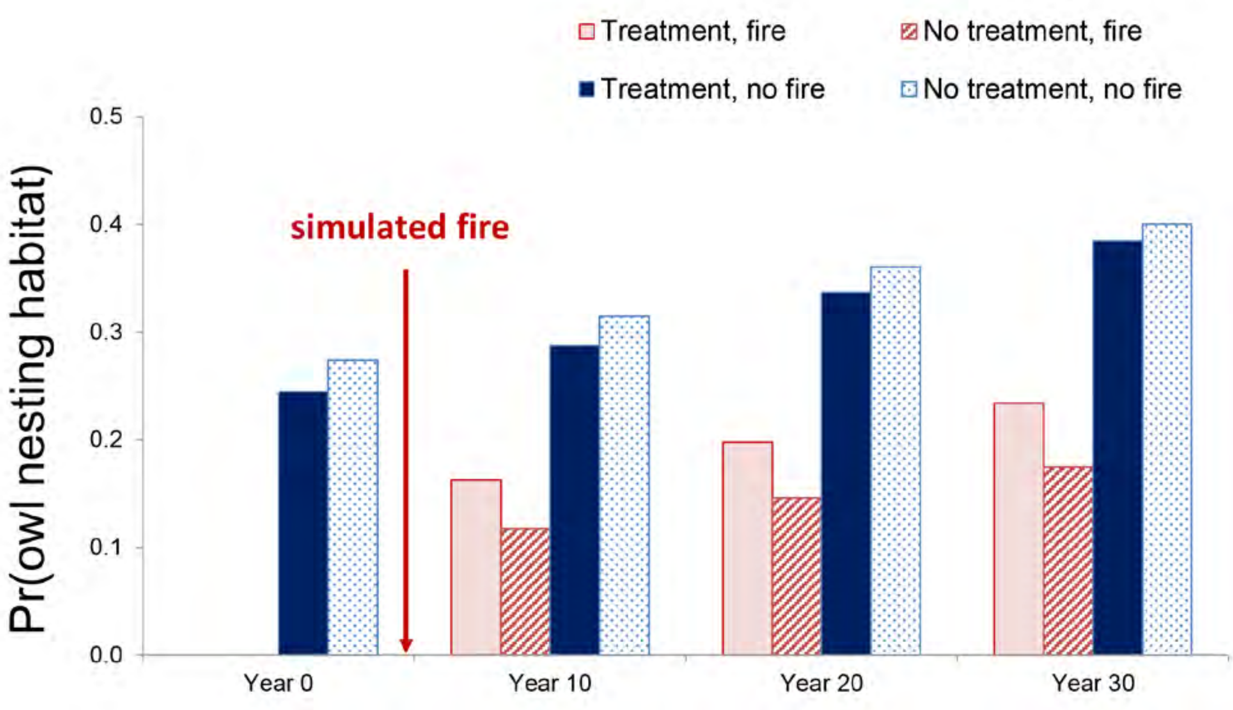

Figure 4-S1: Changes in the average probability that forest stands contained suitable California spotted owl nesting habitat, by treatment and time at Last Chance, the Sierra Nevada Adaptive Management Project's northern study area in the Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

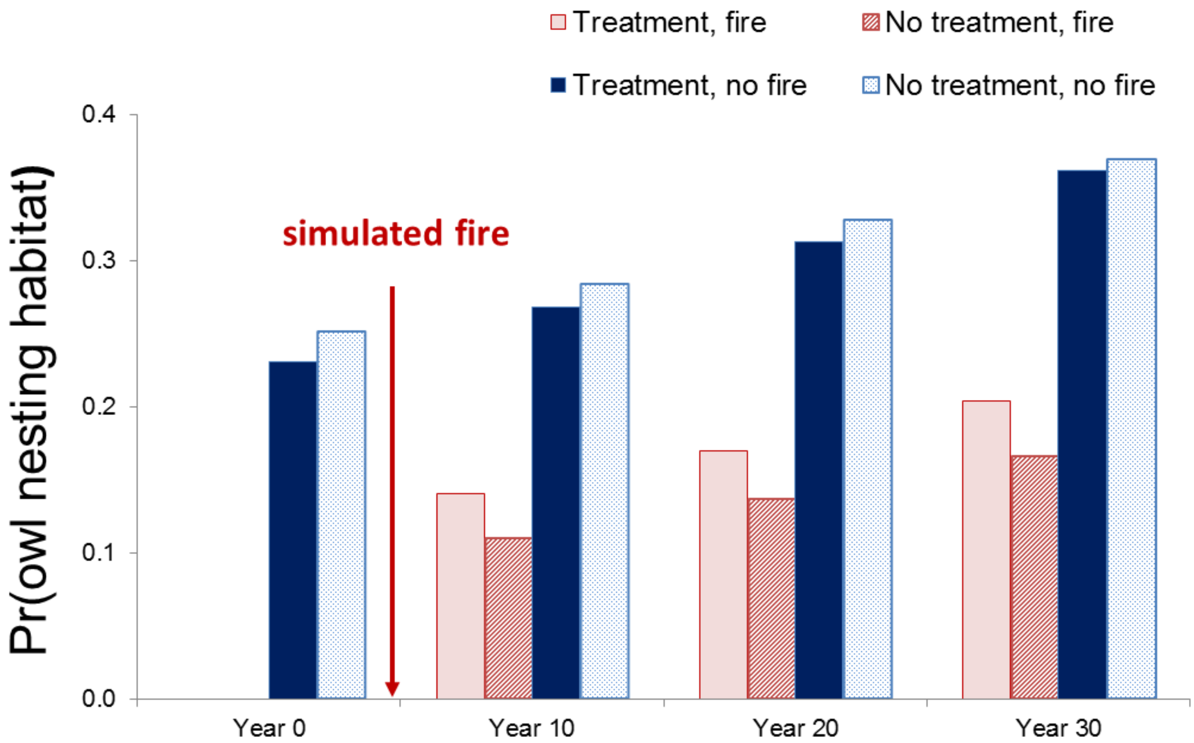

Figure 4-S2: Changes in the average probability that forest stands contained suitable California spotted owl nesting habitat, by treatment and time at Last Chance, the Sierra Nevada Adaptive Management Project's northern study area in the Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the control and treated firesheds combined.

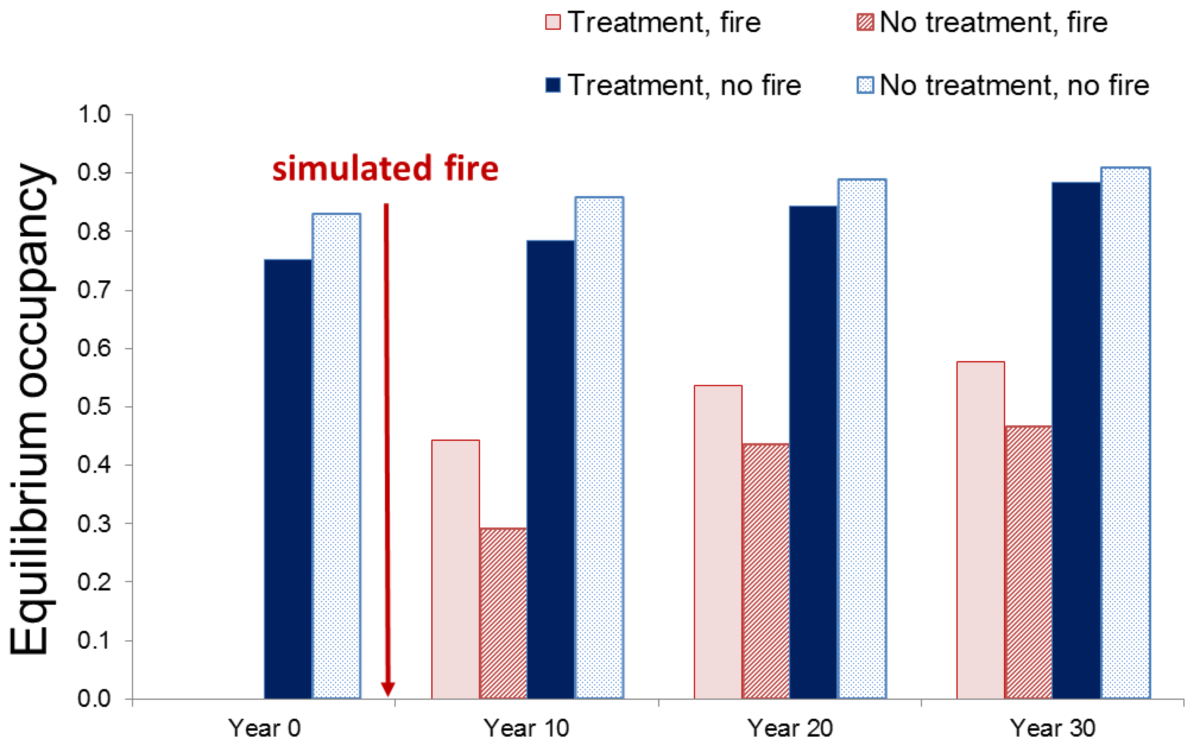

Figure 4-S3: Changes in average California spotted owl territory equilibrium occupancy, by treatment and time at Last Chance, the Sierra Nevada Adaptive Management Project's northern study area in the Sierra Nevada, California. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for four California spotted owl territories located within both the control and treated firesheds.

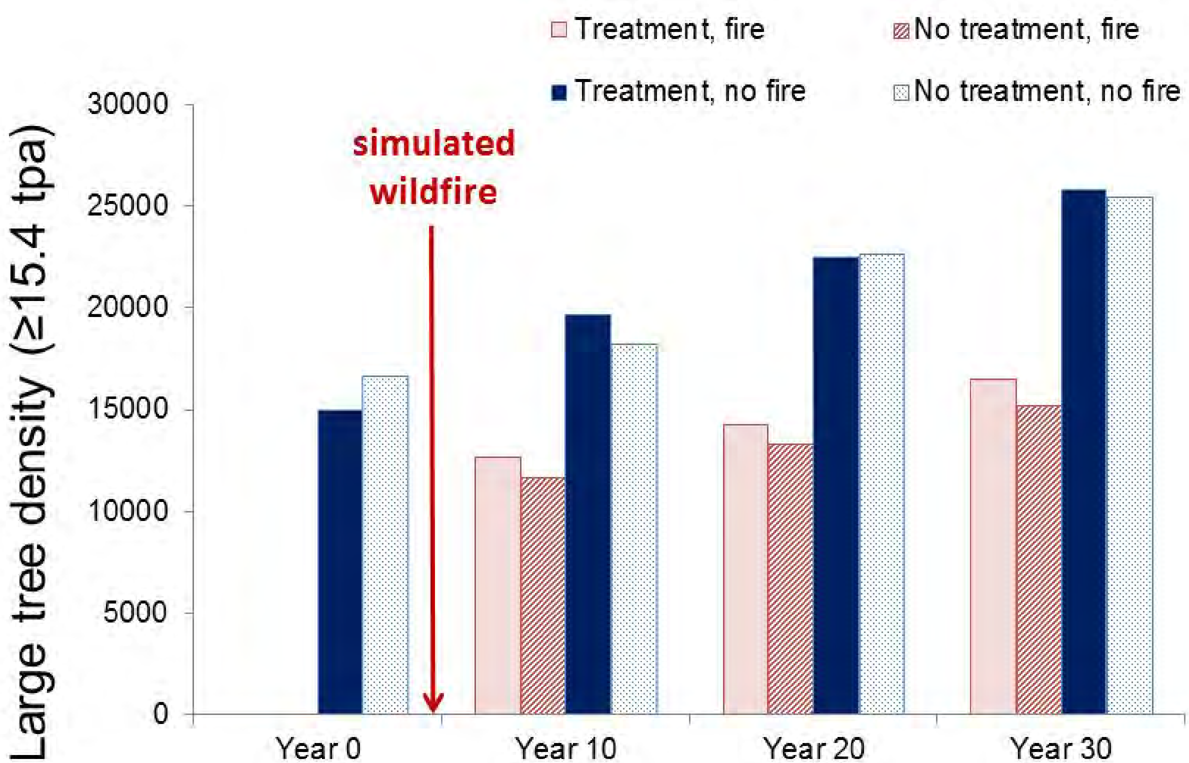

Figure 4-S4: Changes in acreage meeting the large tree (greater than 24 inches [61 cm] diameter at breast height) density criteria (≥ 15.4 trees per acre) for Pacific fisher under four alternative scenarios at Sugar Pine, the Sierra Nevada Adaptive Management Project's southern study area in the Sierra Nevada, California. Models were parameterized using plot level data; pre-treatment data in the case of no treatment scenarios, and post-treatment data in the case of treatment scenarios. Forest recovery and succession was modeled using FVS, and fire behavior was modeled using FARSITE.

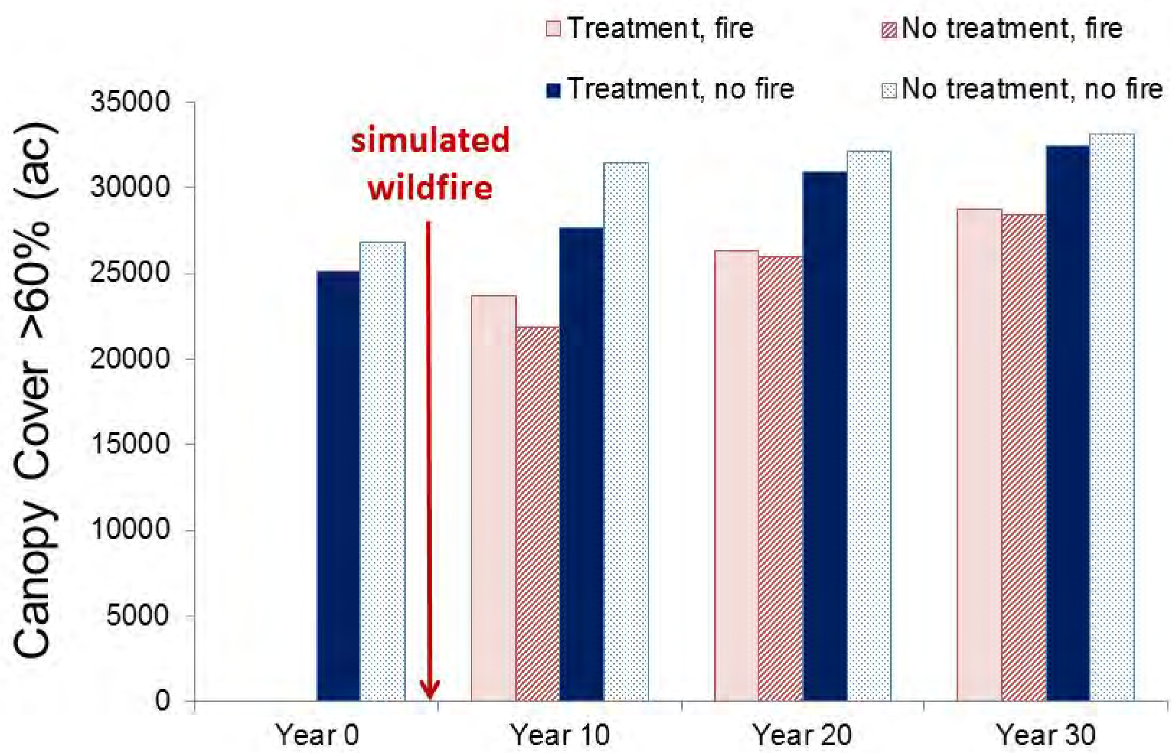

Figure 4-S5: Changes in acreage meeting the canopy cover criteria (> 60%) for Pacific fisher under four alternative scenarios at Sugar Pine, the Sierra Nevada Adaptive Management Project's southern study area in the Sierra Nevada, California. Models were parameterized using plot level data; pre-treatment data in the case of no treatment scenarios, and post-treatment data in the case of treatment scenarios. Forest recovery and succession was modeled using FVS, and fire behavior was modeled using FARSITE.

Chapter 5. INTEGRATED MANAGEMENT RECOMMENDATIONS

Introduction

Chapters 4 and 5 form one of the primary products of the Sierra Nevada Adaptive Management Project: an assessment of the impact of SPLATs integrated across the SNAMP focal resources as a group. Individual team chapters (Appendices A-F) include management recommendations relevant to their respective resources. The following management recommendations consider the SNAMP focal resources as an integrated group.

These recommendations were developed by the UC Science Team working together. Although each recommendation was written by one or two authors, the entire team has provided input and critique for the recommendations. The entire UC Science Team endorses all of these integrated management recommendations.

Each management recommendation is linked to a management goal. In some instances, an action recommended to achieve a goal may conflict with achieving one or more of the other management goals. For example, several of our recommendations suggest placing SPLATs across the landscape in a way that minimizes negative effects on wildlife (e.g., recommendations 4, 5, 7, and 26). Designing SPLATs to satisfy multiple management goals may reduce the efficiency with which SPLATs reduce wildfire behavior and impacts, and may require treating a greater proportion of the landscape to have the same effect (e.g., recommendation 21). We highlight these potential conflicts to emphasize that while SNAMP has demonstrated that many of the following management recommendations do not clash, a few may. The resulting "decision points" are occasions on which decision-makers will likely have to weigh negative impacts against one another.

Chapter 5 is divided into two sections. The first section contains integrated management recommendations that are a direct product of SNAMP scientific investigation. The second section contains recommendations that look forward to an uncertain future and draw not only on SNAMP science but also on the broader scientific expertise of the UC Science Team.

Each management recommendation comprises a conditional recommendation statement followed by a paragraph explaining the reasoning behind the recommendation. For further information about the science underlying chapters 4 and 5, please see Chapter 3, which compiles summaries from each team intended to inform the integrated assessment and management recommendations. Chapter 3 briefly describes each team's methodology and those results most relevant to integration. Complete details are, of course, to be found in the team chapters that form the appendices of this report.

Section 1: Integrated management recommendations based directly on SNAMP science

i) Wildfire hazard reduction

1. If your goal is to reduce severity of wildfire effects, SPLATs are an effective means to reduce the severity of wildfires.

Strategic siting of fuel treatments places treated areas in locations where the topology of fire (i.e., biophysical conditions that contribute to adverse wildfire effects) is the highest. Owing to the complexity of modeling fire and fuels treatment across real landscapes, fuels treatment project design is often based on local knowledge of both the project area and past fire patterns. Managers at the two SNAMP study areas designed and deployed effective SPLAT treatments that differed in their spatial characteristics: the northern site had more of a clumped treatment allocation whereas the southern site was more dispersed. In modeling, both were effective in reducing the potential for flame lengths > 6.5 ft (2 m), which is related to conservation of large, older trees. Our modeling, modeling by others, and empirical studies by others have demonstrated that SPLAT networks will reduce the risk of uncharacteristically severe fire.

ii) SPLAT impacts on forest ecosystem health

2. If your goal is to improve forest ecosystem health, SPLATs have a positive effect on tree growth efficiency.

Forest growth efficiency, defined here as the basal area increment per unit leaf area, is a proven indicator of forest health (Waring 1983). The reductions in tree basal area and density related to SPLATs implementation increased the modeled growth efficiency at both Last Chance and Sugar Pine. However, the magnitude of the improvement in growth efficiency depends on both the extent and intensity of the SPLATs treatment and on the structure of the pre-treatment forests.

The site that started with the higher basal area and canopy cover (i.e., Sugar Pine) showed a larger relative increase in growth efficiency from SPLATs, even though by some measures the treatment impact on forest structure was less.

iii) SPLAT impact assessment

3. If your goal is to integrate across firesheds, an accurate vegetation map is essential, and a fusion of optical, lidar and ground data is necessary.

Lidar data can produce a range of mapped products that in many cases more accurately map forest height, structure, and species than optical imagery alone. Our work indicated that the combination of high-resolution multi-spectral aerial/satellite imagery with lidar is very helpful in mapping vegetation communities as well as characterizing forest structure zones.

4. If your goal is to understand the effects of SPLATs, lidar is essential to accurately monitor the intensity and location of SPLAT treatments.

Lidar data can effectively penetrate the forest canopy and can be used to accurately detect forest understory changes. Our work indicated that the use of lidar-derived vegetation structure products (e.g., canopy cover and vegetation height) significantly outperformed the aerial image in identifying the SPLAT treatment extent and intensity.

iv) SPLAT impacts on California spotted owl and Pacific fisher

5. If your goal is to maintain existing owl and fisher territories, SPLATs should continue to be placed outside of owl Protected Activity Centers (PACs) and away from fisher den sites, in locations that reduce the risk of high-severity fire occurring within or spreading to those areas.

Spotted owl PACs contain about 310 acres (~125 ha) of the best habitat around owl nest and roost locations, and as such, they protect the core area of use within owl territories. Furthermore, owls have consistently used PACs for nesting and roosting over long time periods (up to 24 years; Berigan et al. 2012). Fisher den buffers contain 700 acres (~285 ha) of the most suitable habitat around known den sites, and reuse rates support the importance of these sites. Thus, the U.S. Forest Service should continue its current policy that restricts timber harvest within these sites, and PACs should remain a cornerstone of the agency's spotted owl management strategy. In addition, SPLATs should be designed to limit the potential for high-severity fire to spread into PACs and den buffers.

6. If your goal is to maintain landscape connectivity between spotted owl territories, SPLATs should be implemented in forests with lower canopy cover whenever possible.

Recent studies have shown that spotted owl populations in the Sierra Nevada have declined by as much as 50% over the last 20 years (Tempel et al. 2014a). Therefore, we believe a cautious approach is warranted regarding the placement of SPLATs with respect to existing owl habitat. Spotted owl territory fitness and occupancy were strongly correlated with the amount of high-canopy-cover forest within spotted owl territories (Tempel et al. 2014b), where we defined 'high-canopy-cover forest' as forest dominated by trees ≥ 12 in (30.5 cm) dbh and having ≥ 70% canopy cover. Thus, SPLATs should target younger forests or forests with lower canopy cover when possible, recognizing that the ultimate objective of SPLAT placement is to significantly modify wildfire behavior.

7. If your goal is to increase owl nest and fisher den sites, retain oaks and large conifers within SPLAT treatments.

Fishers den exclusively in cavities, while owls nest in both cavities and platforms. Both species consistently utilize larger diameter trees that exhibit some form of structural decay or damage, and levels of reuse indicate that these structures may be a limiting factor. Cavities suitable for den or nest sites may take decades to centuries to develop; therefore, it is critical not only to protect current structures but to enhance the development of these structures over time. Protection of these structures may take the form of retention during thinning activities as well as raking away duff or other ground fuels during burning operations, particularly where a basal hollow may allow ground fire access into the tree. Spotted owls will sometimes use areas without large trees if there are suitable nest sites available and if they are adjacent to high-canopy-cover forest.

8. If your goal is to maintain fisher habitat quality, retention of canopy cover is a critical consideration.

SNAMP data, as well as numerous other research projects, consistently indicate that contiguous canopy cover is an important factor in fisher habitat selection. Within the SNAMP key watersheds, predicted fisher occupancy increased from 0.65 to 0.80 as the proportion of the landscape with >40% canopy increased from 0.25 to 0.75. Wherever possible, SPLATs should emphasize the reduction of surface and ladder fuels and retain dominant trees. Where high fire risk requires canopy reduction, SPLATs should be placed such that they provide protection for dense canopy refuges, and canopy should be retained above 40% at the landscape scale.

9. If your goal is to increase fisher foraging activity, limit mastication and implement more post-mastication piling and/or burning to promote a faster recovery of the forest floor condition.

The SNAMP fisher assessment identified a short-term reduction in fisher occupancy following non-commercial fuel reduction, particularly mastication. This reduction is likely associated with the loss of understory and the residual matrix of small to mid-sized woody debris scattered on the landscape. Where feasible, post-mastication burning or some other follow-up treatment would help promote a faster recovery of natural forest floor conditions and facilitate fisher activity. Dispersing smaller mastication projects across the landscape, to insure that an animal can move freely around them, could also help minimize negative impacts and retain fisher activity in an area.

10. If your goal is to understand SPLAT effects on owl and fisher, it is necessary to consider a larger spatial scale than firesheds.

Both wildlife teams found a limited number of animals within the original study areas at Last Chance and Sugar Pine and thus had to expand their study areas to obtain sufficient sample sizes (see Popescu et al. 2012). Both the owl and fisher have large home ranges relative to the spatial scale of a fireshed, and to understand how SPLATs may affect populations of these species (as opposed to individual animals or territories) will necessarily require study areas that incorporate multiple firesheds.

v) SPLAT impacts on water quantity and quality

11. If your goal is to detect increases in water yield from forest management, fuel treatments may need to be more intensive than the SPLATs that were implemented in SNAMP.

Model results show that reduced vegetation density from the implementation of SPLATs may not be enough of a vegetation change to definitively observe an increase in water yield. Fireshed scale simulations do show small increases in precipitation being routed to the stream outlet following treatments. The increases in water yield might not be large enough to be easily measured and likely require a control structure grounded in bedrock for more precise streamflow observations. The small reductions in vegetation from treatments were temporary, with regrowth exceeding the original pre-treatment vegetation density in the first decade. Maintaining any water yield increases from light vegetation treatments would either require frequent application or more intensive treatments to extend water yield increases over time. However, vegetation in the treated catchments remained at lower densities compared to *untreated forest conditions, with the increased water yield from implementation of SPLATs persisting relative to catchments without vegetation treatments.*

12. If your goal is to maintain water quality, SPLATs as implemented in SNAMP have no detectable effect on turbidity.

Given that monitored water chemistry parameters (dissolved oxygen, temperature, and turbidity) are within healthy ranges for the SNAMP watersheds, the most elevated risk to water quality in these aquatic systems is sediment movement resulting from forest treatments. Stream turbidity patterns indicate that in-channel erosion is the main sediment source, with accumulation and depletion cycles tied to low and high flow periods – results similar to previous regional monitoring. Channel bed movement patterns suggest that under stable forest conditions (no treatment or fire), the stream channel experiences seasonal changes in storage of bed material, but remains stable on an inter-annual basis. Increases in sediment transport from treatments would then likely be related to increases in discharge. The post-treatment monitoring period was completed during a second consecutive year of drier than normal conditions. Additionally, the implemented treatments were light and located a significant distance from stream channels, in accordance with standard forest practices. These treatments were not intensive enough to produce an increase in discharge during the low precipitation year and show that SPLATS as implemented in SNAMP had no detectable effect on turbidity when followed by dry conditions.

vi) Stakeholder participation in SPLAT implementation and assessment

13. If your goal is to increase acceptance of fuel treatments, employ outreach techniques that include transparency, shared learning, and inclusiveness that lead to relationship building and the ability to work together.

Throughout the literature, across other projects, and in SNAMP, transparency, shared learning, and inclusiveness have been found to be critical for building relationships that can lead to collaboration. A collaborative atmosphere is needed before conflicts about fuel treatments can be discussed and their efficacy tested effectively enough to promote acceptance. Our results show that, in SNAMP, the many and varied outreach activities where participants learned together in an inclusive and transparent setting ultimately contributed to improved relationships even between those traditionally opposed to each other. In this context, the acceptability of fuels treatments by groups was tested, thoroughly viewed and discussed by participants, and ultimately preferred as a management strategy by most SNAMP participants. Through the increased engagement with Forest Service District Rangers and other staff, our data show a dramatic increase in learning and understanding about the Forest Service and its constraints. This could help improve collaboration with the agency going forward, as long as the agency *continues a strong effort to interact sincerely and transparently with the public. As has been found in the literature, facilitation was key to making it work, as was reaching out to people in different walks of life; holding a meeting and expecting people to show up was not enough. Participation Team personnel lived in local communities and brought information to meetings convened in local communities, including those of Boards of Supervisors, local environmental groups, and locally important natural resource industries. Finally, emphasis needs to be on multi-directional learning: stakeholders, including scientists and Forest Service managers, learn from other stakeholders. Even in a "top down" agency-initiated process like SNAMP, emphasis on shared learning helped build social capital and the ability to work together.*

14. If your goal is the increased acceptance of fuel treatments, the public needs to understand the tradeoffs between the impacts of treatments and wildfire.

In SNAMP, participants differentiated between short and long term impacts of treatments and fire, and much of the UC Science Team's work attempted to address these details. This deep level of learning and discussion was needed for participants to consider the tradeoffs that are part of forest management. Face-to-face meetings with scientists were an important part of helping the public learn about the effects of treatments, and helping the scientists appreciate the concerns and interests of the other stakeholders. Scientists were available to answer questions from the public through multiple channels: annual meetings, integration meetings, and the interactive website. Field trips were especially important, both in building relationships and understanding what occurred on the ground. Integration meetings allowed small groups of stakeholders to focus on a particular aspect of the project to discuss findings and their implications in-depth. SNAMP personnel living in the local communities were also available to stakeholders on a regular basis to answer questions, and to learn from the communities and the agency. Overall, within the adaptive management model, it is important to emphasize stakeholder learning and participation whenever possible through all aspects of the process, from the selection of foci for scientific investigation to the interpretation of results.

vii) Successful collaborative adaptive management processes

15. If your goal is to establish a third party adaptive management project with an outside science provider, the project also needs to include an outreach component.

A third party science perspective is often sought in controversial resource management matters where there is not only a lack of knowledge (hence the need for scientific investigation) but also a shortage of trust (hence the need for a third party). This third party information can help to support the mutual learning component of adaptive management. At the onset of SNAMP, the investment in outreach was recognized as a priority. At the conclusion of SNAMP, the investment *in public participation via the UC Cooperative Extension proved invaluable. Thus, a specific commitment of staffing and resources to extend the insights from the third party to all participants is essential to the success of a third party adaptive management project.*

16. If your goal is to develop an engaged and informed public, you need to have a diverse portfolio of outreach methods that includes face to face meetings, surveys, field trips, and web-based information.

Segments of the public differ in their proximity, understanding of issues, and ability to participate in national forest management. To involve the broadest segment of the public in SNAMP, the broadest methods of participation were used. These included outreach events that allowed people to participate occasionally or regularly, and methods that accommodated participation both locally and from afar (through web technologies such as hosting a comprehensive website, producing webinars, and webcasting meetings).

17. If your goal is to understand or improve outreach effectiveness, track production, flow, and use of information.

Some of the factors that can contribute to the success of collaborative adaptive management – such as social learning, open communication, and trust - are built upon a foundation of the open exchange of information about science and management between participants and the public. Currently, there exist opportunities to develop strategies for increasing the exchange of information, as well as to track information flow in such contexts. We recommend what we used in SNAMP: a mixed methods (citation analysis, web analytics, and content analysis) approach borrowed from the information processing and management field to track and facilitate the flow and use of digital information. We archived meeting notes, attendance, publication records, website statistics, and other SNAMP outputs throughout the life of the project. Analysis of these data sources showed SNAMP facilitated a dramatic transfer of scientific knowledge.

18. If your goal is to engage in collaborative adaptive management at a meaningful management scale, secure reliable long term sources of funding.

Forest management decisions often address processes at spatial and temporal scales that challenge empirical efforts to gain new knowledge. Thus, management-relevant science requires long term funding that acknowledges the move towards a landscape-based approach, the uncertainty in operational schedules associated with implementing treatments, and the consequences of delays and funding reductions on project outcomes. The SNAMP workplan never made provisions for "closing the adaptive management loop" by tracking the use of the new information to revise management actions as needed after the assessment was finished. This omission was noted at the onset, but extending SNAMP to "close the loop" would have extended *the project beyond what was deemed feasible to fund. Thus, a key recommendation from SNAMP is to secure the long term funding required to accommodate delays and complete the adaptive management cycle at the outset.*

19. If your goal is to maintain a successful long-term collaborative adaptive management process, establish long-term relationships with key people in relevant stakeholder groups and funding agencies.

Consistency and inclusivity in participants are important goals. The principle that all interested parties could join the collaboration at any time was important in the SNAMP process. New participants add viewpoints and information as well as broaden the group that will learn from and participate in the project. The SNAMP website provided extensive background and historical information of use to these new stakeholders, making it easier for new participants to catch up. On the other hand, consistency is crucial from funding agency contacts and science providers as well as lead stakeholders. In general, there was little turnover on the UC Science Team, a bit of change within the participant groups, and a lot of new faces within the Memorandum of Understanding (MOU) Partner contacts over the 10 years of the project. SNAMP struggled, more than once, with funding constraints. Turnover in agency leadership, as well as in administrative or accounting staff, intensified the difficulty of these funding crises. Multi-year projects such as SNAMP need champions within the participating agencies in order for the projects to maintain internal interest and funding. During these fiscal crises, the lead nonprofit stakeholders came to the defense of the project and strongly encouraged the agencies to continue funding. A strong commitment to the project from long term stakeholders was necessary to continue the project.

Section 2: Looking forward - Integrated management recommendations based on expert opinion of the UC Science Team

i) Implementation of SPLATs

20. If your goal is to maximize the value of SPLATs, complete treatment implementation, especially the reduction of surface fuels.

Fuels can be divided into four classes: ground, surface, ladder, and crown. Ground fuels are the decomposing organic layer on the soil surface and do not contribute to fireline intensity or fire spread. Surface fuels are the dead and down woody materials, grasses, forbs, and small shrubs that contribute to flaming combustion and the potential for crown fire. They are therefore the most important fuel class when reducing fire hazards in forests. Ladder fuels are small trees and tall shrubs that can provide vertical fuel continuity to move a fire from the surface to tree *crowns; they are the 2nd most important fuel layer regarding fire hazards in forests. Crown fuels are those in the overstory and do not contribute a large portion of fire hazards in California forests. Effective forest fuel treatments will therefore target surface and ladder fuels.*

21. If your goal is to efficiently reduce fire behavior and effects, SPLATs need to be strategically placed on the landscape.

To efficiently reduce fire behavior and effects, fuel treatments need to be strategically placed on the landscape (the first letter in SPLAT stands for strategic). There are many ways that the placement of fuel treatments can occur in forests: near roads that have good fire suppression access, near the urban-wildland interface to protect people and homes, on gentle slopes that machines can safely operate on, between patches of important late-seral habitat, and in areas with an excessive density of shade tolerant species such as white fir. While all of these are sound reasons to install fuels treatments, none of them addresses the topology of fire and therefore would not lead to a strategic treatment placement. Placement of fuel treatments for the above reasons would be classified as random, and approximately 50% of the landscape would need to be treated to reduce fire behavior and effects. In contrast, if approximately 20% of an area received a strategic placement of fuel treatments it would perform similarly to the 50% randomly placed system. It is possible to exclude some parts of a landscape for consideration in the strategic placement of fuel treatments, but when this becomes excessive it is not possible to produce a SPLAT design.

22. If your goal is to improve SPLAT effectiveness, increase heterogeneity within treatment type and across the SPLAT network.

Reduction of surface and ladder fuels will reduce fire hazards in mixed conifer and ponderosa pine forests. Restoration focuses on re-establishing the composition, structure, pattern, and ecological processes necessary to facilitate ecosystem sustainability, resilience, and health under current and future conditions. One way a SPLAT network can be designed to incorporate restoration objectives is to increase heterogeneity of treatment areas. Creating treatment areas that includes clumps of trees, individual trees, and openings will increase resiliency and provide diverse habitats. Fires interacting with this type of structure will produce mixed effects including the mortality of trees, but forests in these areas will still be conserved into the future. Allowing some forested areas with high hazards (high canopy cover, high snag, and large woody debris) within a matrix of low to moderate hazards from installed SPLATs may conserve forest ecosystems into the future.

ii) Forest ecosystem restoration

23. If your goal is to restore Sierra Nevada forest ecosystems and improve forest resilience to fire, SPLATs can be used as initial entry, but fire needs to be reintroduced into the system or allowed to occur as a natural process (e.g., managed fire).

Installing an initial SPLAT network (as the Forest Service did in the SNAMP treatment firesheds) will reduce potential fire behavior and effects when the landscape eventually burns. SPLATs can also be used to anchor managed wildfire or large scale prescribed burning operations in a fireshed (North et al. 2012). A SPLAT network would moderate fire effects during burning, and this should result in increased forest resilience to fire. Allowing fire to return to these ecosystems as a natural process is a critical objective for the long term sustainability of forests.

24. If your goal is to manage the forest for long-term sustainability, you need to consider the pervasive impacts of climate change on wildfire, forest ecosystem health, and water yield.

Climate change is already increasing temperatures and reducing the period when snow is on the forest floor in Sierra Nevada forests; these changes will increase the incidence of fire throughout the range. Droughts will increase the populations of native tree-killing insects such as bark beetles, and they could have a massive impact on large, old trees. Development of landscape strategies that increase the resiliency of forests to these expected disturbances is critical. SPLATs are a good first step in this journey. Once areas have received SPLATs, moving some of these landscapes (unroaded, remote) to a lightning fire maintenance regime may be appropriate. The spatial scale of the restoration work needed in the Sierra Nevada is immense. One big operational challenge is how to balance the need for new treatments versus maintenance of existing treatments. Moving some areas that have received SPLAT treatments to lightning fire maintenance would allow managers to continue to treat new additional areas. Since we know that forest ecosystems are dynamic, this journey never ends. Continued use of managed fire, prescribed fire, and mechanical treatments will be necessary for the conservation of the ecosystems of the Sierra Nevada. There is no alternative.

iii) Management impacts on California spotted owl and Pacific fisher

25. If your goal is to enhance landscape habitat condition for owl and fisher, hazard tree removal of large trees should be carefully justified before removing.

Large trees create cooler microclimates within stands that may benefit spotted owls, and large trees also increase the suitability of intermediate-aged forests for both spotted owls and fisher. These residual trees may allow owls to use intermediate-aged forests for nesting and roosting when they otherwise only use them as foraging habitat. Similarly, fishers frequently use these remnant trees as rest sites in the midst of more intermediate-aged stands.

26. If your goal is to minimize the effects of SPLATs on fisher, SPLAT treatments should be dispersed through space and time.

SPLATs do represent a short-term loss in habitat quality for fishers. Therefore, these costs need to be dispersed in space and time, such that there is not a concentrated reduction in habitat quality in one particular area. SNAMP data indicate that forest restoration / fuel reduction management does reduce fisher occupancy in the short term, with a 47% reduction in occupancy following treatment. However, there was no multi-season impact on the population, indicating that fishers remained in the surrounding area. This is likely due to the fact that fishers have large home ranges, and because the overall percentage of a territory treated at any given time is small (<2% per year), they are able to move around treated areas and remain viable. Furthermore, evidence indicates that treated landscapes become suitable for use again in 5-25 years, depending on the treatment applied. Concentrations of SPLATs in space or time could risk limiting this movement and landscape recovery, while dispersing them helps retain local occupancy.

iv) Management impacts on water quantity and quality

27. If your goal is to optimize water management, consider the range of potential fluctuations in precipitation and temperature.

Even during the short SNAMP study period, precipitation conditions ranged from some of the wettest conditions on record to some of the driest. The response of the hydrologic system to forest management will depend on the specific precipitation patterns exhibited, from a lack of response due to light thinning and low precipitation to a strongly significant response after intensive treatments and high precipitation. When determining if measureable changes in water yield will occur in response to reducing vegetation density, the monitoring period should be of appropriate length to include a range of precipitation conditions. This study was successful in *the range of annual precipitation during the pre-treatment period, but only low precipitation years have followed SPLAT implementation. Although this study did not specifically address climate change, regional studies suggest that warmer conditions expected through the end of the century will result in more rain, smaller snowpack storage, and longer growing seasons, leading to higher evapotranspiration loss and lower annual water yield.*

v) Successful collaborative adaptive management processes

28. If your goal is to implement collaborative adaptive management, commit enough time, energy, and training of key staff to complete the adaptive management cycle.

Vital elements to whatever collaborative approach is used include clarification of roles, relationships, and responsibilities for each of the participants in the collaborative effort, development of an explicit decision-making process including a fall-back strategy if decisions cannot be agreed on, and clear definition of the relationship between the group and decision making authority to avoid false expectations. Agencies committing to carry out collaboration should be prepared to commit the staff time and resources to the effort. Staff engaged in collaborative efforts and all participants should receive some fundamental training in effective meeting management and how to practice facilitative behaviors during meetings. Collaboration takes funding, time, effort, and enduring dedication to the process.

29. The role of a third party science provider for an adaptive management program can be realized in a variety of ways.

As a third party science provider, UC Science Team scientists communicated directly with stakeholders as well as the MOU Partners and Forest Service managers. Monitoring and management impact assessment from a source independent of the entity responsible for management is similar to having an independent auditor review the books of a company, and we hypothesize it can increase stakeholder confidence in the information. SNAMP data suggest that stakeholders appreciated this in SNAMP. However, it can be costly. This role could be fulfilled at least partially in other ways, for example, by involving stakeholders in monitoring processes as part of joint monitoring programs, or involving a third agency or group with a reputation for neutrality and no regulatory authority to conduct monitoring and/or research. For example, the Natural Resources Conservation Service is now conducting monitoring for the Bureau of Land Management in some areas. At the least, research and monitoring should be transparent to stakeholders. On public lands today, the public needs to be brought along with management decisions, and part of that is understanding and feeling confident about the results of research and monitoring.

30. If the goal is to implement adaptive management, managers must adopt clear definitions and guidelines for how new information will be generated, shared, and used to revise subsequent management as needed.

Adaptive management, as a concept, has many different definitions. To implement adaptive management, agencies must adopt, for each project at the outset, a clear operational definition and process guidelines for all aspects of the adaptive management cycle. It is important to clarify what information is being developed and how it will be considered in future management decisions. Clear record keeping of what was actually implemented on the ground and the outcomes are essential to success. It is important to document, track, and monitor how information is used in the next management cycle in a public and transparent manner.

31. If your goal is to increase forest health in the Sierra Nevada, we now know enough to operationalize some of the aspects of SNAMP more broadly.

SNAMP and other landscape-scale projects in the Sierra Nevada have demonstrated how to reduce fire hazards and increase forest health. Increasing the spatial heterogeneity of treated areas will also provide important restoration objectives. With this information, it is desirable to operationalize these treatments across the larger Sierra Nevada landscape. There is currently a great need for forest restoration and fire hazard reduction treatments to be implemented at large spatial scales in the Sierra Nevada. The next 1-3 decades are a critical period: after this time it may be very difficult to influence the character of Sierra Nevada forests, especially old forest characteristics.

References

Berigan, W.J., R.J. Gutiérrez, and D.J. Tempel. 2012. Evaluating the efficacy of protected habitat areas for the California spotted owl using long-term monitoring data. Journal of Forestry 110:299-303.

North, M., B.M. Collins, and S. Stephens. 2012. Using fire to increase the scale, benefits, and future maintenance of fuels treatments. Journal of Forestry 110(7):392–401.

Popescu, V.D., P. de Valpine, D. Tempel, and M.Z. Peery. 2012. Estimating population impacts via dynamic occupancy analysis of Before–After Control–Impact studies. Ecological Applications 22:1389-1404.

Tempel, D.J., R.J. Gutiérrez, S.A. Whitmore, M.J. Reetz, R.E. Stoelting, W.J. Berigan, M.E. Seamans, and M.Z. Peery. 2014b. Effects of forest management on California spotted owls:

implications for reducing wildfire risk in fire-prone forests. Ecological Applications 24:2089-2106.

Tempel, D.J., M.Z. Peery, and R.J. Gutiérrez. 2014a. Using integrated population models to improve conservation monitoring: California spotted owls as a case study. Ecological Modelling 289:86-95.

Waring, R.H. 1983. Estimating forest growth and efficiency in relation to canopy leaf area. Advances in Ecological Research 13: 327-354.

Chapter 6. EXECUTIVE SUMMARIES OF TEAM RESOURCE-SPECIFIC FINDINGS

Note: this chapter is in draft form, awaiting the final version of the Water Team chapter

Introduction

This chapter compiles the executive summaries from all the individual team chapters (Appendices A-F), including each team's resource-specific findings and management recommendations.

Fire and Forest Ecosystem Health

The 2004 Amendment to the Sierra Nevada Forest Plan identified a coordinated system of fuel treatments distributed across the landscape as the preferred management alternative. The goals of this approach, defined as strategically placed land area treatments (SPLATs), were to modify dangerous fire behavior and improve forest health in the National Forests in the Sierra Nevada region of California. The 2004 amendment also introduced the concept of fireshed management. Firesheds are analogous to watersheds in concept, but are topographic units based on the behavior of a problem fire – a fire that has the greatest potential impact based on the local topography, weather, and fire history. We tested the performance of SPLATs as designed and implemented by US Forest Service in two firesheds, Last Chance in the Tahoe National Forest and Sugar Pine in the Sierra National Forest. We conducted detailed field measurements before and after treatments in order to quantify changes in forest structure and fuel loads resulting from SPLATs. To account for potential changes unrelated to forest management, a control fireshed was paired with the treated fireshed at each site. Data from the field measurements were used to parameterize fire and forest growth models. These models were then used to simulate wildfire effects on fire behavior and to explore the responses of tree growth efficiency (a measure of tree vigor) to the treatments. At Last Chance, fuel treatments distributed across 18% of the landscape reduced the percentage of the forest exposed to damaging flame lengths from 33% (no SPLATs) to 22% (with SPLATs). The impact of SPLATs on fire behavior was less at Sugar Pine. Fire simulations for Sugar Pine showed that SPLATs completed on 29% of the area, reduced exposure to damaging flame lengths from 29% of the landscape to 25% – a minimal decline of 4 percentage points. In contrast, trees in the treated fireshed at Sugar Pine nearly doubled their growth efficiency in the ten years following SPLATs while there were only minor improvements in growth efficiency following treatments at Last Chance. This dichotomy in the response to SPLATs was related to differences in the extent and intensity of the treatments applied at the two sites as well as ecological and land use variations. The treated fireshed at Sugar Pine supported a mixed conifer forest that was more crowded with bigger trees but exposed to a lower initial fire hazard. Nevertheless, in aggregate our results support the promise of SPLATs. Coordinated treatments across part of the landscape can help minimize the hazards posed by severe fires and at the same time meet forest health objectives.

Spatial

The SNAMP Spatial Team was formed to provide support for the other SNAMP science teams through spatial data acquisition and analysis. The objectives of the SNAMP Spatial Team were: (1) to provide base spatial data; (2) to create quality and accurate mapped products of use to other SNAMP science teams; (3) to explore and develop novel algorithms and methods for Lidar data analysis; and (4) to contribute to science and technology outreach involving mapping and Lidar analysis for SNAMP participants. The SNAMP Spatial Team has focused on the use of Lidar – Light Detection and Ranging, an active remote sensing technology that has the ability to map forest structure.

Lidar data were collected for Sugar Pine (117km^2) in September 2007 (pre-treatment), and Nov 2012 (post-treatment); and for Last Chance (107km^2) on September 2008 (pre-treatment) and November 2012 and August 2013 (post-treatment). Field data were collected at each site according to an augmented protocol based on the Fire and Forest Ecosystem Health (FFEH) Team plot method. From the Lidar data, field data and aerial imagery (for some of the products), a range of map products were created, including: canopy height model, digital surface model and digital terrain model; topographic products (digital elevation model, slope, aspect); forest structure products (mean height, max height, diameter at breast height (DBH), height to live canopy base (HTLCB), canopy cover, leaf area index (LAI), and map of individual trees); fire behavior modeling products (max canopy height, mean canopy height, canopy cover, canopy base height, canopy bulk density, basal area, shrub cover, shrub height, combined fuel loads, and fuel bed depth), as well as a map of individual trees, and a detailed vegetation map of each site. Lidar data have been used successfully in the SNAMP project in a number of ways: to capture forest structure; to map individual trees in forests and critical wildlife habitat characteristics; to predict forest volume and biomass; to develop inputs for forest fire behavior modeling, and to map forest topography. The SNAMP Spatial Team also explored several avenues of research with Lidar data that resulted in eleven peer-reviewed publications, listed in Appendix B2. Our research has been significant over a range of areas.

Technical advances from the SNAMP Spatial Team

In a comprehensive evaluation of interpolation methods, we found simple interpolation models are more efficient and faster in creating DEMs from Lidar data, but more complex interpolation models are more accurate, and slower (Guo et al. 2010 SNAMP Publication #4). The Lidar point cloud (as distinct from the canopy height model) can be mined to identify and map key ecological components of the forest. For example, we mapped individual trees with high accuracy in complex forests (Li et al. 2012 SNAMP Publication #6 and Jakubowski et al. 2013c SNAMP Publication #24), and downed logs on the forest floor (Blanchard et al. 2011 SNAMP Publication #7). We investigated the critical tradeoffs between Lidar density and accuracy and found that low-density Lidar data may be capable of estimating plot-level forest structure metrics reliably in some situations, but canopy cover, tree density and shrub cover were more sensitive to changes in pulse density (Jakubowski et al. 2013b SNAMP Publication #18).

Lidar data used to map wildlife habitat

Lidar can be used to map elements of the forest that are critical for wildlife species. We used our data to map large residual trees and canopy cover – two key elements of forests used by California spotted owl (*Strix occidentalis occidentalis*) for nesting habitat (Garcia-Feced et al. 2012 SNAMP Publication #5). Lidar also proved useful for characterizing the forest habitat conditions surrounding trees and snags used by the Pacific fisher (*Pekania* [*Martes*] *pennanti*) for denning activity. Large trees and snags used by fishers as denning structures were associated with forested areas with relatively high canopy cover, large trees, and high levels of vertical structural diversity. Den structures were also located on steeper slopes, potentially associated with drainages with streams or access to water (Zhao et al. 2012b SNAMP Publication #16).

Lidar products used in fire behavior modeling

Forest fire behavior models need a variety of spatial data layers in order to accurately predict forest fire behavior, including elevation, slope, aspect, canopy height, canopy cover, crown base height, crown bulk density, as well as a layer describing the types of fuel found in the forest (called the "fuel model"). These spatial data layers are not often developed using Lidar (light detection and ranging) data for this purpose (fire ecologists typically use field-sampled data), and so we explored the use of Lidar data to describe each of the forest-related variables. We found that stand structure metrics (canopy height, canopy cover, shrub cover, etc.) can be mapped with Lidar data, although the accuracy of the product decreases with canopy penetration. General fuel types, important for fire behavior modeling, were predicted well with Lidar, but specific fuel types were not predicted well with Lidar (Jakubowski et al. 2013a SNAMP Publication #13).

Use of Lidar for biomass estimation

Accurate estimation of forest above ground biomass (AGB) (all aboveground vegetation components including leaves/needles) has become increasingly important for a wide range of end-users. Lidar data can be used to map biomass in forests. However, the availability of, and uncertainty in, allometric equations used to estimate tree volume influences the accuracy with which Lidar data can predict biomass from Lidar-derived volume metrics (Zhao et al. 2012a SNAMP Publication #14). Many Lidar metrics, including those derived from individual tree mapping are useful in estimating biomass volume. We found that biomass can be accurately estimated with regression equations that include tree crown volume and that include an explicit understanding of the overlapping nature of tree crowns (Tao et al. 2014 SNAMP Publication #29). Satellite remote sensing has provided abundant observations to monitor forest coverage. Validation of coarse-resolution above ground biomass derived from satellite observations is difficult because of the scale mismatch between the footprints of satellite observations and field measurements. Lidar data when fused with course scale, fine temporal resolution imagery such as MODIS, can be used to estimate regional scale above ground forest biomass (Li et al. 2015 SNAMP Publication #37).

Management implications

Our work has several management implications. Lidar will continue to play an increasingly important role for forest managers interested in mapping forests at fine detail. Understanding the structure of forests – tree density, volume and height characteristics - is critical for management, fire prediction, biomass estimation, and wildlife assessment. Optical remote sensors such as Landsat, despite their synoptic and timely views, do not provide sufficiently detailed depictions of forest structure for all forest management needs. We provide management implications in four areas:

1. Lidar maps and products

- Lidar data can produce a range of mapped product that in many cases more accurately map forest height, structure and species than optical imagery alone.
- Lidar software packages are not yet as easy to use as the typical desktop GIS software.
- There are known limitations with the use of discrete Lidar for forest mapping - in particular, smaller trees and understory are difficult to map reliably.
- Discrete Lidar can be used to map the extent of forest fuel treatments; treatment methods cannot be detected using discrete Lidar, but waveform Lidar might be alternative choice to map understory change.

2. Wildlife

- Lidar is an effective tool for mapping important forest habitat variables – such as individual trees, tree sizes, and canopy cover - for sensitive species.
- Lidar will increasingly be used by wildlife managers, but there remain numerous technical and software barriers to widespread adoption. Efforts are still needed to link Lidar data, metrics and products to measures more commonly used by managers such as CWHR habitat classes.

3. Fire behavior modeling

- Lidar data are not yet operationally included into common fire behavior models, and more work should be done to understand error and uncertainty produced by Lidar analysis.

4. Forest management

- There is a trade-off between detail, coverage and cost with Lidar. The accurate identification and quantification of individual trees from discrete Lidar pulses typically requires high-density data. Standard plot-level metrics such as tree height, canopy cover, and some fuel measures can reliably be derived from less dense Lidar data.
- Standard Lidar products do not yet operationally meet the requirements of many US forest managers who need detailed measures of forest structure that include understanding of forest heterogeneity, and understanding of forest change. More work is needed to translate between the remote sensing community and the forest management community in some areas of the US to ensure that Lidar products are useful to and used by forest managers.
- The fusion of hyperspectral imagery with Lidar data may be very useful to create detailed and accurate forest species maps.

The future of Lidar for forest applications will depend on a number of considerations. These include: 1) costs, which have been declining; 2) new developments to address limitations with discrete Lidar, such as the use of waveform data; 3) new analytical methods and more easy-to-use software to deal with increasing data sizes, particularly with regard to Lidar and optical imagery fusion; and 4) the ability to train forest managers and scientists in Lidar data workflow and appropriate software.

Blanchard, S., M. Jakubowski, and M. Kelly. 2011. Object-Based Image Analysis of Downed Logs in Disturbed Forested Landscapes using Lidar. Remote Sensing 3: 2420-2439.

Garcia-Feced, C., D. Tempel, and M. Kelly. 2011. LiDAR as a tool to characterize wildlife habitat: California spotted owl nesting habitat as an example. Journal of Forestry 108(8): 436-443.

Guo, Q., W. Li, H. Yu, and O. Alvarez. 2010. Effects of topographic variability and lidar sampling density on several DEM interpolation methods. Photogrammetric Engineering and Remote Sensing 76(6): 701–712.

Jakubowski, M. Q. Guo, B. Collins, S. Stephens, and M. Kelly. 2013a. Predicting surface fuel models and fuel metrics using lidar and CIR imagery in a dense, mountainous forest. Photogrammetric Engineering and Remote Sensing 79(1): 37–49.

Jakubowski, M.K., Q. Guo, and M. Kelly. 2013b. Tradeoffs between lidar pulse density and forest measurement accuracy. Remote Sensing of Environment 130: 245–253.

Jakubowski, M.K., W. Li, Q. Guo, and M. Kelly. 2013c. Delineating individual trees from lidar data: a comparison of vector- and raster-based segmentation approaches. Remote Sensing 5: 4163-4186.

Li, W., Q. Guo, M. Jakubowski, and M. Kelly. 2012. A new method for segmenting individual trees from the lidar point cloud. Photogrammetric Engineering and Remote Sensing 78(1): 75-84.

Li, L., Q. Guo, S. Tao, M. Kelly, and G. Xu. 2015. Lidar with multi-temporal MODIS provide a means to upscale predictions of forest biomass. ISPRS Journal of Photogrammetry and Remote Sensing 102: 198-208.

Tao, S., Q. Guo, L. Li, B. Xue, M. Kelly, W. Li, G. Xu, and Y. Su. 2014. Airborne lidar-derived volume metrics for aboveground biomass estimation: a comparative assessment for conifer stands. Agricultural and Forest Meteorology 198-199: 24-32.

Zhao, F., Q. Guo, and M. Kelly. 2012a. Allometric equation choice impacts lidar-based forest biomass estimates: a case study from the Sierra National Forest, CA. Agricultural and Forest Meteorology 165: 64– 72.

Zhao, F., R.A. Sweitzer, Q. Guo, and M. Kelly. 2012b. Characterizing habitats associated with fisher den structures in southern Sierra Nevada forests using discrete return lidar. Forest Ecology and Management 280: 112–119.

Wildlife: California Spotted Owl

We conducted a two-part analysis to assess the effects of SPLATs on California spotted owls (*Strix occidentalis occidentalis*). First, we performed a retrospective analysis using 20 years of demographic data collected at 74 spotted owl territories that included the Last Chance Study Area (LCSA) and the nearby Eldorado Study Area (ESA). This approach deviated from our original plan to directly estimate the effects of SPLATs on spotted owls at Last Chance using a Before-After Control-Impact experimental design, similar to the approach used by some of the other SNAMP Science Teams. The revised approach was necessary because too few owls were present on the LCSA and the delay in implementing the Last Chance fuels-reduction project resulted in only one year of post-treatment data collection. As a result, we needed to spatially and temporally expand the retrospective analysis to achieve sufficient power to detect changes in owl demographic parameters (Popescu et al. 2012). The drawback to our revised approach was that we could no longer specifically estimate the effects of SPLATs on owls because many different types of timber harvest, as well as wildfire and forest succession, occurred within owl territories during our study period (1993-2012). Second, we performed a prospective analysis (30 years into the future) of the effects of SPLATs and wildfire on spotted owl habitat and demography within the LCSA only. This analysis represented our integration effort with the research conducted by the Fire and Forest Ecosystem Health [FFEH] and Spatial teams.

The retrospective analysis has been published in a peer-reviewed journal (Tempel et al. 2014), and we have reproduced this paper in the first section of this appendix. We assessed the effects of forest conditions, timber harvest, and wildfire on spotted owl reproduction, non-juvenile survival, and territory occupancy using the previously mentioned 20-year data set. All habitat and timber harvest variables that we extracted from our vegetation maps were time-varying and could change annually because of natural disturbance, timber harvest, or regrowth. We categorized timber harvest into three broad categories for analytical purposes—low-intensity, medium-intensity, and high-intensity. The classification scheme was based on the expected change in forest structure and was developed after consultation with three local forest managers who were naïve to the objectives of our study. SPLATs and other U.S. Forest Service treatments conducted prior to the adoption of SPLATs were considered to be medium-intensity harvests. Adult survival and territory colonization were relatively high, while territory extinction was relatively low, in territories that had greater amounts of high-canopy-cover forest (≥70% canopy cover, dominated by trees ≥12” [30.5 cm] diameter at breast height). Reproductive success was negatively associated with the area of medium-intensity timber harvests characteristic of SPLATs. Our results also suggested that the amount of edge between older forests and shrub/sapling vegetation and increased habitat heterogeneity may result in higher spotted owl demographic rates. We found some evidence that high-severity fire was correlated with a reduced likelihood of territory colonization, but the standard error was unestimable for the parameter coefficient, suggesting that we lacked a sufficient sample size of burned territories to draw definitive conclusions. Despite correlations between owl demographic rates and several habitat variables, life-stage simulation (sensitivity) analyses indicated that the amount of high-canopy forest was the primary driver of population growth and equilibrium occupancy at the territory scale. Greater than 90% of medium-intensity harvests converted high-canopy forests into lower-canopy vegetation classes, suggesting that landscape-scale fuel treatments in such stands could have short-term negative impacts on California spotted owl populations. Moreover, high-canopy forests declined by an average of 7.4% across territories during our study, suggesting that habitat loss could have contributed to declines in abundance and territory occupancy detected in a previous study of this population. Thus, we recommend that managers consider the existing amount and spatial distribution of high-canopy-cover forest before implementing SPLATs and that SPLATs be accompanied by a rigorous monitoring program within an adaptive management framework.

We present the prospective analysis in the second section of this appendix. For this analysis, the FFEH Team simulated forest growth 30 years into the future under four combinations of modeled wildfire and treatment (i.e., Last Chance fuels-reduction project): treated with fire, untreated with fire, treated without fire, and untreated without fire. We compared spotted owl habitat on the LCSA under the four scenarios using a habitat suitability index developed from canopy cover and large-tree measurements at nest sites on the ESA. In addition, we compared population growth rate and equilibrium occupancy at four spotted owl territories within the LCSA for each scenario using the statistical relationships between forest structure and these population parameters that we developed in the retrospective analysis. We found that effects of fuels treatments were contingent on fire occurrence. Treatments had a positive effect on owl nesting habitat and demographic rates up to 30 years after simulated fire, but they had a persistently negative effect throughout the 30-year period in the absence of fire. We conclude that SPLATs may provide long-term benefits to spotted owls if fire occurs under escaped wildfire conditions, but can have long-term negative effects on owls if fire does not occur. However, we only simulated one fire under the treated and untreated scenarios and therefore had no measures of associated uncertainty. In addition, the net benefits of fuels treatments on spotted owl habitat and demography will depend on the future probability that fire will occur under similar weather and ignition conditions, and such probabilities remain difficult to quantify. Therefore, we recommend adopting a landscape approach that restricts timber harvest within territory core areas of use (~125 ha in size) that contain critical owl nesting and roosting habitat (Berigan et al. 2012) and locates fuels treatments in the surrounding areas to reduce the potential for hazardous fire to spread into PACs.

Berigan, W. J., R. J. Gutiérrez, and D. J. Tempel. 2012. Evaluating the efficacy of protected habitat areas for the California spotted owl using long-term monitoring data. Journal of Forestry 110:299–303.

Popescu, V. D., P. d. Valpine, D. Tempel, and M. Z. Peery. 2012. Estimating population impacts via dynamic occupancy analysis of Before–After Control–Impact studies. Ecological Applications 22:1389–1404.

Tempel, D. J., R. J. Gutiérrez, S. A. Whitmore, M. J. Reetz, R. E. Stoelting, W. J. Berigan, M. E. Seamans, and M. Z. Peery. 2014. Effects of forest management on California spotted owls: implications for reducing wildfire risk in fire-prone forests. Ecological Applications 24:2089–2106.

Wildlife: Pacific Fisher

Fishers (*Pekania pennanti*) are a medium-sized mammalian carnivore with a pre-European distribution encompassing the boreal forest zone of Canada, the Great Lakes region and northeastern United States, a relatively limited portion of the Rocky Mountains in the United States, and mountainous areas of Washington, Oregon, and California, USA (Powell 1993). Ecologically, fishers are a mature or old forest-obligate species (Zielinski et al. 2005), and in central to eastern Canada and the northeastern United States their numbers were reduced historically by the combination of intensive trapping and loss of forest habitats (Powell 1993, Powell and Zielinski 1994). The species is uncommon to rare in the western United States. It is listed as a sensitive species by the Oregon Department of Fish and Wildlife and endangered by Washington State. In July 2015, the California Fish and Game Commission voted to list the southern Sierra Nevada fisher population as threatened, and the species is currently a candidate for listing under the US Endangered Species Act. In advance of federal and state listing decisions, conservation planning has been underway in California since 2013 to develop an approach to maintaining viable populations of fishers in both northwestern California and in the southern Sierra Nevada. Information from the SNAMP Fisher Project (published manuscripts, submitted manuscripts, and unpublished data) described herein has been included in a Southern Sierra Nevada Fisher Conservation Assessment developed by the Conservation Biology Institute, with input from a team of 13 fisher researchers and scientists.

The SNAMP Fisher Project was initiated by the UC Science Team in fall 2007, in association with multiple other SNAMP research programs, to provide an independent evaluation of how vegetation management, prescribed by the 2004 Sierra Nevada Forest Plan Amendment, affects fire risk, wildlife, forest health and water. A major goal of the SNAMP Fisher Project was to determine whether current rates of survival and reproduction will allow fishers to persist in the Sierra Nevada in the context of active forest management to reduce fuels and the risk of catastrophic wildfire. Our approach for assessing how fishers would respond to Strategically Placed Landscape Area Treatments (SPLATs) was designed to be multifaceted including (1) life history responses to fuels reduction (changes in survival, reproduction/fecundity, lifespan), (2) changes in local scale habitat use within individual home ranges, and (3) shifts or changes in habitat use at the home range scale of animal resource use/resource selection.

A range of standard methods were used in the study to live-trap, radiocollar and monitor survival status of individual fishers. Monitoring was accomplished almost entirely by fixed-wing aerial radiotelemetry, supported by an "in house" aviation program developed specifically for SNAMP Fisher and administered by the Forest Service. Ground-based radiotelemetry was used to monitor female fishers during denning seasons, and to recover carcasses of deceased fishers. Cameras were systematically placed throughout the study area at the center points of 1-km^2 grid cells. Grid cells within the SNAMP study area and the key watershed region were surveyed annually, while grid cells outside these areas were surveyed opportunistically. We used the camera survey data to support an occupancy analysis, investigating the impacts of different forest management actions on fisher occupancy, persistence, and extinction.

A total 110 individual fishers were captured and radiocollared from Dec 2007 to Dec 2013 (62 females, 48 males). Sixty-six (60%) of the 110 individual fishers radiocollared during the study were known to have died, including 32 females and 34 males. On average 10.5 radiocollared fishers died in each population year over the course of the study, and the most common cause of death was predation by felid carnivores (bobcats, *Lynx rufus*, and mountain lions, *Puma concolor*). Two radiocollared fisher deaths were roadkills on Highway 41, and five others were directly linked to anticoagulant rodenticides being used in association with illegal marijuana grow sites in the Sierra National Forest.

Seventy-six (85%) breeding-age female fishers either exhibited denning behavior (n = 63) or were determined to have denned and weaned at least 1 kit. Among the 76 breeding-age females that initiated denning, 64 (84%) were identified as weaning kits. Overall, 72% of adult female fishers for which reproductive status was known produced at least 1 weaned kit. We were able to determine litter size for 48 of 59 denning females. A total of 73 kits were known produced, with an average litter size of 1.5.

Fisher population sizes ranged from 48 in 2010 to 62 in 2012, whereas mean population density ranged between 0.072 fishers/km^2 in 2010 and 0.093 fishers/km^2 in 2012. Lambda across all years was 0.90, which was suggestive of general population decline, however, the annual and cumulative 95% confidence intervals all overlapped with 1.0.

Camera surveys were completed in 905 unique 1-km^2 grid cells throughout the overall study area, including 56 grid cells within the southern region of Yosemite National Park. Fishers were detected in 448 of the unique grid cells surveyed, which helped to identify that fishers in this part of the southern Sierra Nevada were most common between 4500 and 6500 feet elevation (1372 and 1981 m elevation). Occupancy estimates for multi-year surveyed grid cells corrected for imperfect detection < 1.0 ranged from 0.62 to 0.80.

Occupancy modelling indicated that fishers reduced their use of forest patches exposed to higher levels of restorative fuel reduction; i.e. persistence of occupancy declined with additional acreage treated for fire resiliency. However, neither restorative nor extractive (i.e., commercial thinning) fuel reduction was related to either initial probability of occupancy or local extinction. We found that SPLATs caused an immediate 6% reduction in potential fisher habitat. However, they also moderated the impact of fire, resulting in greater available fisher habitat within 30 years. In the absence of simulated fire, the amount of habitat steadily increased over time due to forest succession, and was actually slightly greater on the treated landscape in year 30 than in year 0.

The combination of an overall negative population growth rate and the relatively small abundance estimate (*n* = 93, range 80-107), warrants concern for the long term viability of the fishers in the region. Any small population will be at high risk to stochastic events such as disease and large perturbations to critical habitats (e.g., forest fires or drought; Noss et al. 2006), and genetic limitation resulting from genetic drift after founder events (Tucker et al. 2014) will hinder population recovery and expansion (Reed et al. 2003). Minimum viable population size has been under debate (Shoemaker et al. 2013, Reed and McCoy 2014), but at <500 individuals (Spencer et al. 2015), the current southern Sierra Nevada fisher population will likely require active management and conservation measures to maintain a positive growth rate across its entire range. The estimated population growth rate in the SNAMP Fisher study area reaffirms the vulnerability of the small, isolated population to external threats (Spencer et al. 2015), especially wildfires that are likely to increase in frequency and intensity with climate change. Moreover, the SNAMP Fisher study spanned a limited period of six years during which multiple novel threats to fisher survival within the study area were identified, and three large wildfires significantly reduced availability of suitable habitat for fishers immediately to the south and north of the study site. We recommend continuous monitoring of the status of fisher populations in the southern Sierra Nevada region. Development of ways to mitigate for major threats to fisher survival and fisher habitats and population viability analyses are necessary for evaluating the long-term prospects for fishers in the southern Sierra Nevada. Data from the SNAMP Fisher study have provided important new insights on the status of a fisher population at the north margin of their current distribution in the southern Sierra Nevada Range, which will be useful towards developing a comprehensive conservation strategy for fishers in California.

Noss, R.F., J.F. Franklin, W.L. Baker, T. Schoennagel, and P.B. Moyle. 2006. Managing fire-prone forests in the western United States. Frontiers in Ecology and the Environment 4: 481-487.

Powell, R.A. 1993. The fisher: life history, ecology, and behavior, 2nd ed. Minneapolis, MN: University of Minnesota Press.

Powell, R.A. and W.J. Zielinski. 1994. Fisher. In: L.F. Ruggiero, K.B. Aubry, S.W. Buskirk, and W.J. Zielinski, editors. The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Reed, D.H., J.J. O'Grady, B.W. Brook, J.D. Ballou, and R. Frankham. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. Biological Conservation 113:23–34.

Reed, J.M. and E.D. McCoy. 2014. Relation of Minimum Viable Population Size to Biology, Time Frame, and Objective. Conservation Biology 28: 867–870.

Shoemaker, K.T., A.R. Breisch, J.W. Jaycox, and J.P. Gibbs. 2013. Reexamining the minimum viable population concept for long-lived species. Conservation Biology 27:443–452.

Spencer, W., S. Sawyer, W.J. Zielinski, R. Sweitzer, C. Thompson, K. Purcell, D. Clifford, L. Cline, H. Safford, S. Britting, R. Powell, J. Sherlock, and J. Tucker. 2015. Draft Southern Sierra Nevada Fisher Conservation Assessment. San Diego, CA: Conservation Biology Institute.

Tucker, J.M., M.K. Schwartz, R.L. Truex, S.M. Wisely, and F.W. Allendorf. 2014. Sampling affects the detection of genetic subdivision and conservation implications for fisher in the Sierra Nevada. Conservation Genetics. 15: 123-136. doi: 10/1007/s10592-013-0525-4.

Zielinski, W.J., R. L. Truex, F.V. Schlexer, L.A. Campbell, and C. Carroll. 2005. Historic and contemporary distributions of carnivores in forests of the Sierra Nevada, California, USA. Journal of Biogeography 32:1385-1407.

Water Quantity and Quality (DRAFT)

Part I of Appendix E addresses water quantity measurement and modeling to determine the impacts of forest fuel treatments and wildfire on hydrologic fluxes. For this study, a spatially explicit hydro-ecological model, based on observed data, was used to scale from small to large catchments. The Regional Hydro-Ecological Simulation System (RHESSys) was calibrated using headwater catchment observations of climate, snow, soil moisture, and stream discharge for the three pre-treatment years (2010-2012), which encompassed wet, average, and dry precipitation conditions. The successful headwater calibrations were then transferred to the fireshed scale, based on geologic similarities between catchments. Changes in forest structure were determined by differences in Leaf Area Index (LAI), overstory canopy cover, and understory shrub cover.

Implementation of Strategically Placed Landscape Treatments (SPLATs) at Last Chance resulted in a vegetation decrease of 8% leading to runoff increases of at least 12% for the initial 20 years, falling to 9.8% by year 30, when compared to the no treatment scenario. Predicted vegetation growth following SPLATs showed the reduced biomass densities only lasted for about 10 years; after 10 years runoff decreased to pre-treatment levels. Two other modeled scenarios were also assessed: fire without SPLATs reduced vegetation by 49.8% while fire with SPLATs reduced vegetation by 38.1%, increasing runoff respectively by 66.7% and 54.9%.

SPLAT implementation at Sugar Pine resulted in a 7.5% decrease in vegetation, but increases in runoff were less than 3% compared to the no treatment scenario over 30 years. Predicted vegetation growth following SPLATs again showed the reduced biomass densities only lasted for about 10 years. Fire without SPLATs reduced vegetation by 42.5% while fire with SPLATs reduced vegetation by 39.5%, increasing runoff by 15.2% and 13.1% respectively.

Implementing SPLATs, both with and without wildfire, had a greater effect on annual runoff in Last Chance than in Sugar Pine. The difference in the two study area responses can largely be attributed to the differences in precipitation rates. Changes in vegetation at Sugar Pine had minimal effect on annual evapotranspiration (ET) rates, suggesting the forest is more water-limited than at Last Chance, where changes in ET were more closely linked to forest density. This response can be illustrated using the scenario of greatest vegetation change, wildfire without SPLATs, where a 42.5% reduction in Sugar Pine vegetation led to a 2.9% decrease in ET. The 49.8% reduction in Last Chance vegetation resulted in a 22.8% decrease in evapotranspiration. Although the high-intensity fires can result in greater vegetation reductions and lead to increased runoff, these results did not specifically address water quality issues related to these wildfires such as soil erosion into the stream channel, hydrophobic soils, and elevated snowmelt rates.

Part II of Appendix E addresses water quality measurements that were made to determine potential effects of treatments on water quality which could impact aquatic life and downstream water resources. Stream water temperature, conductivity, turbidity, and dissolved oxygen were recorded at 15-minute intervals using continuous recoding sensors from WY 2010 to WY 2013 in all four watersheds. Additional grab samples were collected and analyzed on a bi-weekly to bi-monthly basis for major ion chemistry and stable isotope chemistry. Movement of channel bed material was measuring using load cell pressure sensors and also recorded at 15-minute intervals for WY 2012-2014.

Water temperature, conductivity, and major ion concentrations were found to be higher in the 2012 and 2013 concurrent- and post-treatment water years respectively (referred hereafter in this chapter as the post-treatment period); however, these years were dry years and these patterns are typical of drought conditions. Dissolved oxygen remained fairly stable throughout the years of the study. Water chemistry parameters were found to all be within healthy ranges for aquatic life with the exception of low dissolve oxygen values during very low flows of dry years when stream flow was intermittent.

Much of the water quality measurement effort was focused on turbidity and bedload movement due to the healthy ranges for other water quality parameters and a lack of sources for chemical pollutants in these headwater systems. An analysis of seasonal turbidity patterns and sediment source areas has been published in a peer-reviewed journal (Martin et al. 2014) and we have summarized key findings in Appendix E.

The observed timing of turbidity versus discharge event peaks indicates that sediment is coming from localized in-channel sources that are easily transported. Data also indicate periods of accumulation and depletion tied to high and low flows. Because SPLATs were light and set far back from stream channels we hypothesized that any changes in water quality (namely turbidity) due to treatments would be due to changes in stream discharge. Mean peak turbidity values were compared for pre- and post- treatment periods in the treatment watersheds but no significant difference was found. This may have been due in part to small sample sizes and large standard deviations caused by the infrequent and episodic nature of sediment movement in these streams. Channel bed movement data indicated that the channel bed acts as temporary storage for sediment, but that it remains stable over the long term.

We found evidence of a drought signal in the water chemistry and turbidity data. In addition, the treatments were light and set far back from the active stream channel. The treatments as implemented were not intensive enough to show an increase in discharge during a low precipitation year and SPLATs as implemented in SNAMP had no detectable effect on turbidity.

Martin, S.E., M.H. Conklin, and R.C. Bales. 2014. Seasonal accumulation and depletion of localized sediment stores of four headwater catchments. Water 6(7): 2144-2163.

Participation

Appendix F is a report on the diverse activities carried out by the Participation Team to assess participation in SNAMP, improve our methods of outreach, and contribute to the integrated chapters (chapters 3, 4 and 5 of this report).

The Sierra Nevada Adaptive Management Project (SNAMP) was developed to incorporate stakeholders into an adaptive management framework where the University of California (UC) used scientific experiments to assess the impacts of Forest Service fuels reduction projects. The first pillar of the UC 2007 SNAMP workplan was that adaptive management involved "deliberate experimentation" and this dictated the way the UC Science Team structured the science conducted in SNAMP (in addition to the Participation Team, SNAMP teams studied the following subjects: fire and forest ecosystem health, Pacific fisher, California spotted owl, and water quality and quantity, and spatial analysis). The workplan's second pillar was "...that adaptive management must be a participatory process that engages scientists, stakeholders, and managers in a long term relationship grounded in shared learning about the ecosystem and society." We considered the Participation Team role to be two-fold: a demonstration of a model of participatory, or collaborative, adaptive management and an analysis of the participant experience in SNAMP. While the primary mode of stakeholder interaction with scientists and the Forest Service was necessarily consultative rather than the power-sharing of a full collaboration, the participatory adaptive management process used by SNAMP was defined for the project as "collaborative adaptive management" or CAM. For this reason, the participatory process as implemented in SNAMP has the following stated definition of collaborative adaptive management (CAM):

> CAM is a science-driven, stakeholder-based process for decision-making while dealing with the scientific unknowns inherent in many physical and biological systems. In the SNAMP process, adaptive management incorporates stakeholder participation in order to improve the amount and breadth of information for decision-making, create meaningful engagement and build mutual understanding, learning, and trust.

Over the last century, the Forest Service has shifted from an emphasis on management based solely on technical expertise to models using more participatory methods. Increasing litigation in the 1980s reflected continued frustrations and conflict as stakeholders demanded more input into the decision-making process. The third party model that SNAMP used, in which an agency, the public and an outside science and outreach provider in a sense act as checks and balances to each other was derived out of the concept of shared, multi-party, or joint monitoring, and to some extent, citizen science. Both increase the participation of stakeholders in the science that drives management decisions. As true co-management, where power is shared equally, is not legally possible for the Forest Service or for scientists adhering to strict experimental protocols, projects like SNAMP can be seen to allow for more transparency in the decision-making process by opening up the science and planning processes, and providing additional pathways for input and feedback. An unforeseen benefit was the stakeholder enthusiasm for increased participation in and understanding of the science that became apparent in the course of the project. SNAMP provided some direct communication channels between scientists and the public, and this turned out to be one of the most appreciated aspects of SNAMP.

To address our focal question and engage stakeholders in the adaptive management process, the Participation Team conducted outreach based on long evolved University of California Cooperative Extension principles, and produced extensive assessments of the participant experience in SNAMP. We developed a participation process and analysis framework based on our best practices for collaboration expertise as well as an extensive review of the literature. The five core elements of our effort were inclusivity, transparency, learning, relationship building and effectiveness. We collected input from both SNAMP participants and non-participants with regard to these core elements in SNAMP via written surveys immediately at the end of meetings as well as through two online email surveys of the SNAMP listserv and three separate rounds of in-depth interviews. Our Team employed the following varied outreach methods to address these elements.

The Team focused on both in-person events and presentations as well as at-a-distance methods that were web-based. Each type of participation event had its advantages and limitations and each allowed certain kinds of learning to occur or relationships to be fostered (Tables F3 and F4 in Appendix F). Face-to-face interactions with scientists and managers were a focal point of the in-person outreach program. Our large public meetings gave broad access to the project, though with little time for details, and provided a forum for interest group positions to be shared. The smaller technical integration team meetings were focused on individual topics. These provided in depth data sharing with advanced discussions and were incredible learning opportunities based on the presentations of the lecturers but also as participants learned from each other's less formal questions and comments. Field trips, where participants could "kick the dirt" together and actually see the forest, were touted as most valuable for learning about management context, scientific methods and findings as well as for building relationships through intimate and casual conversations. Subject matter workshops, which conveyed all the most relevant science on managing a resource including findings beyond the scope of SNAMP, were highly appreciated by managers. Taking SNAMP to targeted audiences by going to their meetings and events proved to be a powerful way to spread the scientific outcomes of SNAMP as well increase project inclusiveness and transparency.

The project's at-a-distance methods such as the website and its document archive, science briefs, newsletters, and blogs provided the basis for all other SNAMP contacts because of their accessibility and transparency. The email list was invaluable for getting information out to interested parties though it is not particularly interactive. Webinars were found to be useful at the end of the project (they saved time and money), but none of the online interactions could replace the importance of face-to-face connections with scientists, managers, or other stakeholders. We observed that our webinars were mainly successful because they occurred at the end of the project when relationships were solidified and there was a group comfort level that could overcome the impersonal nature of the webinar.

To transfer the SNAMP collaborative lessons and to train stakeholders and the agencies to conduct or participate in future collaborative adaptive management projects, we created and implemented a multi-day workshop curriculum and companion workbook. Participants in these trainings gained a clearer understanding of adaptive management and how to include the public in the process, how and when to use an independent third party, and how participants can utilize facilitation tools to help defuse conflict. Evidence from the post-workshop surveys suggests that these trainings increased participant commitment to collaboration and it is these key stakeholders and agency participants that could help ultimately complete the SNAMP adaptive management cycle.

A review of our participation model by core element starts with the two most basic and primary elements: transparency and inclusivity. We attempted to attract and reach out to the broadest extent possible by varying our events, presenting at other groups' events and extending our contact through online and traditional media. Our goal was to include as many voices and perspectives as possible to foster the strongest buy-in for the final results as well as input during the process. Transparency was a focal point from the beginning, starting with the SNAMP website. Within its contractual constraints, SNAMP strove to be as open and transparent in its processes and decision-making as it could be. Our surveys showed that the strong effort put in by the UC Science Team to focus on inclusivity and transparency was recognized by participants.

Learning was the next goal of the SNAMP Participation Team and was also the overall purpose of SNAMP, as reflected in the title of the project: "Learning how to apply adaptive management…" Each of the science teams produced copious amounts of novel data with regard to their subjects and presented these findings to the public multiple times a year. We found that learning in these kinds of social settings helped SNAMP produce shared understandings about basic biological and ecological conditions as well as larger concepts about forest health and adaptive management.

The other crucial outcome of shared learning and understandings was new and improved relationships between the participants in SNAMP. Our results show that over the long life of the project, in which there were many and varied opportunities to interact or observe other participants, relationships improved even among those historically opposed to each other such as environmental and forest products groups. Unfortunately, some relationships in the project were strained not because of the shared learning experience but due to limitations of the project such as funding. Though not an explicit goal of SNAMP, participants also learned about the Forest Service and the constraints faced in Sierran forest management that could help improve collaboration with the agency in the future. The shared scientific understandings and the hybrid culture they fostered, combined with the improved relationships between participants and familiarity with the Forest Service, could be the foundation for more productive and continued collaborations in the future. The Forest Service will need to continue to engage intensely with the public in order for the positive trends to continue.

We interpreted our goal of effectiveness as encompassing the collaboration's process or structure as well as the project's ability to accomplish the goals that the literature suggested and participants felt were important for the project to be interpreted as successful. Much of the basic communication structure of the project worked well: the project invested in trained outreach and facilitation staff, meetings were set up to encourage productive discussions, events were evaluated and continually adapted to meet participant suggestions, and a large variety of outreach strategies were implemented and supported for the duration of the project. In addition, the Forest Service treatments were implemented, the academic experiments were completed and this report was drafted, reviewed by peers and the public, and published; those were milestones that were not always assured of completion during the project and now can also be considered examples of SNAMP's effectiveness.

Ultimately, participants in collaborations like SNAMP intend for the project to have far-reaching and broader impacts past the study areas, timeframes, and agencies involved. One agency participant suggested that the most important goal of SNAMP was to create a group of stakeholders prepared to collaborate with the Forest Service and reduce conflict around forest management in the Sierra. The Participation Team worked to exemplify a model process for conducting collaborative adaptive management and training that could be implemented by agencies to hopefully reduce conflict. Though there was almost complete turnover of the Forest Service participants in SNAMP, many of the public, environmental group, forest products, and other agency representatives were able to stick with the project all the way through. A group of stakeholders had formed at the end of the project who had developed long-term relationships with each other, shared common understandings about the resources, and had similar expectations about the process of adaptive management. This modeling and training, combined with the shared understandings and improved relationships between participants, bodes well for future collaboration in the Sierra.

But was SNAMP effective at reducing conflict? A large majority of our email survey participants felt that SNAMP increased trust within the three party model. Yet both email survey respondents and interviewee participants were ambivalent as to the project's ability to reduce conflict over forest management in the Sierra. The dominant sentiment was that appeals and litigation were inevitable because they are driven by the entrenched philosophies and agendas of interest groups. The two solutions offered by email survey respondents were the cornerstones of the SNAMP three party effort: independent science and increased stakeholder participation.

SNAMP's three party model structure was effective in a most critical aspect – the university and its science were seen as independent, unbiased, and responsive to stakeholder input. But with this new model came miscommunications and disappointed expectations. The two biggest issues were the separation between management and science, and financial constraints. Initially, there were disagreements as to what subjects would be studied in SNAMP. Next, some stakeholders and managers hoped that SNAMP would bring university experts into the Forest Service's planning processes, but this was the opposite of what the UC Science Team imagined due to their interpretation of how to conduct a controlled experiment. A related misinterpretation was connected to definitions of monitoring. Some stakeholders expected the university to "blow the whistle" on the Forest Service if it implemented the treatments differently than planned. This too was not the role of the university as interpreted by the UC Science Team. A Neutrality Agreement was created by the UC Science Team to clarify some of these concerns.

The financial structure of the project was a serious challenge to our effectiveness, though not surprising given the dollar amounts and years of commitment. For large scale adaptive management projects, sizeable and consistent funding over many years is vital yet very difficult to achieve (Gregory et al. 2006). The difficulties of carrying out long term projects with federal agencies under an annual funding regime have been well documented (Nelson 1995). In addition, the recession that started in August of 2008, just a few years into the project, caused havoc with state and federal budgets and threw the project into years of financial stress and uncertainty. Throughout the interviews, there were many comments about the tensions within the MOU Partner funding agencies with regard to how much each contributed, staff turnover, as well as a perception that the university did not understand the financial constraints and had unrealistic expectations. Eventually, the project was completed but with less funding and over a longer period of time than originally planned.

In 2015, UC completed its role in SNAMP. It is left to the Forest Service to work directly with stakeholders to use SNAMP's products, results and recommendations, and to adapt them to future needs. How and whether UC Science Team results and public input are used in the next and future forest treatment plans will determine how SNAMP's effectiveness is ultimately seen. Throughout this project, we have considered this a crucial step that is outside of the funded and UC Science Team part of SNAMP (Figure F1 in Appendix F). The SNAMP collaborative adaptive management workshop teachings offer tools for both the public and the agencies to improve their communication to complete the cycle of adaptive management and begin the next cycle of learning.

Participants from all three sides of the three party model concluded the project with positive aspirations for the future. The third party science provider model was well demonstrated and should be transferable in parts or in whole to other situations or places given adequate attention and funding. It is now up to the Forest Service to close the adaptive management loop and for all of us to use the lessons learned from SNAMP to improve collaboration and management of the forests of the Sierra.

> "… we are the beneficiaries of the work and I think that the investments that we made, no one has groused about them. That wasn't the motivator for us. Benefits to the landscape over the long term and over the entire Sierra landscape were our motivators." MOU Partner 2014

Gregory, R., D. Ohlson, and J.L. Arvai. 2006. Deconstructing adaptive management: criteria for applications to environmental management. Ecological Applications 16(6): 2411-2425.

Nelson, R.H. 1995. Public lands and private rights: The failure of scientific management. Landham, MD: Rowman & Littlefield Publishers.

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Appendix A: Fire and Forest Ecosystem Health Team Final Report

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August 31, 2015

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EXECUTIVE SUMMARY

The 2004 Amendment to the Sierra Nevada Forest Plan identified a coordinated system of fuel treatments distributed across the landscape as the preferred management alternative. The goals of this approach, defined as strategically placed land area treatments (SPLATs), were to modify dangerous fire behavior and improve forest health in the National Forests in the Sierra Nevada region of California. The 2004 amendment also introduced the concept of fireshed management. In concept, firesheds are analogous to watersheds, but are topographic units based on the behavior of a problem fire – a fire that has the greatest potential impact based on the local topography, weather, and fire history. We tested the performance of SPLATs as designed and implemented by US Forest Service in two firesheds, Last Chance in the Tahoe National Forest and Sugar Pine in the Sierra National Forest. We conducted detailed field measurements before and after treatments in order to quantify changes in forest structure and fuel loads resulting from SPLATs. To account for potential changes unrelated to forest management, a control fireshed was paired with the treated fireshed at each site. Data from the field measurements were used to parameterize fire and forest growth models. These models were then used to simulate wildfire effects on fire behavior and to explore the responses of tree growth efficiency (a measure of tree vigor) to the treatments. At Last Chance, fuel treatments distributed across 18% of the landscape reduced the percentage of the forest exposed to damaging flame lengths from 33% (no SPLATs) to 22% (with SPLATs). The impact of SPLATs on fire behavior was less at Sugar Pine. Fire simulations for Sugar Pine showed that SPLATs completed on 29% of the area, reduced exposure to damaging flame lengths from 29% of the landscape to 25% – a minimal decline of 4 percentage points. In contrast, trees in the treated fireshed at Sugar Pine nearly doubled their growth efficiency in the ten years following SPLATs while there were only minor improvements in growth efficiency following treatments at Last Chance. This dichotomy in the response to SPLATs was related to differences in the extent and intensity of the treatments applied at the two sites as well as ecological and land use variations. The treated fireshed at Sugar Pine supported a mixed conifer forest that was more crowded with bigger trees but exposed to a lower initial fire hazard. Nevertheless, in aggregate our results support the promise of SPLATs. Coordinated treatments across part of the landscape can help minimize the hazards posed by severe fires and at the same time meet forest health objectives.

INTRODUCTION

Overview

A century of forest and fire management in the Sierra Nevada has resulted in a sharp decrease in species richness and a dramatic change in the structure of the Sierran forest (Collins et al. 2011, Knapp et al. 2013, Taylor et al. 2014). Abundances of shade-tolerant white fir (*Abies concolor),* Douglas-fir (*Pseudotsuga menziesii* var. *menziesii)* and incense-cedar (*Calocedrus decurrens)* have increased at the expense of the shade-intolerant ponderosa pine *(Pinus ponderosa)* and sugar pine (*Pinus lambertiana*) which require canopy gaps to regenerate successfully (York et al. 2011). Under an intact disturbance regime these canopy gaps would have been created by small patches of tree mortality resulting from fire, insects, and disease; these gaps are largely absent in contemporary fire-suppressed forests (Larson and Churchill 2012, Lydersen et al. 2014, Fry et al. 2014). Dense stands of young white fir, Douglas-fir, and incense-cedar are characterized by increased numbers of small diameter trees and increased canopy cover (Scholl and Taylor 2010, McIntyre et al. 2015). In some particularly vulnerable communities, these changes may have already increased the likelihood of uncharacteristic impacts from fire and insects Knapp et al. 2013, Taylor et al. 2014).

The regional assessment of current forest conditions in the 2004 Sierra Nevada Forest Plan Amendment (USFS 2004) acknowledged how these changes in forest structure and composition associated with past land management practices have exacerbated the risk of severe fire (Biswell 1989, van Wagtendonk 1998) and made modifying wildland fire behavior the management priority. The preferred alternative identified in the 2004 Plan amendment (USFS 2004) was to apply strategically placed area treatments (SPLATs). SPLATs consist of discrete treatment units arranged in a strategic pattern across a landscape, which collectively slow fire spread and moderate fire effects across the landscape (Finney 2001). Simulations have shown that with as little as 30% of the area in SPLATs, fire risk can be decreased for the entire landscape at a disproportionate rate. For example, model results demonstrated that a realistic SPLAT design that treated 33% of a landscape in the Tahoe National Forest reduced the mean flame length by 46% and the mean fire-line intensity by 48% (Vaillant 2008). The landscape unit of management is defined as a fireshed. In concept, firesheds are analogous to watersheds in concept, but are topographic units based on the behavior of a problem fire – a fire that has the greatest potential impact based on the local topography, weather, and fire history. The size of firesheds can vary but they need to be sufficiently large to assess the effectiveness of fuel treatments and encompass characteristic fire sizes for a given area (Bahro et al. 2007).

Despite the promise of SPLATs, there are only a few spatially relevant, fully implemented landscape treatment projects in mixed conifer forests in the Sierra Nevada from which to evaluate and guide management decisions (Moghaddas et al. 2010). The 2004 Amendment (USFS 2004) recognizes this uncertainty as well as the concern for how SPLATs might affect other forest resources. On one hand, SPLATs may provide important co-benefits. For example, the preferred alternative noted the specific objectives of improving tree vigor and overall forest health that might accrue from reducing tree density. This concern over the health of the Sierran forests due to increased competition in crowded stands is shared by the state (FRAP 2003). More recent evidence has linked rising tree morbidity and mortality in Sierran forests with worsening climatic water deficits (van Mantgem and Stephenson 2007), continued exposure to chronic air pollution (Panek et al. 2013), and greater susceptibility to beetle kill (Hicke et al. 2013). On the other hand, SPLATs may degrade habitat for wildlife species dependent on attributes in late-seral forests (Stephens et al. 2014a) or increase sediment yields to streams.

The Sierra Nevada Adaptive Management Project (SNAMP) was formed to address the uncertainty regarding the efficacy of SPLATs in modifying fire behavior and concern regarding potential impacts on wildlife and water resources. Moreover, given the history of debate over land and resource management in the Sierra Nevada, SNAMP followed a specific mandate not only to engage stakeholders and promote active public participation but also to study the adaptive management process itself (Chapter 1). In this report, we address two objectives at the heart of the 2004 Amendment (USFS 2004):

1) What is the effect of SPLATS on wildland fire behavior?
2) Do SPLATs improve forest ecosystem health?

Background

Fire

Recent research has demonstrated an increased proportion of high-severity fire in yellow pine and mixed-conifer forests of the Sierra Nevada between 1984 and 2010 (Miller and Safford 2012, Miller et al. 2009). In addition, these studies demonstrated that fire sizes and annual area burned have also risen during the same period. The authors point out that these increases co-occur with rising regional temperatures and increased long-term precipitation. Westerling et al. (2006) also demonstrated increased area burned over a similar time period, which they attributed to regional increases in temperature and earlier spring snow melts. Despite these documented increases over the last few decades, California and the western United States as a whole are in what Marlon et al. (2012) described as a large "fire deficit." This is based on reconstructed fire occurrence over the last 1,500 years using sedimentary charcoal records. Marlon et al. (2012) argue that the current divergence between climate (mainly temperature) and burning rates is unprecedented throughout their historical record. In other words, with temperatures warming as they have been over the last several decades, we would expect to see much higher fire activity, based on historical fire-climate associations. This divergence is due to fire management practices, which, as the authors point out, may not remain effective over the long term if warming trends continue. It is likely, given increasing temperature and the precipitation patterns since the onset of fire suppression, that fire activity would have increased over the 20th century rather than decreased had fire suppression not been implemented (Skinner and Taylor 2006, Stine 1996), further exacerbating the current fire deficit. This departure in current fire activity relative to what would be expected given current climate combined with the departed contemporary fire patterns (greater proportions and patch sizes of stand-replacing fire) suggests more problematic fire occurrence in the future.

The large wildfires that are occurring annually throughout the Sierra Nevada demonstrate the pressing need to scale up restoration efforts to larger landscapes. Yet implementing fuels treatment across an entire landscape may conflict with desired conditions or may be operationally constrained by funding, access, and land designations (e.g., wilderness areas, protected wildlife habitats, archaeological preserves, Collins et al. 2010, North et al. 2015). In response, scientists and managers have developed and refined concepts like SPLATs that do not require saturation coverage of the landscape to achieve meaningful modification of fire behavior (Ager et al. 2007, 2010; Finney 2001, 2004; Finney et al. 2007). Owing to the complexity of modeling fire and fuels treatment across landscapes (e.g., data acquisition, data processing, and model execution), fuels treatment project design is often based on local knowledge of both the project area and past fire patterns. Recent studies in the northern Sierra Nevada and southern Cascade Range suggests that these types of landscape-level fuels treatment projects (where treatment arrangement is based more on local knowledge and fairly simple fire behavior modeling rather than intensive modeling associated with an optimization approach) can be quite effective at reducing potential fire behavior at the landscape scale (Collins et al. 2011, 2013, Moghaddas et al. 2010).

Although only a few studies have explicitly modeled effectiveness of landscape fuels treatments using different proportions of treated area, there are some common findings: (1) noticeable reductions in modeled fire size, flame length, and spread rate across the landscape relative to untreated scenarios occurred with 10 percent of the landscape treated, but the 20-percent treatment level appears to have the most consistent reductions in modeled fire size and behavior across multiple landscapes and scenarios (Ager et al. 2007, 2010; Finney et al. 2007; Schmidt et al. 2008); (2) increasing the proportion of area treated generally results in further reductions in fire size and behavior; however, the rate of reduction diminishes more rapidly when more than 20 percent of the landscape is treated (Ager et al. 2007, Finney et al. 2007); (3) random placement of treatments requires substantially greater proportions of the landscape to be treated compared to optimized or regular treatment placement (Finney et al. 2007, Schmidt et al. 2008); however, Finney et al. (2007) noted that the relative improvement of optimized treatment placement breaks down when larger proportions of the landscape (about 40 to 50 percent) are excluded from treatment because of land management constraints that limit treatment activities. It should be emphasized that this is not to preclude treating more than 20 percent of a landscape to achieve restoration, resilience, or other resource objectives. These studies suggest that when beginning to deal with fire hazard in a landscape, the initial objective would be to strategically reduce fire hazard on between 10 and 20 percent of the area to effectively limit the ability of uncharacteristically high-intensity fire to easily move across the landscape. This would buy time to allow restoration activities to progress in the greater landscape (North et al. 2015).

Forest health

The terms "healthy forest" and "forest health" are used often in natural resources, yet rarely are they qualified or standardized. The confusion surrounding the term forest health is understandable, as there is no single, universally accepted definition. However, there are some recurring themes in the literature that create a basis for understanding.

Forest health is not exclusively a scientific concept (Kimmins 1997, Patel 1999, Sulak and Huntsinger 2012). Forest health is often defined by the social, cultural or economic values of a specific audience. For example, those with an interest in forest products and sustained local economies may define forest health as a sustainable, actively managed forest that is free of disease, with a diversity of tree species for future product markets (Lankford and Craig 1994). Indeed forest pathologists typically consider health to mean the extent and virulence of tree disease present in a forest whether it is timberlands or wildlands (Pautasso et al. 2014). This definition is focused exclusively on trees. However, an audience interested in maintaining vigorous wildlife populations may insist that the definition be expanded beyond tree health to include the capacity of a forest to maintain viable populations of native species and retain biodiversity of flora *and* fauna (Dellasalla et al. 1995). The first definition measures disease and species diversity of trees, and the second measures wildlife populations. Both definitions of "forest health" may mean opposite management regimes. Ultimately, forest health becomes a social construct, defined not by an inherent, "scientifically correct" state (Warren 2007) but by variables society considers most important (Sulak and Huntsinger 2012).

Many definitions of forest health fall under the general term "utilitarian": a forest is healthy if its condition does not threaten management objectives, current or future (Kolb et al. 1994). While it is easy to diagnose an unhealthy forest under this definition (i.e., a forest is threatening management objectives), the concept can suffer from its own circular logic, where "forest health" is defined by meeting management objectives, yet "forest health" *is* the management objective.

In contrast with anthropocentric utilitarian definitions, forest health has also been defined by specific types and rates of ecological processes (e.g., Tierney et al. 2009) or by the presence of specific indicators (Woodall et al. 2011). Unfortunately, these definitions come with their own set of management problems; quantitative rates and data are not widely available for many ecosystems (Kolb et al. 1994), and there is no gold standard for all rates and processes. Indicators are multifaceted and can provide conflicting information. The challenge then becomes how to integrate multiple lines of information to assess health. Using historical rates and patterns is also tricky. Changing climate and land uses by humans make the selection of the desired parameters difficult, and even if parameters were chosen, it is unlikely that our knowledge of past ecosystem processes is sufficient to design a management regime (Wagner et al. 2000).

Often in the literature, a forest is considered healthy if is resilient or sustainable. Under this guise, a healthy forest is "one that is resilient to change" (Joseph et al. 1991, EPA 2015); "resistant to catastrophic change and/or ability to recover after catastrophe" (Kolb et al. 1994) and has "sustained ecosystem functioning" (Wagner et al. 2000). This definition is also troublesome because resilience is very difficult to measure. The resilience of a forest remains a relative unknown until exposure to disturbance or stress.

The concept of "forest health" is difficult to apply to landscape-level processes because its origins lie at the individual level. Ecosystem health is a metaphor borrowed from human health (Kimmins 1997) and is problematic when applied to whole ecosystems, just as human health is difficult to apply to whole populations (Raffa et al. 2009). A dead or dying single tree is inherently unhealthy, but a dead or dying stand is more difficult to diagnose. Kolb et al. (1994) define an unhealthy stand as only unhealthy if the rate of mortality exceeds the capacity for stand replacement, but this may not necessarily apply at a forest or landscape level.

For SNAMP, we have built on the idea that individual tree growth and survivorship are fundamental components of forest health. While this focus on tree vigor recognizes the foundational role of trees in forests (Ellison et al. 2005), it does not encompass the term's broader usage (Sulak and Huntsinger 2012). Thus in addition to measuring tree vigor we also assessed the impact of SPLATs on forest structure and species composition.

Adaptive Management Experiment

SNAMP was structured as a deliberate experiment in adaptive management (Chapter 1). Thus, the design and implementation of the SPLATs on the landscape was left entirely to the US Forest Service. We measured forest and fuel characteristics before and after treatments. These data serve as the basis for both direct comparisons as well as input for the necessary simulation experiments of fire behavior.

METHODS

Site Description

Last Chance, the northern study area (Figure A1) is defined by the boundaries of four adjoining watersheds. The treatment fireshed consists of the two central watersheds: Deep Canyon and Grouse Creek. We used the two immediately adjacent watersheds as the control (Screwauger Canyon and Peavine Creek). In total, the study site encompasses an area 38.4 mi^2 (99.5 km2), with elevation ranging from 2,625 ft (800 m) in the southwest to almost 7,218 ft (2,200 m) in the northeast portion of the study area. Soils are moderately deep, well-drained Inceptisols with a gravely loam texture. The Crozier and Hurlbut soil series that are most common at Last Chance are derived from andesite and metasedimentary parent material (NRCS 2015). The climate is Mediterranean with a predominance of winter precipitation, a majority of which is snow. Total precipitation averages 46.5 in/yr (1,182 mm/year). Mean monthly temperatures are 37.4 °F (3°C) in January and 69.8 °F (21°C) in July (1990–2008; Hell Hole Remote Automated Weather Station).

Sugar Pine, the southern study area (Figure A2) is located in central Sierra Nevada, approximately 124 mi (200 km) south of Last Chance. Encompassing approximately 12.9 mi^2 (33.6 km^2), elevation at Sugar Pine ranges from 3.936 ft (1,200 m) in the southwest to almost 7,216 ft (2,200 m) in the northeast portion of the study area at Speckerman Mountain. The deep, well-drained soils at Sugar Pine developed from weathered granodiorite. Holland family soils (Inceptisols) with a sandy loam texture are most common (NRSC 2015). The climate is also Mediterranean with snow dominating the 42.9 in/yr of precipitation (1,091 mm/year). Mean monthly temperatures are 35.6 °F (2 °C) in January and 64.4 °F (18°C) in July (1941-2002; Yosemite National Park).

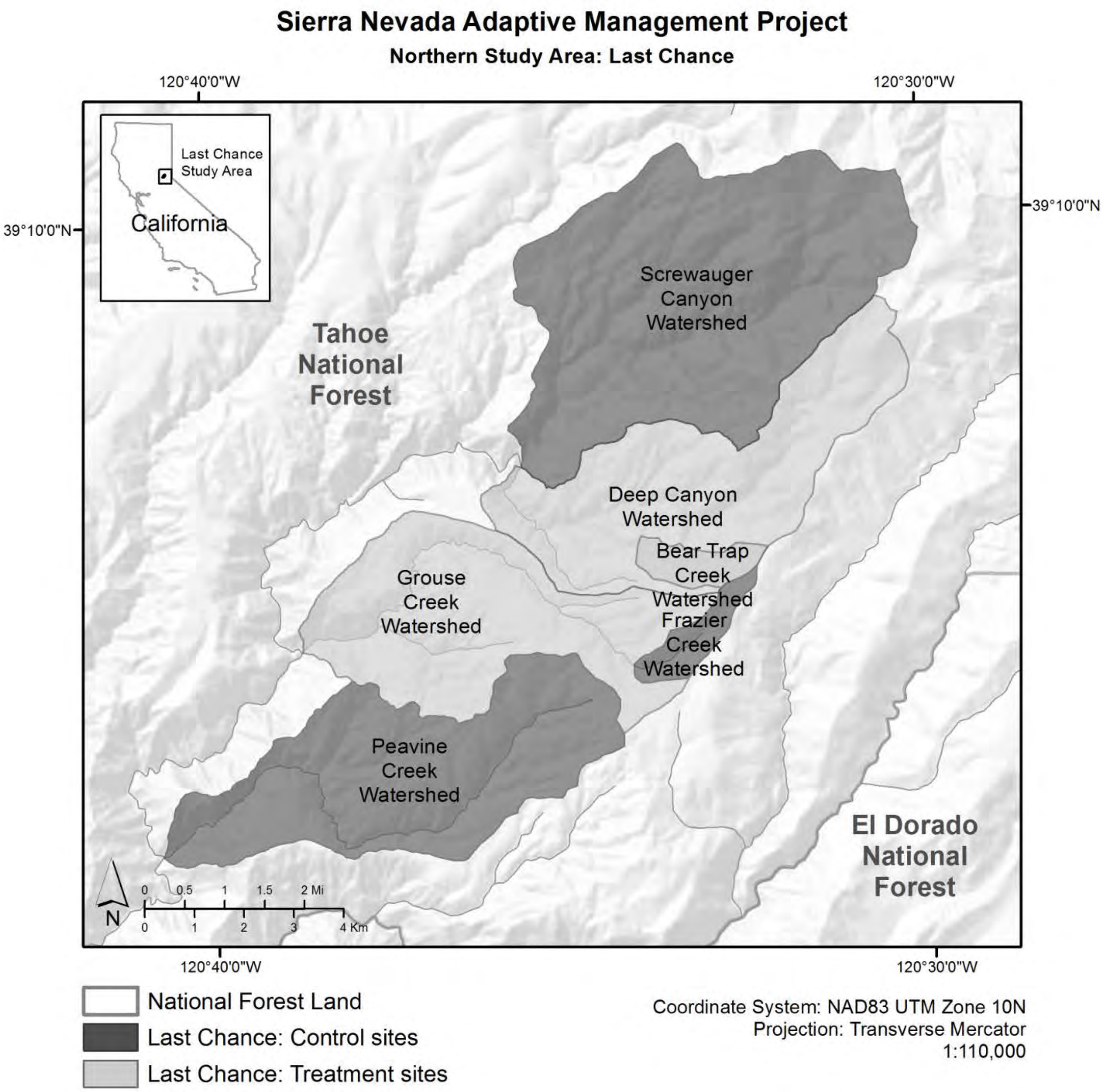


Figure A1: Control (dark grey) and treatment (light grey) areas at Last Chance, the Sierra Nevada Adaptive Management Project's northern study site in the Sierra Nevada, California. Bear Trap and Frazier Creek were the headwater catchments evaluated by the Water Team.

Vegetation at Last Chance is dominated by the Sierra Nevada mixed conifer forest. White fir (*Abies concolor*) and Douglas-fir (*Pseudotsuga menziesii*) are the two most abundant species but incense-cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), and California black oak (*Quercus kelloggii*) appear as codominants at variable densities. Stands of montane chaparral dominated by manzanita (*Arctostaphylos* spp) are interspersed throughout.

The mixed conifer forest is also the most common vegetation type at Sugar Pine but species composition differs from Last Chance in that there is no Douglas-fir, and the Nelder Grove watershed contains a small grove of giant sequoia (*Sequoiadendron giganteum*). In addition to black oak and interior live oak (*Quercus wislizeni*), typical hardwood and shrub species include white alder (*Alnus rhombifolia*), Pacific dogwood (*Cornus nuttallii*), mountain whitethorn (*Ceanothus cordulatus*), deerbrush (*Ceanothus integerrimus*), and greenleaf manzanita (*Arctostaphylos patula*).

Fire history, inferred from fire scars recorded in tree rings, suggests the fire regime prior to systematic fire suppression and widespread timber harvesting in Sierra Nevada west-side pine-mixed conifer forests was dominated by frequent, low-severity fires occurring at regular intervals (Stephens and Collins 2004, Scholl and Taylor 2010). Based on fire scars collected on site, the median fire interval for Last Chance was 15.0 years and 11.0 years for Sugar Pine (Krasnow 2012). Native American activity in the study areas was likely high before European settlement. The Nisenan Native American community once inhabited the forests of north-central Sierra Nevada. Up until 1901, the area that is now Bass Lake (approximately 5.5 mi [9 km] from the Sugar Pine watershed) was a large, lush meadow inhabited by Chuckchansi and Mono tribes. Fire was used extensively to keep the forest open, encourage herbaceous growth for game animals, and produce vegetative growth conducive to basket weaving and arrow construction (Krasnow 2012).

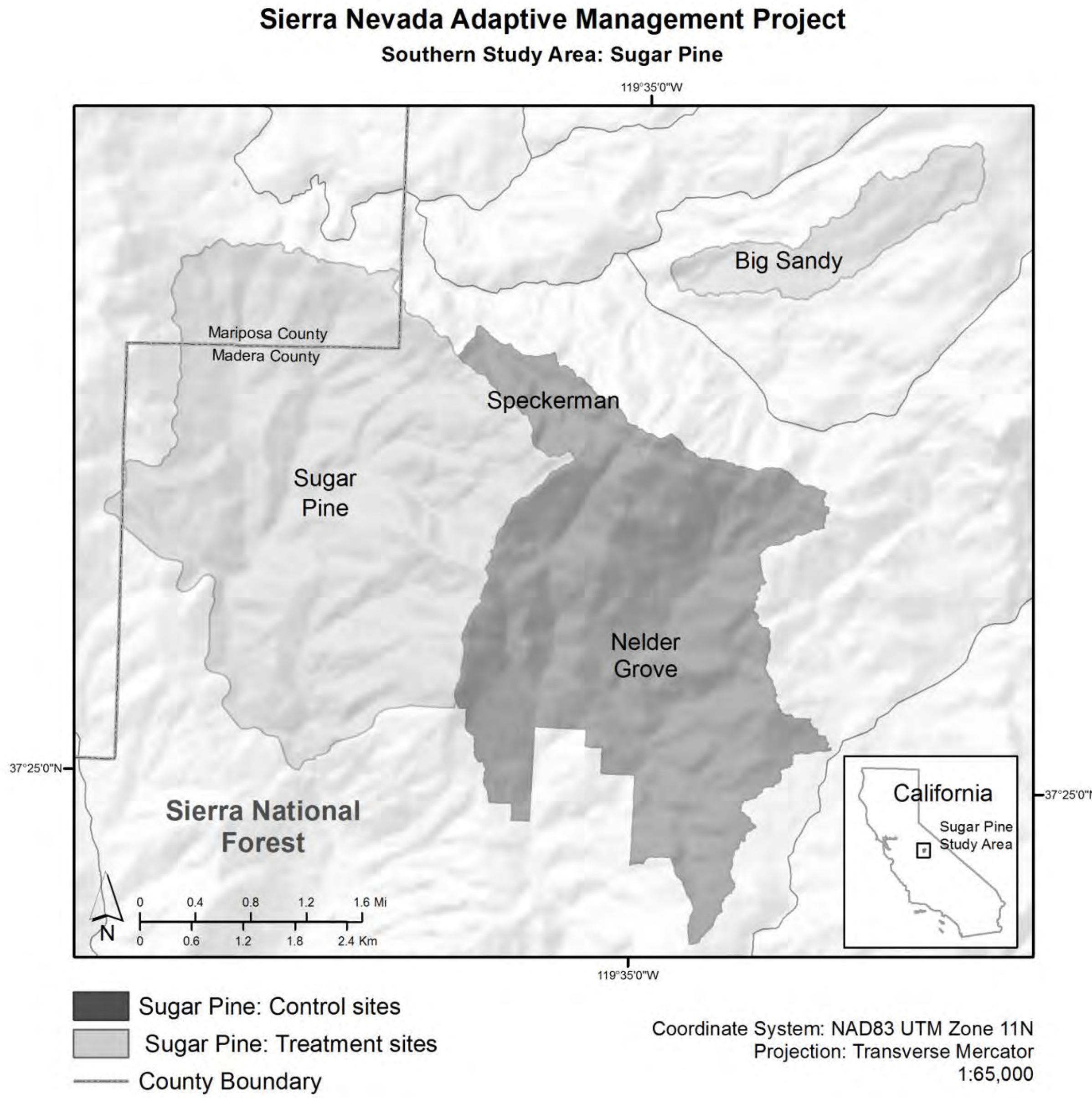


Figure A2: Control (dark grey) and treatment (light grey) areas at Sugar Pine, the Sierra Nevada Adaptive Management Project's southern study site in the Sierra Nevada, California. Big Sandy and Speckerman were the headwater catchments evaluated by the Water Team.

Field Measurements

From a random starting point, we established forest inventory plots at 1640 ft (500 m) spacing across both study areas to characterize stand structure and record changes in conditions due to treatments (Figure A3). This core grid resulted in 328 plots in Last Chance (LC) and 127 plots in Sugar Pine (SP). In the small instrumented catchments used to measure hydrological responses, we increased the sampling effort by reducing the spacing to 820 ft (250 m) or 410 ft (125 m) between plots. To better characterize fire effects, we doubled the number of plots in a recently burned area in LC (Peavine fire) by adding plots at every 820 ft and extended the core plot network to a site with recent fuel treatments just south of SP (Cedar Valley). As a result we have a total of 408 and 284 pre-treatment plots in LC and SP, respectively. Pre-treatment plot measurements were collected during the summer in 2007-08. In order to maximize the time since treatment, we completed the post-treatment sampling in one field season -- 2013. The consolidated field season coupled with limited access due to wildfire (the American Fire began burning on August 10, 2015 just west of LC) forced us to prioritize our sampling efforts. Thus we first re-measured the plots on the core grid followed by plots in treated areas. Our total plot sample size with both pre and post-measurements is 369 at LC and 257 at SP. For vegetation mapping and the development of fire models, we used all available plots. For quantifying forest composition and structure differences between the reference and treated firesheds, we used only the plots on the core grid.

Plots were circular with an area of 0.12 ac (0.05 ha) and located with either a Trimble GeoXH or Garmin handheld global positioning systems (GPS). We used a nested sampling methods based on tree diameter (measured at breast height (dbh 4.5 ft or 1.37 m above the ground): Overstory trees with dbh ≥ 7.67 in (19.5 cm) were sampled on the entire plot (0.12 ac or 0.05 ha); understory trees with dbh between 2.0 – 7.67 in (5- 19.5 cm) were sampled on a random one-third "pie-slice" of the plot (0.04 ac or 167 m^2); small trees with dbh < 2 in dbh (5.0 cm) were sampled with 6.6 ft (2 m) wide radial transect (0.018 ac or 76 m^2). We recorded

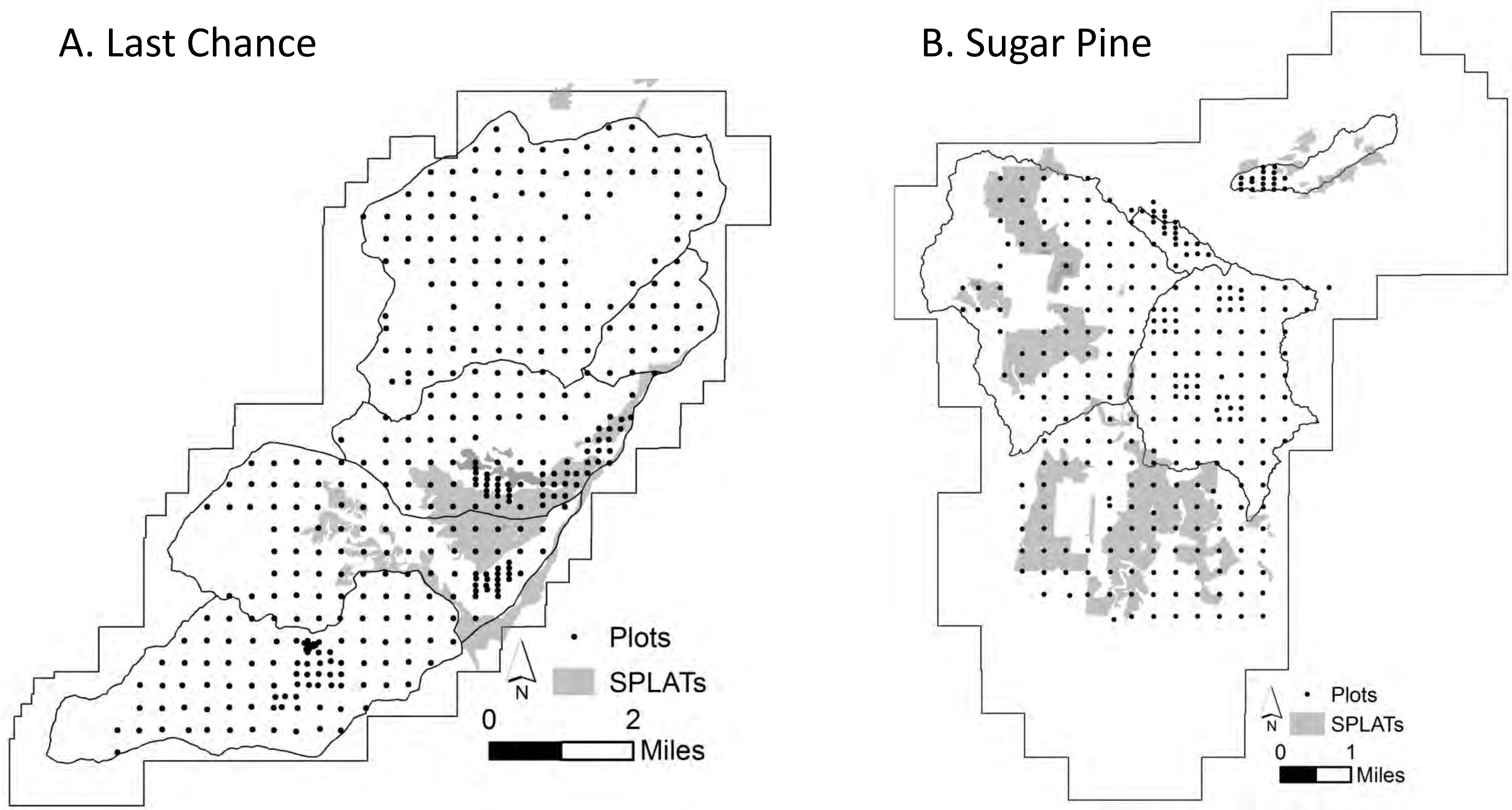


Figure A3: Location of plot network and SPLATs at Last Chance (A) and Sugar Pine (B).

species, vigor, crown position, dbh, total height, and height to live crown base (live trees only) for overstory and understory trees. For small trees, we recorded species and dbh in 0.4 in-classes (1 cm). We tagged all live overstory trees in the plots and tracked the fate of these trees between surveys.

We sampled surface and ground fuels along three radial transects (41.4 ft or 12.62 m) in each plot. We choose the direction of the first transect at random and then placed the remaining two at ±120°angles. Using the line-intercept method (Brown 1974), duff, litter, and surface fuel depths were measured at two points along each transect. Downed woody fuels were tallied along subsets of each transect: 0–1 m (0–0.64 cm and 0.64–2.54 cm branch diameters), 1–3 m (2.54–7.62 cm), and 0–12.62 m (>7.62 cm). Fuel loads were calculated using species-specific coefficients from van Wagtendonk et al. (1996, 1998), weighted by basal area for tree species recorded in the plot (Stephens 2001). On the same three transects we measured shrub species cover via line-intercept and recorded the height of the intercepted shrubs. We used a tube densitometer to estimate canopy cover. We gridded the circular plot into 25 evenly spaced points and recorded if canopy was present directly overhead at each point.

Fuel Treatments

Fuel treatments (Figure A3) were typical of mixed conifer forests (Agee and Skinner 2005). In general, the prescriptions called for treating approximately 25-40% of the treatment firesheds by thinning, mastication, and prescribed fire. Thinning treatments included commercial and biomass thin from below (both sites) and cable harvesting (LC only) followed by mechanical/hand piling and burning. At LC, thinning treatments were designed to retain at least 40% of the existing basal area, reduce ladder fuels by removing trees > 10 in and < 30 in dbh, and maintain a minimum canopy cover of 40%. At SP, residual basal area targets ranged from 55-65% of normal stocking in pine-dominated stands to 80% in the mixed conifer stands. Retention of these higher basal areas ensures minimum canopy cover close to 60%. At both sites, there was an emphasis on increasing vertical and horizontal heterogeneity. Mastication involved the removal of both shrubs and small trees. At LC, mastication occurred primarily within 20- to 30-year-old plantations. At SP, mastication followed some thinning treatments. Prescribed fire focused on understory burning as the primary fuel reduction method (USFS 2009, USFS 2010).

For a host of reasons, treatments were initially delayed and then implemented over several years (2008–2012). During the project planning process some treatments were moderated at SP due to wildlife habitat requirements. At both sites, not all of the planned treatments were completed by 2013 when the final field measurements were obtained. Within the LC study area, the 2008 Peavine Fire (551 ac [223 ha]) burned in August prior to our pre-treatment survey. While not considered a component of our fuel treatment network, post-burn forest structure was measured and incorporated into the landscape forest structure. At SP, fuel treatments in Cedar Valley, the fireshed just south of our paired firesheds (i.e., Sugar Pine and Nelder Grove, Figure A2) started in 2007. Although not part of the experimental design, we extended our plot network into Cedar Valley and obtained pre and post-treatment measurements. Results from Cedar Valley were used to augment our analysis of treatment impacts on forest structure and fuel loads.

We used information from three sources to identify actual treatment area, treatment type, and extent of change. First, changes to forest structure were obtained by repeated measurements of the aforementioned plot network; field observers noted type of treatment. Second, Forest Service District offices supplied GIS-based polygon files identifying treated areas. Lastly, remotely sensed change detection maps, produced by determining areas where differences between pre-treatment and post-treatment maps surpassed threshold values denoting structural change (e.g., > 10% reduction in canopy cover or mean tree height), identified areas that were potentially treated (Su et al. 2015a). Because there can be inconsistencies between agency-generated treatment maps and actual treatment extent, and change detection maps were limited in the ability to identify some treatment types, all three sources were required to ascertain treatment boundaries.

Vegetation Mapping

We developed a vegetation map from our plot and remote sensing data . This map served as the base layer for the development of all landscape map layers required for fire and forest growth simulations. The map consisted of stands, or polygons, classified into vegetation types that captured gradients in tree species composition and forest structure. Classification used both multispectral aerial imagery and lidar-derived metrics (Appendix B-Spatial in this report, Su et al. 2015b). The pre-treatment forest landscape was divided into seven vegetation types at LC and four at SP (Figure A4, Figure A5). We then used the field-plot data to impute detailed vegetation attributes for each polygon (LC, n=1363; SP, n=1100), thereby obtaining the pre-treatment and post-treatment forest structure maps used in the fire and forest-growth modeling. We developed an imputation procedure to assign three field plots to each map polygon based on their similarity in "gradient space" (Ohmann and Gregory, 2002). We performed a multivariate analysis of the plot data to define the gradient space. Variables used in the imputation included treatment type, vegetation type, canopy cover, relative density of big trees, and a suite of topographic metrics. To recreate the fine-scale heterogeneity observed in the field, we identified all plots ranked in the 95th percentile in terms of similarity and then randomly assigned three of those plots to the stand. Some plots were used to populate multiple stands. Each plot contributed data to an average of 12.6 stands (range: 1-77) for LC, and 12.8 stands (range: 1-109) for SP.

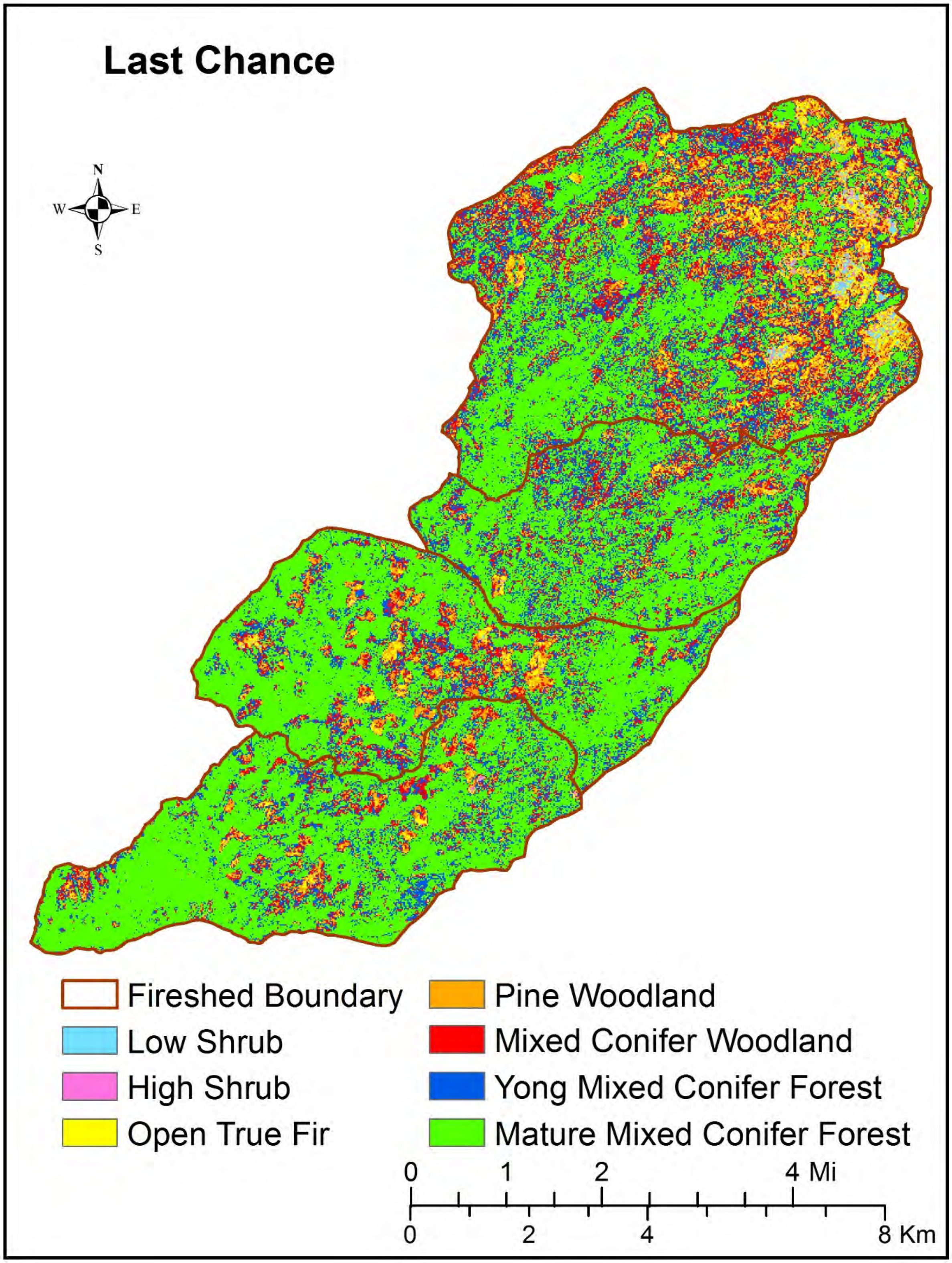


Figure A4: Vegetation map of firesheds at the Last Chance site.

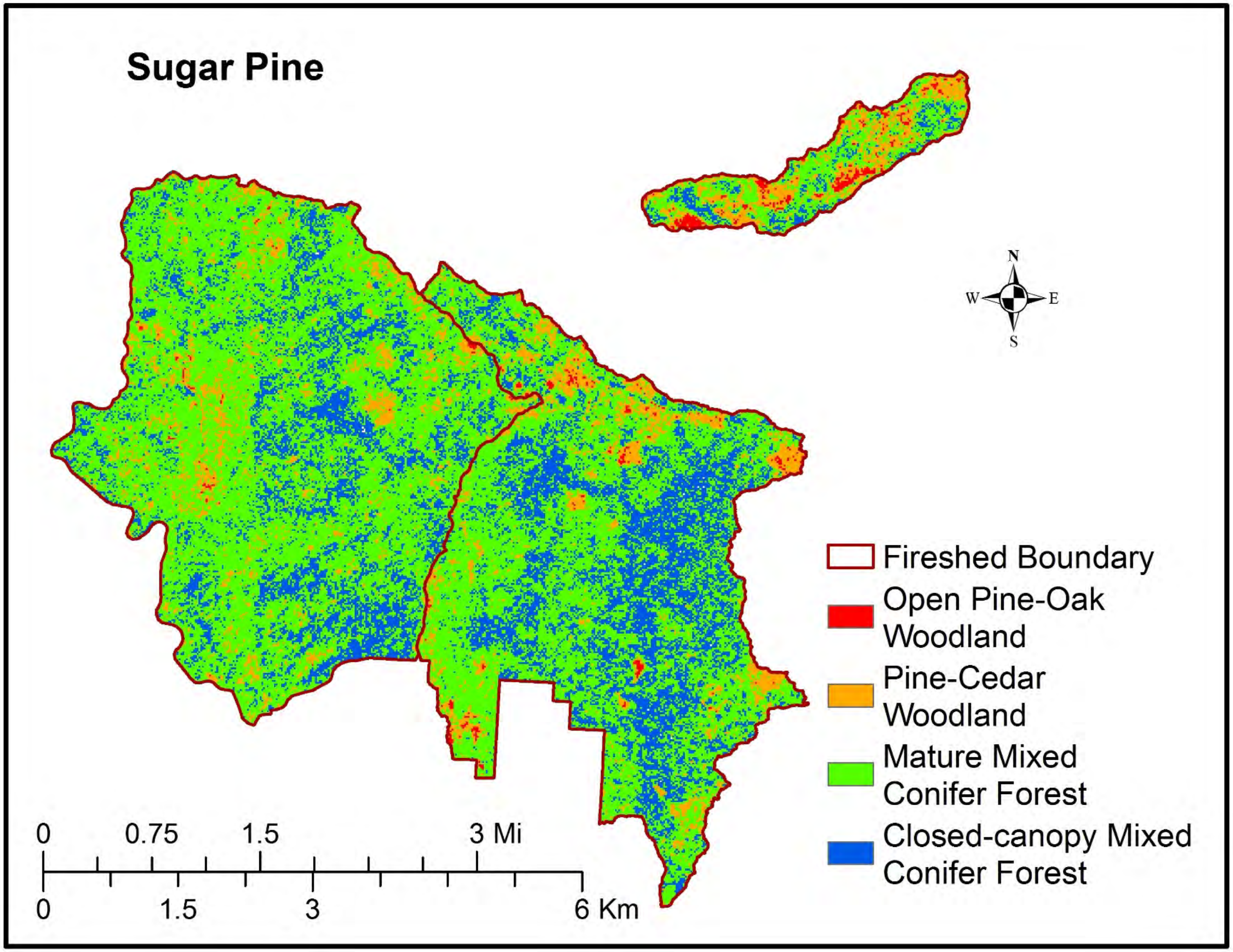


Figure A5: Vegetation map of firesheds at the Sugar Pine site.

Modeling Forest Dynamics

We considered four scenarios: 1) with SPLATs and with fire; 2) without SPLATs and with fire; 3) with SPLATs and without fire; and 4) without SPLAT and without fire. We used the tree list databases associated with the 2008 pre-treatment and 2013 post-treatment field plots when simulating fire and forest growth under the 'no SPLATs' and 'with SPLATs' scenarios, respectively. The Forest Vegetation Simulator (FVS) (Dixon 2002) with the Fire and Fuels Extension (FFE) (Reinhardt and Crookston 2003) is an integrated system of forest growth models that can simulate a wide range of silvicultural treatments. We used the western Sierra variant of FVS, which does not explicitly simulate establishment of new trees in the absence of disturbance, or ingrowth. To simulate ingrowth users must input the number, species, and frequency of establishment events. We used a random number generator to choose the actual number of seedlings, within species-specific bounds, that established for a given stand in a given FVS cycle (e.g., Collins et al. 2011). This was to done to attempt to represent the variable regeneration conditions observed across the studied landscapes. Additionally, we regulated seedling height growth to simulate more realistic conditions in a mixed conifer forest. FVS generates estimates of forest stand structure and surface fuel loads for all four scenarios, at four time steps: 1a) 2008 pre-treatment (no SPLATs); 1b) 2013 initial post-treatment (with SPLATs); 2) 2018/2023 2nd cycle (10-year); 3) 2028/2033 3rd cycle (20-year); 4) 2038/2043 4th cycle (30-year). The forest and fuel parameter estimates from FVS were then used to create the necessary stand structure/fuel map layers required by the fire behavior models (Finney 2004, 2006).

We retained the tree lists generated by FVS for each scenario in order to estimate leaf area from basic inventory parameters. For each live tree, we applied a robust set of species-specific prediction models for the dominant species at our sites. These equations were based on an extensive sample of trees (n = 105) in the Sierran mixed conifer forests (Jones et al. 2015). Allometric equations using tree basal area as the primary variable to estimate whole tree leaf area (one-sided) produced excellent fits (generalized $R^2 > 0.95$ for all conifers). We combined the data from Jones et al. (2015) with allometric data for black oak from Gersonde (2003) and recalculated the allometric equations using basal area as the primary variable. However our result vary from Jones et al. (2015) in that we restricted the covariables to those that could be calculated from the tree lists produced by FVS. These revised equation predicted leaf area based on species, basal area, height, and crown length. In all cases, the fits had $R^2 \geq 0.87$. Individual tree leaf areas were summed and expressed as leaf area index (LAI), measured as the projected leaf surface area (one-sided) per unit of land surface area covered.

Fire Simulations

We employed a dual approach to model landscape-scale fire behavior (Table A1, Figure A6). For both approaches, we derived the necessary topographic inputs, slope, aspect, and elevation from the lidar data (Appendix B-Spatial in this report). Stand structure layers were derived from the FVS outputs for each stand: canopy cover, canopy base height (CBH), canopy height, and canopy bulk density. First, for the fire scenarios (1. with SPLATs and with fire; 2. without SPLATs and with fire), we used FARSITE v.4.1.005 (Finney 2004) to simulate a 'problem' forest fire based on the weather conditions during a recent wildfire (Table A1). FARSITE is a spatially explicit fire growth model that uses several topographic, forest structure, and fuel model map layers to project fire behavior parameters over a complex landscape. For wildfire weather conditions at LC, we used the 2001 Star Fire, which burned 16,838 ac (6,817 ha), including 776 ac (314 ha) on the northeast edge of the study area. Approximately 39% of this fire burned at high severity (www.mtbs.gov; accessed on 4 February 2015). For SP, we used the 2014 French Fire, which burned 13, 837 ac (5,602 ha) approximately 12.5 mi (20 km) southeast of the study area (fire severity data not available). We obtained weather information from the Duncan Peak and Batterson Automated Weather Stations (RAWS) for LC and SP, respectively. We used 95th percentile fuel moistures, as these are the conditions associated with large fire growth and difficulty in control (Table A2). The simulation duration was set to allow the fire perimeter to expand through the entire study area. Crown fire using the Scott and Reinhardt (2001) method was enabled, as well as spot-fire growth with an ignition frequency of 2% and a two-minute ignition delay. FARSITE fire behavior outputs (i.e., flame lengths and fire type) were used to simulate fire effects (i.e., changes in forest structure through tree mortality and fuel consumption) in FVS-FFE.

Table A1: Overview of the approach for landscape-scale fire behavior simulations.

Fire model	**Purpose**	**Scenarios**	**Outputs**
FARSITE	Model fire behavior during a single 'problem' wildfire	No SPLATs (2008 pre-treatment data), SPLATs (2013 post-treatment data)	Flame lengths, Fire type
FlamMap	Model fire behavior during a 'problem' wildfire spread events	No SPLATs/No Fire: 2008 pre-treatment (0-yr), modeled forest conditions in 2018 (10-yr), 2028 (20-yr), and 2038 (30-yr) No SPLATs/Fire: modeled forest conditions in 2018(10-yr) following modeled wildfire (FARSITE), 2028 (20-yr), and 2038 (30-yr) SPLATs/No Fire: 2013 post-treatment (0-yr), modeled forest conditions in 2023 (10-yr), 2033 (20-yr), and 2043 (30-yr) SPLATs/Fire: modeled forest conditions in 2023 (10-yr) following modeled wildfire (FARSITE), 2033 (20-yr), and 2043 (30-yr)	Conditional burn probability (flame lengths > 6 ft (2 m)), Fire size

This approach of using a single simulated fire for each treatment scenario (with and without treatment) limits inference that can be drawn from these results due to potentially different fire spread and behavior associated with different ignition locations. We used a single fire in order to obtain specific predictions on how fire would impact forest structure via tree mortality, as opposed to probabilistic predictions on fire occurrence at a specific location (e.g., Ager et al. 2007). By having spatially explicit predictions of fire effects on forest structure, we were able to track the impacts of fire on owl habitat and make more direct assessments of owl demography over time.

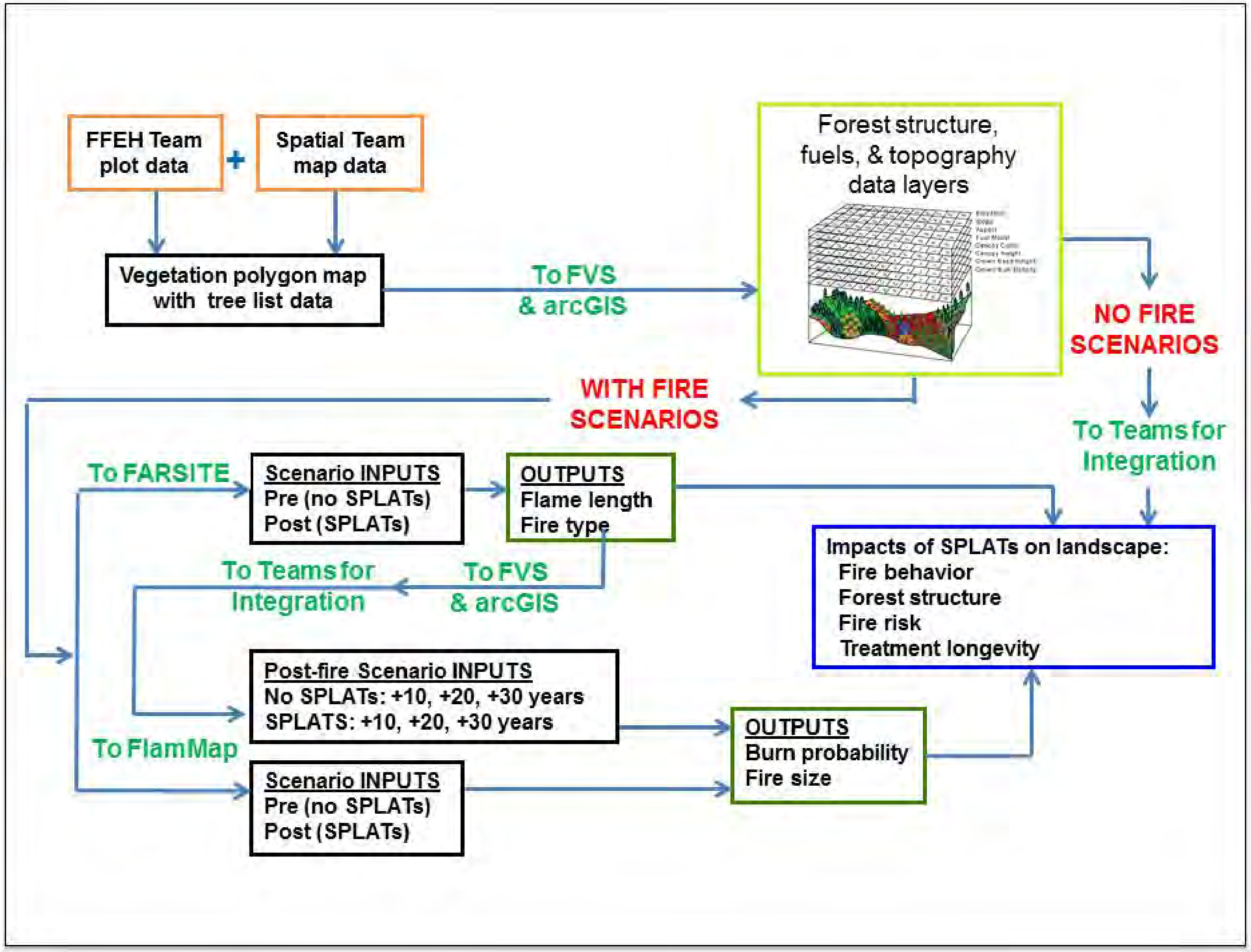


Figure A6: Flowchart of fire behavior and forest dynamics modeling.

Table A2: Weather parameters for fire simulations using FARSITE and RANDIG. We used 90th percentile and above winds (RANDIG only) and the 95th percentile fuel moistures (both simulations) for the predominant fire season in the area (June 1–September 30) based on data from one or more RAWS data near study sites.

	Last Chance	**Sugar Pine**
Temperature (°F)	54-93	59-99
Relative Humidity (%)	11-54	9-68
Wind (mph)	6.3 (3-13.5)	10 (3-20)
Wind direction	S-SW	SE, W
Fuel Moisture (%)		
1-hr	2	3
10-hr	3	4
100-hr	5	6
Live herbaceous	30	35
Live woody	60	65

To address the limitations associated with the single ignition approach, we employed a second fire modelling approach using a command-line version of FlamMap (Finney 2006) called RANDIG to model fires across both study areas to assess temporal changes in fire risk, thereby estimating the effectiveness of the SPLAT network at mitigating simulated fire effects, treatment longevity, and forest recovery. RANDIG uses the minimum travel time method (Finney 2002) to simulate fire spread based on a user-inputs for: number/pattern of ignitions, fire duration, wind speed and direction, fuel moistures, topography, stand structure, and fuels. We used the same stand structure layers as described in the first approach. In the absence of simulated ingrowth in FVS, stand CBH increases over time in untreated stands, which occurs at a rate that is difficult to justify ecologically, and results in an unrealistic decrease in fire risk in fire simulations (Collins et al. 2011, 2013). Instead, we used CBH-adjusted values as follows: initial stand CBH calculated in FVS used in 1st and 2nd cycle fire simulations, and 3rd cycle stand CBH calculated in FVS used in 3rd and 4th cycle. For each scenario and time step we simulated 10,000 randomly placed ignitions, burning for 240 and 360 minutes for LC and SP, respectively. This burn period duration was selected such that simulated fire sizes (for one burn period) approximated large-spread events (daily) observed in actual fires that occurred near the study areas (Ager et al. 2010). Given the limited number of wildfires from which to compare large spread events, especially for Sugar Pine, our burn period calibration represents a reasonable normative for large spread events in Sierra Nevada mixed-conifer forests (Collins et al. 2011).

For the weather information obtained from the Duncan Peak (LC) and the Batterson RAWS (SP), we restricted the analysis period to the dominant fire season for the area (June 1 – September 30). Observations were available from 2002 to 2009. We identified the dominant direction and average speed of all observations at or above the 90th percentile value. This resulted in several different dominant wind directions, each with its own wind speed and relative frequency (based on the proportion of observations recorded at or above the 90th percentile value for each dominant direction). We used 95th percentile fuel moistures, as these are the conditions associated with large fire growth and difficulty in control (Table A2).

Fuel Model Selection

To assign fuel models (Scott and Burgan 2005) to the pre- and post-treatment landscapes we analyzed relationships between fuels, shrub cover, and forest structure data collected from field plots. This approach was used for post-treatment fire simulations in Collins et al. (2011), where a selection logic was developed from regression trees and fuel models were assigned in consideration of the forest characteristics. Regression trees are ideal for such an analysis because they identify break values for predictor variables that can be used to repeatedly assign fuel models to stands. Statistical fits were moderate for each site (R^2=0.2–0.6), but were deemed appropriate for categorizing stands into discrete fuel models (Collins et al. 2011, 2013). The chosen fuel models for each terminal point in the selection logic was based on our familiarity with the study area and fire modeling, and input from local fire/fuel managers. Table A3 summarizes the fuel models used in the pre-treatment landscape.

A different selection logic was used for treated stands based on treatment type and time since treatment , as well as average flame length and fire type (percent of stand crowning) produced through FARSITE (first modeling approach described above) for the fire scenarios. Thinned stands that had reduced surface fuels through pile burning were left in the general selection logic. Stands that were thinned followed by mastication were assigned moderate load timber-litter model. Cable-logged stands (LC only) increased activity fuels and therefore were assigned a slash blowdown model. Masticated stands were assigned a moderate load timber-understory model, increasing to a high load timber-litter model in the second cycle. Stands that were underburned followed a progression of timber-litter fuel models but with slightly lower fuel loads. In the first fire modeling approach where all stands were burned, fuel model succession followed the methods of Davis et al. (2009). Post-burn fuel model assignment would be contingent on pre-burn fuel model, stand average flame length, and percent of the stand crowning.

Table A3: Pre-treatment fuel model assignments (Scott and Burgan 2005) and their proportion throughout both study areas. Fuel model selection logic was based on multiple regression tree analyses using stand-level data for dependent variables (shrub cover and fuel loads by category) and independent forest structure variables summarized using FVS.

Fuel model	**Description of stands with fuel model assigned**	**Last Chance**	**Sugar Pine**
SH3 (143)	Low basal area, low canopy cover, low stature shrub dominated fuels	0.155	-
SH5 (145)	Low basal area, low canopy cover, high stature shrub dominated fuels	0.054	0.044
TU2 (162)	Low basal area, high canopy cover	0.154	0.135
TU5 (165)	Moderate to high basal area, high tree density, moderate fuel load dominated by shrub and forest litter	0.318	0.451
TL3 (183)	Peavine Fire (2008) area	0.014	-
TL5 (185)	Low basal area, low canopy cover, moderate fuel load with coarse fuels present	-	.044
TL9 (189)	Moderate to high basal area, moderate to low tree density, moderate to low site productivity	0.042	.067
SB3 (203)	Moderate to high basal area, moderate to low tree density, high site productivity, moderate fuel load with coarse fuels present	0.263	0.26

Analytical Framework

To evaluate the effects of SPLATs, we used a before-after-control-impact study design (Stewart-Oaten et al. 1986). At each site, a control fireshed was paired with the treated fireshed. Measurements were made before treatments and after treatments. This framework accounts for temporal changes that are unrelated to the treatment and thus any observed differences between firesheds can be attributed to SPLATs. Formally, the impact of the treatment can be quantified as the difference in the response between sites observed over time:

$$\text{Treatment Impact} = (\mu_{ta} - \mu_{tb}) - (\mu_{ca} - \mu_{cb}) \qquad \text{Equation 1}$$

where μ is the mean of the response variable; c represents the control fireshed; a the period after treatments; b the period before treatments; and t the treated fireshed. A key assumption with this approach is that in absence of SPLATs, the differences between the sites would be constant (Stewart-Oaten et al. 1986). Note on usage: To improve clarity, we describe the "before" measurements as "pre-treatment" and the "after" as "post-treatment."

Plot-based summaries of pre- and post-treatment forest structure and surface fuels were produced for both sites, separated by control (untreated) and treatment types. Forest structure variables include canopy cover, tree density, and basal area, and shrub cover. For both fire modeling approaches, outputs of flame length, fire type, and conditional burn probabilities (both overall and proportional for 20 flame length classes [0 –10 m in 0.5 m increments]) were obtained for individual 30 m pixels, spanning the entire study areas. Conditional burn probabilities are computed by dividing the total number of times a pixel burned by the total number of simulated fires (n=10,000). To separate out more problematic simulated fire occurrence, both from a fire effects and a fire suppression standpoint, we only performed analysis on the burn probabilities for which modeled flame lengths were > 6.6 ft (2 m). Flame lengths > 6.6 ft typically correspond with crown fire initiation and present substantial challenges for suppression efforts (NWCG 2004). We imported flame length and conditional burn probability surfaces into ArcGIS software for further data analysis. For each of the four scenarios we computed overall mean flame length, fire type (percent of stand crowning), and conditional burn probability for each stand only using those pixels within the core study areas (i.e., stands within firesheds). We compared these outputs by stand (control vs. treated by type) and fireshed (control vs. treated).

Forest Health Assessment

Mortality was quantified by tracking the status of all tagged trees initially assessed as live in 2007 or 2008 in the re-measured 2013 plots. Harvested and masticated trees in the treated firesheds were noted. We calculated annual mortality (with and without harvested trees) after Sheil et al. (1995). Confidence intervals for mortality by fireshed were determined by profile likelihood (Wyckoff and Clark 2000).

The impact of treatments on forest structure and species composition was also assessed at the scale of the fireshed. Specifically, we used a two-factor analysis of variance (ANOVA) to test for differential changes (Equation 1) in forest structural characteristics (e.g., tree basal area, tree density, canopy cover) between control and treated firesheds. The interaction term in the ANOVA table served as the test of the statistical significance of the treatment effect (Smith 2002).

We developed histograms of tree-size based on dbh to document potential shifts in tree-size distributions (pre- to post-treatment) at each fireshed. Changes in size class were evaluated with a distribution departure index (Menning et al. 2007). This approach uses cumulative histograms to visualize overall trends and shifts in distributions. Specifically

$$M = \left(\frac{2}{k-1}\right)\sum_{i=1}^{k}\left[\left(\hat{p}_i - \frac{f_i}{n_f}\right)(k+1-i)\right] \quad \text{Equation 2}$$

Where k is the number of size classes; i designates the size class; f_i is the density of trees in size class i of the test distribution; n_f is the total tree density in the test distribution; and $\hat{p}_i$ is the relative density in size class i in the reference distribution (Menning et al. 1997). The departure index is typically reported by stating the value and the range endpoints (e.g., –0.10 [-0.4 to 1.6]). The range endpoints refer to the possible changes in distribution depending on the type of reference distribution used. For example, if the reference distribution is symmetrical (e.g., a normal distribution), the possible departure index values will range from –1 to +1. However, if the reference distribution is asymmetrical (e.g., an inverse J-distribution with many smaller trees and fewer larger trees), the possible magnitude of any changes is also asymmetric. For an inverse-J distribution, there is the potential for a greater shift to the right than the left. A test distribution that has shifted to the right of the reference distribution will always have a positive value, while one that has shifted to the left will always display a negative value. The magnitude of the index indicates how far the test distribution has shifted. To statistically evaluate tree-size shifts from pre-measurement to post-measurement, we used a randomization approach with the pre-treatment size distribution serving as the reference (Menning et al. 2007). For each realization, the reference distribution was randomly shifted up to a maximum of 10% in either direction. We obtained 1,000 realizations and the 0.025 and 0.975 percentiles from their respective departure indices. These percentiles served as 95% confidence intervals. Observed changes that fell outside these bounds signified shifts of 10% or more in the tree-size distribution.

Tree species composition was quantified with relative basal area. The value for each species present in the fireshed was calculated as its mean relative basal area in every plot measured. Within-fireshed variance in dominance was expressed as the standard error of this mean.

Integration Analysis

An important goal of SNAMP was to provide an integrated assessment of the impacts of SPLATs not only on fire behavior but also on forest health, populations of spotted owl and Pacific fisher, water quality, and water quantity (Chapter 4). Thus we designed the four modeling scenarios described above: no fire and no SPLATs; fire and no SPLATs; no fire and SPLATs; fire and SPLATs. Initial parameters (pre-treatment and post-treatment) were defined using our field data with models extended for 30 years. In the fire scenarios, one explicit “severe” wildfire was modeled immediately after the field measurements (time = 0.1 yr). To ensure consistency, all results were reported for 10 year time intervals from Year 0 to Year 30 at the spatial scale of the fireshed. To keep the analysis succinct, each team was charged to select one informative "integration metric." For fire behavior, we used the conditional burn probability (described above, see **Fire Simulations**). For forest health, we defined two different metrics: one for scenarios without simulated fire and one with simulated fire.

Tree growth has proven to be a reliable indicator of tree survivorship in these forests (Das et al. 2007, Battles et al. 2008, Collins et al. 2014) and overall a robust indicator of forest health

(Tierney et al. 2009). In this context, forest health is narrowly defined in terms of the growth of canopy-sized trees. It is an admittedly narrow definition, but forest health in all its complexity is difficult to capture. We can measure the performance of trees. Therefore for the integration analysis, our fundamental premise is that “healthy” trees are necessary components, but are not sufficient to comprise a “healthy” forest. However, growth rate by itself is not an ideal measure in the no-fire scenario because of its mutual dependence on individual traits (e.g., tree size, tree age) and community characteristics (e.g., tree density, soil fertility, moisture regime). Waring (1983) argued that a good index of forest health is the efficiency with which a stands grows. Growth efficiency (GE) was defined as the increment in stand basal area produced per unit leaf area. Specifically:

$$\text{Growth efficiency} = \frac{\text{Basal area}_{\text{time 1}} - \text{Basal area}_{\text{time 0}}}{\text{mean}(\text{LAI}_{\text{time 1}}, \text{LAI}_{\text{time 0}})} \qquad \text{Equation 3}$$

where time 0 refers to the starting conditions, time 1 refers to conditions ten years in the future, basal area is the cross-sectional area of trees per unit area, and LAI is the leaf area index. For the fire scenario, we used the rate of return to pre-fire basal area to quantify forest health differences between treatment and no-treatment. Specifically for each post-fire interval, we reported the "fraction retained" of the pre-fire (Year 0) basal area. Since the basal area response was reported on a relative scale, we expressed growth efficiency relative to the maximum efficiency observed for the no-fire scenario.

RESULTS

Fuel Treatments and Changes in Forest Structure

Pre-treatment forest structure varied between the two sites (Table A4). In general, the mixed conifer forests at SP had more late-seral characteristics including high basal area (242 ft^2/ac), dense canopy cover (70%), and tall trees (92 ft). Compared to LC, basal area at SP was 80% greater; the canopy was a third taller; and canopy cover was 46% higher on average. The more open structure at LC supported more trees (i.e., higher tree density) and almost double the shrub cover (Table A4).

Table A4: Pre-treatment forest structure at the two study sites. Results based on pre-treatment measurements were made in 2007 and 2008. Only plots on the core sampling grid were included. Basal area was calculated for all live trees ≥ 2 in in diameter at breast height (dbh); density was calculated for live trees ≥ 2 in dbh; canopy cover was defined as tree cover ≥ 6.6 ft; tree height includes all live trees ≥ 2 in dbh; shrub cover excludes cover from trees < 6.6 ft tall. Means are reported with standard errors in parentheses. Results include plots with no trees present.

Site	**Basal Area** (ft^2/ac)	**Density** (stems/ac)	**Canopy Cover** (%)	**Tree Height** (ft)	**Shrub Cover** (%)
Last Chance	133 (5.9)	252 (12)	48 (1.9)	47 (1.1)	43 (1.5)
Sugar Pine	242 (11.0)	218 (13)	70 (1.8)	63 (1.9)	26 (2.8)

There were three main types of fuel reduction treatments: thinning, mastication, and prescribed fire. In the treated fireshed at Last Chance, SPLATs occurred on 18.4% of the area; considerably more area was treated at Sugar Pine -- 29.3% (Table A5). Thinning at LC was separated into two types, tractor thinning and cable logging, based on harvest prescriptions and subsequent post-treatment fuel conditions. Some tractor thinning units at SP were followed by mastication, which removes small trees and shrubs, converting ladder fuels to surface fuels. At the time of our re-measurement (2013) at SP, no prescribed fire treatments had been implemented.

For all surface fuels categories, pre-treatment plot averages were higher at SP compared to LC (Table A6, Table A7). Although treatment area was more extensive at SP (Table A5), treatments tended to be more intensive at LC. As results, we observed greater changes in fuels and forest structure variables (e.g., litter, woody fuels, canopy cover, tree density, and basal area) for a given treatment type at LC (Table A6, Table A7, Figure A7). Plots in cable logging units had to be relocated, prohibiting direct comparisons of pre- and post-treatment plot measurements. For plots that were in masticated units, shrub cover decreased by 50% at LC and only 10-15% at SP (Figure A7).

Table A5: Cumulative area treated (ac, [% of total watershed area]) for all treatment watersheds, separated by treatment type.

Type	Last Chance	Sugar Pine
Mastication	348 (3.1)	217 (3.5)
Thinning	915 (8.3)	1298 (20.7)
Cable Logging	193 (1.7)	-
Thinning+Mastication	-	328 (5.2)
Prescribed burn	577 (5.2)	-
Total	2033 (18.4)	1843 (29.3)

Table A6: Average (1 standard error) of surface fuels (tons ac^{-1}) and shrub cover, by treatment type, collected from plots in the Last Chance study area. C-thin, cable logging.

	Control	**Burn**	**Mastication**	**Thinning**	**C-thin**
	Pre-treatment				
Litter	7.7 (0.3)	8.2 (1.4)	3.5 (0.8)	11.0 (0.1)	4.7 (0.3)
Litter + 1-hr	7.9 (0.3)	8.4 (1.4)	3.6 (0.7)	11.2 (0.1)	4.9 (0.3)
1000-hr	10.8 (1.3)	2.8 (0.8)	1.9 (1.7)	13.7 (0.3)	17.7 (15.0)
1–1000-hr	13.1 (1.4)	5.4 (1.2)	3.3 (1.7)	16.9 (0.3)	22.0 (14.9)
Total	37.3 (1.9)	28.7 (4.8)	12.5 (2.9)	49.1 (0.4)	41.9 (13.3)
Fuel depth (in)	1.4 (0.1)	1.2 (0.1)	0.6 (0.2)	1.7 (0.0)	2.2 (0.0)
Shrub cover (%)	45.6 (1.5)	37.0 (9.8)	50.3 (9.8)	24.0 (0.4)	42.5 (4.2)
Shrub height (ft)	2.4 (0.1)	1.6 (0.4)	2.3 (0.4)	1.1 (0.0)	1.6 (0.4)
	Post-treatment				
Litter	6.7 (0.3)	5.3 (1.2)	4.3 (0.6)	6.6 (0.1)	22.0 (17.3)
Litter + 1-hr	7.0 (0.3)	5.5 (1.2)	4.5 (0.6)	6.8 (0.1)	22.2 (17.4)
1000-hr	10.0 (1.2)	3.5 (1.5)	4.4 (3.8)	8.2 (0.2)	3.4 (1.7)
1–1000-hr	14.0 (2.4)	6.1 (1.8)	6.5 (3.9)	12.3 (0.2)	7.4 (1.9)
Total	42.2 (3.1)	32.6 (5.7)	23.2 (4.3)	44.9 (0.4)	94.0 (46.1)
Fuel depth (in)	1.5 (0.1)	1.1 (0.3)	1.1 (0.2)	1.8 (0.0)	4.4 (1.8)
Shrub cover (%)	46.5 (2.5)	42.4 (9.5)	26.9 (8.1)	12.3 (0.3)	0.7 (0.7)
Shrub height (ft)	2.2 (0.1)	1.3 (0.2)	1.8 (0.8)	0.9 (0.0)	0.2 (0.2)

Table A7: Average (1 standard error) of surface fuels (tons ac^{-1}) and shrub cover, by treatment type, collected from plots in the Sugar Pine study area. Thin+Mast, thinning followed by mastication.

	Control	**Mastication**	**Thinning**	**Thin+Mast**
	Pre-treatment			
Litter	12.0 (2.1)	11.2 (2.7)	21.4 (3.0)	15.7 (2.3)
Litter + 1-hr	12.1 (2.2)	11.3 (2.7)	21.5 (3.0)	15.8 (2.2)
1000-hr	13.4 (6.2)	5.3 (1.8)	14.1 (5.4)	9.4 (2.3)
1–1000-hr	25.4 (10.4)	9.0 (2.7)	21.4 (7.2)	17.9 (3.8)
Total	65.7 (14.2)	37.0 (7.0)	72.4 (9.9)	65.8 (6.9)
Fuel depth (in)	2.0 (0.4)	2.3 (0.7)	3.3 (0.5)	2.4 (0.4)
Shrub cover (%)	25.1 (7.4)	39.6 (6.9)	20.1 (6.9)	20.3 (7.1)
Shrub height (ft)	3.0 (0.7)	7.0 (0.8)	2.6 (0.7)	3.9 (0.6)
	Post-treatment			
Litter	11.0 (2.5)	9.6 (1.6)	13.1 (2.1)	12.2 (2.3)
Litter + 1-hr	11.1 (2.5)	9.9 (1.6)	13.4 (2.1)	12.4 (2.3)
1000-hr	12.6 (5.0)	9.1 (4.4)	18.0 (10.2)	16.5 (7.1)
1–1000-hr	19.0 (7.3)	14.5 (4.5)	23.8 (10.3)	21.0 (6.7)
Total	60.9 (11.1)	43.8 (5.7)	72.5 (13.8)	72.1 (14.9)
Fuel depth (in)	2.3 (0.6)	2.4 (0.5)	3.3 (0.8)	4.0 (1.2)
Shrub cover (%)	27.6 (7.4)	24.1 (8.0)	15.8 (5.3)	9.1 (4.2)
Shrub height (ft)	2.3 (0.5)	2.9 (0.9)	1.4 (0.3)	2.7 (0.6)

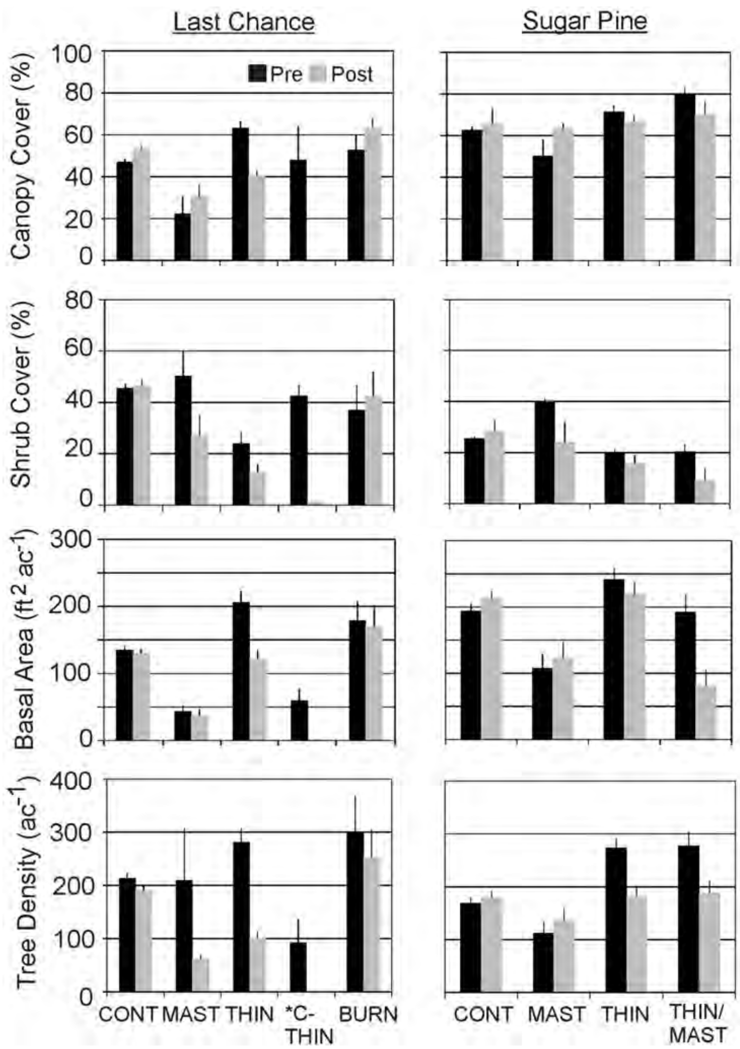


Figure A7: Changes in forest structure by treatment type at both SNAMP study sites. Results based on pre- and post-treatment forest inventory plot measurements. Tree density and basal area are for trees with diameters > 2 in. CONT, control; MAST, mastication; THIN, thinning; C-THIN, cable logging; THIN/MAST, thinning followed by mastication; BURN, prescribed fire. *Only two plots were located in cable logging units and these had to be relocated for post-treatment measurements, prohibiting direct comparisons to pre-treatment measurements.

From 2007-08 to 2013, the mortality rate of overstory trees (dbh ≥ 7.67 in) in the control firesheds ranged from 1.57%/yr (95%CI: 1.2 – 2.0 %/yr) at LC to 1.05%/yr (95%CI: 0.6 to 1.7%/yr) at SP (Figure A8). The implementation of SPLATs significantly increased (based on non-overlap of 95% CI) the death rate in treatment firesheds by about 1.2 percentage points at each site. This increase can be directly attributed to SPLATs and not background differences between control and treatment firesheds. When harvest removals were excluded in the calculation of mortality in the treatment firesheds, we obtained values indistinguishable from controls (Figure A8).

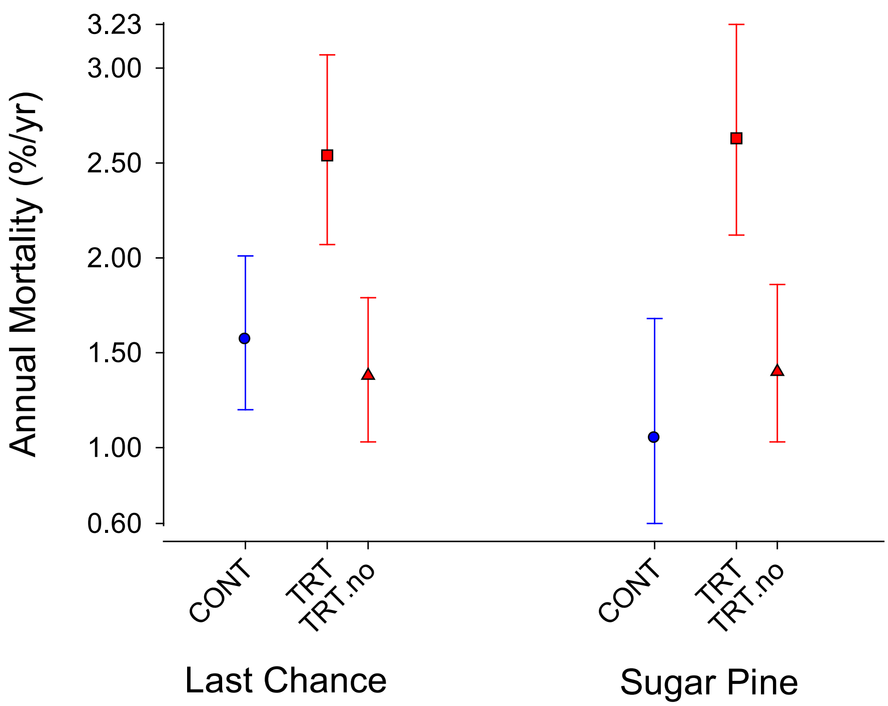


Figure A8: The mean annual mortality rate of overstory trees (dbh ≥ 7.67 in) in the control and treated plots at the SNAMP study sites in the Sierra Nevada, CA. Rates were calculated by tracking the fate of tagged trees between 2007-08 and 2013 inventories. Only trees in the plots from the core grid were included to ensure a representative sample. CONT refers to the control firesheds; TRT refers to the treatment firesheds; TRT-no is the mortality rate in the treatment firesheds if harvested trees are excluded from consideration. Error bars represent 95% confidence intervals.

The higher mortality rate in the treatment firesheds translated into net reductions in tree basal area and tree density in the treatment firesheds (Table A8, Table A9). For both basal area and density, the magnitude of forest structural changes was smaller in the control firesheds than in the treatment firesheds. At Last Chance, the treatments led to an approximate 10% net decrease in tree basal area and an 11% decrease in total (overstory + understory) tree density (Table A8). The emphasis on mastication treatments at SP was evident. The largest changes related to SPLATs at SP were a 15% net reduction in understory tree density and a 35% reduction in shrub cover (Table A9). Canopy cover and big tree density (defined as trees that serve as critical habitat elements for spotted owl and Pacific fisher, Chapter A4) barely changed between control and treatment firesheds at either site (Table A8, Table A9).

It is important to note that despite the documented treatment effects at the plot and fireshed level, none of the treatment impacts (Equation 1) reported in Table A8 and Table A9 were statistically significant ($p \leq 0.05$) based on test of the interaction term in the full-factorial analysis of variance (Smith 2002). In other words, we did not detect a SPLATs effect on forest structure in the treated firesheds compared to the changes with time in the control firesheds. At the standard of $p \leq 0.1$ level, treatment impacts on shrub cover at Sugar Pine were significant.

Forest Health

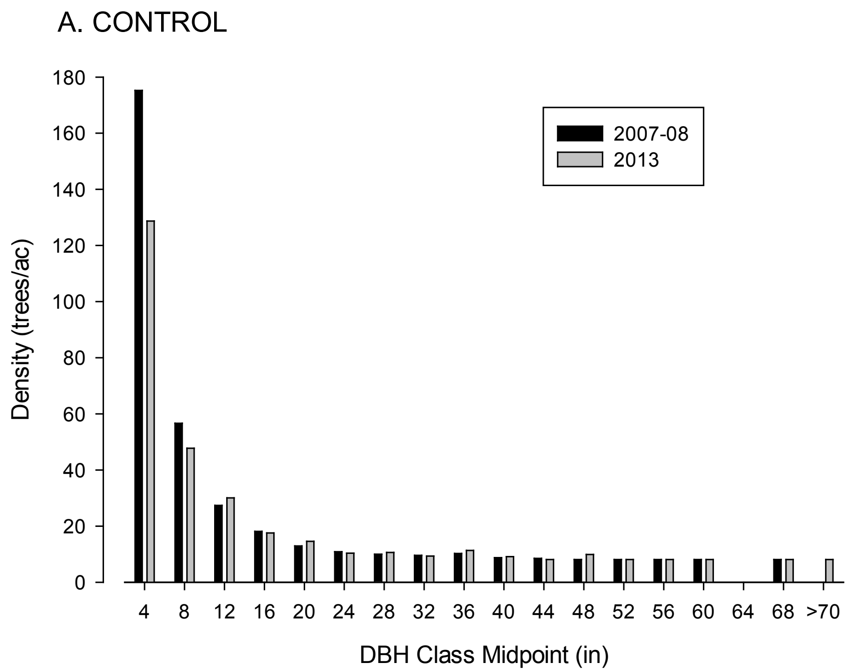
There were no changes in tree size distribution in pre-to-post treatment greater than 10% in any of the firesheds. At all sites, tree density declined exponentially with size class (Figure A9, Figure A10). The largest shift from this reverse-J shaped distribution was observed in the control fireshed at LC (Figure A9A). The post-treatment size distribution is less concentrated in the small diameter classes that the pre-treatment distribution. Such a shift results in a departure index (M) = 0.30 [min-max: -0.36; 1.64]. However, this move toward a more uniform size distribution was still within the 95% CI of a 10% change: M (95%CI) = -0.14; 0.37.

Table A8: SPLATs treatment impact on forest structure at the Last Chance site. Results based on forest inventories. Pre-treatment measurements were made in 2007 and 2008. Post-treatment measurements were made in 2013. Only plots on the core sampling grid were included. Basal area was calculated for all live trees ≥ 2 in in diameter at breast height (dbh); overstory density was calculated for live trees ≥ 7.67 in dbh; understory density was calculated for live trees trees ≥ 2 in dbh and < 7.67 in dbh; big tree density was calculated for live tree ≥ 28 in in dbh; canopy cover was defined as tree cover ≥ 6.6 ft. Means are reported with standard errors in parentheses. For change over time/treatment (Δ), the 95% confidence interval for the difference in means is reported in brackets. The estimate of treatment impact is the difference of means between control and treatment (Equation 2.1).

	Control Fireshed				**Treatment Fireshed**				**Treatment Impact**
	pre	**post**	**Δ**		**pre**	**post**	**Δ**		
Basal area (ft^2/ac)	138 (8)	134 (9)	-4 [-29; 20]		142 (8)	125 (8)	-18 [-45; 3]		-14 (17)
Overstory density (stems/ac)	76 (4)	73 (4)	-3 [-13; 8]		86 (4)	77 (4)	-9 [-20; 3]		-6 (8)
Understory density (stems/ac)	193 (15)	147 (12)	-46 [-84; -10]		241 (19)	169 (16)	-72 [-122; -23]		-26 (31)
Big tree density (stems/ac)	16 (1)	16 (1)	0 [-3; 4]		16 (1)	16 (1)	0 [-3; 4]		0 (2)
Canopy cover (%)	46 (1.7)	52 (1.9)	6 [-8.5; 1.2]		48 (2.1)	53 (2.2)	5 [-10.5; 1.7]		-1 (3.9)
Shrub cover (%)	46 (2.0)	45 (2.0)	-1 [-5.1; 6.0]		42 (2.1)	45 (4.9)	3 [-14.1; 7.7]		4 (5.8)

Table A9: SPLATs treatment impact on forest structure at the Sugar Pine site. Results based on forest inventories. Pre-treatment measurements were made in 2007 and 2008. Post-treatment measurements were made in 2013. Only plots on the core sampling grid were included. Basal area was calculated for all live trees ≥ 2 in in diameter at breast height (dbh); overstory density was calculated for live trees ≥ 7.67 in dbh; understory density was calculated for live trees trees ≥ 2 in dbh and < 7.67 in dbh; big tree density was calculated for live tree ≥ 28 in in dbh; canopy cover was defined as tree cover ≥ 6.6 ft. Means are reported with standard errors in parentheses. For change over time/treatment (Δ), the 95% confidence interval for the difference in means is reported in brackets. The estimate of treatment impact is the difference of means between control and treatment (Equation 2.1).

	Control Fireshed				Treatment Fireshed				Treatment
	pre	**post**	**Δ**		**pre**	**Post**	**Δ**		**Impact**
Basal area (ft^2/ac)	265 (19)	267 (20)	2 [-53; 57]		231 (13)	223 (14)	-8 [-44; 29]		-10 (32)
Overstory density (stems/ac)	89 (7)	87 (7)	-2 [-22; 19]		125 (7)	114 (7)	-11 [-30; 8]		-9 (14)
Understory density (stems/ac)	100 (14)	103 (15)	3 [-40; 45]		158 (15)	137 (14)	-21 [-62; 19]		-24 (31)
Big tree density (stems/ac)	23 (2)	23 (2)	0 [-4; 6]		17 (1)	18 (2)	1 [-3; 5]		1 (3)
Canopy cover (%)	68 (2.9)	69 (3.1)	1 [-9.1; 7.6]		71 (2.3)	72 (2.7)	1 [-8.1; 6.1]		0 (5.6)
Shrub cover (%)	21 (4.1)	22 (4.4)	1 [-12.8; 10.9]		30 (3.8)	22 (3.4)	-8 [-2.1; 17.8]		-9 (7.9)



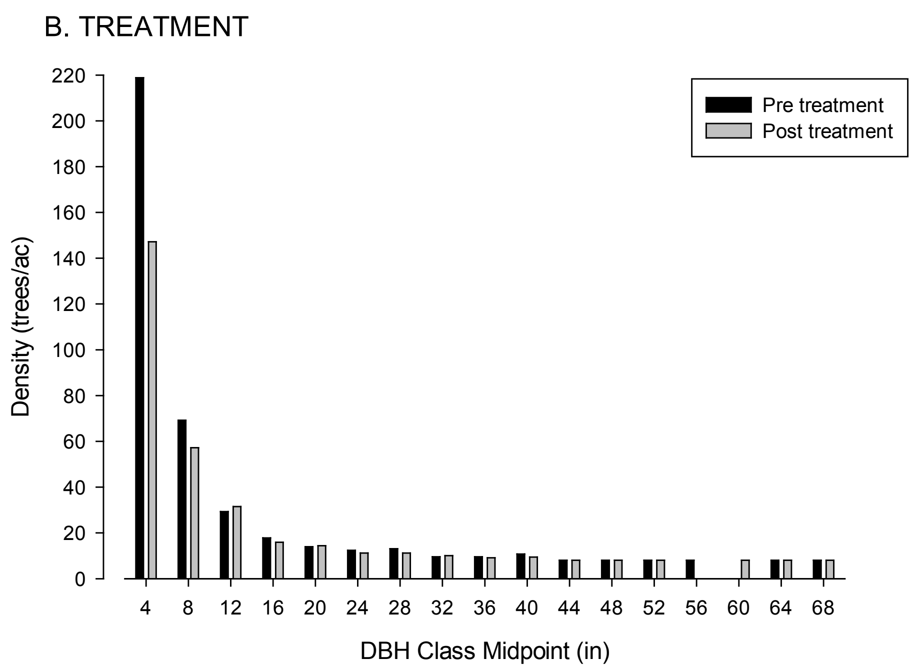


Figure A9: Changes in tree diameter distributions in the Last Chance site in the Sierra Nevada, CA. Pre-treatment results based on data from the 2007-08 inventory data collected from plots in the core grid. Post-treatment results based on data from 2013 inventory. DBH class represents 4-in dbh classes.

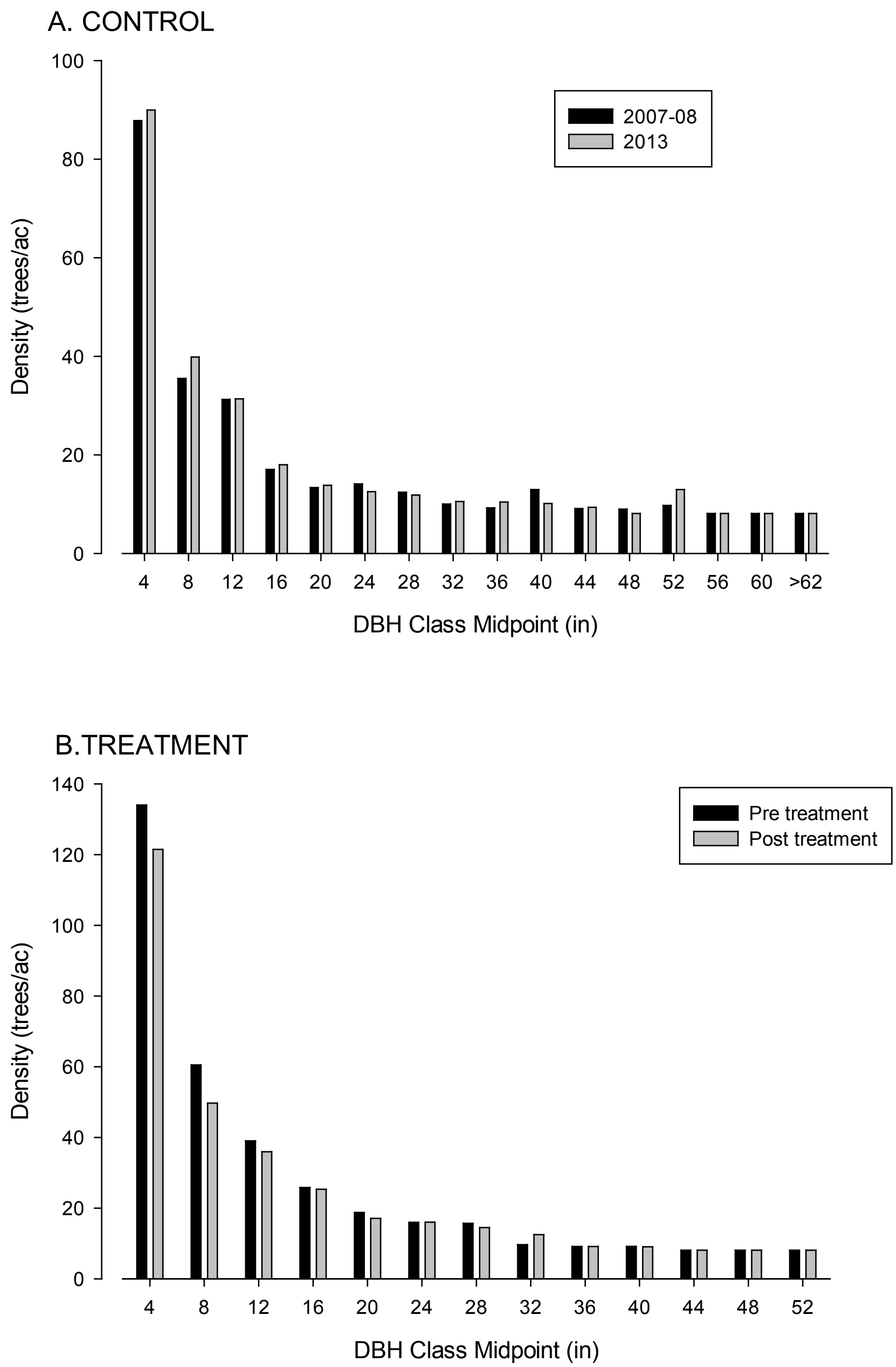


Figure A10: Changes in tree diameter distributions in the Sugar Pine site in the Sierra Nevada, CA. Pre-treatment results based on data from the 2007-08 inventory data collected from plots in the core grid. Post-treatment results based on data from 2013 inventory. DBH class represents 4-in dbh classes.

All the firesheds were dominated by tree species representative of the mixed conifer forest (Fites-Kaufman et al. 2007). While there was variation in species dominance between LC and SP and between control and treatment firesheds (Figure A11, Figure A12), implementation of SPLATs resulted in only modest changes in composition. At LC, the largest shift related to treatments was a 14% decrease in white fir (ABCO) with corresponding increases of 16% in ponderosa pine (PIPO) and 12% in sugar pine (PILA) (Figure A11). At SP, the fuel treatments reduced the relative basal area of the most dominant species in the fireshed -- incense-cedar (CADE) -- by 7% (Figure A12). White fir and black oak (QUKE) both increased by 9%.

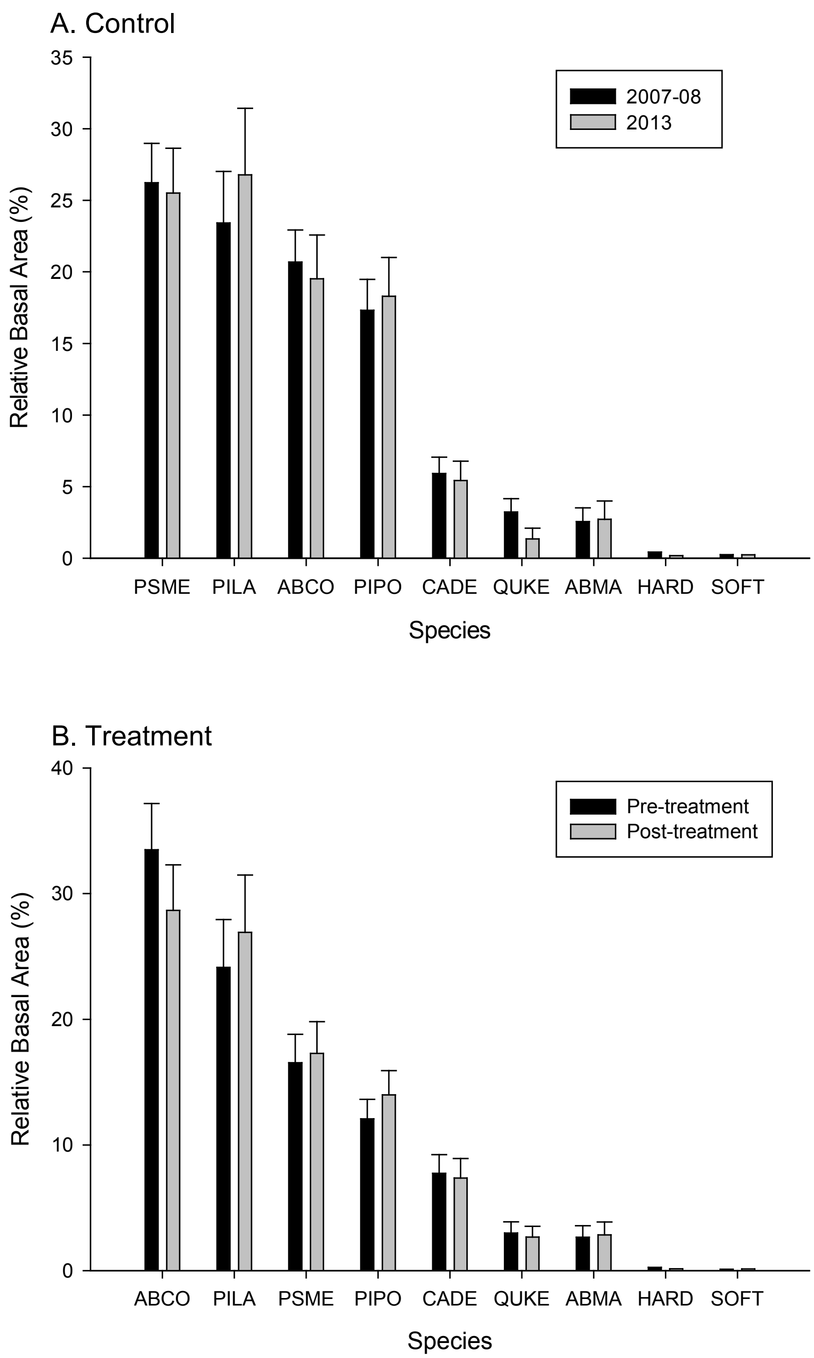
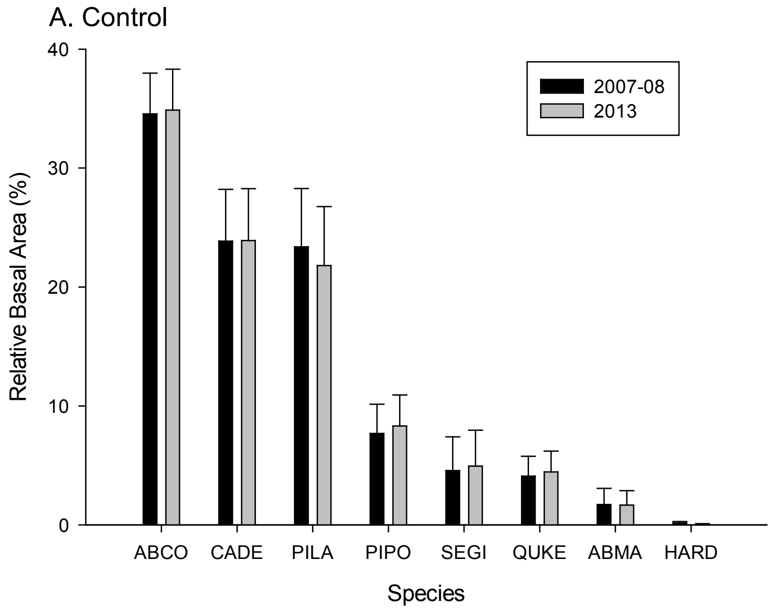


Figure A11: Changes in tree species composition in the Last Chance site in the Sierra Nevada, CA. Pre-treatment results based on data from the 2007-08 inventory data collected from plots in the core grid. Post-treatment results based on data from 2013 inventory. Means with standard errors reported. Species codes: ABCO, white fir (*Abies concolor*); ABMA, California red fir (*A. magnifica*); CADE, incense-cedar (*Calocedrus decurrens*); PILA, sugar pine (*Pinus lambertiana*); PIPO, ponderosa pine (*P. ponderosa*); PSME, Douglas-fir, (*Pseudotsuga menziesii*); QUKE, black oak (*Q. kelloggii*); HARD, other hardwood species; SOFT, other conifer species.



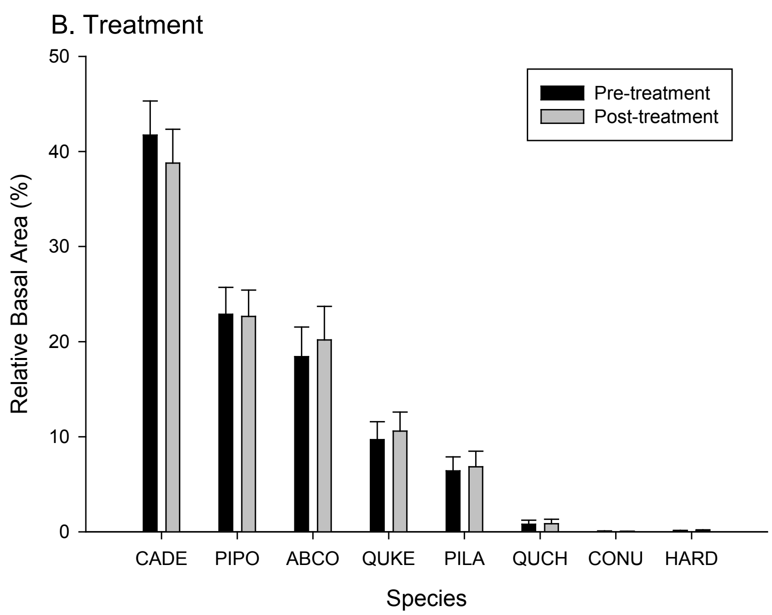


Figure A12: Changes in tree species composition in the Sugar Pine site in the Sierra Nevada, CA. Pre-treatment results based on data from the 2007-08 inventory data collected from plots in the core grid. Post-treatment results based on data from 2013 inventory. Means with standard errors reported. Species codes: ABCO, white fir (*Abies concolor*); ABMA, California red fir (*A. magnifica*); CADE, incense-cedar (*Calocedrus decurrens*); CONU, mountain dogwood, (*Cornus nuttallii*); PILA, sugar pine (*Pinus lambertiana*); PIPO, ponderosa pine (*P. ponderosa*); PSME, Douglas-fir, (*Pseudotsuga menziesii*); QUCH, canyon live oak (*Quercus chrysolepis*); QUKE, black oak (*Q. kelloggii*); SEGI, giant sequoia (*Sequoiadendron giganteum*); HARD, other hardwood species.

Fire Simulations

Despite similarities in weather and fuel moisture conditions (Table A2) and fuel model assignments (Table A3) used in the fire modeling, overall fire behavior tended to be higher at LC compared to SP. Differences are partly due to forest structure attributes; for example, average shrub cover and small tree density were higher at LC compared to SP (Table A4, Figure A7, Figure A9, Figure A10). FARSITE fire modeling showed that most treatments reduced flame length and fire type not only within the treated units (Figure A13), but also across the study areas (Figure A14). The largest decrease in average flame length was within prescribed fire (LC only) and thinning followed by mastication (SP only) treatment units. Cable logging at LC left activity fuels on site (Table A6), which resulted in a slash-blowdown fuel model being assigned, and consequently had higher post-treatment flame lengths and crowning. To estimate potential offsite effects from treatments we extracted FARSITE output pixel values within a 1,640 ft (500 m) buffer area outside treatment boundaries. There was a decrease of 23% and 44% in average flame length at LC and SP, respectively. Treatments were effective at decreasing the proportion of stand crowning in the buffer area by 51% at LC but not at SP (decrease of 1%).

Similarly, overall conditional burn probability (CBP; fire occurring with flame lengths > 6.6 ft) tended to be higher at LC (Figure A15) compared to SP (Figure A16). This was also reflected in the average fire size for either treatment scenario from the wildfire simulations (Year 0 in Figure A17). Topography and dominant wind direction influenced fire spread resulting in higher CBPs on the west side of the study area at LC and on the east side at SP.

There was a low to moderate decrease in hazardous fire potential (flame lengths > 6.6 ft) for the treatment fireshed relative to the control fireshed (Table A10). However, the effect of time (i.e., pre- to post-treatment changes in the control fireshed) was mixed; with decreases in both fire metrics at LC but only one at SP. Thus the treatment impact on hazardous fire potential varied with a greater reduction in the extent of the fireshed with flame lengths > 6.6 ft obtained for SP and a larger decrease in high conditional burn probabilities for LC (Table A10).

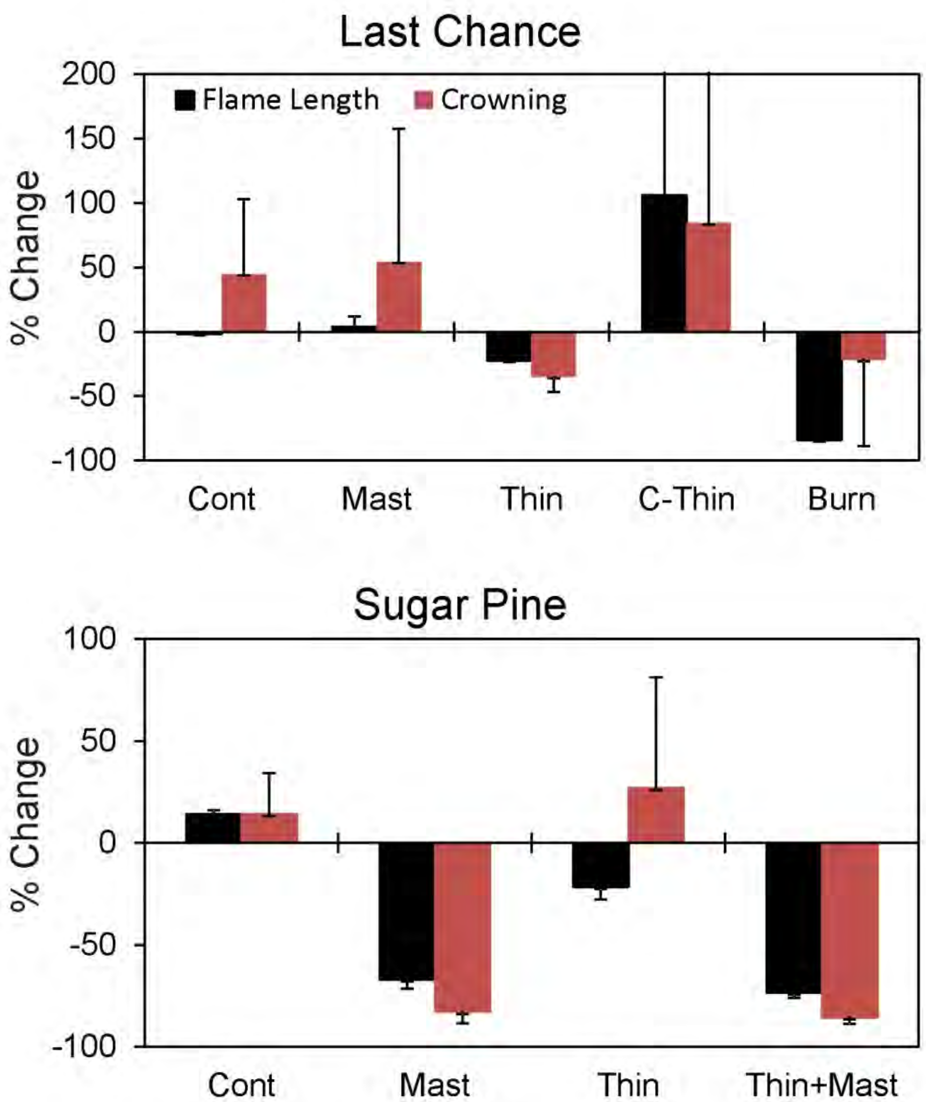


Figure A13: Changes in average flame length and proportion of the stand crowning by treatment type. Results based on comparisons of FARSITE pre- and post-treatment fire growth simulations. Cont, control; Mast, mastication; Thin, thinning; C-Thin, cable logging; Thin+Mast, thinning followed by mastication; Burn, prescribed fire.

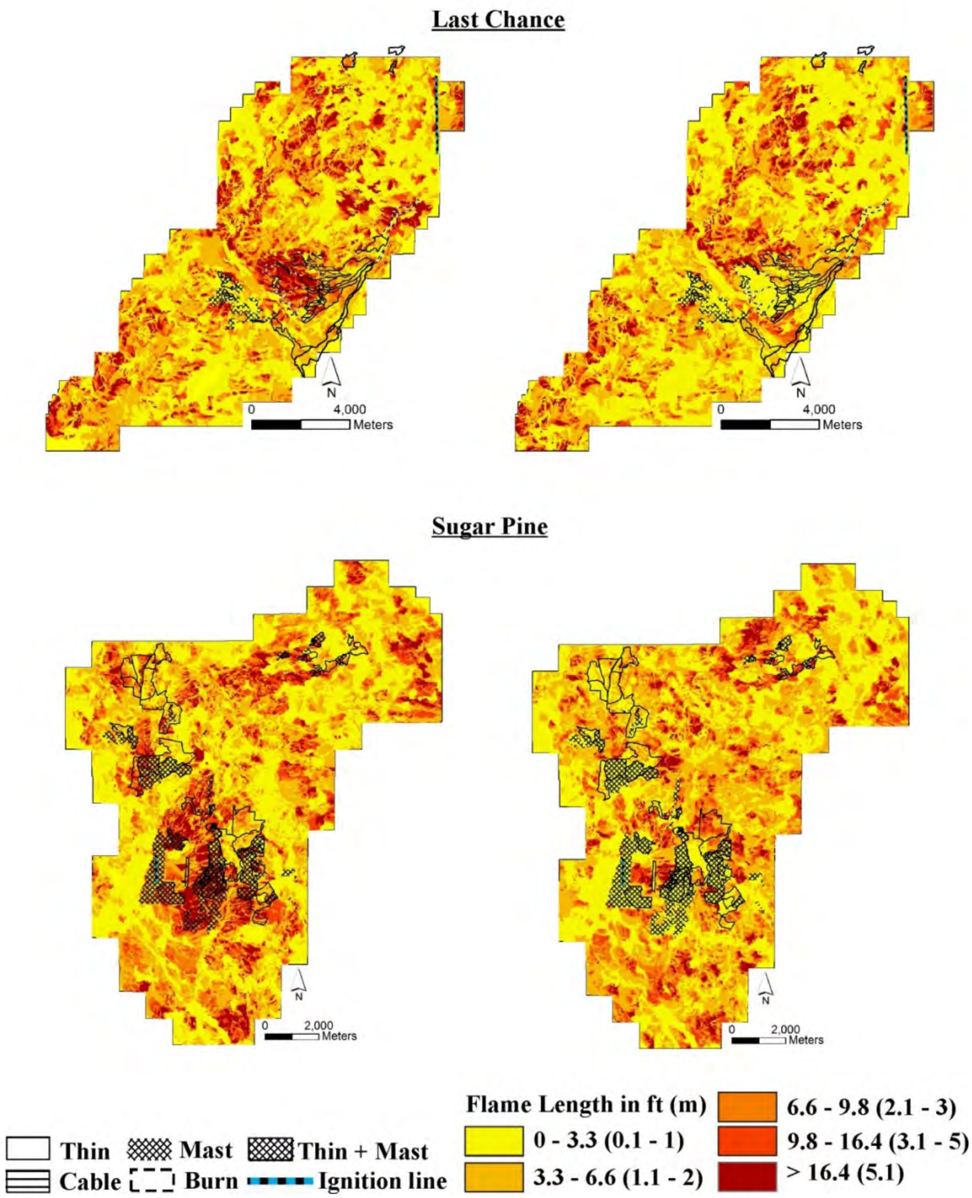


Figure A14: Simulated flame lengths for forest conditions pre- (left) and post-(right) implementation of SPLATs. Results based on FARSITE fire growth simulations. Models were parameterized with plot-level tree lists and scaled to stand polygons using vegetation map. The simulated wildfire occurs immediately after pre- and post-treatment plot measurements. Thin, thinning; Mast, mastication; Thin+Mast, thinning followed by mastication; Cable, cable logging; Burn, prescribed fire.

The lower post-treatment CBP relative to the pre-treatment scenario (2008) was evident across both study sites in 2023 and 2033, returning to pre-treatment levels by 2043 (Figure A15 and A16). Patterns of forest growth derived from the FVS showed either a leveling or continuous increase in most attributes, for both treatment scenarios, up to 30 years post-treatment (Figure A18, Figure A19). However, as indicated by the fire size comparisons (pre- and post-treatment without fire scenarios), the effects of SPLATs was negligible by 2033 at SP (Year 20 in Figure A17).

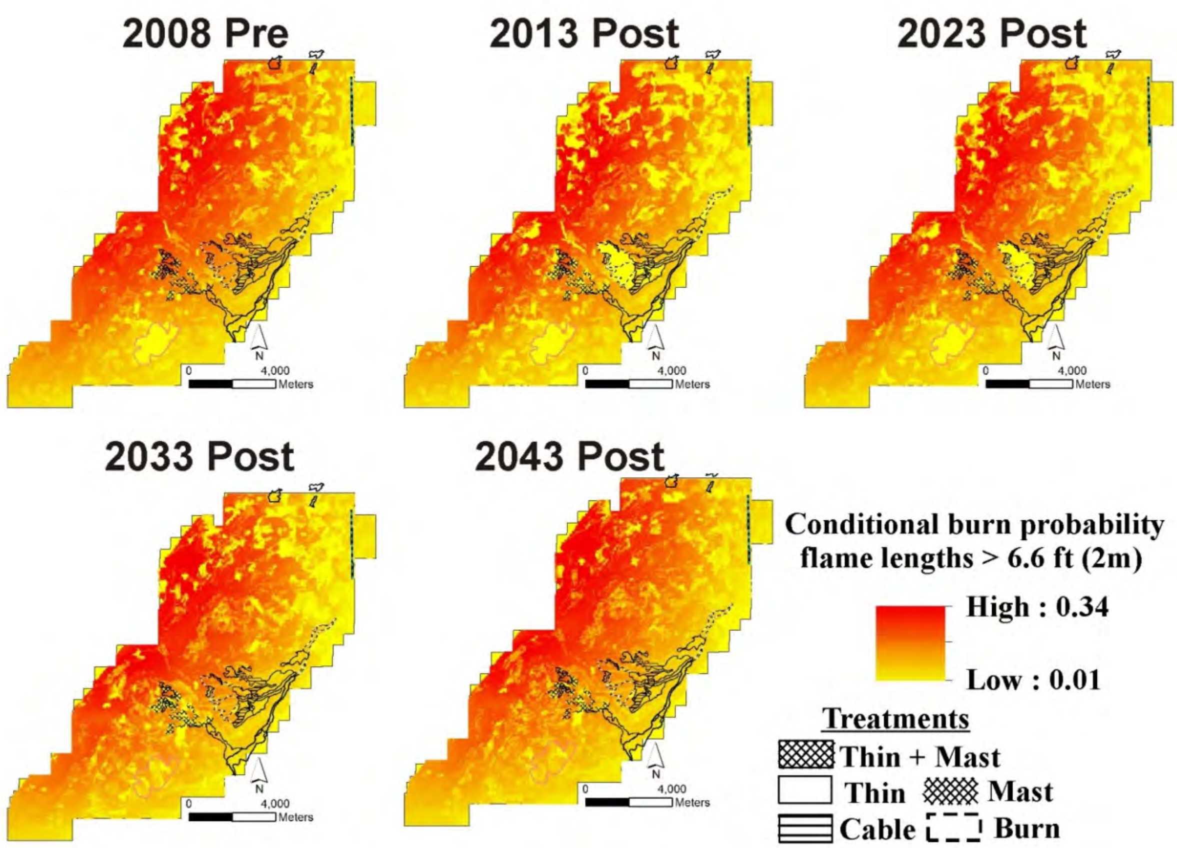


Figure A15: Conditional burn probabilities for which flame lengths > 6.6 ft at Last Chance. Burn probabilities are reported for pre- and post-implementation of fuel reduction treatments as well as during 30 years of simulated forest growth. Estimates are based on 10,000 random ignitions under 90th percentile wind and fuel moisture conditions. Cable, cable logging; Thin, thinning; Mast, mastication; Burn, prescribed fire.

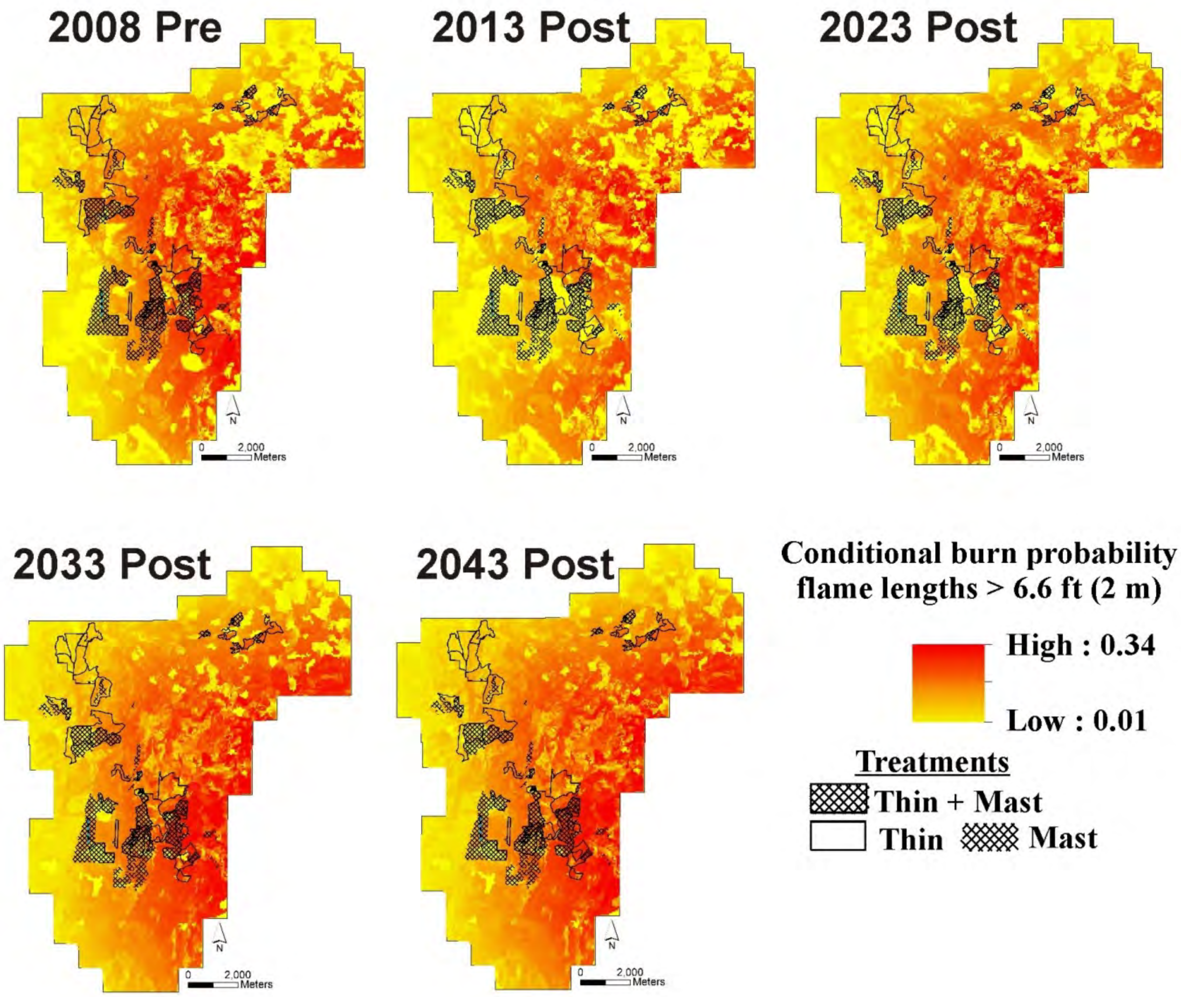


Figure A16: Conditional burn probabilities for which flame lengths > 6.6 ft at Sugar Pine. Burn probabilities are reported for pre- and post-implementation of fuel reduction treatments, as well as during 30 years of simulated forest growth. Estimates are based on 10,000 random ignitions under 90th percentile wind and fuel moisture conditions. Thin, thinning; Mast, mastication; Thin+Mast, thinning followed by mastication.

Incorporating effects of a wildfire and forest growth through FVS on both treatment scenarios show pronounced differences in recovery rates for most forest attributes (Figure A18, Figure A19), and therefore much different rates of change in CBP (CBP maps for fire scenarios not shown, see Figure A17). Following 30 years of forest growth in the fire scenario, the recovery towards pre-treatment averages was higher for the treatment scenario.

Table A10: Changes in fireshed-level fire behavior at both study sites. CBP, conditional burn probability for flame lengths > 6.6 ft (2 m).

Last Chance	**Control Fireshed**				**Treatment Fireshed**				**Treatment Impact**
	Pre	Post	**Δ**		Pre	Post	**Δ**		
Percentage of fireshed with flame lengths > 6.6 ft (2 m)	28.3	24.1	-4.2		32.9	22.5	-10.4		-6.2
Percentage of fireshed with CBP > 0.1	54.3	40.5	-13.8		59.3	40	-19.3		-5.5
Sugar Pine	**Control Fireshed**				**Treatment Fireshed**				**Treatment Impact**
	Pre	Post	**Δ**		Pre	Post	**Δ**		
Percentage of fireshed with flame lengths > 6.6 ft (2 m)	25	28.7	+3.7		29.3	25.3	-4		-7.7
Percentage of fireshed with CBP > 0.1	67.3	54.3	-13		29	12.3	-16.7		-3.7

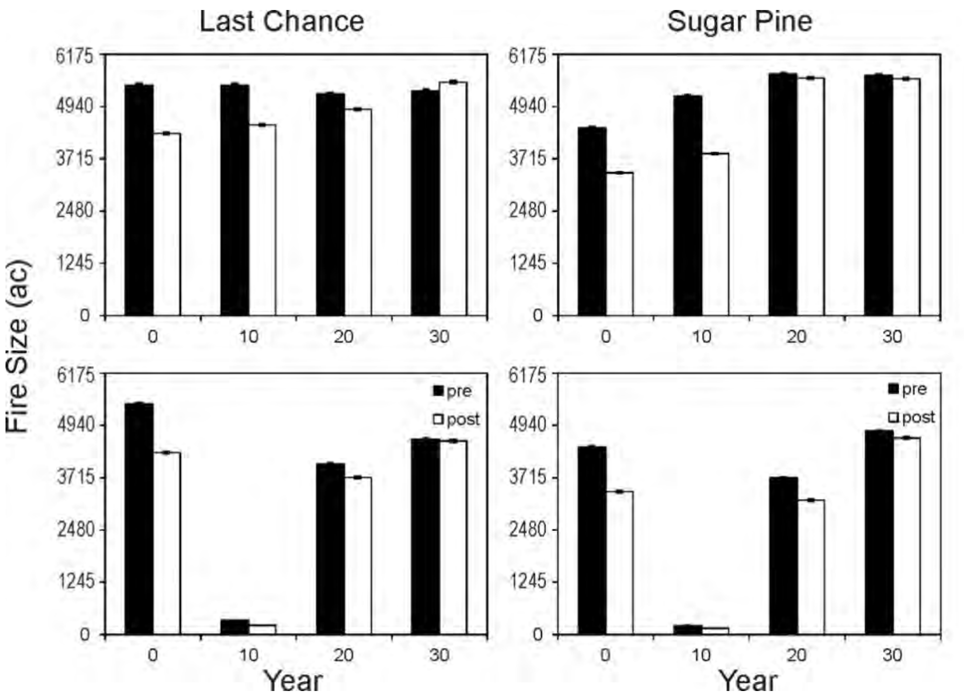


Figure A17: Average (1 standard error) fire sizes for wildfire simulations performed using RANDIG. Fire sizes are reported for all four treatment-fire scenarios (see Table A1), with pre- and post-implementation of fuel reduction treatments reflected at Year 0, and without (top) and with (bottom) incorporating the effects of a FARSITE wildfire simulation expressed at Year 10. The simulated fire occurs immediately after Year 0 is measured. For all four scenarios, RANDIG simulations were performed during 30 years of simulated forest growth. Estimates are based on 10,000 random ignitions under 90^{th} percentile wind and fuel moisture conditions.

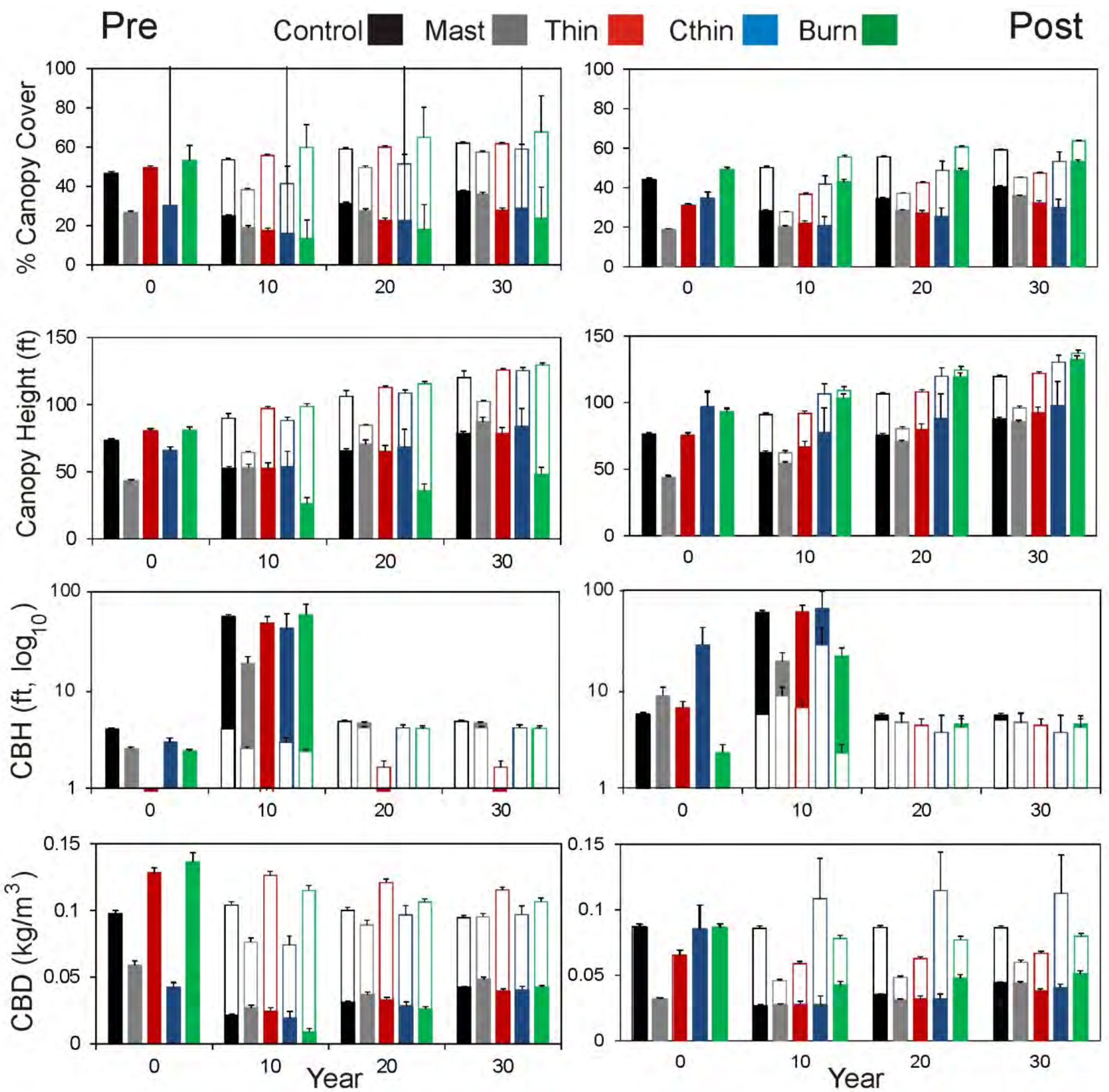


Figure A18: Average (one standard error) forest stand attributes, by treatment type, for all four fire-treatment scenarios at Last Chance. Treatment scenarios are pre- and post-implementation of fuel reduction treatments reflected at Year 0, combined with (filled bars) and without (open bars) incorporating the effects of a FARSITE wildfire simulation, with differences shown at Year 10. The simulated fire occurs immediately after Year 0 is measured. Attributes were calculated for each scenario during 30 years of simulated forest growth. Cable, cable logging; Thin, thinning; Mast, mastication; Burn, prescribed fire; CBH, canopy base height; CBD, canopy bulk density.

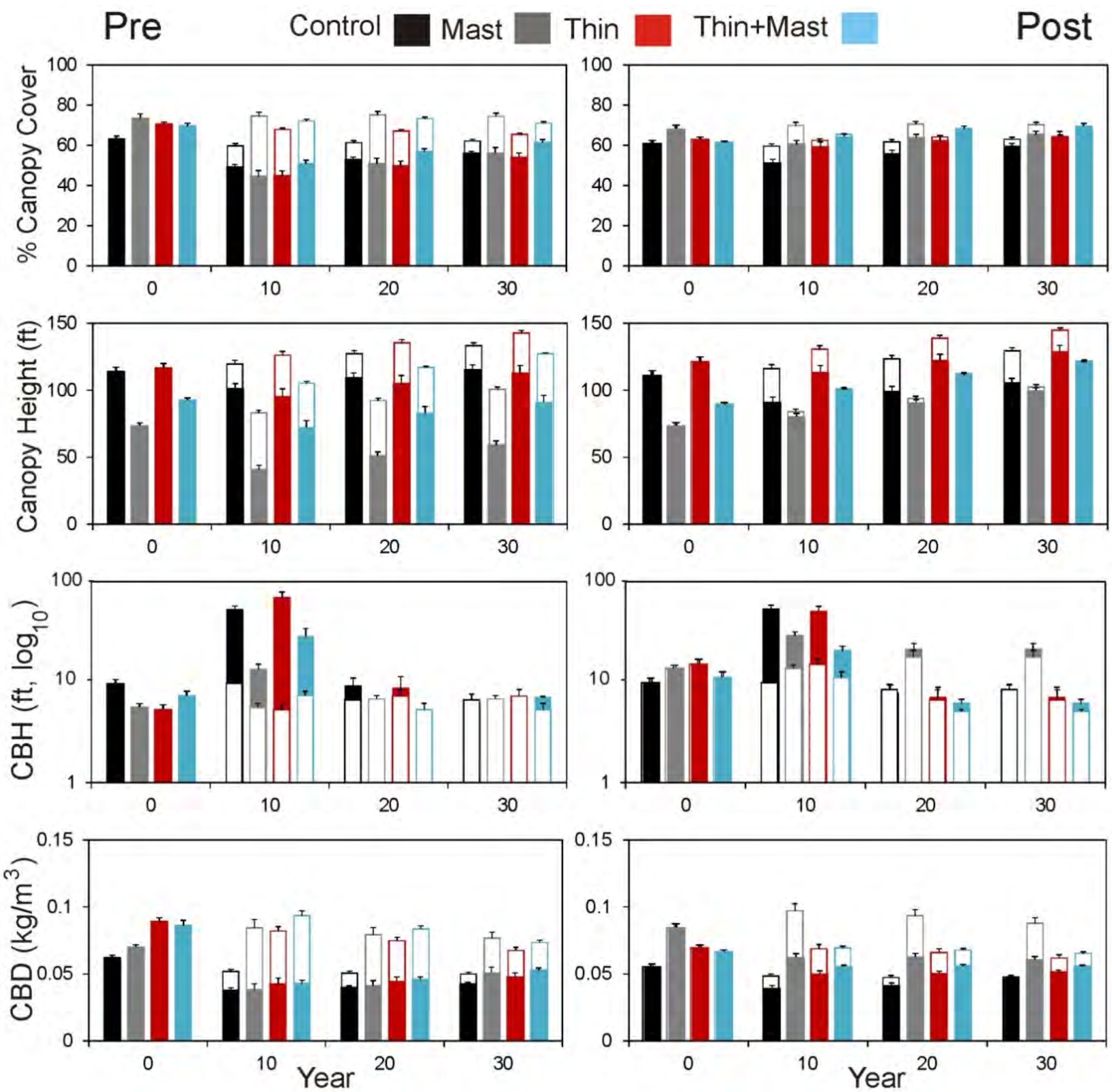


Figure A19: Average (one standard error) forest stand attributes, by treatment type, for all four fire-treatment scenarios at Sugar Pine. Treatment scenarios are pre- and post-implementation of fuel reduction treatments reflected at Year 0, combined with (filled bars) and without (open bars) incorporating the effects of a FARSITE wildfire simulation, with differences shown at Year 10. The simulated fire occurs immediately after Year 0 is measured. Attributes were calculated for each scenario during 30 years of simulated forest growth. Thin, thinning; Mast, mastication; Thin+Mast, thinning followed by mastication; CBH, canopy base height; CBD, canopy bulk density.

Integration

Pre-treatment crown fire potential was much higher at LC (Figure A20A) compared to SP (Figure A20B) in the treatment fireshed. The effect of SPLATs on CBP is evident at Year 0 (no fire scenario, blue bars in Figure A20), a 28% and 34% decrease at LC and SP, respectively. This difference wanes over time to only 2-4% by Year 30. Following essentially a zero CBP for either scenario immediately following simulated fire (red bars in Year 10), by Year 20 the recovery in CBP towards initial values (blue bars in Year 0) for the treatment scenario (light red bar) reached 67% at LC and 96% at SP. For the no treatment scenarios at Year 20 (stripe red bar) the recovery was slower, reaching 44% and 72% at LC and SP, respectively.

Overall the modeling results show consistent improvements in forest health with SPLATs. At both sites, a higher fraction of the pre-treatment basal area was retained (red bars) with SPLATs when there was a simulated fire (Figure A21). The treatment effect was greater at LC (Figure A21A). In Year 10 at LC, SPLATs reduced overall losses due to fire from 52% (no SPLATs, 0.48 fraction retained) to only 34% (with SPLATs, 0.66 fraction retained). As the forest grew, these differences were maintained through Year 30 (Figure A21A). In contrast, under the no-fire scenario, SPLATs improved growth efficiency more at SP. Between Year 0 and Year 10, growth efficiency was more than double with treatments (Figure A21B). At LC, small increases in growth efficiencies with SPLATs only emerged 20 years after the fire (Figure A21A). Despite the small relative improvement in growth efficiency at LC, in absolute terms trees at LC had a much higher growth efficiency. For example, at Year 10 in the untreated, no-fire scenario, growth efficiency at LC was 7.1 ft2/ac per unit leaf area. This efficiency was almost ten times greater than the rate at SP -- 0.8 ft2/ac per unit leaf area. Apparently, the relatively small changes in density and canopy cover associated with SPLATs lead to disproportionately large improvements in growth efficiency at the site that started with more basal area and higher canopy cover (Table A4).

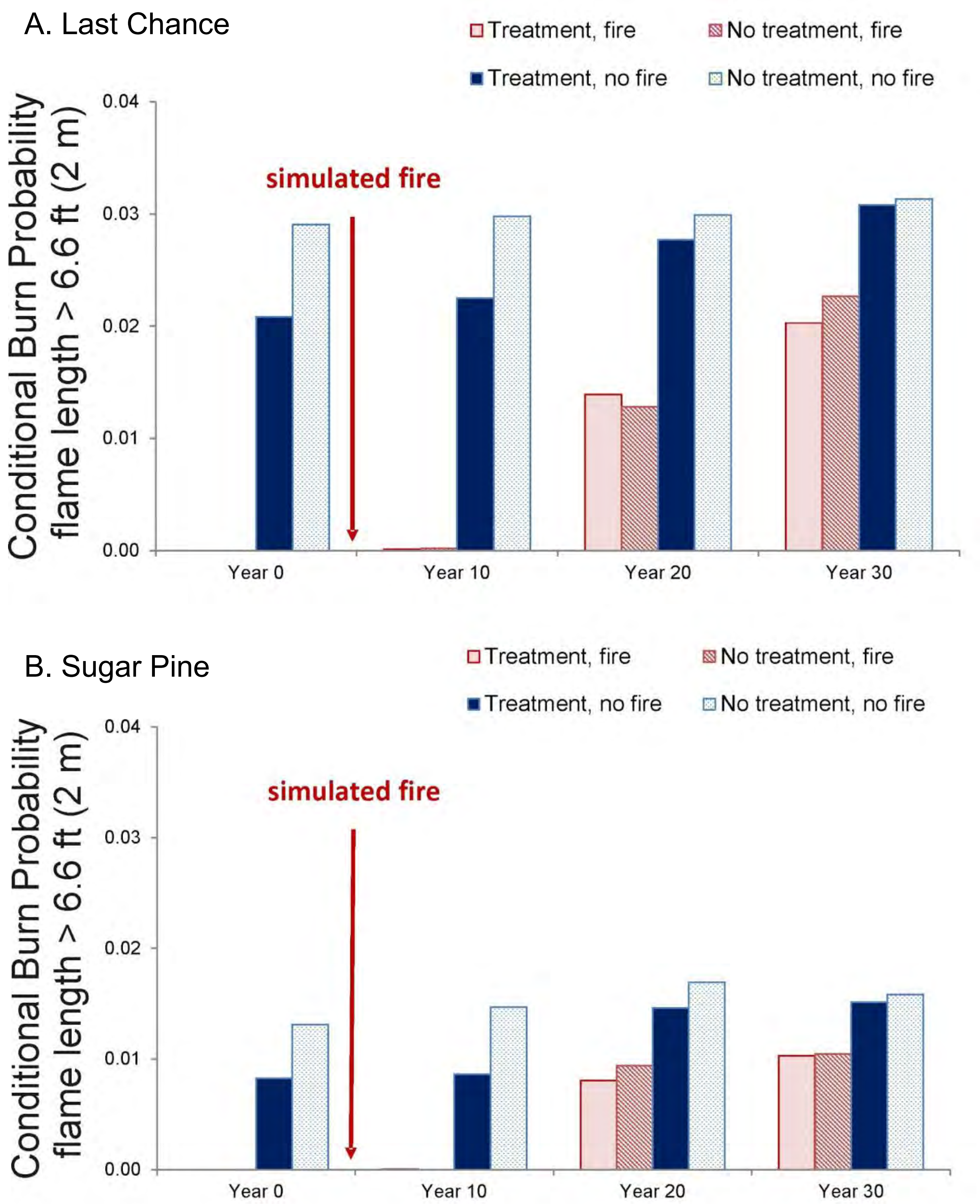


Figure A20: Changes in conditional burn probability by treatment and time. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire occurs immediately after Year 0 is measured. Results for the treated fireshed only.

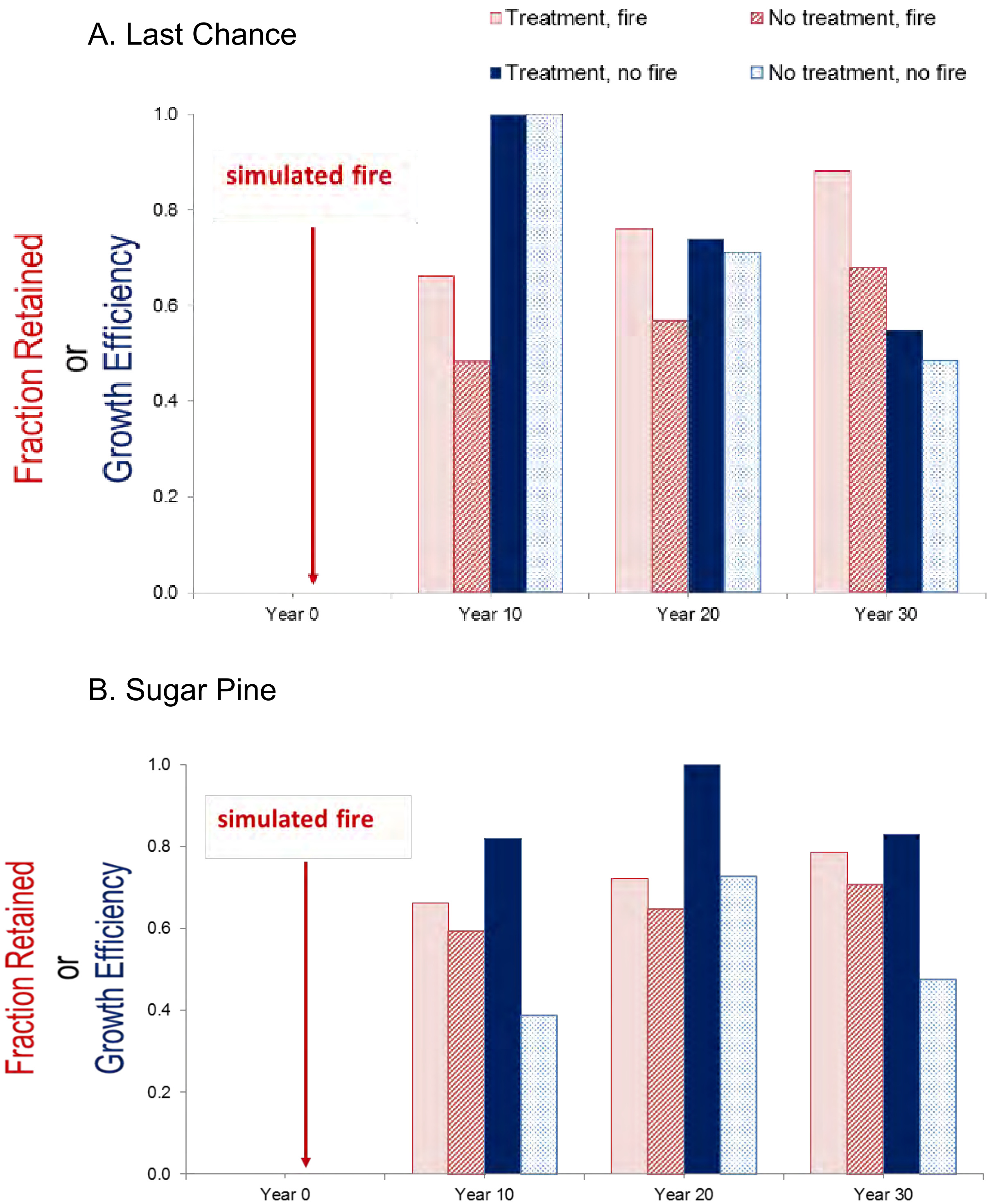


Figure A21: Trends in measures of forest health by treatment scenario. For the fire scenarios, forest health is expressed as the fraction of the Year 0 basal area that is retained (red bars). For the no fire scenarios, forest health is expressed as the relative growth efficiency (blue bars). The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

DISCUSSION

Response to SPLATS

Our results demonstrate that SPLAT networks as implemented according to the Sierra Nevada Forest Plan Amendment (USFS 2004) do reduce the risk and effects of uncharacteristically severe fire. This conclusion is based on a fully implemented treatment project, with a detailed inventory plot network, incorporating simulated wildfire effects to model fire behavior and forest growth. Comparable studies of SPLATs on fire behavior in fire-frequent conifer forests support this conclusion (Ager et al. 2007, Moghaddas et al. 2010, Collins et al. 2011, 2013). Our results are also consistent with SPLAT theory (Finney 2001) in that fire behavior was reduced not only in treated areas but also across the landscape, particularly on the leeside of treatments (Weatherspoon and Skinner 1996, Collins et al. 2013). Fuel treatments that targeted both ladder and surface fuels (e.g., thinning and prescribed fire at LC, thinning followed by mastication at SP) were the most effective at reducing simulated fire behavior (Stephens et al. 2009, Moghaddas et al. 2010).

When we scaled our results via landscape imputation and simulation modeling, results suggest that SPLATs improved forest health as measured by the fraction of basal area retained (fire scenario) and growth efficiency (no-fire scenario). The increase in the fraction of basal area retained in the treated firesheds with a simulated problem fire (Figure A21) is the expected outcome given that SPLATs reduced the probability of trees being exposed to damaging flame lengths (Figure A20). In the no-fire scenario, ecological theory (e.g., Ford 1975) and forestry practice (e.g., Lemmon and Schumacher 1962) predict improved growth resulting from a reduction in tree density. Indeed we did detect absolute increases in growth. For example, at SP basal area increased in the treated fireshed at a rate of 0.89 ft^2/ac per year – a rate more than double that of the control fireshed (0.34 ft^2/ac per year). In contrast at LC, there was no treatment related increase in absolute basal area in the model results. Both LC firesheds grew fast at an average rate of 2.8 ft^2/ac per year. However, by focusing on growth efficiency as the measure of tree vigor, we did see improvements realized at both sites (Figure A21). As noted by Waring (1983) and supported by Zierel (2004), the ratio of foliage extent to tree growth is a sensitive indicator of tree vigor. Thus, the increase in growth efficiency at both sites implies that the trees in the treated firesheds are healthier and less susceptible to mortality agents (Waring 1985).

Fire

Based on our simulations, fuel treatment scale and intensity should have the capacity to modify landscape fire behavior at both sites for two to three decades. Last Chance has an overall higher fire risk compared to Sugar Pine as indicated by the higher fireshed-level CBP, which is attributed to differences in forest structure--Sugar Pine has lower tree density and higher basal area and canopy base height-- and management history. It appears that hazard in untreated areas continues to increase (Collins et al. 2013), which is also demonstrated empirically at the stand-level by Stephens et al. (2012). This increased hazard in untreated areas over time may reduce the overall effectiveness of the fuel treatment network. Although we do not model it, maintenance treatments that would reduce surface fuels, namely prescribed fire, would probably extend treatment longevity across both landscapes. This is especially true considering most of the treatments focused on reducing ladder fuels, resulting in augmented surface fuels or a negligible change compared to pre-treatment fuel conditions.

The overall 4% reduction in potential fire behavior after SPLATs were installed at the Sugar Pine site is small and does not reduce the potential for high severity fire as much as intended by the project. Since this southern Sierra Nevada site is within the Pacific Fisher's range the intensity of fuels treatments were limited. Almost no change in the forest canopy was detected and surface fuels were still moderate after treatment because of no use of prescribed fire mainly because of air quality constraints. Ladder fuels were the main component removed at this site which can lower the probability of passive crown fire (Agee and Skinner 2005, Stephens et al. 2009) but can still leave the overall landscape at relatively high risk to severe fire.

The overall goal of protecting the Pacific Fisher is logical but leaving large forested landscapes that are the core of its habitat with high fire hazards is likely to fail in the long-term, especially with warming climates. A recent paper that analyzed 1911 landscape-scale (> 25,000 acres) forest structure from mixed conifer and ponderosa pine forests in the southern Sierra Nevada found high heterogeneity in structure before the impacts of harvesting or fire suppression

(Stephens et al. 2015). In 1911, total tree basal area ranged from 4 – 261 ft^2 $acre^{-1}$ (1 to 60 m^2 ha^1) and tree density from 1 – 67 trees $acre^{-1}$ (2 - 170 ha^1)(based on trees > 12 inches dbh). Comparing forest inventory data from 1911 to the present indicates that current forests have changed drastically, particularly in tree density, canopy cover, the density of large trees, dominance of white fir in mixed conifer forests, and the similarity of tree basal area in contemporary ponderosa pine and mixed conifer forests. Average forest canopy cover increased from 25–49% in mixed conifer forests, and from 12–49% in ponderosa pine forests from 1911 to the present. Current forest restoration goals in the southern Sierra Nevada are often skewed toward the higher range of these historical values, which will limit the effectiveness of these treatments if the objective is to produce resilient forest ecosystems into the future, as was found in the Sugar Pine site. Allowing more of the mixed conifer forests in the Sugar Pine area to received treatments that produced forest structures similar to those found in 1911 would have reduced potential fire behavior more than the 4% observed in this study.

One of the main limitations in evaluating the effectiveness of landscape fuel treatments is the reliance on simulated fire behavior from a single fire. Recent studies have been critical of commonly used fire behavior modeling techniques (Alexander and Cruz, 2013). In particular, these and other studies (Hall and Burke, 2006) have noted a general under prediction of crown fire. Characterization of surface and ladder fuels, represented as surface fuel models and canopy base height in commonly used modeling software, are the most influential inputs determining predicted fire behavior (Hall and Burke, 2006). In addition to their importance in capturing static assessments of altered fuel conditions in treated areas (e.g., Moghaddas et al., 2010), surface fuel models and canopy base height are essential for dynamic characterizations of changing surface and ladder fuels over time as well (e.g., Seli et al., 2008; Collins et al., 2011, 2013). Despite the importance of these two input variables, little work has been done to analyze the sensitivity of landscape fire behavior predictions, thus assessments of landscape fuel treatment effectiveness, to changes in these two variables. Furthermore, the coupling of forest dynamics models with landscape-scale fire behavior models is being implemented operationally in forest planning (e.g., Collins et al., 2010). Our findings provide guidance in the use of these models, which potentially improve planning outcomes and management on-the-ground.

Our previous research showed that stand canopy base heights (CBH), when projected using the forest dynamics models in FVS, increased considerably over time in untreated stands (Collins et al. 2011). This occurs at a rate that is difficult to justify ecologically, especially given the large proportion of shade-tolerant species present in many stands. Since predictions of hazardous fire potential are sensitive to CBH, modifications have been made by manipulating regeneration ingrowth levels (Collins et al. 2011, 2013). For this study, in addition to ingrowth levels used in Collins et al. (2011), we modified the default CBH in FVS by using the FVS output from the previous cycles, thereby slowing the rate of change. For fire scenarios we only modified the last cycle (2043) by using CBH values from the previous cycle (2033). While CBH still increased over time, this resulted in a more stabilized, realistic change in CBP over time.

It is likely that the fuel model selection logic we developed had an impact on conditional burn probability and fire size outputs over the simulated duration. Our assumptions that thinned and burned stands progressed from moderate-load conifer litter to high-load conifer litter surface fuel models and, by the final cycle, entered into the untreated selection logic may or may not represent realistic fuel recovery (Collins et al. 2011). Our fuel model succession logic was aided by Davis et al. (2009), in which transitions from one fuel model to the next were based on both fire severity and time since fire. Very little research has been done in this area, and more empirical studies of fuel recovery after wildfires, prescribed fires, and mechanical fuel treatments are needed to form robust methodologies for dynamically assigning fuel models in long-term simulation studies.

Finally, a source of error in our study is the use of a stand-level model (FVS-FFE) to generate fire behavior modeling inputs across our study landscape. Our approach used a base vegetation map to delineate stands, with vegetation and fuel data from over 600 field plots in an attempt to capture the diverse vegetation conditions across our large study areas, allowing for a more detailed quantification of vegetation structure and fuels, which are then simulated independently for the study duration. The base map combined the lidar data with multispectral aerial imagery to predict composition and structure in a 20x20 m^2 grid (Su et al. 2015b). This "pixel-based" product was then aggregated to stands using an object-of-interest segmentation method (Appendix B-Spatial in this report). Aggregating pixels to stands in order to create the continuous vegetation structure and fuel inputs needed to execute the fire models introduces abrupt transitions at stand boundaries. These transitions could potentially lead to unrealistic fire behavior predictions across the landscape. Correlating surface fuel models and forest conditions is a major limiting factor in fire behavior modeling research (but see Lydersen et al. 2015). Lidar data has unlimited potential to provide quantitative information at finer spatial scales that will inevitably help improve fire behavior and fire effects modeling. Despite these potential sources of error, and the uncertainties associated with FVS-FFE projections, our analyses capture the effects of the fuel treatment network in both study sites reasonably well.

Forest health

The implementations of SPLATs at Last Chance and Sugar Pine led to only minor immediate effects on forest structure and species composition. While we did detect the post-treatment increase in overstory tree mortality due to thinning, fireshed-scale changes related to forest health were more subtle. Indeed based on the plot inventory data, none of the structural changes were statistically different from the baseline trends observed in the control firesheds (Table A8, Table A9). Several factors account for this lack of structural change. The management priorities at both sites focused on reducing surface and ladder fuels with explicit goals to retain large trees and maintain canopy cover (USFS 2009, 2010). Thus treatment impacts were greatest for understory tree density and shrub cover with minimal shifts in canopy cover and big tree density (Table A8, Table A9). Also only a fraction of the landscape was treated. Thus the majority of plots received no treatment (Table A5). Finally at LC, trends in the control fireshed also seemed to "track" management goals. For example, tree basal area and density declined between 2007/08 and 2013 in the control fireshed at LC (Table A8). In the case of understory trees, the decrease was substantial (24%) and statistically significant (t-test, $p < 0.05$). These structural changes were also reflected in the fire models. Both fire behavior metrics at LC declined in the control fireshed under post-treatment conditions (Table A10). There was no obvious explanation for the observed decrease in understory tree density aside from self-thinning dynamics in a maturing stand (Vospernik and Sterba 2015).

Changes in tree species composition were also modest (Figure A11, Figure A12). At LC, reducing white fir dominance while increasing the pine component was an explicit treatment goal (USFS 2009). To some extent this target was met. Treatments at LC accounted for a decline in the relative basal area of white fir (14%) with corresponding increases in both ponderosa and sugar pine (Figure A11B).

Both sites identified the need to reduce stand densities in order to improve the resiliency, growth, and vigor of the remaining trees (USFS 2009, USFS 2010). While results from the FVS growth models support the contention that SPLATs did improve tree vigor (Figure A11), forest growth and yield simulators like FVS struggle to predict tree mortality accurately (Hamilton 1990, Battles et al. 2008, Robards 2009). Thus ultimately the measure of success of treatments in terms of tree vigor is to improve tree survival. This criterion is explicitly stated in the LC environmental impact assessment (USFS 2009). Subsequent treatment impacts on tree mortality can be tracked directly by repeat measurements. In addition, Collins et al. (2014) demonstrated a promising method to measure changes in forest resilience caused by fuel treatments. In fact, Collins et al. (2014) applied growth-mortality models developed for LC as part of the SNAMP pre-treatment field campaign. The initial work plan for SNAMP envisioned a post-treatment follow-up to provide empirical support to the model results, but the abbreviated post-treatment period (1-2 years) was too short to measure the tree growth response. Thus future work should prioritize documenting the growth response in order to quantify treatment impacts on future forest vulnerability.

Summary

There were clear differences in the extent and intensity of the treatments between LC and SP (Table A5, Figure A7). SPLATs impact on fire behavior and forest health was further modified by the ecological and historical differences between the two sites. The treated fireshed at SP supported a mixed conifer forest that was more crowded with bigger trees (Table A4) but exposed to a lower initial fire hazard (Table A10). Thus there was a dichotomy in the response to SPLATS. In terms of modifying fire behavior, the impact of SPLATs was greater at LC; in terms of improving forest health, the impact was greater at SP. The longevity of the impacts differed as well. The gains in growth efficiency were maintained through time while the reductions in flame lengths dissipated with time (Figure A20, Figure A21).

Results from SNAMP support the promise of SPLATs. Coordinated treatments across part of the landscape can help minimize the hazards posed by severe fires and at the same time meet forest health objectives. However, as noted above, to fully realize the potential of SPLATs further refinements are needed. For example, prioritizing surface and ladders fuels may be an effective means to decrease the risk of crown fire (Safford et al. 2012) while preserving structural elements (e.g., large trees and high canopy cover) important to wildlife species dependent on old-forest characteristics (Zelinski et al. 2013); it may not create gaps of sufficient size to recruit disturbance-dependent trees like ponderosa pine and sugar pine (York et al. 2011). Devising solutions that support the integrity and function of Sierra Nevada forest ecosystem will require more strategic thinking (e.g., North et al. 2009, North 2012, Stephens et al. 2014). Given the extent of the changes wrought by past management and the challenges posed by global change, the successful strategy will also need to plan for a great deal more management activity in the forest (North et al. 2015).

REFERENCES

Agee, J.K., and C.N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management 211: 83–96.

Ager, A.A., M.A. Finney, B.K. Kerns, and H. Maffei. 2007. Modeling wildfire risk to northern spotted owl (*Strix occidentalis caurina*) habitat in central Oregon, USA. Forest Ecology and Management 246: 45-56.

Ager, A.A., N.M. Vaillant, and M.A. Finney. 2010. A comparison of landscape fuel treatment strategies to mitigate wildland fire riosk in the urban interface and preserve old forest structure. Forest Ecology and Management 259: 1556-1570.

Alexander, M.E., and M.G. Cruz. 2013. Are the applications of wildland fire behaviour models getting ahead of their evaluation again? Environmental Modeling Software 41: 65– 71.

Battles, J.J., T. Robards, A. Das, K. Waring, J.K. Gilless, G. Biging, and F. Schurr. 2008. Climate change impacts on forest growth and tree mortality: a data-driven modeling study in a mixed-conifer forest of the Sierra Nevada. Climatic Change 87: S193-S213.

Brown, J.K. 1974. Handbook for Inventorying Downed Woody Material. USDA Forest Service General Technical Report INT-197. Forest and Range Experiment Station, Ogden, UT.

Brown, P.M., C.L. Wienk, and A.J. Symatad. 2008. Fire and forest history at Mount Rushmore. Ecological Applications, 18: 1984–1999.

Collins, B.M., H.A. Kramer, K. Menning, C. Dillingham, D. Saah, P.A. Stine, and S.L. Stephens. 2013. Modeling hazardous fire potential within a completed fuel treatment network in the northern Sierra Nevada. Forest Ecology and Management 310:156–166.

Collins, B.M. and S.L. Stephens. 2007. Fire scarring patterns in Sierra Nevada wilderness areas burned by multiple wildland fire use fires. Fire Ecology 3: 53-67.

Collins, B.M., and S.L. Stephens. 2010. Stand-replacing patches within a ‘mixed severity’ fire regime: quantitative characterization using recent fires in a long-established natural fire area. Landscape Ecology 25: 927-939.

Collins, B.M., S.L. Stephens, J.J. Moghaddas, and J. Battles. 2010. Challenges and approaches in planning fuel treatments across fire-excluded forested landscapes. Journal of Forestry 108: 24–31.

Collins, B.M., S.L. Stephens, G.B. Roller, and J.J. Battles. 2011. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. Forest Science 57: 77–88.

Collins, B.M., A.J. Das, J. J. Battles, D. L. Fry, K. D. Krasnow, and S. L. Stephens. 2014. Beyond reducing fire hazard: fuel treatment impacts on overstory tree survival. Ecological Applications 24: 1870-1886.

Dellasalla, D.A., D.M. Olson, S.E. Barth, S.L. Crane, and S.A. Primm. 1995. Forest health: moving beyond rhetoric to restore healthy landscapes in the inland Northwest. Wildlife Society Bulletin 23: 346-356.

Dixon, G.E. 2002. Essential FVS: A user's guide to the Forest Vegetation Simulator. USDA Forest Service, Internal Report, Fort Collins, CO.

Ellison, A.M., M.S. Bank, B.D. Clinton et al. 2005. Loss of foundation species: Consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment 588 3: 479-486.

EPA. 2015. The United States Environmental Protection Agency. Impacts and Adaptation to Climate Change: Forests Adaption Examples. http://www.epa.gov/climatechange/impacts-adaptation/forests-adaptation.html. Accessed June 2015.

Finney, M.A. 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. Forest Science 47: 219-228.

Finney, M.A. 2002. Fire growth using minimum travel time methods. Can. J. For. Res. 32(8): 1420–1424.

Finney, M.A. 2004. FARSITE: fire area simulator-model development and evaluation. Rocky Mountain Research Station Research Paper RMRS-4. United States Department of Agriculture, Washington, DC, US.

Finney, M.A. 2006. An overview of FlamMap modeling capabilities. P. 213-220 in Proc. of conf. on *Fuels management - how to measure success*, Andrews, P.L., and B.W. Butler (eds.). USDA For. Serv. RMRS-P41.

Finney, M.A., R.C. Seli, C.W. McHugh, A.A. Ager, B. Bahro, and J.K. Agee. 2007. Simulation of long-term landscape-level fuel treatment effects on large wildfires. Int. J. Wildland Fire 16(6): 712–727.

Fites-Kaufman, J.A., P. Rundel, N. Stephenson and D.A. Weixelman. 2007. Montane and subalpine vegetation of the Sierra Nevada and Cascade ranges. Pages 456-501 in Terrestrial Vegetation of California. Edited by M. G. Barbour, T. Keeler-Wolf, and A A. Schoenher. University of California Press, Berkeley.

Ford, E. D. 1975. Competition and stand structure in some even-aged plant monocultures. Journal of Ecology 63: 311-333.

FRAP. 2003**.** The Changing California*:* Forest and Range 2003 Assessment Summary. Fire and Resource Assessment Program. California Department of Forestry and Fire Protection. http://frap.fire.ca.gov/data/assessment2003/index.html.

Fry, D.L., S.L. Stephens, B.M. Collins, M.P. North, E. Franco-Vizcaino, and S.J. Gill. 2014. Contrasting Spatial Patterns in Active-Fire and Fire-Suppressed Mediterranean Climate Old-Growth Mixed Conifer Forests. PLOS ONE 9(2): e88985. doi:10.1371/journal.pone.0088985.

Gersonde, R.F. 2003. Developing a hybrid growth model for multiaged Sierra Nevada mixed-conifer forests. Dissertation. University of California, Berkeley.

Hall, S.A.,Burke, I.C., 2006. Considerations for characterizing fuels as inputs for fire behavior models. Forest Ecology and Management 227: 102–114.

Hamilton, D.A. 1990. Extending the range of applicability of an individual tree mortality model. Canadian Journal of Forest Research 20: 1212–1218

Hicke, J.A., A.J.H. Meddens, C.D. Allen and C.A. Kolden. 2013. Carbon stocks of trees killed by bark beetles and wildfire in the western United States. Environmental Research Letters 8, 035032. doi: 10.1088/1748-9326/8/3/035032.

Jones, D., K.O. O'Hara, J.J. Battles, and R. Gersonde. 2015. Alternative procedures for leaf area estimation in Sierra Nevada conifer trees. Forests 6: 6, 2631-2654.

Joseph, P., T. Kieth, L. Kline, J. Schwanke, A. Kanaskie, and D. Overhulser. 1991. Restoring forest health in the Blue Mountains: a 10-year strategic plan. Forest Log 61: 3-12.

Knapp, E.E., C.N. Skinner, M.P. North, and B.L. Estes. 2013. Long-term overstory and understory change following logging and fire exclusion in a Sierra Nevada mixed-conifer forest. Forest Ecology and Management 310: 903-914.

Kimmins, J.P. 1997. Biodiversity and its relationship to ecosystem health and integrity. The Forestry Chronicle 73: 229-232.

Kolb, T.E., M.R. Wagner and W.W. Covington. 1994. Utilitartian and ecosystem perspectives: concepts of forest health. Journal of Forestry 92: 10-15.

Krasnow, K. 2012. Managing novel forest ecosystems: understanding the past and present to build a resilient future. PhD dissertation. University of California Berkeley. http://escholarship.org/uc/item/31w9g2jz.

Lankford, L. 1994. Forest health on nonindustrial private forestland: ecosystem forestry from the ground up. Journal of Forestry 92: 26-29.

Larson, A.J., and D. Churchill. 2012. Tree spatial patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments. Forest Ecology and Management 267: 74–92.

Lemmon, P.E., and F.X. Schumacher. 1962. Volume and diameter growth of ponderosa pine trees as influenced by site index, density, age, and size. Forest Science: 236-249.

Lydersen, J.M., M.P. North, and B.M. Collins. 2014. Severity of an uncharacteristically large wildfire, the Rim Fire, in forests with relatively restored drequent fire regimes. Forest Ecology and Management 328: 326-334.

Lydersen, J.M., B.M. Collins, E.E. Knapp, G.B. Roller, and S.L. Stephens. 2015. Relating fuel loads to overstory structure and composition in a fire-excluded Sierra Nevada mixed conifer forest. International Journal of Wildland Fire 24: 484-494.

Marlon, J.R.,P.J. Bartlein, D.G. Gavin, C.J. Long, R.S. Anderson, C.E. Briles, K.J. Brown, D. Colombaroli, D.J. Hallett, M.J. Power, E.A. Scharf, and M.K. Walsh. 2012. Long-term perspective on wildfires in the western USA. Proceedings of the National Academy of Sciences, USA 109: E535–E543.

McIntyre, P.J., Thorne, J.H., Dolanc, C.R., Flint, A.L., Flint, L.E., Kelly, M., and D.D. Ackerly. 2014. Twentieth-century shifts in forest structure in California: denser forests, smaller trees, and increased dominance of oaks. Proceedings of the National Academy of Sciences. doi: http://dx.doi.org/10.1073/pnas.1410186112.

Menning, K.M., J.J. Battles and T.L. Benning. 2007. Quantifying change in distributions: a new departure index that detects, measures and describes change in distributions from population structures, size-classes and other ordered data. Oecologia 154: 75-84.

Miller, J. and H. Safford. 2012. Trends in wildfire severity: 1984 to 2010 in the Sierra Nevada, Modoc Plateau, and Southern Cascades, California, USA. Fire Ecology 8: 41–57.

Miller, J., H. Safford, M. Crimmins, and A. Thode. 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. Ecosystems 12: 16-32.

Moghaddas, J.J., B.M. Collins, K. Menning, E.E.Y. Moghaddas, and S.L. Stephens. 2010. Fuel treatment effects on modeled landscape-level fire behavior in the northern Sierra Nevada. Canadian Journal of Forest Research 40: 1751-1765.

Naficy, C., A. Sala, E.G. Keeling, J. Graham, and T.H. DeLuca. 2010. Interactive effects of historical logging and fire exclusion on ponderosa pine forest structure in the northern Rockies. Ecological Applications 20: 1851–1864. http://dx.doi.org/10.1890/09-0217.1

North, M., P. Stine, K. O'Hara, W. Zielinski, and S. Stephens. 2009. An ecosystem management strategy for Sierran mixed-conifer forests. USDA Forest Service General Technical Report PSW-GTR-220. Albany, California, USA.

North, M. 2012. Managing Sierra Nevada forests. USDA Forest Service General Technical Report PSW-GTR-237, Albany, California, USA.

North, M.P., A. Brough, J. Long, B.M. Collins, P. Bowden, D. Yasuda, J. Miller, and N. Sugihara. 2015. Constraints on mechanized treatment significantly limit mechanical fuels reduction extent in the Sierra Nevada. Journal of Forestry 113: 40-48.

NRCS. 2015. Web Soil Survey USDA Natural Resources Conservation Service online service available at: http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. Accessed June 2015.

NWCG, 2004. Fireline Handbook – Appendix B, Fire Behavior. National Wild-fire Coordinating Group, Incident Operations Standards Working Team PMS 410-1, 124p.

Ohmann, J.L. and M.J. Gregory. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, USA. Canadian Journal of Forest Research 32: 725–741.

Panek, J., D. Saah, A. Esperanza, A. Bytnerowicz, W. Fraczek, and R. Cisneros. 2013. Ozone distribution in remote ecologically vulnerable terrain of the southern Sierra Nevada, CA. Environmental Pollution 182: 343-356.

Patel, A., D.J. Rapport, L. Vanderlinden and J. Eyles. 1999. Forests and societal values: comparing scientific and public perception of forest health. The Environmentalist 19: 239-249.

Pautasso, M., M. Schlegel, and O. Holdenrieder. 2014. Forest health in a changing world. Microbial ecology: 1-17.

R Development Core Team. 2010. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Raffa, K.F., B. Aukema, B.J. Bentz, et al. 2009. A literal use of “forest health” safeguards against misuse and misapplication. Journal of Forestry 107: 276-277.

Reinhardt, E.D., R.E. Keane, D.E. Calkin, and J.D. Cohen. 2008. Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States. For. Ecol. Manage. 256(12): 1997–2006.

Reinhardt, E., and N.L. Crookston. 2003. The fire and fuels extension to the forest vegetation simulator. US For. Serv. Gen.Tech. Rep. RMRS-GTR-116. 209 p.

Robards, T.A. 2009. Empirical forest growth model evaluations and development of climate-sensitive hybrid models. Ph.D. Dissertation. University of California, Berkeley.

Safford, H.D., J.T. Stevens, K. Merriam, M.D. Meyer, and A.M. Latimer. 2012. Fuel treatment effectiveness in California yellow pine and mixed conifer forests. Forest Ecology and Management 274: 17-28.

Schmidt, D.A., A.H. Taylor, and C.N. Skinner. 2008. The influence of fuels treatment and landscape arrangement on simulated fire behavior, southern Cascade range, California. Forest Ecology and Management 255: 3170-3184.

Scholl, A.E. and A.H. Taylor. 2010. Fire regimes, forest change, and self-organization in an old-growth mixed-conifer forest, Yosemite National Park, USA. Ecological Applications 20: 362-380.

Scott, J.H., and E.D. Reinhardt. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. USDA For. Serv. Res. Pap. RMRS-RP-29. 59 p.

Scott, J.H., and R.E. Burgan. 2005. Standard fire behavior models: a comprehensive set for use with Rothermel's surface fire spread model. USDA For. Serv. Gen. Tech. Rep. RMRS-GTR-153. 72 p.

Seli, R.C., A.A. Ager, N.L. Crookston, M.A. Finney, B. Bahro, J.K. Agee, and C.W. McHugh. 2008. Incorporating landscape fuel treatment modeling into the Forest Vegetation Simulator. P. 27-39 in Proc. of conf. on *Third Forest Vegetation Simulator Conference*, Havis, R.N., and N.L. Crookston (eds.). USDA For. Serv. Conf. Proc. RMRS-P-54.

Sheil, D., D.F. Burslem, and D. Alder. 1995. The interpretation and misinterpretation of mortality rate measures. Journal of Ecology 83: 331-333.

Skinner, C. and A.H. Taylor. 2006. Southern Cascades Bioregion. In, N.G. Sugihara, J.W. van Wagtendonk, J. Fites-Kaufman, A.E. Thode (Eds.), Fire in California's Ecosystems. University of California Press, Berkeley, pp. 195-224.

Smith, E.P. 2002. BACI design. Pages 141-148 in the Encyclopedia of Environmetrics. Edited by A.h. El-Shaarawi and W.W. Piegorsch. John Wiley and Sons. Chichester.

Stephens, S.L. and B.M. Collins. 2004. Fire regimes of mixed conifer forests in the north-central Sierra Nevada at multiple spatial scales. Northwest Science 78: 12-23.

Stephens, S.L., R.E. Martin, and N.D. Clinton. 2007. Prehistoric fire area and emissions from California's forests, woodlands, shrublands and grasslands. Forest Ecology and Management 251: 205-216.

Stephens, S.L., J.J. Moghaddas, C. Ediminster, C.E. Fiedler, S. Hasse, M. Harrington, J.E. Keeley, E.E. Knapp, J.D. McIver, K. Metlen, C.N. Skinner, and A. Youngblood. 2009. Fire treatment effects on vegetation structure, fuels, and potential fire severity in western U.S. forests. Ecological Applications 19: 305-320.

Stephens, S.L., D.L. Fry, B.M. Collins, C.N. Skinner, E. Franco-Vizcaíno, and T.J. Freed. 2010. Fire-scar formation in Jeffrey pine –mixed conifer forests in the Sierra San Pedro Mártir, Mexico. Canadian Journal of Forest Research 40: 1497-1505.

Stephens, S.L., B.M. Collins, G.B. Roller. 2012. Fuel treatment longevity in a Sierra Nevada mixed conifer forest. Forest Ecology and Management 285: 204–212.

Stephens, S.L., S.W. Bigelow, R.D. Burnett, B.M. Collins, C.V. Gallagher, J. Keane, D.A. Kelt, M.P. North, L.J. Roberts, P.A. Stine, and D.H. Van Vuren. 2014a. California Spotted Owl, Songbird, and Small Mammal Responses to Landscape Fuel Treatments. Bioscience 64:893-906.

Stephens, S.L., J.M. Lydersen, B.M. Collins, D.L. Fry, and M.D. Meyer. 2015. Historical and current landscape-scale ponderosa pine and mixed-conifer forest structure in the Southern Sierra Nevada. Ecosphere 304: 492–504.

Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "Pseudoreplication" in time? Ecology 67: 929-940.

Stine, S. 1996. Climate, 1650-1850. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chap. 2. Davis: University of California, Centers for Water and Wildland Resources.

Sulak, A. and L. Huntsinger. 2012. Perceptions of forest health among stakeholders in an adaptive management project in the Sierra Nevada of California. Journal of Forestry 110: 312-317.

Su, Y., Q. Guo, B.M. Collins, D.L. Fry, and M. Kelly. 2015a. Forest fuel treatment detection using multi-temporal airborne lidar data and high resolution aerial imagery ---- A case study at Sierra Nevada Mountains, California. Agricultural and Forest Meteorology (in review)

Su, Y., Q. Guo, D.L. Fry, B.M. Collins, M. Kelly, J.P. Flanagan, and J.J. Battles. 2015b. A new vegetation mapping strategy for conifer forests by combining airborne lidar data and aerial imagery. Forest Ecology and Management (in review)

Taylor, A.H., A.M. Vandervlugt, R.S. Maxwell, R.M. Beaty, C. Airey, and C.N. Skinner. 2014. Changes in forest structure, fuels and potential fire behaviour since 1873 in the Lake Tahoe Basin, USA. Applied Vegetation Science 17: 17-31.

Tierney, G.L., D. Faber-Langendoen, B.R. Mitchell, W.G. Shriver, and J.P. Gibbs. 2009. Monitoring and evaluating the ecological integrity of forest ecosystems. Frontiers in Ecology and the Environment 7: 308-316.

USFS. 2004. Sierra Nevada Forest Plan Amendment—Final supplemental environmental impact statement. United States Forest Service Pacific Southwest Region 5. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5416715.pdf.

USFS. 2009. Environmental Assessment: Last Chance Integrated Management Project. United States Forest Service, Pacific Southwest Region, Tahoe National Forest. http://snamp.cnr.berkeley.edu/static/documents/2009/08/12/SNAMPLastChanceEA1.pdf

USFS. 2010. Final Environmental Impact Statement. Record of Decision. Sierra National Forest Sugar Pine Adaptive Management Project. United States Forest Service, Pacific Southwest Region. http://snamp.cnr.berkeley.edu/documents/426/

Vaillant, N.M. 2008. Sagehen Experimental Forest Past, Present, and Future: An Evaluation of the Fireshed Assessment Process. Dissertation. University of California, Berkeley.van Mantgem, P.J., Nesmith, J.C.B., Keifer, M, and M. Brooks. 2013. Tree mortality patterns following prescribed fire for *Pinus* and *Abies* across the southwestern United States. Forest Ecology and Management 289: 463–469.

van Mantgem, P.J., Stephenson, N.L., 2007. Apparent climatically-induced increase of tree mortality rates in a temperate forest. Ecology Letters 10: 909-916.

van Wagtendonk, J.W., J.M. Benedict, and W.M. Sydoriak. 1998. Fuel bed characteristics of Sierra Nevada conifers. Western Journal of Applied Forestry 13: 73-84.

Vospernik, S. and H. Sterba. 2015. Do competition-density rule and self-thinning rule agree? Annals of Forest Science 72: 379-390.

Wagner, M.R., W.M. Block, B.W. Geils, and K.F. Wenger. 2000. Restoration Ecology. Journal of forestry 98: 22-27.

Warren, W.A. 2007. What is a health forest? Definitions, rationales, and the lifeworld. Society and Natural Resources 20: 99-117.

Waring, R.H. 1983. Estimating forest growth and efficiency in relation to canopy leaf area. Advances in Ecological Research 13: 327-354.

Waring, R.H. 1987. Characteristics of Trees Predisposed to Die. Bioscience 37: 569-574.

Weatherspoon, C.P., Skinner, C.N., 1996. Landscape-level strategies for forest fuel management. In: Sierra Nevada Ecosystem Project: Final Report to Congress. Assessments and scientific basis for management options. Wildland Resources Center Report No. 37, vol. II. University of California, Davis, USA, pp. 1471–1492.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan , and T.W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. Science 313: 940-943.

Woodall, C.W., M.C. Amacher, W.A. Bechtold et al. 2011. Status and future of the forest health indicators program of the USA. Environmental Monitoring and Assessment 177: 419-436.

Wyckoff, P.H., and J.S. Clark. 2000. Predicting tree mortality from diameter growth: a comparison of maximum likelihood and Bayesian approaches. Canadian Journal of Forest Research: 156-167.

York, R. A., J. J. Battles, R. C. Wenk, and D. Saah. 2011. A gap-based approach for regenerating pine species and reducing surface fuels in multi-aged mixed conifer stands in the Sierra Nevada, California. Forestry 85: 203-213.

Zielinski, W.J., C. M. Thompson, K.L. Purcell, and J.D. Garner. 2013. An assessment of fisher (*Pekania pennanti*) tolerance to forest management intensity on the landscape. Forest Ecology and Management 310: 821-826.

Zierl, B. 2004. A simulation study to analyse the relations between crown condition and drought in Switzerland. Forest Ecology and Management 188: 25-38.

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Appendix B: Spatial Team Final Report

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August 31, 2015

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Executive Summary – Spatial Team

The SNAMP Spatial Team was formed to provide support for the other SNAMP science teams through spatial data acquisition and analysis. The objectives of the SNAMP Spatial Team were: (1) to provide base spatial data; (2) to create quality and accurate mapped products of use to other SNAMP science teams; (3) to explore and develop novel algorithms and methods for Lidar data analysis; and (4) to contribute to science and technology outreach involving mapping and Lidar analysis for SNAMP participants. The SNAMP Spatial Team has focused on the use of Lidar – Light Detection and Ranging, an active remote sensing technology that has the ability to map forest structure.

Lidar data were collected for Sugar Pine (117km^2) in September 2007 (pre-treatment), and Nov 2012 (post-treatment); and for Last Chance (107km^2) on September 2008 (pre-treatment) and November 2012 and August 2013 (post-treatment). Field data were collected at each site according to an augmented protocol based on the Fire and Forest Ecosystem Health (FFEH) Team plot method. From the Lidar data, field data and aerial imagery (for some of the products), a range of map products were created, including: canopy height model, digital surface model and digital terrain model; topographic products (digital elevation model, slope, aspect); forest structure products (mean height, max height, diameter at breast height (DBH), height to live canopy base (HTLCB), canopy cover, leaf area index (LAI), and map of individual trees); fire behavior modeling products (max canopy height, mean canopy height, canopy cover, canopy base height, canopy bulk density, basal area, shrub cover, shrub height, combined fuel loads, and fuel bed depth), as well as a map of individual trees, and a detailed vegetation map of each site. Lidar data have been used successfully in the SNAMP project in a number of ways: to capture forest structure; to map individual trees in forests and critical wildlife habitat characteristics; to predict forest volume and biomass; to develop inputs for forest fire behavior modeling, and to map forest topography. The SNAMP Spatial Team also explored several avenues of investigation with Lidar data that resulted in eleven peer-reviewed publications, listed in Appendix B1. Our work has been significant over a range of areas.

Technical advances from the SNAMP Spatial Team

In a comprehensive evaluation of interpolation methods, we found simple interpolation models are more efficient and faster in creating DEMs from Lidar data, but more complex interpolation models are more accurate, and slower (Guo et al. 2010 SNAMP Publication #4). The Lidar point cloud (as distinct from the canopy height model) can be mined to identify and map key ecological components of the forest. For example, we mapped individual trees with high accuracy in complex forests (Li et al. 2012 SNAMP Publication #6 and Jakubowski et al. 2013 SNAMP Publication #24), and downed logs on the forest floor (Blanchard et al. 2011 SNAMP Publication #7). We investigated the critical tradeoffs between Lidar density and accuracy and found that low-density Lidar data may be capable of estimating plot-level forest structure metrics reliably in some situations, but canopy cover, tree density and shrub cover were more sensitive to changes in pulse density (Jakubowski et al. 2013 SNAMP Publication #18).

Lidar data used to map wildlife habitat

Lidar can be used to map elements of the forest that are critical for wildlife species. We used our data to map large residual trees and canopy cover – two key elements of forests used by California spotted owl (*Strix occidentalis occidentalis*) for nesting habitat (Garcia-Feced et al. 2012 SNAMP Publication #5). Lidar also proved useful for characterizing the forest habitat conditions surrounding trees and snags used by the Pacific fisher (*Pekania* [*Martes*] *pennanti*) for denning activity. Large trees and snags used by fishers as denning structures were associated with forested areas with relatively high canopy cover, large trees, and high levels of vertical structural diversity. Den structures were also located on steeper slopes, potentially associated with drainages with streams or access to water (Zhao, et al. 2012 SNAMP Publication #16).

Lidar products used in fire behavior modeling

Forest fire behavior models need a variety of spatial data layers in order to accurately predict forest fire behavior, including elevation, slope, aspect, canopy height, canopy cover, crown base height, crown bulk density, as well as a layer describing the types of fuel found in the forest (called the "fuel model"). These spatial data layers are not often developed using Lidar (light detection and ranging) data for this purpose (fire ecologists typically use field-sampled data), and so we explored the use of Lidar data to describe each of the forest-related variables. We found that stand structure metrics (canopy height, canopy cover, shrub cover, etc.) can be mapped with Lidar data, although the accuracy of the product decreases with canopy penetration. General fuel types, important for fire behavior modeling, were predicted well with Lidar, but specific fuel types were not predicted well with Lidar (Jakubowski et al. 2013 SNAMP Publication #13).

Use of Lidar for biomass estimation

Accurate estimation of forest above ground biomass (AGB) (all aboveground vegetation components including leaves/needles) has become increasingly important for a wide range of end-users. Lidar data can be used to map biomass in forests. However, the availability of, and uncertainly in, equations used to estimate tree volume allometric equations influences the accuracy with which Lidar data can predict biomass from Lidar-derived volume metrics (Zhao et al. 2012a SNAMP Publication #14). Many Lidar metrics, including those derived from individual tree mapping are useful in estimating biomass volume. We found that biomass can be accurately estimated with regression equations that include tree crown volume and that include an explicit understanding of the overlapping nature of tree crowns (Tao et al. 2014 SNAMP Publication #29). Satellite remote sensing has provided abundant observations to monitor forest coverage, validation of coarse-resolution above ground biomass derived from satellite observations is difficult because of the scale mismatch between the footprints of satellite observations and field measurements. Lidar data when fused with course scale, fine temporal resolution imagery such as MODIS, can be used to estimate regional scale above ground forest biomass (Li et al. 2015 SNAMP Publication #37).

Management implications

Our work has several management implications. Lidar will continue to play an increasingly important role for forest managers interested in mapping forests at fine detail. Understanding the structure of forests – tree density, volume and height characteristics - is critical for management, fire prediction, biomass estimation, and wildlife assessment. Optical remote sensors such as Landsat, despite their synoptic and timely views, do not provide sufficiently detailed depictions of forest structure for all forest management needs. We provide management implications in four areas:

1. Lidar maps and products

- Lidar data can produce a range of mapped product that in many cases more accurately map forest height, structure and species than optical imagery alone.
- Lidar software packages are not yet as easy to use as the typical desktop GIS software.
- There are known limitations with the use of discrete Lidar for forest mapping - in particular, smaller trees and understory are difficult to map reliably.
- Discrete Lidar can be used to map the extent of forest fuel treatments; treatment methods cannot be detected using discrete Lidar, but waveform Lidar might be alternative choice to map understory change.

2. Wildlife

- Lidar is an effective tool for mapping important forest habitat variables – such as individual trees, tree sizes, and canopy cover - for sensitive species.
- Lidar will increasingly be used by wildlife managers, but there remain numerous technical and software barriers to widespread adoption. Efforts are still needed to link Lidar data, metrics and products to measures more commonly used by managers such as CWHR habitat classes.

3. Fire behavior modeling

- Lidar data are not yet operationally included into common fire behavior models, and more work should be done to understand error and uncertainty produced by Lidar analysis.

4. Forest management

- There is a trade-off between detail, coverage and cost with Lidar. The accurate identification and quantification of individual trees from discrete Lidar pulses typically requires high-density data. Standard plot-level metrics such as tree height, canopy cover, and some fuel measures can reliably be derived from less dense Lidar data.

- Standard Lidar products do not yet operationally meet the requirements of many US forest managers who need detailed measures of forest structure that include understanding of forest heterogeneity, and understanding of forest change. More work is needed to translate between the remote sensing community and the forest management community in some areas of the US to ensure that Lidar products are useful to and used by forest managers.
- The fusion of hyperspectral imagery with Lidar data may be very useful to create detailed and accurate forest species maps.

The future of Lidar for forest applications will depend on a number of considerations. These include: 1) costs, which have been declining; 2) new developments to address limitations with discrete Lidar, such as the use of waveform data; 3) new analytical methods and more easy-to-use software to deal with increasing data sizes, particularly with regard to Lidar and optical imagery fusion; and 4) the ability to train forest managers and scientists in Lidar data workflow and appropriate software.

1 Introduction

The SNAMP Spatial Team provided support for the other SNAMP science teams through spatial data acquisition and analysis. The objectives of the SNAMP Spatial Team were to:

1) To provide base spatial data;
2) To create quality and accurate mapped products of use to other SNAMP science teams;
3) To explore and develop novel algorithms and methods for Lidar data analysis; and
4) To contribute to science and technology outreach around mapping and Lidar analysis for SNAMP participants.

The SNAMP Spatial Team has focused on the use of Lidar – Light Detection and Ranging, an active remote sensing technology that has the ability to map forest structure. In this report we refer to the technology as "Lidar", it is although referred to elsewhere as "LIDAR" and "LiDAR".

Lidar works by "sounding" light against a target in a similar way to sonar or radar. The actual concept that makes Lidar work is quite simple. First, the system generates a short pulse of electromagnetic energy at a specific wavelength (i.e., a laser pulse) and directs it towards a target. In our case, the sensor is attached to the underside of an aircraft and the laser is directed towards the ground. The wavelengths used are typically in the visible or near infrared region of the electromagnetic spectrum, mostly because the production of such lasers is inexpensive. The laser pulse is emitted towards the earth, reflected back towards the airborne sensor where it is detected and recorded. Because the speed of light is known, the round-trip

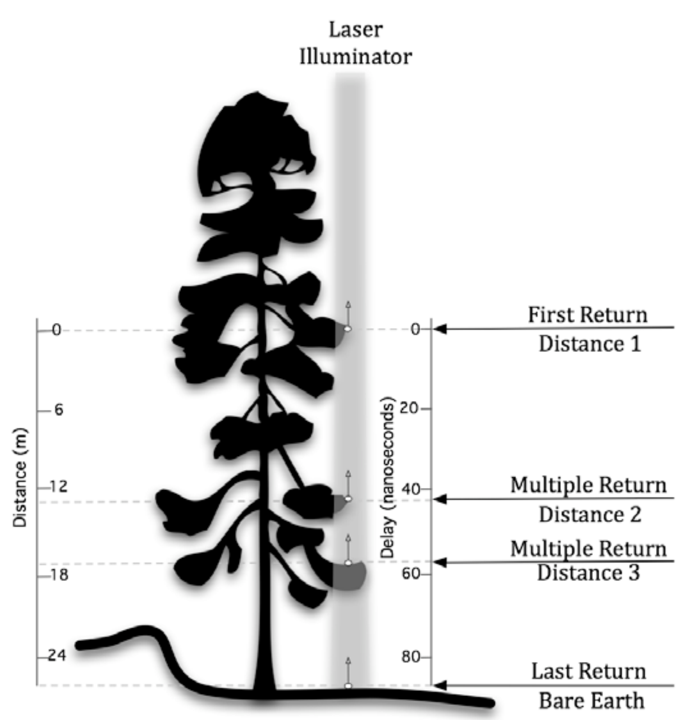

Figure B1: Discrete return Lidar System**.** Graphic modified from Lefsky et al. 2002 with tree from globalforestscience.org**.**

time for the pulse of light is converted to distance. Simultaneously, the aircraft's exact position and orientation is measured by an attached global positioning system (GPS) and inertial measurement unit (IMU). The combination of all the above measurements allows us to backtrack and calculate the three-dimensional position where the light pulse was reflected (Dubayah and Drake 2000; Lefsky et al. 2002; Roth et al. 2007; Vierling et al. 2008).

In the simplest case, light is reflected by the ground back to the airborne sensor where it is measured and converted to ground elevation. In a more complex situation, for example over a forest, the light can be reflected either by the ground, by the top of a tree, or it can be bounced around by the branches and leaves before returning to the sensor. In a more realistic situation, light can also undergo more convoluted behaviors such as scattering by the atmosphere and bouncing from a target towards a completely different direction, in which case it is never detected. The above process is repeated many times per second (the laser pulse repetition frequency) to map out the surface structure below. The collection method quickly leads to immense number of measurements over a relatively small area, and large file size is one of the challenges in processing and storing Lidar data. This predicament is compounded by the fact that there are multiple possible measurements for any sensed light pulse, as described below. Initially, laser systems were capable of simply detecting a returned pulse (or "a return"). Better understanding of the laser ranging system and improvements in technology led to more comprehensive measurements. Many commercial Lidar systems are now capable of collecting four or more returns *and* their intensities for each sent pulse – that is eight recorded values for every sensed location. Although this significantly increases the size of data and slows down its analysis, the additional information is very valuable. In a forest setting, multiple returns are fractions of the primary laser pulse reflected by the many parts of tree crown, branches, shrubs, or the understory. Their significance comes in the ability to describe forest structure as opposed to simply the average elevation of an area. The pulses intensity can also be recoded. The intensity of a pulse is related to the reflectance (i.e., albedo) of the target material – high intensity indicates a highly reflective material such as white paint or bright sand.

There are currently two common types of Lidar systems: full waveform and discrete, small footprint pulse. Thus far, we have only described a discrete pulse system. The major difference between waveform and discrete system can be attributed to their characterization of vertical structure of measurement – where a pulse system collects, four vertical points at a location, the waveform system completely describes the vertical characteristic. A discrete return system is demonstrated in Figure B1. Waveform Lidar can provide a better description of forest structure than a discrete system. However, the footprint and spatial resolution of a waveform system is typically much larger and therefore does not provide as much detail about the forest system as a discrete system. The benefits and efficacy of a discrete system outweigh currently available waveform Lidar for the purposes of the SNAMP project.

Another important aspect of discrete Lidar data is its point density, usually specified in number of points per unit of area. There are a number of aspects that influence the density of laser data. From the physical perspective, point density depends on the aircraft's altitude or above ground level (AGL). The closer the sensor is to the ground, the higher the density of the data. On the contrary, as AGL decreases, the aircraft must stay in the air for a longer time to cover the same amount of area, which significantly increases the acquisition costs. Point density also depends on the technical aspects of the sensor. Earlier systems collected data at about one pulse per square meter, although this figure varies from project to project and on average increases over time. Our data have been collected at six to twelve points per square meter. Lidar data are typically delivered as a point cloud, a collection of elevations (x, y, z coordinates) and their intensities that can be projected in a three-dimensional space. These data are used to produce a number of valuable spatial information products. Good reviews of the system, data, and analyses can be found in Gatziolis and Andersen (2008).

One of the most common uses of laser altimetry and typically the first step in analyses is to transform the data into a bare earth model, or digital elevation model. As defined by the U.S. Geological Survey, a grid Digital Elevation Model (DEM) is the digital cartographic representation of the elevation of the land at regularly spaced intervals in x and y directions, using z-values referenced to a common vertical datum (Aguilar et al. 2005; Raber et al. 2007). A DEM is essential to various applications such as terrain modeling, soil-landscape modeling and hydrological modeling (Anderson et al. 2005). Consequently, the quality of a DEM and derived terrain attributes become important in spatial modeling (Anderson et al. 2005; Thompson et al.

2001). Lidar has emerged as an important technology for the acquisition of high quality DEM due to its ability to generate 3D data with high spatial resolution and accuracy. Compared to traditional DEM derived from photogrammetric techniques such as a widely used DEM within the United States produced by the U.S. Geological Survey (USGS), Lidar-derived DEM has much higher resolution with high accuracy and precision.

Another typical step in processing Lidar data is to extract individual trees, or to derive stand-level forest characteristics (Anderson et al. 2008; Dubayah and Drake 2000; Henning and Radtke 2006; Leckie et al. 2003; Naesset 2004; Popescu and Wynne 2004; Popescu et al. 2004; Popescu and Zhao 2008; Radtke and Bolstad 2001; Zhao et al. 2009). Chen and colleagues (2006) used discrete return Lidar data to isolate individual trees with 64% absolute accuracy. The project was located near Ione, CA, in a savannah woodland mostly composed of blue oaks (Chen et al. 2006). Naesset and Bjerknes (2001) developed regression models between field and Lidar data for mean canopy height and tree density of stands in a young forest in Norway. Their tree height model was explained 83% of the variability in field mean tree height (Naesset and Bjerknes 2001). Airborne Lidar data have also been used to map course woody debris volumes in a forest (Pesonen et al. 2008), and biomass (Naesset and Gobakken 2008). Other research shows that it may be more accurate to isolate trees by combining laser altimetry with remotely sensed imagery. For instance, Leckie and colleagues were able to separate trees with 80-90% correspondence with ground truth by combining Lidar data with multispectral imagery (Leckie et al. 2003).

The vertical structure of forests is also an important driver of forest function, affecting microclimate, controlling fire spread, carbon and energy balance, and impacting the behavior of species. But there are no standard metrics of preferred data format to capture vertical structure of forests. The analysis of Lidar data holds promise for the theoretical development of functionally relevant metrics that capture the vertical structure in forests. For example, Zimble and colleagues (2003) demonstrated that Lidar data could be used to classify a forest into single-story and multistory vertical structural classes. Their landscape-scale map of forest structure was 97% accurate (Zimble et al. 2003).

The intensity of the return pulse has also been used to assist the classification of tree species in some cases. Ørka and colleagues (2007) discriminated between spruce, birch, and aspen trees using the return intensity from a multiple return Lidar system with overall classification accuracies from 68 to 74% (Ørka et al. 2007).

Where aerial photography and optical remote sensing once provided the inputs to fire models, Lidar data are increasingly being used alone or fused with remote sensing imagery to derive parameters used in fire modeling (Mutlu et al. 2008; Riano et al. 2003). For example, stand height, canopy cover, canopy bulk density, and canopy base height have been correlated with ground truth data based on height quintile estimators of the laser data (Andersen et al. 2005). The reported accuracies ranged between r^2=0.77 and r^2=0.98, with canopy height being most accurate and canopy base height the least accurate. This study is particularly interesting because its objective was to derive input parameters for the FARSITE wildfire model (Finney 1995; Finney 1998).

Full waveform Lidar systems record the entire waveform of the reflected laser pulse, not only the peaks as with the discrete multiple return Lidar. The reflected signal of each emitted pulse is sampled in fixed time intervals, typically 1 ns, equal to a sampling distance of 6 in (15 cm). This provides a quasi-continuous extremely high-resolution profile of the vegetation canopy structure, making it suitable for the analysis of vegetation density, vertical structure, fuels analysis, and wildlife habitat mapping. The downside of the waveform technology is the huge amount of data that need to be stored and processed; full waveform datasets drastically increase processing time and complexity compared with discrete data also, and there are fewer commercial software packages designed to process of full waveform data over large project areas (Kelly and Tommaso 2015).

The Spatial Team conducted several workshops and public meetings throughout the life of the project, including a series of hands-on workshops for the public and forest managers to learn about and use Lidar data. The full list of these meetings is found in Appendix B2. Lidar related newsletters that highlighted the Spatial Team’s work are found in Appendix B3.

2 Data Description

2.1 Base data

Base geospatial data were collected for each study area. Base data are listed in Appendix B4. Projection information for the northern site was NAD 83, UTM Zone 10N; for the southern site was NAD 83, UTM Zone 11N. The vertical datum for data with a z-dimension we used NAVD 1988 in meters.

2.2 Lidar – Light Detection and Ranging

Lidar data were used to quantify forest structure and topography at high spatial resolution and precision. Lidar was collected pre-treatment and post-treatment for our two study areas: Sugar Pine and Last Chance. We contracted with the National Center for Airborne Lidar Mapping (NCALM) for our data. They collected the data using the Optech GEMINI instrument at approximately 600-800 m above ground level, with 67% swath overlap. The sensor was operated at 100-125 kHz laser pulse repetition frequency with a scanning frequency of 40–60 Hz and a scan angle of 12–14° on either side of nadir. The instrument collected up to 4 discrete returns per pulse, with intensity readings of 12-bit dynamic range per measurement, at 1047nm. The delivered data had an average density of 10 points per m^2 and ranged from 6-12 pt/m^2. Data were collected for Sugar Pine (117km^2) in September 2007 (pre-treatment), and Nov 2012 (post-treatment); and for Last Chance (107km^2) on September 2008 (pre-treatment) and November 2012 and August 2013 (post-treatment). Over 800 ground check points, positioned by ground GPS, were set to calibrate and assess the vertical and horizontal accuracy of the lidar flights. The obtained horizontal accuracy was around 10 cm and the vertical accuracy was from 5 to 35 cm.

2.3 Field data

2.3.1 GPS protocol

Ground control for airborne Lidar data is critical to correctly map individual trees, and to scale up forest parameters to stands. The Lidar ground protocol was developed based on the FFEH field protocol which established a 12.6m radius area from the plot center ("the plot") in which all trees above DBH=15cm were tagged, identified and measured and within which linear transects were developed to collect fuel information. The ideal position for the GPS was at the plot center with a large opening in the canopy above it. When the canopy was closed, thick, or very tall, we moved the GPS away from the plot center by no more than 30 meters. We collected at least 300 GPS measurements at PDOP ≤ 5. The GPS record often contained about 1,000 and up to 7,000 measurements collected at 1-second intervals for each plot. We used a Trimble GeoXH differential GPS with a Trimble Zephyr Antenna on top of a 3-meter GPS antenna pole to minimize multipath problems. The positioning accuracy was within 10 cm. In the northern study area, we used Continuously Operating Reference Stations (CORS) and University NAVSTAR Consortium (UNAVCO) stations less than 20 km away from all field measurements for differential GPS post-processing. In the southern area, all publicly available CORS and UNAVCO data were used in addition to our own base station. The DGPS base station was established 12.8 km away from the farthest field measurement. Once the center point was marked, we recorded the bearing and distance from directly below the antenna to the plot center in degrees. A compass was used to measure the bearing (according to true north), and the horizontal distance is measured using a Vertex hypsometer.

For every plot, we established a laser position near the plot boundary. The laser position was chosen such that all critical locations, and all or most tree trunks within the plot are visible from it. Critical locations include the GPS, the plot center, and any additional measurements, such as hemispherical photograph. Originally, we established two laser positions at approximately 90 degrees to each other, to increase the positional precision of each target. However, our analysis throughout the field season indicated that two laser angles do not sufficiently improve the positional accuracy of the tree locations to justify their collection at each plot. Further analysis required measurements taken from a single laser location, unless the tree density is so high that tree occlusion became problematic. Once the laser and GPS positions were established, we calibrated the laser equipment. Most importantly, we leveled the laser with the help of an electronic sensor, and calibrated the electronic compass using an established routine. We used a reflector and collected laser distances with the "filter" rangefinder setting to minimize measurement error. Typical errors of the rangefinder and the electronic compass are 0.02 m and 0.5 degrees, respectively. The field protocol is illustrated in Figure B2.

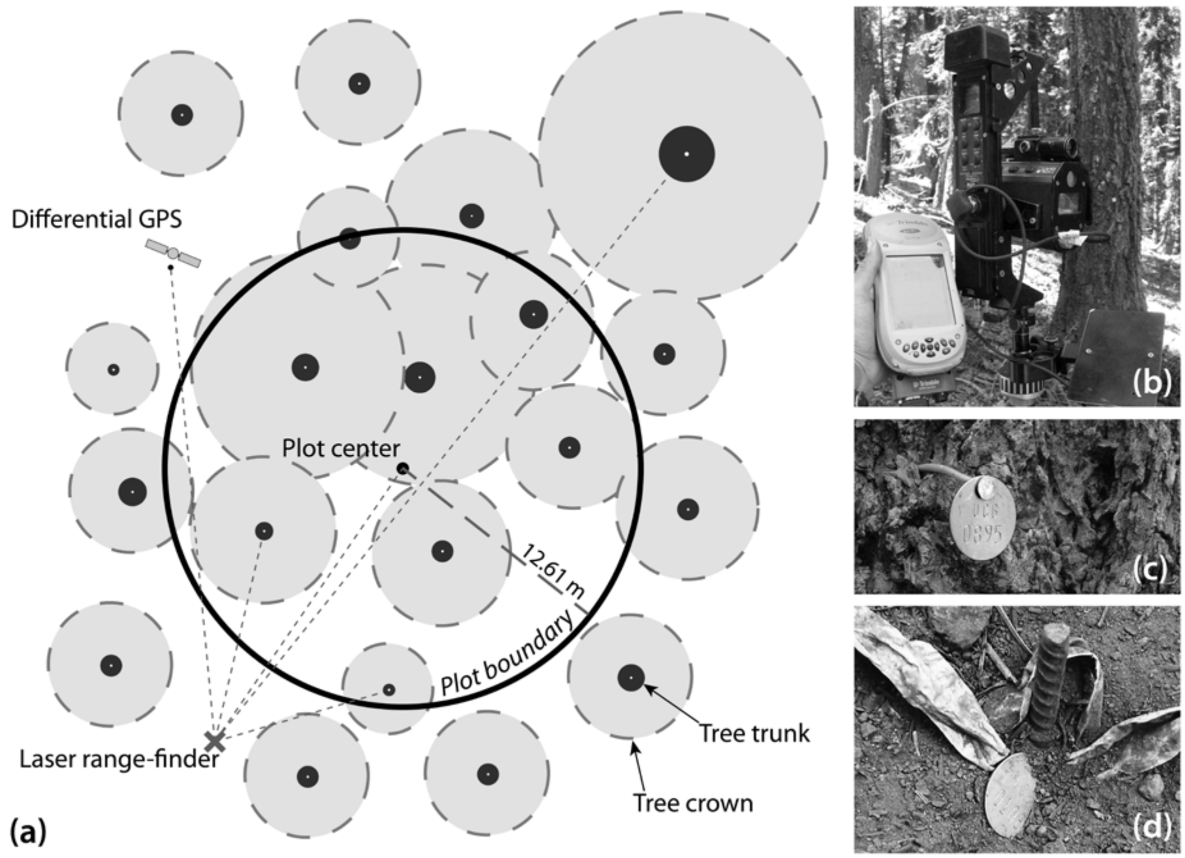

Figure B2: Diagram of field method: a) plot, b) equipment used to collect positions of trees, c) individual tree marker, and d) plot center mark.

2.3.2 Stand map data collection

The laser rangefinder was connected to the electronic compass, which was connected to ArcPad on a Trimble GeoExplorer. We used ArcPad to generate a stand map shapefile; the shapefile included all tagged trees, the plot center, GPS position, hemispherical photo position, and any additional measurements. We took at least three measurements of the critical locations (described above) to minimize positional error. The unique tree ID (previously established by the FFEH team) was recorded for each tree measurement. In case of the marker trees, we measured and recorded the tree species, height, and DBH.

2.3.3 Plot photos

We took plot photographs to have a general idea of the terrain after the field season. They were also used as an indicator of the site fuel model for fire simulation input (the most important variable). Five photographs were taken from north, east, south, and west towards the plot center, as well as one photograph from the plot center directly up toward the sky.

3 Methods

3.1 Standard Lidar products: DTM, DSM, CHM

The main protocol for deriving terrain and forest variables from airborne LIDAR data is to separate the ground returns from the vegetation returns. This process involves first extracting the digital surface model (DSM) from the *first* return data and then extract the digital terrain model (DTM) or elevation model from the *last* return data. The canopy height model (CHM) is calculated as CHM = DSM – DTM, and can be used with field data to map some forest attributes over space (e.g., canopy height, canopy cover, etc.). The accuracy of the Lidar product was verified with field plot data. Other forest variables make use of the multiple returns, and calculate metrics based on the density of returns at specific heights from the ground. Determination of canopy base height and canopy bulk density for example require analysis of the vertical structure of multiple returns.

These products are made from "first return" data (Figure B1). The method involved classifying the highest reflections, and interpolating the missing points to create a smoothed surface. This is often expressed as a raster grid of a chosen cell size (e.g., 1m resolution). The canopy height model is the difference between the DSM and the DTM, and can be used to map tree height, canopy cover, and individual trees over space. Other forest attributes require more processing of the multiple return data.

3.2 Topographic products

3.2.1 Digital Terrain or Elevation Model

The Lidar derived DEM product is made from "last return" data (Figure B1). The method involves filtering out the false ground, and interpolating to a continuous surface of a chosen cell size. Interpolation methods can vary, and might include Kriging, nearest neighbor, inverse distance weighted, and Spline. We created a DTM at 1-m grid from which slope and aspect grids were created. We systematically evaluated the impact of slope variation and Lidar density on different interpolation methods (Figure B3). Our result indicated that the Kriging-based methods consistently outperformed the other interpolation methods in all different elevation conditions in the Sugar Pine study area (Guo et al. 2010). We produced Digital Elevation Models (DEM) at 1m, slope and aspect at 1m, and all topographic products were also resampled as needed at user-defined scales (e.g., up to 30m).

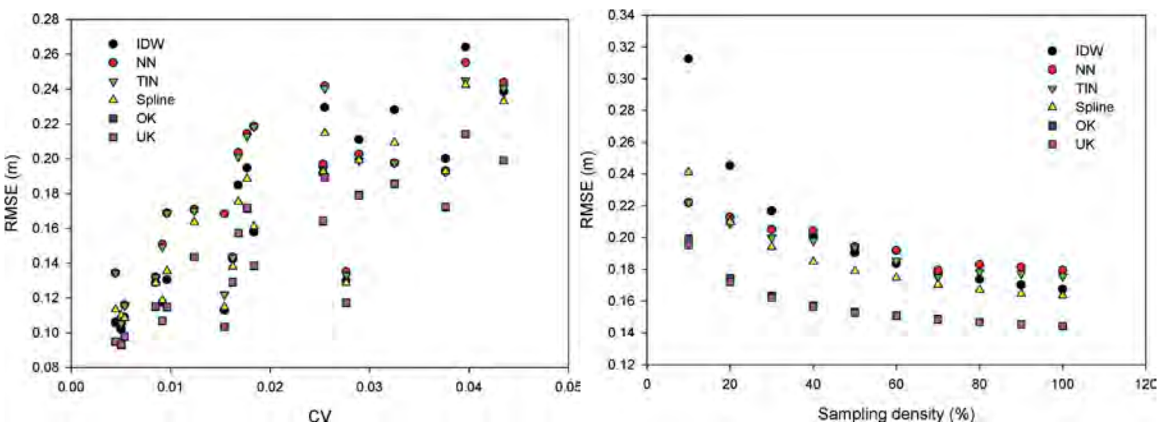

Figure B3: Influence of slope variation (denoted by the elevation CV (coefficient of variation)) (left) and sampling density on the accuracy of DTMs (denoted by the RMSE (root mean squared error)) at 1 m resolution. IDW, NN, TIN, Spline, OK, and UK represent inverse distance weighted, natural neighbor, triangulated irregular network, spline, ordinary kriging, and universal kriging interpolation schemes, respectively.

3.3 Individual trees

A challenge of Lidar is to convert the raw data, which are just a collection or cloud of points (indicating x, y location and height above the ground), into meaningful information about individual trees. Information about individual trees is useful for wildlife studies, carbon estimates, and forest planning, for example. Most methods to delineate individual trees from Lidar data do not use the raw data – rather they use a transformed version of the data. We used the raw Lidar data cloud, and thus were able to work with more detailed data. Our method started with the highest point in an area, and grows individual trees by adding points within a certain distance of the original point. It worked iteratively from top to bottom and isolates trees individually and sequentially from the tallest to the shortest. We compared our results to field data across dense and sparse forests (Li et al. 2012). The location of, and other attributes of these delineated trees were used in subsequent work. For example, we characterized individual trees in a range of metrics used to model fisher denning habitat (Table B1) (Zhao et al. 2012b). We further evaluated our method in comparison with other standard methods in (Jakubowski et al. 2013a).

3.4 Lidar metrics

The raw Lidar data were processed by NCALM using TerraSolid's TerraScan software (Soininen 2004) to remove obvious outlier points, including isolated point removal (points with no neighbors within 5 meters) and "air point" removal, where points clearly above the canopy when compared to their neighbors. The point cloud was then classified to ground and aboveground points using an iterative triangulated surface model. The two point classes were separated into individual files to simplify processing that requires only ground points (digital elevation model generation) and above-ground points (vegetation analysis). A digital elevation model (DEM) was processed at 1m resolution using Inverse Distance Weighted interpolation based on suggestions from past investigations (Guo et al. 2010). We subtracted the DEM elevation from the elevation of individual aboveground points, making them relative to ground-elevation.

We developed a set of MATLAB functions to extract Lidar metrics in a raster format at a user-defined spatial resolution. The Lidar metrics (listed in Table B1) include descriptive metrics (e.g., maximum height, or number of points from 0.5 to 1 m) and statistically based metrics (e.g., 0.05 percentile and standard deviation). All metrics were calculated with respect to ground level. For example, maximum height describes the distance between the highest recorded Lidar point within a moving window cell and the ground elevation as defined by the DEM. Similarly, number of points from 0.5 to 1 m is the total number of Lidar returns within a raster cell recorded between 0.5 m and 1.0 m above the DEM elevation.

The MATLAB functions processed all data at variable resolutions. For example, we processed the data using 20 m cell size because it matches our ground truth data and in order to produce results meaningful for forest fire management (20m is a common resolution for wildfire behavior models). For the spotted owl and Pacific fisher studies the data may be processed at lower resolution, while the hydrologic analysis may require much finer sampling. Each plot can automatically be processed separately since the actual physical distance between reference ground plots in the field is inconsistent. This is done to avoid cell mis-registration among plots.

In other words, each individual plot raster is generated based on the position of its plot center in such a way that the central pixel precisely overlaps the plot center.

In addition, we appended topographical information based on the DEM derived from the Lidar data. All topographical measures (listed in Table B1) were derived from the DEM using ITT's ENVI 4.5 Topographical Modeling feature (ITT Visual Information Solutions 2009). The plot rasters described above and the topographical information were combined into a raster dataset (Lidar data cube, or the LDC) with a set of bands similar to a hyperspectral image cube, where each band describes different Lidar data or topography metrics. The LDC is saved in the Tagged Image File Format (TIFF) raster format to increase compatibility with external analysis software. An ENVI header file is generated to preserve metadata and description of each metric. All metrics are listed in Table B1.

Table B1: Example of all metrics extracted from Lidar data, used to create forest structure and other products with regression.

Topographic variables 1m, 10, 20m	Elevation Slope Aspect
Topographic variables 1m	Profile convexity Planar convexity Longitudinal convexity Cross-sectional convexity Minimum curvature Maximum curvature
Height metrics	Height: minimum Height: mean Height: maximum Height: standard deviation Skewness of heights Kurtosis of heights Coefficient of heights Quadradic mean of heights Lorey's height (modeled variable)
Percentile metrics	Percentile 0.01 Percentile 0.05 Percentile 0.10 Percentile 0.25 Percentile 0.50 Percentile 0.75 Percentile 0.90 Percentile 0.95 Percentile 0.99 Minimum Maximum Mean

	Standard deviation Coefficient of variation
Pulse density metrics	Total number of returns Point density 0 to .5 m Point density .5 to 1 m Point density 1 to 1.5 m Point density 1.5 to 2 m Point density 2 to 3 m Point density 3 to 4 m Point density 4 to 5 m Point density 5 to 10 m Point density 10 to 15 m Point density 15 to 20 m Point density 20 to 25 m Point density 25 to 30 m Point density 30 to 35 m Point density 35 to 40 m Point density 40 to 45 m Point density 45 to 50 m Point density 50 to 55 m Point density 55 to 60 m
Individual tree metrics	Maximum height Mean of heights Standard deviation of heights Skewness of heights Kurtosis of heights Coefficient of heights Mean of canopy radius Standard deviation of canopy radius Skewness of canopy radius Kurtosis of canopy radius Number of trees

3.5 Forest structure products

We produced the following products for the two study area: Mean height, Max height, Diameter at Breast Height (DBH), Height to Live Canopy Base (HTLCB), Canopy Cover, Leaf Area Index (LAI), and map of individual trees. These products were created with ground truth plot level analysis that is about 20 m wide. Therefore, the resolution for these grid products is also 20 m.

3.5.1 Vegetation products

Mean Height, Max Height, Height to Live Canopy Base and Diameter at Breast Height (DBH) products are created using a regression-based approach. This approach starts by first extracting a subset of Lidar points in the same location as each plot, matching the plot radius

(12.62 m). The Lidar points were normalized by subtracting the ground points (DEM) from the extracted Lidar points. A height profile is created on the normalized points using the following groups: z values for minimum, percentiles (1st, 5th, 10th, 25th, 50th, 75th, 90th, 95th, 99th), maximum, mean, standard deviations and the coefficient of variation.

The Lidar-based predictors (height profile) are fitted against the field measurements by stepwise regression modeling (Andersen et al., 2005). The best models are then applied to the entire study area. This is done by iterating through each pixel of the product grid, extracting Lidar points that fall within that pixel and calculating the pixel value using the relation found in the previously mentioned analysis.

3.5.2 Canopy cover

Canopy Cover (CC) is determined by analyzing the canopy height model (CHM). CHMs typically have a resolution of 1 m, and the canopy covers have a resolution of 20 m. Each pixel in the canopy cover grid is iterated and CHM pixel values that fall within the canopy cover pixel are extracted. The value of the canopy cover pixel is calculated as the ratio of CHM pixels that have a value above a threshold to the total number of extracted pixels from the CHM (Lucas et al. 2006). The height threshold of 1.5 m is used to differentiate between trees and shrubs.

3.5.3 Leaf area index

The leaf area index (LAI) product is created using the Lidar vegetation points, normalized by the DEM. Each pixel in the LAI grid is iterated and Lidar points that fall within the pixel are extracted. An average scan angle is calculated using the extracted Lidar points and the following equation:

$$ang = \frac{\sum_{i=1}^{n} angle_i}{n}$$

where ang is the average scan angle, n is the number of extracted points and $angle_i$ is the scan angle for a single extracted point i. Next the gap fraction (GF) is calculated using the following equation:

$$GF = \frac{n_{ground}}{n}$$

where n_{ground} is the number of extracted points that have a z value smaller than 1.5 m (equivalent to the height of a hemispherical camera) and n is the total number of extracted points. Finally, the LAI value is calculated using the following equation:

$$LAI = -\frac{\cos(ang) \times \ln(GF)}{k}$$

where LAI is the extinction coefficient and ln is the natural logarithm (Richardson et al. 2009). The value 0.5 is used for the extinction coefficient k, as suggested in the literature (Richardson et al. 2009).

3.6 Fire behavior modeling inputs

Forest fire behavior models need a variety of spatial data layers in order to accurately predict forest fire behavior, including elevation, slope, aspect, canopy height, canopy cover, crown base height, crown bulk density, as well as a layer describing the types of fuel found in the forest (called the "fuel model"). These spatial data layers are not often developed using Lidar data for this purpose (fire ecologists typically use field-sampled data), and so we explored the use of Lidar data to describe each of the forest-related variables (Jakubowski et al. 2013b). We conducted a comprehensive examination of forest fuel models and forest fuel metrics derived from Lidar and color infrared (CIR) imagery (CIR is often used for mapping vegetation since plants reflect infrared light well) for use in fire behavior modeling. Specifically, we used high-density, discrete return airborne Lidar data and National Agriculture Imagery Program (NAIP) 1-meter resolution imagery to find the optimal combination of data input (Lidar, imagery, and their various combinations/transforms), and method (we used three types of methods: clustering, regression trees, or machine learning algorithms) in order to extract surface fuel models and canopy metrics from Sierra Nevada mixed conifer forests. All Lidar-derived metrics were evaluated by comparing them to field data and deriving correlation coefficients.

3.7 Tradeoffs in Lidar density

Collection of Lidar (light detection and ranging) data can be costly, and costs depend on the density of the resulting data (pulses or "hits" per m^2). The density of our Lidar product is shown in Figure B4, where we have progressively thinned the data from 10 pulses/m^2 to 0.02 pulses/m^2. Most Lidar acquisitions capture the highest possible density of data (up to 12 pulses/m^2); but it is not known if that level of detail is always required. The benefit of collecting less dense data might be that data would be able to be captured over a larger area for the same cost. We investigated the ability of different densities of Lidar data to predict forest metrics at the plot scale (e.g., 1/5-hectare or ½-acre).

We examined ten canopy metrics (maximum and mean tree height, total basal area, tree density, mean height to live crown base (HTLCB), canopy cover, maximum and mean diameter at breast height (DBH), and shrub cover and height) based on varying pulse density of Lidar data – from low density (0.01pulses/m^2) to high density (10 pulses/m^2). We tested the agreement between each metric and field data across the range of Lidar densities to see when and if accuracy dropped.

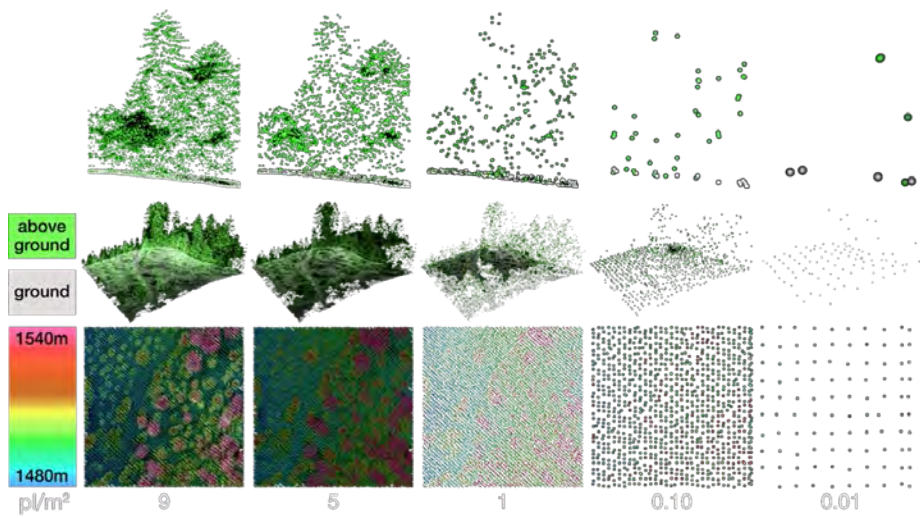

Figure B4: Figure showing progressively less dense Lidar point cloud from left to right.

3.8 Vegetation maps

Accurate and up-to-date vegetation maps are critical for managers and scientists, because they serve a range of functions in natural resource management (e.g., forest inventory, forest treatment, wildfire risk control, and wildlife protection), as well as ecological and hydrological modeling, and climate change studies. Traditional methods for vegetation mapping are usually based on field surveys, literature reviews, aerial photography interpretation, and collateral and ancillary data analysis (Pedrotti 2012). However, these methods can be very expensive and time-consuming, and usually the vegetation maps obtained from these traditional methods are time sensitive. Remote sensing has proved to be very powerful in vegetation mapping by employing image classification techniques. Multispectral remote sensing imagery such as Landsat, SPOT, MODIS, AVHRR, IKONOS, and QuickBird are among of the most commonly used. However, most studies using both multispectral and hyperspectral imagery usually only focus on either mapping the land cover type or mapping the vegetation composition. Examining the vertical structure in forests has rarely been considered because the limited penetration capability for multispectral and hyperspectral data. We developed a new strategy to map vegetation communities in the SNAMP study areas by considering both the tree species composition and vegetation vertical structure characteristics. We developed a novel unsupervised classification scheme using an automatic cluster determination algorithm based on Bayesian Information Criterion (BIC) and k-means classification which was applied to the Lidar and imagery data (NAIP imagery) to map the vegetation community, and the post-hoc analysis based on field measurements was used to define the property for each vegetation group.

3.9 Forest fuel treatment detection

The planned forest fuel treatment boundaries are often geographically distinct from the planned extents due to the operational constraints and protection of resources (e.g., perennial streams, cultural resources, wildlife habitat, etc.). Knowing the actual (as opposed to planned) extent of forest fuel treatments is critical for understanding how they affect wildfire risk, wildlife and forest health. Traditionally, the method for reporting complete forest fuel treatment extent is highly dependent on field observations, which is very labor-intensive and expensive. Moreover, since forest fuel treatments typically focus on reducing ladder and surface fuels and decreasing small tree density, aerial imagery with limited penetration capability through forest canopy can be hardly used to identify their extent. In this study, we examined the capability of multi-temporal Lidar data on forest fuel treatment detection. Our approach involved the combination of a pixel-wise thresholding method and an object-of-interest (OBI) segmentation method. Firstly, the differences between the pre- and post-treatment Lidar derived canopy cover were used to represent the change information. We assumed that this change information should be normally distributed, and the variation within the 95% confidence should be recognized as the background information. Thus, μ +/- 1.96σ was used as the threshold to differentiate the treated and untreated pixels, where μ and σ are the mean and standard deviation of the change image, respectively. Finally, to further remove noise, the OBIA segmentation method was used to filter the pixel-wise result considering the fact that forest fuel treatments were usually conducted in spatially continuous areas (Zhang et al. 2013).

4 Results

4.1 Standard Lidar products: DTM, DSM, CHM

Slope based filtering method is an efficient method to discriminant ground returns from Lidar point cloud in areas with flat terrain. Its accuracy linearly decreases with the rise of slope. While vegetation density has a great influence on other filtering algorithms, such as interpolation-based filtering algorithm and morphological filtering algorithm. Fine resolution DTM and DSM products can be interpolated from the obtained ground returns and first returns of the Lidar point cloud. Results show that the accuracy of the interpolated DTM and DSM products increases with the sampling density. Finally, the CHM product can be directly calculated from the difference between the DTM and DSM (Figure B5). The accuracy of these products is reported in Table B2.

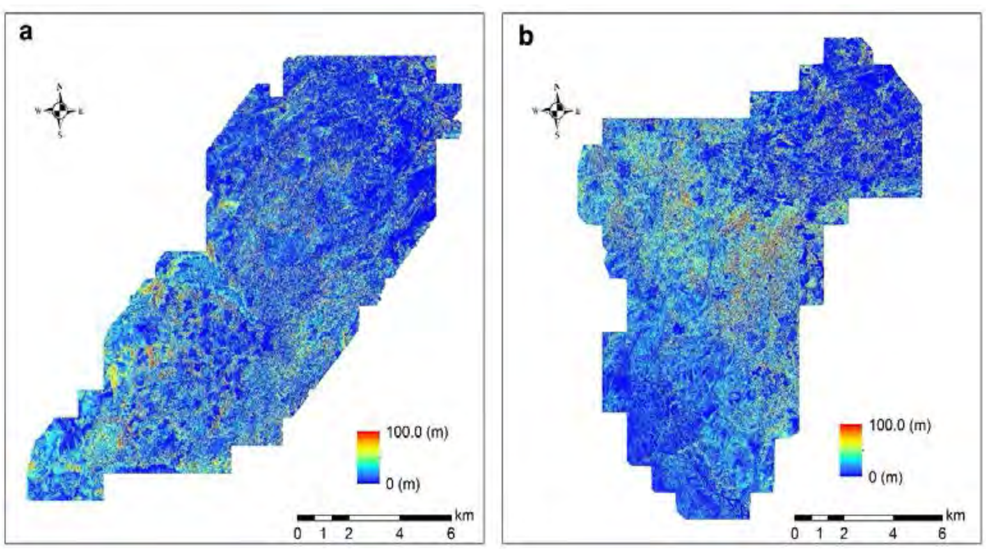

Figure B5: Lidar-derived canopy height model (CHM): a) Last Chance study area, b) Sugar Pine study area.

4.2 Topographic products

We created detailed Digital Elevation Model (DEM) products or both study sites (Figure B6). In our investigation of different interpolation methods, our results show that simple interpolation methods, such as IDW, NN, and TIN, are more efficient algorithms, and generate DEMs from Lidar data faster than the more complex algorithms, but kriging-based methods, such as OK and UK, produce more accurate DEMs. We also show that topography matters: in areas with higher topographic variability, the DEM has higher uncertainties and errors no matter what interpolation method and resolution are used. DEM error increases as Lidar sampling density decreases, especially at smaller cell sizes. Finally, spatial resolution also plays an important role when generating DEMs from Lidar data: at larger cell sizes, the choice of interpolation methods becomes increasingly important, as some of the methods (for example: spline), produce high error at larger cell sizes (Guo et al. 2010) (Table B2).

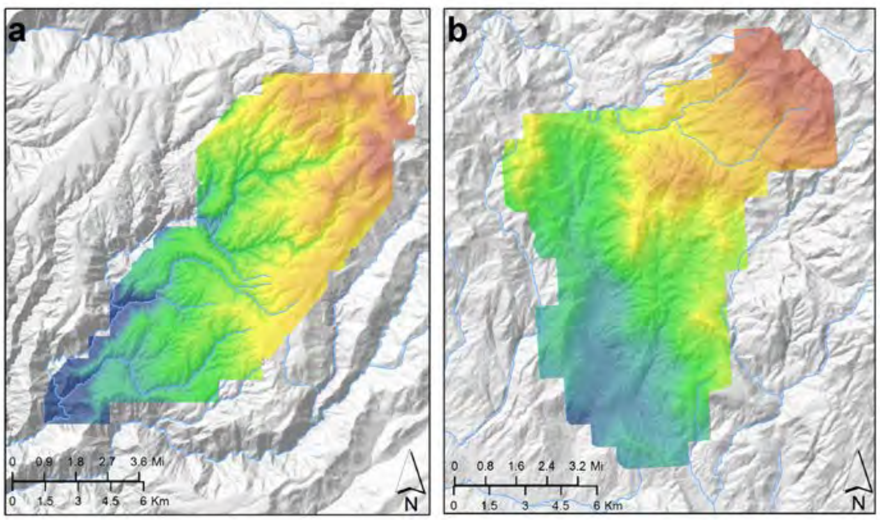

Figure B6: Lidar-derived Digital Elevation Model (DEM): a) Last Chance study area, b) Sugar Pine study area.

4.3 Individual trees

We compared the number of existing trees (from field surveys) and the number of Lidar-derived trees within 30 plots. In general, our method underestimated the number of trees. There were 380 trees in total in our 30 test plots, but only 347 trees were segmented. The algorithm missed 53 trees, and falsely detected 20 trees. Overall, the accuracy was about 90% (Table B2). The method performed well at mapping individual trees from the lidar point cloud in complex mixed conifer forests on rugged terrain. The accuracy is relatively high, indicating that the new algorithm has good potential for use in other forested areas, and across broader areas than is possible with fieldwork alone.

4.4 Lidar metrics

We created a suite of Lidar metrics that were used in the creation of a range of maps and products through various regression approaches. The accuracy of these products is summarized below in Table B2.

4.5 Forest structure products

Mean height, max height, DBH, HTLCB, canopy cover, and LAI products were made for both sites. The product showing canopy cover for both sites is in Figure B7.

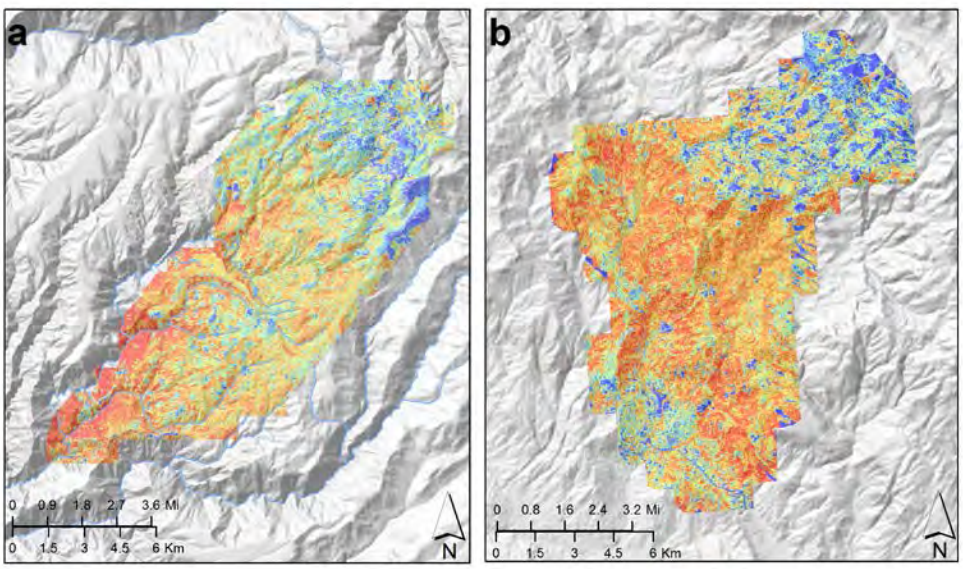

Figure B7: Lidar-derived canopy cover: a) Last Chance study area, b) Sugar Pine study area.

4.6 Fire behavior modeling inputs

Specific surface forest “fuel models” (these are detailed descriptions like “dwarf conifer with understory” or “low load compact conifer litter”) proved difficult to predict in this dense forest environment, although general fuel types (such as predominantly shrub, or mostly timber) were estimated with reasonable (up to 76% correct) accuracy because fewer of the light energy from the Lidar penetrated to the forest floor in denser forests, making accurate characterization of understory shrubs more difficult. The predictive power of canopy metrics increases as we describe metrics higher up in the canopy. The accuracy—in terms of Pearson’s correlation coefficient—ranged from 0.87 for estimating canopy height, through 0.62 for shrub cover, to 0.25 for canopy base height.

4.7 Tradeoffs in Lidar density

The accuracy of the Lidar predictions for all ten metrics increased as the Lidar density increased from 0.01 pulses/m^2 to 1 pulse/m^2. However, the accuracy of many of the metrics showed very little improvement after that. Metrics that described forest cover (e.g., forest canopy and shrub cover) required higher densities of Lidar data to be mapped accurately. In general, the results confirm findings from previous studies: the overall accuracy of a predicted forest structure metric decreased roughly with its vertical position within the canopy: metrics that estimate the tops of forests are more accurately mapped with Lidar than those in the middle of the canopy or on the forest floor and so require less dense data for most applications (Jakubowski et al. 2013c).

Many plot-scale forest canopy measures (e.g., maximum and mean tree height, total basal area, maximum and mean diameter at breast height (DBH)) are well predicted with moderate density Lidar data: 1 pulse/m^2. More detailed features, such as individual trees, would likely require high-density Lidar data. Coverage metrics (canopy cover, tree density, and shrub cover) were more sensitive to pulse density.

4.8 Vegetation maps

The vegetation map created for each site shows complex and unique vegetation structure characteristics and vegetation species composition. The overall accuracy and kappa coefficient of the vegetation mapping results are over 78% and 0.64 for both study sites. The vegetation map product, and in particular the boundaries of forest stands created was used by the FFEH Team in their fire behavior modeling work.

4.9 Forest fuel treatment extent

The forest fuel treatment detection result is well in agreement with the proposed forest treatment operation extent. By assessing with the field observations, the result also shows a satisfactory accuracy. The overall accuracy is 93.5% and the kappa coefficient is 0.70. Although there are some detected treated areas are not within the proposed forest treatment operation extents, most of them may have been treated based on field observations and direct Lidar point cloud comparison. Figure B8 shows a direct comparison between the pre-treatment and post-treatment Lidar point cloud. Moreover, the same forest treatment detection routine was also applied on airborne imagery. Results show that Lidar derived canopy cover outperformed the aerial image and is more robust to detect light forest treatment areas. Accuracy of all products is listed in Table B2.

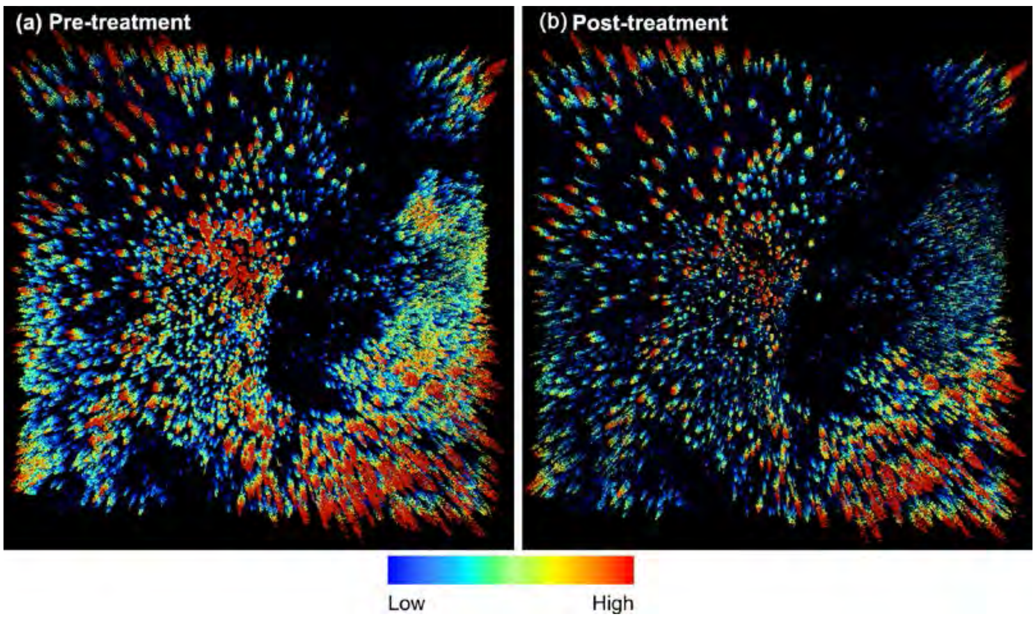

Figure B8: An example of direct point cloud comparison in an area with forest fuel treatments.

Table B2: Accuracy results for most of the products created by the SNAMP Spatial Team.

Product	*Type/Method*	*Accuracy*[a]	*SNAMP Publication*
	Standard Lidar products		
DTM[b]	Derived from Lidar point cloud	20-30 cm	NCALM report
DSM[b]	Derived from Lidar point cloud	20-30cm	NCALM report
CHM[b]	Direct: from DTM + DEM	20-30 cm	NCALM report
	Topographic products		
DEM[b]	Direct, from DTM	20-30 cm	#4
	Individual trees		
Individual trees	Derived from Lidar point cloud	90%	#6
Individual trees	Derived from Lidar + imagery	0.91 - 0.95	#24
	Forest structure products (20m)		
Mean height	Indirect: from regression	0.67	
Max height	Indirect: from regression	0.78	
DBH	Indirect: from regression	0.61	
HTLCB	Indirect: from regression	0.62	
Canopy Cover	Indirect: from regression	0.62	
LAI	Direct	Not measured	
	Fire behavior modeling inputs (20m)		
Canopy height (max)	Indirect: from regression	0.87	#13
Canopy cover	Indirect: from regression	0.83	#13
Total basal area	Indirect: from regression	0.82	#13
Shrub cover	Indirect: from regression	0.62	#13
Canopy height (mean)	Indirect: from regression	0.60	#13
Shrub height	Indirect: from regression	0.59	#13
Canopy base height	Indirect: from regression	0.41	#13
Canopy bulk density	Indirect: from regression	0.25	#13
Combined fuel loads	Indirect: from regression	0.48	#13
Fuel bed depth	Indirect: from regression	0.35	#13
	Vegetation map		
Vegetation map	Derived from Lidar + imagery	78%	Publication to be submitted

[a] Accuracy is listed as best r^2, unless otherwise noted.

[b] The accuracy of DTM, DSM, CHM, and DEM were evaluated by the ground measured GPS transects data provided by NCLAM. All other vegetation-related products were evaluated by in-situ measurements.

5 Discussion

Mapping has always been critical for forest inventory, fire management planning, and conservation planning. Understanding the structure of forests – tree density, volume and height characteristics - is critical for management, fire prediction, biomass estimation, and wildlife assessment. In California, these tasks are particularly challenging, as our forests exhibit tremendous variability in composition, volume, quality, and topography. Optical remote sensors such as Landsat, despite their synoptic and timely views, do not provide sufficiently detailed depictions of forest structure for all forest management needs. We anticipate that Lidar will continue to play an increasingly important role for forest managers interested in mapping forests at fine detail. We discuss our broader findings in the following five areas.

5.1 Lidar maps and products

Lidar data can produce a range of mapped product that in many cases more accurately map forest height, structure and species than optical imagery alone. Mapped products include topographic maps, locations of individual trees, forest height, canopy cover, shrub cover, fuels, and detailed species, among other variables. Accuracies in these products ranged greatly; generally the closer to the ground the lower the accuracy, especially in dense canopy. Many of these mapped products can be produced at a range of spatial resolutions, from 1m to 20m and larger. The 20m resolution adequately matches the approximate resolution of a 12.54m radius plot.

However, Lidar data can be large in size, and there are few commonly used and easy-to-use software packages to produce the products. Our work required a range of tools, most of them requiring specialized coding in python, Matlab and other languages and software packages.

Moreover, although Lidar data can be used to generate maps that depict accurate forest structure, the lack of spectral reflectance data makes the production of vegetation maps with Lidar data alone difficult. The recorded intensity information of the Lidar data cannot be used to reflect the forest surface reflectance characteristics due to the influence of the multi-path effect. Our work indicated that the combination of high resolution multi-spectral aerial/satellite imagery and lidar data is very helpful in mapping vegetation communities as well as characterizing forest structure zones.

5.2 Wildlife

Lidar is an effective tool for mapping important potential forest habitat variables – such as individual trees, tree sizes, and canopy cover - for sensitive species (Temple et al., 2015). We believe that Lidar can help forest managers and scientists in the assessment of wildlife–habitat relationships and conservation of important wildlife species by allowing managers to better identify habitat characteristics on a large scale. More work can be done to link Lidar products with CWHR habitat classes. More work needs to be done to define a particular set of habitat characteristics that can be measured or estimated by lidar, e.g., particular height, density, overstory/understory, and biomass criteria.

5.3 Forest management

The accurate identification and quantification of individual trees from discrete Lidar pulses typically requires high-density data. Standard plot-level metrics such as tree height, canopy cover, and some fuel measures can reliably be derived from less dense Lidar data. However, standard Lidar products do not yet operationally meet the requirements of forest managers who need detailed measures of forest structure that include understanding of forest heterogeneity, and understanding of forest change. Additionally, typical forest management metrics such as leaf area index (LAI), quadratic mean diameter (QMD), trees per acre (TPA) are not commonly created, nor easily validated using Lidar data.

Our work on Lidar density might help managers evaluate tradeoffs between Lidar density, cost and coverage: if a manager needs plot-scale forest measurements (i.e., measurements summarized at scale around ½-acre or 1/5-hectare), they might be able to cover a larger area with lower density Lidar data for the same cost as high density Lidar data over a smaller area.

Forest fuel treatments are among the main forest management activities used to reduce the wildfire risks. However, planned forest fuel treatment boundaries are often geographically distinct from the planned extents due to the operational constraints and protection of resources (e.g., perennial streams, cultural resources, wildlife habitat, etc.). Lidar derived multi-temporal canopy cover products are highly sensitive the forest changes brought by the forest fuel treatment, and therefore can be used to accurately map the fuel treatment extent.

5.4 Fire behavior modeling

While there is great promise for the use of Lidar in fire behavior models, there is more work necessary before Lidar data can be operationally included into common fire behavior models. Discrete return Lidar cannot accurately capture all forest structural features near the ground when the canopy is very dense.

5.5 Biomass

Our work suggests that airborne Lidar data provide the most accurate estimates of forest biomass, but rigorous procedures should be taken in selecting appropriate allometric equations to use as reference biomass estimates. We also showed that Lidar data when fused with course scale, fine temporal resolution imagery such as MODIS, can be used to estimate regional scale above ground forest biomass.

6 Resource-specific management implications and recommendations

Our work using Lidar and other remote sensing products contributes to the current discussion around the use of mapping for forest management. We discuss several management implications here.

6.1 Lidar maps and products

6.1.1 Management implications

- Lidar data can produce a range of mapped product that in many cases more accurately map forest height, structure and species than optical imagery alone.
- Lidar software packages are not yet as easy to use as the typical desktop GIS software.
- There are known limitations with the use of discrete Lidar for forest mapping - in particular, smaller trees and understory are difficult to map reliably.
- The fusion of hyperspectral imagery with Lidar data may be very useful to create detailed and accurate forest species maps.

6.2 Wildlife

6.2.1 Management implications

- Lidar is an effective tool for mapping important forest habitat variables – such as individual trees, tree sizes, and canopy cover - for sensitive species.
- Lidar will increasingly be used by wildlife managers, but there remain numerous technical and software barriers to widespread adoption. Efforts are still needed to link Lidar data, metrics and products to measures more commonly used by managers such as CWHR habitat classes.

6.3 Fire behavior modeling

6.3.1 Management implications

- Lidar data are not yet operationally included into common fire behavior models, and more work should be done to understand error and uncertainty produced by Lidar analysis.

6.4 Forest management

6.4.1 Management implications

- There is a trade-off between detail, coverage and cost with Lidar. The accurate identification and quantification of individual trees from discrete Lidar pulses typically requires high-density data. Standard plot-level metrics such as tree height, canopy cover, and some fuel measures can reliably be derived from less dense Lidar data.
- Standard Lidar products do not yet operationally meet the requirements of forest managers who need detailed measures of forest structure that include understanding of forest heterogeneity, and understanding of forest change. More work is needed to translate between the remote sensing community and the forest management community to ensure that Lidar products are useful to and used by forest managers.
- Discrete Lidar can be used to map the extent of forest fuel treatments. However, the method of treatment (e.g., mastication, thinned, cable thinned) cannot be detected using discrete Lidar data due to its limitation of understory forest.

The future of Lidar for forest applications will depend on a number of considerations. These include: 1) costs, which have been declining; 2) new developments to address limitations with discrete Lidar, such as the use of waveform data; 3) new analytical methods and more easy-to-use software to deal with increasing data sizes, particularly with regard to Lidar and optical imagery fusion; and 4) the ability to train forest managers and scientists in Lidar data workflow and appropriate software.

7 References

Aguilar, F.J., Agüera, F., Aguilar, M.A. and Carvajal, F., 2005. Effects of terrain morphology, sampling density, and interpolation methods on grid DEM accuracy. Photogrammetric Engineering & Remote Sensing. 71(7): 805-816.

Andersen, H.-E., McGaughey, R.J. and Reutebuch, S.E., 2005. Estimating forest canopy fuel parameters using LIDAR data. Remote Sensing of Environment. 94: 441-449.

Anderson, E.S., Thompson, J.A. and Austin, R.E., 2005. LiDAR density and linear interpolator effects on elevation estimates. International Journal of Remote Sensing. 26(18): 3889-3900.

Anderson, J.E., Plourde, L.C., Martin, M.E., Braswell, B.H., Smith, M.-L., Dubayah, R.O., Hofton, M.A. and d, J.B.B., 2008. Integrating waveform lidar with hyperspectral imagery for inventory of a northern temperate forest Remote Sensing of Environment. 112: 1856-1870.

Blanchard, S., M. Jakubowski and Kelly, M., 2011. Object-based image analysis of downed logs in a disturbed forest landscape using lidar. Remote Sensing. 3(11): 2420-2439.

Chen, Q., Baldocchi, D., Gong, P. and Kelly, M., 2006. Isolating individual trees in a savanna woodland using small footprint LIDAR data. Photogrammetric Engineering and Remote Sensing. 72(8): 923-932.

Dubayah, R. and Drake, J., 2000. Lidar remote sensing for forestry. Journal of Forestry. 98(6): 44-46.

Finney, M.A., 1995. FARSITE fire area simulator. Systems for Environmental Management, Missoula, MT.

Finney, M.A., 1998. FARSITE: Fire Area Simulator - Model development and evaluation. Usda Forest Service Rocky Mountain Forest and Range Experiment Station Research Paper(RP-4): 1-+.

Garcia-Feced, C., Temple, D.J. and Kelly, M., 2012. Characterizing California Spotted Owl nest sites and their associated forest stands using Lidar data. Journal of Forestry. 108(8): 436-443.

Gatziolis, D. and Andersen, H.-E., 2008. A Guide to LIDAR Data Acquisition and Processing for the Forests of the Pacific Northwest, Department of Agriculture Forest Service. Pacific Northwest Research Station.

Guo, Q., Li, W., Yu, H. and Alvarez, O., 2010. Effects of Topographic Variability and Lidar Sampling Density on Several DEM Interpolation Methods. Photogrammetric Engineering & Remote Sensing. 76(6): 701-712.

Henning, J.G. and Radtke, P.J., 2006. Detailed stem measurements of standing trees from ground-based scanning lidar. Forest Science. 52(1): 67-80.

ITT Visual Information Solutions, 2009. ENVI software. http://www.ittvis.com/ENVI.

Jakubowski, M.J., Li, W., Guo, Q. and Kelly, M., 2013a. Delineating individual trees from lidar data: a comparison of vector- and raster-based segmentation approaches. Remote Sensing. 5(4163-4186).

Jakubowski, M.K., Guo, Q., Collins, B., Stephens, S. and Kelly, M., 2013b. Predicting surface fuel models and fuel metrics using lidar and imagery in dense, mountainous forest. Photogrametric Engineering & Remote Sensing. 79(1): 37-49.

Jakubowski, M.K., Guo, Q. and Kelly, M., 2013c. Tradeoffs between lidar pulse density and forest measurement accuracy. Remote Sensing of Environment 130: 245-253.

Kelly, M. and Tommaso, S.D., 2015. Mapping forests with Lidar provides flexible, accurate data with many uses. California Agriculture. 69(1): 14-20.

Leckie, D., Gougeon, F., Hill, D., Quinn, R., Armstrong, L. and Shreenan, R., 2003. Combined high-density lidar and multispectral imagery for individual tree crown analysis. Canadian Journal of Remote Sensing. 29(5): 633-649.

Lefsky, M.A., Cohen, W.B., Parker, G.G. and Harding, D.J., 2002. Lidar remote sensing for ecosystem studies. BioScience. 52(1): 19-30.

Li, W., Guo, Q., Jakubowski, M. and Kelly, M., 2012. A new method for segmenting individual trees from the lidar point cloud. Photgrammetric Engineering and Remote Sensing. 78(1): 75-84.

Lucas, R.M., Cronin, N., Lee, A., Moghaddam, M., Witte, C. and Tickle, P., 2006. Empirical relationships between AIRSAR backscatter and LiDAR-derived forest biomass, Queensland, Australia. Remote Sensing of Environment. 100(3): 407-425.

Mutlu, M., Popescu, S.C., Stripling, C. and Spencer, T., 2008. Mapping surface fuel models using lidar and multispectral data fusion for fire behavior. Remote Sensing of Environment. 112: 274-285.

Naesset, E., 2004. Practical large-scale forest stand inventory using a small-footprint airborne scanning laser. Scandinavian Journal of Forest Research. 19: 164-179.

Naesset, E. and Bjerknes, K.-O., 2001. Estimating tree heights and number of stems in young forest stands using airborne laser scanning data. Remote Sensing of Environment. 78: 328-340.

Naesset, E. and Gobakken, T., 2008. Estimation of above- and blow-ground biomass across regions of the boreal forest zone using airborne laser. Remote Sensing of Environment. 112: 3079-3090.

Ørka, H.O., Næsset, E. and Bollandsås, O.M., 2007. Utilizing airborne laser intensity for tree species classification, ISPRS Workshop on Laser Scanning 2007 and SilviLaser 2007, Finland.

Pedrotti, F., 2012. Plant and vegetation mapping, 1. Springer Science & Business Media.

Pesonen, A., Maltamo, M., inen, K.E. and n, P.P., 2008. Airborne laser scanning-based prediction of coarse woody debris volumes in a conservation area Forest Ecology & Management. 255: 3288-3296.

Popescu, S.C. and Wynne, R.H., 2004. Seeing the trees in the forest: using lidar and multispectral data fusion with local filtering and variable window size for estimating tree height. Photogrammetric Engineering & Remote Sensing. 70(5): 589-604.

Popescu, S.C., Wynne, R.H. and Scrivani, J.A., 2004. Fusion of small-footprint lidar and multispectral data to estimate plot-level volume and biomass in deciduous and pine forests in Virginia, USA. Forest Science. 50(4): 551-565.

Popescu, S.C. and Zhao, K., 2008. A voxel-based lidar method for estimating crown base height for deciduous and pine trees. Remote Sensing of Environment. 112: 767-781.

Raber, G.T., Jensen, J.R., Hodgson, M.E., Tullis, J.A., Davis, B.A. and Berglund, J., 2007. Impact of lidar nominal post-spacing on DEM accuracy and flood zone delineation. Photogrammetric Engineering and Remote Sensing. 73(7): 783-791.

Radtke, P.J. and Bolstad, P.V., 2001. Laser point-quadrat sampling for estimating foliage-height profiles in broad-leaf forests. Canadian Journal of Forest Research. 31: 410-418.

Riano, D., Meier, E., Allgower, B., Chuvieco, E. and Ustin, S.L., 2003. Modeling airborne laser scanning data for the spatial generation of critical forest parameters in fire behavior modeling Remote Sensing of Environment. 86: 177-186.

Richardson, J.J., Moskal, L.M. and Kim, S.-H., 2009. Modeling approaches to estimate effective leaf area index from aerial discrete-return LIDAR. Agricultural and Forest Meteorology. 149(6): 1152-1160.

Roth, B.E., Slatton, K.C. and Cohen, M.H., 2007. On the ptoential for high-resolution lidar to improve rainfall interception estimates in forest ecosystems. Frontiers in Ecology and the Environment. 5(8): 421-428.

Soininen, A., 2004. Terra Scan for MicroStation, User's Guide. Terrasolid Ltd., Jyvaskyla, Finland.

Tao, S., Li, L., Guo, Q., Li, L., Xue, B., Kelly, M., Li, W., Xu, G. and Su, Y., 2014. Airborne Lidar-derived volume metrics for aboveground biomass estimation: A comparative assessment for conifer stands. Agriculture and Forest Management. Agriculture and Forest Management. 189-199: 24-32.

Tempel, D.J., Gutierrez, R.J., Battles, J.J., Fry, D.L., Su. Y., Guo., Q., Reetz, M., Whitmore, S.A., Jones, G.M., Collins, B.M., Stephens, S.L., Kelly, M., Berigan W.J., and Perry, M.Z., 2015. Evaluting short- and long-term impacts of fuels treatments and simulated wildfire on an old-forest species. Ecoshpere (accepted).

Thompson, J.A., Bell, J.C. and Butler, C.A., 2001. Digital elevation model resolution: effects on terrain attribute calculation and quantitative soil-landscape modeling. Geoderma. 100: 67-89.

Vierling, K.T., Vierling, L.A., Gould, W.A., Martinuzzi, S. and Clawges, R.M., 2008. Lidar: shedding new light on habitat characterization and modeling. Frontiers for Ecology and the Environment. 6(2): 90-98.

Zhang, X., Xiao, P. and Feng, X., 2013. Impervious surface extraction from high-resolution satellite image using pixel-and object-based hybrid analysis. International Journal of Remote Sensing. 34(12): 4449-4465.

Zhao, F., Guo, Q. and Kelly, M., 2012a. Allometric equation choice impacts lidar-based forest biomass estimates: A case study from the Sierra National Forest, CA. Agricultural and Forest Meteorology. 165: 64-72.

Zhao, F., Sweitzer, R.A., Guo, Q. and Kelly, M., 2012b. Characterizing habitats associated with fisher den structures in the Southern Sierra Nevada, California using discrete return lidar. Forest Ecology & Management. 280: 112-119.

Zhao, K., Popescu, S. and Nelson, R., 2009. Lidar remote sensing of forest biomass: A scale-invariant estimation approach using airborne lasers Remote Sensing of Environment. 113: 182-196.

Zimble, D.A., Evans, D.L., Carlson, G.C., Parker, R.C., Grado, S.C. and Gerard, P.D., 2003. Characterizing vertical forest structure using small-footprint airborne LiDAR. Remote Sensing of Environment. 87: 171-182.

8 Spatial Team Appendices

8.1 Appendix B1: Spatial Team publications

SNAMP PUB #4:
Guo, Li, Yu, and Alvarez. 2010. Effects of topographic variability and Lidar sampling density on several DEM interpolation methods. *Photogrammetric Engineering and Remote Sensing* 76(6): 701–712.

> **Abstract:** We used Lidar data to create a detailed digital elevation model for our two study sites. We investigated five different interpolation methods to create the DEMs. We examined how topography, sampling density, and spatial resolution affected accuracy of the DEMs. We found that simple interpolation models are more efficient and faster in creating DEMs, but more complex interpolation models are more accurate, but slower. We found that DEMs are less accurate in areas with more complex topography. We found that DEM error also increases as Lidar sampling density decreases. We found that some of the interpolation methods do not work well with larger cell sizes. These results might be helpful to guide the choice of appropriate Lidar interpolation methods for DEM generation.

SNAMP PUB #5:
Garcia-Feced, Tempel, and Kelly. 2011. Lidar as a tool to characterize wildlife habitat: California spotted owl nesting habitat as an example. *Journal of Forestry* 108(8): 436-443.

> **Abstract**: We demonstrate the use of an emerging technology, airborne light detection and ranging (Lidar), to assess forest wildlife habitat by showing how it can improve the characterization of California spotted owl (*Strix occidentalis occidentalis*) nesting habitat. Large residual trees are important elements for many wildlife species and often, apparently, facilitate selection of habitat by spotted owls. However, we currently lack the ability to identify such trees over large spatial scales. We acquired multiple-return, high-resolution Lidar data for a 107.1-km^2 area in the central Sierra Nevada, California. We surveyed for spotted owls within this area during 2007−2009 and located 4 nest trees. We then used the Lidar data to measure the number, density and pattern of residual trees ($\geq$ 90 cm dbh) and to estimate canopy cover within 200 m of four nest trees. Nest trees were surrounded by large numbers of residual trees and high canopy cover. We believe that Lidar would greatly benefit forest managers and scientists in the assessment of wildlife-habitat relationships and conservation of important wildlife species.

SNAMP PUB #6:
Li, Guo, Jakubowski, and Kelly. 2012. A new method for segmenting individual trees from the Lidar point cloud. *Photogrammetric Engineering and Remote Sensing* 78(1): 75-84.

> **Abstract**: Light Detection and Ranging (Lidar) has been widely applied to characterize the 3-dimensional (3D) structure of forests as it can generate 3D point data with high spatial resolution and accuracy. Individual tree segmentations, usually derived from the canopy height model, are used to derive individual tree structural attributes such as tree

height, crown diameter, canopy-based height, and others. In this study we develop a new algorithm to segment individual trees from the small footprint discrete return airborne Lidar point cloud. The new algorithm adopts a top-to-bottom region growing approach that segments trees individually and sequentially from the tallest to the shortest. We experimentally applied the new algorithm to segment trees in a mixed coniferous forest in the Sierra Nevada Mountains in California, USA. The results were evaluated in terms of recall, precision, and *F*-score, and show that the algorithm detected 86% of the trees ("recall"), 94% of the segmented trees were correct ("precision"), and the overall *F*-score is 0.9. Our results indicate that the proposed algorithm has good potential in segmenting individual trees in mixed conifer stands of similar structure using small footprint, discrete return Lidar data.

SNAMP PUB #7:
Blanchard, Jakubowski, and Kelly. 2011. Object-Based Image Analysis of Downed Logs in Disturbed Forested Landscapes using Lidar. *Remote Sensing* 3: 2420-2439.

Abstract: Downed logs on the forest floor provide habitat for species, fuel for forest fires, and function as a key component of forest nutrient cycling and carbon storage. Ground-based field surveying is a conventional method for mapping and characterizing downed logs but is limited. In addition, optical remote sensing methods have not been able to map these ground targets due to the lack of optical sensor penetrability into the forest canopy and limited sensor spectral and spatial resolutions. Lidar (light detection and ranging) sensors have become a more viable and common data source in forest science for detailed mapping of forest structure. This study evaluates the utility of discrete, multiple return airborne Lidar-derived data for image object segmentation and classification of downed logs in a disturbed forested landscape and the efficiency of rule-based object-based image analysis (OBIA) and classification algorithms. Downed log objects were successfully delineated and classified from Lidar derived metrics using an OBIA framework. 73% of digitized downed logs were completely or partially classified correctly. Over classification occurred in areas with large numbers of logs clustered in close proximity to one another and in areas with vegetation and tree canopy. The OBIA methods were found to be effective but inefficient in terms of automation and analyst's time in the delineation and classification of downed logs in the Lidar data.

SNAMP PUB #13:
Jakubowski, Guo, Collins, Stephens, and Kelly. 2013. Predicting surface fuel models and fuel metrics using Lidar and CIR imagery in a dense, mountainous forest. *Photogrammetric Engineering and Remote Sensing* 79(1): 37-49.

Abstract: We compared the ability of several classification and regression algorithms to predict forest stand structure metrics and standard surface fuel models. Our study area spans across a dense, topographically complex Sierra Nevada mixed-conifer forest. We used clustering, regression trees, and support vector machine algorithms to analyze high density (average 9 pulses/m2), discrete return, small footprint Lidar data, along with multispectral imagery. Stand structure metric predictions generally decreased with increased canopy penetration. For example, from the top of canopy, we predicted canopy

height ($r2 = 0.87$), canopy cover ($r2 = 0.83$), BA ($r2 = 0.82$), shrub cover ($r2 = 0.62$), shrub height ($r2 = 0.59$), combined fuel loads ($r2 = 0.48$), and fuel bed depth ($r2 = 0.35$). While the general fuel types were predicted accurately, specific surface fuel model predictions were poor (76 percent and 50 percent correct classification, respectively) using all algorithms. These fuel components are critical inputs for wildfire behavior modeling, which ultimately support forest management decisions. This comprehensive examination of the relative utility of Lidar and optical imagery will be useful for forest science and management.

SNAMP PUB #14:
Zhao, Guo, and Kelly. 2012. Allometric equation choice impacts Lidar-based forest biomass estimates: A case study from the Sierra National Forest, CA. *Agriculture and Forest Meteorology* 165: 64– 72.

Abstract: Plot-level estimates of biomass were derived from field data and two different allometric equations. Estimates differed between allometric equations, especially in plots with high biomass. Selection of allometric equations can influence the capacity of Lidar data to estimate biomass. The best fit between field data and Lidar data were found using a regional allometric equation and a combination of Lidar metrics and individual tree data.

SNAMP PUB #16:
Zhao, Sweitzer, Guo and Kelly. 2012. Characterizing habitats associated with fisher den structures in southern Sierra Nevada forests using discrete return Lidar. *Forest Ecology and Management* 280: 112–119.

Abstract: This study explored the ability of Lidar-derived metrics to capture topography and forest structure surrounding denning trees used by the Pacific fisher (*Martes pennanti*) as a case study to illustrate the utility of Lidar remote sensing in studying mammal-habitat associations. We used Classification and Regression Trees (CART) to statistically compare the slope and Lidar-derived forest height and structure metrics in the circular area (with radius of 10–50 m) surrounding denning trees and randomly selected non-denning trees. We accessed our model accuracy using resubstitution and cross-validation methods. Our results show that there is a strong association between fisher denning activity and its surrounding forested environment across scales, with high classification accuracy (overall accuracies above 80% and cross-validation accuracies above 70%) at 20, 30 and 50 m ranges. The best classification accuracies were found at 20 m (optimal resubstitution accuracy 86.2% and cross-validation accuracy 78%). Tree height and slope were important variables in classifying the area immediately surrounding denning trees; at scales larger than 20 m, forest structure and complexity became more important.

SNAMP PUB #18:
Jakubowski, Guo, and Kelly. 2013. Tradeoffs between Lidar pulse density and forest measurement accuracy. *Remote Sensing of Environment* 130: 245–253.

Abstract: Discrete Lidar is increasingly used to analyze forest structure. Technological improvements in Lidar sensors have led to the acquisition of increasingly high pulse densities, possibly reflecting the assumption that higher densities will yield better results. In this study, we systematically investigated the relationship between pulse density and the ability to predict several commonly used forest measures and metrics at the plot scale. The accuracy of predicted metrics was largely invariant to changes in pulse density at moderate to high densities. In particular, correlations between metrics such as tree height, diameter at breast height, shrub height and total basal area were relatively unaffected until pulse densities dropped below 1 pulse/m2. Metrics pertaining to coverage, such as canopy cover, tree density and shrub cover were more sensitive to changes in pulse density, although in some cases high prediction accuracy was still possible at lower densities. Our findings did not depend on the type of predictive algorithm used, although we found that support vector regression (SVR) and Gaussian processes (GP) consistently outperformed multiple regression across a range of pulse densities. Our results suggest that low-density Lidar data may be capable of estimating typical forest structure metrics reliably in some situations. These results provide practical guidance to forest ecologists and land managers who are faced with tradeoff in price, quality and coverage, when planning new Lidar data acquisition.

SNAMP PUB #24:
Jakubowski, Li, Guo, and Kelly. 2013. Delineating individual trees from Lidar data: a comparison of vector- and raster-based segmentation approaches. *Remote Sensin*g 5: 4163-4186

Abstract: This work concentrates on delineating individual trees from discrete Lidar data in topographically-complex, mixed conifer forest across the California's Sierra Nevada. We delineated individual trees using vector data and a 3D Lidar point cloud segmentation algorithm, and using raster data with an object-based image analysis (OBIA) of a canopy height model (CHM). The two approaches are compared to each other and to ground reference data. We used high density (9 pulses/m^2), discreet Lidar data and WorldView-2 imagery to delineate individual trees, and to classify them by species or species types. We also identified a new method to correct artifacts in a high-resolution CHM. Our main focus was to determine the difference between the two types of approaches and to identify the one that produces more realistic results. We compared the delineations via tree detection, tree heights, and the shape of the generated polygons. The tree height agreement was high between the two approaches and the ground data (r^2: 0.93–0.96). Tree detection rates increased for more dominant trees (8-100 percent). The two approaches delineated tree boundaries that differed in shape: the Lidar-approach produced fewer, more complex, and larger polygons that more closely resembled real forest structure.

SNAMP PUB #29
Tao, Guo, Li, Xue, Kelly, Li, Xu, and Su. 2015. Airborne Lidar-derived volume metrics for aboveground biomass estimation: a comparative assessment for conifer stands. *Agricultural and Forest Meteorology* 198–199: 24–3

Abstract: Estimating aboveground biomass (AGB) is essential to quantify the carbon balance of terrestrial ecosystems, and becomes increasingly important under changing global climate. Volume metrics of individual trees, for example stem volume, have been proven to be strongly correlated to AGB. In this paper, we compared a range of airborne Lidar-derived volume metrics (i.e., stem volume, crown volume under convex hull, and crown volume under Canopy Height Model (CHM)) to estimate AGB. In addition, we evaluated the effect of horizontal crown overlap (which is often neglected in Lidar literature) on the accuracy of AGB estimation by using a hybrid method that combined marker-controlled watershed segmentation and point cloud segmentation algorithms. Our results show that: 1) when the horizontal crown overlap issue was not addressed, models based on point cloud segmentation outperformed models based on marker-controlled watershed segmentation; models using stem volume estimated AGB more accurately than models using crown volume under convex hull and crown volume under CHM. 2) Once the horizontal crown overlap issue was taken into consideration, the model using crown volume under individual trees in the Lidar cloud CHM yielded a more accurate estimation of AGB. Our study provides a comprehensive evaluation of the use of airborne Lidar-derived volume metrics for AGB estimation and could help researchers choose the appropriate airborne Lidar-derived volume metric. Moreover, the results also indicate that horizontal crown overlap should be addressed when the airborne Lidar-derived forest crown volume is used for estimating AGB.

SNAMP PUB #37

Li, Guo, Tao, Kelly, and Xu. Lidar with multi-temporal MODIS provide a means to upscale predictions of forest biomass. *ISPRS Journal of Photogrammetry and Remote Sensing*.

Abstract: Accurate estimation of forest AGB has become increasingly important for a wide range of end-users. Although satellite remote sensing provides abundant observations to monitor forest coverage, validation of coarse-resolution AGB derived from satellite observations is difficult because of the scale mismatch between the footprints of satellite observations and field measurements. In this study, we use airborne Lidar to bridge the scale gaps between satellite-based and field-based studies, and evaluate satellite-derived indices to estimate regional forest AGB. We found that: 1) Lidar data can be used to accurately estimate forest AGB using tree height and tree quadratic height, 2) Artificial Neural Networks, among four tested models, achieved the best performance with R^2= 0.75 and root-mean-square error (RMSE) around 165 Mg/ha; 3) for MODIS-derived vegetation indices at varied spatial resolution (250 – 1000 m), accumulated NDVI, accumulated LAI, and accumulated FPAR can explain 53 – 74% of the variances of forest AGB, whereas accumulated NDVI derived from 1 km MODIS products resulted in a higher R^2 (74%) and lower RMSE (13.4 Mg/ha) than others. We conclude that Lidar data can be used to bridge the scale gap between satellite and field studies. Our results indicate that combining MODIS and Lidar data has the potential to estimate regional forest AGB.

8.2 Appendix B2: Spatial Team Integration Team meetings, workshops, and webinars

- May 1, 2014, Spatial IT webinar, online.
- July 15, 2013, UC Merced Library Exhibit, Merced CA.
- May 17, 2012, Lidar workshop – northern site, Foresthill, CA.
- May 16, 2012, Lidar workshop – southern site, O’Neals, CA.
- June 4, 2009, Lidar workshop – northern site, Foresthill, CA.
- June 3, 2009, Lidar workshop – southern site, North Fork, CA.

8.3 Appendix B3: Spatial Team newsletters

8 April 2011. Spring 2011 Newsletter: Vol 5. No. 1 - Spatial Team

The SNAMP Spatial Team is using Lidar data to map forests before and after vegetation treatments and measuring forest habitat characteristics across treatment and control sites. These data will provide detailed information about how forest habitat was affected by fuel management treatments. Airborne Lidar (light detection and ranging) works by bouncing light against a target in a similar way to sonar or radar.

20 October 2008. Fall 2008 SNAMP Newsletter: Vol 2. No 3 - Spatial Team

Geospatial data, or data linked to a place on the surface of the earth, are increasingly a part of our everyday lives and an important resource for environmental research. Geospatial data play a large role in the SNAMP project. We are mapping the forest before and after SPLAT treatments, and measuring forest habitat characteristics across our treatment and control sites. This newsletter discusses one of our datasets, called LIDAR, a new tool that shows great promise for mapping forests.

8.4 Appendix B4: Base GIS data

- Government:
  - City/town locations (CaSIL, ESRI, and geonames/geocities.org)
  - County boundaries (source: ESRI)
  - State boundaries (source: ESRI)
  - Ownership (private vs. public) (source: ESRI)
  - Federal lands (e.g., FS areas, etc.) (source: FS)
  - Yosemite area (source: nps.gov)

- Other FS data:
  - Cedar Valley Project (source: FS)
  - Fishcamp project (source: FS)
  - Nelder Grove (source: FS)
  - SNAMP SPLATs (source: FS)
  - Fishcamp SPLATs (source: FS)

- Transportation:
  - Highways, roads, local roads (source: CaSIL)
  - Trails (source: NF)
  - Rail networks (source: ESRI)

- Hydrology:
  - Reservoirs and lakes (source: NHD)
  - Streams and rivers (source: NHD)

- Topo:
  - 30m and 90m DEM (source: CaSIL)
  - Mountain peaks (source: mountainpeaks.net)

- SNAMP:
    - Main study area boundaries (source: SNAMP)
    - Water study areas (source: SNAMP)
    - Owl and Fisher study areas (source: SNAMP)
    - Plot locations (source: SNAMP)
    - SNAMP base station (source: SNAMP)

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Appendix C: California Spotted Owl Team Final Report

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August 31, 2015

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i. Executive summary

We conducted a two-part analysis to assess the effects of SPLATs on California spotted owls (*Strix occidentalis occidentalis*). First, we performed a retrospective analysis using 20 years of demographic data collected at 74 spotted owl territories that included the Last Chance Study Area (LCSA) and the nearby Eldorado Study Area (ESA). This approach deviated from our original plan to directly estimate the effects of SPLATs on spotted owls at Last Chance using a Before-After Control-Impact experimental design, similar to the approach used by some of the other SNAMP Science Teams. The revised approach was necessary because too few owls were present on the LCSA and the delay in implementing the Last Chance fuels-reduction project resulted in only one year of post-treatment data collection. As a result, we needed to spatially and temporally expand the retrospective analysis to achieve sufficient power to detect changes in owl demographic parameters (Popescu et al. 2012). The drawback to our revised approach was that we could no longer specifically estimate the effects of SPLATs on owls because many different types of timber harvest, as well as wildfire and forest succession, occurred within owl territories during our study period (1993-2012). Second, we performed a prospective analysis (30 years into the future) of the effects of SPLATs and wildfire on spotted owl habitat and demography within the LCSA only. This analysis represented our integration effort with the research conducted by other Science Teams (i.e., Fire and Forest Ecosystem Health [FFEH], Spatial).

The retrospective analysis has been published in a peer-reviewed journal (Tempel et al. 2014), and we have reproduced this paper in the first section of this appendix. We assessed the effects of forest conditions, timber harvest, and wildfire on spotted owl reproduction, non-juvenile survival, and territory occupancy using the previously mentioned 20-year data set. All habitat and timber harvest variables that we extracted from our vegetation maps were time-varying and could change annually because of natural disturbance, timber harvest, or regrowth. We categorized timber harvest into three broad categories for analytical purposes—low-intensity, medium-intensity, and high-intensity. The classification scheme was based on the expected change in forest structure and was developed after consultation with three local forest managers who were naïve to the objectives of our study. SPLATs and other U.S. Forest Service treatments conducted prior to the adoption of SPLATs were considered to be medium-intensity harvests. Adult survival and territory colonization were relatively high, while territory extinction was relatively low, in territories that had greater amounts of high-canopy-cover forest (≥70% canopy cover, dominated by trees ≥12" [30.5 cm] diameter at breast height). Reproductive success was negatively associated with the area of medium-intensity timber harvests characteristic of SPLATs. Our results also suggested that the amount of edge between older forests and shrub/sapling vegetation and increased habitat heterogeneity may result in higher spotted owl demographic rates. We found some evidence that high-severity fire was correlated with a reduced likelihood of territory colonization, but the standard error was unestimable for the parameter coefficient, suggesting that we lacked a sufficient sample size of burned territories to draw definitive conclusions. Despite correlations between owl demographic rates and several habitat variables, life-stage simulation (sensitivity) analyses indicated that the amount of high-canopy forest was the primary driver of population growth and equilibrium occupancy at the territory scale. Greater than 90% of medium-intensity harvests converted high-canopy forests into lower-canopy vegetation classes, suggesting that landscape-scale fuel treatments in such stands could have short-term negative impacts on California spotted owl populations. Moreover, high-canopy forests declined by an average of 7.4% across territories during our study, suggesting that habitat loss could have contributed to declines in abundance and territory occupancy detected in a previous study of this population. Thus, we recommend that managers consider the existing amount and spatial distribution of high-canopy-cover forest before implementing SPLATs and that SPLATs be accompanied by a rigorous monitoring program within an adaptive-management framework.

We present the prospective analysis in the second section of this appendix. For this analysis, the FFEH Team simulated forest growth 30 years into the future under four combinations of modeled wildfire and treatment (i.e., Last Chance fuels-reduction project): treated with fire, untreated with fire, treated without fire, and untreated without fire. We compared spotted owl habitat on the LCSA under the four scenarios using a habitat suitability index developed from canopy cover and large-tree measurements at nest sites on the ESA. In addition, we compared population growth rate and equilibrium occupancy at four spotted owl territories within the LCSA for each scenario using the statistical relationships between forest structure and these population parameters that we developed in the retrospective analysis. We found that effects of fuels treatments were contingent on fire occurrence. Treatments had a positive effect on owl nesting habitat and demographic rates up to 30 years after simulated fire, but they had a persistently negative effect throughout the 30-year period in the absence of fire. We conclude that SPLATs may provide long-term benefits to spotted owls if fire occurs under escaped wildfire conditions, but can have long-term negative effects on owls if fire does not occur. However, we only simulated one fire under the treated and untreated scenarios and therefore had no measures of associated uncertainty. In addition, the net benefits of fuels treatments on spotted owl habitat and demography will depend on the future probability that fire will occur under similar weather and ignition conditions, and such probabilities remain difficult to quantify. Therefore, we recommend adopting a landscape approach that restricts timber harvest within territory core areas of use (~125 ha in size) that contain critical owl nesting and roosting habitat (Berigan et al. 2012) and locates fuels treatments in the surrounding areas to reduce the potential for hazardous fire to spread into PACs.

Berigan, W. J., R. J. Gutiérrez, and D. J. Tempel. 2012. Evaluating the efficacy of protected habitat areas for the California spotted owl using long-term monitoring data. Journal of Forestry 110:299–303.

Popescu, V. D., P. d. Valpine, D. Tempel, and M. Z. Peery. 2012. Estimating population impacts via dynamic occupancy analysis of Before–After Control–Impact studies. Ecological Applications 22:1389–1404.

Tempel, D. J., R. J. Gutiérrez, S. A. Whitmore, M. J. Reetz, R. E. Stoelting, W. J. Berigan, M. E. Seamans, and M. Z. Peery. 2014. Effects of forest management on California spotted owls: implications for reducing wildfire risk in fire-prone forests. Ecological Applications 24:2089–2106.

Retrospective Analysis of the Effects of Timber Harvest, Wildfire, and Forest Succession on California Spotted Owls
(reproduced with permission of © 2014 Ecological Society of America)

I. Introduction

Forest managers in North America are challenged by the need to balance the potentially competing objectives of reducing wildfire risk and protecting threatened species. For millennia, low- to moderate-severity wildfires occurred at frequent (often less than 20-year) intervals in many western forests, naturally removed fuels such as woody debris, shrubs, and small trees, and shaped the ecology of these forests (Agee 1993, Noss et al. 2006). However, decades of wildfire suppression have disrupted historic fire regimes, increased the amount of surface and ladder fuels, and have led to uncharacteristic proportions and patch sizes of stand-replacing fire that now threaten ecological and human communities (Mallek et al. 2013; Stephens et al. 2013, Stephens et al. 2014; Stephens et al. 2015). In addition, warmer and drier conditions associated with climate change may lead to further increases in fire activity over the next century (Westerling and Bryant 2008, Liu et al. 2013). As a result, policy makers and forest managers have proposed landscape-scale forest treatments to remove surface and ladder fuels and reduce the risk of high-severity fires in many western forests (e.g., USFS 2004).

Proposed fuel-reduction measures pose a potential risk to wildlife species associated with older forests because they change forest structure in ways that may negatively affect the species' ability to survive and reproduce. Species such as the spotted owl (*Strix occidentalis*), fisher (*Pekania pennanti*), and American marten (*Martes americana*) have already declined because of habitat loss and fragmentation resulting from more than a century of timber harvest (Gutiérrez 1994, Zielinski et al. 2005). While fuels management may provide long-term benefits to such species by reducing future habitat loss from high-severity fires (Finney 2001, Ager et al. 2007, Finney et al. 2007, Collins et al. 2011), regulations protecting sensitive species often constrain the placement and number of potential fuel treatments (Collins et al. 2010). Thus, there is an urgent need to understand the effects of fuel-reduction treatments on old-forest-associated species so that fire risk can be managed while maintaining viable populations of these species

(Zielinski et al. 2013). Doing so, however, is challenging because many of these species are rare and long-lived such that impacts may not be immediately apparent. Thus, long-term studies are needed to provide sufficient statistical power to discriminate between the effects of forest management and other sources of variation in demographic rates.

A high-profile example of the attempt to balance wildfire risk and species conservation is the management of public forests and spotted owls in the Sierra Nevada, California. As with other western forests, the area burned by high-severity fires in the Sierra Nevada has increased over the past several decades (Miller et al. 2009; Miller and Safford 2012). However, the implementation of landscape-scale fuel treatments in the Sierra Nevada (USFS 2004) has been contentious because of the potential for these fuel treatments to negatively affect the spotted owl and other sensitive species. For example, site occupancy of California spotted owls declined following the alteration of >20 ha of habitat within territories (Seamans and Gutiérrez 2007*a*). However, Seamans and Gutiérrez (2007*a*) did not attribute habitat changes to specific causes (e.g., fire, different types of logging) or assess the relationship between these events and reproduction, survival, or fitness. Thus, considerable uncertainty remains about the impact of forest management on California spotted owls.

We assessed the effects of timber harvest, wildfire, and vegetation conditions on a declining population of California spotted owls in the central Sierra Nevada, California, from 1993-2012. Specifically, we assessed the effects of forest treatments and vegetation conditions on reproduction, survival, and territory occupancy of California spotted owls and used these vital rates to determine the sensitivity of population growth and occupancy to changes in vegetation conditions due to wildfire or timber harvest. Our objectives were to understand the potential direct, short-term impacts of management actions intended to reduce wildfire risk on spotted owls, and to gain insight into the causes of an approximate 30% decline in abundance on our study area over the past two decades (Tempel and Gutiérrez 2013). Moreover, our study is particularly timely because of heightened public concern following the 2013 fire season in the Sierra Nevada, which included one of the largest wildfires in California history (Rim Fire; http://www.inciweb.org/incident/3660/) and a wildfire that burned part of our study area (American Fire; http://inciweb.org/incident/3624/).

II. Study area

We expanded our study area beyond the Last Chance Study Area (LCSA) used by other Science Teams in order to achieve a larger sample size of individual spotted owls and owl territories. We had a 345-km^2 Density Study Area (DSA) that we completely surveyed for spotted owls each year from 1993-2012, regardless of land ownership or past occupancy by owls. About 60% of the DSA was National Forest, and the remainder was privately owned land. In 1997, we established a Regional Study Area (RSA) surrounding the DSA. The RSA consisted of historical (previously known) owl territories and territories that we began surveying during 1997-1999. We then conducted annual surveys within owl territories on the RSA from 1997-2012, but we did not completely survey the landscape between these territories. In 2007, we established the 248-km^2 LCSA as part of the Sierra Nevada Adaptive Management Project (SNAMP). The LCSA that we used for our analyses included a 2.4-km buffer around the Last Chance site described in Chapter 2 of this report. The LCSA was adjacent to the northern boundary of the DSA and was also completely surveyed for spotted owls each year from 2007-2012, regardless of land ownership or past occupancy by owls. We detected no barred owls (*Strix varia*) during our study, although we did detect 2 barred × spotted owl hybrids that were not included in our assessment.

The study area consisted of mountainous terrain bisected by steep river canyons with elevations ranging from 300 to 2,500 m. The study area had a Mediterranean climate with cool wet winters and hot dry summers. Sierran mixed-conifer forest was the principal vegetation type and had a canopy dominated by ponderosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), sugar pine (*P. lambertiana*), and Douglas-fir (*Pseudotsuga menziesii*). California black oak (*Quercus keloggii*), tanoak (*Lithocarpus densiflora*), and big leaf maple (*Acer macrophyllum*) were common understory species. Forests dominated by red fir (*A. magnifica*) and lodgepole pine (*P. contorta*) occurred at the highest elevations. Montane chaparral and black oak woodlands were vegetation types that were locally distributed at lower and middle elevations. The area has experienced a complex history of timber harvests over the past century, which added to the spatial complexity of vegetation conditions.

III. Methods

Spotted owl surveys

Each year we conducted nighttime surveys from April through August to locate individuals by imitating vocalizations of spotted owls for a minimum of 10 min at call stations spaced ~0.8 km apart or while walking routes that connected multiple call stations. If owls were detected, we conducted walk-in surveys at dawn or dusk in an attempt to identify owls and locate nests and roosts. We attempted to capture and band all spotted owls following the methods of Franklin et al. (1996). We fitted captured owls with a U.S. Geologic Survey (USGS) locking aluminum band on one leg and a unique color band and tab combination on the other leg. We determined sex of individuals by the pitch of calls and behavior (Forsman et al. 1984). We identified four age classes based on plumage characteristics: juvenile, first-year subadult, second-year subadult, and adult (≥3 years old) (Moen et al. 1991).

We estimated reproduction of spotted owls (i.e., the number of young produced per pair per year) by feeding live mice to owls (Franklin et al. 1996). Reproducing owls usually take offered prey to their nest or young, while non-reproducing owls usually eat or cache the mice. We inferred that owl pairs were non-reproductive if: 1) an owl took ≥2 mice and cached the last mouse without bringing a mouse to a nest or young; 2) an owl ate or cached ≥4 mice without bringing a mouse to a nest or young; 3) an owl ate two mice and ignored a third mouse for >1 hour; 4) a female owl was captured prior to 1 June and did not have a brood patch; or 5) a female owl was observed roosting for ≥60 minutes before 1 June, which suggested that the female was not incubating eggs or brooding. The number of young fledged from successful nests was determined by observing the delivery of offered mice from parents to young and by counting young during visual searches of the nest stand.

We determined site occupancy following the protocol of Tempel and Gutiérrez (2013). We divided the survey season each year into 10 bimonthly sampling periods (i.e., April 1-15, April 16-30, May 1-15, May 16-31, etc.). We identified 74 owl territories using the criterion that reproduction must have been observed at least once at that location during our study. We considered the detection of at least one owl at a territory to indicate site occupancy. We eliminated nocturnal detections >400 m from the territory core area (i.e., areas frequently used by nesting and roosting owls at a territory; Berigan et al. 2012) to minimize the inclusion of false positive detections of non-territorial floaters or residents straying from nearby territories.

Vegetation and forest treatment mapping

We interpreted aerial photographs to map vegetation cover types and changes in cover type that resulted from forest management, succession, and wildfire within all 74 owl territories during 1993-2012. Our vegetation map represented a spatial and temporal expansion of a similar map developed for our study area that also relied upon aerial-photo interpretation, but which was limited to a subset of territories and years (Chatfield 2005, Seamans and Gutiérrez 2007*a*). We mapped cover types within a 1,128-m radius (400-ha) circle around each owl territory center; this radius was equal to 1/2 the mean nearest neighbor distance during our study. We did not know if territorial owls used the entire 400 ha, but owls responded to our vocal surveys within these areas, and these areas encompassed all known nest locations on our study area (Seamans and Gutiérrez 2007*a*). We estimated a single center for each owl territory as the geometric mean of the most informative owl location(s) from each year that the territory was occupied. We used a nest location if one was located that year, but if we did not find a nest, we used the mean location of all roost trees located that year.

Vegetation cover was assigned to one of nine possible classes based on species composition, canopy cover, and the size class of dominant trees (Table C1; Fig. C1). We used vegetation classes based upon the California Wildlife Habitat Relationships system (CWHR; Mayer and Laudenslayer 1988). As noted, we used a cover map developed by Chatfield (2005) as our base map, which had an overall accuracy (i.e., correct classification of cover types) of 83% based on randomly sampled vegetation plots. We updated this map for each year of our study using National Agriculture Imagery Program images, USGS 1-m digital orthophoto quarter quads (DOQQs), and geo-rectified aerial photographs (1:15,840 scale) obtained for the following years: 1993, 1996-1998, 2000, 2005, 2009, and 2010-2012. We drew polygons around relatively homogenous vegetation classes visible on the images using a minimum polygon size of ~1 ha. When we could not reliably assign a year to a visible change in cover type between available images (see below), we assumed the change occurred at the midpoint between image years (see Fig. C2 as an example of the vegetation cover map for a single owl territory).

We identified the timing, location, and type of timber harvests from the U.S. Forest Service (USFS) Activity and Tracking System (FACTS; www.fs.usda.gov/main/r5/landmanagement/gis), California Department of Forestry and Fire Protection (CDFFP) Timber Harvest Plans (ftp.fire.ca.gov/forest/), and information provided by private landowners. These databases contained 16 different timber harvest practices that we pooled into three broad categories for analytical purposes—low-intensity, medium-intensity, and high-intensity timber harvest. The classification scheme was based on the expected change in forest structure and was developed after consultation with three local forest managers (Dr. Rob York, Ken Somers, and Frieder Schurr) at the University of California-Berkeley's Blodgett Forest Research Station who were naïve to the objectives of our study. We provided each expert with a list of the 16 harvest types and instructed them to independently categorize the harvest types into no more than 5 groups based on how the treatments would typically be expected to alter forest structure. Based on their feedback, we categorized 15 of the harvest types as follows:

1) High intensity—clear cut, seed tree removal cut, shelterwood removal cut, shelterwood removal/commercial thin, overstory removal, seed tree seed cut, shelterwood seed step.
2) Medium intensity—group selection, selection, single-tree selection cut, thinning for hazardous fuels reduction, fuel break, commercial thin.
3) Low intensity—pre-commercial thin, sanitation salvage.

The final harvest type was "salvage cut" and consisted of salvage logging in burned areas after a severe wildfire in 2001. We included this harvest type in the acreage of fire (another covariate in our analyses) because the post-fire salvage logging occurred within two years of the fire and its effects were confounded with the effects of the fire itself. We confirmed or modified the year and boundary of all treatments in the databases by visually examining the imagery and obtaining supplementary information from field visits, the USFS, and private landowners. We acquired fire perimeter data from the CDFFP Fire and Resource Assessment Program (frap.fire.ca.gov/data/frapgisdata/frapdata.html).

We did not specifically test for effects on spotted owls of Forest Service-implemented fuel-reduction treatments as proposed in USFS (2004) because implementation of these treatments was relatively recent (only 11 owl territories were affected by these treatments after 2007). However, these recent fuel-reduction treatments had similar effects on forest structure as other treatments in the medium-intensity category, most of which also occurred on USFS land. Prior to 2004, USFS timber harvests were governed by an "interim" management plan designed to maintain viable spotted owl populations (USFS 1993). Similar to the 2004 plan, the 1993 interim plan was designed to protect known owl nest stands from any significant modification, to protect large trees (≥ 76.2 cm dbh), to retain at least 40% canopy cover, and to reduce the threat of stand-destroying fires. The primary change implemented by the 2004 plan was a greater emphasis placed on the removal of understory fuels. Thus, we identified the occurrence of understory treatments through conversations with USFS and private timber company personnel and visual interpretation of aerial photos, and further categorized these treatments as "medium-intensity with understory removal."

We extracted spatial data relevant to spotted owl ecology (see Methods—*A priori model development and selection*) from the cover maps with ArcGIS 10.0 (ESRI, Redlands, California, USA) using Patch Analyst 5.1.0.0 (Rempel et al. 2012) for subsequent use in demographic analysis. To calculate the amount of edge between vegetation classes, we used Patch Grid after first converting vector data to raster data at a 30-m scale (Rempel et al. 2012). All other spatial variables were calculated directly from the vector maps. All habitat and timber harvest variables that we extracted from our vegetation maps were time-varying and could change annually because of natural disturbance, timber harvest, or regrowth. We expected that reproduction, survival, and occupancy at a territory would be impacted by timber harvest and wildfire in previous years, as well as the current year. Thus, we calculated harvest and wildfire covariates over three temporal scales—3 years, 6 years, and 9 years. For example, at the 6-year time scale, the area of a specific disturbance type was the sum of those disturbances that occurred in the previous five years and the current year.

A priori model development and selection

We modeled putative relationships between vegetation classes and four vital rates (reproduction, survival, territory colonization, and territory extinction) by evaluating the level of support for competing, *a priori* models. We used Akaike's Information Criterion (AIC) values to rank competing models (Burnham and Anderson 2002). When evaluating support for covariate effects within a given model, we assessed whether the 95% confidence interval of the associated parameter estimate overlapped zero. We conducted the modeling in 3 steps to reduce the number of candidate models and thus reduce the likelihood of finding spurious relationships (Table C2). In the first step, we evaluated covariates that represented the amount of potential owl nesting and roosting habitat within territories. In the second step, we used the covariates from the top-ranked model from the first step and included additional covariates for potential owl foraging habitat, amount of private land, and the spatial distribution of forest cover types. In the third step, we used the covariates from the top-ranked model in the second step and included additional covariates that represented different types of forest disturbance. By using this hierarchical approach, we were able to control for existing habitat conditions within each territory when assessing the impacts of forest disturbance. For steps 1 and 2 of our modeling, we used the entire 20-year data set. For step 3, we used the covariates from the most parsimonious models from step 2, but then used reduced data sets for the three temporal scales because we lacked timber harvest data for years prior to 1993. None of the covariates that we used were highly correlated with each other (r >0.60).

Previous studies of our study population revealed that high canopy cover and large trees were important components of nesting and roosting conditions used by spotted owls (Bias and Gutiérrez 1992, Moen and Gutiérrez 1997). Therefore, in step 1 of our analysis we evaluated support for the combined areas of vegetation classes 5 and 7 (57; model 1.1) and the combined areas of vegetation classes 6 and 7 (67; model 1.4). Vegetation classes 5 and 7 represented the amount of forest with high (≥70%) canopy cover and a dominant tree size of ≥ 30.5 cm diameter at breast height (dbh). In addition to providing nesting and roosting conditions, this forest type provides habitat for northern flying squirrels (*Glaucomys sabrinus*; Waters and Zabel 1995), which were the primary prey item of spotted owls on our study area (unpublished data). Vegetation classes 6 and 7 represented the amount of forest dominated by large trees (≥61.0 cm dbh) with a lower threshold (≥30%) for canopy cover. The current management plan for national forests in the Sierra Nevada contains harvest limits on both canopy cover (minimum 40-50% post-harvest) and tree size (<76.2 cm dbh) (USFS 2004). Although these two covariates (57, 67) were correlated (r = 0.60), we chose to retain both covariates in our analyses to test whether high canopy cover or large trees were more important components of owl habitat. We also considered log-linear (models 1.2, 1.5) and quadratic (models 1.3, 1.6) relationships because such relationships between habitat and spotted owl vital rates have been detected in other regions (Franklin et al. 2000, Dugger et al. 2005, Forsman et al. 2011). We included a covariate for age (subadult = 1 or 2 years old, adult ≥3 years old) when modeling survival and reproduction, and a covariate for sex when modeling survival, because age and sex have been shown to be important predictors of these vital rates for spotted owls (Blakesley et al. 2010). Finally, we included a null model without explanatory covariates where each vital rate had a constant value over time.

In step 2 of our analysis we hypothesized that hardwood forests (vegetation class 1; model 2.1) may support greater densities of dusky-footed woodrats than other forest types (*Neotoma fuscipes*; Sakai and Noon 1993, Innes et al. 2007); woodrats are an important prey item for spotted owls on our study area, especially at lower elevations (unpublished data). We posited that the amount of edge between shrubs or saplings (vegetation class 2) and forests dominated by trees ≥ 30.5 cm (vegetation classes 4, 5, 6, and 7; model 2.2) may have positively affected spotted owl vital rates because the presence of brushfields adjacent to older forest may increase the availability of woodrats to owls (Sakai and Noon 1997). We hypothesized that the area of private land (model 2.3) may negatively affect spotted owl vital rates because data from a radio-telemetry study conducted in our study area during 2006-2007 suggested that owls use private lands less than expected, possibly owing to a history of more intensive timber harvests on private land (Williams et al., in review). Finally, we hypothesized that the spatial arrangement of owl habitat may affect owl vital rates (Franklin et al. 2000). For example, high interspersion of different forest cover types within a territory may allow owls to more easily meet all of their life-history requirements (nesting, roosting, foraging). We first examined the correlation between several potential territory spatial metrics (mean distance between patches, mean patch size, number of patches, diversity) and found that most were correlated with each other or with habitat covariates from step 1 (r >0.60). Thus, we chose to use two metrics which were not highly correlated with each other or with the step 1 covariates—the Shannon-Wiener diversity index (model 2.4) and the mean size of owl habitat patches (model 2.5). We calculated these metrics for the owl habitat type (57 or 67) found in the best model from step 1. We log-transformed all step 2 covariates (except for the Shannon-Wiener diversity index) for our analyses because their distributions were right-skewed.

In step 3 of our analysis we introduced covariates that represented the potential effects of forest disturbances. Disturbances generally consisted of timber harvest, but also included wildfires that occurred within 12 owl territories during our study. We expected all types of disturbance to negatively impact vital rates of spotted owls, and ranked them in order of the expected magnitude of their effects as follows—high-intensity harvests, wildfire, medium-intensity harvests with understory removal, all medium-intensity harvests, and low-intensity harvests (models 3.1-3.5). We ranked wildfire second because most of the acreage burned on our study area was the result of a single fire in 2001 that was predominantly a stand-replacing fire and impacted eight territories to varying degrees. We then sequentially added the disturbance covariates to the best model from step 2 in order of their expected impact and retained the covariate in the model if it reduced the model's AIC value. Finally, we considered a model (model 3.6) in which the amount of habitat (57 or 67) interacted with the disturbance covariate(s) from the best model among models 3.1-3.5. We considered this a test of the hypothesis that territories containing relatively large amounts of spotted owl habitat would be more resilient to disturbance (Seamans and Gutiérrez 2007*a*). All step 3 covariates were right-skewed, so we added 1 to their values and log-transformed them for our analyses.

Statistical modeling

Reproduction

We used mixed model analysis of variance (PROC MIXED in SAS 9.3; Littell et al. 2006) to test the *a priori* hypotheses described above with respect to reproduction. In these analyses, we treated reproduction (i.e.; the number of young fledged per territory per year) as the dependent variable, habitat covariates and female age (subadult or adult) as fixed effects, and territory identity and year (1993-2012) as random effects. We considered territory to be a random blocking factor because reproduction within a territory may not be independent among years. We treated reproduction as a normally distributed variable because McDonald and White (2010) found that analysis of variance procedures based on a normal distribution performed well for small count data similar to ours. Moreover, before examining *a priori* habitat models, we used restricted maximum likelihood estimation to model the following potential variance-covariance structures within territories across years: compound symmetric, first-order autoregressive, heterogeneous first-order autoregressive, and log–linear (Littell et al. 2006). Once we identified the best variance-covariance structure (i.e., lowest AIC value), we used full maximum likelihood estimation to model the influence of the fixed effects on reproduction according to the framework described above. We considered female age a factor in all models based on differences in reproduction between subadults and adults in previous studies (Blakesley et al. 2010).

Survival

We used the Cormack–Jolly–Seber open population model (CJS; Cormack 1964, Jolly 1965, Seber 1965) implemented in the R package *marked* (Laake et al. 2013) to test the *a priori* hypotheses described above with respect to apparent survival of spotted owls. Apparent survival refers to the inability to differentiate between true mortality and permanent emigration from the study area. While capture histories were developed based on the capture and resighting of individual spotted owls, our goal was to make inferences based on the habitat occupied by an owl, which varied by territory. Thus, we modified the capture histories used for the temporal analyses to reflect movement among territories (*sensu* Franklin et al. 2000). If an individual was not resighted for one or more years and was then resighted on a new territory, we removed the portion of its capture history pertaining to the original territory. We did this to avoid making assumptions about the owl's location during the intervening period. As a result, we used partial capture histories for 14 of the 350 individuals in our data set.

No methods exist for estimating overdispersion ($\hat{c}$) in CJS models containing individual covariates (Jeff Laake, pers. comm.), so instead we used Program MARK to estimate $\hat{c}$ for our most highly parameterized model without covariates, φ(age*sex*year) and *p*(age*sex*year). We found no evidence for a lack of model fit ($\hat{c}$ = 0.998). Prior to modeling survival rates, we first examined *a priori* model structures for the probability of recapture (p). We examined three covariates that may influence recapture probabilities: age (subadult or adult), sex, and survey effort (the amount of time spent conducting walk-in surveys each year) (Blakesley et al. 2010). Using the best model structure for p, we then followed the framework described above to model the influence of habitat and forest disturbance on apparent survival.

Occupancy

We used a multi-season occupancy model with parameters for local extinction (ε_t) and local colonization (γ_t) of spotted owl territories (MacKenzie et al. 2003). We separately modeled the extinction and colonization processes using Program PRESENCE v. 5.9 (Hines 2006). When modeling extinction, we specified a full time structure for colonization (i.e., different parameter estimates for each year), and vice versa when modeling colonization. The primary sampling periods were each year of the study, and the secondary sampling periods were the 10 bimonthly intervals within each year (see above). Two critical assumptions of this model were: 1) occupancy status at each territory did not change during the survey season (i.e., no permanent emigration); and 2) detections at each territory were independent (MacKenzie et al. 2006). Because nearly all of the owls on our study area were marked, we could determine when individuals moved among territories during the survey season. Such movements only occurred on 10 occasions during our study, and we only considered one of the territories to be occupied in these situations (i.e., where the individual was most frequently detected). In addition, we excluded nocturnal detections > 400 m from a territorial core area to help ensure independence of detections at territories. Finally, we interpreted occupancy as the proportion of territories used by owls during a breeding season because some territories may not have been continuously occupied throughout the entire season (MacKenzie et al. 2006).

We first examined *a priori* model structures for detection probabilities (p). For the occupancy analyses, p represented the probability of detecting an owl during a survey when the territory was occupied. Note that for the mark-recapture analyses, p represented the probability of recapturing an individual during a given year. We modeled within-year p using two covariates, *initial* and *repro* (Tempel and Gutiérrez 2013). *Initial* specified a different p for all survey occasions subsequent to the first detection at a territory each year, and *repro* indicated whether owls attempted to nest at a territory that year. We then modeled annual p with the following temporal effects—linear, log-linear, quadratic, different for each year, and constant. We selected the model with the best-fitting time structure and then introduced covariates for vegetation class (57 and 67) relative to p and initial occupancy probability (ψ_1). Using the best model structure, we then followed the framework described above to model the relationships between vegetation class and forest disturbance on territory extinction and colonization.

Sensitivity analyses

Life-stage simulation

We conducted life-stage simulation analyses (LSA) to assess which covariates had the greatest influence on annual population growth rate of spotted owls (λ) by estimating the amount of variation in λ explained by each covariate that appeared in the top-ranked models of reproduction and survival (Wisdom et al. 2000). We used a stage-based, post-breeding census Lefkovitch matrix model parameterized with reproductive and survival rates to represent changes in female population size:

$$\begin{bmatrix} N_{J,t+1} \\ N_{S1,t+1} \\ N_{S2,t+1} \\ N_{A,t+1} \end{bmatrix} = \begin{bmatrix} 0 & \varphi_{S,t} b_{S,t} & \varphi_{S,t} b_{A,t} & \varphi_{A,t} b_{A,t} \\ \varphi_{J,t} & 0 & 0 & 0 \\ 0 & \varphi_{S,t} & 0 & 0 \\ 0 & 0 & \varphi_{S,t} & \varphi_{A,t} \end{bmatrix} \begin{bmatrix} N_{J,t} \\ N_{S1,t} \\ N_{S2,t} \\ N_{A,t} \end{bmatrix} \qquad (1)$$

where $N_{J,t}$, $N_{S1,t}$, $N_{S2,t}$, and $N_{A,t}$, were the number of juvenile, first-year subadult, second-year subadult, and adult females at time t, respectively; $\varphi_{J,t}$, $\varphi_{S,t}$, and $\varphi_{A,t}$ were the apparent survival rates of juvenile, subadult, and adult females from time t to t+1, respectively; and $b_{S,t}$ and $b_{A,t}$ were the fecundity rates for subadult and adult females at time t, respectively. Fecundity was the number of female offspring produced per female in the population. We assumed a 1:1 sex ratio of offspring and divided the reproductive rate from our reproduction model by two. We estimated λ as the dominant eigenvalue of the matrix.

We expressed apparent survival and fecundity as functions of covariates and set the beta coefficients for all covariate effects equal to their estimated values from the top-ranked models for apparent survival and fecundity (Table C3). As an example, apparent survival was estimated as:

$$\text{logit}(\varphi) = \beta_0 + \beta_1*\text{sex} + \beta_2*\text{age} + \beta_3*\log(57) + \beta_4*\text{edge} \qquad (2)$$

where sex = 0 for females and 1 for males, and age = 0 for subadults and 1 for adults. Thus, apparent survival for non-juvenile females was estimated as:

$$\text{logit}(\varphi) = -1.010 + 0.452*\text{age} + 1.004*\log(57) + 0.763*\text{edge} \qquad (3)$$

We allowed the vegetation covariates to vary between the minimum and maximum values observed within any territory during the 20-year study period (range for area of 57 = 0–332.8 ha; range for edge = 0–28.5 km). In addition, we lacked reliable estimates of juvenile survival for our study area, so we used the reported estimate from an insular population of California spotted owls ($\varphi_{J,t}$ = 0.368; LaHaye et al. 2004). We ran additional simulations where we allowed juvenile survival to range from 0.318–0.418, and the results were nearly identical. We used SAS 9.3 (SAS Institute Inc., Cary, North Carolina, USA) to conduct 1,000 simulations in which we randomly generated sets of vegetation class covariate values from uniform probability distributions, estimated λ for each simulation, and regressed λ against each vegetation covariate for all 1,000 simulations. The percentage of variation in λ that was explained by each vegetation covariate was a measure of the sensitivity of λ to changes in the vegetation covariate (Wisdom et al. 2000).

Occupancy

Analogous to the LSA, we assessed which vegetation covariates had the greatest influence on the equilibrium territory occupancy (ψ_{Eq}) by estimating the variation in ψ_{Eq} explained by each covariate that appeared in our best-fitting dynamic occupancy models. If local extinction (ε) and local colonization (γ) rates are constant, ψ_{Eq} can be calculated as $\gamma/(\gamma + \varepsilon)$ (MacKenzie et al. 2006). This equation was equivalent to a mainland-island metapopulation model with no rescue effect (Hanski 1999), where each territory was a "subpopulation" within a larger population of spotted owl territories. While owl territories were not strictly subpopulations, they represented breeding units within our study area because we defined them as locations where reproduction was observed at least once. The proportion of occupied territories probably never reached equilibrium during our study, so the actual values of ψ_{Eq} should be interpreted with caution. Nevertheless, we believe our approach provided general insight into the importance of habitat and forest disturbance to occupancy dynamics of spotted owls.

We again set the beta coefficients for all covariate effects equal to their estimated values from the top-ranked models and allowed the vegetation covariates (except for the amount of wildfire; see below) to vary between their minimum and maximum observed values. As with the LSA, we used SAS 9.3 to conduct 1,000 simulations, determined ψ_{Eq} for each simulation, and regressed ψ_{Eq} against each vegetation covariate for all 1,000 simulations.

We handled the wildfire covariate, which appeared in the territory colonization model, in a more spatially explicit manner. The effect of wildfire on territory colonization was strongly negative due to a high-severity fire that occurred on our study area in 2001 and completely burned two territories, which were subsequently never colonized by owls. However, most owl territories were unaffected by wildfire as fire occurred within only 12 territories during our study. Therefore, we defined two types of territories—burned and unburned. For each simulation, we randomly varied the number of territories that burned from 1 to 12. For burned territories, we then randomly varied the amount of wildfire from 0-400 ha. We separately calculated γ and ψ_{Eq} for burned and unburned territories and calculated an overall ψ_{Eq} for the 74 territories as a weighted average of ψ_{Eq}. We regressed ψ_{Eq} against the average amount of wildfire in all 74 territories; for example if 100 ha of wildfire occurred in 6 territories during a simulation, then the average amount of wildfire per territory was 8.1 ha (600/74). In addition, we conducted 1,000 additional simulations where we varied the number of burned territories from 1 to 24 to represent a scenario of increased wildfire activity.

IV. Results

The results from the reproduction, survival, and occupancy analyses were similar for the three temporal scales (3, 6, and 9 years) used to calculate the timber harvest and wildfire covariates. Thus, we only present results for models containing timber harvest and wildfire covariates using the 6-year time frame and used this time frame for the sensitivity analyses as well.

Reproduction

We assessed reproduction on 676 occasions at 70 territories, excluding territories with fewer than three reproductive observations and cases where territories were occupied by a single owl. Mean number of young fledged per territory per year was 0.612 (SE = 0.032), and we detected 0, 1, 2, and 3 young on 62.1%, 14.8%, 22.8%, and 0.30% of the sampling occasions, respectively. The auto-regressive variance-covariance structure was supported over the compound-symmetric (ΔAIC = 7.6) or default (ΔAIC = 13.9) variance-covariance structures. This structure indicated that reproduction in consecutive years was negatively correlated (ARH1 = -0.148, SE = 0.048) and was used in all subsequent modeling of fixed effects. The random year and territory effects were either statistically significant or nearly statistically significant (year: Z = 2.74, p = 0.003; territory: Z = 1.28, p = 0.100), so we retained both random effects when modeling fixed effects.

None of the vegetation covariates considered in step 1 (linear and nonlinear forms of 57 and 67) lowered the AIC value when added to a model containing only female age. The top-ranked model from step 2 included covariates for the area of hardwood forest within a territory and female age, and was 2.90 AIC units lower than the second-ranked model. The best overall model from step 3 contained a covariate for the area of medium-intensity timber harvests, but this model was only 0.50 AIC units lower than the best model from step 2 (Table C3). This model suggested a negative influence of medium-intensity timber harvests on reproduction of spotted owls, but we found only weak support for this effect based on the degree to which the 95% CI of the beta coefficient overlapped zero ($\beta_{medium} = -0.065$, 95% CI = −0.145 to 0.016; Fig. C3a). In addition, adult females had higher reproduction than subadults ($\beta_{adult} = 0.335$, 95% CI =

0.136—0.533), and reproduction was negatively related to the area of hardwood forests ($\beta_{hardwood}$ = −0.123, 95% CI = −0.219 to −0.027) (Fig. C3a).

Survival

We estimated apparent survival using 350 individual capture histories. The best structure for recapture probability contained covariates for age, sex, and survey effort. Recapture probability was higher for adults (β_{adult} = 1.320, 95% CI = 0.522—2.119) and males (β_{male} = 0.571, 95% CI = 0.121—1.022) and was positively correlated with annual survey effort (β_{effort} = 1.607, 95% CI = 0.342—2.872). We used this structure for recapture probability in all subsequent modeling of survival. Real values of recapture probability estimates were high. When annual survey effort was set equal to its mean value, recapture probability was estimated to be 0.92, 0.87, 0.75, and 0.63 for adult males, adult females, subadult males, and subadult females, respectively.

The top-ranked survival model in step 1 contained covariates for sex, age, and the logarithm of the combined area of vegetation classes 5 and 7. The constant model was 7.16 AIC units behind this top-ranked model. The top-ranked model from step 2 also contained a covariate for the amount of habitat edge within a territory, and was 7.14 AIC units lower than the second-ranked model. None of the step 3 covariates (timber harvest, wildfire) lowered the AIC value when added to the best model from step 2. The second-ranked overall model (ΔAIC = 1.71) contained a covariate for the area of medium-intensity timber harvests (Table C3), but this model was poorly supported given that the maximum possible ΔAIC is 2 when an uninformative parameter is added (Arnold 2010). In the top-ranked model, adults (β_{adult} = 0.452, 95% CI = 0.016—0.889) and males (β_{male} = 0.304, 95% CI = 0.034—0.575) had higher survival rates than subadults and females, respectively. Survival was positively correlated with the area of 57 ($\beta_{log(57)}$ = 1.004, 95% CI = −0.337 to 2.345) (Fig. C3b) and the amount of edge (β_{edge} = 0.763, 95% CI = −0.104 to 1.629) (Fig. C3b), but the 95% CI for the beta coefficients overlapped zero. If we set the habitat covariates equal to their mean value for all territories, apparent survival was estimated to be 0.73, 0.66, 0.63, and 0.56 for adult males, adult females, subadult males, and subadult females, respectively. These values were lower than previous estimates of annual survival (cf. Tempel and Gutiérrez 2013) because we removed portions of the capture history for

14 individuals that switched territories during our study but did not reappear on the new territory until a number of years had elapsed (see Methods—*Statistical modeling*), and thus lost information on their survival during the intervening period.

Occupancy

We estimated territory extinction and colonization probabilities using 4,907 survey occasions. The best model for detection probability (p) indicated that p was different for each year. Within years, p was higher at territories with reproducing owls (β_{repro} = 1.566, 95% CI = 1.339–1.794), at territories containing more forest dominated by large trees (β_{67} = 0.017, 95% CI = 0.000–0.033), and on surveys subsequent to the initial detection of owls at a territory ($\beta_{initial}$ = 1.185, 95% CI = 1.011–1.359). The probability of initial occupancy (ψ_1) was not dependent on the amount of vegetation classes 57 or 67 within a territory (i.e., ψ_1 was constant). We used this structure for detection and initial occupancy probabilities for all subsequent modeling of territory extinction and colonization. Real values of detection probability estimates were high. When the area of forest with large trees was set equal to its mean value for all territories, detection probability was estimated to be 0.94, 0.83, 0.77, and 0.50 at territories with reproducing owls after the initial detection, territories with reproducing owls before the initial detection, territories with non-reproducing owls after the initial detection, and territories with non-reproducing owls before the initial detection, respectively.

Territory extinction

The top-ranked model from step 1 contained a covariate for the combined area of vegetation classes 5 and 7. The top-ranked model from step 2 included a covariate for habitat diversity in addition to the area of 57 and was 4.28 AIC units lower than the second-ranked model. The best overall model from step 3 also included the area of high-intensity timber harvests. In this model, territory extinction was negatively correlated with the area of 57 (β_{57} = −0.117, 95% CI = −0.189 to −0.044), such that occupied territories with greater amounts of 57 were less likely to become extinct (Fig. C3c). Surprisingly, territory extinction was also negatively correlated with the area of high-intensity timber harvests (β_{high} = −0.776, 95% CI = −1.327 to −0.224). Finally, territory extinction was positively correlated with habitat diversity ($\beta_{diversity}$ = 1.509, 95% CI = 0.148−2.871) (Fig. C3c).

Territory colonization

The top-ranked model from step 1 contained a covariate for the logarithm of the combined area of vegetation classes 5 and 7. The top-ranked model from step 2 contained an additional covariate for habitat diversity and was 1.57 AIC units lower than the second-ranked model. The best overall model from step 3 included the area of wildfire that occurred within a territory. In this model, wildfire had a strong negative effect on territory colonization (β_{fire} = −24.057), but the standard error was unestimable because of the small number of territories that experienced fire. However, the value for β_{fire} was consistent across all of the models. Territory colonization was positively correlated with the area of 57 ($\beta_{log(57)}$ = 1.299, 95% CI = −0.857 to 3.456) (Fig. C3d) and habitat diversity ($\beta_{diversity}$ = 2.985, 95% CI = −0.222 to 6.191) (Fig. C3d), but the beta coefficients had 95% CI's that overlapped zero, suggesting that these effects were relatively weak.

Sensitivity analyses

Life-stage simulation

Estimates of apparent survival from our simulations ($\bar{\bar{\varphi}}_A$ = 0.68, 95% CI = 0.54–0.76; $\bar{\bar{\varphi}}_S$ = 0.58, 95% CI = 0.42–0.67) were lower than those previously reported for this population (Blakesley et al. 2010) because we removed part of the capture histories for 14 individuals that relocated to different territories after a "missing" interval of one or more years (see Methods—*Sensitivity analyses*). Estimates of fecundity from our simulations were higher for adults ($\bar{\bar{b}}_A$ = 0.22, 95% CI = 0.18–0.28) than for subadults ($\bar{\bar{b}}_S$ = 0.05, 95% CI = 0.02–0.11), a pattern that has been previously reported for this study population (Blakesley et al. 2010).

Population growth rate was most sensitive (positive correlations) to the area of 57 and habitat edge, the two covariates that also best explained variation in apparent survival. We noted that population growth rate and the area of 57 were clearly related in a non-linear fashion, so we calculated R^2 using a logarithmic relationship for this covariate; we specified a linear relationship for all other covariates. Population growth rate was positively correlated with the area of 57 (R^2 = 0.74, Fig. C4a) and habitat edge (R^2 = 0.32; Fig. C4b). In contrast, population growth rate was not sensitive to either of the covariates used to model reproduction (area of medium-intensity harvests: R^2 <0.01; area of hardwood forests: R^2 = 0.02; Fig. C4c-d). Population growth rate was always less than 1.0 ($\bar{\bar{\lambda}}$ = 0.73, 95% CI = 0.57–0.82), but we expected our matrix model to underestimate λ in the presence of immigration (Peery et al. 2006). Additionally, as we noted above, our apparent survival estimates were biased low. Nonetheless, changes in population growth rate allowed us to evaluate the relative importance of each covariate.

Occupancy

Estimates of territory colonization from our simulations were strongly dependent upon the occurrence of wildfire during the previous six years ($\bar{\bar{\gamma}}_{\text{no fire}}$ = 0.21, 95% CI = 0.04–0.52; $\bar{\bar{\gamma}}_{\text{fire}}$ = 0.00, 95% CI = 0.00–0.00) because we only observed three post-fire colonization events at burned territories in the following six years. However, fire did not negatively affect territory occupancy in all cases. For example, the largest and most intense fire occurred on our study area in 2001 and impacted nine owl territories. Five of these territories remained occupied every year after the fire, and thus, post-fire colonization could not occur at these sites. Estimates of territory extinction were low ($\bar{\bar{\varepsilon}}$ = 0.03, 95% CI = 0.00–0.12), which reflected the strong site fidelity displayed by spotted owls (e.g., Blakesley et al. 2005, Seamans and Gutiérrez 2007*a*).

Equilibrium occupancy was most sensitive (positive correlation) to the area of 57 within a territory. We again noted a non-linear relationship between equilibrium occupancy and the area of 57 and calculated R^2 using a logarithmic relationship for this covariate (R^2 = 0.87; Fig. C5a). Equilibrium occupancy was not sensitive to changes in habitat diversity (R^2 = 0.02; Fig. C5b) or high-intensity timber harvests (R^2 = 0.01; Fig. C5c). Equilibrium occupancy was weakly negatively correlated with wildfire when it occurred at the same frequency as during our study (R^2 = 0.02; Fig. C5d). However, when we doubled the frequency of wildfire to represent a future scenario of increased fire activity, we found a stronger negative association between the area burned and equilibrium occupancy (R^2 = 0.11; Fig. C5e). As a result, equilibrium occupancy was higher under the scenario with fewer fires ($\bar{\bar{\psi}}$ = 0.78, 95% CI = 0.37–0.96) than the scenario with more fires ($\bar{\bar{\psi}}$ = 0.72, 95% CI = 0.36–0.94).

V. Discussion

We characterized associations between territory-scale changes in forest conditions and demographic rates in a declining population of California spotted owls to assess the potential consequences of implementing landscape-scale fuel treatments in the Sierra Nevada. While the correlative nature of our study posed constraints on inferences (see below), we used 20 years of data on owl demography, forest treatments, and detailed changes in forest conditions. Our study differed from most previous, long-term spotted owl studies in that we quantified habitat within owl territories on an annual basis, rather than assuming that habitat was static over time. Thus, we believe that the relationships we detected can help guide forest management intended to balance reductions in high-severity fires with the needs of a key old-forest associated species in the Sierra Nevada, as well as provide insight into mechanisms responsible for observed declines in California spotted owls in this region.

The amount of high (>70%) canopy cover forest dominated by medium- or large-sized trees was the most important predictor of variation in demographic rates as this variable occurred in the top-ranked models for survival, territory extinction, and territory colonization rates, and explained far more variation in population growth rate and equilibrium occupancy than other covariates based on our simulations. This result is consistent with previous studies of northern and California spotted owls that found the area of high-canopy forest was strongly correlated with adult survival, and in some cases, reproduction and occupancy of territories (Franklin et al. 2000, Blakesley et al. 2005, Dugger et al. 2005, Seamans and Gutiérrez 2007*a*). We also found that forests with large trees and a lower canopy cover threshold (>30%) was not a significant predictor of owl vital rates. This finding suggested that high canopy cover was a more important habitat component than large trees, although forests containing both were likely the highest quality habitat. The specific reasons for why high-canopy forests are important for California spotted owls are unknown, but prey availability, predator avoidance, or microclimate may all be important factors (Verner et al. 1992). Nevertheless, consistent positive associations between demographic rates of spotted owls and high-canopy forest across studies and subspecies indicate the importance of these forest conditions for spotted owl populations.

The positive association between owl demographic rates and high-canopy forest, coupled with the average loss of 10.6 ha (7.4%) of high-canopy forest within territories on the DSA from 1993-2012 (Fig. C6a), suggests that habitat loss may have been at least partially responsible for the observed ~30% decline in abundance and territory occupancy in our study population (Tempel and Gutiérrez 2013). We were unable to assess the potential lag effects associated with habitat change prior to 1993 when more stringent harvesting guidelines were implemented on public land (USFS 1993), and thus, observed declines could also reflect the historic legacy of timber harvesting. Nevertheless, many factors not considered here such as predation, prey availability, and disease could also have contributed to population declines. Associations between high-canopy forest and both population growth and equilibrium occupancy were non-linear such that further loss of habitat could lead to relatively rapid declines in abundance and occupancy (Figs. C3a and C4a). For example, 26 owl territories currently contain between 100 and 150 ha of high-canopy forest (Fig. C6b). If the average amount of high-canopy forest within territories were reduced from 150 to 100 ha, the estimated decrease in population growth rate ($\lambda_{150\text{ ha}} = 0.740$, $\lambda_{100\text{ ha}} = 0.720$) would lead to a significant difference in realized population change when extrapolated over long time periods. We expected our estimates of population growth rate to be biased low, but the importance of high-canopy forest nevertheless can be assessed by relative changes in population growth rate.

As predicted, medium-intensity timber harvests characteristic of proposed fuel treatments were negatively related to reproduction of spotted owls in our study. Reproduction appeared sensitive to modest amounts of medium-intensity harvests, and was predicted to decline from 0.54 to 0.45 when 20 ha were treated (assuming the mean area of hardwoods in territories [60 ha]). Greater areas harvested in this manner only resulted in slightly larger declines in reproduction (Fig. C3a). The mechanism linking medium-intensity timber harvests to declines in reproduction is not entirely clear, but the thinning practices characteristic of medium-intensity harvests typically reduce the vertical forest structure and understory complexity that are believed to be important characteristics of foraging conditions used by spotted owls (Verner et al. 1992). While we detected an overall effect of medium-intensity timber harvests on reproduction, we did not detect an effect of understory removal independent of modifications to the overstory for medium-intensity harvests. While understory removal is generally an important component of fuel-reduction strategies, we caution that medium-intensity harvesting with understory treatments occurred on only 5.2% of the total area within owl territories, which could have limited our power to detect effects.

Unlike reproduction, we did not detect a relationship between the area of medium-intensity harvests and apparent survival or territory occupancy. The absence of an association is perhaps not surprising given the spotted owl's "bet-hedging" life-history strategy where individuals have evolved long-life spans and forgo reproduction when environmental conditions are unfavorable without compromising life-time reproductive success (Seamans and Gutiérrez 2007*b*). In addition, only 42.8% of medium-intensity harvests occurred in high-canopy forests; thus, over half of these harvests occurred in habitats that might be less important to spotted owls (Fig. C6c). When medium-intensity harvests *were* implemented within high-canopy forests, they reduced the canopy sufficiently for mapped polygons to be reclassified into a lower-canopy vegetation class in 90.1% of these treated areas (Fig. C6d). As described above, such changes were associated with reductions in survival and territory colonization rates, as well as increases in territory extinction rates. As a result, we believe the most appropriate inference about the influence of medium-intensity harvesting practices is that they appear to reduce reproductive potential, and when implemented in high-canopy forests, likely reduce survival and territory occupancy as well.

Contrary to our prediction, the probability of a territory going extinct was reduced in proportion to the area harvested with high-intensity practices such as clearcutting and shelterwood harvest. In principle, harvesting prescriptions creating small gaps might promote brushy habitat suitable for prey species such as woodrats and increase prey availability for spotted owls along the edges of forested habitats (Sakai and Noon 1997). Similarly, we found that owl survival and population growth were positively associated with the amount of habitat edge between shrubs/saplings and forests dominated by trees ≥30.5 cm dbh, so the juxtaposition of owl and prey habitat could be important as suggested by Franklin et al. (2000). Nevertheless, these associations are largely speculative without direct evidence of foraging by owls and elevated prey availability along ecotones. Moreover, high-intensity treatments occurred on only 5.4% of the total area within our owl territories and larger scale implementation of heavy harvesting could have adverse impacts on spotted owls. Finally, flying squirrels are the most important prey by biomass within our study area (Gutiérrez, *unpublished data*), and intensive harvesting practices are believed to negatively impact this species (Waters and Zabel 1995, Manning et al. 2012). Thus, while detailed studies of prey availability and spotted owl foraging near brush habitat are merited, we believe it would be premature to implement such timber harvesting practices as a tool for managing prey availability for California spotted owls.

While our results suggested that fuel treatments can have negative and direct impacts on spotted owl habitat quality in the short-term, comprehensive assessments must consider the potential long-term benefits of reduced wildfire risk. Long-term benefits will depend on both the risk that fire poses to spotted owls and the extent to which fuel treatments reduce high-severity fires. We detected a large decline in territory colonization following wildfire, but not all burned territories were negatively affected by fire. Several burned territories remained occupied in all years after a fire (see Results—*Sensitivity analyses*), and as a result, colonization could not occur by definition. Post-fire salvage logging occurred within two years of the Star Fire, and its effects on territory colonization were confounded with the effects of the fire itself. However, we believe that the negative effect of the fire on colonization was primarily due to habitat loss that resulted directly from the fire. While our results were somewhat consistent with other studies that detected adverse impacts of high-severity fires on spotted owls, particularly when coupled with salvage logging (Clark et al. 2013, Lee et al. 2013), the effect of wildfire on spotted owls and their habitat is undoubtedly complex (Bond et al. 2009, 2013). Nonetheless, because equilibrium occupancy declined more under a scenario of increased fire activity (Fig. C5e), which is projected under some climate change scenarios (Liu et al. 2013), we believe a valid need exists to reduce the risk of wildfire to spotted owls. Previous modeling efforts indicated that the benefits of reducing habitat loss from high-severity fires outweighed the impacts of fuel treatments on forest conditions used by spotted owls (Lee and Irwin 2005, Ager et al. 2007). However, these studies were either conducted for northern spotted owls in another physiographic province (Ager et al. 2007) or did not assess the immediate effects of fuel treatments on California spotted owl demographic rates using empirical data (Lee and Irwin 2005). Thus, additional research is needed to determine the long-term trade-offs between direct reductions in owl habitat from fuel treatments versus habitat loss from increased fire frequency or severity.

We suggest the following caveats from our study when considering the impact to spotted owls from forest fuel treatments and wildfire. First, our study was observational, not experimental, and thus observed relationships between covariates and owl demographic rates were correlative and not directly attributable to cause-and-effect. Second, a broad range of timber harvests occurred within owl territories during our study, which may have confounded our ability to assess specific management practices (e.g., fuel-reduction treatments following current management prescriptions; USFS 2004). Nevertheless, proposed fuel-reduction treatments have similar effects on forest structure to those in our medium-intensity timber harvest category (see Methods—*Vegetation and forest treatment mapping*). Third, we used aerial photos to compile our vegetation map, which required us to subjectively categorize vegetation classes into relatively coarse bins. Thus, we were unable to assess the potential effects of small (e.g., 10%) reductions in canopy cover that did not result in changes in vegetation class. Our mapping approach also precluded the inclusion of potentially important habitat elements such as large, residual trees and understory structure. Large trees are known to be important components of nesting and roosting conditions used by spotted owls (Bias and Gutiérrez 1992, Moen and Gutiérrez 1997), and the high-canopy forest that we found to be highly correlated with owl demographic rates included vegetation class 7 (trees with dbh ≥76.2 cm). Finally, the potential effects of habitat, forest treatments, and wildfire within owl territories were likely confounded with differences in individual quality, which can be an important source of variation in avian demographic rates (e.g., Goodburn 1991, Espie et al. 2004, Sergio et al. 2009). Despite these caveats, we identified several reasonable predictors of spotted owl demographic parameters supported by prior knowledge of spotted owl environmental requirements that we believe can contribute to forest management.

VI. Management implications for spotted owls

Our results suggest that reductions in the area of high-canopy forest resulting from either logging or high-severity wildfire could reduce the viability of California spotted owl populations and may be contributing to ongoing declines in abundance and territory occupancy (Conner et al. 2013, Tempel and Gutiérrez 2013). Nevertheless, our results also suggest that fuel treatments that occur in lower-canopy forests (<70%) or do not significantly reduce canopy cover in high-canopy forests are less likely to have adverse impacts on spotted owls. While such a constraint may seem restrictive because fuels-reduction treatments necessarily target dense, fire-prone stands, we note that 50.7% of all medium-intensity harvests implemented from 1993-2012 occurred in medium-sized forest with low canopy cover (vegetation class 4 = 40.1%) or large-sized forest with low canopy cover (vegetation class 6 = 10.6%; Fig. C6c). Moreover, fuel treatments in dense stands can emphasize thinning from below while maintaining sufficient canopy cover and some vertical stand structure (Verner et al. 1992). Zielinski et al. (2013) recently concluded that it may be possible to implement fuel-reduction treatments that achieve fire-reduction goals without affecting occupancy by fishers, another species associated with older forests in the Sierra Nevada. However, they did not distinguish among different types of timber harvest, nor did they assess where timber harvests occurred with respect to pre-existing vegetation types. We recommend that landscape-scale fuel treatments intended to reduce fire risk in the Sierra Nevada proceed with caution to reduce the chance of impacting old-forest associated species, particularly in high-canopy forests. Specifically, we recommend that fuel treatments focus on ladder fuels and reduction in tree density while maintaining relatively high canopy cover. Given the uncertain relationship between timber harvest and demography of spotted owls, we suggest that landscape-scale fuel treatments be accompanied by a rigorous monitoring program.

VII. References

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Washington, D.C.: Island Press.

Ager, A.A., M.A. Finney, B.K. Kerns, and H. Maffei. 2007. Modeling wildfire risk to northern spotted owl (*Strix occidentalis caurina*) habitat in Central Oregon, USA. Forest Ecology and Management 246: 45–56.

Arnold, T.W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management 74: 1175–1178.

Berigan, W.J., R.J. Gutiérrez, and D.J. Tempel. 2012. Evaluating the efficacy of protected habitat areas for the California spotted owl using long-term monitoring data. Journal of Forestry 110: 299–303.

Bias, M.A., and R.J. Gutiérrez. 1992. Habitat associations of California spotted owls in the central Sierra Nevada. Journal of Wildlife Management 56: 584–595.

Blakesley, J.A., B.R. Noon, and D.R. Anderson. 2005. Site occupancy, apparent survival, and reproduction of California spotted owls in relation to forest stand characteristics. Journal of Wildlife Management 69: 1554–1564.

Blakesley, J.A., M.E. Seamans, M.M. Conner, A.B. Franklin, G.C. White, R.J. Gutiérrez, J.E. Hines, J.D. Nichols, T.E. Munton, D.W.H. Shaw, J.J. Keane, G.N. Steger, and T.L. McDonald. 2010. Population dynamics of spotted owls in the Sierra Nevada, California. Wildlife Monographs 174: 1–36.

Bond, M.L., D.E. Lee, R.B. Siegel, and M.W. Tingley. 2013. Diet and home-range size of California spotted owls in a burned forest. Western Birds 44: 114–126.

Bond, M.L., D.E. Lee, R.B. Siegel, and J.P. Ward, Jr. 2009. Habitat use and selection by California spotted owls in a postfire landscape. Journal of Wildlife Management 73: 1116–1124.

Burnham, K.P. and D.R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. New York, NY: Springer-Verlag.

Chatfield, A.H. 2005. Habitat selection by a California spotted owl population: a landscape scale analysis using resource selection functions. Thesis, University of Minnesota, Saint Paul, MN.

Clark, D.A., R.G. Anthony, and L.S. Andrews. 2013. Relationship between wildfire, salvage logging, and occupancy of nesting territories by northern spotted owls. Journal of Wildlife Management 77: 672–688.

Collins, B.M., S.L. Stephens, J.J. Moghaddas, and J. Battles. 2010. Challenges and approaches in planning fuel treatments across fire-excluded forested landscapes. Journal of Forestry 108: 24–31.

Collins, B.M., S.L. Stephens, G.B. Roller, and J.J. Battles. 2011. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. Forest Science 57: 77–88.

Conner, M.M., J.J. Keane, C.V. Gallagher, G. Jehle, T.E. Munton, P.A. Shaklee, and R.A. Gerrard. 2013. Realized population change for long-term monitoring: California spotted owl case study. Journal of Wildlife Management 77: 1449–1458.

Cormack, R.M. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51: 429–438.

Dugger, K.M., F. Wagner, R.G. Anthony, and G.S. Olson. 2005. The relationship between habitat characteristics and demographic performance of northern spotted owls in southern Oregon. Condor 107: 863–878.

Espie, R.H.M., P.C. James, L.W. Oliphant, I.G. Warkentin, and D.J. Lieske. 2004. Influence of nest-site and individual quality on breeding performance in Merlins *Falco columbarius*. Ibis 146: 623–631.

Finney, M.A. 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. Forest Science 47: 219–228.

Finney, M.A., R.C. Seli, C.W. McHugh, A.A. Ager, B. Bahro, and J.K. Agee. 2007. Simulation of long-term landscape-level fuel treatment effects on large wildfires. International Journal of Wildland Fire 16: 712–727.

Forsman, E.D., E.C. Meslow, and H.M. Wight. 1984. Distribution and biology of the spotted owl in Oregon. Wildlife Monographs 87: 1–64.

Forsman, E.D., R.G. Anthony, K.M. Dugger, E.M. Glenn, A.B. Franklin, G.C. White, C.J. Schwarz, K.P. Burnham, D.R. Anderson, J.D. Nichols, J.E. Hines, J.B. Lint, R.J. Davis, S.H. Ackers, L.S. Andrews, B.L. Biswell, P.C. Carlson, L.V. Diller, S.A. Gremel, D.R. Herter, J.M. Higley, R.B. Horn, J.A. Reid, J. Rockweit, J.P. Schaberl, T.J. Snetsinger, and S.G. Sovern. 2011. Population demography of northern spotted owls. Studies in Avian Biology, No. 40. Berkeley, CA: University of California Press.

Franklin, A.B., D.R. Anderson, E.D. Forsman, K.P. Burnham, and F.W. Wagner. 1996. Methods for collecting and analyzing demographic data on the northern spotted owl. Studies in Avian Biology 17: 12–20.

Franklin, A.B., D.R. Anderson, R.J. Gutiérrez, and K.P. Burnham. 2000. Climate, habitat quality, and fitness in northern spotted owl populations in northwestern California. Ecological Monographs 70: 539–590.

Goodburn, S.F. 1991. Territory quality or bird quality? Factors determining breeding success in the Magpie *Pica pica*. Ibis 133: 85–90.

Gutiérrez, R.J. 1994. Changes in the distribution and abundance of spotted owls during the past century. Studies in Avian Biology 15: 293–300.

Hanski, I. 1999. Metapopulation ecology. Oxford, UK: Oxford University Press.

Hines, J.E. 2006. PRESENCE2—software to estimate patch occupancy and related parameters. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, MD. Available at: <http://www.mbr-pwrc.usgs.gov/software/presence.html>, accessed June 15, 2013.

Innes, R.J., D.H.V. Vuren, D.A. Kelt, M.L. Johnson, J.A. Wilson, and P.A. Stine. 2007. Habitat associations of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forest of the northern Sierra Nevada. Journal of Mammalogy 88: 1523–1531.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika 52: 225–247.

Laake, J.L., D.S. Johnson, and P.B. Conn. 2013. *marked*: an R package for maximum likelihood and Markov Chain Monte Carlo analysis of capture-recapture data. Methods in Ecology and Evolution 4: 885–890.

LaHaye, W.S., G.S. Zimmerman, and R.J. Gutiérrez. 2004. Temporal variation in the vital rates of an insular population of spotted owls (*Strix occidentalis occidentalis*): contrasting effects of weather. Auk 121: 1056–1069.

Lee, D.E., M.L. Bond, M.I. Borchert, and R. Tanner. 2013. Influence of fire and salvage logging on site occupancy of spotted owls in the San Bernardino and San Jacinto Mountains of southern California. Journal of Wildlife Management 77: 1327–1341.

Lee, D.C., and L.L. Irwin. 2005. Assessing risks to spotted owls from forest thinning in fire-adapted forests of the western United States. Forest Ecology and Management 211: 191–209.

Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O. Schnabenberger. 2006. SAS for Mixed Models. Cary, NC: SAS Institute Inc.

Liu, Y., S.L. Goodrick, and J.A. Stanturf. 2013. Future U.S. wildfire potential trends projected using a dynamically downscaled climate change scenario. Forest Ecology and Management 294: 120–135.

MacKenzie, D.I., J.D. Nichols, J.E. Hines, M.G. Knutson, and A.B. Franklin. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. Ecology 84: 2200–2207.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2006. Occupancy estimation and modeling. Boston, MA: Elsevier/Academic Press.

Mallek, C., H. Safford, J. Viers, and J. Miller. 2013. Modern departures in fire severity and area vary by forest type, Sierra Nevada and southern Cascades, California, USA. Ecosphere 4:153.

Manning, T., J.C. Hagar, and B.C. McComb. 2012. Thinning of young Douglas-fir forests decreases density of northern flying squirrels in the Oregon Cascades. Forest Ecology and Management 264: 115–124.

Mayer, K.E., and W.F. Laudenslayer, Jr. 1988. A guide to wildlife habitats of California. California Department of Fish and Game, Sacramento, CA.

McDonald, T.L., and G.C. White. 2010. A comparison of regression models for small counts. Journal of Wildlife Management 74: 514–521.

Miller, J.D., and H. Safford. 2012. Trends in wildfire severity: 1984 to 2010 in the Sierra Nevada, Modoc Plateau, and southern Cascades, California, USA. Fire Ecology 8: 41–57.

Miller, J.D., H.D. Safford, M. Crimmins, and A.E. Thode. 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. Ecosystems 12: 16–32.

Moen, C.A., A.B. Franklin, and R.J. Gutiérrez. 1991. Age determination of subadult northern spotted owls in northwest California. Wildlife Society Bulletin 19: 489–493.

Moen, C.A., and R.J. Gutiérrez. 1997. California spotted owl habitat selection in the central Sierra Nevada. Journal of Wildlife Management 61: 1281–1287.

Noss, R.F., J.F. Franklin, W.L. Baker, T. Schoennagel, and P.B. Moyle. 2006. Managing fire-prone forests in the western United States. Frontiers in Ecology and the Environment 4: 481–487.

Peery, M.Z., B.H. Becker, and S.R.Beissinger. 2006. Combining demographic and count-based approaches to identify source-sink dynamics of a threatened seabird. Ecological Applications 16: 1516–1528.

Rempel, RS., D. Kaukinen., and AP. Carr. 2012. Patch Analyst and Patch Grid. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada.

Sakai, H.F., and B.R. Noon. 1993. Dusky-footed woodrat abundance in different-aged forests in northwestern California, USA. Journal of Wildlife Management 57: 373–382.

Sakai, H.F., and B.R. Noon. 1997. Between-habitat movement of dusky-footed woodrats and vulnerability to predation. Journal of Wildlife Management 61: 343–350.

Seamans, M.E. and R.J. Gutiérrez. 2007*a*. Habitat selection in a changing environment: the relationship between habitat alteration and spotted owl territory occupancy and breeding dispersal. Condor 109: 566–576.

Seamans, M.E., and R.J. Gutiérrez. 2007*b*. Sources of variability in spotted owl population growth rate: testing predictions using long-term mark-recapture data. Oecologia 152: 57–70.

Seber, G.A.F. 1965. A note on the multiple recapture census. Biometrika 52: 52.

Sergio, F., J. Blas, R. Baos, M.G. Forero, J.A. Donázar, and F. Hiraldo. 2009. Short- and long-term consequences of individual and territory quality in a long-lived bird. Oecologia 160: 507–514.

Stephens, S.L., J.K. Agee, P. Z. Fulé, M.P. North, W.H. Romme, T.W. Swetnam, and M.G. Turner. 2013. Managing forests and fire in changing climates. Science 342:41–42.

Stephens, S.L., S.W. Bigelow, R.D. Burnett, B.M. Collins, C.V. Gallagher, J. Keane, D.A. Kelt, M.P. North, L.J. Roberts, P.A. Stine, and D.H. Van Vuren. 2014. California spotted owl, songbird, and small mammal responses to landscape-scale fuel treatments Bioscience 64:893–906.

Stephens, S.L., M.P. North, and B.M. Collins. 2015. Large wildfires in forests: what can be done. American Institute of Biological Sciences, Action Bioscience http://www.actionbioscience.org/environment/large_wildfires_in_forests_what_can_be_done.html#learnmore.

Tempel, D.J., and R.J. Gutiérrez. 2013. Relation between occupancy and abundance for a territorial species, the California spotted owl. Conservation Biology 27: 1087–1095.

USFS. 1993. California spotted owl Sierran Province interim guidelines environmental assessment. US Forest Service, Pacific Southwest Region, Albany, CA.

USFS. 2004. Sierra Nevada forest plan amendment: final supplemental environmental impact statement. US Forest Service, Pacific Southwest Region, Vallejo, CA.

Verner, J., R.J. Gutiérrez, G.I. Gould, Jr., K.S. McKelvey, B.R. Noon, and T.W. Beck. 1992. The California spotted owl: general biology and ecological relations. Pages 55–77 *in* J. Verner, K. S. McKelvey, B. R. Noon, R. J. Gutiérrez, G. I. Gould, Jr., and T. W. Beck, editors. The California spotted owl: a technical assessment of its current status. U.S. Forest Service, Pacific Southwest Research Station, Albany, CA.

Waters, J.R., and C.J. Zabel. 1995. Northern flying squirrel densities in fir forests of northeastern California. Journal of Wildlife Management 59: 858–866.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313: 940–943.

Westerling, A.L., and B.P. Bryant. 2008. Climate change and wildfire in California. Climatic Change 87(Suppl 1): S231–S249.

Williams, P.J., R.J. Gutiérrez, and S.A. Whitmore. 2014. Use of private lands for foraging by California spotted owls in the central Sierra Nevada. Wildlife Society Bulletin 38: 705–709.

Wisdom, M.J., L.S. Mills, and D.F. Doak. 2000. Life stage simulation analysis: estimating vital-rate effects on population growth for conservation. Ecology 81: 628–641.

Zielinski, W.J., R.L. Truex, F.V. Schlexer, L.A. Campbell, and C. Carroll. 2005. Historical and contemporary distributions of carnivores in forests of the Sierra Nevada, California, USA. Journal of Biogeography 32: 1385–140.

Zielinski, W.J., C.M. Thompson, K.L. Purcell, and J.D. Garner. 2013. An assessment of fisher (*Pekania pennanti*) tolerance to forest management intensity on the landscape. Forest Ecology and Management 310: 821–826.

Table C1: Description of vegetation classes used to characterize forest conditions used by spotted owls in the central Sierra Nevada, California.

Veg class	Description	dbh (cm)	Canopy cover (%)
1	Hardwood forest		>10 hardwood and <10 conifer
2	Shrubs and/or saplings	<15.2	
3	Pole conifer forest	15.2 - 30.4	
4	Medium-sized, low-canopy conifer forest	30.5 - 60.9	30 - 69
5	Medium-sized, high-canopy conifer forest	30.4 - 60.9	≥70
6	Large-sized, low-canopy conifer forest	≥61.0	30 - 69
7	Large-sized, high-canopy conifer forest	≥61.0	≥70
8	Water or barren rock		
9	Medium/large-sized, very low canopy conifer forest	≥30.4	<30

Table C2: List of *a priori* models for three-step modeling of reproduction, survival, and territory occupancy of spotted owls in the central Sierra Nevada, California. We used the same models for all 3 time scales that we considered (3, 6, and 9 years). We define the vegetation classes in Table C1.

Model #	Covariates	Description
Step 1:		
1.1	57	linear relationship with area (ha) of classes 5 + 7
1.2	log(57)	log-linear relationship with area (ha) of classes 5 + 7
1.3	$57 + (57)^2$	quadratic relationship with area (ha) of classes 5 + 7
1.4	67	linear relationship with area (ha) of classes 6 + 7
1.5	log(67)	log-linear relationship with area (ha) of classes 6 + 7
1.6	$67 + (67)^2$	quadratic relationship with area (ha) of classes 6 + 7
1.7	constant (.)	constant over time
Step 2:		
2.1	[step 1][a] + hardwoods	[step 1] + area (ha) of hardwoods
2.2	[step 1] + edge	[step 1] + edge (km) between vegetation class 2 and classes 4, 5, 6, and 7
2.3	[step 1] + private	[step 1] + area (ha) of private land
2.4	[step 1] + habitat diversity	[step 1] + habitat diversity (Shannon-Wiener)[b]
2.5	[step 1] + mean patch size	[step 1] + mean habitat patch size (ha)[b]
Step 3:		
3.1	[step 2][c] + high	[step 2] + area (ha) of high-intensity harvests
3.2	[step 2] + fire	[step 2] + area (ha) of wildfire
3.3	[step 2] + understory	[step 2] + area (ha) of medium-intensity harvests with understory removal

3.4	[step 2] + medium	[step 2] + area (ha) of all medium-intensity harvests
3.5	[step 2] + low	[step 2] + area (ha) of low-intensity harvests
3.6	[step 2] + [treatment] + interaction between habitat and treatment	[step 2] + variables from best model among 3.1–3.6 + interaction with step 1 habitat

[a]The variables from the top model in step 1.
[b]Habitat diversity and mean patch size were calculated using either 57 or 67, depending on which habitat variable (if any) was in the best step 1 model.
[c]The variables from the top model in step 2.

Table C3: Model results for analyses of California spotted owl reproduction (number of young fledged), apparent survival, territory extinction, and territory colonization at a 6-year time scale in the central Sierra Nevada, 1993-2012. We provide definitions of covariates in Table C2.

Model covariates	k^a	AIC[b]	ΔAIC[c]	w_i^d
Reproduction:				
Female age + hardwoods + medium	8	1205.1	0.00	0.29
Female age + hardwoods	7	1205.6	0.50	0.23
Female age + hardwoods + high	8	1206.0	0.90	0.19
Female age + hardwoods + fire	8	1207.1	2.00	0.11
Female age + hardwoods + low	8	1207.4	2.30	0.09
Female age + hardwoods + understory	8	1207.5	2.40	0.09
Adult survival:				
Sex + age + log(57) + edge	9	1311.11	0.00	0.32
Sex + age + log(57) + edge + medium	10	1312.82	1.71	0.14
Sex + age + log(57) + edge + understory	10	1313.07	1.96	0.12
Sex + age + log(57) + edge + high	10	1313.07	1.96	0.12
Sex + age + log(57) + edge + low	10	1313.10	1.99	0.12
Sex + age + log(57) + edge + fire	10	1313.11	2.00	0.12
Sex + age + log(57) + edge + medium + medium*log(57)	11	1314.39	3.28	0.06
Territory extinction:				
57 + diversity(57) + high	39	3808.93	0.00	0.30
57 + diversity(57) + high + medium	40	3809.63	0.70	0.21
57 + diversity(57) + high + fire	40	3810.34	1.41	0.15

57 + diversity(57) + high + understory	40	3810.80	1.87	0.12
57 + diversity(57) + high + low	40	3810.85	1.92	0.11
57 + diversity(57) + high + high*57	40	3810.92	1.99	0.11
57 + diversity(57)	38	3815.70	6.77	0.01
Territory colonization:				
log(57) + diversity(57) + fire	39	3800.63	0.00	0.32
log(57) + diversity(57) + fire + medium	40	3802.25	1.62	0.14
log(57) + diversity(57) + fire + understory	40	3802.28	1.65	0.14
log(57) + diversity(57) + fire + low	40	3802.38	1.75	0.14
log(57) + diversity(57) + fire + fire*log(57)	40	3802.63	2.00	0.12
log(57) + diversity(57)	38	3803.02	2.39	0.10
log(57) + diversity(57) + high	39	3804.94	4.31	0.04

[a]Number of model parameters
[b]Akaike's Information Criterion
[c]Difference in AIC value from the top-ranked model
[d]AIC weight

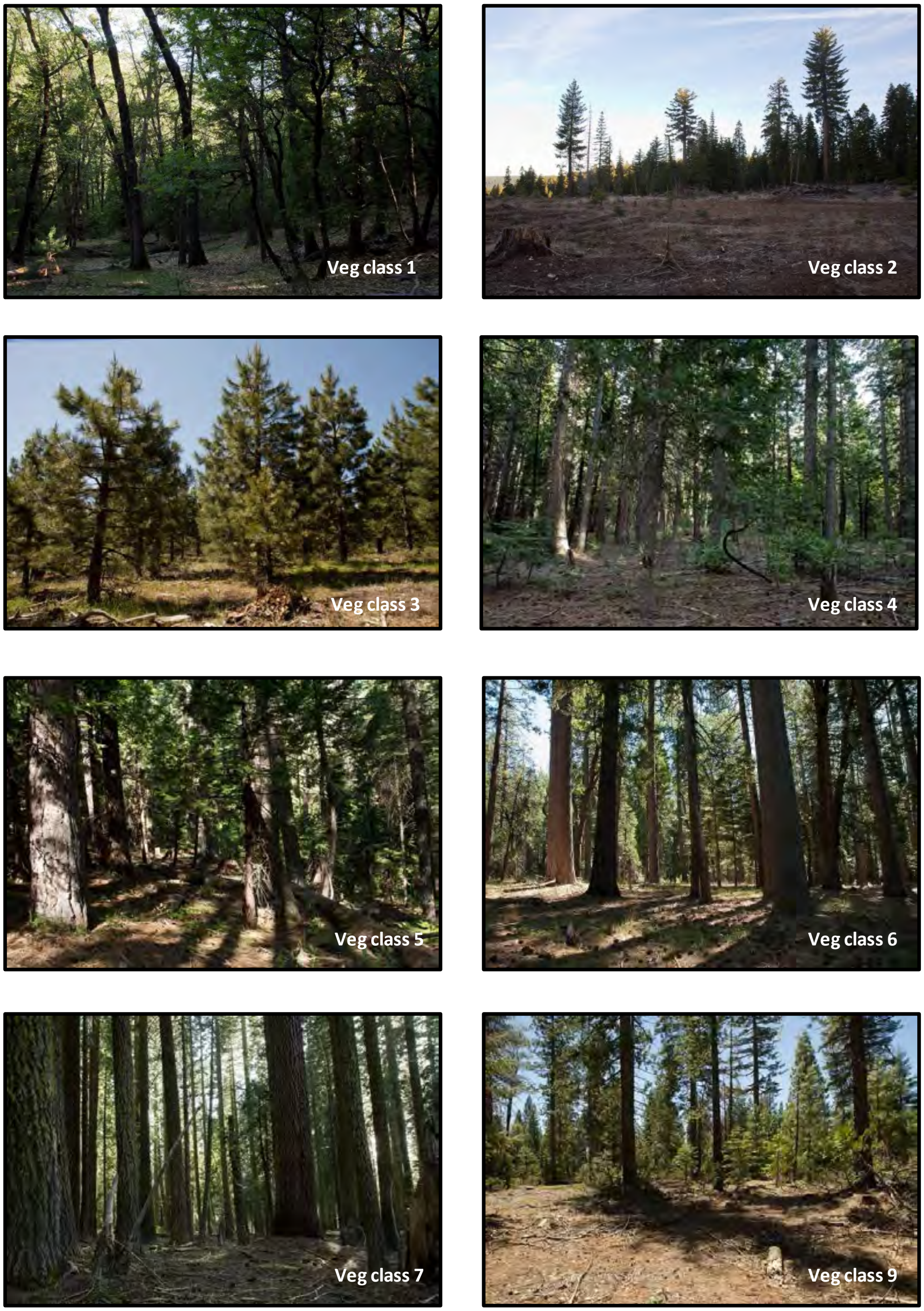


Figure C1: Photos from our study area in the central Sierra Nevada, California, that show examples of vegetation cover types that we used to characterize spotted owl habitat. See Table C1 for definitions of cover type classes. Photo credits: Sheila A. Whitmore.

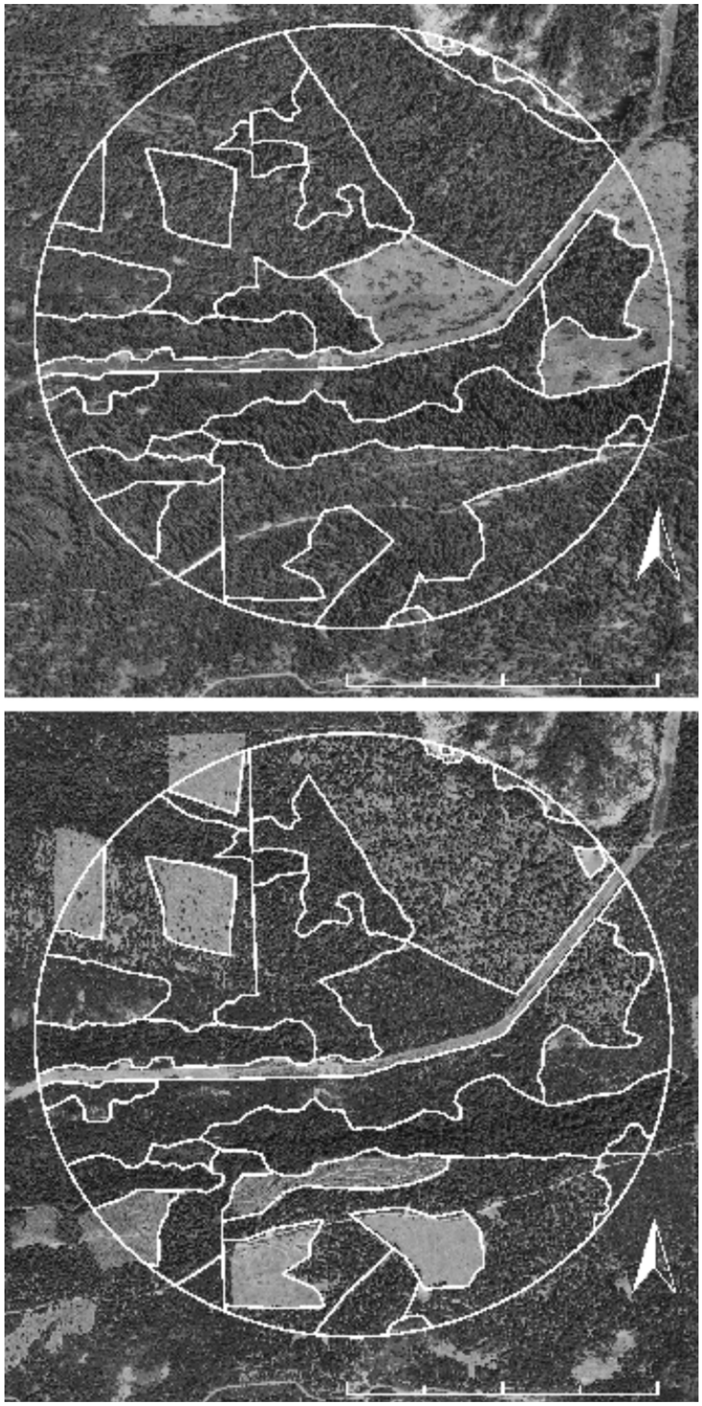


Figure C2: Example of a vegetation cover map based on aerial photographs taken in 1993 (a) and 2012 (b) for a California spotted owl territory on our study area in the central Sierra Nevada, California. The territory is delineated by a circular boundary that encompasses 400 ha. See Table C1 for definitions of vegetation classes.

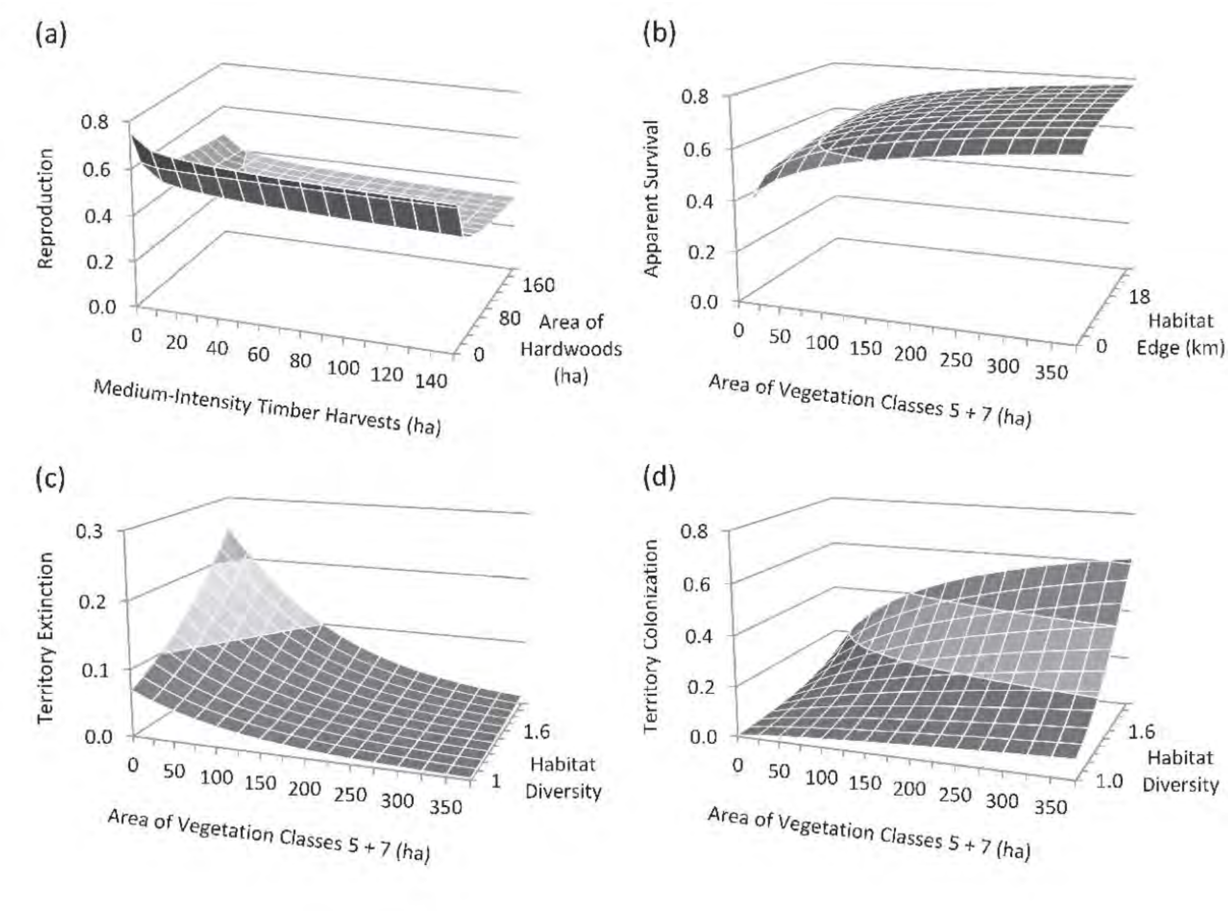


Figure C3: Vital rates of California spotted owls in the central Sierra Nevada, California, 1993-2012, as a function of habitat, timber harvest, and wildfire covariates. We show (a) reproduction for adult females versus the total area of medium-intensity timber harvests in the previous 6 year (ha) and the area of hardwood forests (ha) within owl territories; (b) apparent survival for adult males versus the total area of vegetation classes 5 and 7 (ha) and the amount of habitat edge (km) within owl territories; (c) territory extinction; and (d) territory colonization as a function of the total area of classes 5 and 7 and habitat diversity (Shannon-Wiener index).

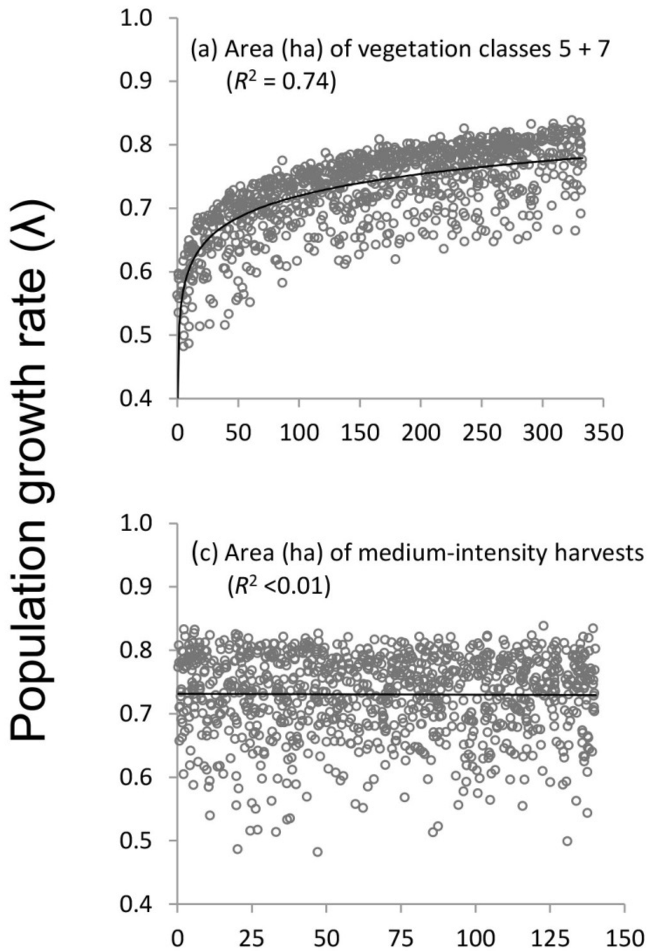


Figure C4: Results of a life-stage simulation analysis we used to assess the sensitivity of annual population growth rate (λ) of California spotted owls to changes in forest vegetation conditions within owl territories. We generated 1,000 λ values by randomly drawing (a) area (ha) of vegetation classes 5 and 7; (b) amount (km) of habitat edge; (c) area (ha) of medium-intensity timber harvests; and (d) area (ha) of hardwood forest from a uniform distribution.

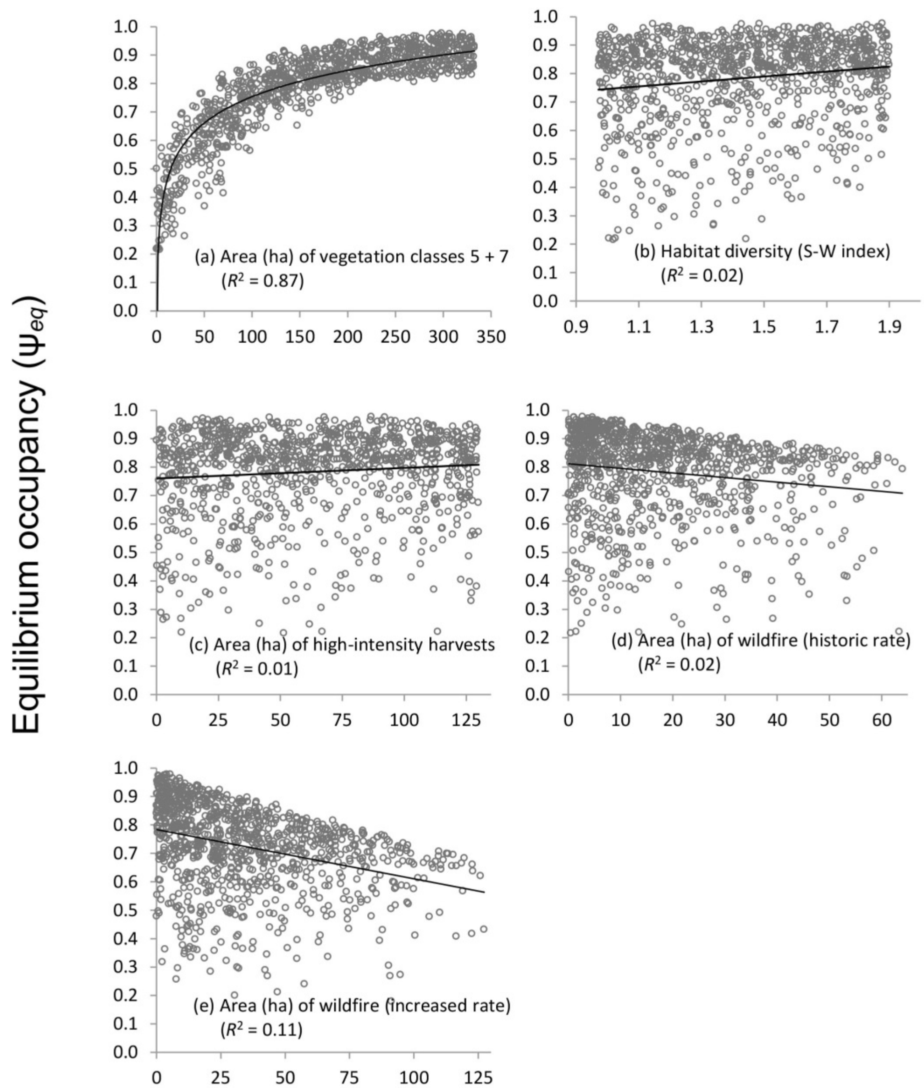


Figure C5: Assessment of the sensitivity of equilibrium occupancy (ψ_{Eq}) of California spotted owl territories to changes in forest vegetation conditions within owl territories. We generated 1,000 ψ_{Eq} values by randomly drawing: (a) area (ha) of vegetation classes 5 and 7; (b) habitat diversity (Shannon-Wiener index); and (c) area (ha) of high-intensity timber harvests from a uniform distribution. Fig. C5(d)-(e) were generated under two different wildfire scenarios—a maximum of 12 territories burned (the observed number during our study) and a maximum of 24 territories burned (representing the potential for increased fire frequency in the future).

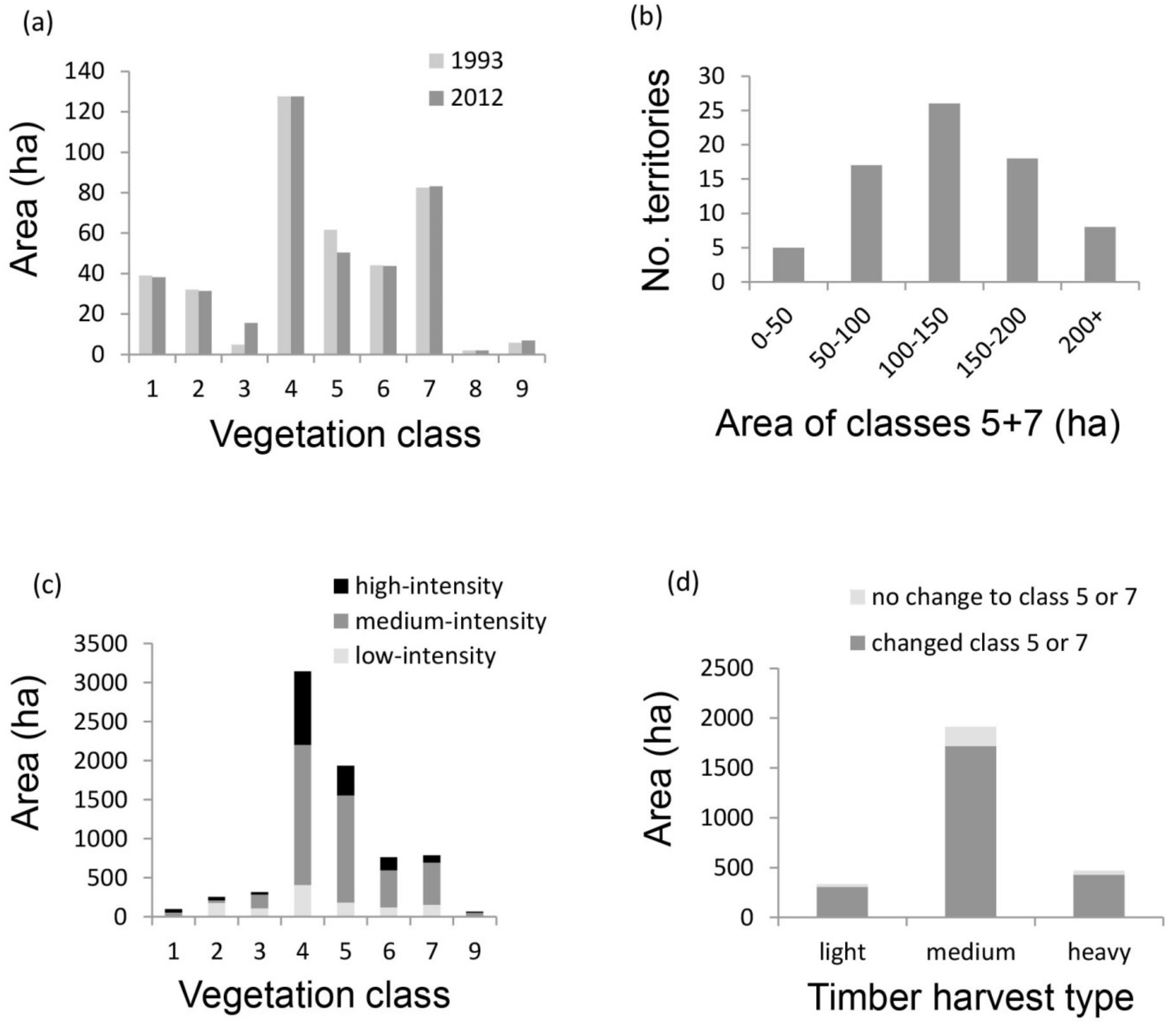


Figure C6: Vegetation conditions within California spotted owl territories on our study area in the central Sierra Nevada, California, as represented by (a) the area (ha) of each vegetation class in owl territories on the Density Study Area in 1993 and 2012; (b) the number of owl territories containing different areas (ha) of vegetation classes 5 and 7 in 2012; (c) the area (ha) of low-, medium-, and high-intensity timber harvests that occurred in each vegetation class from 1993-2012; and (d) the area (ha) of low, medium, and high-intensity timber harvests occurring in vegetation classes 5 and 7 that did or did not result in a change in vegetation class from 1993-2012.

Prospective Analysis of the Effects of SPLATs and Wildfire on California Spotted Owls

I. Introduction

The management of fire-adapted forests in the western U.S. is increasingly challenged by the need to consider the ecological impacts of wildfire (Stephens et al., 2013). Historic fire regimes in many of these forests were characterized by fires burning primarily at low to moderate severity at intervals of less than 20 years (Agee, 1993; Skinner and Chang, 1996), although some high-severity fire apparently occurred with regularity (Collins and Stephens, 2010; Hanson and Odion, 2014). However, decades of fire exclusion have increased forest fuel loads, disrupted historic fire regimes, and led to increases in the frequency of large fires (Westerling et al., 2006), as well as increases in proportions and patch sizes of high-severity fire (Miller et al., 2009; Miller and Safford, 2012). In addition, further increases in fire activity are expected under most climate change scenarios (Westerling and Bryant, 2008; Liu et al., 2013). High-severity fire effects (defined by >75% mortality of overstory trees) can impact ecosystem processes such as erosion rates, stream sedimentation, and carbon sequestration (Benavides-Solorio and MacDonald, 2001; Breshears and Allen, 2002), as well as modify forest structure and wildlife habitat. While some wildlife species become more abundant after high-severity fire (Smucker et al., 2005; Fontaine and Kennedy, 2012), other species, particularly those associated with older forests, may be negatively impacted by habitat loss resulting from large patches of high-severity fire (e.g., Lee et al., 2013). Old-forest species with large home ranges are typically rare and preventing their populations from reaching critically small sizes is widely regarded as an important policy objective (e.g., National Forest Management Act of 1976), in part because meeting the habitat needs of such species can protect broader old-forest communities (Temple, 1997).

To reduce the potential for large patches of high-severity fire, forest managers are implementing fuels-reduction treatments in many western U.S. forests (e.g., USDA, 2004). Fuels-reduction treatments primarily remove surface and ladder fuels, and fire models suggest that these treatments can reduce potential fire hazard across landscapes (Ager et al., 2007; Finney et al., 2007). However, these treatments also reduce canopy cover and vertical forest structure, which could have negative short-term impacts on old-forest-associated species such as spotted owls (*Strix occidentalis*) (Weatherspoon et al., 1992). Ideally, such short-term negative impacts would be outweighed by the longer-term benefits from reductions in the amount of habitat lost during future wildfires, as has been suggested by previous simulations (Ager et al., 2007; Roloff et al., 2012). Similarly, the current management plan for the national forests in the Sierra Nevada posits that fuels-reduction treatments will result in long-term increases in the amount of suitable California spotted owl (*S. o. occidentalis*) habitat while acknowledging the potential for short-term negative impacts (USDA, 2004). Indeed, a recent study found that fuels-reduction treatments can negatively impact spotted owl populations over shorter time frames (<10 years) if they reduce the amount of high-canopy-cover (≥70%) forest dominated by trees ≥30.5 cm diameter at breast height (dbh) within owl territories (Tempel et al., 2014a). However, whether short-term impacts of fuels treatments to spotted owls and their habitat in the Sierra Nevada will be offset by long-term gains resulting from reductions in high-severity fire is unknown.

Here, we used fire and forest-growth models to simulate how fuels treatments altered the effects of fire on spotted owl habitat and demographic rates at the "fireshed" scale over a 30-year period in the Sierra Nevada. Firesheds are contiguous areas with similar fire histories and have been identified by the U.S. Forest Service as meaningful landscape units for fuels-treatment planning and effective fire suppression (Bahro et al., 2007; North et al., 2015). Firesheds are commonly delineated by sub-watershed boundaries and range in size from ~3,200–16,200 ha within the Sierra Nevada (North et al., 2015). We chose this spatial scale because of its management relevance (i.e., project planning) and because our field-based vegetation sampling would not have been feasible at larger spatial scales. In contrast to previous studies that relied upon simulated treatments (Ager et al., 2007; Roloff et al., 2012; but see Stephens et al., 2014), our study involved actual fuels-reduction treatments implemented by the U.S. Forest Service and was intended to assess the efficacy of existing management guidelines governing forest management at a bio-regional scale. We intensively sampled the vegetation within field plots before and after the implemented treatments and coupled this fine-scale vegetation data with LiDAR data to quantify changes in forest structure and parameterize fire and forest-growth models. Finally, we linked spotted owl demographic rates to changes in vegetation conditions resulting from fuels treatments and wildfire using data from a long-term demography study, as no previous study has simulated the potential short- versus long-term trade-offs of fuel treatments and wildfire on wildlife population dynamics. We specifically considered two demographic parameters at the scale of an owl territory: 1) fitness, which we defined as the population growth rate (λ) conferred on resident owls by habitat conditions within the territory (Franklin et al., 2000); and 2) equilibrium occupancy, which is the level at which occupancy probability at a territory will stabilize when colonization and extinction probabilities remain constant (MacKenzie et al., 2006).

We hypothesized that fuels treatments would result in a short-term loss of owl habitat that would be mitigated by longer-term reductions in the loss of owl habitat from wildfire. If a fire burned under extreme weather conditions shortly after treatment implementation, we expected the treatments to reduce the amount of habitat lost during the fire and to result in greater habitat amounts 30 years post-fire because forest growth would be insufficient to compensate for the loss of overstory trees during this timeframe. If no fire occurred after treatment implementation, we expected that the amount of habitat would initially decline, but that similar amounts would be present on treated and untreated landscapes after 30 years because of forest regrowth (Collins et al., 2011). Because owl demographic rates are strongly and positively correlated with the amount of high-canopy-cover (≥70%) forest within owl territories (Tempel et al., 2014a), we predicted that owl demographic rates would follow similar patterns as habitat amount. Thus, we expected fuels treatments to reduce territory fitness and occupancy in the short-term, but to promote higher fitness and occupancy after 30 years in the event of high-severity fire.

II. Study area

Our 13,482-ha Last Chance Study Area (LCSA) was located within the Tahoe National Forest in the central Sierra Nevada, California (Fig. C7). Elevations ranged from 600 to 2,200 m. The vegetation was primarily mixed-conifer forest dominated by white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), incense-cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), and California black oak (*Quercus kelloggii*), with lesser amounts of other forest types and montane chaparral. The LCSA had a Mediterranean climate with an average of 1,182 mm of precipitation, most of which fell as snow, from 1990–2008 (Hell Hole Remote Automated Weather Station). The historic fire regime in this region mainly consisted of frequent, low-to moderate-severity fire occurring every 5 to 15 years (Stephens and Collins, 2004).

As part of the experimental design for SNAMP, the study area was composed of a central treatment fireshed (4,293 ha) and two adjacent watersheds to the north and south that together served as a control 'fireshed' (5,658 ha) (Fig. C7). We further expanded the study area by an additional 3,531 ha of untreated landscape covered by the LiDAR footprint to incorporate additional owl territories (Fig. C7). Fuels-reduction treatments were implemented within the treatment fireshed by the U.S. Forest Service during 2011-2012 as part of the Sierra Nevada Adaptive Management Project (SNAMP; Sierra Nevada Adaptive Management Project, 2014). The fuels treatments, also known as Strategically Placed Landscape Area Treatments (SPLATs), followed the guidelines specified in the 2004 management plan for national forests in the Sierra Nevada (USDA, 2004). The management plan specified that no trees ≥76.2 cm can be harvested, at least 40% canopy cover must be retained, and at least 40% of a stand's basal area must be retained. Treatments were implemented on 942 ha (7.0% of the total study area) as follows: 561 ha of mechanical thinning (tractor and cable), 247 ha of prescribed fire, and 134 ha of mastication of shrubs and small trees. Although no treatments were implemented in the control fireshed, the 2008 Peavine Fire burned 268 ha within the southern unit of the control fireshed (Fig. C7). Collins et al. (2011) modeled treatments and hazardous fire potential in the same study area, but focused on the treatment fireshed only.

III. Methods

Development of vegetation map

We developed a pre-treatment vegetation map using a combination of LiDAR, high-resolution digital color-infrared (CIR) aerial imagery, and an intensive network of field plots. First, we used LiDAR and CIR data to create an initial polygon-based map where the polygons represented areas of homogeneous vegetation in terms of species, vertical structure, basal area, and canopy cover. We collected the LiDAR and CIR data before the fuels-reduction treatments, and we sampled vegetation at the field plots before and after treatment. We then used the field-plot data to impute detailed attributes (e.g., tree lists and fuels models) for each polygon. Thus, we derived two different maps (with and without treatment), which we used in fire and forest-growth modeling.

We contracted with the National Center for Airborne LiDAR Mapping (National Center for Airborne Laser Mapping, 2011) to collect small-footprint, multiple-return airborne LiDAR data with a point density of 6–10 points/m2 in September 2008, and we obtained 1×1 m2 resolution CIR data collected by the National Agriculture Imagery Program (NAIP) in 2005. After initial processing of the LiDAR and CIR data, we used an object-based segmentation approach to delineate polygons of homogeneous vegetation types. We then applied an unsupervised classification strategy to label the different vegetation types based on the Bayesian Information Criterion algorithm, which is used to automatically determine the optimized number of vegetation groups (Su et al., in review). We identified 8 vegetation types on our study area—low shrub, high shrub, open true fir, pine forest, cedar forest, young mixed-conifer forest, and mature mixed-conifer forest. The dominant vegetation type on the study area was mixed-conifer forest (56% mature, 19% young); the other forest types were present in lesser amounts (13% cedar, 7% pine, 4% open true fir). Chaparral (low and high shrubs) covered only 1% of the study area. Post-treatment LiDAR was collected in 2013 and was used to delineate actual treatment areas based on a change-detection algorithm to identify where forest structure noticeably changed between the two LiDAR acquisitions (Su et al., in review). This approach was employed because there can be inconsistencies between agency-generated treatment polygons and actual treatment extent on the ground.

We sampled forest vegetation at field plots that were spaced at 500-m intervals across the LCSA, except the southwest corner of the LCSA where extreme topography precluded sampling (Fig. C7). We sampled more intensively at 125- and 250-m spacing around instrument locations for a separate hydrological study. In August 2008, we also intensively sampled the area burned by the Peavine Fire. In total, we sampled 408 plots in 2007–2008 (pre-treatment) and 369 plots in 2013 (post-treatment). We briefly summarize the vegetation sampling here, but refer the reader to Collins et al. (2011) for greater detail. We sampled within 0.05-ha circular plots and recorded information on individual trees using three different sampling intensities based on tree size: 1) throughout the entire plot for trees ≥19.5 cm dbh; 2) within a random one-third of the plot (167 m2) for trees 5.0–19.4 cm dbh; and 3) along a random belt transect (76 m2) for trees <5.0 cm dbh. We recorded tree species, vigor, crown position, dbh, total height, and height to live crown base (live trees only) for all trees in the upper two size classes, and species and dbh for trees in the smallest size class. In addition, we sampled downed wood, litter, duff fuels, and woody shrub cover on three randomly chosen transects within each plot. We used the line-intercept method to sample downed woody fuels (van Wagner 1968, Brown 1974), and we recorded cover (%) and average height for woody shrubs intersecting each transect.

We then used the field-plot data to impute detailed vegetation attributes for each polygon of the vegetation map for use in the fire and forest-growth modeling. We developed an imputation procedure to assign three field plots to each map polygon based on their similarity in "gradient space" (Ohmann and Gregory, 2002). We performed a multivariate analysis of the plot data to define the gradient space. The definition of the gradient nearest neighbors for each polygon (sensu Ohmann and Gregory, 2002) included topographic variables (e.g., slope, aspect, elevation), canopy structure (% canopy cover and an index of large tree density), and vegetation type. To maintain some of the fine-scale heterogeneity observed in the field, we identified all plots in the 95^{th} percentile in terms of nearest neighbor distance for each stand and then randomly assigned three of those plots to the stand. Our pre-treatment map represented conditions after the Peavine Fire occurred (see *Study area*) because we collected the remotely sensed data and sampled additional field plots within the burned area after the fire. The treatment scenario differed from the no treatment scenario in what field-plot data were used to impute vegetation attributes for polygons where treatments occurred. For the treatment scenario, we used post-treatment tree lists from treated plots (n = 49) for polygons that experienced noticeable structural change based on LiDAR change detection or were confirmed on-the-ground to have been burned by prescribed fire.

Modeling forest dynamics and fire

We considered four scenarios when modeling forest dynamics and wildfire: 1) with treatments and with fire; 2) without treatments and with fire; 3) with treatments and without fire; and 4) without treatments and without fire. For the "with fire" scenarios, we used FARSITE (Finney, 1998) to simulate a likely wildfire scenario based on the weather conditions during the

2001 Star Fire, which burned 6,817 ha, including 314 ha on the northeast edge of our study area (Fig. C8). Approximately 39% of this fire burned at high severity (www.mtbs.gov; accessed on 4 February 2015). FARSITE is a spatially explicit fire-growth model that uses several topographic, forest structure, and fuel model map layers to project fire behavior parameters over a complex landscape. Topographic inputs such as slope, aspect, and elevation were obtained from the LiDAR-derived surface elevation model at 30-m resolution (Su et al., in review). We derived forest structure map layers for canopy cover, canopy bulk density, canopy base height, and canopy height using the imputation procedure previously described. We calculated fuel model assignments using a selection logic based on surface fuels and forest structure measured at the plots (Collins et al., 2011, 2013). This approach has proven sufficient at assigning fuel models based on actual fuel loads rather than relying on the Forest Vegetation Simulator (FVS; Dixon, 2002), which has been shown to use fuel models that underestimate fire behavior (Collins et al., 2013). This approach for assigning fuel models was different for treated and untreated stands. For untreated stands, we used a regression tree analysis with several response variables representing surface fuels: shrub cover, litter, 1- to 100-hour woody fuels, and 1000-hour woody fuels. Forest structure and stand vegetation classification were used as independent variables. Model fits were moderate (R^2 = 0.3-0.6), but given the known variability in surface fuels in mixed-conifer forests (Lydersen et al. 2015), we deemed the assignments to be sufficient in describing the generalized fuel conditions represented by surface fuel models (Collins et al. 2011, 2013). For treated stands, post-treatment fuel models were based on treatment type and post-treatment fuel measurements. Prescribed-burn plots were assigned a moderate-load timber-litter fuel model (Scott and Burgan 2005). We assigned a low-load, timber-understory model to initial post-treatment masticated stands based on observed fire behavior from Knapp et al. (2011). There were two types of tree-harvest treatments: thinning and cable logging. Prescriptions for the cable logging units indicated that the slash was to remain on site, so we used a moderate-load, timber-slash model followed by timber-understory models. Thinning treatments used whole-tree removal in which slash typically was removed, so we used the same selection logic for these treatments that we used for untreated stands.

We obtained weather information from the Duncan Remote Automatic Weather Station, limited to the active burning period of the Star Fire (August-September 2001), which served as the basis of our fire modeling. Moisture content for live and dead woody fuels and live herbaceous fuels used in the model were equivalent to 97th percentile weather conditions. Our ignition location was established in the northeast corner of the study area where the Star Fire perimeter overlapped our study area boundary. The simulation duration was set to allow the fire perimeter to expand through the entire study area.

We used the tree list databases associated with the 2008 pre-treatment field plots when simulating fire under the "no treatment" scenario, and we used the 2013 post-treatment field plots when simulating fire under the "treatment" scenario. Stand average flame lengths and proportion burned by fire type (surface fire, conditional crown fire, and active crown fire) were calculated for both scenarios and used as inputs for fire effects simulation using the keyword SIMFIRE in FVS with the Fire and Fuels Extension (FFE; Reinhardt and Crookston, 2003).

For all four scenarios, we then simulated 30 years of forest growth on the study area in 10-year time steps using FVS with FFE. The simulations were performed using the integrated platform ArcFuels (Ager et al., 2006; Vaillant et al., 2011), which runs FVS-FFE to produce the forest structure inputs needed for FARSITE. We used the western Sierra variant of FVS to simulate forest growth, supplemented by inputs of regeneration through stand development. Users can set parameters for regeneration by identifying number, species, and frequency of establishment. Following the methods of Collins et al. (2011, 2013), we used a random-number generator to set the number of seedlings at each time step in FVS while regulating height-growth rates to simulate realistic conditions in a mixed-conifer forest.

Assessing effects of fuels treatments and fire on spotted owl habitat

We identified canopy cover and large trees as the most important predictors of spotted owl habitat because nest locations were characterized by greater amounts of these elements in the central Sierra Nevada (Bias and Gutiérrez, 1992; Moen and Gutiérrez, 1997; Williams et al., 2011). To determine a biologically meaningful definition of a large tree, we examined 101 spotted owl nest trees on the nearby Eldorado Demography Study Area (EDSA). The size distribution of these nest trees was not significantly different from a normal distribution (Shapiro-Wilk test, $p = 0.052$), so we estimated the standard deviation of the 101 nest tree diameters and used the 10% quantile value of a normal distribution to identify the minimum size of a large tree as 71.3 cm dbh. Thus, 90% of owl nest trees on our study area were expected to be ≥71.3 cm dbh. We then performed a logistic regression of owl nesting habitat as a function of canopy cover and large tree density using data collected by Bond et al. (2004) within 0.02-ha plots at 25 nest trees and 36 random locations within potentially suitable owl nesting habitat on the EDSA (Fig. C9). We identified the following logistic regression equation (Hosmer et al., 2013) for canopy cover (CC; %) and large tree density (LT; ha^{-1}) using SAS (SAS Institute, Cary, NC, USA):

$$\text{logit}(\Pr[\text{nesting habitat}]) = -4.141 + 0.026 \times CC + 0.052 \times LT \qquad (4).$$

The parameter estimate for large tree density was statistically significant ($p < 0.01$), but the parameter estimate for canopy cover was not ($p = 0.19$). However, we elected to include CC in the model given that canopy cover is known to be an important component of spotted owl nesting habitat (Bias and Gutiérrez, 1992; Moen and Gutiérrez, 1997).

We used the logistic regression equation to predict the suitability of forest stands as owl nesting habitat on our study area under each of the four treatment/wildfire scenarios at four points in simulated time (years 0, 10, 20, and 30). Using the values for canopy cover and large tree density from each map polygon, we calculated its suitability as nesting habitat and obtained an average suitability (weighted by the area of each map polygon) for the entire study area. We also obtained separate habitat suitability values for the control and treatment fireshed within the study area (see above) because we expected the direct and indirect (i.e., through modification of fire behavior) effects of fuels treatments to be more pronounced near the treatments.

Assessing effects of fuels treatments and fire on spotted owl demography

Under each of the four treatment/wildfire scenarios, we projected how changes in owl habitat were expected to affect fitness and equilibrium occupancy (ψEq) at the spatial scale of a spotted owl territory. We defined an owl territory as the area contained within a 1,128-m radius (400-ha) circle around each owl territory center; this radius was equal to 1/2 the mean nearest neighbor distance between owl territory centers on the EDSA (Tempel et al., 2014a). We estimated the territory center as the geometric mean of the most informative owl location(s) from each year that the territory was occupied. We used a nest location if one was located that year; otherwise we used the mean of the roost locations for that year. We found nest and roost locations during surveys that we conducted annually from 2007 to 2013 during the spotted owl breeding season (April to August; see Tempel, et al. [2014a]). We limited this analysis to four owl territories that were largely within our study area (≥80% of the 400-ha territory). Three of the territories were occupied by an owl pair every year from 2007 to 2013, and the other was occupied in all but one of those years. For the demographic analyses, we defined owl habitat as high-canopy-cover forest dominated by trees ≥30.5 cm dbh because previous analyses showed that this vegetation type had a strong positive relation with λ and ψEq (Tempel et al., 2014a). On the 2008 pre-treatment map, forest stands with ≥70% canopy cover always contained a substantial number of trees ≥30.5 cm dbh (mean density = 55.8 ha-1, range = 16.0–130.7 ha-1), so we considered all of these stands to be dominated by trees ≥30.5 cm dbh.

To assess how changes in the amount of high-canopy-cover forest impacted fitness and ψ_{Eq} at each of the four territories, we used the habitat maps developed under each scenario at four points in simulated time (years 0, 10, 20, and 30) to quantify the proportion of each territory that consisted of high-canopy-cover forest. For fitness, we used a stage-based, Lefkovitch matrix model parameterized with fecundity and survival rates to represent changes in the female population size:

$$\begin{bmatrix} N_{J,t+1} \\ N_{S1,t+1} \\ N_{S2,t+1} \\ N_{A,t+1} \end{bmatrix} = \begin{bmatrix} 0 & \varphi_{S,t} b_{S,t} & \varphi_{S,t} b_{A,t} & \varphi_{A,t} b_{A,t} \\ \varphi_{J,t} & 0 & 0 & 0 \\ 0 & \varphi_{S,t} & 0 & 0 \\ 0 & 0 & \varphi_{S,t} & \varphi_{A,t} \end{bmatrix} \begin{bmatrix} N_{J,t} \\ N_{S1,t} \\ N_{S2,t} \\ N_{A,t} \end{bmatrix}$$

where $N_{J,t}$, $N_{S1,t}$, $N_{S2,t}$, and $N_{A,t}$, were the number of juvenile, first-year subadult, second-year subadult, and adult females at time t, respectively; $\varphi_{J,t}$, $\varphi_{S,t}$, and $\varphi_{A,t}$ were the apparent survival rates of juvenile, subadult, and adult females from time t to t+1, respectively; and $b_{S,t}$ and $b_{A,t}$ were the fecundity rates for subadult and adult females at time t, respectively. Fecundity was the number of female offspring produced per female in the population, assuming a 50:50 sex ratio for fledged owls. Based on previous analyses in Tempel et al. (2014a), we estimated survival at each territory as a function of female age and the logarithm of the hectares of high-canopy-cover forest (HCF):

$$\text{logit}(\varphi) = -0.005 + 0.557*\text{age} + 0.497*\log([\text{HCF}/10] + 1) \qquad (5),$$

where age = 0 for subadults and 1 for adults, and we divided the amount of HCF by 10 to facilitate model fitting. However, we estimated fecundity solely as a function of female age because high-canopy-cover forest was not a significant predictor of reproductive output:

$$b = 0.153 + 0.178*\text{age} \qquad (6),$$

where age = 0 for subadults and 1 for adults. Using the territory-specific estimates of survival and fecundity, we then computed a territory-specific fitness (i.e., λ) as the dominant eigenvalue of the matrix. As noted in Tempel et al. (2014a), we expected our estimates of fitness to be biased low because: i) we did not incorporate immigration into the projection matrix, and ii) if an individual was not resighted for one or more years and was then resighted on a new territory, we removed the portion of its capture history at the original territory (which lowered the estimates of annual survival) to avoid making assumptions about the owl's location during the intervening period. Nevertheless, differences in fitness allowed us to evaluate the relative simulated effects of fuels treatments and wildfire.

We calculated equilibrium occupancy (ψ_{Eq}) from the territory extinction (ε) and colonization (γ) rates at each territory where $\psi_{Eq} = \gamma/(\gamma + \varepsilon)$ (MacKenzie et al. 2006). Again, based on previous analyses in Tempel et al. (2014a), we estimated extinction probability at each territory as a linear function of the hectares of HCF:

$$\text{logit}(\varepsilon) = -1.944 - 0.058*(\text{HCF}/10) \qquad (7),$$

and we estimated colonization as a function of the logarithm of the hectares of HCF:

$$\text{logit}(\gamma) = -3.528 + 2.149 * \log([\text{HCF}/10] + 1) \quad (8).$$

As we did when estimating survival, we divided the amount of HCF by 10 to facilitate model fitting.

IV. Results

Effects of treatment on forest structure

We compared pre- and post-treatment measurements at 49 field plots located within the fuels-treatment network (Table C1). Fuels treatments reduced both canopy and woody shrub cover by ~10% and reduced total tree density from 540.8 to 263.6 trees/ha. Large tree density increased slightly from 20.8 to 22.8 trees/ha, perhaps because of tree growth during the five years that elapsed between pre- and post-treatment measurements. Fuels treatments decreased the amount of 1-1000 hour woody fuels from 31.5 to 24.9 Mg/ha, whereas duff fuels increased from 64.2 to 67.2 Mg/ha.

Fire modeling

The simulated fires spread across nearly all of the study area for both scenarios (with and without treatment) because of the prevailing winds (Fig. C10). Fuels treatments reduced the intensity of the fire, as evidenced by the predicted flame lengths, with the greatest reductions occurring within treated areas. Overall, when fire occurred on the untreated landscape, 70.2%, 16.6%, 9.3%, and 3.9% of the study area experienced flame lengths of <2, 2-4, 4-8, and >8 m, respectively. In contrast, when fire occurred on the treated landscape, 76.2%, 14.3%, 6.8%, and 2.7% of the study area burned at these flame lengths. Collins et al. (2011) noted that flame lengths >2 m often corresponded to areas with crown fire initiation (i.e., torching). Differences in fire behavior between the two scenarios (i.e., a greater proportion of the fire burned at <2 m after fuels treatments) also generally held true for the land encompassed by the four owl territories. Interestingly, the one territory where this pattern did not hold true was at the territory located within the fuels-treatment network (the territory in the southeastern part of the study area; Fig. C10) where 29.3% of the territory burned at flame lengths >2 m under the treatment scenario compared to 19.7% under the no treatment scenario. This result may have been influenced by differences in the direction of fire spread and time-of-day that the territory burned, which would influence burning conditions via fuel moisture, relative humidity, and air temperature.

Effects of fuels treatments and fire on spotted owl habitat

When we applied the predictive equation for nesting habitat (Equation 4) to the habitat maps under the four treatment/wildfire scenarios, we found that fuels treatments had a persistent, slightly negative effect on owl nesting habitat across the entire study area when no wildfire occurred (Fig. C11). Implementing fuels treatments immediately decreased the average habitat suitability (0.25 for 2008 pre-treatment map compared to 0.23 for 2013 post-treatment map), and this small difference was still present after 30 years of simulated forest growth (0.37 without treatment versus 0.36 with treatment). Conversely, we found that fuels treatments had a persistent, slightly positive effect on the amount of suitable owl nesting habitat across the entire study area after wildfire was simulated (Fig. C11). After 30 years of simulated forest growth following fire, habitat suitability under the treatment scenario was 0.20 compared to 0.17 under the no treatment scenario. The results were very similar when we summarized habitat suitability separately for the control and treatment fireshed.

Effects of fuels treatments and fire on spotted owl demography

We estimated that fuels treatments had a slight, persistent negative effect on fitness at four spotted owl territories within our study area when no wildfire occurred (Fig. C12). The mean fitness of owls at the four territories using the 2013 post-treatment map was 0.825 (SE = 0.012) compared to 0.839 (SE = 0.007) using the 2008 pre-treatment map. This difference was still present after 30 years of simulated forest growth (fitness with treatments = 0.850, SE = 0.008; fitness with no treatments = 0.856, SE = 0.005). In contrast, the simulations suggested that fuels treatments had a larger positive effect on territory fitness after wildfire (Fig. C12). Thirty years after the occurrence of fire, the simulations projected the mean territory fitness with treatments to be 0.796 (SE = 0.009) versus 0.776 (SE = 0.008) with no treatments.

The general patterns for equilibrium occupancy were similar to those for territory fitness, but there was greater variation in ψEq under the different scenarios (Fig. C12). Fuels treatments again had a slight negative effect if fire did not occur, but they had a larger positive effect if simulated fire did occur. When fire did not occur, the projected mean equilibrium occupancy for the four territories after 30 years was 0.883 (SE = 0.037) with fuels treatments and 0.911 (SE = 0.023) with no fuels treatments. In contrast, the projected mean equilibrium occupancy 30 years after fire was 0.577 (SE = 0.053) with treatments compared to 0.468 (SE = 0.042) with no treatments.

V. Discussion

Several studies have investigated the short-term and long-term impacts of fuel treatments on habitat availability for old-forest species using various treatment simulations (Lee and Irwin, 2005; Ager et al., 2007; Thompson et al., 2011; Roloff et al., 2012), but ours was unique in several respects. First, we simulated the effects of actual (as opposed to hypothetical) fuels treatments that reflected a regional strategy currently being implemented to reduce landscape-level fire spread and intensity on public lands (USFS 2004). Second, we combined field-collected vegetation data and LiDAR data to develop a detailed map of forest structure used to parameterize our fire and forest-growth models. The LiDAR data provided information on vertical structure that was unattainable with other sources of remotely sensed data (Lefsky et al., 2002) and allowed us to determine the actual extent of treatments. Finally, in addition to projecting changes in habitat over time, we linked vegetation conditions under the different scenarios to territory fitness and occupancy within our study area using previously modeled relationships between forest structure and owl demography (Tempel et al., 2014a). For these reasons, we believe our study provided a more realistic simulation of the effects of fuels-reduction treatments on an old-forest species that has regional-scale implications for forest management.

We modeled the behavior of a fire (both with and without fuels treatments) parameterized using actual conditions during the 2001 Star Fire; this fire burned large areas at high severity (2,677 of 6,817 total ha; Fig. C8). We then simulated forest growth 30 years into the future under four landscape scenarios: treated/fire, untreated/fire, treated/no fire, and untreated/no fire. As predicted, we projected that fuels-reduction treatments had a negative short-term impact on spotted owl habitat and demographic rates in the absence of fire, but contrary to our expectations, a very slight negative effect was still evident after 30 years. Conversely, treatments had a projected long-term positive effect on owls up to 30 years later when we simulated a fire that burned 30% of our study area at high severity (i.e., >2 m flame length). Thus, our findings were in general agreement with previous modeling efforts for the northern spotted owl (*S. o. caurina*) in the Pacific Northwest where simulated treated landscapes contained more owl habitat after simulated fire, either immediately afterwards (Ager et al., 2007) or up to 75 years later (Roloff et al., 2012).

The observed differences in owl habitat and demographic rates under the different scenarios were modest. For example, the average habitat suitability on our study area 30 years after simulated fire was 0.20 and 0.17 for the treated and untreated landscapes, respectively. Within the four owl territories 30 years after fire, we estimated the mean territory fitness to be 0.796 and 0.776 for the treated and untreated landscapes, respectively. Only 7% of the entire study area was treated (Fig. C7), and previous fire modeling studies suggested that at least 20% of the landscape should be treated to significantly reduce fire spread and intensity (e.g., Ager et al., 2007; Finney et al., 2007; Moghaddas et al., 2010). However, we expanded our study area to include additional owl territories, and even if we considered only the treated fireshed where 18% of the area was treated, we observed similar results. Furthermore, the simulated fire spread through the northern half of the study area before encountering treated areas that altered fire behavior (Fig. C10). Although the projected effects on owl fitness are relatively small, even small reductions in annual growth rates (a function of fitness parameters) can translate into large population declines over longer time periods (Tempel et al., 2014b). For example, if the annual growth rate is 1.00, then the population size remains unchanged after 30 years. In contrast, if the annual growth rate is 0.98, then population size would decline by 45% after 30 years. Importantly, California spotted owl populations have already declined by up to 50% throughout the Sierra Nevada in the past 20 years (Conner et al., 2013; Tempel et al., 2014b), and any further declines could jeopardize their long-term persistence.

We linked spotted owl demography to fuels treatments and fire behavior via their effects on high-canopy-cover forests because relationships between owl territory fitness/occupancy and this forest type have been well-established in the Sierra Nevada (Blakesley et al., 2005; Tempel et al., 2014a). Moreover, previous studies have shown that large (>50 ha) areas of high-severity fire within owl territories may reduce territory occupancy (Lee et al., 2013). In addition, territory extinction has been positively correlated with the combined area of early-seral forests, high-severity burn, and post-fire salvage logging within owl territories (Clark et al., 2013). As such, a reasonable ecological basis exists for inferring that simplification or elimination of high-canopy-cover forests by fuels treatments or high-severity fire will adversely affect spotted owl populations. However, the effects of wildfire on spotted owls are undoubtedly complex and owls may benefit from the presence of a mosaic of habitat types promoted by mixed-severity fire, and particularly from shrub patches and early-seral forests that harbor diverse prey assemblages (Roberts et al., 2015). For example, Bond et al. (2009) found that spotted owls in the southern Sierra Nevada selectively foraged in burned areas, even those that burned at high severity. We further note that not all previous studies of spotted owls have found reduced occupancy rates in burned areas relative to unburned areas (Roberts et al., 2011; Lee et al., 2012). Therefore, to the extent that low- or moderate-severity fire may benefit owls, the modeled declines in territory fitness and occupancy in our fire scenarios might be overestimated, and by extension the long-term (30-year) benefits of fuels reduction treatments overly optimistic. Clearly, additional empirical work is needed to assess the complex effects of wildfire on spotted owls, particularly longer-term studies of marked individuals in landscapes that have experienced a range of fire severities (with and without existing fuel treatment networks on the landscape) and that are not confounded by the effects of salvage logging.

Other Sierra Nevadan species of conservation concern have similar habitat needs as the spotted owl (i.e., mature forests with high canopy cover), particularly the Pacific fisher (*Pekania pennanti*) and northern goshawk (*Accipter gentilis*) (Greenwald et al., 2005; Davis et al., 2007). Thus, similar forest-management trade-offs may exist for these species such that fuels-reduction treatments may reduce available habitat in the short-term but result in greater, long-term habitat amounts if fire occurs. Indeed, Thompson et al. (2011) performed an analogous study to ours, in which they modeled fire and forest growth under treatment and no treatment scenarios and assessed fisher habitat suitability in the southern Sierra Nevada. They projected that fuels treatments had slight negative effects on fisher habitat in the absence of fire, but provided significant positive benefits up to 37 years after simulated fire. Truex et al. (2013) suggested that less fisher resting habitat was present immediately after mechanical fuels treatments were implemented in the Sierra Nevada. However, fishers consistently used areas in the southern Sierra Nevada where some timber harvest had occurred, so it may be possible to implement fuels-reduction treatments at an extent and rate that achieves fire-hazard-reduction goals (Zielinski et al., 2013). Therefore, we believe that our results, although specific to the spotted owl, have broader applicability to other species of management concern in the Sierra Nevada that selectively use forests characterized by large trees and high canopy cover.

We note, however, several caveats from our study when assessing the long-term effects of fuels treatments and wildfire on spotted owls. First, our projections were based on a single simulated fire for each treatment scenario (with and without treatment), and additional fire simulations may have suggested alternative fire patterns with differing effects on the components of owl habitat that we considered (canopy cover, large tree density). We used FARSITE to simulate a single fire in order to obtain specific predictions for fire behavior and effects as opposed to probabilistic predictions (e.g., Ager et al., 2007). By having spatially explicit predictions of fire effects, we were able to track the impacts of fire on owl habitat and make more direct assessments of owl demography over time. Second, our simulation was conducted at the relatively fine spatial scale of the fireshed (10s of km2) because of its management relevance (North et al., 2015) and the difficulty of collecting detailed vegetation data for improved parameterization of fire models at larger spatial scales. However, conducting simulations such as ours at a larger spatial scale would increase the sample size of owl territories used to assess the potential effects of fire and fuels treatments on spotted owls. Future studies should carefully weigh the trade-off between collecting more accurate vegetation data at smaller spatial scales, and therefore deriving more accurate inputs for fire modeling, and increasing the number of owl territories by using larger spatial scales. Third, both of our simulated fires exhibited burn patterns that were substantially different than the burn patterns of the 2001 Star Fire that we attempted to simulate and the large 2014 King Fire (39,545 ha) that burned near our study area (cf. Figs. C8 and C10). Whereas our simulations resulted in relatively small, evenly distributed patches of high-severity fire, the Star Fire and King Fire burned large, contiguous areas at high severity. Indeed, our past experience suggests that existing fire models are generally incapable of replicating the burn patterns seen in the most extreme real fires. Thus, improved fire models are needed to more reliably assess how fuels treatments modify fire behavior and effects on forest structure especially under extreme conditions. Fourth, we did not simulate post-fire salvage logging (which often occurs after fires) on the habitat suitability of burned areas, and post-fire salvage logging has been shown to negatively affect spotted owl occupancy rates (Clark et al., 2013; Lee et al., 2013). Finally, the net effect of fuels treatments on spotted owls depends upon the true, but unknown, probability that high-severity fire effects will occur within individual owl territories. If individual territories have a low probability of experiencing high-severity fire effects, a relatively small portion of the owl population would accrue the long-term benefits of fuels reductions, whereas a greater portion of the population would experience the unfavorable short-term impacts. However, it is difficult to estimate spatially explicit, future probabilities for specific fire behaviors (e.g., crown-fire initiation) on specific areas of the landscape, and it is thus difficult to quantify trade-offs associated with fuel treatments on large spatial scales and in absolute terms (Finney 2005). We note, however, that the area burned by high-severity fire in the Sierra Nevada has increased in the past 30 years (Miller et al., 2009; Miller and Safford, 2012) and may increase further in upcoming years because of climate change (Westerling and Bryant, 2008; Liu et al., 2013). In addition, several fires on or near our study area have burned large areas of the landscape in the last 15 years (2001 Star Fire [6,817 ha], 2013 American Fire [11,305 ha], 2014 King Fire [39,545 ha]) and provide circumstantial evidence that a significant probability of large-scale, high-severity fire effects can be expected, at least in this region of the north-central Sierra Nevada. All three of these fires were human-ignited, which further complicates the estimation of future fire probabilities. In sum, future research on the short- versus long-term benefits of fuels treatments would benefit from a greater understanding of the probability of fire under various climate change scenarios, and linking replicated fire and forest-growth simulations to spotted owl population dynamics at landscape scales using spatially explicit population models.

In conclusion, our results suggest that fuels-reduction treatments, as currently implemented by the U.S. Forest Service in the Sierra Nevada, have the potential to provide long-term (30-year) benefits to spotted owls in the event of fire under extreme weather conditions, but can have long-term negative effects on owls if fire does not occur. Furthermore, major uncertainties remain (e.g., what is the future probability that high-severity fire effects will occur within individual owl territories?). In conjunction with the observed population declines in the last 20 years (Conner et al., 2013; Tempel et al., 2014b), we believe these uncertainties warrant a an informed approach to landscape fuels management that explicitly balances the seemingly conflicting goals of providing habitat for owls and reducing hazardous fire potential. Specifically, we recommend that the U.S. Forest Service continue its current policy that restricts timber harvest within spotted owl Protected Activity Centers (PACs), which contain ~ 125 ha of the best habitat that owls use for nesting and roosting over long time periods (up to 24 years; Berigan et al., 2012). Furthermore, fuels-treatment arrangements should be designed to limit the potential for hazardous fire to spread into PACs.

VII. References

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Washington, D.C.: Island Press.

Ager, A.A., B. Bahro, and K. Barber. 2006. Automating the fireshed assessment process with ArcGIS. Pages 163–168 *in* P.L. Andrews and B.W. Butler, editors. Fuels management–how to measure success: conference proceedings, March 28-30, 2006, Portland, OR. U.S. Forest Service Proceedings RMRS-P-41, Rocky Mountain Research Station, Fort Collins, CO.

Ager, A.A., M.A. Finney, B.K. Kerns, and H. Maffei. 2007. Modeling wildfire risk to northern spotted owl (*Strix occidentalis caurina*) habitat in central Oregon, USA. Forest Ecology and Management 246: 45–56.

Bahro, B., K.H. Barber, J.W. Sherlock, and D.A. Yasuda. 2007. Stewardship and fireshed assessment: a process for designing a landscape fuel treatment strategy. Pages 41–54 *in* R.F. Powers, technical editor. Restoring fire-adapted ecosystems: proceedings of the 2005 National Silviculture Workshop. U.S. Forest Service General Technical Report PSW-GTR-203, Pacific Southwest Research Station, Albany, CA.

Benavides-Solorio, J., and L.H. MacDonald. 2001. Post-fire runoff and erosion from simulated rainfall on small plots, Colorado Front Range. Hydrological Processes 15: 2931–2952.

Berigan, W.J., R.J. Gutiérrez, and D.J. Tempel. 2012. Evaluating the efficacy of protected habitat areas for the California spotted owl using long-term monitoring data. Journal of Forestry 110: 299–303.

Bias, M.A., and R.J. Gutiérrez. 1992. Habitat associations of California spotted owls in the central Sierra Nevada. Journal of Wildlife Management 56: 584–595.

Blakesley, J.A., B.R. Noon, and D.R. Anderson. 2005. Site occupancy, apparent survival, and reproduction of California spotted owls in relation to forest stand characteristics. Journal of Wildlife Management 69: 1554–1564.

Bond, M.L., D.E. Lee, R.B. Siegel, and J.P. Ward, Jr. 2009. Habitat use and selection by California spotted owls in a postfire landscape. Journal of Wildlife Management 73: 1116–1124.

Bond, M.L., M.E. Seamans, and R.J. Gutiérrez. 2004. Modeling nesting habitat selection of California spotted owls (*Strix occidentalis occidentalis*) in the central Sierra Nevada using standard forest inventory metrics. Forest Science 50: 773–780.

Breshears, D.D., and C.D. Allen. 2002. The importance of rapid, disturbance-induced losses in carbon management and sequestration. Global Ecology and Biogeography 11: 1–5.

Brown, J.K., 1974. Handbook for inventorying downed woody material. U.S. Forest Service General Technical Report INT-16, Ogden, UT.

California Department of Fish and Game. 2008. California Interagency Wildlife Task Group. CWHR version 8.2 personal computer program. Sacramento, CA. Available at: <http://www.dfg.ca.gov/biogeodata/cwhr/>, accessed on June 15, 2013.

Clark, D.A., R.G. Anthony, and L.S. Andrews. 2013. Relationship between wildfire, salvage logging, and occupancy of nesting territories by northern spotted owls. Journal of Wildlife Management 77: 672–688.

Collins, B.M., H.A. Kramer, K. Menning, C. Dillingham, D. Saah, P.A. Stine, and S.L. Stephens. 2013. Modeling hazardous fire potential within a completed fuel treatment network in the northern Sierra Nevada. Forest Ecology and Management 310: 156–166.

Collins, B.M., and S.L. Stephens. 2010. Stand-replacing patches within a 'mixed severity' fire regime: quantitative characterization using recent fires in a long-established natural fire area. Landscape Ecology 25: 927–939.

Collins, B.M., S.L. Stephens, G.B. Roller, and J.J. Battles. 2011. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. Forest Science 57: 77–88.

Conner, M.M., J.J. Keane, C.V. Gallagher, G. Jehle, T.E. Munton, P.A. Shaklee, and R.A. Gerrard. 2013. Realized population change for long-term monitoring: California spotted owl case study. Journal of Wildlife Management 77: 1449–1458.

Davis, F.W., C. Seo, and W.J. Zielinski. 2007. Regional variation in home-range-scale habitat models for fisher (*Martes pennanti*) in California. Ecological Applications 17: 2195–2213.

Dixon, G.E. 2002. Essential FVS: a user's guide to the Forest Vegetation Simulator. U.S. Forest Service Internal Report, Fort Collins, CO (revised on November 19, 2013).

Finco, M., B. Quayle, Y. Zhang, J. Lecker, K.A. Megown, and C.K. Brewer. 2012. Monitoring trends and burn severity (MTBS): monitoring wildfire activity for the past quarter century using Landsat data. Pages 222–228 *in* R.S. Morin, R.S. and G.C. Liknes, compilers. Moving from status to trends: Forest Inventory and Analysis (FIA) Symposium. December 4-6, 2012, Baltimore, MD. U.S. Forest Service General Technical Report NRS-P-105, Northern Research Station, Newtown Square, PA.

Finney, M.A. 1998. FARSITE: Fire Area Simulator– model development and evaluation. U.S. Forest Service Research Paper RMRS-RP-4, Missoula, MT.

Finney, M.A. 2005. The challenge of quantitative risk analysis for wildland fire. Forest Ecology and Management 211: 97–108.

Finney, M.A., R.C. Seli, C.W. McHugh, A.A. Ager, B. Bahro, and J.K. Agee. 2007. Simulation of long-term landscape-level fuel treatment effects on large wildfires. International Journal of Wildland Fire 16: 712–727.

Fontaine, J.B., and P.L. Kennedy. 2012. Meta-analysis of avian and small-mammal response to fire severity and fire surrogate treatments in U.S. fire-prone forests. Ecological Applications 22: 1547–1561.

Franklin, A.B., D.R. Anderson, R.J. Gutiérrez, and K.P. Burnham. 2000. Climate, habitat quality, and fitness in northern spotted owl populations in northwestern California. Ecological Monographs 70: 539–590.

Greenwald, D.N., D.C. Crocker-Bedford, L. Broberg, K.F. Suckling, and T. Tibbitts. 2005. A review of northern goshawk habitat selection in the home range and implications for forest management in the western United States. Wildlife Society Bulletin 33: 120–129.

Hanson, C.T., and D.C. Odion. 2014. Is fire severity increasing in the Sierra Nevada, California, USA? International Journal of Wildland Fire 23: 1–8.

Hosmer, D.W., Jr., S. Lemeshow, and R.X. Sturdivant. 2013. Applied logistic regression. Third edition. Hoboken, NJ: John Wiley & Sons Inc.

Knapp, E.E., J.M. Varner, M.D. Busse, C.N. Skinner, and C.J. Shestak. 2011. Behaviour and effects of prescribed fire in masticated fuelbeds. International Journal of Wildland Fire 20: 932–945.

Lee, D.C., and L.L. Irwin. 2005. Assessing risks to spotted owls from forest thinning in fire-adapted forests of the western United States. Forest Ecology and Management 211: 191–209.

Lee, D.E., M.L. Bond, M.I. Borchert, and R. Tanner. 2013. Influence of fire and salvage logging on site occupancy of spotted owls in the San Bernardino and San Jacinto Mountains of southern California. Journal of Wildlife Management 77: 1327–1341.

Lee, D.E., M.L. Bond, and R.B. Siegel. 2012. Dynamics of breeding-season site occupancy of the California spotted owl in burned forests. Condor 114: 1–11.

Lefsky, M.A., W.B. Cohen, G.G. Parker, and D.J. Harding. 2002. Lidar remote sensing for ecosystem studies. BioScience 52: 19–30.

Liu, Y., S.L. Goodrick, and J.A. Stanturf. 2013. Future U.S. wildfire potential trends projected using a dynamically downscaled climate change scenario. Forest Ecology and Management 294: 120–135.

Lydersen, J.M., B.M. Collins, E.E. Knapp, G.B. Roller, and S. Stephens. 2015. Relating fuel loads to overstory structure and composition in a fire-excluded Sierra Nevada mixed conifer forest. International Journal of Wildland Fire. Available at: <http://dx.doi.org/10.1071/WF13066>, accessed on April 1, 2015.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2006. Occupancy estimation and modeling. Amsterdam, Netherlands: Elsevier/Academic Press.

Miller, J.D., and H. Safford. 2012. Trends in wildfire severity: 1984 to 2010 in the Sierra Nevada, Modoc Plateau, and southern Cascades, California, USA. Fire Ecology 8: 41–57.

Miller, J.D., H.D. Safford, M. Crimmins, and A.E. Thode. 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. Ecosystems 12: 16–32.

Moen, C.A., and R.J. Gutiérrez. 1997. California spotted owl habitat selection in the central Sierra Nevada. Journal of Wildlife Management 61: 1281–1287.

Moghaddas, J.J., B.M. Collins, K. Menning, E.E.Y. Moghaddas, and S.L. Stephens. 2010. Fuel treatment effects on modeled landscape-level fire behavior in the northern Sierra Nevada. Canadian Journal of Forest Research 40: 1751–1765.

National Center for Airborne Laser Mapping. 2011. <http://ncalm.org>, accessed on October 6, 2011.

North, M., A. Brough, J. Long, B. Collins, P. Bowden, D. Yasuda, J. Miller, and N. Sugihara. 2015. Constraints on mechanized treatment significantly limit mechanical fuels reduction extent in the Sierra Nevada. Journal of Forestry 113: 40–48.

Ohmann, J.L., and M.J. Gregory. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, USA. Canadian Journal of Forest Research 32: 725–741.

Reinhardt, E., and N.L. Crookston. 2003. The Fire and Fuels Extension to the Forest Vegetation Simulator. U.S. Forest Service General Technical Report RMRS-GTR-116, Fort Collins, CO.

Roberts, S.L., J.W. van Wagtendonk, A.K. Miles, and D.A. Kelt. 2011. Effects of fire on spotted owl site occupancy in a late-successional forest. Biological Conservation 144: 610–619.

Roberts, S.L., D.A. Kelt, J.W. van Wagtendonk, A.K. Miles, and M.D. Meyer. 2015. Effects of fire on small mammal communities in frequent-fire forests in California. Journal of Mammalogy 96: 107–119.

Roloff, G.J., S.P. Mealey, and J.D. Bailey. 2012. Comparative hazard assessment for protected species in a fire-prone landscape. Forest Ecology and Management 277: 1–10.

Scott, J.H., and R.E. Burgan. 2005. Standard fire behavior models: a comprehensive set for use with Rothermel's surface fire spread model. U.S. Forest Service General Technical Report RMRS-GTR-153, Fort Collins, CO.

Sierra Nevada Adaptive Management Project. 2014. <http://snamp.cnr.berkeley.edu>, accessed on September 29, 2014.

Skinner, C.N., and C. Chang. 1996. Fire regimes, past and present. Pages 1041–1069 *in* Sierra Nevada Ecosystem Project: final report to Congress, Vol. II, Chap. 38. University of California, Centers for Water and Wildland Resources, Davis, CA.

Smucker, K.M., R.L. Hutto, and B.M. Steele. 2005. Changes in bird abundance after wildfire: importance of fire severity and time since fire. Ecological Applications 15: 1535–1549.

Stephens, S.L., J.K. Agee, P.Z. Fulé, M.P. North, W.H. Romme, and T.W. Swetnam. 2013. Managing forests and fire in changing climates. Science 342: 41–42.

Stephens, S.L., S.W. Bigelow, R.D. Burnett, B.M. Collins, C.V. Gallagher, J. Keane, D.A. Kelt, M.P. North, L.J. Roberts, P.A. Stine, and D.H. Van Vuren. 2014. California spotted owl, songbird, and small mammal responses to landscape-scale fuel treatments. BioScience 64: 893–906.

Stephens, S.L., and B.M. Collins. 2004. Fire regimes of mixed conifer forests in the north-central Sierra Nevada at multiple spatial scales. Northwest Science 78: 12–23.

Su, Y., Q. Guo, B. Collins, D. Fry, and M. Kelly. Forest fuel treatment detection using multi-temporal airborne lidar data and high resolution aerial imagery—a case study at Sierra Nevada Mountains, California. Agricultural and Forest Meteorology: in review.

Su, Y., Q. Guo, D. Fry, B. Collins, M. Kelly, J. Flanagan, and J. Battles. A new vegetation mapping strategy by combining airborne Lidar data and aerial imagery for the conifer forests in the Sierra. Canadian Journal of Remote Sensing: in review.

Tempel, D.J., R. J. Gutiérrez, S.A. Whitmore, M.J. Reetz, R.E. Stoelting, W.J. Berigan, M.E. Seamans, and M.Z. Peery. 2014a. Effects of forest management on California spotted owls: implications for reducing wildfire risk in fire-prone forests. Ecological Applications 24: 2089–2106.

Tempel, D.J., M.Z. Peery, and R.J. Gutiérrez. 2014b. Using integrated population models to improve conservation monitoring: California spotted owls as a case study. Ecological Modelling 289: 86–95.

Temple, S.A. 1997. Maintaining the integrity of managed ecosystems: the challenges of preserving rare species. Pages 77–93 *in* M.S. Boyce, and A. Haney, editors. Ecosytem management: applications for sustainable forest and wildlife resources. New Haven, CT: Yale University Press.

Thompson, C.M., W.J. Zielinski, and K.L. Purcell. 2011. Evaluating management risks using landscape trajectory analysis: a case study of California fisher. Journal of Wildlife Management 75: 1164–1176.

Truex, R.L., and W.J. Zielinski. 2013. Short-term effects of fuel treatments on fisher habitat in the Sierra Nevada, California. Forest Ecology and Management 293: 85–91.

USDA, 2004. Sierra Nevada Forest Plan Amendment: Final Supplemental Environmental Impact Statement. USDA Forest Service, Pacific Southwest Region, Vallejo, CA.

Vaillant, N.M., A.A. Ager, J. Anderson, and L. Miller. 2011. ArcFuels 10 system overview. U.S. Forest Service General Technical Report PNW-GTR-875, Portland, OR.

van Wagner, C.E. 1968. The line intercept method in forest fuel sampling. Forest Science 14: 20–26.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313: 940–943.

Westerling, A.L., and B.P. Bryant. 2008. Climate change and wildfire in California. Climatic Change 87 (Suppl. 1): S231–S249.

Williams, P.J., R.J. Gutiérrez, and S.A. Whitmore. 2011. Home range and habitat selection of spotted owls in the central Sierra Nevada. Journal of Wildlife Management 75: 333–343.

Wisdom, M.J., L.S. Mills, and D.F. Doak. 2000. Life stage simulation analysis: estimating vital-rate effects on population growth for conservation. Ecology 81: 628–641.

Zielinski, W.J., C. M. Thompson, K.L. Purcell, and J.D. Garner. 2013. An assessment of fisher (*Pekania pennanti*) tolerance to forest management intensity on the landscape. Forest Ecology and Management 310: 821–826.

Table C4: Comparison of pre- and post-treatment canopy cover (%), total tree density (ha-1), large tree density (≥71.3 cm dbh; ha-1), shrub cover (%), duff fuels (Mg/ha), and woody fuels (1-1000 hour; Mg/ha) at 49 field plots located within a fuels-treatment network on the Last Chance Study Area in the central Sierra Nevada, California. Standard errors are shown in parentheses.

Vegetation attribute	Pre-treatment	Post-treatment
Canopy cover	56.6 (3.2)	45.8 (2.7)
Total tree density	540.8 (31.6)	263.6 (21.1)
Large tree density	20.8 (4.4)	22.8 (4.6)
Shrub cover	31.6 (4.0)	22.2 (3.3)
Duff fuels	64.2 (5.4)	67.2 (5.6)
Woody fuels	31.5 (4.9)	24.9 (4.1)

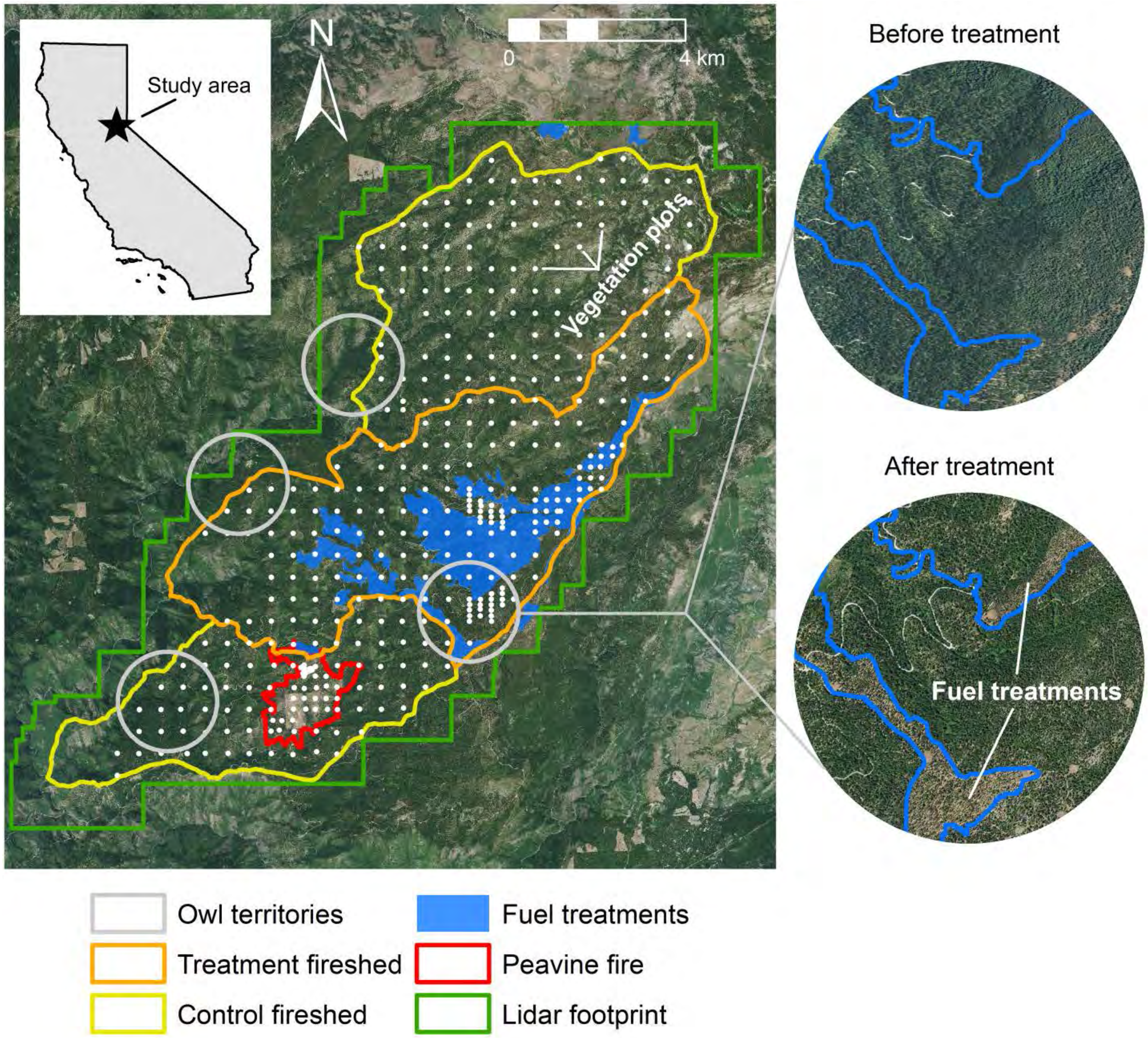
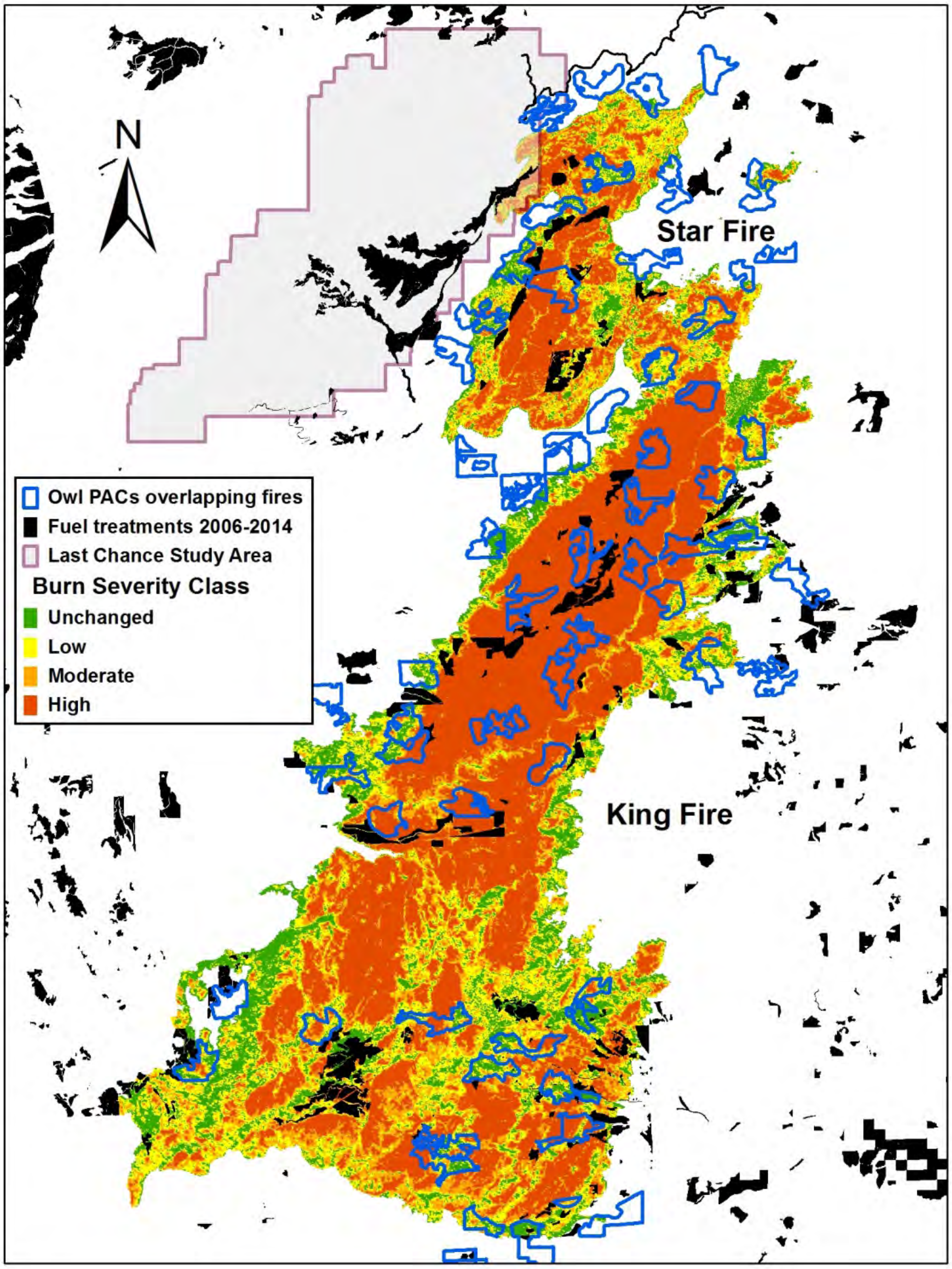


Figure C7: Map of the Last Chance Study Area in the central Sierra Nevada, California, showing the delineation of treatment and control firesheds, the locations of four California spotted owl (*Strix occidentalis occidentalis*) territories used in our demographic analyses, fuel treatments conducted in 2011-2012, the plot network for ground-based sampling of forest vegetation before and after the fuel treatments, and an aerial overview of part of the treated area before and after the fuel treatments.



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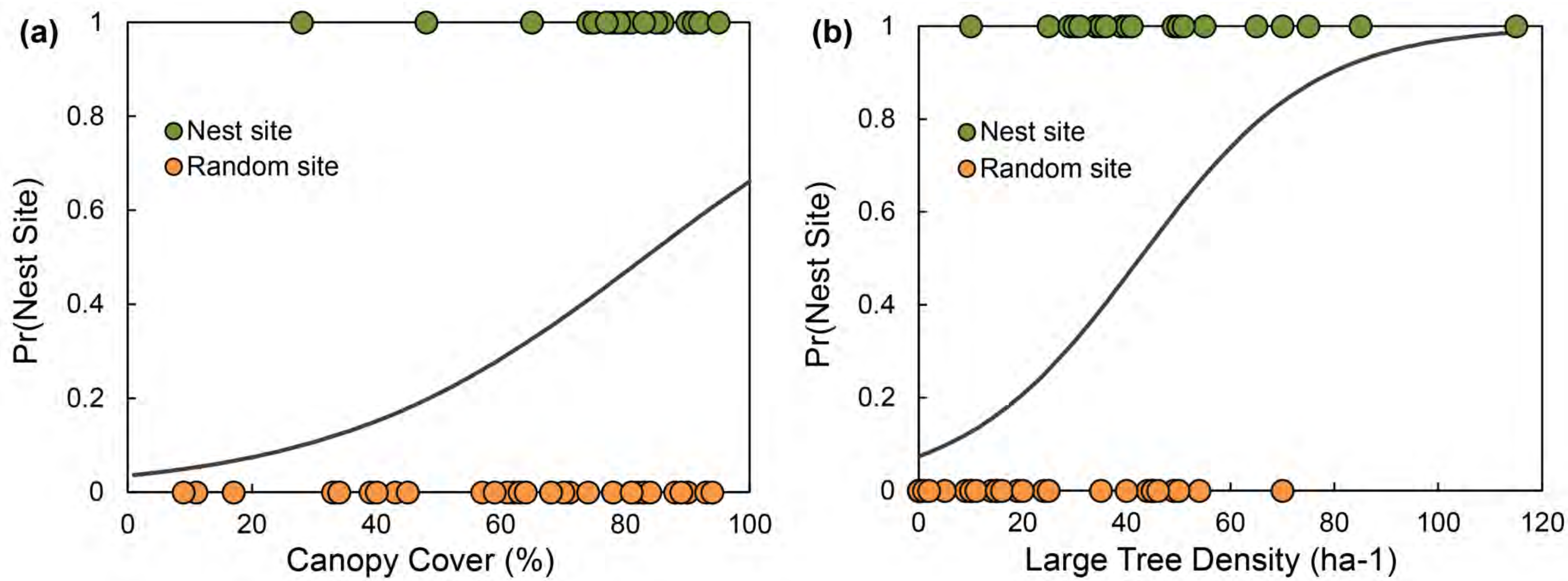

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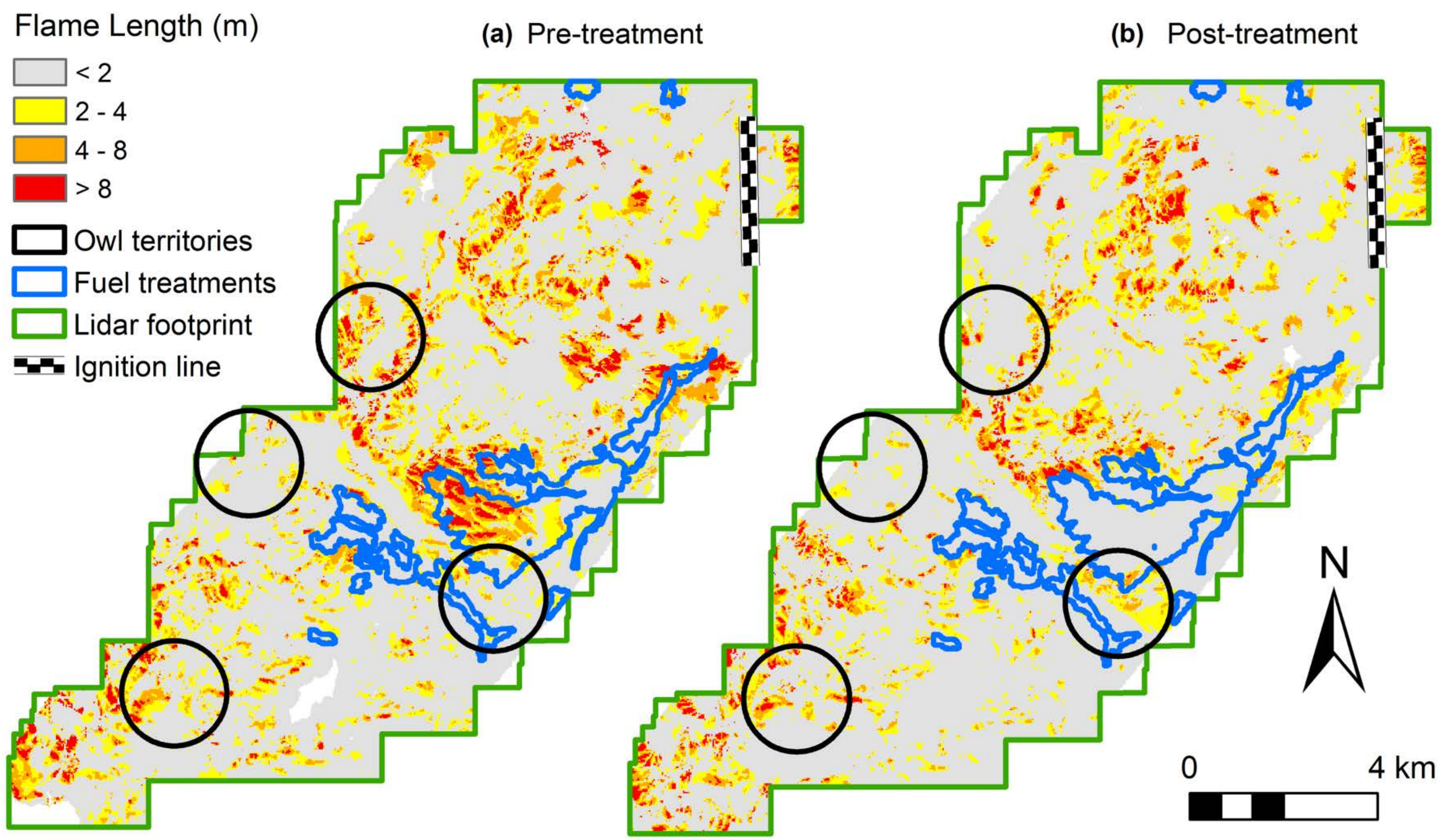

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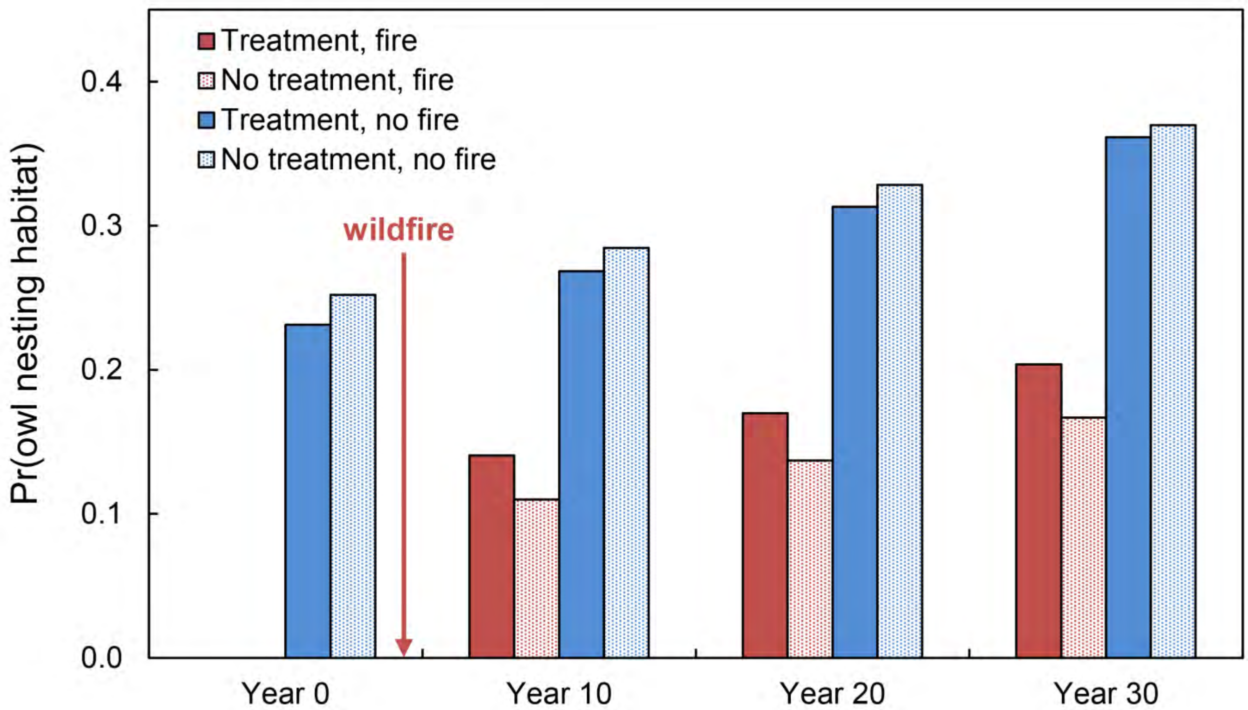

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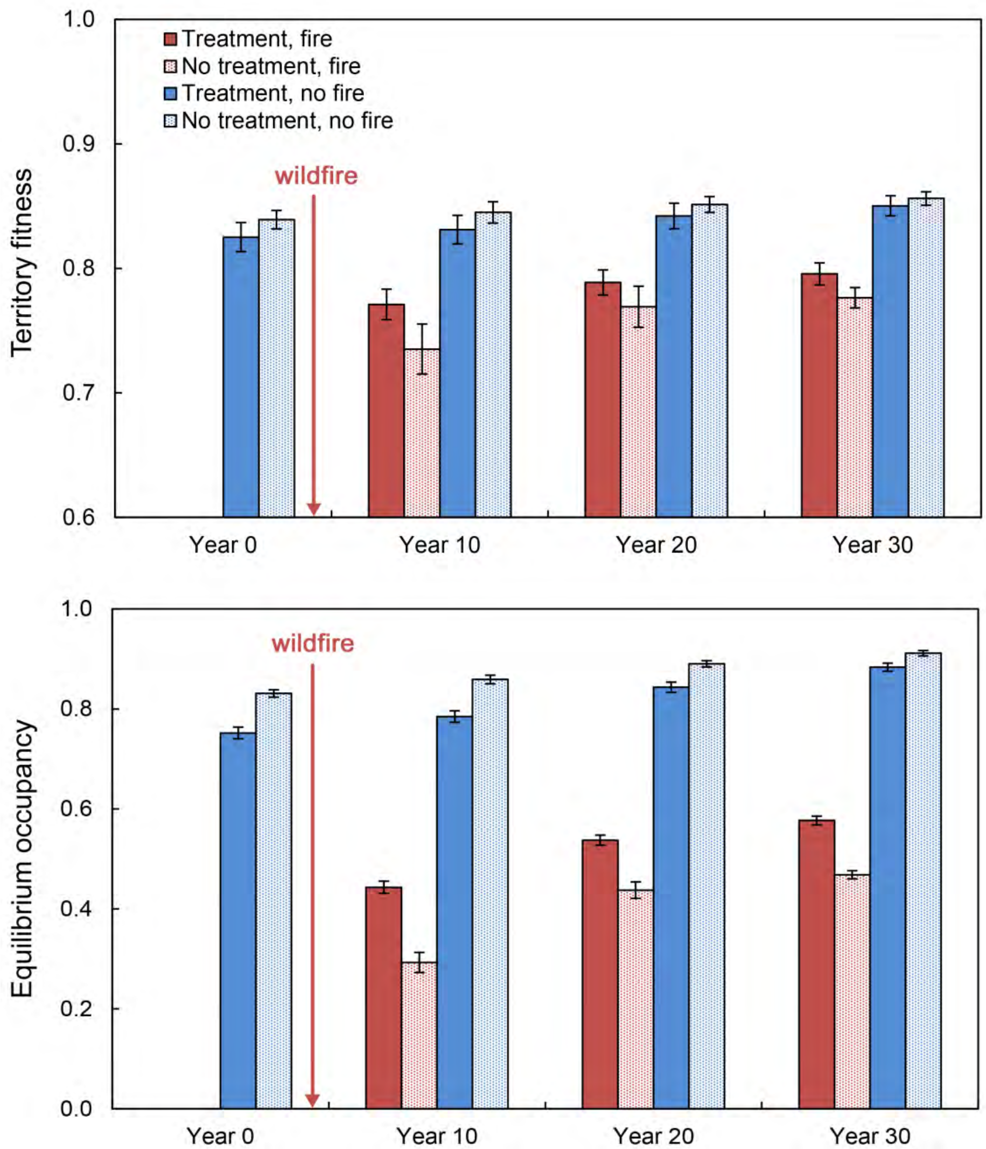

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Appendix D: Fisher Team Final Report

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i. Executive Summary

Illustration D1: Image of an adult female fisher on a den tree in spring 2009.

Fishers (*Pekania pennanti*) are a medium-sized mammalian carnivore with a pre-European distribution encompassing the boreal forest zone of Canada, the Great Lakes region and northeastern United States, a relatively limited portion of the Rocky Mountains in the United States, and mountainous areas of Washington, Oregon, and California, USA (Powell 1993). Ecologically, fishers are a mature or old forest-obligate species (Zielinski et al. 2005), and in central to eastern Canada and the northeastern United States their numbers were reduced historically by the combination of intensive trapping and loss of forest habitats (Powell 1993, Powell and Zielinski 1994). The species is uncommon to rare in the western United States. It is listed as a sensitive species by the Oregon Department of Fish and Wildlife and endangered by Washington State. In July 2015, the California Fish and Game Commission voted to list the southern Sierra Nevada fisher population as threatened, and the species is currently a candidate for listing under the US Endangered Species Act. In advance of federal and state listing decisions, conservation planning has been underway in California since 2013 to develop an approach to maintaining viable populations of fishers in both northwestern California and in the southern Sierra Nevada. Information from the SNAMP Fisher Project (published manuscripts, submitted manuscripts, and unpublished data) described herein has been included in a Southern Sierra Nevada Fisher Conservation Assessment developed by the Conservation Biology Institute, with input from a team of 13 fisher researchers and scientists.

The SNAMP Fisher Project was initiated by the UC Berkeley Science Team in Fall 2007, in association with multiple other SNAMP science programs, to provide an independent evaluation of how vegetation management, prescribed by the 2004 Sierra Nevada Forest Plan Amendment, affects fire risk, wildlife, forest health and water. A major goal of the SNAMP Fisher Project was to determine whether current rates of survival and reproduction will allow fishers to persist in the Sierra Nevada in the context of active forest management to reduce fuels and the risk of catastrophic wildfire.

Our approach for assessing how fishers would respond to Strategically Placed Landscape Area Treatments (SPLATs) was designed to be multifaceted including (1) life history responses to fuels reduction (changes in survival, reproduction/fecundity, lifespan), (2) changes in local scale habitat use within individual home ranges, and (3) shifts or changes in habitat use at the home range scale of animal resource use/resource selection.



Illustration D2*:* Fuel reduction management treatments observed in the SNAMP Fisher Study area; *mastication/mowing, control burning, commercial thinning*

A range of standard methods were used in the study to live-trap, radiocollar and monitor survival status of individual fishers. Monitoring was accomplished almost entirely by fixed-wing aerial radiotelemetry, supported by an "in house" aviation program developed specifically for SNAMP Fisher and administered by the USDA Forest Service. Ground-based radiotelemetry was used to monitor female fishers during denning seasons, and to recover carcasses of deceased fishers. Cameras were systematically placed throughout the study area at the center points of 1-km^2 grid cells. Grid cells within the SNAMP study area and the key watershed region were surveyed annually, while grid cells outside these areas were surveyed opportunistically. We used the camera survey data to support an occupancy analysis, investigating the impacts of different forest management actions on fisher occupancy, persistence, and extinction.

A total 110 individual fishers were captured and radiocollared from Dec 2007 to Dec 2013 (62 females, 48 males). Sixty-six (60%) of the 110 individual fishers radiocollared during the study were known to have died, including 32 females and 34 males. On average 10.5 radiocollared fishers died in each population year over the course of the study, and the most common cause of death was predation by felid carnivores (bobcats, *Lynx rufus*, and mountain lions, *Puma concolor*). Two radiocollared fisher deaths were roadkills on Highway 41, and five others were directly linked to anticoagulant rodenticides being used in association with illegal marijuana grow sites in the Sierra National Forest.

Seventy-six (85%) breeding-age female fishers either exhibited denning behavior (n = 63) or were determined to have denned and weaned at least 1 kit. Among the 76 breeding-age females that initiated denning, 64 (84%) were identified as weaning kits. Overall, 72% of adult female fishers for which reproductive status was known produced at least 1 weaned kit. We were able to determine litter size for 48 of 59 denning females. A total of 73 kits were known produced, with an average litter size of 1.5.

Fisher population sizes ranged from 48 in 2010 to 62 in 2012, whereas mean population density ranged between 0.072 fishers/km^2 in 2010 and 0.093 fishers/km^2 in 2012. Lambda across all years was 0.90, which was suggestive of general population decline, however, the annual and cumulative 95% confidence intervals all overlapped with 1.0.

Camera surveys were completed in 905 unique 1-km^2 grid cells throughout the overall study area, including 56 grid cells within the southern region of Yosemite National Park. Fishers were detected in 448 of the unique grid cells surveyed, which helped to identify that fishers in this part of the southern Sierra Nevada were most common between 4500 and 6500 feet elevation (1372 and 1981 m elevation). Occupancy estimates for multi-year surveyed grid cells corrected for imperfect detection < 1.0 ranged from 0.62 to 0.80.

Occupancy modelling indicated that fishers reduced their use of forest patches exposed to higher levels of restorative fuel reduction; i.e., persistence of occupancy declined with additional acreage treated for fire resiliency. However, neither restorative nor extractive (i.e., commercial thinning) fuel reduction was related to either initial probability of occupancy or local extinction. We found that SPLATs caused an immediate 6% reduction in potential fisher habitat. However, they also moderated the impact of fire, resulting in greater available fisher habitat within 30 years. In the absence of simulated fire, the amount of habitat steadily increased over time due to forest succession, and was actually slightly greater on the treated landscape in year 30 than in year 0.

The combination of an overall negative population growth rate and the relatively small abundance estimate (n = 93, range 80-107), warrants concern for the long term viability of the fishers in the region. Any small population will be at high risk to stochastic events such as disease and large perturbations to critical habitats (e.g., forest fires or drought; Noss et al. 2006), and genetic limitation resulting from genetic drift after founder events (Tucker et al. 2014) will hinder population recovery and expansion (Reed et al. 2003). Minimum viable population size has been under debate (Shoemaker et al. 2013, Reed and McCoy 2014), but at <500 individuals (Spencer et al. 2015), the current southern Sierra Nevada fisher population will likely require active management and conservation measures to maintain a positive growth rate across its entire range. The estimated population growth rate in the SNAMP Fisher study area reaffirms the vulnerability of the small, isolated population to external threats (Spencer et al. 2015), especially wildfires that are likely to increase in frequency and intensity with climate change. Moreover, the SNAMP Fisher study spanned a limited period of six years during which multiple novel threats to fisher survival within the study area were identified, and when three large wildfires significantly reduced availability of suitable habitat for fishers immediately to the south and north of the study site. We recommend continuous monitoring of the status of fisher populations in the southern Sierra Nevada region. Development of ways to mitigate for major threats to fisher survival and fisher habitats and population viability analyses are necessary for evaluating the long-term prospects for fishers in the southern Sierra Nevada. Data from the SNAMP Fisher study have provided important new insights on the status of a fisher population at the north margin of their current distribution in the southern Sierra Nevada Range, which will be useful towards developing a comprehensive conservation strategy for fishers in California.

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Introduction

Background

Fishers are a medium-sized mammalian carnivore with a historic distribution encompassing the boreal forest zone of Canada, the Great Lakes region and northeastern United States, a relatively limited portion of the Rocky Mountains in the United States, and mountainous areas of Washington, Oregon, and California, USA (Powell 1993). In the west coast states, indigenous fishers currently exist in three remnant populations in southern Oregon, northern California, and the southern Sierra Nevada, California (Zielinski et al. 2005). In California the fisher occupies less than half of its historical range as described by Grinnell in the early 1900s (Grinnell et al. 1937), and the two remnant populations are separated by approximately 400 km. This fragmentation had been considered to be due to widespread timber harvest and fur trapping during the early to mid-1900s (Zielinski et al. 2005), but recent genetic research suggests that the northern California and southern Sierra Nevada populations may have been genetically isolated prior to European settlement (Tucker et al. 2012). Whether this isolation stemmed from extirpation of fishers in the central Sierra Nevada, or from reduced genetic flow due to local topographic obstacles is unknown. Notwithstanding uncertainty regarding the timing or cause of the range retraction, there may be fewer than 500 total fishers in the southern Sierra Nevada population (Spencer et al. 2011), where the species currently occupies approximately 4,400 km^2 of mid-elevation, mixed-coniferous forest (Spencer et al. 2015).

In October, 2014 the US Fish and Wildlife Service proposed listing the West Coast Fisher Distinct Population Segment, meaning fishers in California, Oregon, and Washington, as threatened under the federal Endangered Species Act (http://federalregister.gov/a/2014-23456). The public comment period on the proposed rule closed in May, 2015, and a final decision is scheduled for April, 2016. The fisher is currently listed as state endangered by the Washington Department of Fish and Wildlife. In California and Oregon, the fisher is currently a candidate species for listing under the state Endangered Species Acts, and on August 5, 2015 the California Fish and Game Commission voted to list the southern Sierra Nevada fisher population as threatened.

Fisher Range and Population Trends

Grinnell et al. (1937) described the original range of the fisher in California as including the entire western slope of the Sierra Nevada, the southern Cascades, Klamath Mountains, and northern Coast Range, a total area of ~100,000-110,000 km^2 (Spencer et al. 2015) (Fig. D1). Lofroth et al. (2010) estimated that the current range of the fisher in California represents <50 percent of the historical range, and fishers are currently absent from most of the northern and central Sierra Nevada, leaving a ~400-km gap separating the two remnant populations in the state (Zielinski et al. 1995) (Fig. D1), one in the northern Coast Range and one in the southern Sierra Nevada (Spencer et al. 2015). Spencer and Zielinski (in review) used an updated fisher locality database to estimate their current geographic range in California at 55,000-60,000 km^2, with ~45,000-50,000 km^2 in northern California and 10,000-12,000 km^2 in the southern Sierra Nevada. Although the range areas estimated by Spencer and Zielinski (In review) included a mix of suitable and unsuitable habitats, the analysis suggested a 30-50 percent reduction compared to the historical range of the species.

Figure D1: Historical and estimated current distribution of fisher in the western United States and Canada. Map source: Lofroth et al. 2010

The southern Sierra Nevada fisher population is small (≈500 total individuals and <300 adult fishers; Spencer et al. 2011), but appears to be stable over about the past decade (Zielinski et al. 2013). Following substantial population contractions in the past (Knaus et al., 2012), fishers in this part of California may have expanded in the late 20th century (Tucker et al. 2014). The overall distribution of fisher in the southern Sierra Nevada has been monitored using a combination of track plates and motion detecting cameras since the mid-1990s (Truex et al. 1998, Zielinski et at al. 2005, Jordan 2007). Zielinski et al. (2013) analyzed occupancy records from this effort for the period 2002 to 2012, when a systematic survey design was in place, and found no detectable change in occupancy for the entire area or for any of the three subareas examined. Furthermore, the authors stated that "Constant and positive persistence values suggested that sample units rarely changed status from occupied to unoccupied or vice versa" (Zielinski et al. 2013). However, this evidence can be interpreted one of two ways. On one hand, the lack of a decreasing trend may indicate a small but stable population. On the other, the lack of an increasing trend may indicate that despite fishers being protected from fur harvest for over 60 years during a time when large scale clearing of forest habitat was diminished (Collins et al. 2010), the population isolate is not showing evidence of recovery. Interpretation is further complicated by a combination of genetic patterns and survey data suggesting that the population north of the Kings River may have expanded during the 1990s, before the regional monitoring program was established (Tucker et al. 2014).

Insight from prior research in the High Sierra District, Sierra National Forest (KRFP study, ≈60 km southeast of the Key Watersheds) suggests that fisher population densities range from 0.07 to 0.28 fishers/km^2 (Jordan et al. 2011, Thompson et al. 2012). Records from research in northern California (Hoopa Study) indicate the potential for fisher densities to change rapidly. In the Hoopa Valley area of Northern California, fisher densities were estimated at 0.52 fishers/km^2 in 1998, but fell to 0.14 fishers/km^2 in 2005 (Matthews et al. 2013). Due to the apparent variability in density estimates, developing precise density estimates for different subpopulations and in different habitat types is critical for effective management.

Management and Conservation Planning

Federal and state resource agencies are currently developing strategies to aid in the maintenance of viable populations of fishers in both northwestern California and in the southern Sierra Nevada. It is possible that the isolated population of fishers in the southern Sierra Nevada will be impacted as the USDA Forest Service implements fuel reduction measures (Strategically Placed Land Allocation Treatments; SPLATS) to mitigate risk of catastrophic wildfire (Scheller et al. 2011). Fuel reduction treatments are becoming the dominant forest management activity in western forests in response to increases in the frequency of intense, stand-replacing forest fires over the past several decades (Mallek et al. 2013, Safford 2013). Advances in fire modeling have greatly improved managers' ability to plan and evaluate various landscape fuel treatment scenarios intended to reduce fire risks (Collins et al. 2010, Scheller et al. 2011). However, there remains a considerable gap between modeling landscape-scale fuel treatments and implementing them due to concern over the status of rare and uncommon species associated with multi-storied, late-seral stage forests, such as the fisher and spotted owl (*Strix occidentalis occidentalis*) (Naney et al. 2012, Truex and Zielinski 2013). Presence of fishers has strongly influenced managers' ability to delineate landscape-scale fuel treatments in this fire-prone region (Collins et al. 2010, Thompson et al. 2011). The Sierra Nevada Forest Plan Amendment (SNFPA) represents the most recent attempt to reconcile the need to reduce fuel loadings in Sierra Nevada mixed-conifer forests and retain characteristics of late-successional forests that are important for these species. The strategy involves a network of "Strategically Placed Area Fuel Treatments" (SPLATS) that allow up to a 60% reduction in basal area and a 30% reduction in canopy cover in Sierra mixed conifer forest. In the long-term, this strategy may increase availability of important habitats for species such as the fisher and California spotted owl by reducing wildfire-induced losses (Spencer et al. 2011), but treatments may also impact habitat quality for fishers in the near-term (Thompson et al. 2011).

To provide a framework for balancing the habitat needs of fishers with fuel treatments intended to reduce fire risks, SNAMP initiated a coordinated effort to assess the effects of fuel treatments on many environmental features including the fisher, spotted owl, forest health, and water quality and quantity in the central Sierra Nevada. SNAMP began in 2007 and was designed to evaluate the effects and effectiveness of fuel treatments implemented according to the revised Sierra Nevada Framework (USFS 2004) under a design that incorporated stakeholder participation. SNAMP is a landscape-scale, ecosystem-level experiment in natural resource management and involves a Before-After-Control (BACI) design developed specifically to assess the impacts of SPLATs on the overall forest ecosystem (Popescu et al. 2012).

Study Goals and Primary Objectives

1. Estimate population parameters including age and sex-specific survival, and fecundity
    a. What are the vital rates (reproduction, survival, population growth rates)?
    b. What is the population size and density in the study area?
    c. What are the patterns of dispersal movements?
2. Identify population limiting factors in the region encompassed by the study area
    a. What are the causes of mortality? Are predators, parasites or diseases important?
    b. What are the reproductive rates?

c. What are the patterns of home range, dispersal, and habitat use?

3. Evaluate effects of SPLATS on occupancy, survival and fecundity
    a. Characterize resource use by fishers; do SPLATs influence habitat use
    b. What are the patterns of fisher occupancy in relation to forest management?
    c. Do patterns of fisher occupancy change before and after by SPLATS?

Site Description and Study Area

The SNAMP Fisher Project study area is at the northern end of the southern Sierra Nevada fisher population in California, encompassing the area bounded by the Merced River in the north and the San Joaquin River in the south (Fig. 2). It consists of three nested landscapes: the SNAMP study area (34 km^2), the key watershed region (128 km^2), and the SNAMP Fisher study area (1300 km^2). We expanded into the key watershed region to facilitate an evaluation of the impacts of fuel and vegetation management on fisher survival, habitat selection, and reproduction. The key watershed region

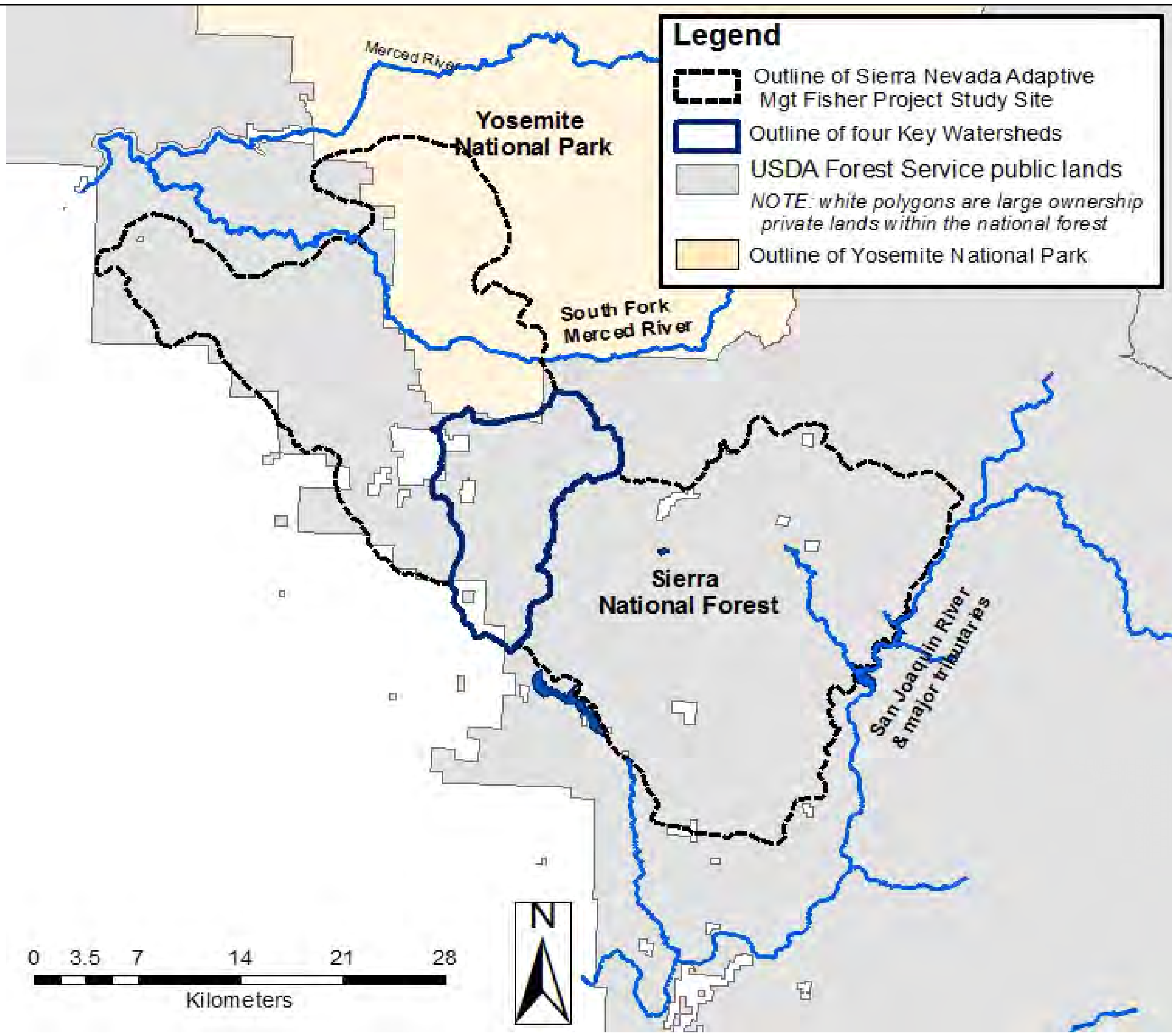
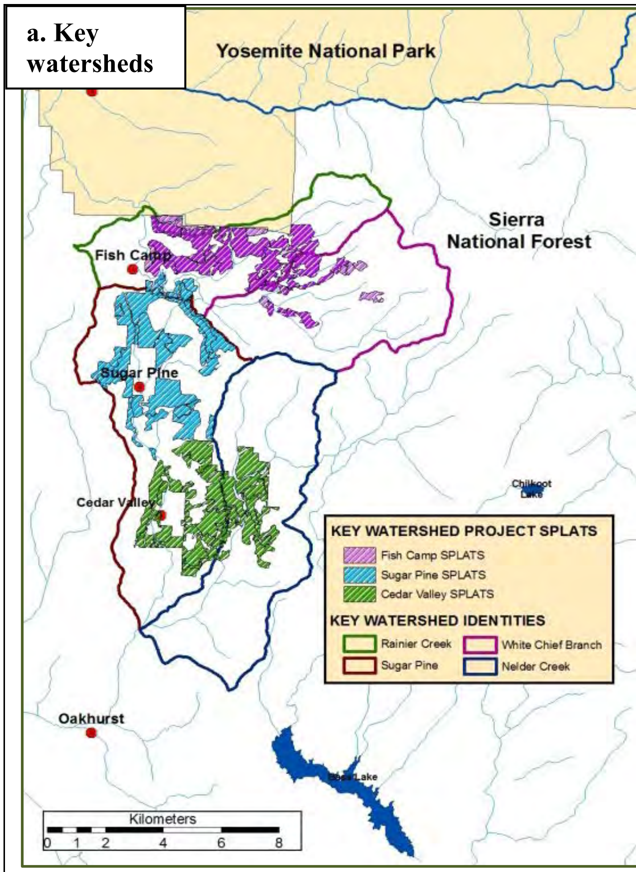


Figure D2: Overall Study Area of the SNAMP Fisher Project, including administrative boundaries and the outer boundary of the "Key Watersheds" focal study area in the approximate center of the map region.

encompassed three Forest Service projects expected to occur in the study period near the communities of Fish Camp (Fish Camp Project), Sugar Pine (Sugar Pine Project), and Cedar Valley (Cedar Valley Project). The four Key Watersheds are the Sugar Pine, Nelder Creek, Rainier Creek and White Chief Branch watersheds (Fig. D3).

Due to the large movement capacity and space use of fishers, further expansion into the SNAMP Fisher study area was necessary to reach and maintain the stated goal of monitoring 20 radiocollared animals at all times to obtain more precise estimates of demographic rates. This larger study area encompasses a mix of public and private land and is topographically complex with elevations ranging from 758 m to 2652 m. Administratively, the focal study area for the study is the non-wilderness region of the Bass Lake Ranger District in the Sierra National Forest, however it extends into the southern portion of Yosemite National Park. Field work was carried out between 1,000 m and 2,400 m in elevation, corresponding to fisher occurrence in the region. This elevation gradient corresponds with a mix of hardwoods (California bay *[Umbellularia californica],* Canyon live oak [*Quercus chrysolepis*], CA black oak *[Quercus kelloggii*]) and several conifer species at lower elevations (ponderosa pine [*Pinus ponderosa*], incense cedar [*Calocedrus decurrens*]; California Wildlife Habitat Relationship system MHW, PPN, and MHC habitat types). Between 1300 and 1900 m habitat consists of a mix of multiple conifers (Jeffrey pine [*P. jeffreyi],* white fir (*Abies concolor*), incense cedar), and hardwoods (black oak, white alder [*Alnus rhombifolia]*, mountain dogwood [*Cornus nuttallii]*) (CWHR Habitat types SMC, MHC, PPN). Above 1900 m habitat transitions into red fir (*Abies magnifica*) and lodgepole pine (*P. contorta*) (CWHR Type RFR). Common shrubs and tree-like shrubs include whiteleaf manzanita (*Arctostaphylos viscida*), greenleaf manzanita (*Arctostaphylos patula*), mountain misery (*Chamaebatia foliolosa*), bush chinquapin (*Chrysolepis sempervirens*), mountain whitethorn (*Ceanothus cordulatus)*, and snowberry (*Symphoricarpos mollis*). Giant sequoia (*Sequoiadendron giganteum*) are present, but primarily restricted to the Nelder Grove Historic Area within the Nelder Creek watershed. Permanent streams in the Key Watersheds are important for fishers and other wildlife and include Big Creek and Rainier Creek in the Rainier Creek watershed, Lewis Creek in the Sugar Pine watershed, and California Creek and Nelder Creek in the Nelder Creek watershed.



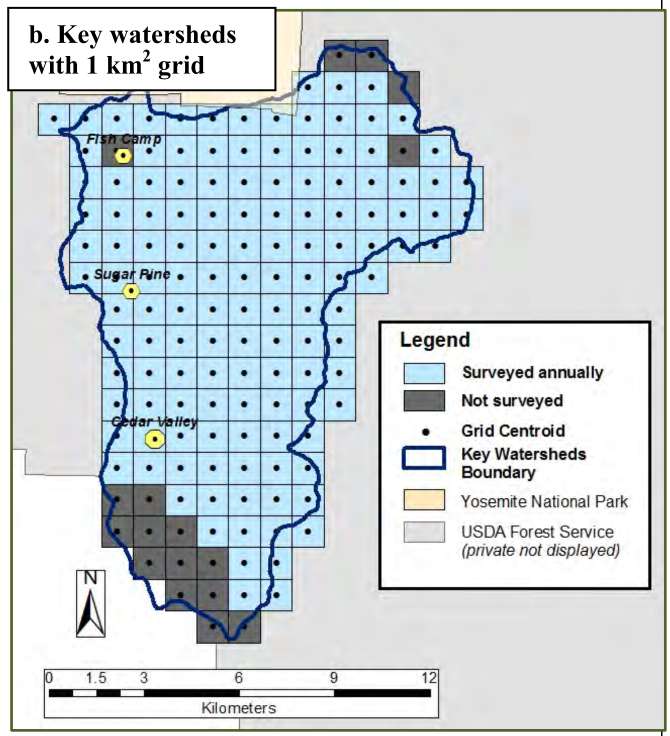


Illustration D3 (bottom right): Photograph of study area from Chiquito Ridge looking east

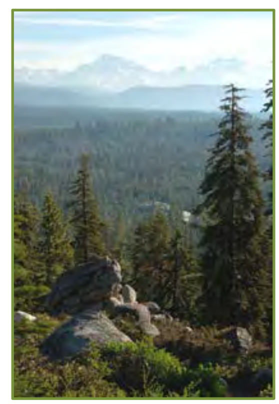


Figure D3: (a) Map views of Key Watersheds focal study area, including the SPLAT polygons originally produced for the Sugar Pine, Cedar Valley, and Fish Camp forest management projects. (b) Key Watersheds overlain with 1km^2 grid used to organize study effort for camera surveys. Yellow circles indicate the three communities located within the watersheds. NOTE: cameras were placed at or very near the grid cell center points as plotted.

Methods

Vital Rates and Basic Population Parameters

Field Methods

Live Trapping.--Although noninvasive methods can be used to generate important data on wildlife populations (Long 2008), estimating vital rates (survival, reproduction, dispersal) almost always requires trapping to radiocollar and then closely monitor the study animals. We followed standard live-trapping procedures previously developed for fishers in California (Jordan 2007, Matthews et al. 2013*a*), with only a few minor changes. Individual fishers were live-captured in steel mesh traps (Tomahawk Live Trap Company, Tomahawk, WI) modified to include a plywood cubby box to provide the animals with a secure refuge where they were less likely to injure themselves (Wilbert 1992). Trapping to mark animals with radiocollars was focused during the fall and winter seasons between December 2007 and March 2012. Also, with the exception of the first year of the study when we needed to capture fishers to initiate the study, we did not trap during the spring denning period (late March to mid-June) to minimize disturbance to reproduction. Live traps were baited with venison, and checked daily by late morning. Captured animals were restrained in a handling cone, and sedated using a mixture of Ketamine hydrochloride and Diazepam (1 mg Diazepam/200 mg Ketamine) injected intramuscularly. Sedated fishers were weighed, classified by age and sex based on examination of teeth and genitalia, and measured for standard morphological features. Small samples of ear tissue were collected for microsatellite DNA analysis using a sterile dermal biopsy punch. Several strands of hair were removed from the nape and rump region, also for DNA analysis. Hair samples were stored in a dry paper envelope, whereas tissue samples were stored in 95% ethanol until analysis at the USDA Forest Service Wildlife Genetics Lab (Rocky Mountain Research Station, Missoula MT). Teats on females were measured for base diameter and height using digital calipers (± 1mm), and those data were used to identify females that weaned at least 1 kit when they had not been monitored during the denning period (Matthews et al. 2013*b*). Each animal was permanently identified by subcutaneous insertion of passive integrated transponder (PIT) tags (Biomark, Boise, ID), and fitted with a radio collar (Holohil Systems Model MI-2M, Ontario, Canada) modified by attaching small bands (0.5-1.0 cm) of infrared reflective tape (3M® Scotchlite™) along the lengths of the antennas. Custom breakaway devices were inserted into radiocollars fitted to juvenile fishers to reduce the risk of injury or strangulation between recaptures (Thompson et al. 2012). Bands of infrared reflective tape and breakaways were modifications, not used in previous studies. After handling, we returned animals to the cubby box and released them at the point of capture after recovery from anesthesia. Capture and handling procedures followed American Society of Mammologist guidelines (Sikes and Gannon 2011), and were approved by the Institutional Animal Care and Use Committee of the University of California, Berkeley (protocol R139).

Live-trapping is labor intensive, and the effort was designed to gain advantage from detections of non-collared fishers at cameras. Live traps were most frequently placed in the same area of camera stations after cameras had been removed (to prevent interference with camera surveys). Data from camera detections were used to design linear traplines of 5-10 traps bracketing positive detection stations. Distance of separation between traps was typically ≥500 m, and traplines were usually successful at capturing targeted animals within five nights of trapping. Live-trap success was further enhanced in later years of the study by placing traps in locations where fishers had been captured in the past. Trap success was also enhanced by cleaning and sanitizing traps after captures. In winter, snow falling from tree branches can ice up the treadle mechanism inside live traps. We used lightweight, rectangular canvas tarps to protect the inside of the live traps from falling snow, and debris used to camouflage the traps. Traplines were generally removed the day after targeted fishers were captured, and always after 10 nights of trapping when no fishers were captured.

Illustration D4: Camouflaged live trap near the base of a white fir tree, and a radiocollared fisher being released after processing.

Aerial Telemetry and Radiotelemetry Monitoring.--Tracking radiocollared animals from an aircraft is an alternative to locating them from the ground by homing or triangulation (Thompson et al. 2012). Researchers have been using fixed-wing aircraft to locate wildlife since the early 1970s (Mech 1974). The unique ability of observers in aircraft to rapidly search and locate radiocollared animals over large and inaccessible areas while allowing for nearly line of sight reception between transmitter and receiver makes aerial radio telemetry an effective research technique in general (Gilmer et al. 1981), and specifically for studying fishers, which often occur in remote mountainous areas where access can be difficult (Weir and Corbould 2008). Partly for these reasons, we used fixed-wing airplanes to monitor and relocate radiocollared fishers for the entirety of the SNAMP Fisher Project. Beginning in December 2007, we worked with USDA Forest Service Supervisory Pilot John Litton to develop an aviation program in support of SNAMP Fisher, which was fully established in August 2008 when a full time pilot was hired and the first of two dedicated aircraft were based at the Mariposa-Yosemite Airport in Mariposa, CA.

The two USDA Forest Service-owned aircraft acquired for supporting the project were a Cessna 185 (Cessna Aircraft Co., Wichita, KS) and a Piper PA-18 Super cub (Piper Aircraft Inc., Vero Beach FL). Two aircraft were considered necessary to maintain continuous monitoring of radiocollared fishers when routine maintenance or engine repair was necessary (John Litton, personal communication).

Illustration D5: Forest Service-owned Piper Supercub (left) and Cessna 185 (right) on the tarmac at the Mariposa Airport, California.

Illustration D6*:* Forest Service Cessna 185 airplane, and antenna configuration on the right side wing strut.

The optimal search procedure used when locating animals from light aircraft varies depending on the number of animals tracked, and the antenna configuration supported and approved for the airplane being used (Gilmer et al. 1981). Additional details are provided elsewhere (Thompson et al. 2012), but we used two, 2-element H antennas (Telonics Inc., Mesa, AZ) mounted in a sideways configuration on each wing strut, and a single 3-element Yagi antenna (Advanced Telemetry Systems, Isanti, MN) mounted forward-facing on the right wing strut. This antenna configuration was effective in allowing the pilot and biologist to search for radiocollared fishers using the Yagi antenna (detection range 5-20 km), and then switching to the H-antennas to localize to a relatively precise location above the animal using a circling technique (Seddon and Maloney 2004).

Fixed-wing flights (aerial telemetry missions) to locate radiocollared fishers in the study area were scheduled in advance for 4-6 missions/week, depending on weather conditions considered safe for departure and return to the Mariposa-Yosemite Airport. Flights typically occurred in the morning hours, and lasted 2-3 hours. Afternoon telemetry flights were relatively infrequent, and the large majority of aerial radiotelemetry locations were acquired in the AM period of the day. As part of each aerial-telemetry mission, we systematically searched for all active radiocollars deployed on fishers in the study area. Biologists in the airplane recorded (1) active/inactive status for each fisher, (2) time of location, (3) an estimated UTM location for each fisher (typically logged into a handheld GPS unit; Garmin 60 CSx, Olathe, KS), (4) a qualitative ranking for each location (poor, fair, good, excellent), and (5) a record of any radiocollared fishers that were not located. Additional descriptive details were often recorded that related to the nature of weather conditions influencing the aircraft at the time of the location (turbulence, "bumpy", clouds occluding visibility to the ground, etc.), or if the animal had moved an unusual distance or to an atypical area. At the end of each aerial telemetry mission, the biologists summarized details on departure and return times and weather and flight conditions during the flight.

Aerial radiotelemetry can be efficient for locating animals that range over large areas in difficult terrain (Gilmer et al. 1981), but the accuracy, or precision of aerial telemetry locations is generally less than for ground-based radiotelemetry (e.g., triangulation; Koen 2005, Gantz et al. 2006). Location error from fixed-wing airplanes varies with flight speed, elevation above ground level, pilot and biologist experience, and signal reflection in rugged topography (Thompson et al. 2012). We assessed error for aerial radiotelemetry locations on the SNAMP Fisher project by calculating the Euclidean distance between GPS locations logged by biologists in the airplane and positions of test collars placed at known locations on the ground. Test collar locations were generally radiocollars that were placed in locations unknown to the biologist in the airplane; biologists were required to regularly estimate positions for test collars during aerial telemetry missions. Other aerial radiotelemetry locations used to quantify accuracy included dropped radiocollars, carcass locations, fishers in live traps, and female fishers in a cavity in a den tree whose locations were also unknown to the biologist in the airplane.

Fisher Reproduction

Background.--Den sites, where female fishers bear and raise their kits, are a critical habitat element for fisher populations in California. Females typically use more than one den during the denning season (late March to mid-June). Natal dens are where adult female fishers give birth and initially care for young, and they may then move kits to one or more maternal dens from early April to June until they are weaned (Powell et al. 2003, Matthews et al. 2013*a*). Reproductive dens, both natal and maternal, are nearly always cavities in large trees, live or dead, and are found in forest stands with dense canopy cover and complex multi-layered structure (Zhao et al. 2012). Suitable denning sites are likely a subset of suitable resting sites because the requirements are more stringent: (1) den cavities must be large enough to shelter both mother and kits for weeks rather than days; (2) the female needs to provision her young while they are restricted to the den, so dens must be located close to high-value foraging areas; (3) cavity entrances must be small enough to exclude males; and (4) denning begins in late March-early April, when temperature are colder and slope position may be more critical in assisting with kit thermoregulation.

Identifying den trees and evidence of reproduction.—Female fishers exhibiting behavior consistent with denning were identified during late March-mid April and then monitored. Denning behavior was characterized by an abrupt change from a pattern of successive aerial radiotelemetry locations being dispersed within a female's home range, to a pattern where locations were spatially clustered (3-5 locations within 500 m over a 7-day period; Zhao et al. 2012). When clustering of locations occurred, a biologist navigated to the area with a handheld Global Positioning System device to investigate. Standard ground-based radiotelemetry techniques with a handheld receiver (model R1000; Communication Specialists, Inc. Orange, California) and an H-type antenna were then used to home towards telemetry signals of radiocollared females. Once a collared female was isolated in an area, the biologist circled the fisher until the individual tree or snag was identified (Matthews et al. 2013*a*). When female fishers were localized to a possible den structure, 2-4 automatic "den cameras" that had been cleaned and de-scented were attached to nearby trees and focused on the bole of the den structure (scent and bait lures were not applied around den trees to avoid attracting other predators). We returned to these structures the day after initial placement of den cameras, and then every 3-5 days to confirm use for denning based on regular occupancy and images indicating up and down movements on the tree or snag. Trees and snags used ≥3 times in succession and with camera-based evidence of up-down movements were considered denning structures (Zhao et al. 2012). We defined "denning opportunities" as the total number of individual, breeding-age female fishers (≥24 months) either directly monitored in mid-March to June (Matthews et al. 2013*a*), or measured for teat size during July to January to assess weaning status (Matthews et al. 2013*b*). We considered kits weaned when denning behavior continued until 31 May or later (Matthews et al. 2013*a*).

Activities of known-denning female fishers were chronicled for the duration of each denning season by continuous monitoring with cameras and ground checks of den trees. Female fishers typically transfer kits from natal den trees in which they were born to 1-6 other maternal dens during April to June (Matthews et al. 2013*a*). Each time we had evidence that a denning fisher moved kits to a new maternal den (images of females transporting kits away from den trees, cessation of occupancy over multiple checks), we searched for the female using ground telemetry and repositioned cameras around the next den structure (Zhao et al. 2012). Den cameras were removed in mid-June when females ceased localizing to den structures.

Illustration D7: Female fisher F46 moving a 1-month old fisher kit from her natal den tree.

Information on litter size was determined from images from den cameras, or, less frequently, by climbing den trees and using a video camera (Peep-A-Roo Video Probe System, Sandpiper Technologies, Manteca, CA) to count kits inside den cavities (Matthews et al. 2013*a*). We minimized disturbance to denning females by (1) restricting visits to den structures to service cameras to once every 3-5 days, (2) using deployments of multiple den cameras for obtaining the majority of kit counts, and (3) by not approaching den trees for climbing until ground-based telemetry indicated the female was well away from the den structure (Zhao et al. 2012).

Maximum reproductive rate was estimated as the sum of the number of adult-age female fishers in the population that localized to den trees during the den season (Mar 21 to Jun 20), plus the number of adult females with enlarged teats that were not monitored but captured and measured before January, divided by the number of adult-age female fishers in the population during mid-March to late January. Weaning rate was estimated as the number of adult-age females known to have survived and localized to den trees through May plus those with enlarged teats that were captured after the den season, divided by the number of adult-age female fishers in the population during mid-March to late January. We note that measurements of teat size were shown to correctly identify over 90% of current year reproducing females that weaned at least 1 kit, and all but 3 adult females for which teat measurements were used to determine reproductive status were part of the Matthews et al. (2013*b*) dataset. Annual estimates of fecundity were calculated as the number of female offspring produced: proportion of adults weaning kits * average weaned litter size * 0.5 (assuming equal sex ratio).

Habitat Characteristics within Fisher Denning Areas.--Denning structures are considered a limiting habitat element for fishers in California and elsewhere (Weir et al. 2012), but site characteristics immediately surrounding the denning structures may also limit fisher use of a site for denning (Zhao et al. 2012). Current forest vegetation management to reduce hazardous fuel levels, improve the vigor of selected trees (pines and oaks), increase spatial heterogeneity, and provide forest products for society may impinge on denning habitats in a variety of ways (Naney et al. 2012, Powell and Zielinski 1994,). These management actions can negatively affect fisher habitat (Weir and Corbould 2008), at least in the short term (Thompson et al. 2011), while others may have little impact on fisher habitat suitability (Spencer et al. 2015). Without detailed "local scale" information on habitat characteristics directly associated with fisher denning structures, it will not be possible to adequately manage Sierra Nevada forests in ways that will maintain viable fisher populations.

Habitat characteristics for denning structures.—We developed a protocol for determining the combination of biotic and abiotic characteristics female fishers are likely selecting/using for denning habitats. The protocol was designed to collect similar types of data as those being recorded by the Forest Health Team on the Core Plots in the Sugar Pine area, while also capturing the same types of data being recorded by the USDA Forest Service PSW Kings River Fisher Project at den trees used by fishers in the High Sierra District, Sierra National Forest. Full details on how different habitat data were assessed are provided in Appendix D1. Briefly, we used an 18m radius circular plot centered on the denning structure (Fig. D4) to organize collection of data on (1) canopy cover, (2) litter, duff, and coarse woody debris (associated abundance of fuels), (3) cover and height of herbaceous plants and understory woody shrubs (concealment cover), (4) slope and aspect, and (5) size, number, and height of trees and snags (3 size classes, 4 crown classes). Data on habitat characteristics for den trees were typically collected during late spring or summer, and always when the den trees were no longer in use for denning.

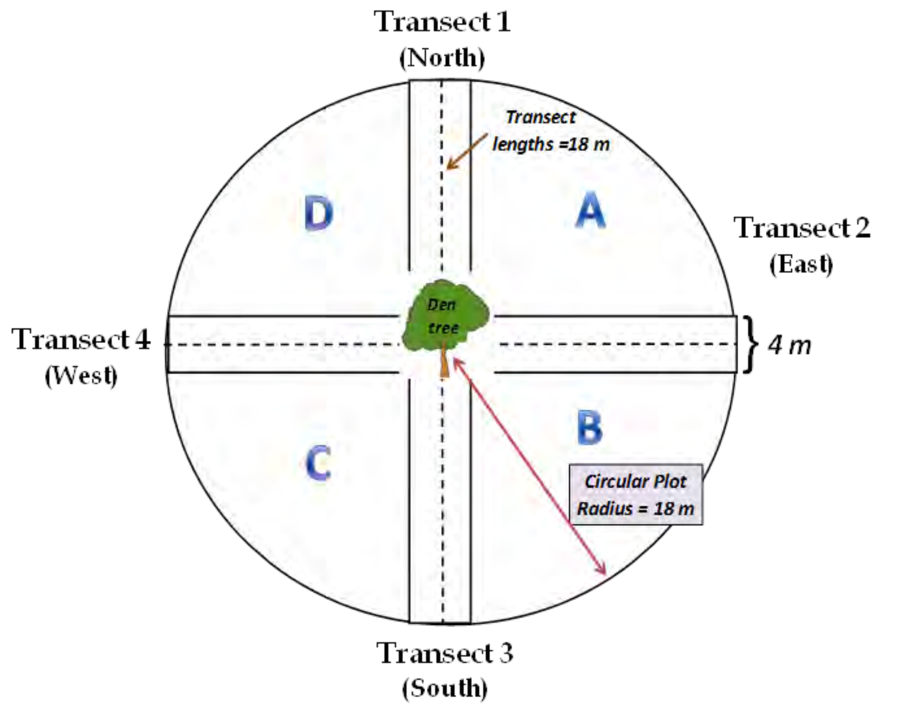


Figure D4: Diagram illustrating the layout of 18m radius circular plots and associated measurement transects for fisher denning structures for the SNAMP Fisher Project in the Bass Lake District, Sierra National Forest.

Fisher Survival

Background.--Understanding survival and the details of cause-specific mortality is fundamental for insight into the population biology of any species, and crucial for understanding the limits to population growth and recovery for rare or endangered species of wildlife. Historical loss and fragmentation of important habitats, combined with overexploitation by hunting and trapping are the most common drivers of endangerment of wildlife (Lande 1993). Although changes in management may sometimes succeed in reversing problems associated with loss of critical habitats, emergence of new threats that impinge on survival or reproduction can counteract improvements that might otherwise reverse population declines. Emerging threats to survival and population persistence may be obvious such as exposure to novel pathogens and increased occurrence of road-kill deaths (Gaskill 2013, Litvaitis and Tash 2008), or less discernible and linked to changes in community structure or composition that produces an imbalance in predator-prey relations (Roemer et al. 2001).

Factors that contribute to limited growth and expansion of fisher populations in the southern Sierra Nevada are likely linked to a combination of resource and population phenomena. Fishers may be challenged by limited access to suitable resting and denning habitats (Purcell et al. 2009) or insufficient numbers of prey (Zielinski and Duncan 2004), whereas survival may be reduced by high rates of predation (Wengert 2013), wildlife-vehicle collisions (Chow 2009), and exposure to anticoagulant rodenticides (Gabriel et al. 2012a, Thompson et al. 2013). Although habitat requirements of fishers and their responses to forest management are increasingly well known (Aubry et al. 2013, Garner 2013, Zielinski et al. 2013), it has only recently been documented that high numbers of otherwise healthy fishers were succumbing to attacks by other forest carnivores (Wengert et al. 2014) and that illegal use of anticoagulant rodenticides and other toxicants associated with illegal marijuana grow sites on national forests and parks in the southern Sierra Nevada was contributing to both direct mortality and reduced survival of fishers in this region (Gabriel et al. 2012a, 2013, Thompson et al. 2013). Because of heightened concern over the stability of the small population of fishers in the southern Sierra Nevada, our primary objective was to evaluate factors contributing to variation in survival among fishers in the region. Young mammals (particularly males) often experience higher mortality early in life associated with dispersal and establishing independent home ranges (Chepko-Sade and Halpin 1987), and general naiveté with predators and other environmental risks (Farias et al. 2005, Murdoch et al. 2010). Fishers typically disperse before they reach maturity at ≈ 24 months (Arthur et al. 1993), and may suffer lower subadult survival rates as a result. Fishers may also experience lower survival during fall and winter due to the combined effects of higher energetic costs associated with movements in deep snow cover (Powell 1979) and prey limitation when several species of rodent prey utilized by fishers (Zielinski and Duncan 2004) enter into torpor. Therefore, we hypothesized that (1) survival would be lower for juvenile and yearling fishers compared to adults, (2) males would experience lower survival than females related to higher rates of movement and potentially longer dispersal distances, and (3) survival would be lower during fall and winter than in spring and summer.

Determination of survival rates.--We monitored the status (alive, dead, or missing) of radio-collared fishers from time of first capture until death, censorship (due to dropped or failed collars on animals that were not quickly recaptured), or the end of the study. Breakaway devices in the radio-collars occasionally resulted in premature detachment, requiring efforts to re-collar animals that were short-term missing (1-2 months). Because of the relatively common incidences when animals were missing for less than one month, we evaluated survival on monthly intervals rather than weekly or bi-weekly. Overall patterns of survival were determined using the Kaplan-Meier (KM) staggered entry method (Koen et al. 2007, Pollock et al. 1989, Price et al. 2010). KM models were used to produce estimates for annual survival and combined year survival (data pooled by month across all years). The population year was defined as April 1 to March 31 based on the timing of reproduction for female fishers in California with most offspring produced from March 21 to early April (Matthews et al. 2013*a*). Annual survival can be moderately to highly variable and may result in a negative population growth trajectory that may not be appropriate for a long-lived species with a generation time of two or more years. We therefore smoothed survival estimates by grouping data into 2-year increments (e.g., population years 2 and 3, population years 3 and 4, etc.) and generating KM estimates for each 2-year increment. Live-trapping to capture young-of-the year juveniles was focused during mid-October to February (a few juvenile fishers were occasionally captured before October or in early March). Kaplan-Meier models to estimate "annual" survival for juveniles were typically initiated in December, thereby producing survival estimates for juveniles for a 3-4 month period from December or January to March. When data for juveniles were pooled across population years, however, the dataset allowed for evaluating juvenile survival for the 6 month period from October to March. Z-tests were used to compare estimates for combined year survival for all possible age and sex combinations. Significance levels (α) for multiple comparisons were adjusted for Type I error rates using the Bonferroni procedure (McCann et al. 2010).

Causes of Mortality

Background—In addition to the challenges described previously, it has been hypothesized that changes to more open canopy forest conditions with an understory of small trees and more shrubs, following either management or wildfire, is contributing to higher rates of predation by bobcats (*Lynx* *rufous*) and coyotes (*Canis latrans*) (Wengert 2013). Although the habitat requirements for fishers are generally known (Lofroth et al. 2010), details of cause-specific mortality in the southern Sierra Nevada had not been rigorously evaluated until the SNAMP and KRFP studies were initiated in 2007.

Monitoring to detect mortality.-- All radio-collars fitted to fishers on the SNAMP study were equipped with either mortality or activity sensors, internal mercury switches that change the pulse rate when the collar is stationary for over 8 hours (mortality switch) or active (activity sensor). These sensors allowed us to detect inactive signals, investigate fisher mortalities, and recover carcasses soon after death in most cases. When a mortality signal was detected, immediate attempts were made to locate the collar and recover either the carcass or the dropped radiocollar. Carcasses were generally recovered within 24 hours of death.

Radiocollared fishers have been monitored effectively and relocated by intensive ground-based radiotelemetry as part of the KRFP study centered approx. 60 km southeast of the SNAMP Fisher Study Area (Garner 2013). However, most prior studies have been unable to identify causes of death for many deceased study animals because carcasses were not retrieved within 12-48 hours after death (Truex et al. 1998, Aubry and Raley 2006, Jordan 2007). Decomposition begins immediately after death, which can prevent identification of underlying disease processes (Gabriel 2013, Keller et al. 2012), and scavenging can mask both the cause of death and the responsible predator (Wengert 2013). Because of this, our primary rationale for monitoring radiocollared fisher by fixed-wing aircraft up to 6 days/week was to recover carcasses of animals as soon after death as possible. The protocol that was in place from the start of the study until approx. June 2012 was for the biologist in the airplane to use the audio system in the airplane to (1) transmit the estimated location coordinates for any radiocollared fishers detected on inactive pulse to the SNAMP fisher office, whereupon (2) a staff biologist in the vicinity would immediately investigate the location and recover the carcass following an approved forensic protocol, (3) transport the carcass to the SNAMP fisher office where they were placed in -20^0 C freezer for storage until (4) a necropsy could be scheduled at the UC Davis School of Veterinary Medicine.

Once a radiocollar is activated and deployed, it will typically function (emit a radio signal) for 18-24 months until the battery is expended. In 2011 the SNAMP Fisher project began using radiocollars from Advanced Telemetry Systems (ATS), but discovered that many of the electronic "mortality switches" built into the ATS radiocollars became defective within 8-10 months of being deployed on study animals. Electronic mortality switches are designed to emit pulses at twice the normal pulse rate when the radiocollar has been stationary for at least 8 hours. When the mortality switches in the ATS brand radiocollars became defective they began to emit intermittent and then consistent false inactive signals. SNAMP Fisher was forced to modify the inactive signal protocol by first plotting locations determined for inactive signals in ArcGIS, whereupon a decision on whether to investigate the location was based on a judgment of the distance of separation between successive aerial radiotelemetry locations (investigation triggered when successive locations were <1000 m apart). The revised protocol was situation specific: the first time a collar was detected emitting an inactive signal, efforts were made to investigate the location immediately. Subsequent inactive signals from that collar were examined carefully prior to on-the-ground investigation. This process may have delayed the recovery of a limited number of carcasses. Efforts were made to correct for the problem of false inactive signals by replacing defective collars with collars of a different manufacture as soon as possible.

When fisher carcasses were discovered we followed a standardized forensic protocol for collecting samples and documenting evidence at mortality sites using photographs and diagrams (Wengert et al. 2013). When predation was suspected as the cause of death (e.g., obvious punctures, partial consumption), we recorded information on the characteristics of the predation event including patterns of consumption and evidence of caching or burying. Samples included swabs of visible bite wounds, clipped fur from near the bite wounds (clipped to avoid fisher DNA in root bulbs), swabs of the claws and teeth, and any non-fisher hairs left on or near the carcass (Wengert et al. 2013). Carcasses were double-bagged in plastic bags, labeled, and transported back to the field offices where they were frozen in a -20°C freezer until being shipped to University of California, Davis for necropsy.

Pathology.--We submitted all carcasses for necropsy and disease and DNA assessment to cooperating pathologists at the University of California Davis, Veterinary Medical Teaching Hospital, and California Animal Health and Food Safety Laboratory in Davis, CA. When possible, the team of pathologists determined cause of death for each fisher using all available information, including necropsy examination, disease and toxicological results, DNA forensics, evidence recovered or identified as important from the mortality site, and habitat characteristics around the carcass. During necropsy, liver samples were collected and subsequently tested for the presence of anticoagulant rodenticide residues; liquid chromatography-tandem mass spectrometry was used to screen for presence of anticoagulant rodenticides and high-performance liquid chromatography was used to quantify positive samples. When predation was determined to be the cause of death, all lesions attributed to predation were described in detail. To distinguish between ante and post-mortem wounds (i.e., between predation and scavenging), we noted whether the lesions had associated hemorrhage and edema. In 14 cases, too few remains were present to identify hemorrhaging at wound sites, so only molecular analyses were conducted in these cases. Age-class at time of death was estimated as adult (≥24 months), subadult (12-23 months), and juvenile (<12 months) based either on tooth wear or cementum annuli counts.

Molecular Analyses-- Forensic samples were processed and analyzed for predator (either felid or canid) DNA following the methods of Wengert et al. (2013). Because multiple polymerase chain reaction (PCR) products were occasionally obtained when the products were visualized on an agarose gel, we gel-excised the appropriately sized fragment (200–300bp for felids and 400 for canids) and extracted DNA using Qiagen Qiaquick Gel Extraction kit according to the manufacturer's instructions. The PCR products were sequenced, then aligned using RidomTraceEdit (Ridom GmbH, Würzberg, Germany). Sequences were cross-referenced on GenBank using Basic Local Alignment Search Tool (BLAST) to match them to the most closely aligned sequence to identify species of predator DNA.

Population Growth Rates

Background.—Individuals will respond to changes in habitat, food availability, and weather conditions and these factors may cause fluctuations in abundance or density. Fishers are no exception to this general pattern (Jensen et al. 2012). As a rare species, however, the effects of these factors on population stability and viability are a significant conservation concern (Spencer et al. 2011, Reed and McCoy 2014).

Information on the growth trajectory for the fisher population in the SNAMP Fisher study area is uncertain, but there are several competing hypotheses regarding population status in the broader region encompassing the SNAMP Fisher study area. Evidence indicates that fishers in the Sierra Nevada experienced a range contraction of 30-50% over the last 75-100 years (Zielinski et al. 2005, 2013, Spencer et al. 2015), and research conducted between 2002 and 2012 provided no evidence of for an increasing population (Zielinski et al. 2013). Therefore this "no increase" hypothesis suggests that despite protection from fur trapping and the development of policies to better sustain sensitive birds and mammals (North et al. 2009), fishers in the southern Sierra Nevada are not recovering. An alternative hypothesis is that fishers were very uncommon in our study area prior to 1990, and the current population resulted from a northward expansion from south of the Kings River (Tucker et al. 2014), equivalent to an approx. 30% increase in distribution in the overall southern Sierra Nevada region based on analyses of fisher habitat by Spencer et al. (2014). This alternative view is based primarily on genetic evidence of population subdivision (Tucker et al. 2012, 2014), and potentially supported by increasing fisher detections from track plate and camera monitoring after the mid-1990s (Zielinski et al. 1995, 2005, 2013). Research into the ecological relationships of fishers in the southern Sierra Nevada has increased dramatically since the mid-1990s, and although much insight on fisher ecology has been gained with regards to home range size, population density, and habitat use for resting and other activities (Jordan et al. 2011, Thompson et al. 2012, Purcell et al. 2009), no prior study has reported on the growth rate of any fisher population in this area.

Population growth rates and Leslie-matrix modeling.— Intensive investigation as part of the SNAMP Fisher study has generated information on all key vital rates needed to evaluate the population growth rate (λ) in the area, critical for understanding whether the population has the potential to persist, or if it is in decline. We developed an age-structured matrix model to estimate a deterministic population growth rate (λ) for the SNAMP Fisher study population using observed data on denning, fecundity, and survival. We defined 2 "adult" age classes (24 months, ≥36 months) for developing and including estimates of fertility in the matrix model for the population. Fertilities (F_i) were calculated for adult-age female fishers as:

$$F_i = b(_i)Pi \qquad \text{Equation 1}$$

where fecundity, *b(i)*, was the mean number of female kits weaned per reproductive female (sex ratio at birth assumed = 0.5), and P_i was the age-specific survival rate (Gotelli 2001). Fertility for juveniles (F1) and subadults (F2) was fixed at 0. Age-specific survival rates were estimated for radiocollared juvenile (P1: 6-11 months), subadult (P2: 12-23 months) and adult-age (P3: ≥24 months) female fishers in the study area using monthly encounter histories in Kaplan-Meier staggered entry model analyses (KM survival). Survival estimates were produced for combined data on numbers of radiocollared fishers in each age class during the six year study period (All-year), given a natural transition of surviving individuals into a subsequent age class. Insufficient data was available to generate accurate annual survival estimates, so data was combined into 2-year increments (e.g., 2008-

2009, 2009-2010, etc.). Data on numbers of fishers in each age class for each 2-year increment were combined to generate survival estimates, starting with population years 2008-09 and 2009-10, and ending with population years 2012-13 and 2013-14.

Data from radiocollared animals from the study area indicated that female fishers commonly die by 6-8 years of age. We therefore included 8 age classes in our Leslie Matrix (**A**) formulation, where the numbers of fishers in each age class n_1 to n_8 at time $t+1$ = **A** X **n** vector at t_0 according to equation 2:

$$\begin{bmatrix} n1\ (t+1) \\ n2\ (t+1) \\ n3\ (t+1) \\ n4\ (t+1) \\ n5\ (t+1) \\ n6\ (t+1) \\ n7\ (t+1) \\ n8\ (t+1) \end{bmatrix} = \begin{bmatrix} F1 & F2 & F3 & F4 & F4 & F4 & F4 & F4 \\ P1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & P2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & P3 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & P3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & P3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & P3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & P3 & 0 \end{bmatrix} X \begin{bmatrix} n1(t0) \\ n2(t0) \\ n3(t0) \\ n4(t0) \\ n5(t0) \\ n6(t0) \\ n7(t0) \\ n8(t0) \end{bmatrix} \qquad \text{Equation 2}$$

Estimates for adult fertility were determined from data on weaning rates, fecundity, and survival for young adult (F_3; 24 months), and mature adult fishers ($F_4 \geq 36$ months) separately.

Numbers of fishers in age classes n_2, n_3, and n_4 for the **n** vector at time t_0 were based on the number of radiocollared female fishers present at the start of population year 3 on April 1, 2009 (n_2 = 5, n_3= 6, n_4 = 5, n_5 = 5), whereas n_1 was the number of juvenile females in the radiocollared population on Dec 31, 2009 (4 animals). We multiplied the Leslie matrix by the new vector of abundances for N_{t+1} for 20 successive years, and summed the number of individuals in each age class each year to obtain a total N, and the population growth rate (λ) for year t+1 was calculated as N_{t+1}/N_t. After several years a stable age distribution was achieved and λ converged to a constant value, which was the estimate of λ for the set of demographic parameters evaluated. We calculated a lower and upper range for λ based on the 95% lower and 95% upper C.I.s for age-specific survival and age-specific fertility. Finally, due to uncertainty in estimates for several demographic parameters related to methodology [small body size prevents radiotelemetry-based monitoring of survival for juveniles until 6 months of age (Facka et al. 2013); teat measures used to identify weaning for a small subset of adult females were less than 100% accurate in assigning reproductive status (Matthews et al. 2013*a*), estimates of litter size may be biased low if the movements of kits between dens was missed by cameras], we evaluated the sensitivity of the matrix model to 20% reductions in rates of survival and fertility for each age class. Fertility is linked to age-specific survival according to Equation 1, and changes to fertility associated with reductions in survival were carried into the model when evaluating sensitivities.

Population Size and Density

Background

Information on population size and demographic parameters are fundamental for managing wildlife populations, especially when declines in abundance or range size have occurred and the species is the focus of conservation management. As previously noted, the overall southern Sierra Nevada fisher population is small (<350 adult fishers; Spencer et al. 2015), but appears to be stable over about the past decade (Zielinski et al. 2013). Research focused on the ecology and habitat use of fishers in the southern Sierra Nevada has been ongoing since the mid-1990s (Jordan 2007, Mazzoni 2002, Truex et al. 1998), but primarily for the area encompassed by the Kings River Fisher Project in the High Sierra District, Sierra National Forest. For that area, Jordan et al. (2011) used a capture-mark-resight/recapture design (CMR) to estimate a density of 0.063-0.109 fishers/km^2 in 2002-2004, whereas Thompson et al. (2012) used scat detector dogs and genetic detections in a spatially explicit CMR framework to estimate a fisher density of 0.065-0.28 fishers/km^2. Information on density is needed for other areas of the southern Sierra Nevada as well, because as the area of suitable habitat available to fishers in the southern Sierra Nevada is refined by improved modeling (Spencer et al. 2015), density values can be used to develop more accurate estimates of fisher abundance for conservation planning. Here, we estimated fisher population size and density in the middle four years of the study using mark-resight techniques (McClintock and White 2009) from camera surveys and live trapping.

General Methods for Camera Surveys and Cameras

Motion sensing cameras (Silent Image Professional, Rapidfire PC85; RECONYX Inc., Holmen, WI) were systematically deployed near the center of 1–km^2 grid cells in the study area beginning at the start of each of five "fall-winter" camera survey years (October 15-October 14 the following year). Placement of cameras within 1-km^2 grid cell cells was determined based on the presence of habitat elements important for fishers (e.g., presence of mature or large diameter trees, moderate to steep slopes, canopy cover ≥60%, proximity to permanent streams; Purcell et al. 2009, Zielinski et al. 2004). Cameras were focused on bait trees upon which we attached baits and applied scent lures as attractants. Baits were small pieces of venison (140-250 grams) in a dark colored sock (reduced consumption by insects), and 8-10 hard-shell pecans strung onto a wire (initial purpose was to index squirrel abundance, but were also consumed by fishers). Scent lures were Hawbaker's Fisher Scent Lure (Fort Loudon, PA) dabbed on the bait sock, Caven's "Gusto" scent lure (Minnesota Trapline Products, Pennock, MN) applied near the base of the bait trees and on several nearby trees, and ~4 grams of peanut butter smeared on the nut ring (Popescu et al. 2014). Camera survey stations were typically visited (checked) every 8-10 days over 32-40 days to refresh scent lures and bait, and to maintain camera units, but the protocol varied depending on whether the survey station was within the Key Watershed part of the study area, or outside that area. Survey cameras within the Key Watersheds were left in place a minimum of 32 days (four 8-10 day checks), whereas cameras outside this area were deployed for a minimum two 8-10 day checks but removed on check two or three if fishers had been detected. We removed survey cameras after four checks unless the unit had been disturbed (most frequently by black bears, *Ursus americanus*) to where the bait tree was out of view or if the unit had been inoperative due to expended batteries or malfunction for more than five days during a check period. In those cases the survey was extended by one or more 8-10 day periods to assure adequate survey effort (Slauson et al. 2009).

Camera surveys, live trapping, and radiocollar data.—Camera surveys were done during all months of each camera survey year, but the time frame of interest for this part of the study was October 15 to March 15, related to assumptions for mark-resight analyses of a closed population scenario. There are 145 1-km^2 grid cells within or overlapping the Key Watersheds boundary; 128 of them are at least 50% USDA Forest Service ownership, and were surveyed in all four survey years. A total 319 1-km^2 grid cells external to the Key Watersheds and within the study area boundary (Fig. D3) were surveyed in at least one fall-winter camera survey year, and 221 (69%) of those were surveyed in two or more years.

Full details on live-trapping to radiocollar and mark individual fishers were provided above. However, for the purposes of mark-resight analyses, data on captures and recaptures of known fishers were included in the mark-resight dataset. Also, fishers sometimes shed their radiocollars, or collars separated at the breakaways as designed. Dropped radiocollars were retrieved from the field, and the locations of shed radiocollars were included in the resight dataset.

Monitoring and home ranges.—Radio collared fishers were monitored for activity status and relocated 4-6 days/week throughout the year by fixed-wing airplane. Standard methods were used to obtain locations from the airplane as previously detailed, and mean error associated with aerial telemetry locations was estimated at 339 m.

Location records were used to develop home range models for individual fishers using the fixed kernel density method in Home Range Tools for ArcGIS 9.3 (Rodgers et al. 2007). Ninety-five percent fixed kernel home ranges were produced for individual animals for four fall-winter (October 15 to March 16) periods from 2008 to 2012 when ≥ 25 locations were available for an individual fisher. Home range area estimates from fixed kernel utilization distributions are sensitive to the choice of bandwidth as a smoothing parameter (Gitzen and Millspaugh 2003). We used the Ad Hoc method to identify the most appropriate reference bandwidth for smoothing fisher home ranges and minimizing formation of multiple polygons (Kie et al. 2010, Kie 2013). This procedure starts with identifying a reference bandwidth (h_{ref}), then reducing h_{ref} in 10% increments. A fixed kernel estimate is plotted for each increment, then visually inspected to determine at what point the home range estimate begins to fracture into multiple polygons. The bandwidth value (h) immediately prior to fracturing is selected as the most appropriate choice for that individual, and the procedure is repeated for each individual (Berger and Gese 2007, Kie 2013.

Resighting and Mark-resight Analyses.—Radiocollared fishers detected by cameras were identified by the pattern of infrared reflective tape bands on the antennae (Popescu et al. 2014). Detections of known fishers were counted once per camera station per calendar day. We were not able to unambiguously identify all radiocollared fishers detected at cameras due to occasional loss of bands and breakage of antennas; these detections were scored as collared unknown. Non-collared animals were counted as unmarked seen.

We considered the population as approximating closure during Oct 15 to Mar 16 because (1) most mortalities in the study site occurred between mid-March and September, (2) natal dispersal by juvenile-age fishers in the population was focused during March to August, and (3) fisher reproduction in California begins the third week in March (Matthews et al. 2013*a*, this study). Data on individual fisher resightings at camera stations or live traps were scored based on presence within 1-km^2 grid cells. Individual animal

Illustration D8: Example of infrared tape on collar antenna used to identify individual fishers for mark-resight analyses.

detection histories were developed identifying whether fishers were available for resighting based on the presence of survey cameras or live traps within the boundaries of their 95% fixed kernel fall-winter home ranges. Data were also compiled on the numbers of survey cameras and live traps deployed, survey camera nights, and live trap nights for the fall-winter resight period.

The resighting data were analyzed using robust design mark-resight, log-normal Poisson models (McClintock and White 2009). The mark-resight robust design is analogous to the mark-recapture robust design of Kendall et al. (1995) and Kendall et al. (1997), in that it allows for individual covariates in modeling resighting probabilities, and an open population between primary sampling occasions. Along with data on marked animals, mark-resight models incorporate sightings of unmarked animals, while the robust design allows for estimating abundance (*N*), apparent survival between primary intervals (ϕ), mean (α) and overall resighting probabilities (λ), random individual heterogeneity (σ^2), and transition probabilities between observable and unobservable states (γ'' and γ') (McClintock and White 2009). The parameter of interest, abundance (*N*), is a derived parameter, as Poisson log-normal models estimate the number of unmarked individuals in the population, *U* (McClintock and White 2009).

The Poisson log-normal mark-resight model takes the following form:

$$[\alpha(.)\ \sigma(.)\ U(.)\ \phi(.)\ \gamma''(.)\ \gamma'(.)]$$

in which ϕ and γ'' (and γ') were modeled using a *sin* link, while α, σ, and *U* were modeled using a *log* link.

The model assumptions are: (1) geographic closure, (2) population closure within primary intervals, (3) no loss of marks, (4) no error in identifying marked and unmarked animals, (5) equal resighting probability for both marked and unmarked individuals, and (6) sampling is with replacement within secondary periods (McClintock and White 2009). We used camera survey years as the primary sampling intervals and the number of resights and live trap recaptures for marked fishers within each primary occasion as the resighting histories. Along with capture histories, robust-design Poisson log-normal models require three other quantities: (1) marked superpopulation, the number of marked individuals known to be in the population during primary interval *j*, (2) number of times marked individuals were sighted, but individual marks could not be identified, and (3) total unmarked individual sightings during primary interval *j*.

Because camera and live trapping was unbalanced across the study region among years, we added a grouping variable for subregion, with three subregions defined by the spatial segregation of camera efforts (Fig. D5). Each fisher was assigned to a particular mark-resight subregion based on the position of its 60% fall-winter home range isopleth. In addition, we included *area* and *time* (primary sampling interval) covariates, *cams* (camera effort for each subregion during each primary sampling interval in hours), and *live* (number of days live trapping was conducted) to account for variation in resighting probabilities, individual covariates *weight* and *sex* to account for individual and sex-based resighting probabilities. In the model parameterization, state transition probabilities remained constant [γ'(.) and γ''*(.)*], apparent survival was modeled as function of region [ϕ*(area)*], and different combinations (additive and interactions) of the individual and time and region-based covariates were allowed.

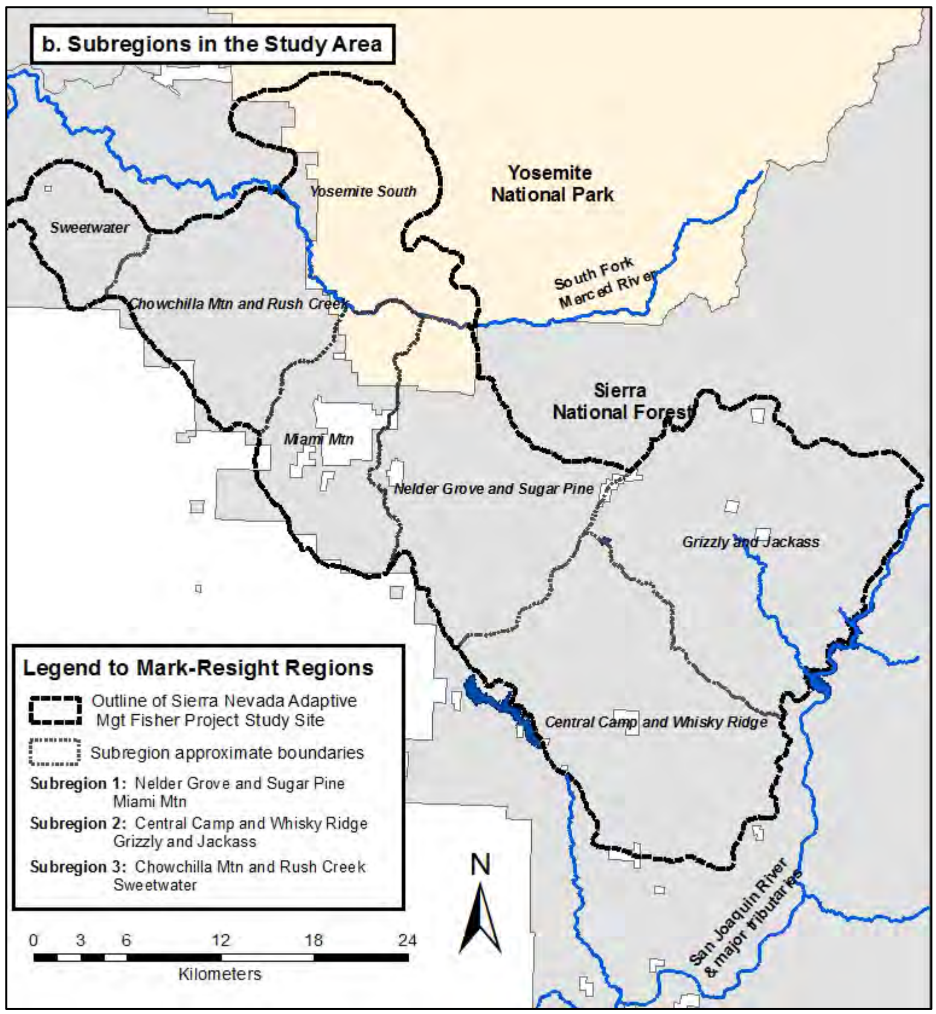


Figure D5: Map illustrating the outlines of subregions used to organize camera and live trap data for mark-resight analyses. The study area is within the Bass Lake Ranger District, Sierra National Forest, California, but also included a relatively small portion Yosemite National Park.

We considered 19 candidate models and used AICc [Akaike Information Criterion adjusted for small sample size; (Burnham and Anderson 2002)] to rank models. We used model averaging for the top ranked models with a cumulative Akaike weight >0.95 to compute parameters and unconditional variances. The *Area* grouping parameter allowed for estimating population size and density for each subregion separately. We conducted analyses in program RMark v2.1.7 (Laake 2013) for R 3.0.2 (R_Core_Team 2013), which is an interface for program MARK (White and Burnham 1999). Lastly, the subregion and year-specific abundances were converted to densities by dividing population estimates by the area sampled by cameras and traps for each subregion and year. Areas sampled were estimated from subregion- and year-specific polygons created in ArcGIS 10.2 that encompassed the centroids of all 1-km^2 grid cells with a survey camera or a live trap with a fisher capture during October 15 to March 16. We then plotted the fall-winter home ranges with the sampling polygons and, based on visual assessment of spatial intersection of the 95% home range isopleths, applied a 1300 m buffer for each polygon. The width of the buffer for the polygons was the radius of the mean 95% fixed kernel fall-winter home range for subadult and adult female fishers in the population (mean = 20.8 km^2 ± SE 0.89, *n* = 70; Jordan 2007), which encompassed most areas used by radiocollared fishers resident in each subregion and excluded areas below or above the typical elevation range of fisher camera detections in the study area.

Dispersal Movements

Background

By simply moving from one habitat patch to another, dispersal of individuals has consequences not only for fitness, but also for population dynamics, population genetics, and species distribution at the landscape scale (Chepko-Sade and Halpin 1987, Lambin 1994, Clobert et al. 2001). For these reasons, processes that foment dispersal behavior have been the focus of research interest in relation to inbreeding avoidance, intraspecific competition for mates and resources (Estes-Zumpf and Rachlow 2009, Wolff et al. 1988), and costs and benefits of dispersal, particularly in relation to gender (Pusey 1987).

Natal dispersal, permanent movement from the natal area to the location where individuals reproduce or would have reproduced depending on survival (Howard 1960), is the most common type of dispersal. Gender bias in which one sex, typically males, disperses more frequently or farther than the other, has been documented in many mammals (Greenwood 1980; Pusey 1987, Sweitzer and Berger 1998). Proximate mechanisms triggering natal dispersal and potentially influencing dispersal distance include population density (Gaines and McClenaghan 1980), habitat quality (Lidicker 1975), and body condition (Dufty and Belthoff 2001, Nunes and Holekamp 1996). Information on dispersal provides insights on how far, and over what sorts of terrain, individuals may move and therefore how populations may be demographically and genetically interconnected or isolated. Barriers or impediments to dispersal reduce gene flow and may prevent populations from colonizing or recolonizing suitable habitat areas.

Dispersal behavior by fishers is of high management interest in California where the species currently occupies less than half of its historical range as described in the early 1900s (Grinnell et al. 1937). In the southern Sierra Nevada conservation planning area, fishers occupy approx. 4,400 km^2 of mid-elevation, mixed-coniferous forest between the Merced River in Yosemite National Park in the north to the Greenhorn Mountains in the Sequoia National Forest in the south. The southern Sierra Nevada population does not appear to be expanding geographically (Zielinski et al. 2013), despite changes in management promoting redevelopment of suitable fisher habitat in the Sierra Nevada (North et al. 2009). Dispersal movements by fishers are potentially inhibited by exposure to multiple restrictive habitat and landscape features (Spencer et al. 2015, Tucker 2013). Moreover, Matthews et al. (2013a) suggested that because of their relatively limited vagility, conservation-directed management to promote fisher recovery in formerly occupied portions of their range in California may require translocations, unless population growth rates significantly exceed 1.0 in the future.

We used information on juvenile home ranges, likely maternal home ranges (determined by genetic analyses), and adult home ranges to evaluate patterns in natal dispersal for fishers in the SNAMP Fisher study area. We hypothesized that (1) a greater proportion of the juvenile male population would disperse than the juvenile female population, (2) dispersal distances for males would be longer than for females, and (3) long distance movements would be more frequent for males compared to females. In addition to estimating Euclidean distance between juvenile or maternal home ranges and adult home ranges, we also used a least-cost corridor analyses with an expert opinion-based cost surface to estimate both short and longer distance movement paths associated with natal dispersal. Both methods likely underestimate the actual dispersal distance travelled, because we are unable to plot that actual path followed and must presume based on what we know about the species. At the same time, both methods present critical information for management and conservation planning.

Assessing dispersal using home range models

Location records were used to develop home range models for individual fishers by using the fixed-kernel density method in Home Range Tools for ArcGIS 9.3 (Rodgers et al. 2007; ESRI, Redlands, CA). We developed 95% fixed-kernel home range models for juvenile, subadult, and adult-age fishers when ≥ 25 locations were available for the pre-dispersal or post-dispersal period of interest. Approximate center positions (centroids) were estimated for each home range using the XTools extension in ArcGIS (Data East LLC, Novolsibirsk, Russia). Because both area estimates and shapes of fixed kernel home ranges are sensitive to the choice of bandwidth as a smoothing parameter (Gitzen and Millspaugh 2003), w used the Ad Hoc method to identify the most appropriate reference bandwidth for smoothing fisher home ranges and minimizing formation of multiple polygons (Kie 2013). Finally, in some cases radiocollars were shed by juveniles within a few weeks of initial capture, before ≥25 locations records had been acquired. In these cases we used centroids from 100% Minimum Convex Polygons for natal area centroids (Aubry and Raley 2006).

Dispersal distance by Euclidean geometry

Minimum distances moved between natal or maternal home ranges, and subadult or adult home ranges were estimated as the Euclidean distance between each pair of centroids. For juvenile fishers without maternity assignments, we used fall and winter location records to identify a centroid for natal areas, but excluded locations that were associated with initiation of dispersal. Fall and winter location records for juvenile fishers were visually screened in ArcGIS to identify calendar dates associated with initiation of the exploratory, or transitional, period of the dispersal process (Vangen et al. 2001). Location datasets used to develop home ranges for juvenile fishers (natal area home ranges) were truncated by date to exclude transitional movements. Transitional movements were not apparent for all juvenile fishers, however, and in these cases we used the pool of location records from capture to approx. March 31 for the natal area home range.

Microsatellite genetic analyses for identifying maternity

We used microsatellite genotypes to assign maternity for juvenile and subadult fishers, which allowed for estimating natal dispersal from the centroids of denning season home ranges for their mothers. Whole genomic DNA was extracted from fisher tissues and hair using the QIAGEN Dneasy Tissue Kit (Qiagen, Valencia, CA, USA) according to manufacturer's instructions. We analyzed 111 samples at the following thirteen microsatellite loci: *Ma1*, *MP059*, *MP144*, *MP175*, *MP197*, *MP200*, *MP247*, *Ggu101*, *Ggu216*, *Lut604*, *Lut733*, *Mer022* and *Mvis002* (Davis and Strobeck 1998; Flemming et al. 1999, Dallas and Piertney 1998; Jordan et al. 2007). These loci were previously found to be variable in fishers in the Southern Sierra (Jordan et al. 2007; Tucker et al. 2014).

Maternity of kits was evaluated using two approaches; the first was by evaluating allele sharing. However fishers in the southern Sierra Nevada were previously known to be genetically limited (Wisely et al. 2004, Knaus et al. 2011), and we also used insight from field associations (capture positions, home range patterns, denning season data to identify small subsets of 3-6 adult females considered possible mothers for each juvenile/subadult. These subsets of possible mothers were further narrowed to a smaller "candidate set" by excluding those that did not share alleles with the juveniles. We applied the maximum likelihood approach in program CERVUS v3.03 (www.fieldgenetics.com) to evaluate the candidate set of females for maternity assignment. CERVUS is a Windows-based software package for inferring parentage in natural populations wherein laboratory typing error is considered along with data on population allelic frequencies, the number of candidate mothers, and the proportion of potential mothers sampled in Monte Carlo simulations, which produce confidence levels for the candidate set of putative parents (Slate et al. 2000). The confidence measure of CERVUS is based on delta, which is the difference between the likelihood ratio for the most likely candidate and the second most likely candidate (Marshall et al. 1998). We assigned maternal-offspring pairs based on likelihood ratio LOD scores (natural log of the likelihood ratio) using both strict (99%), and relaxed (95%) confidence. In the last step we considered the maternity assignments with field data to verify, or select the next most likely female from the LOD scores based on the known biological status of putative mothers (reproductive or non-reproductive, age as juvenile, subadult or adult in the season juveniles were born).   In several cases, the overall analysis was unable to link juveniles to a known, radiocollared female in the population. Developers of CERVUS previously determined that the analytical procedure correctly assigned parentage for ~92% of known fathers in red deer (*Cervus elaphus*) (Slate et al. 2000). In our study we evaluated the performance of CERVUS to correctly identify mothers using five known mother-offspring pairs.

Dispersal distances for juvenile or subadult-age fishers with maternity assignments were estimated as the Euclidean distance between the geometric centroid of the denning season home range of the mother, and the geometric centroid for the home range where the juvenile settled. In some cases the mother had not been monitored during the denning season when a juvenile was produced. In these cases we used the centroid for the female's "annual" home range. Annual home ranges were calculated when we had at least 75 location records, with a minimum of five locations in at least three of the four seasons of the year. Seasons were spring (Mar 21 to Jun 20), summer (Jun 21 to Sep 20), fall (Sep 21 to Dec 20), and winter (Dec 21 to Mar 20).

Least-cost paths for natal dispersal

Dispersal is most often reported as the Euclidean, or straight-line distance between the natal area and the subadult or adult home range (Matthews et al. 2013). Fishers in the southern Sierra Nevada inhabit mountainous areas within a limited elevation range and with a mix of forested areas with mild topography, and ridges and deep river canyons with extreme topographic relief. In these types of landscape and habitat conditions opportunities for straight-line movement traversing multiple kilometers will be constrained.

Least-cost modeling is an approach for assessing potential animal routes across the landscape based on the assumed cost of movement between locations or termini (Beir et al. 2008). Least-cost models have previously been used to predict dispersal paths for mammals from empirical data (Driezen et al. 2007), and we took a similar approach in this study. Connectivity analysis was performed between centroids of natal and established juvenile home ranges for 24 female and 20 male fishers with Linkage Mapper (McRae and Kavanagh 2011). Linkage Mapper uses a resistance to movement (cost) surface layer to delineate least cost paths between focal point pairs. A cost surface layer was developed that assigned a resistance score (inverse permeability value) representing the cost to fishers of moving through each land cover type, including potential risk and averse responses to roads and steep topography in river canyons (Fig. D6).

Expert opinion resistance scores were modified from those developed previously for Sierra Nevada fisher least-cost corridor models (Spencer and Rustigian-Romsos 2012) by (1) simplifying the land cover divisions, (2) expanding the overall cost range, and (3) incorporating recent published and unpublished data on fisher ecology summarized in a conservation assessment developed for fishers in the southern Sierra Nevada by a group of 13 research scientists (Spencer et al. 2015). We used the Polynomial Approximation with Exponential Kernel (PAEK) algorithm in ArcMap 9.3.1 (ESRI 2009) to smooth the movement paths for purpose of display. Length of least cost paths between juvenile or maternal home range centers and subadult or adult home range centers were calculated in ArcGIS 10.2. Basic metrics on least cost paths (means, range, standard error of the mean) were produced and summarized for comparison with mean dispersal distances from Euclidean geometry.

Analysis

Mean dispersal distances were compared between female and male fishers using two-sample *t*-

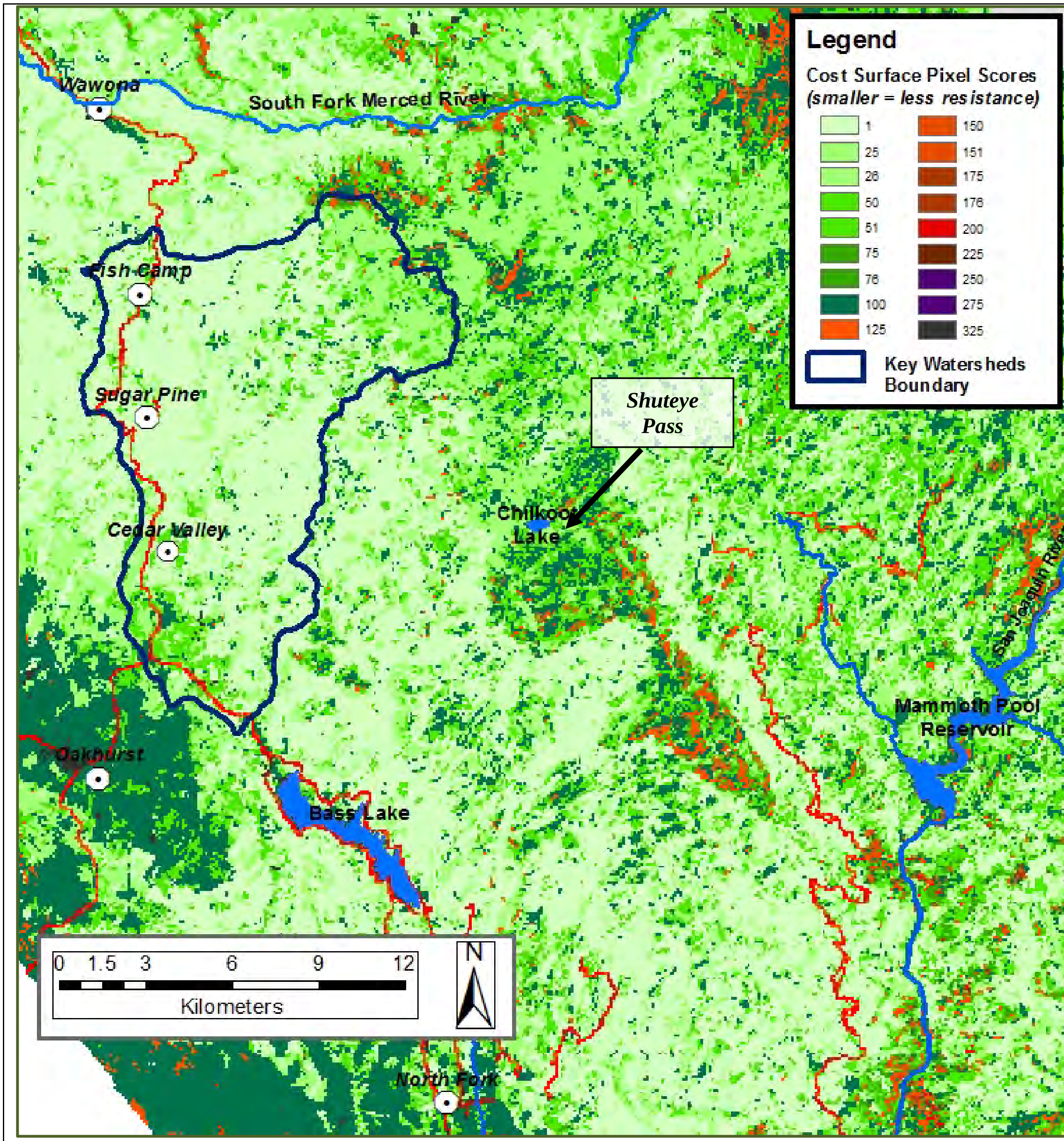


Figure D6: Illustration of the Expert opinion cost surface used to develop Least Cost movement path for dispersing fishers. The map encompasses the portion of the SNAMP Fisher Study Area including the Key Watersheds and the area to the southeast including Chilkoot Lake and Mammoth Pool Reservoir. Note: Chilkoot Lake is at the northwestern edge of the Chiquito Ridge, a high elevation region including Little Shuteye Peak, Shuteye Peak, and Shuteye Pass; notice the narrowness of restrictive habitat at the Shuteye Pass topographic feature.

tests. We also assessed potential male/female differences in dispersal behavior using Pearson χ^2 or log-linear model analyses. We used dispersal distances to classify each fisher as being either philopatric (dispersal distance ≤ 5.4 km) or a disperser (dispersal distance > 5.4 km), where 5.4 km was the diameter of average 95% fixed kernel home range of adult females fishers in the study population (22.93 km^2, n = 56; Table D25). We also assessed the overall pattern in dispersal behavior by assessing the proportion of each sex that was very philopatric (dispersal distance <2.7 km; one-half the diameter of the mean 95% fixed-kernel home range for adult female fishers), short distance philopatric (2.7 km ≤ dispersal distance < 5.4 km), a mid-distance disperser (5.4 km ≤ dispersal distance < 10.8 km), or a long distance disperser (dispersal distance greater than 10.8 km; 2x the diameter of the average adult female home range).

Home Range Dynamics Methods

Background

Among terrestrial vertebrates, mammalian carnivores have the largest home ranges for their body size of any organism. The fisher, like other mammalian carnivores, occupies a relatively large amount of space for its body mass, with average annual home range areas of 38 km^2 for adult males and 15 km^2 for adult females across North America (Powell 1994). Studies of the two remnant populations in California have produced home range area estimates generally consistent with North American averages: 22 to 58 km^2 for adult males and 5 to 15 km^2 for adult females (Boroski et al. 2002, Zielinski et al. 2004). Zielinski et al. (2004) also reported intraspecific variation in home range size between adult females of the northern coastal and southern Sierra Nevada populations.

Intraspecific variation in home range size has been linked to ecological factors such as population density, prey availability, body mass, and latitude (Buskirk and McDonald 1989, Gompper and Gittleman 1991), and to methodological factors such as sampling interval and duration (Buskirk and McDonald 1989, Swihart and Slade 1985). Our review of the literature suggests that little attention has been paid to potential relationships between home range size and field techniques used to obtain animal locations. Further, the choice of an appropriate bandwidth, or smoothing parameter when creating utilization distributions is a critical step during kernel-based home range estimation in need of standardization (Kie et al. 2013).

We present and discuss home range dynamics for fisher in the Sierra National Forest, while also describing seasonal variation in home range movements for female and male fishers. We hypothesized that aerial telemetry would be more likely than ground telemetry to detect animals outside of their core use areas and during dispersal events and sallies, and would therefore produce larger home range estimates. Our primary objective was to compare our fisher home range sizes with those generated by other studies in the southern Sierra Nevada, where ecological factors would be held relatively constant. Additionally, we wished to characterize variation in space use between sexes, among age classes, and across seasons for our study population.

Locations and analyses

Fisher locations from live-trap captures, dropped or shed radiocollars, carcasses, dens and rest trees, camera detections, a small number of GPS radiocollars (Telemetry Solutions, Livermore, CA) and position estimates from fixed-wing aerial radiotelemetry (Table D1) were used to delineate home

Table D1: Types of locations determined for fishers during the study period from December 2007 to December 2013. Data are for work in the Bass Lake District, Sierra National Forest, CA.

Location type	No. of locations	UTM accuracy	Description of methods and details
Aerial telemetry[a]	31,367	± 339 m	Standard methods by fixed-wing airplane (Sweitzer 2013)
Camera detections	2,454	± 10 m	Position of camera; individuals fishers identified by infrared tape on radiocollar antennas (Popescu et al. 2014)
GPS radiocollar[b]	633	± 15 m	Used on limited number of animals (N = 8) in 2009 and 2010
Den or rest tree	526	± 10 m	Homing to trees by ground radiotelemetry during spring denning seasons; did not identify rest trees in other seasons
Live trap capture	277	± 10 m	Trap positions for known ID captures; most live-trapping was in October to March
Shed radiocollars, fisher carcass	97	± 10 m	Homing to inactive signals by ground radiotelemetry

[a] Accuracy determined as the mean Euclidean distance between aerial telemetry location and fixed position of test collars (*n* = 501) on the ground. Test locations also included locations to dropped radiocollars, carcass locations, and fishers in live traps (Technicians were "blind" to locations of test collars, or other test locations).

[b] Used for limited duration and primarily on male fishers (596 locations for 6 different males; 37 locations for 2 females). SNAMP Fisher ceased using GPS collars due to poor reliability and bias in fix rates; fix rates were high when GPS collars were left in open areas with mild topography, and low when GPS collars were placed at locations with dense overhead canopy and steep topography.

ranges. Accuracy of locations obtained by homing to den tree or rest tree locations by ground telemetry, camera detections, capture positions, and carcass and dropped collar positions were generally ± 15 m from a handheld global positioning system device. We addressed and minimized autocorrelation by discarding locations in excess of two per animal per day, or less than 8 hours apart per individual. Location records were used to develop home range models for individual fishers using the fixed kernel density method in Home Range Tools for ArcGIS 9.3 (Rodgers et al. 2007). Ninety-five percent fixed kernel home ranges were produced for individual animals for four seasons, and for "annual" population years. Season-specific home range models were produced when ≥25 locations were available for a fisher. Annual home range models were developed when we had location records in fall, winter, and least one other season, and sample size was ≥75 for all annual home range models. Kernels were smoothed using the minimum proportion of reference bandwidth that produced a contiguous home range polygon (Kie 2013). We defined core use areas using the procedure described by Bingham and Noon (1997), calculating adaptive kernel isopleths at 10% intervals and then identifying at which isopleth actual use exceeds predicted use, assuming a uniform distribution of locations. While more defensible, this approach can yield different core use isopleths for different individuals. We tested for differences in home range areas between males and females, stratified by age and season, using two sample t-tests ($P<0.05$). Potential differences in home range size among seasons was assessed using repeated measures analysis of variance (ANOVA) ($P<0.05$).

SNAMP Fisher Management Indicators

Background

In 2008 there was great interest in new information developing from SNAMP Fisher that might be important for management and management planning. We therefore developed three Indicators for fisher management that would provide insight on the status of the study population of fishers in the Bass Lake District, Sierra National Forest. These management indicators were chosen based on information that could be summarized annually, and that linked to the likely responses of fishers to management and potential habitat change at the local (sub home range scale), home range, and population level (larger landscape scale relevant to District-level forest management; Table D2).

Mgt. Indicator 1: Occupancy/Activity of fishers within Key Watersheds.

Beginning October 2007 we implemented regular camera surveys of all 1-km^2 grid cells that are partly or entirely encompassed by the boundary of the SNAMP Fisher Key Watersheds (Fig. D3). Several grid cells that were predominantly private lands (e.g., the Fish Camp area), or that were below the typical elevation range of fishers in the region (< 914 m) were not surveyed unless we had permission of access from the landowner. The annual resurvey of the Key Watersheds was a research priority in all years, and camera surveys were initiated at the start of each camera survey year (mid-October), continuing until most grid cells had been surveyed by late winter or early spring. High elevation areas (northeast portion of Key Watersheds) were generally surveyed first, due to more difficult access during mid and late winter. Deep snow conditions in most winters required use of snowmobiles or an all-terrain-vehicle modified with tracks to access high elevation grid cell centers. Results of the Key Watersheds camera surveys were summarized according to (1) fisher presence or absence, and (2) level of fisher activity based on the number of days fishers were detected in each grid cell.

Mgt. Indicator 2: Number of male and female resident fishers using Key Watersheds area. Juvenile fishers exhibit exploratory movements, and sometimes dispersed away from their natal areas where we first captured and monitored them. Dispersal by juvenile fishers often extends into summer when they are 13-15 months old and considered subadults. We considered subadult fishers(12 to 23 months old) to be "settled" after natal dispersal in late August/September. Ninety-five percent fixed kernel home range models were developed from location records during September 1 to March 15 for all radiocollared fishers (Sept-March home range). Analyses were completed in ArcGIS 9.3.1 to estimate the proportion of each Sept-March home range for subadult and adult fishers that were included or "intersected" within the boundary of the Key Watersheds. Management Indicator 2 was calculated as the sum of the proportions of individual subadult and adult Sept-March home ranges within the Key Watersheds focal study area. Management Indicator 2 was calculated for female and male fishers for each of six September to March 15 periods beginning September 2008 and ending March 2013.

Table D2: Overview of potential negative effects of fuel reduction treatments and other forest management activities on the biology and natural history of fishers, organized according to three scales in the SNAMP Fisher study area, Bass Lake District, Sierra National Forest.

Scale of effect, Description	*Likely response*	*Data requirements*	*Management Indicator*
LOCAL: SPLATS may cause habitat patches to become less suitable for current use; foraging, refuge/escape cover	Use of treated areas declines or ceases	Before/After and ongoing use of areas altered by management activities	Use of 1-km^2 grid cells within Key Watersheds (or in other areas), estimated annually using camera surveys
HOME RANGE: SPLATS may reduce availability of key resources such as den sites, rest sites, availability of prey	Individual fishers cease use of treated areas	Monitor individual fishers, acquire locations, develop home range models, track dispersal movements	Estimate of the number of individual fishers using the Key Watershed focal study area during population years
POPULATION/REGION: Multiple projects implemented every few years may degrade suitable habitat for fishers; population source areas become sink areas	Survival and reproduction decline; population size and density decline over time	Information on survival and reproduction of individual fishers in the overall study area (min 20 fishers monitored by radiotelemetry at all times)	Survival and reproduction of fishers in the overall study area. Estimate population growth rate, evaluate population viability in the Sierra National Forest

Mgt. Indicator 3: Survival of adult-age female fishers in the SNAMP Fisher Study Area

Survival, and survival of adult females in particular, is an important demographic parameter necessary for understanding the population growth trajectory for most vertebrate wildlife species (Murdoch et al. 2010). All radiocollared fishers were monitored 4-6 days/week by fixed-wing aerial telemetry to assess live/dead status. Information on survival status for radiocollared fishers was organized by month of each population year (Apr 1 to March 31), and analyzed using the Kaplan-Meier (KM) staggered entry method (Koen et al. 2007, Pollock et al. 1989, Price et al. 2010). KM models were used to produce estimates of annual survival and combined year survival for the study population. Annual survival can be moderately to highly variable, thereby suggesting a negative population growth trajectory that may not be appropriate for a long-lived species with a generation time of two or more years. We therefore combined monthly data on survival status for individual fishers for five 2-year periods (population years 2 and 3, population years 3 and 4, population years 4 and 5, population years 5 and 6, population years 6 and 7) beginning April 2008 and ending March 2014. We further extended the inference for this management indicator by estimating survival for juvenile and subadult females, and by compiling data on weaning reproductive rates and weaning litter sizes from data collected on fisher reproduction during April 2008 to June 2013. These data were used to estimate fertility rates, which, along with data on juvenile, subadult, and adult female survival, were used to estimate deterministic population growth rates using a four age class Leslie Matrix population model.

Fisher response to fuel management

Occupancy modeling

For the purpose of occupancy surveys, we deployed cameras in the 128 1-km^2 grid cells that were ≥50% public lands and within the 4 focal watersheds. We also deployed cameras in areas with recent histories of extractive or restorative fuel reduction, between 2002 and October 2008, or because forest management projects were planned to occur in the areas before December 2011. Most of these grid cells were repeat surveyed in 7 different camera survey years, as part of our initial plan of using a BACI framework for the occupancy analyses (Popescu et al., 2012). However because we were not aware of all planned or prior forest management activities within the study area when the project was initiated, some of the multi-season grid cells were added to the group that were repeat surveyed several years after the first camera survey year (2007-08).

The distribution of fishers in the southern Sierra Nevada, CA is constrained by elevation, and closely associated with mixed-conifer forest habitats with relatively large trees, and high canopy cover (Davis et al., 2007). We therefore developed local, patch-specific biophysical covariates for use in analytical models of occupancy. We calculated the mean elevation (*elev*) for each surveyed grid cell, which was always included in occupancy analyses with its quadratic term ($elev^2$). These covariates were standardized. Habitat covariates included the proportion forest (i.e., total tree) and hardwood cover (*denMD*) based on land-cover data derived from satellite imagery (CWHR CalVeg; USDA Forest Service 2012). We did not include covariates representing average tree size and slope because of their collinearity with forest cover and elevation.

There were a diversity of forest management activities that occurred on the Sierra NF from 2002 (5 years before the start of our study) until the last camera survey year starting in October 2013 (period

2002 to 2013). Most of the management activities we used for covariates were developed from the USDA Forest Service FACTs database. FACTs (Forest Service Activity Tracking System; http://www.fs.usda.gov/main/r5/landmanagement/gis), is a tracking system including a geospatial database of forest management activities that occur on national forest service lands in California and elsewhere (FACTs User Guide 2013). Polygon layers included in the FACTS database are associated with attributes detailing management activity codes, and dates for when activities were initiated and completed. There are known uncertainties in FACTS with regards spatial precision, area of treatment polygons, and lack of details on whether a treatment activity was completed for an entire polygon (Garner, 2013). We also know that some entries represent perimeters encompassing smaller subunits treated at the same time as well as some areas unaffected by the management activity (Zielinski et al., 2013). Nevertheless, FACTS data constitute the best available and consistent record of the annual management activities that occurred on national forest lands in our study area.

Two recent studies used FACTS information to assess how fishers respond to disturbances from Forest Projects elsewhere in the southern Sierra Nevada (Garner 2013; Zielinski et al. 2013). We considered FACTS activities that were previously used in those studies, but also reviewed full descriptions of each management activity included in the FACTs User Guide (2013) when identifying a subset of 24 that were considered as potentially influencing local scale habitat use by fishers related to how each altered forest habitat structure or if they represented significant ground-disturbing activities (Zielinski et al. 2013; FACTs User Guide 2013). For example, we included forms of harvest (e.g., code 4152 Group Selection Cut) and vegetation management (e.g., code 4220 Commercial Thinning, code 4580 Mastication/Mowing) that would have direct effects on the basis of their disturbance and alteration of forest structure (Zielinski et al. 2013). We excluded activities that did not meet this criterion, and several that rarely occurred, or that silviculturalist Dave Smith with the Sierra NF recommended against using (e.g., code 4290 Administrative Changes; code 4314 Pretreatment Exam for Reforestation; code 4530 Prune; code 4511 Tree Release and Weed; code 4552 Area Fertilizing; code 4980 Other Tree Improvement; code 4540 Control of Understory Vegetation).

There were 4 other activities or events that were not systematically tracked by the FACTS system; hazard tree removals (e.g., hazard tree logging), private timber harvests (THPs), and historical or recent wildfires. Hazard tree logging was the removal of medium and large trees (no DBH restriction) within 91 m of forest roads when they were considered likely to fall during storms, or if they were decadent or diseased (SNFP 2004). Information on hazard tree logging in the Bass Lake Ranger District was available for 2009, 2010, and 2011, and we were provided with GIS shapefiles identifying road segments along which hazard tree logging occurred. Private timber harvest occasionally occurred on large parcels of private land within or adjacent to the Sierra NF in Madera County and Mariposa County. Harvesting of timber on private lands in California requires preparation of Timber Harvest Plans (THPs) that are reviewed and approved by state agency CAL FIRE, which was our source for geospatial data on private THP activities in Madera County and Mariposa County (ftp://ftp.fire.ca.gov/forest). Basic records on the estimated spatial extent of wildfires that occurred in the national forest portion of study area were maintained by the Sierra NF, and included polygon shapes and ignition dates of wildfires that occurred from 1911 to 2013. We also acquired geospatial data on natural ignition and management fires for Yosemite NP for 1930 to 2008, which was sufficient for our analyses because there were no camera surveys completed in southern Yosemite NP after May 2009. Attribute information included with the various geospatial data were used to assign activities and wildfires to individual camera survey years. For example, if a management activity was identified as completed before October 15, 2009, the disturbance was assigned to camera survey year 2008-09.

We used ArcGIS 10.2 (ESRI, Redlands, CA) to estimate the area of each 1-km^2 surveyed grid cell with hazard tree logging, private timber harvest, and wildfires, which were merged with the FACTs information for 2002 to 2013. After merging, we reviewed the entries, and removed polygons that were duplicated in several years (e.g., those with the same FACTS code with identical shapes and areas but with different years of completion). We also removed any duplicate wildfire records that were included in both the FACTs data and in the local Sierra NF wildfire database. We then used the detailed descriptions of each FACTs activity type to create 3 composite variables for use as covariates for occupancy analyses. Covariates for extractive fuel reduction (*log.5*) and restorative fuel reduction (*hazfuel.5*) included the cumulative areas of these activities in each grid cell in the 5 years immediately preceding each camera survey. For example, the *hazfuel.5* covariate for any grid cells that were surveyed in camera survey year 2012-13, was calculated as the sum of the areas (m^2) of all restorative fuel reduction activities that occurred in those grid cells during fiscal years 2007-08, 2008-09, 2009-10, 2010-11, and 2011-12, from which we calculated the proportion of the grid cell disturbed by the treatment. Because of the coordinated series of extractive and restorative fuel treatments associated with SPLATs, multiple different treatments could be applied on the same forest stand within a 5 year period (Zielinski et al., 2013). It was therefore possible that the cumulative area of a grid cell that was treated during a 5-year period could exceed 1-km^2. In the few cases where this occurred (*hazfuels.5* only), the proportion of the grid cell treated was truncated at 1.0 (100%).

The third composite variable that was related to fisher presence in model analyses was for managed burning and wildfires within each 1-km^2 grid cell. When we reviewed the FACTS and Sierra NF and Yosemite NP databases, it was apparent that managed burning was uncommon in the study area during 2002 to 2013. Although managed burns were commonly planned in the Sierra NF portion of the study area as part of SPLAT-based fuel reduction, many managed burns were cancelled and not rescheduled because weather conditions were not suitable, or because burning was prohibited by the San Joaquin Valley Air District (D. Martin, personal communication). Also, a late summer managed burn in Yosemite NP in 2009 escaped containment and burned 7,425 ha (Big Meadow Fire), which discouraged other managed burns in the region for several years thereafter. We therefore combined information on managed burning and the longer time-series of wildfires in the study area into a single composite variable representing managed burn+wildfires within 50 years of a survey (*burn.1.50*).

We used multi-season occupancy models to evaluate the importance of forest management covariates to explain the persistence of fishers at occupied grid cells and colonization of unoccupied grid cells (Zielinski et al., 2013). We defined colonization (γ) as the probability that a grid cell unoccupied in year *t* would be occupied in year *t* +1, and modeled it as: $\text{logit}(\gamma) = \beta\gamma_0 + \beta_{\gamma 1}x_1 + \beta_{\gamma 2}x_2$ +.... We defined persistence as 1- extinction where extinction (ϕ) was the probability that a grid cell occupied in year *t* would be unoccupied in year *t* +1, and modeled it as: $\text{logit}(\phi) = \beta_{\phi 0} + \beta_{\phi 1}x_1 + \beta_{\phi 2}x_2$ +.... The multi-season models also included a component for occupancy in the initial year a site was surveyed: $\text{logit}(\psi_{\text{initial}}) = \beta_{\psi\text{initial}0} + \beta_{\psi\text{initial}1}x_1 + \beta_{\psi\text{initial}2}x_2 + \ldots$

We created a detection history of whether a fisher was observed by a camera within each grid cell during each consecutive survey period after set-up or re-baiting for up to 5 8-10 day periods during a survey year. This was repeated for up to 6 consecutive years (e.g., 00101 00000 01110 00010 01101 00000) for every grid cell. If surveys did not occur during any of the 5 periods and 6 seasons at any of the grid cells these data were treated as missing data. Models were solved by maximum likelihood estimation (MLE) via R statistical software (Version 3.0.1, www.r-project.org) using the *unmarked* package and the *colext* function (Fiske and Chandler 2011). We followed an information-theoretic approach for evaluating the relative importance of different candidate models, and for assessing the relative importance of individual covariates [sum of AIC weights (AIC_{wi}) for candidate models including each covariate; Burnham and Anderson 2002].

Covariates for potentially explaining detection probability included a categorical, first order Markov process reflecting whether a fisher was detected in the previous survey period in a season (*auto.y*; Hines et al., 2010; Slauson et al., 2012), the number of functional camera days in a survey period divided by 10 (*camdays*), *denMD*, and a categorical variable representing whether the survey was conducted in summer (*summer*) instead of in fall to spring.

Due to the smaller sample size of sites available for fitting multi-season models (n = 361), we only evaluated the role of forest management covariates (*log.5*, *hazfuels.5*, and *burn.1.50*) in explaining annual transitions in occupancy state (colonization and extinction). For the initial occupancy component of the multi-season models, we restricted potential explanatory covariates to *denMD* and $elev + elev^2$. For multi-model evaluations of multi-season models, we first fit models including all 8 combinations of the forest management covariates on the colonization component and an intercept-only extinction component. We considered any covariate with a relative importance value > 0.65 to be predictive and important for colonization. Next, we fit models including all 8 combinations of the forest management covariates on the extinction component multiplied by all combinations of colonization covariates identified as important. We deemed any covariate in the extinction models with a relative importance value > 0.65 as predictive for explaining local extinction. Finally, we computed model-averaged parameter estimates for the colonization and extinction covariates identified as important. Model averaging was based on only those models summing to the top 0.95 of model weights.

Integration

Development of vegetation map

We refer the reader to Appendix C for more complete details because we used the same mapping procedure at Sugar Pine as was done at Last Chance. In summary, we developed a pre-treatment vegetation map using a combination of LiDAR, high-resolution digital color-infrared (CIR) aerial imagery, and an intensive network of field plots. First, we used LiDAR and CIR data to create an initial polygon-based map where the polygons represented areas of homogeneous vegetation in terms of species, vertical structure, basal area, and canopy cover. We collected the LiDAR and CIR data before the SPLAT implementation, and we sampled vegetation at the field plots before and after treatment. We then used the field-plot data to impute detailed attributes (e.g., tree lists and fuels models) for each polygon. Thus, we derived two different maps (with and without treatment), which we used in fire and forest-growth modeling.

Modeling fire and forest dynamics

We again refer the reader to Appendix C for more complete details of the fire and forest-growth simulations because we followed the same general procedure at Sugar Pine as we did at Last Chance. We used FARSITE (Finney 1998) to simulate a likely wildfire scenario based on the weather conditions during the 2014 French Fire, which burned 13,837 ac (5,602 ha) 12.5 mi (20 km) southeast of the study area. We obtained weather information from the Batterson Remote Automatic Weather Station, limited to the active burning period of the French Fire (August-September 2014), which served as the basis of our fire modeling. Moisture content for live and dead woody fuels and live herbaceous fuels used in the model were equivalent to 97th percentile weather conditions. Our ignition location was established using fire-origin point data supplied by the Bass Lake Ranger District of the Sierra National Forest. Based on the mapped data, we identified an area with the highest ignition frequency, which was located on the west ridge of the Cedar Valley watershed. The simulation duration was set to allow the fire perimeter to expand through the entire study area.

For all four scenarios (treated/fire, untreated/fire, treated/no fire, untreated/no fire), we then simulated 30 years of forest growth on the study area in 10-year time steps using the Forest Vegetation Simulator (FVS; Dixon 2002) with the Fire and Fuels Extension (FFE; Reinhardt and Crookston 2003). The simulations were performed using the integrated platform ArcFuels (Ager et al. 2006, Vaillant et al. 2011), which runs FVS-FFE to produce the forest structure inputs needed for FARSITE.

Assessing the effects of fire and SPLATs on fisher habitat

We identified canopy cover and large trees as the most important elements of forest structure for fisher habitat because fisher den and resting locations in the southern Sierra Nevada were associated with high canopy cover and large trees (Zielinski et al. 2004, Purcell et al. 2009, Thompson et al. 2011). We defined fisher habitat as forest stands where the canopy cover was ≥60% and the density of large trees (≥24 in [61.0 cm] dbh) was ≥15.4 trees/ac (38 trees/ha).

We defined the canopy cover threshold for fisher habitat as ≥60% because 95% fixed kernel home ranges for 16 adult female fishers in the Kings River Project area in the Sierra National Forest averaged 63% (Thompson et al. 2011). Furthermore, fisher resting habitat sites are characterized by high canopy cover that is typically >60% (Purcell et al. 2009, Thompson et al. 2011), and the California Wildlife Habitat Relationships database uses a 60% canopy cover threshold as one of the criteria in its definition of high-quality fisher reproductive habitat (California Department of Fish and Game 2008).

We defined a large tree as ≥24 in (61.0 cm) diameter at breast height (dbh) because resting trees at the lower end of the size distribution (i.e., mean minus the standard error) in two different studies were of a similar size (Zielinski et al. 2004, Purcell et al. 2009). Thus, any tree ≥24 in dbh was potentially suitable as a fisher resting site. Next, we determined the threshold density of large trees (i.e., 24 in dbh) by examining stand-level tree lists surrounding den locations of 28 female fishers in the Kings River study area from 2008-2013 (Rebecca Green, unpublished data). When there were multiple dens per female, we randomly chose a single den for that individual. Data for natal dens were used preferentially; natal dens were where the young were born. We used data at maternal den locations for 7 females for which natal den locations were not available; fisher young were moved to maternal dens when conditions were no longer suitable at the natal dens. We defined the threshold density for large trees as ≥15.4 trees/ac (38 trees/ha) because this was the median density of large trees surrounding the 28 den locations.

Results

Basic Fisher Population

A total of 110 individual fishers were captured in live traps as part of the SNAMP Fisher Project from Dec 2007 to Dec 2013 (62 females, 48 males). In the first 3.5 months of trapping in population year 1 we captured 3.6 noncollared ("new") fishers/100 trap nights, and 6.8 total fishers/100 traps nights. During population years 2008-09 to 2011-12 a mean of 0.94 previously unknown individual fishers were captured per 100 trap nights, and there were an average 2.43 total captures per 100 trap nights. Data on traps nights were not available for 2012-13 or for March to December 2013, when a total of 9 new fishers and 19 total captures occurred (Table D3). No fishers died during capture and handling in the study. However, one adult female fisher captured in October 2009 did not fully recover. The female fisher was held in the trap cubby overnight for additional time to recover, but died the next morning while in transit to the Fresno Chaffee Zoo for treatment by a wildlife zoo veterinarian. A necropsy completed for the fisher identified her cause of death as septicemia from a previously fractured jaw, which led to emaciation and starvation.

An overarching goal of the study was to monitor a minimum of 20 radicollared fishers at all times, which was considered a requirement for producing reliable estimates of survival and reproduction for the population. The study achieved that milestone in mid July 2008, about six months after live trapping was initiated in late December 2007 (Fig. D10, Table D4). There were brief periods in several years when the radiocollared population declined below 20 individuals (Fig. D10). The annual oscillation in numbers of radiocollared fishers was related to the combination of dropped or shed radiocollars (breakaway units built into radiocollars parted as designed), and mortality which was focused during spring and summer in all years of the study. After the end of our annual pause in live trapping during the spring denning season, the number of radiocollared fishers gradually or rapidly

Table D3: Summary data on numbers of trap nights, new fishers captured, and recaptures for the SNAMP Fisher Project from December 2007 to December 2013. Population years start April 1 and end March 31

Population Year	Trap nights[a]	New individuals[b]	Recaptures	Total captures
2007-08	280	10	9	19
2008-09	2793	34	40	74
2009-10	2898	20	52	73
2010-11	2173	15	30	44
2011-12	1914	22	27	48
2012-13	*No data*[c]	8	11	19
2013[d]	*No data*	1	8	9

[a] Number of traps set for capture during an overnight period.
[b] Includes one orphan fisher kit captured in a live trap in 2010-11, and one orphan fisher kit captured in a live trap in 2011-12.
[c] PSW Forest Service trapping, no data on trap nights.
[d] Apr 1 to Dec 31; end of SNAMP Fisher.

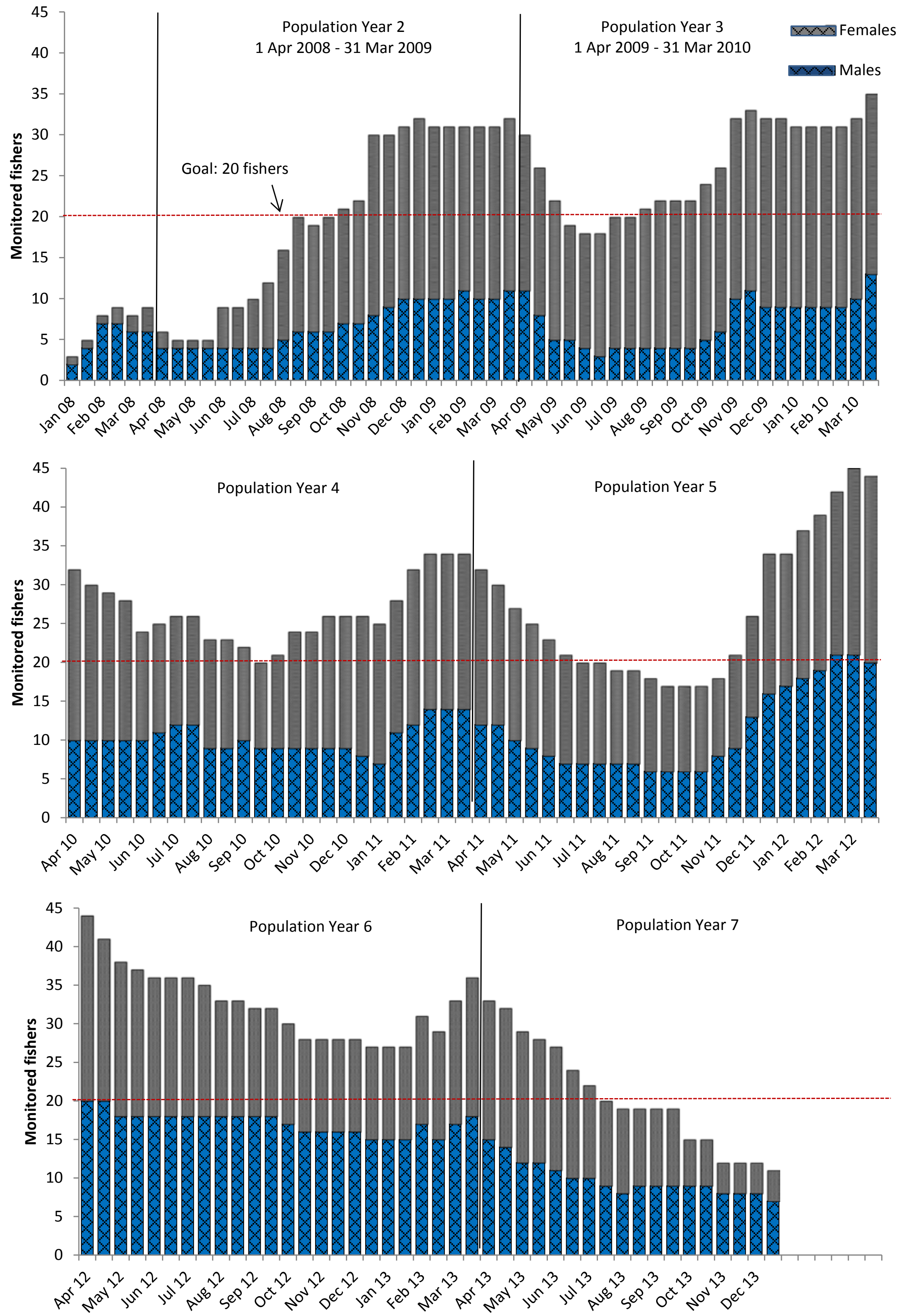


Figure D7: Number of radiocollared fishers that were monitored for survival and reproduction (females) during the period of SNAMP Fisher from December 2007 to December 2013.

increased when trapping resumed, and as young-of the-year juvenile fishers were recruiting into the study population in the fall and winter (Fig. D10). With the exception to the first and last year of the study, we were able to monitor survival for at least 40 different fishers in each population year. Notably, in 2011-12 we were monitoring more than 40 individual fishers for several successive months (Fig. D10, Table D4**).**

Table D4: Number of radiocollared fishers being monitored for the SNAMP Fisher Project at the start and end of six different population years.

Population Year	Start N	End N	Individual fishers N[a]
2007-08	--	7	11
2008-09	6	30	41
2009-10	30	32	51
2010-11	32	32	55
2011-12	32	44	59
2012-13	44	33	50
2013[b]	33	14	33

[a] Number of individual fishers radio-collared and monitored for ≥ 1 day

[b] Apr 1 to Dec 31; end of SNAMP Fisher

Basic Camera Survey Results

Camera surveys were a major aspect of SNAMP Fisher in all years. In the overall period of the study we surveyed for fisher presence in 905 unique 1-km^2 grid cells. The distribution of camera surveys extended from Yosemite Valley in the north, to the slopes above the San Joaquin River canyon to the south and southeast (Fig. D8). Surveys occurred within Yosemite National Park in winter 2009 only, research that was part of a companion study organized by Reginald Barrett and funded by the California Department of Fish and Wildlife. We also obtained data from camera surveys in 24 grid cells located north of the Merced River in Yosemite Valley (not displayed) that were completed by cooperating biologists from Yosemite National Park or the Central Sierra Nevada Environmental Research Center (CSERC). Fishers were not detected in any of the 24 grid cells, reinforcing that the Merced River is the northern edge of the range of fishers in the southern Sierra Nevada.
Fisher activity was identified in 448 of the 905 unique grid cells surveyed (Fig. D8). We used and 6500 feet elevation (1372 and 1981 m elevation). Fisher detections were uncommon above 7500 feet (2286 m) elevation, but the pattern suggested that fishers occasionally use private lands outside of the Sierra National Forest as low as 3000 feet (914 m) elevation (Fig. D9).

Camera effort was focused in the Key Watershed focal study area. The number of 1-km^2 grid cells surveyed ranged from 122 in 2007-08 and 133 in 2012-13 (Table D5). Across the larger overall SNAMP Fisher study area we surveyed 204 1-km^2 grid cells in 2012-13 and 409 grid cells in camera survey year 2010-11 (Table D5).

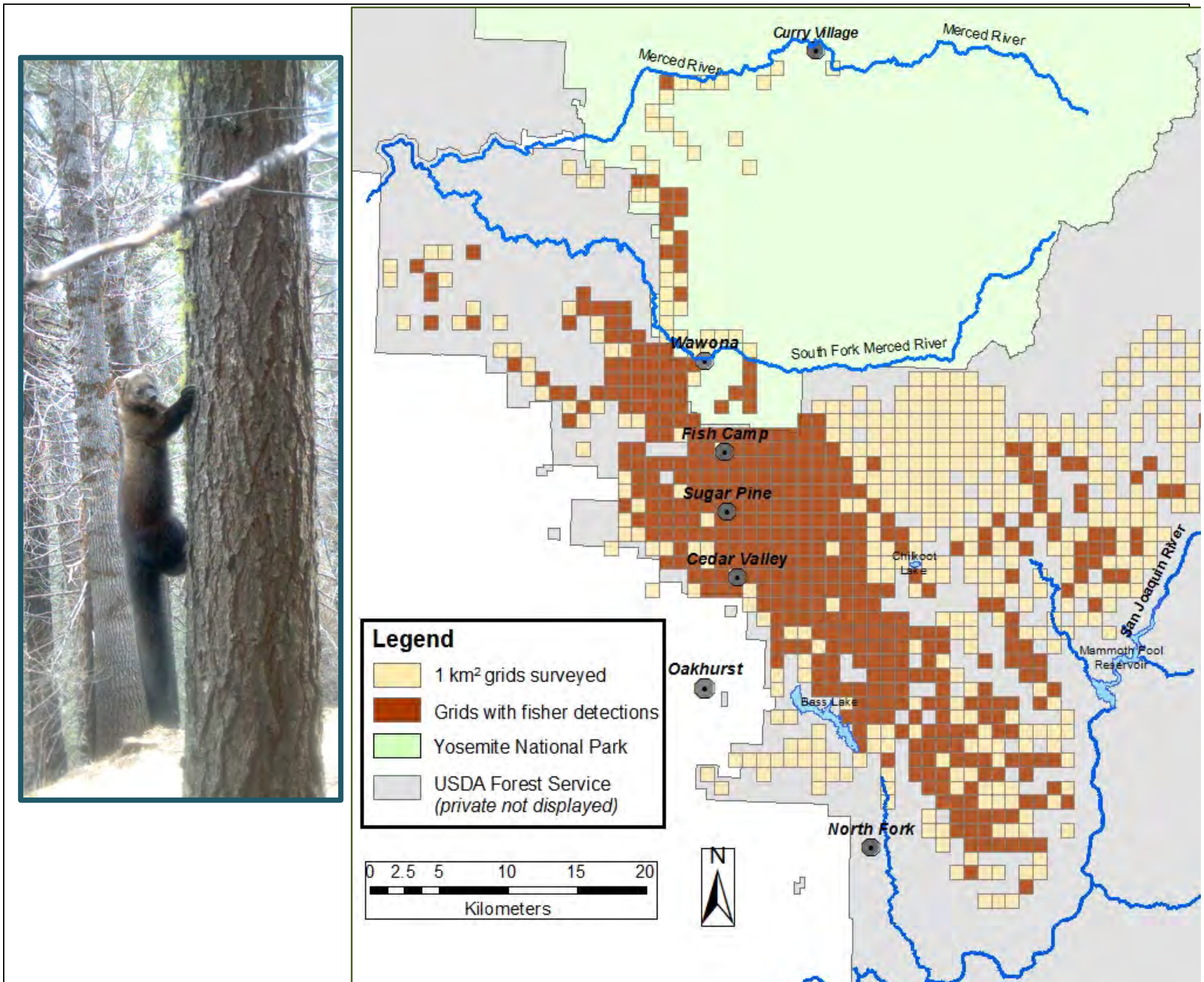


Figure D8: Distribution of survey grid cells and fisher detections from camera surveys in the overall SNAMP Fisher study area in the period from October 2007 to October 2013.

Naïve occupancy for all grid cells surveyed varied from ≈ 0.60 in 2008-09 to ≈ 0.40 in 2009-10 (Table D5). Occupancy for multi-year surveyed grid cells (corrected for probability of detection <1.0) oscillated from ≈ 0.80 in 2007-08 to 0.62 in 2009-10 and then increased back to ≈ 0.80 in 2011-12 (Fig. D10).

In addition to basic naïve occupancy (presence/absence), we assessed fisher activity based on the number of occasions that fishers visited camera stations. Visit occasions were defined as distinct event periods when fishers activated the motion sensors with at least a 15 minute break between successive visits. Review of images suggested this was an appropriate period of time separating distinct visit periods. We scored a total 4727 fisher visits to camera stations during the study (range 583 to 951; Table D6). Fisher visits ranged from 11.6 (2010-11) to 20.4 (2012-13) per 100 trap nights (Table D6). However, and in accordance with our finding of lower probability of detection for fishers during summer season compared to fall and winter seasons (Popescu et al. 2014), fisher visits/100 camera survey days was very low during summer (3.6) , and highest during winter (33.3). Higher probability of detection during winter

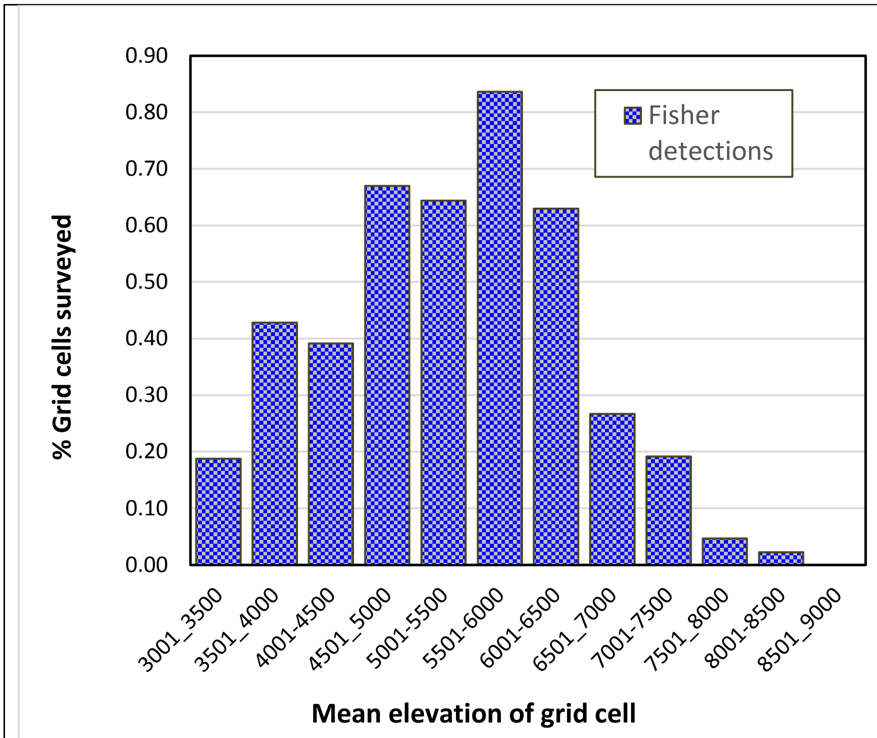


Figure D9: Elevation range of fishers in the SNAMP Fisher study area based on the proportion of grid cells surveyed with fisher detections in 500 foot (152 m) elevation bins.

Table D5: Number of $1km^2$ grid cells surveyed with cameras by camera survey year (Oct 15 to Oct 14).

Camera survey year	Key Watersheds			Outside Key Watersheds			Entire study area		
	Grid cells	Fisher detected	Naïve occupancy	Grid cells	Fisher detected	Naïve occupancy	Grid cells	Fisher detected	Naïve occupancy
2007-08	122	71	0.582	98	41	0.418	220	112	0.509
2008-09	129	75	0.581	212	128	0.604	341	203	0.595
2009-10	127	75	0.591	275	100	0.364	402	175	0.435
2010-11	125	82	0.656	284	80	0.282	409	162	0.396
2011-12	128	98	0.766	226	104	0.460	354	202	0.571
2012-13	133	70	0.526	71	41	0.577	204	111	0.544

All years unique grid cells surveyed: $N = 905$

[a] Some grid cells were surveyed twice during a camera survey year; those grid cells were counted once for this summary.

is likely due to reduced prey availability compared to summer. For example, California ground squirrels (*Otospermophilus beecheyi*) and long-eared chipmunks (*Tamias quadrimaculatus*) enter into torpor (hibernation) during winter, and data on alligator lizards (*Elgaria multicarinata*) and other summer season prey are not available.

Table D6: Summary data on the number of camera days for all cameras used to survey for fishers (effort), and the number of fisher visits during each camera survey year (~Oct 15 to Oct 14).

Camera survey year	Camera days (all cameras)[a]	Camera days (Fisher grid cells)[b]	Fisher visits[c]	Visits per 100 camera days[c]
2007-08	7914	4328	583	13.5
2008-09	10605	5550	794	14.3
2009-10	14955	5990	951	15.9
2010-11	16457	5614	649	11.6
2011-12	14059	7149	949	13.3
2012-13	7584	3926	801	20.4

[a] Estimated days that cameras were functioning and focused on the bait tree
[b] Functional camera days for grid cells with fisher detections
[c] Based on images sequences with fishers (fisher detections) that were separated by a minimum of 15 minutes.
[d] Fisher visits divided by functional camera days for grid cells with fisher detections x 100

Illustration D9: Winter period and summer period fisher detections at camera survey stations.

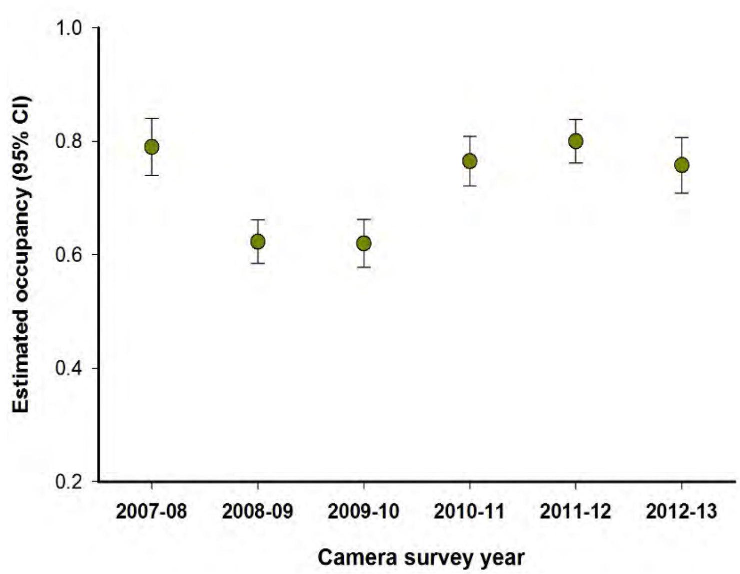


Figure D10: Estimated fisher occupancy (95% CI) for multi-year surveyed (n = 292) during six camera survey years for the SNAMP Fisher study. Occupancy is corrected for imperfect probability of detection.

Fisher Denning and Reproduction

Denning period

Den cameras provided detailed information on the activities of 32 adult female fishers during six spring denning seasons. Based on information from the spatial clustering of aerial telemetry locations, ground-based telemetry, and den cameras, denning was initiated in the last week of March in most years (earliest date was March 22), and females typically ceased regular use of den trees in the first week of June (Table D7). The latest known regular use of a den tree was June 20 in spring 2012. It is likely that females continued to use trees as short term den/rest structures during summer when their dependent kits were trailing them, but we did not attempt to systematically identify those types of short duration use structures.

Table D7: Estimated dates for the initiation and end of denning by female fishers in the Sierra National Forest, California. Data are from March 2008 to June 2013.

	Mean start of denning[a]		Mean end of denning	
Season	# dens	Estimate	# dens	Estimate
2008	1	27-Mar-08	1	4-Jun-08
2009	12	27-Mar-09	9	6-Jun-09
2010	13	25-Mar-10	8	4-Jun-10
2011	8	1-Apr-11	5	5-Jun-11
2012	11	31-Mar-12	7	2-Jun-12
2013	12	27-Mar-13	7	1-Jun-13

[a]Estimated from spatial clustering of sequential aerial radiotelemetry locations (Zhao et al 2012).

In the spring 2008 den season SNAMP Fisher monitored a single female fisher, but in all other years we monitored at least nine individual females (Table D8). The mean number of dens used per female per season was 2.4 (range 1 to 5), and the mean number of cameras used to monitor each den structure was 3.1. On average each denning female was monitored with den cameras 34.3 days/season (range 28.9 to 37; Table D8), excluding days or periods when successive use maternal den trees were yet to be identified. Fifteen female fishers were monitored with den cameras in one den season, 11 were monitored in two seasons, three were monitored in three seasons, two were monitored in four seasons, and one was monitored in five denning seasons.

Denning activity, litter size and weaning rates

Denning status was determined for 89 of 93 total denning opportunities for breeding-age (≥24 months) females in 6 denning seasons from 2008 to 2013 (Table D9). We were unable to adequately monitor 4 breeding-age females for determining denning status when radiocollars were shed (n = 3) or ceased functioning (n = 1) within the first 31 days of a denning season. The average date that females initiated denning behavior was March 28 (range March 22 to April 9). The average date that females

Table D8: Summary data on denning activities by female fishers determined from monitoring den trees with remote cameras. Data are from the Sierra National Forest, California from April 2008 to June 2012.

Spring	Female fishers	Den trees monitored	Monitor days[a]	Avg monitor days/female	Total detections[b]	Daily rates: Detection rate[c]	Daily rates: Up/Down movements[d]
2008	1	3	37	37.0	30	0.568	1.1
2009	13	45	449	34.5	366	0.601	1.2
2010	14	47	479	34.2	353	0.568	1.1
2011	9	28	260	28.9	264	0.725	1.1
2012	11	37	406	36.9	439	0.733	1.3
2013	12	40					

[a] Excludes periods when females moved kits and the next maternal den tree had not yet been located.
[b] All detections identified as a departure or return to the den tree, as well as events when fishers were at the base of den trees but not identified as departing or returning.
[c] Proportion of days den trees were being monitored for which at least one detection was made by den cameras
[d] Mean number of return and departures movements for days when fishers were detected by cameras.

ceased localizing to den trees was June 9 (range May 30 to June 22).

Seventy-six (85%) breeding-age female fishers either exhibited denning behavior (n = 63) or were determined to have denned and weaned at least 1 kit based on size of teats (n = 13; Table D9). Among 76 breeding-age females that initiated denning, 64 (84%) were identified as weaning kits. Overall, 72% of 89 known status, adequately monitored denning opportunities for breeding-age females produced at least one weaned kit (Table D9).

Eleven (17.5 %) of 63 cases of denning for females that were monitored during spring periods failed prior to kits being weaned (Table D10). Three of the 11 denning failures were females that initiated denning but ceased localizing to natal den trees 17, 35, and 41 days later, potentially related to the death of kits. Eight den failures were due to death of the denning female; seven deaths were by attacks by predators, and one was the result of a denning female either dying of internal bleeding induced by exposure to rodenticides, or from the combination of trauma from being struck by a vehicle on a highway and internal bleeding related to exposure to rodenticides. One of the seven females that died from predator attack was infected with canine distemper virus, which may have contributed to her vulnerability (Keller et al. 2012).

Six of eight deaths of denning females occurred when the locations of den trees were known and were being monitored. In one case den camera images included a bobcat with a dead kit in its mouth, and the partial carcass of the denning female was recovered nearby. In a second case the den structure was a large, unstable snag, and we did not attempt to climb the tree to determine litter size due to safety considerations. In each of the other four cases we climbed the den trees to assess litter size, and recover kits in accordance with California Department of Fish and Wildlife policy. A total five live kits were recovered from two of the den trees (litter size 2, 3), two deceased kits were found in a den cavity of the third tree, and we failed to find kits in the fourth tree.

The five orphan kits that were rescued were raised in captivity by a local wildlife rehabilitation organization licensed by the California Department of Fish and Wildlife, and under the care and supervision of a professional zoo veterinarian. One of the orphan kits died in captivity by urinary tract blockage attributed to a parasitic nematode, whereas the other 4 survived captive rearing. Two kits from one litter were released within their mother's home range, and the two kits from the second litter were released into an area with suitable fisher habitat abutting the south margin of the study site.

We used a combination of images from den cameras (n = 43) and den cavity investigations with a video camera (n = 4) to determine litter size for 48 of 59 denning females that were monitored (Table D10). A total 73 kits were known produced, and average litter size was 1.5 (Table D10). After accounting for known mortalities of denning females, we estimated that 64 of the 73 kits produced were weaned from den trees, whereas seven kits died or would have died had they not been rescued (Table D10).

Table D9: Summary of female fisher (≥2 years old) denning and weaning rates by age class and year on the Bass Lake Ranger District in the Sierra National Forest, California, 2008-2013.

Pop Year	No. Adult Females[a]	Monitored mid-Mar to May 31[b]	Teats measured (Jul to Jan)[c]	Denning[d]	Proportion denned[e]	Unknown status[f]	Failed[g]	Died while denning	Weaned[h]	Proportion weaned[i]
Age class (Years)										
2	30	26	1	21	0.78	3	1	2	18	0.67
3-5	63	48	13	55	0.87		3	5	46	0.75
≥6	12	10	2	9	0.75			1	8	0.67
Year										
2008	11	2	9	9	0.82				9	0.82
2009	17	14	3	15	0.88		1	1	13	0.76
2010	17	15	1	14	0.88	1		3	11	0.69
2011	16	11	3	12	0.86	2	1	1	10	0.71
2012	17	17		14	0.82			3	11	0.65
2013	15	15		12	0.86	1	1		10	0.79

[a] All females ≥ 24 months of age that were known in the population during the year. Includes females that were captured after the end of the denning season in mid-June.

[b] Number of females monitored by radio telemetry during all of part of the period before they died or had a dropped/failed collar after denning status had been determined.

[c] Number of females the were uncollared during the denning period, but were captured during July to January when teat measurements were taken and used to determined weaning status as described by Matthews et al. (2013).

[d] Number of females that exhibited denning behavior, or that were determined to have weaned at least one kit based on teat measurements.

[e] Number of denning females divided by the number of adult females minus the number of females of unknown status.

[f] Number of females (≥ 2 years old) for which denning was unknown or suspected, but dropped or failed radiocollars prevented determination of denning status.

[g] Number of females (≥2 years old) that exhibited denning behavior and ceased denning behavior prior to weaning.

[h] Number of denning females that were known alive and exhibited denning behavior until after May 31.

[I] Number of females that weaned kits, divided by the number of adult females minus the number of females with unknown status.

Table D10: Information on female fisher kit production for six spring denning seasons (March 21 to June 31) in the Sierra National Forest, California, October 2008 to June 2013.

Age class (Years)	Denning females[a]	Denning Females with kit counts[b]	Kits [c]	Litter size[d]	Denning female deaths[e]	Known kit deaths[f]	Denned to Weaning[g]	Kits weaned[h]	Kits weaned per litter (fecundity)
2	19	15	21	1.4	1		14	19	1.3
3-5	32	26	40	1.6	3	7	22	34	1.3
≥6	8	7	12	1.7			7	12	1.7
Year									
2008	2	1	1				1	1	
2009	12	9	15	1.5	1		10	15	1.5
2010	13	11	20	1.8	3	7	7	13	1.9
2011	8	7	11	1.6	1		7	11	1.6
2012	14	11	16	1.5	3	2	10	14	1.4
2013	10	8	10	1.3			8	10	1.3

[a] Number of females (≥2 years old) that exhibited denning behavior and were monitored by radiotelemetry, den cameras, or both. Excludes females whose reproductive status was not known and those that initiated denning behavior but ceased denning before May.

[b] Number of denning females for which kit counts were determined by images from den cameras, den cavity video camera, or both.

[c] Total number of kits counted.

[d] Number of denning females with kit counts divided by the number of kits counted.

[e] Number of denning females known to have died during the denning season while provisioning kits in den trees. Numbers of kits in litters were not known for all of the denning females that died.

[f] Kits that were known present in den trees when the mother died, or those that were found dead inside den cavities. This estimate assumes that 5 orphan kits that were removed from den cavities would have perished if they had not been rescued.

[h] Number of monitored denning female fishers exhibiting denning behavior that continued to weaning.

Denning structures

We identified 125 unique structures used as natal or maternal dens, including 54 black oak, 41 incense cedar, 19 white fir, 10 sugar pine or ponderosa pine, and one canyon oak (*Quercus chrysolepsis*) (Table D11).

Repeat use of den trees was not uncommon. Sixteen individual den trees were used more than once; 15 trees were used in two years, and one tree was used in four different den seasons. In all but two cases of repeat den tree use the same individual reused one or several den trees between successive years. In two cases a female used a den that had been used by a different female in a previous year. Successive dens of females that used more than 1 den structure were located an average of 413 m apart (n = 52, range 75-1398). The distance between the natal den tree and the first maternal den tree averaged 419 m, whereas successive use maternal den trees were in closer proximity (mean = 287 m, t_{69} =1.75, P=0.04).

Table D11: Information on the number of times (denning events) different species of trees were used for denning by female fishers in the SNAMP Fisher study. Includes counts for live trees, snags, and both types of denning structures.

Tree type, Species	Denning events[a]	Percent within group	Unique structures[b]	Repeat use structures[c]
Live trees				
Black oak	34	43	31	3
Incense cedar	25	32	19	4
White fir	14	18	14	
Sugar pine	3	4	3	
Ponderosa pine	2	3	2	
Canyon oak	1	1	1	
Snags				
Black oak	27	42	23	
Incense cedar	27	42	22	4
White fir	5	8	5	5
Pine species[d]	5	8	5	
Live tree or snag				
Black oak	61	43	54	3
Incense cedar	52	36	41	8
White fir	19	13	19	5
Pine species	10	7	10	
Canyon oak	1	1	1	
Total den structures	143		125	16

[a] Count of all known denning events for each species of tree.
[b] Count of individual trees; those used in multiple seasons counted once.
[c] Number of individual trees used ≥ two times for denning; one live cedar tree was used by the same female in four successive denning seasons, but all other repeat use trees were known used in two den seasons only.
[d] Pine snags could not always be identified as sugar pine or ponderosa

Fifty-six percent of the

unique individual trees used for denning in the SNAMP area were live trees (*n* = 70), whereas 44% (*n* = 55 were snags (Table D11). Black oak was the most common live tree used for denning, followed by incense cedar (Table D11). Among snags used as denning structures, black oak and incense cedar were both commonly used, whereas white fir and pines (sugar pine or ponderosa pine) were less common as snag-type den trees (Table D11). Overall, black oaks and incense cedar were the two most common tree species used for denning (Table D11).

Habitat characteristics of den structures

Mean diameter at breast height (DBH) of black oak denning structures was smaller than that for other tree species used (Table D12). Mean heights of live trees were taller than snags of the same species (Fig. D11), reflecting that many of the snags used for denning were at advanced stages of decay.

Table D12: Basic information on the size (DBH) and height of trees (live or snag) used as denning structures by female fishers in the SNAMP Fisher study from March 2008 to June 2013.

Tree species	Live trees *n*	Live trees Mean DBH (cm)	Live trees Mean height (m)[a]	Snags or dead trees *n*	Snags or dead trees Mean DBH (cm)	Snags or dead trees Mean height (m)
Black oak	30	74.2	21.7	5	69.5	8.8
Incense cedar	18	127.2	32.5	22	105.1	16.4
White fir	14	110.8	33.9	22	103.7	27.4
Pines	5	112.8	37.4	5	109.6	27.6

[a]Data on mean tree height are for the subset of den trees for which detailed data on habitat measurements were completed (*n* = 84).

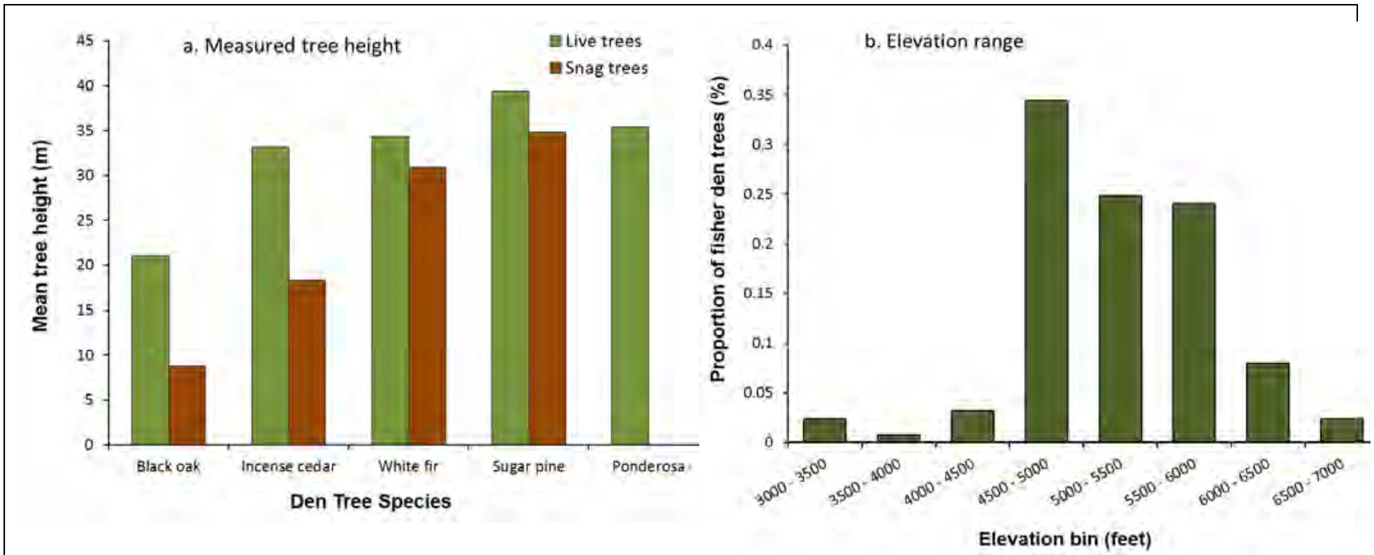


Figure D11: Summary information on the (a) mean height of denning structures (unique trees), and the (b) elevation range for fisher den trees for the SNAMP Fisher Study during 2008 to 2013 (6 denning seasons).

The majority of denning structures used by fishers in the SNAMP Fisher study area were in the elevation range from 4500 (1371 m) to 6000 feet (1829 m; 83%, n = 104; Fig. D11b). Additional information obtained from circular habitat plots assessments included indications of high canopy cover, limited herbaceous cover, and relatively low shrub cover near most den trees (Table D13). Concealment cover was 64% low ground cover, 46% high ground cover, and 38% and 36% low shrub and high shrub cover, respectively. On average, belt transects within the circular habitat plots around den trees included an average of 6.5 down logs (coarse woody debris, CWD; logs/branches with a minimum large end diameter of 15 cm, ≥1 m total length). Many denning structures were on steep slopes (Table D13) but there was no obvious preference for aspect (Fig. D12).

Table D13: Basic habitat attributes around fisher den trees for the SNAMP Fisher Study area in spring 2008 to spring 2012.

Attribute[a]	Mean	Range
Canopy cover	72%	30-94%
Shrub cover	19%	0-82.5%
Herbaceous cover	6%	0-29%
Prevailing slope	37%	3-75%

[a] Habitat attributes are from circular plots (18 m radius) centered on fisher den trees (n = 82). Habitat data were not available for other confirmed den trees.

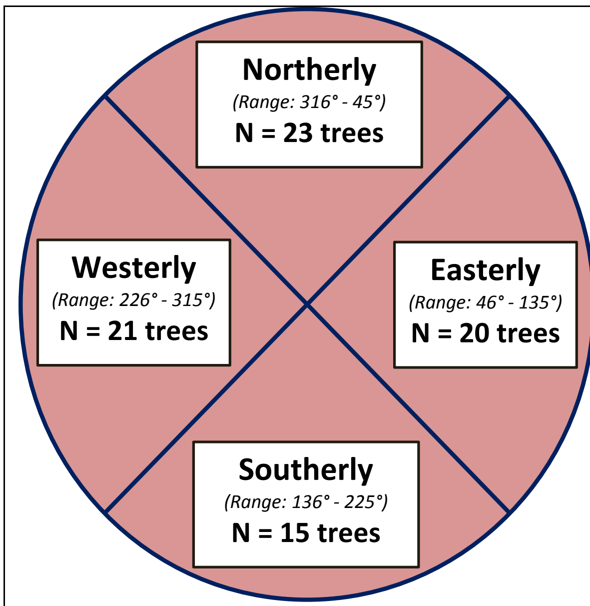


Figure D12: Aspect of fisher den structures on the SNAMP Fisher Study. Data are for 79 den trees.

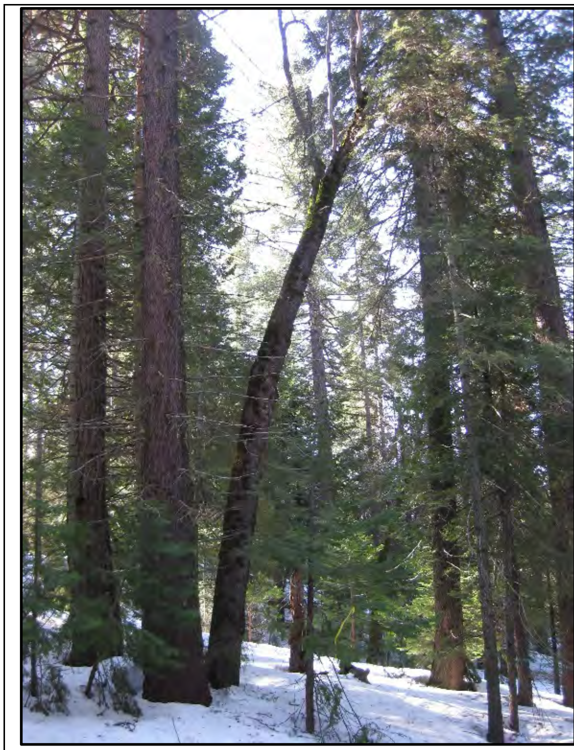
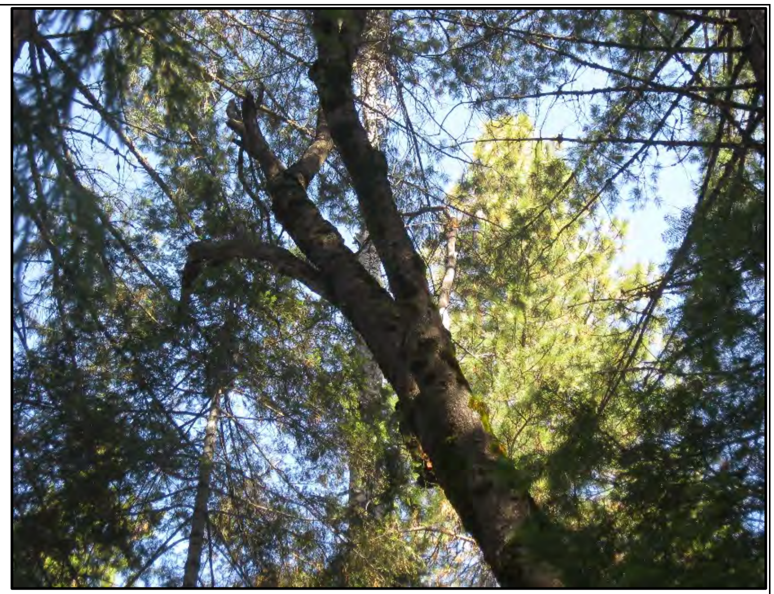



Illustration D10: Black oak used for denning in spring 2011. Image of tree from a distance (left), and view of the forked branching higher up the bole of the denning structure (right).

Activity patterns of denning females

Additional insight on denning activities by adult female fishers was provided by analyses of den camera images. Adult females were detected by den cameras at known active dens an average of 0.64 times/day (range 0.57 to 0.73) (Table D8) and the mean number of detections of up and down movements ranged from 1.1 to 1.3 per day (Table D8), indicating that fishers do not typically leave and return to den trees multiple times a day. In addition to information on male visits to den trees (we obtained image sequences of eight mating, or copulation events at the base of den trees), den cameras identified three occasions when a female fisher briefly returned to a den tree at least one day after she had already moved kits to another tree nearby (Table D14). On eight occasions den cameras detected other female fishers (non-collared or different collared fisher) at den trees of female fishers (Table D14).

Information from the 83 occasions when females were detected moving kits was used to estimate fecundity. A total of 1295 detections were identified as female fishers departing from, or returning to the den tree, whereas there were 99 detections of females at or near the base of den trees that could not be unequivocally classified except as active outside the den cavity (Table D14). We were able to identify 316 image sequences consistent with either continuous den attendance, or continuous time away from the den when denning females were likely foraging. Den attendance bouts were shortest late in the den season and longest in the middle of the den season (Table D15). Forage bouts away from den trees were shortest early in the den season, and approximately equal thereafter (Table D15).

Table D14: Summary data on denning activities by female fishers determined from monitoring den trees with remote cameras. Data are from the Sierra National Forest, California from April 2008 to June 2012.

Spring	Departing	Returning	Base tree[a]	Bringing food to tree[b]	Kit move	At tree after kits moved	Other female at tree
2008	15	9	6		1		
2009	118	198	35		12	1	
2010	133	163	37	1	20		2
2011	120	127	10		14	1	6
2012	178	234	11	8	25	1	
2013[c]					*min 11*		

[a] Detections at base of tree, or on the tree for which directionality or activity was uncertain
[b] Detections when the female was carrying objects as they returned and ascended the den tree
[c] General information only available for 2013.

Table D15: Information on den attendance and foraging excursions, developed from analyses of data from cameras used to monitor fisher den trees during five denning seasons. Data are from the Sierra National Forest, California from April 2008 to June 2012.

Den attendance bouts (minutes)					Forage away bouts (minutes)			
Season[a]	Cases	Mean	Min[b]	Max[c]	Cases	Mean	Min	Max
Early	38	371.0	4.4	1072.5	64	235.1	34	746.1
Middle	43	535.6	2.3	996.2	53	431.8	29.3	811.4
Late	68	323.3	6.0	1049.4	50	405.5	22.8	807.8
Overall	149	396.7	2.3	1072.5	167	348.6	22.8	811.4

[a] Seasons were Early (March 26 to April 20), Middle (April 21 to May 15), and Late, (May 16 to June 11), identified by dividing the overall den season into three 25 day periods from late March to mid-June.
[b] shortest duration bout.
[c] longest duration bout.

Fisher Survival

Sixty-six (60%) of the 110 individual fishers radiocollared during the study were known to have died, including 32 females and 34 males (Table D16). Excluding population year 2007-08, an average of 10.5 radiocollared fishers perished each population year (Fig. D13). The mean number of deaths by sex for population year 2008-09 through population year 2013-14 was 5.3 for females and 5.2 for males.

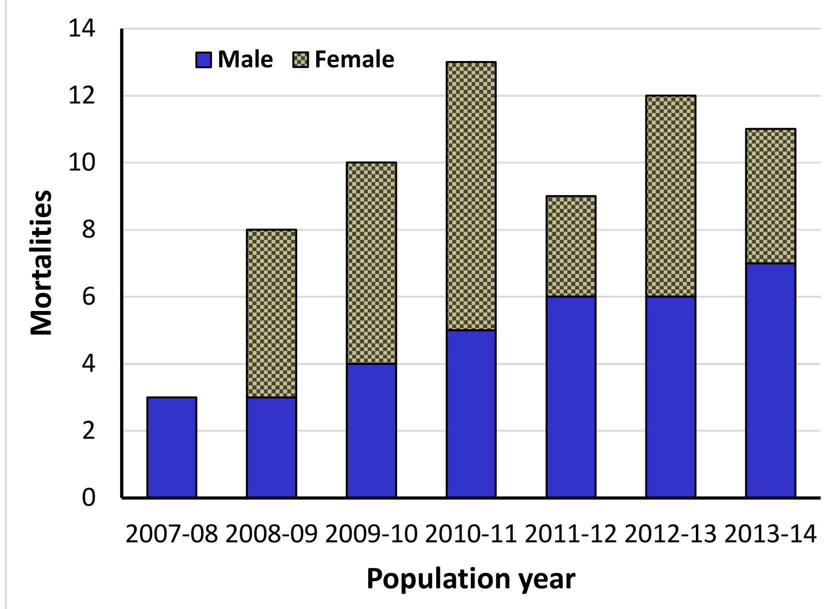


Figure D13: Number of radiocollared female and male fishers known to have died during the SNAMP Fisher Study.

Fisher survival with population data combined into 2-year periods was generally higher for adult and juvenile fishers than for subadults (Table D17). Ninety-five percent confidence intervals overlapped for females and males in all two-year period with the possible exception of subadults in year group 3. Two-year survival rates among females ranged from a low of 47% to a high of 89% for subadult females (Table D17). Two year survival for juvenile females was always ≥ 74%, whereas among adult females it ranged from a low of 0.69% to a high of 0.86 (Table D17). Fisher survival for all years combined was highest for juvenile females and lowest for subadult males (Table D17). Also, although not significantly different, survival was consistently higher for females compared to males (all age classes; Table D17).

Table D16: Review of all known deaths of radiocollared fishers in seven population years (Apr 1 to Mar 31), summarized by sex, and cause-specific mortality from necropsy examinations by pathologists at the UC Davis School of Veterinary Medicine (Davis, CA).

Year, Sex	Predation[a]	Disease[b]	Starvation-related injury, septicemia[c]	Roadkill	Rodenticide toxicosis	Indeterminate, unknown[d]
2007-08						
Female						
Male	1	1		1		
2008-09						
Female	4		1			
Male	1	1		1		
2009-10						
Female	5		1			
Male		3			1	
2010-11						
Female	5		1		1	1
Male	4					1
2011-12						
Female	3					
Male	5		1			
2012-13						
Female	3					
Male	1			1	1	1
2013[e]						
Female						
Male						
All years						
Female	20		3		1	1
Male	12	5	1	3	2	2

[a] One female death by predation in 2009-10 may have been related to the animal being weakened/sick from CDV when it encountered a coyote (*Canis latrans*); further discussed by Keller et al. (2012).
[b] Three disease deaths were associated with canine-distemper virus, one was considered by Toxoplasmosis, and one was due to pleruritus+pneumonia.
[c] Most deaths in this category were associated with prior injury that contributed to starvation and septicemia.
[d] Necropsies were completed, but cause of death could not be determined.
[e] Includes deaths of two male fishers that died January 1, 2014 and March 31, 2014. Although this was after the end of SNAMP Fisher, both of the animals were radiocollared as part of SNAMP.

Table D17: Estimates of survival (s(t)), for radiocollared fishers using population data combined for analysis into a series of five 2-year groups beginning in population year 2 (2008-09) and ending in population year 7 (2013-14), and for all years of data combined. Survival was assessed using Kaplan-Meier staggered entry analyses. Population years were from April 1 to March 31, and ages were defined as juvenile [< 12 months], subadults [12 to 23 months], and adults [≥ 24 months].

	Juveniles		Subadults		Adults	
Year group, Sex	s(t)	95% CI	s(t)	95% CI	s(t)	95% CI
2008-09, 2009-10						
Female	0.80	0.58-1.02	0.47	0.28-0.66	0.81	0.66-0.96
Male	0.83	0.50-1.17	0.40	0.10-0.70	0.73	0.52-0.95
2009-10, 2010-11						
Female	0.80	0.59-1.01	0.67	0.42-0.92	0.70	0.54-0.86
Male	0.60	0.30-0.90	0.43	0.06-0.79	0.71	0.52-0.91
2010-11, 2011-12						
Female	0.74	0.54-0.94	0.89	0.71-1.07	0.69	0.53-0.86
Male	0.67	0.42-0.92	0.50	0.29-0.71	0.56	0.37-0.75
2011-12, 2012-13						
Female	0.80	0.55-1.05	0.73	0.52-0.94	0.86	0.71-1.00
Male	0.83	0.56-1.11	0.92	0.77-1.06	0.61	0.44-0.77
2012-13, 2013-14[a]						
Female			0.73	0.48-0.98	0.74	0.56-0.93
Male			0.75	0.33-1.17	0.66	0.49-0.83
All Years; Dec 07-Mar-14						
Female	0.75	0.60-0.89	0.71	0.57-0.84	0.74	0.64-0.83
Male	0.60	0.42-0.78	0.57	0.40-0.74	0.64	0.54-0.75

[a] Insufficient data for estimating survival for juveniles in this Year group.

Causes of Mortality

Necropsies were completed for 50 of the 66 radiocollared fishers that died during the SNAMP Fisher study. Assignment of cause-specific mortality was possible for 47 of the 50 animals with necropsy reports (94%). Three necropsies reports were indeterminate with regards cause of death for the fisher (Table D16). To date, a known cause of death has been determined for 71% of the 66 mortalities. Among known-cause mortalities predation was the primary cause of death, accounting for 68% of 47 known-cause deaths (Fig. D14). Deaths by disease, injury-related starvation or septicemia, and human-linked factors such as vehicle strike or rodenticide poisoning combined to account for 32% of known-cause mortalities (Fig. D14).

Predation accounted for nearly twice as many known cause deaths for females (43%) than for males (26%), whereas all of the disease and roadkill deaths were males (Fig. D14).

Serological testing of blood samples collected at captures revealed low levels of exposure to canine distemper virus in the study population (Gabriel 2013). However, in spring 2009 a relatively small scale epizootic of CDV occurred in the study population, contributing to the deaths of four fishers; three by direct infection, and one that was killed by a coyote attack, but was likely weakened due to presence of CDV infection (Table D16, Fig. D14; Keller et al. 2012).

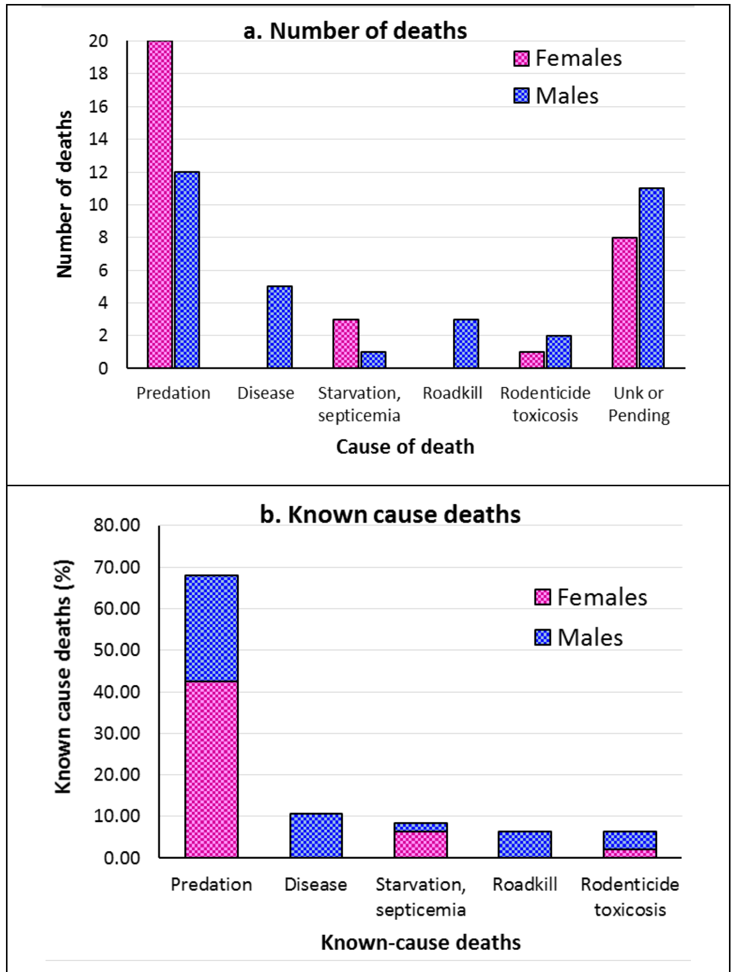


Figure D14: Summary of necropsy-determined causes of death for radiocollared fishers (a), and percent of known cause mortalities (b) on the SNAMP Fisher Project from Dec 2007 to Dec 2013.

In Spring 2009, the SNAMP Fisher Team recovered the first fisher known to have died by toxicosis after exposure to rodenticides. In total, three fishers were known to have died after exposure to rodenticides as of June 2014, including two males and one female. The discovery of death associated with rodenticides led to two peer-reviewed papers. One detailed issues with anticoagulant rodenticides on public lands (Gabriel et al. 2012) and a second paper revealed that female fishers with larger numbers of marijuana grow sites within their home ranges experience reduced survival (Thompson et al. 2013).

Illustration D11: Remains of a female fisher killed by a predator (left), and a male fisher that was determined to have died by infectious disease (right).

Population Growth Rates

Empirically developed estimates of key demographic parameters needed to estimate a deterministic growth rate for the population (λ) were developed during the study (Tables D22, D23). Estimates for λ were below 1.0 (population decline) in two 2-year groups, equal to 1.0 in one 2-year group (stable), and slightly positive in two 2-year groups (increasing population) (Table D18). The All Years λ was 0.90, which was suggestive of population decline, however, the range for all results overlapped 1.0.

Table D18: Demographic parameters and deterministic population growth rates (range) for five two-year groups[a], and for population data for all years of the study combined (All years).

Parameter, Age class	Year group 1	Year group 2	Year group 3	Year group 4	Year group 5	All Years
Weaning reproduction						
Young adult	0.67	0.89	1.00	0.83	0.70	0.68
Adult	0.75	0.67	0.83	0.82	0.87	0.74
Weaning litter size						
Young adult	1.27	1.57	1.50	1.20	1.20	1.19
Adult	1.31	1.31	1.60	1.55	1.40	1.45
Weaning fecundity $(b_i)^b$						
Young adult	0.42	0.70	0.75	0.50	0.42	0.41
Adult	0.49	0.44	0.67	0.64	0.61	0.53
Survival (P_i)						
Juvenile	0.76	0.80	0.74	0.80	1.00	0.75
Subadult	0.47	0.67	0.89	0.73	0.73	0.71
Adult	0.81	0.70	0.69	0.86	0.74	0.73
Fertility $(b_i)P_i$						
Young adult	0.20	0.47	0.67	0.36	0.31	0.29
Adult	0.40	0.30	0.46	0.55	0.45	0.39
Leslie Matrix λ^c	0.87 *(0.65-1.08)*	0.88 *(0.63-1.12)*	1.00 *(0.77-1.22)*	1.04 *(0.81-1.26)*	1.03 *(0.77-1.22)*	0.90 *(0.71-1.12)*

[a] Two-year groups were 2008-09 and 2009-10 (1), 2009-10 and 2010-11 (2), 2010-11 and 2011-12 (3), 2011-12 and 2012-13 (4), and 2012-13 and 2013-14 (5).

[b] Fecundity is the number of female offspring produced, calculated as weaning reproduction*weaning litter size*0.5 (assumes equal sex ratio at birth)

[c] The range for λ was based on the 95% confidence intervals for the survival rates for the five two-year groups (Table D17). The range for λ for the All years data was based on the 95% CIs for the means for weaning reproductive rate and litter size, and for the 95% CIs for age-specific survival (Table D17).

Population Size and Density

Population size was estimated for the middle four population years of the six year study. In population year 1 (2007-08), we had only a small number of fishers radiocollared during the last few months of that period (Tables D9, Fig. D10), and camera images for the entire population year 2012-2013 were not available due to the conclusion of SNAMP Fisher field work. During the central four year period we captured and radiocollared 101 individual fishers (57 females and 44 males) on 258 occasions during 9732 trap-nights between December 2007 and March 2012. Resighting efforts, both by camera and live traps, varied by subregion and, to a lesser extent, year (Table D19). Cameras accounted for 86% of 1421 total radio-marked fisher detections, with live trap recaptures providing 201 sightings.

Table D19: Summary data on camera and live trap activities within 4 fall-winter camera survey years (October 16 to March 15) in the Bass Lake District, Sierra National Forest Study area, October 2008 to March 2012. (see Figure D6 for subregion map).

	Camera surveys		Live traps		Estimated area surveyed
Subregion, Year	Grid cells	Nights	Grid cells	Nights	(km^2)[a]
Subregion 1. Nelder Grove, Sugar Pine, Miami Mountain					
2008-09	147	4462	121	1027	223.2
2009-10	160	5817	161	875	307.2
2010-11	132	4995	72	411	214.3
2011-12	141	5245	147	1016	224.6
Subregion 2. Central Camp, Whisky, Grizzly, Jackass					
2008-09	48	1289	17	158	267.6
2009-10	12	349	56	272	248.0
2010-11	20	1048	47	237	244.2
2011-12	65	2522	80	316	305.5
Subregion 3. Chowchilla Mountain, Rush Creek, Sweetwater					
2008-09	16	400	25	144	128.8
2009-10	2	79	39	252	111.8
2010-11	1	33	22	124	136.2
2011-12	14	513	32	149	132.8

[a] Based on a 1300 m buffer applied to polygons encompassing grid cells surveyed by cameras and grid cells with live trap captures.

Mean overall abundance across all subregions ranged from 48.2 individuals in Year 2 to 61.8 individuals in Year 4. Variation was at least partly related to differences in area surveyed among years (Table D20). Estimates of areas sampled were generally consistent within subregions among years (Table D20). The increase in area surveyed in Subregion 1 in fall-winter 2009-10 was due to a program that extended camera surveys north into the Yosemite South region of Yosemite National Park (Fig. D2) in winter 2010. In fall-winter 2011-12 search effort was expanded in the Grizzly and Jackass subregion when non-collared fishers were detected on camera in areas that had not been surveyed previously. Mean annual population density for the three subregions ranged from 0.072 to 0.097 fishers/km^2 (Fig. D15).

Subregion 1 had consistently high average densities (0.073-0.125 individuals/km^2), with an increasing trend across the last three years of the period (Table D20, Fig. D15). Subregion 3 had initial low density (0.056 ± 0.005 individuals/km^2), but gradually increased by the end of the period (0.106 ± 0.005 individuals/km^2). Subregion 2 showed no particular trend, and average densities varied across seasons between 0.066 (fall-winter 2009-10) and 0.092 individuals/km^2 (fall-winter 2010-11). Temporally, mean population density was lowest in fall-winter 2009-10 at 0.075 ± SE 0.006 individuals/km^2, and increased thereafter to a high of 0.097 ± SE 0.008 in fall-winter 2011-12 (Fig. D15). Mean population density was consistently high in the last 2 years of the study across all subregions (0.089 – 0.106 individuals/km^2).

Table D20: Mark-resight estimates of population size for three subregions in 4 Fall-Winter survey years (October 16 to March 15) in the Bass Lake District, Sierra National Forest, October 2008 to March 2012.

Subregion, Year	*n*	95% C.I.	Density[a]	Density range[b]
Subregion 1: Nelder Grove, Sugar Pine, Miami Mtn				
2008-09	27.9	23.6-32.2	0.125	0.106-0.144
2009-10	22.3	19.0-25.6	0.073	0.062-0.083
2010-11	19.1	16.3-22.0	0.089	0.076-0.103
2011-12	23.2	20.2-26.2	0.103	0.090-0.117
Subregion 2: Central Camp, Whisky Ridge, Grizzly, Jackass				
2008-09	18.8	10.5-21.2	0.070	0.044-0.097
2009-10	16.3	10.4-21.4	0.066	0.037-0.094
2010-11	22.5	15.4-24.5	0.092	0.066-0.118
2011-12	24.6	17.8-26.5	0.080	0.062-0.099
Subregion 3: Chowchilla Mtn, Rush Creek, Sweetwater				
2008-09	7.2	5.8-8.6	0.056	0.045-0.067
2009-10	9.7	8.7-10.6	0.086	0.078-0.095
2010-11	10.0	8.8-11.3	0.074	0.065-0.083
2011-12	14.0	12.8-15.3	0.106	0.096-0.115

[a] Population size (*n*) divided by the estimated sample area for the subregion in the Fall-Winter camera survey year, included in Table D1.

[b] Calculated based on the lower and upper values of the 95% C.I., divided by the estimate of the sampled area provided in Table D1.

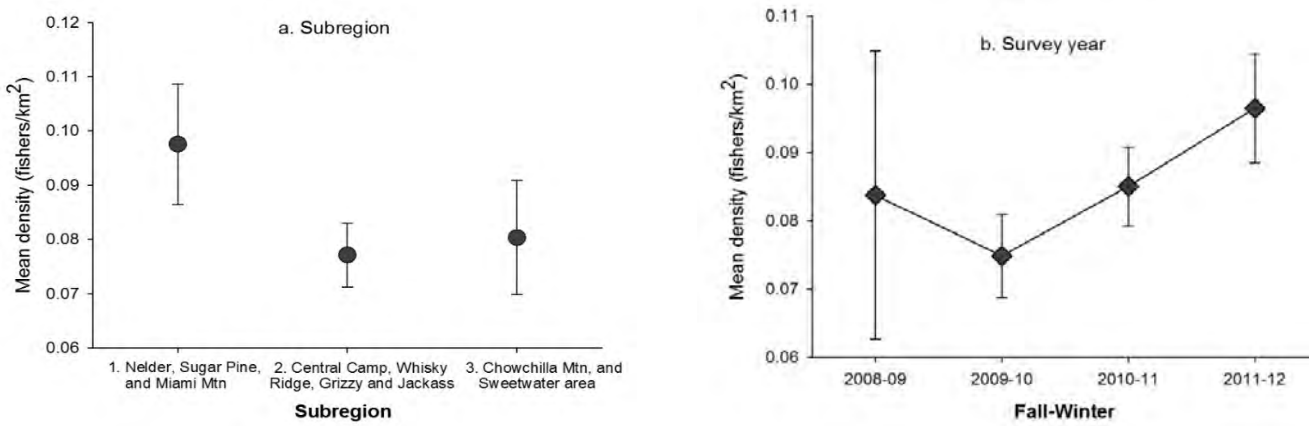


Figure D15: Mean density (± SE) of fishers in three subregions during 4 fall-winter camera survey years (a), and change in mean density (± SE) of fishers during 4 fall-winter camera survey years (b).

Dispersal Behavior and Movements

The combination of field data and genetic data allowed for the *possibility* of assessing dispersal for 33 female and 25 male fishers that were captured as juveniles (n = 53), or young subadults (n = 8; ≤18 months old) (Table D21). Fifteen of those fishers (25.8%) died, disappeared, or were caught too late in the year to define a juvenile home range (Table D21). Dispersal was assessed for 43 (74%) of the 58 animals, based on identification of likely natal areas from either field data or genetic-based maternity assignments (Table D21).

Considering data for dispersal using either field or genetic-based natal area determination and based on Euclidean distances, male fishers tended to disperse longer distances than females, but the difference was not significant (Table D28). The longest Euclidean distance dispersal for a female fisher was 24.53 km, compared to 36.17 km for a male fisher; however the large range of dispersal distances for both sexes precludes precise statistical comparison.

Euclidean dispersal movements often originated from within the Key Watershed focal study area, but other Subregions of the study area produced dispersing animals as well (Fig. D16). There was no clear patterning with regards directionality of dispersal, except perhaps the general northwest to southeasterly orientation associated with the Sierra Nevada range (Fig. D16).

One male fisher immigrated into the SNAMP Fisher Study area in the Bass Lake Ranger District from south of Shaver Lake within the High Sierra District. This fisher, KRFP ID M38 (SNAMP ID M47), was originally captured and marked with a PIT tag on the Kings River Fisher Project in December 2010. M38 was recaptured by the KRFP researchers in February 2012, when he was released without a radiocollar due to a neck injury. M38 was captured 13 months later in March 2013 within the SNAMP study area. Although his Euclidean distance-based dispersal track was estimated at ≈ 36 km, it is more likely that his dispersal track was more circuitous, and in the range of 67-69 km (Fig. D17).

Dispersal movements predicted by Least Cost Movement (LCP) analyses over landscape features considered restrictive to fishers produced longer mean dispersal distances than Euclidean paths (Table D23, Fig. D18). Nevertheless, and in accordance with data from Euclidean distances, there was no evidence for a significant sex-bias in LCP predicted dispersal tracks (Table D23).

Table D21: Review of information on juvenile or subadult fishers captured on the SNAMP Fisher study for which dispersal assessments were possible from field data, maternal assignments from genetic analyses, or from either source.

			Dispersal not assessed[a]			Dispersal assessed			
Maternal year, Sex		*n*	Died	Missing, disappear	Late capture	Field[b]	Genetics[c]	Both[d]	Total
2007									
	Female	3	1			2	2	2	2
	Male	3	1			2	1	1	2
2008									
	Female	8	2			4	5	3	6
	Male	4			1	3	3	3	3
2009									
	Female	7	1	1		5	3	3	5
	Male	4	1			3	3	3	3
2010									
	Female	6	1			5	4	4	5
	Male	8	1			5	6	4	7
2011									
	Female	7	1			4	6	4	6
	Male	4			1	3	3	3	3
2012									
	Female	2	1		1				
	Male	2			1	1			1
All years									
	Female	33	7	1	1	20	20	16	24
	Male	25	3		3	17	16	14	19

[a] Dispersal was not assessed if the animals died before <18 months old, when they were missing and not recaptured, or if they were captured after mid-January (<10 months old).
[b] Animals for which home ranges allowed identification of likely natal areas (juvenile home ranges), as well as post dispersal home ranges as subadults or adults.
[c] Animals for which maternal assignments were made using DNA analyses; natal areas were based on maternal home ranges.
[d] Animals for which dispersal could be assessed using both field data (juvenile home ranges) and maternal assignments from genetic analyses.

Table D22: Estimates of mean Euclidean distances moved by dispersing fishers ≤18 months old on the SNAMP Fisher study. Dispersal was estimated by (1) distance between centroids for juvenile home ranges and subadult or adult home ranges, (2) distance between centroids for maternal home ranges (based on genetic-based maternity assignments) and adult or last known home ranges, or (3) distance between either juvenile home range centroids (fishers without maternity assignments) or maternal home range centroids and adult or last known home ranges.

Dispersal, Sex	*n*	Mean distance (SE)	Range	*t*-test contrasts[a]
1. Juvenile to adult home range (field data)				
Female	20	4.89 (1.36)	0.24-22.26	t_{35}= 1.35, $P = 0.19$
Male	17	8.48 (2.39)	0.94-36.17	
2. Maternal to adult home range (genetics)				
Female	20	5.00 (1.21)	0.46-24.53	t_{34} = 1.32, $P = 0.20$
Male	16	7.44 (1.41)	1.82-21.20	
3. Juvenile or Maternal to adult home range (combined field and genetics)				
Female	24	5.76 (1.26)	0.52-24.53	t_{41} = 1.67, $P = 0.10$
Male	19	9.81 (2.22)	0.94-36.17	

[a] Unequal variance *t*-tests.

Table D23: Mean Least Cost Movement paths (LCP) developed to evaluate dispersal by fishers ≤ 18 months old in the SNAMP Fisher Study area. LCP tracks were estimated for (1) dispersal between centroids for juvenile home ranges and subadult or adult home ranges, (2) for dispersal between centroids for maternal home ranges (based on genetic-based maternity assignments) and adult or last known home ranges, and for (3) dispersal between either juvenile home range centroids (fishers without maternity assignments) or maternal home range centroids and adult or last known home ranges.

Dispersal, Sex	*N*	Mean Least Cost path	Range	*t*-test contrasts[a]
1. Juvenile to adult home range				
Female	20	7.53 (2.39)	0.47-44.09	t_{35}= 0.90, $P = 0.38$
Male	17	11.63 (4.11)	1.03-69.82	
2. Maternal to Adult home range				
Female	20	6.95 (1.62)	0.47-34.06	t_{34}= 1.07, $P = 0.29$
Male	16	9.52 (1.77)	1.85-26.15	
3. Juvenile or Maternal to Adult home range				
Female	24	8.76 (2.11)	0.47-44.09	t_{41}= 1.16, $P = 0.25$
Male	19	13.48 (3.71)	1.03-69.82	

[a] Unequal variance *t*-tests.

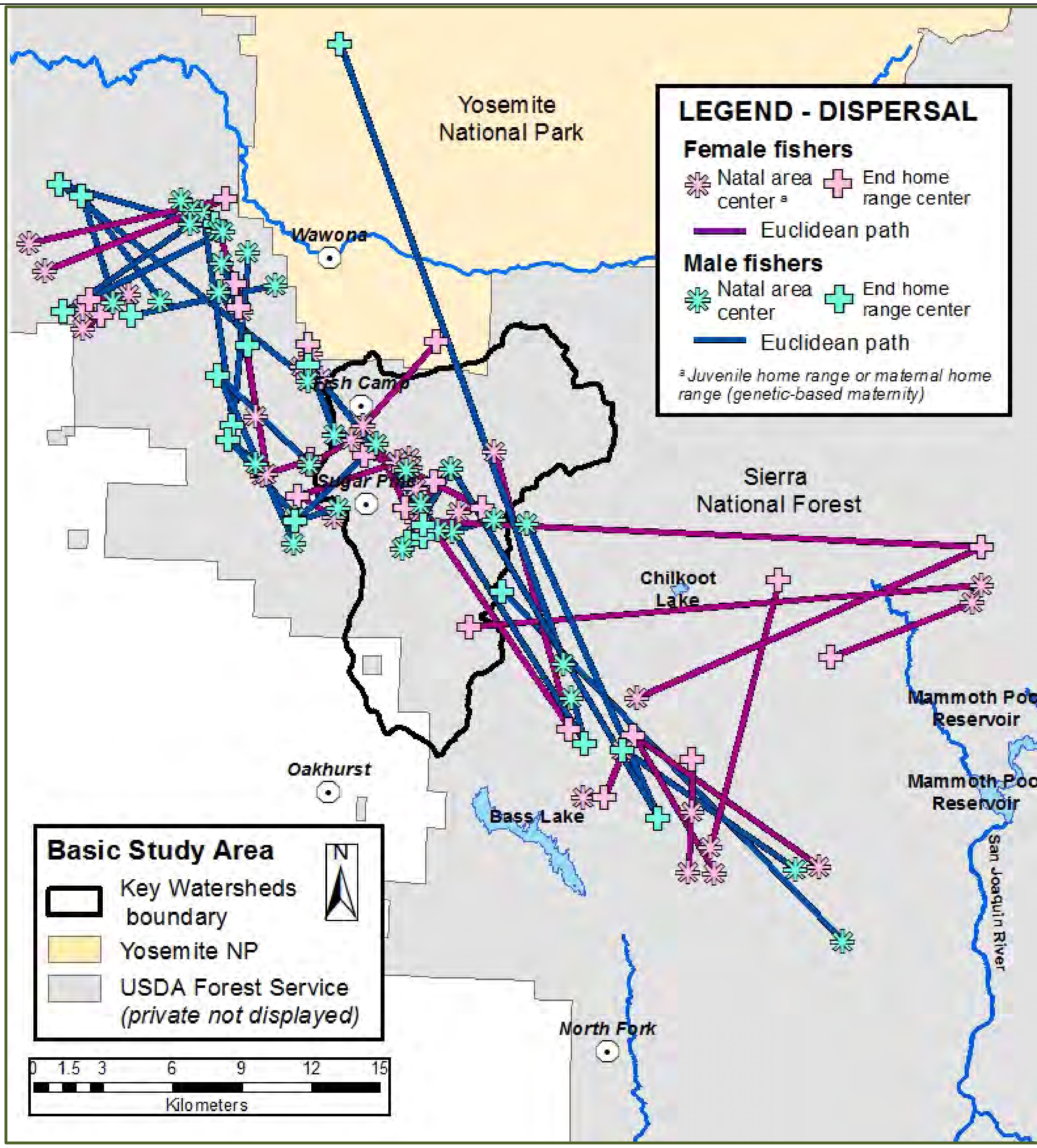


Figure D16: Plot of Euclidean distance dispersal movements for juvenile and young subadult female and male fishers within the SNAMP Fisher Project study area. Note: plot excludes the dispersal track for fisher M47 (KRFP fisher that dispersed north from south of Shaver Lake (High Sierra District) to near "Central Camp" in the Bass Lake District.

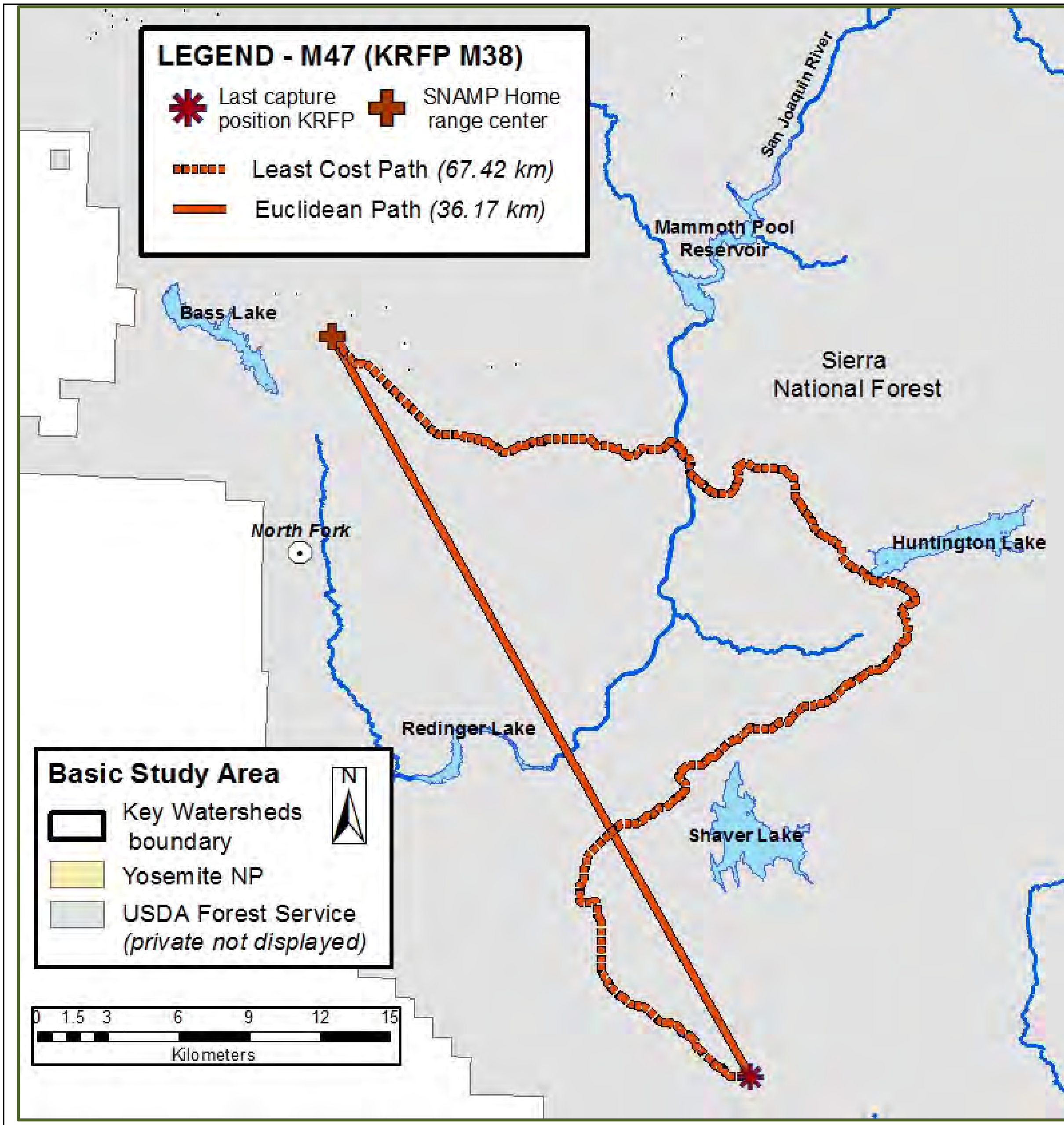


Figure D17: Plot of the potential dispersal tracks for KRFP Fisher M38 from his last live-trap position in February 2012 to his post-dispersal home range centroid near Central Camp within the SNAMP Fisher Study area 13 months later. The plot includes Euclidian distance as well as the estimated Least Cost Movement path, which we consider more realistic given the very steep and vertical cliffs typical of the San Joaquin River canyon east of Redinger Lake.

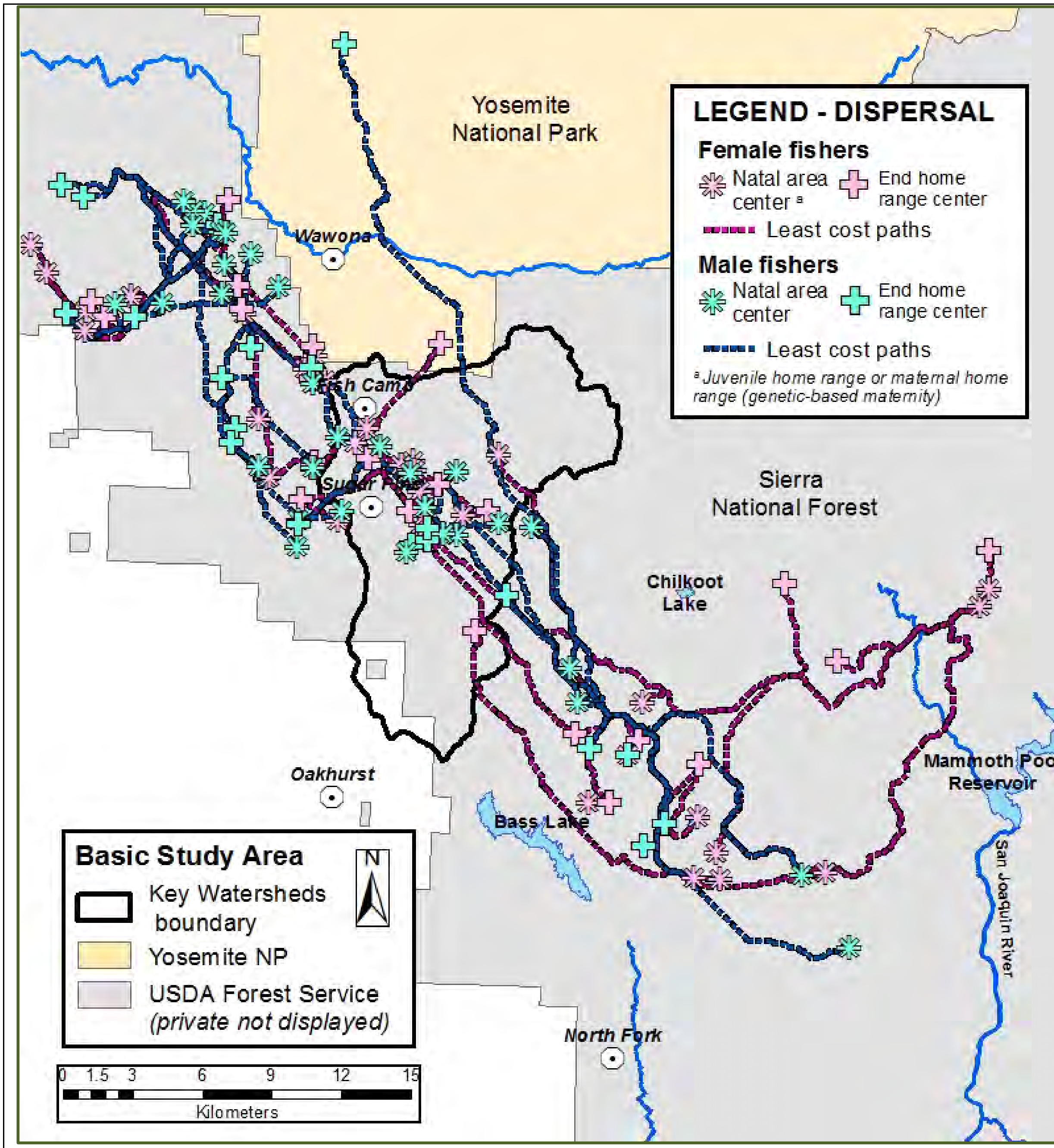


Figure D18: Estimated Least Cost Movement paths for young fishers (≤ 18 months) that were assessed for dispersal in the SNAMP Fisher study area from 2008 to 2013. Least cost movement path were developed as a more realistic way to assess fisher movements given that a number of landscape and habitat features are known avoided or restrictive to fishers as part of their overall natural history.

Young female fishers appeared somewhat more philopatric than male fishers, based on the proportion that moved less than the mean diameter of the annual home range for adult females in the study population) (Fig. D19). The pattern was not significantly different however (Pearson $\chi^2 = 1.12$, $P = 0.29$). Also, there was no statistical evidence that male fishers dispersed farther than female fishers when dispersal distances were scored based on two levels of philopatry and two levels of dispersal (Euclidean distance Likelihood ratio $\chi^2 = 3.89$, P = 0.27; Fig. D20). The same analysis using LCP distances visualized in Fig. D18 was also nonsignificant (LCP Likelihood ratio $\chi^2 = 1.87$, P = 0.60; Fig. D18). However, it was noteworthy from a genetic perspective that 67% of females were philopatric, compared to about 45% of young males (Fig. D20; Table D24).

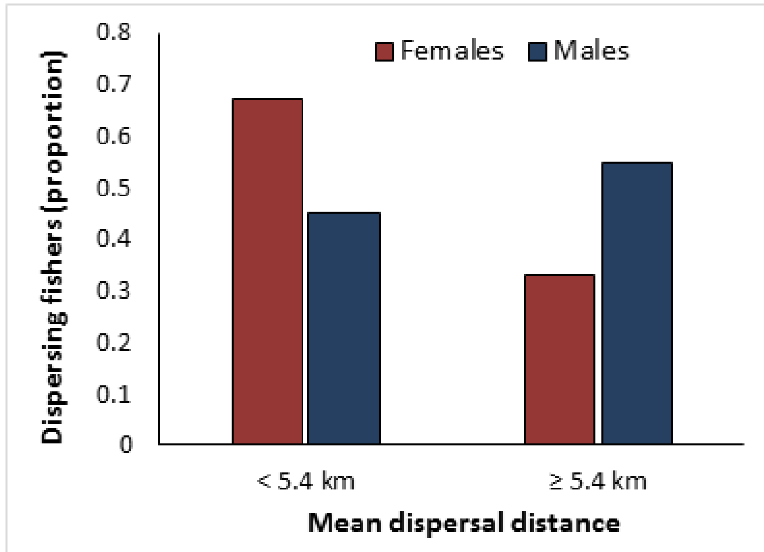


Figure D19: Proportion of female and male fishers that dispersed less than the diameter of the mean annual home range for adult female fishers (22.99 km; diameter = 5.401 km) in the SNAMP Fisher study area. Fishers that dispersed <5.4 km were considered as exhibiting philopatry, whereas those that moved >5.4 km were considered dispersers.

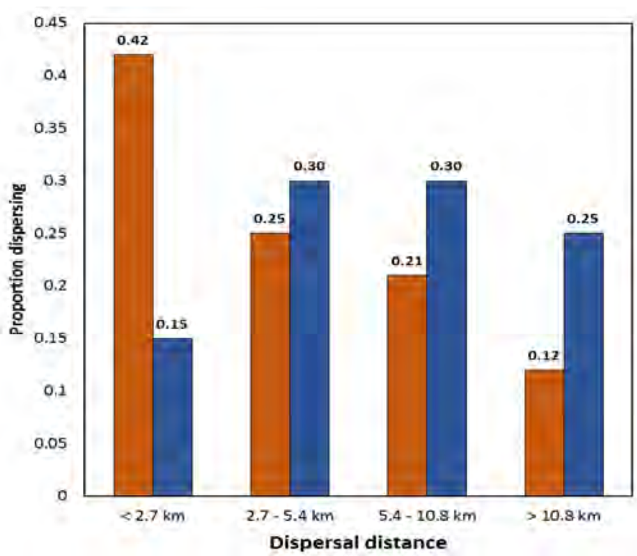


Figure D20: Plot of four different categories of dispersal distances for male and female fishers. Categories are based on dispersal distances of less than 0.5, 1.0, 1.5 and >2 times the mean diameter of the annual adult female home range in the study area. **Illustration D12 (right):** female fisher on the move.

Information on timing of dispersal is important for understanding whether juveniles captured in fall and winter were resident (born near the area of capture and initial locations), or if they originated elsewhere. Five dispersal events (20.8%) were initiated by juvenile fishers during fall to mid-winter (Table D24). Fourteen (58.3%) were initiated during the late winter to mid-spring time frame, and five started in late spring or summer (Table D24). Thus, nearly 80% of natal dispersal events occurred after February 5 when fishers were 11-13 months old.

Table D24: Information on periods of the year when juvenile fishers initiated transitional movements as part of natal dispersal[a], and numbers of young fishers (<18 months old) that were philopatric, or that dispersed more than 1 diameter of the mean adult female home range (22.99 km; diameter = 5.41).

Dispersal parameter	Female	Male	Total
Timing of dispersal initiation			
Fall to mid-winter (Oct 15 - Feb 4)	2	3	5
Late winter to mid-spring (Feb 5 - May 5)	7	7	14
Late spring or summer (May 6 - Sep 20)	2	3	5
Dispersal distance			
Short distance philopatric (< 2.7 km)[b]	10	3	13
Philopatric (2.7 km to 5.4 km)[c]	6	6	12
Medium distance dispersal (5.4-10.8 km)[d]	5	6	11
Long distance dispersal (>10.8 km)[e]	3	5	8

[a] Data on initiation of dispersal were for a smaller subset of juveniles (*n* = 22) that made transitional movement that were apparent based on aerial telemetry locations and home range models
[b] <0.5X diameter of mean adult female home range
[c] 0.5-1X diameter of mean adult female home range
[d] 1-2X diameter of mean adult female home range
[e] >2X diameter of mean adult female home range

Home Range Dynamics

We obtained and processed ≈ 35,365 location records from all sources (Table D3; Fig. D21) from October 2007 to December 2013. The location dataset was screened for errors and duplicates (same day, same animal, <8 hrs apart in time), after which approx. 32,370 of the locations were retained for detailed analyses of movements (home ranges) for 109 different fishers. Most of the location records were from aerial radiotelemetry (88%), which were less accurate than other types of locations in the database (Table D3).

Annual 95% fixed kernel home range areas differed by sex for all age classes (Fig. D22), with mean values ranging from 20.98 km^2 for juvenile females to 86.18 km^2 for adult males (Table D25).

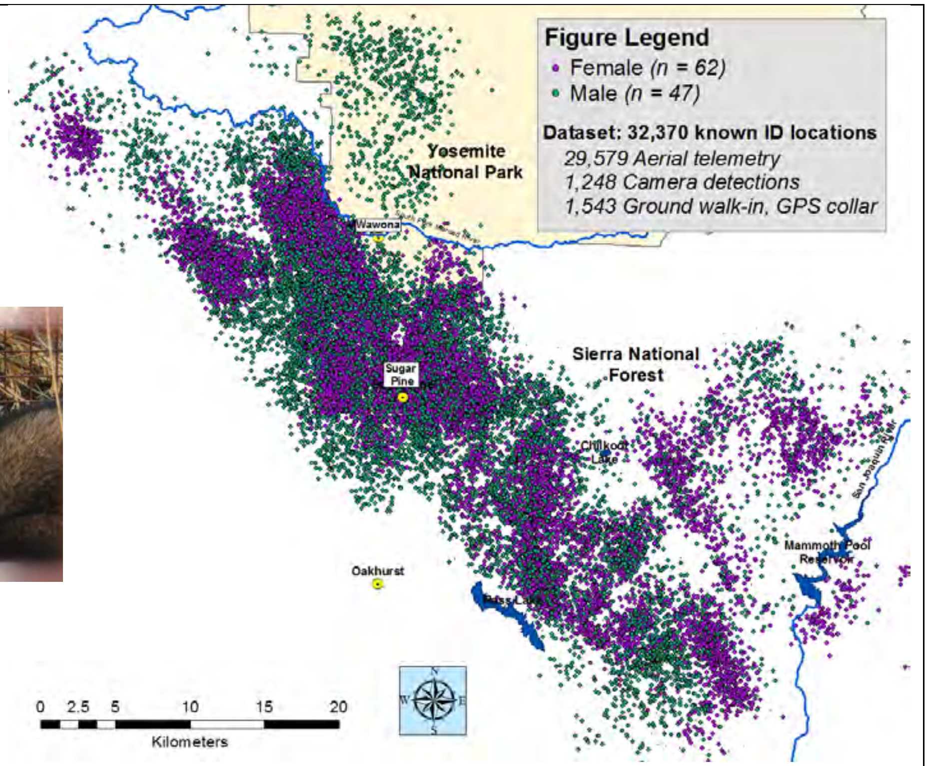


Figure D21: Distribution of location records used to evaluate movements and home range size for fishers that were radiocollared and monitored for survival from Dec 2007 to Dec 2013. **Illustration D13:** juvenile female fisher "bycatch" in a Bobcat Trap in 2011.

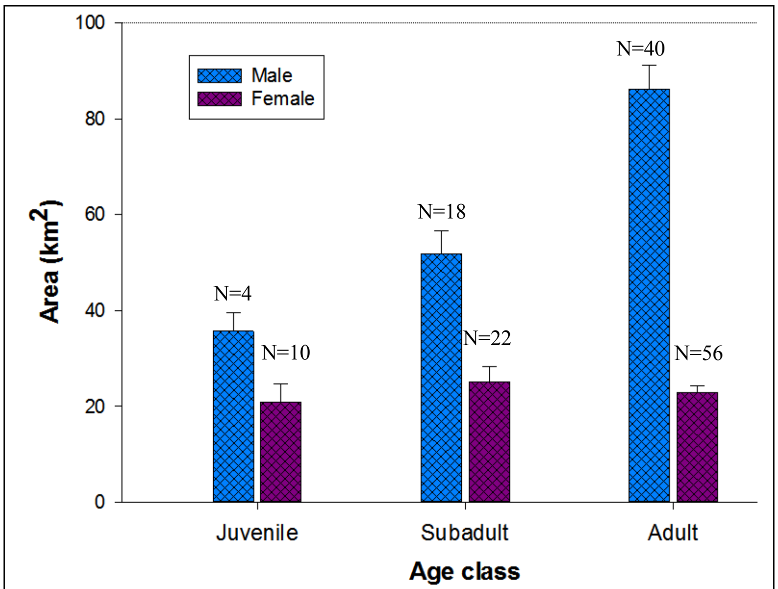


Figure D22: Mean annual home range size (SE bars) for male and female fishers from the SNAMP Fisher Project. More details, including size of core use areas are provided in Table D25.

Male fishers are larger in body mass and morphological size than females (Powell 1993), and size dimorphism was already evident between sexes when juvenile fishers were captured and measured in October and November (7-8 months old) (Table D30). Body size is closely related to home range size in mammals (Swihart et al. 1988), which helps explain the larger size of annual home ranges for all age classes of male fishers in this study (Table D25, Figure D17).

Although fishers have previously

been described as exhibiting intrasexual territoriality (Powell et al. 2003), we noted considerable overlap between the annual home ranges of adults of the same sex (Fig. D23). Annual home ranges

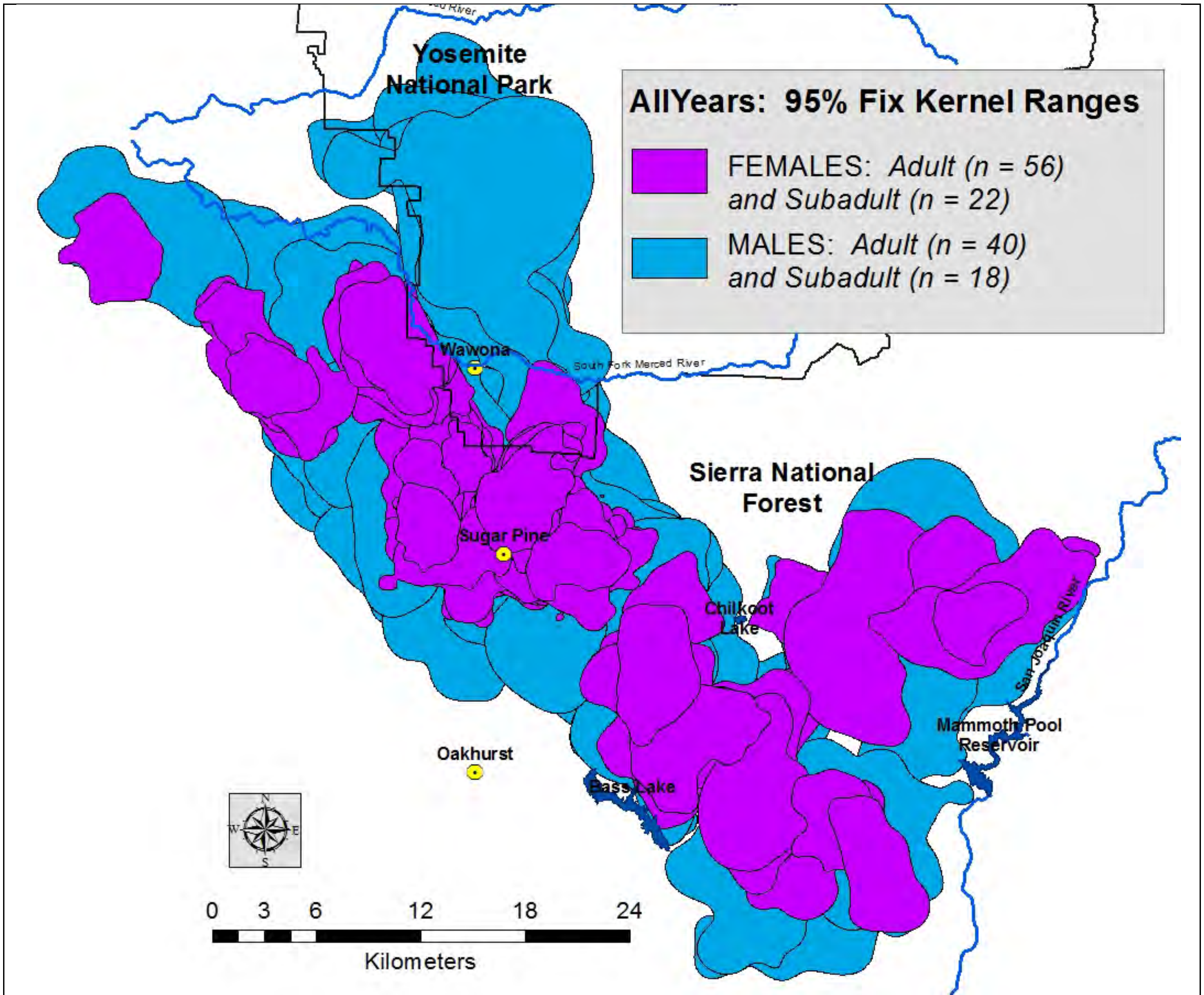


Figure D23: Annual home ranges for female and male fishers. The plot illustrates space use behavior where (1) the larger home ranges of males overlap home ranges of all females in the population, and (2) high overlap in space use among resident females at the 95% home range isopleth.

overlapped extensively among neighboring females, but overlap declined at the 70 or 60 percent fixed-kernel isopleths. These results suggest that female fishers maintain exclusive intra-sexual territories in their core use areas. Adult males move widely during the breeding season, resulting in widely overlapping use areas during spring (Popescu et al. 2014).

Home range sizes for fishers varied seasonally (Table D26; Fig. D24). Adult female home ranges were smallest during the spring, and reproducing females have smaller home ranges than non-reproducing females during this time when mothers are constrained to the den area and provisioning kits at den structures. Home ranges of denning females were smaller than non-reproductive female home ranges through the summer, before offspring become independent. Size of seasonal home ranges among adult male fishers was smallest during the summer and largest during the spring, reflecting wide movement associated with mating during March and April (Table D26). In contrast, seasonal home ranges of subadult males (likely non-reproductive) were largest during winter and relatively stable during spring, summer, and fall (Table D26). Excluding the spring season home range for adult males, home range size was largest for all age and sex classes of fishers during winter, likely due to scarcity of prey.

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Table D25: Mean annual and core use home range sizes ($km^2 \pm$ SE) for radio-tracked fishers at the SNAMP site, December 2007 to March 2013

Age/Sex	N	Annual[a]	Core use[b]
Juvenile (<12 months)[c]			
Female	10	20.98 ± 3.76	6.59 ± 1.18
Male	4	35.68 ± 3.83	11.86 ± 1.02
Subadult (12 to 23 months)			
Female	22	25.15 ± 3.20	8.59 ± 1.09
Male	18	51.85 ± 4.76	18.15 ± 1.66
Adult (≥24 months)			
Female	56	22.93 ± 1.36	7.78 ± 0.59
Male	40	86.18 ± 4.87	30.23 ± 1.78

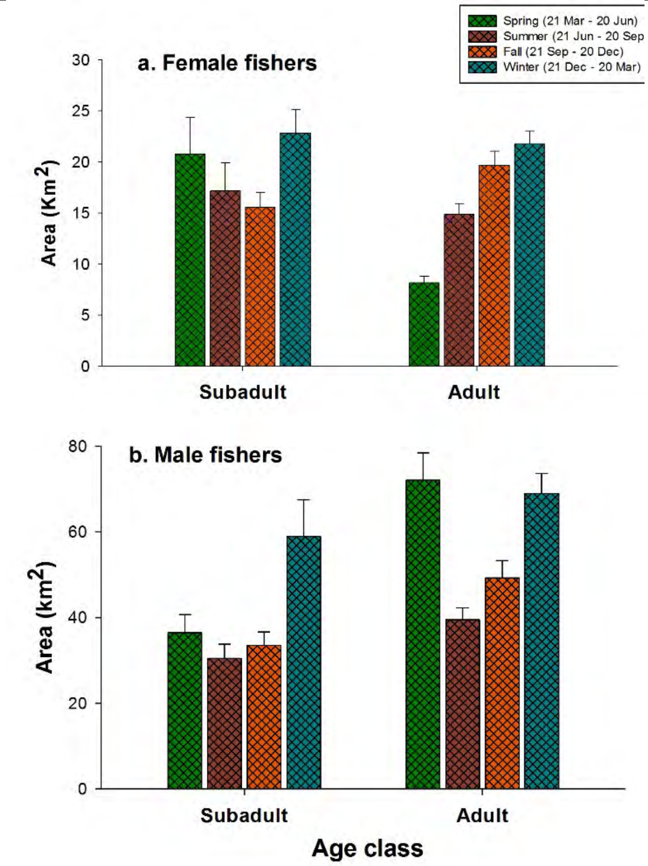
[a]Annual home ranges were estimated for fishers for which locations were available for ≥6 months between Apr 1 and Mar 31; number of location records used for annual home models ranged from 77 to 326.
[b] Core use home range estimated using methods described in Seaman and Powell (1990) and Bingham and Noon (1997); ~2/3 of the core use areas were the 60% isopleth, the remainder were the 70% isopleth.
[c] Home ranges for juvenile fishers monitored ≥5 months in Oct to Mar period; excludes fishers that exhibited dispersal movement behavior.

Table 26: Mean home range sizes (95% Fixed Kernel; $km^2 \pm$ SE) for fishers during four seasons[a] of the year. Data for animals radio-collared on the Sierra National Forest, CA from December 2007 to March 2013.

Age	*n*	Spring	*n*	Summer	*n*	Fall	*n*	Winter
Juvenile[b]								
Female					11	16.24 ± 2.52	17	18.72 ± 2.46
Male					4	20.10 ± 3.51	9	48.92 ± 12.73
Subadult[b]								
Female	17	20.78 ± 3.59	21	17.19 ± 2.73	21	15.61 ± 1.41	22	22.87 ± 2.28
Male	12	36.48 ± 4.26	13	30.49 ± 3.31	14	33.51 ± 3.15	19	58.90 ± 8.61
Adult								
Female[c]	59	8.18 ± 0.64	43	14.92 ± 1.02	50	19.70 ± 1.37	50	21.77 ± 1.28
Male	35	72.07 ± 6.39	34	39.49 ± 2.75	32	49.25 ± 4.04	37	68.91 ± 4.73

[a]Seasons were Spring: 21 Mar to 20 Jun; Summer: 21 Jun to 20 Sep; Fall 21: 21 Sep to 20 Dec; Winter: 21 Dec to 20 Mar.
[b] Excludes home ranges for fishers that exhibited movements associated with dispersal
[c] Includes home ranges for adult females that denned during the spring period of each year and excludes non-denning adults.

Figure D24: Plot illustrating size of the mean seasonal home range size (SE bars) for female (a) and male (b) fishers from the SNAMP Fisher Project. NOTE: the scale is different for the two plots, which helps to illustrate similarities in habitat use patterns for the different age and sex groups. More details are provided in Table 26. (**Illustration D14:** adult female fisher departing a black oak den tree in spring 2011).



SNAMP Fisher Management Indicators

Management indicator 1 (occupancy/presence of fisher detections in 1-km^2 grid cells within the Key Watersheds) ranged from a low of 53% in 2012-13 to a high of 76% in 2011-12 (Table D27). The index of fisher activity developed for Management Indicator 1 indicated that the estimated detection rate (detections/100 camera survey days) was highest in 2012-13 and lowest in 2010-11. It was unusual that the detection rate was highest in the same year that naïve occupancy was lowest (Table D27). Camera survey year 2012-13 was atypical in that many grid cells in the Key Watershed were surveyed during summer when detection rates are significantly lower (Popescu et al. 2014). It was therefore possible that the low occupancy for 2012-13 compared to most other years was related to timing of surveys.

Spatially, the distribution of fisher active grid cells changed among years (Fig. D25). Visually, there was the appearance that fisher detections were somewhat reduced in the Cedar Valley Project region of the Key Watersheds (center-south; Figs. D4, D29) immediately after project implementation.

There were also changes in fisher detections in the northeast region of the Key Watersheds, which may have been associated with mastication and other activities associated with the Fish Camp Project (Figs. D4, D29). Visual comparisons of presence/absence are not appropriate for detecting patterns or trend in occupancy (persistence, extinction, recolonization) related to forest management projects, however. Detailed, multi-year occupancy modeling analyses are underway, which include the proportion of each grid cell treated in each of six years by different forest management activities. Models also include other covariates potentially important for understanding detection histories and habitat use (e.g., season, elevation).

Table D27: Management indicator for fisher activity in the Key Watershed focal study area, based on the number of 1 km^2 grid cells in which fishers were detected during annual camera surveys [a]. Camera surveys were completed in each of six camera survey years (≈ Oct 15 to Oct 14) using our standard protocol.

Camera survey year	Grid cells surveyed	Grid cells with fisher detections	Naïve occupancy	Fisher detections per 100 survey days[c]
2007-08	122	71	0.582	11.4
2008-09	129	75	0.581	13.2
2009-10	127	75	0.591	15.2
2010-11	125	82	0.656	10.5
2011-12	128	98	0.766	14.2
2012-13	133	70	0.526	18.6

[a] Camera surveys were completed in each of six camera survey years (≈ Oct 15 to Oct 14) using a standard protocol.
[b] Number grid cells with fisher detections divided by the total number of grid cells surveyed; occupancy rate is not corrected for a survey-specific probability of detection < 1.0.
[c] Estimated as the number of functional camera survey days with fisher detections, but excluded camera days for grid cells with no fisher detections.

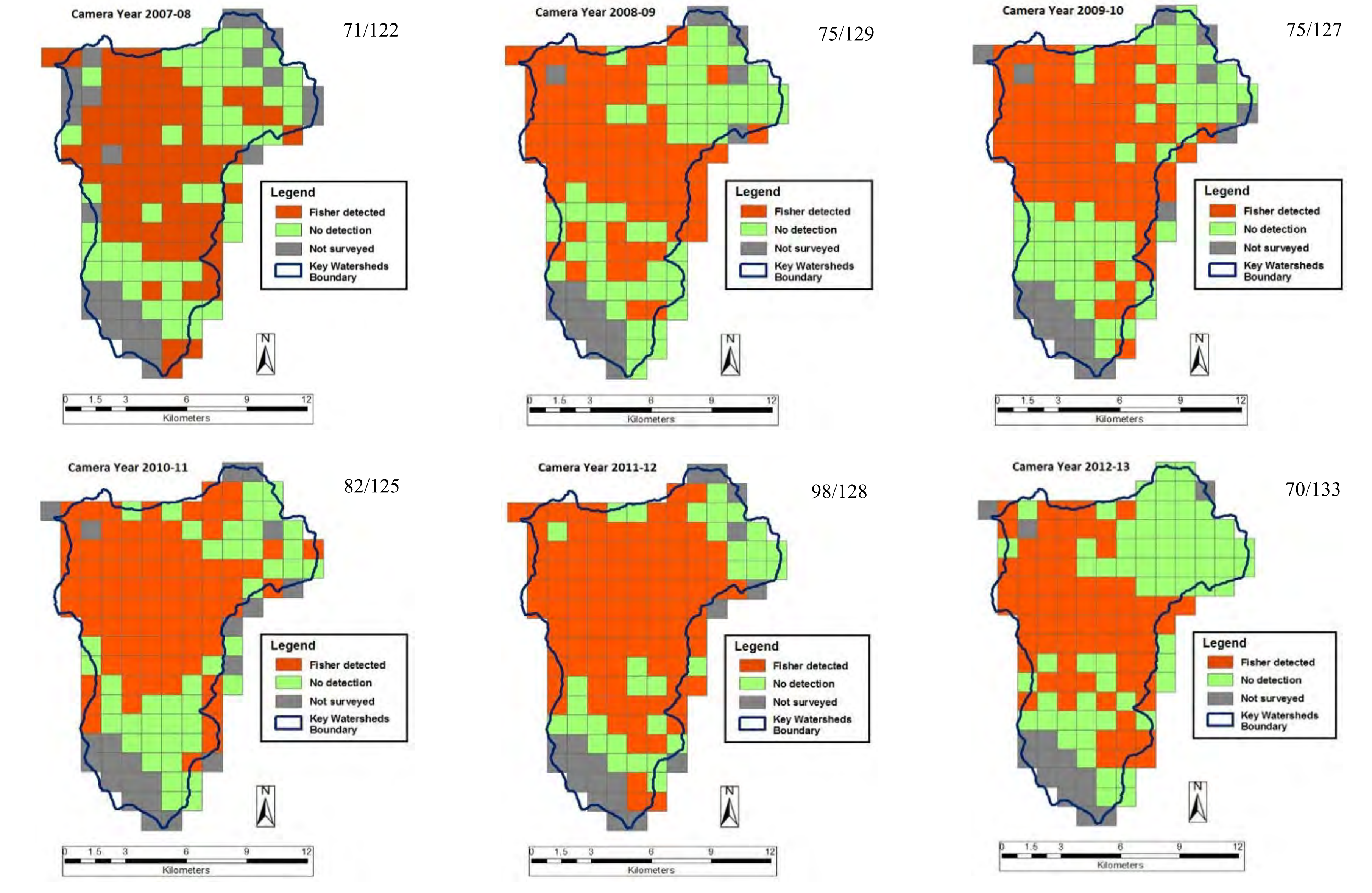


Figure D25: GIS plots illustrating change in patterns of occupancy for Management Indicator 1 for six camera survey years. Ratios indicate the number of grid cells with detections versus total grid cells surveyed. (Table D27 for details).

As an extension to Management Indicator 1, We also created an overall index of fisher activity for each grid cell based on mean number days in each camera survey year with fisher detections and the proportion of survey years with fisher detections (Fig. D26). The index illustrates that fisher activity was consistently high in the center and northwest region of the Key Watersheds and lowest from Cedar Valley southward (Fig. D26).

Table D28: Management indicator for the number of resident subadult and adult fishers using the Key Watershed focal study area for their various home range activities during Sep 1 to Mar 15 of each year.

Year	Females	Males	Both sexes
2007-08[b]			
2008-09	5.6	2.1	7.7
2009-10	6.1	1.4	7.5
2010-11	4.1	2.1	6.2
2011-12	4.0	2.9	6.9
2012-13	5.0	1.7	6.7

[a] Numbers are based on the sum of the proportion of each individual fishers' 95% fixed kernel home range included within the Key Watershed region.
[b] Because of the limited number of fishers radiocollared during the first project year (n = 7, before March 31, 2008) it was not informative to calculate this Management Indicator in that year.

Management Indicator 2 identified an average of 5.0 subadult or adult females and 2.0 subadult or adult males using the Key Watershed focal study area across all years, assuming all animals were identified and collared (Table D28). For both sexes combined, the number of resident fishers using the focal study area ranged from 6.2 to 7.7, and the variation among years was small (Table D28, Fig. D27).

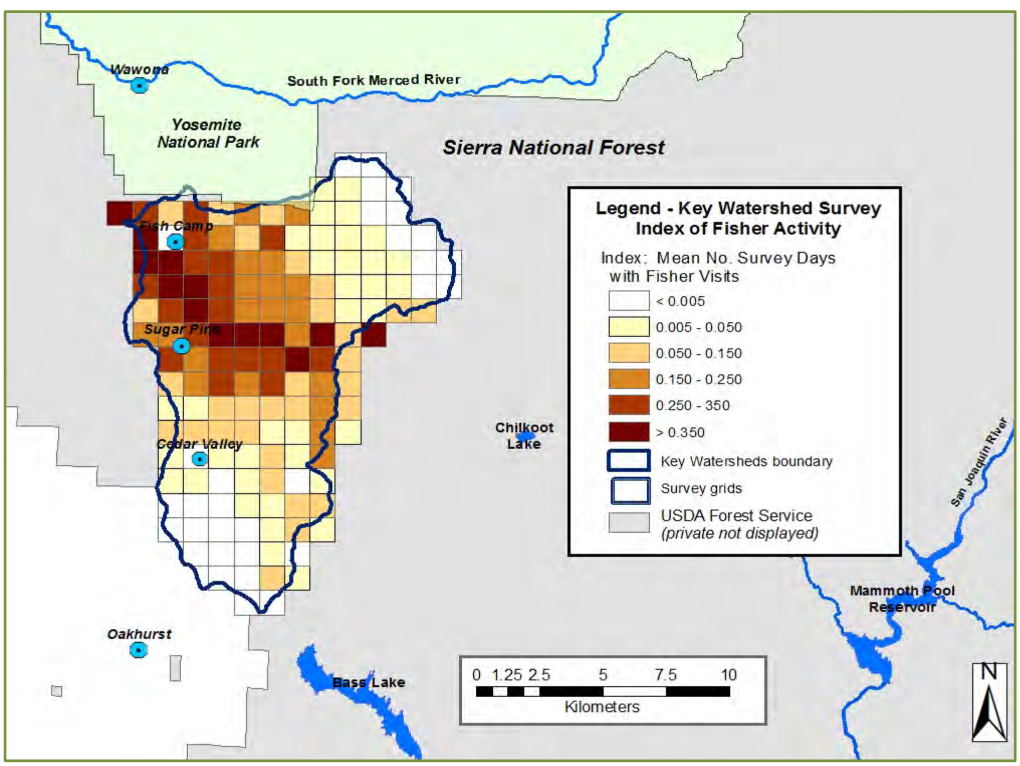
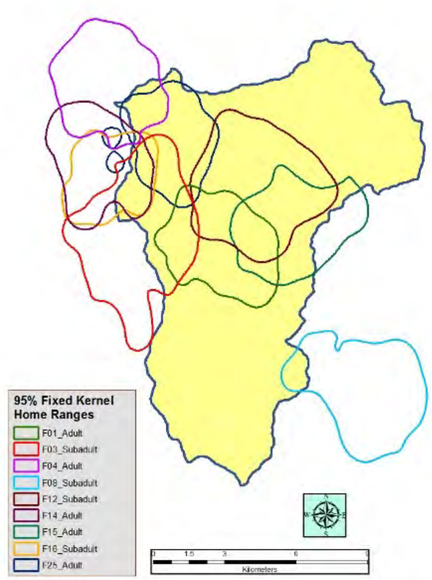
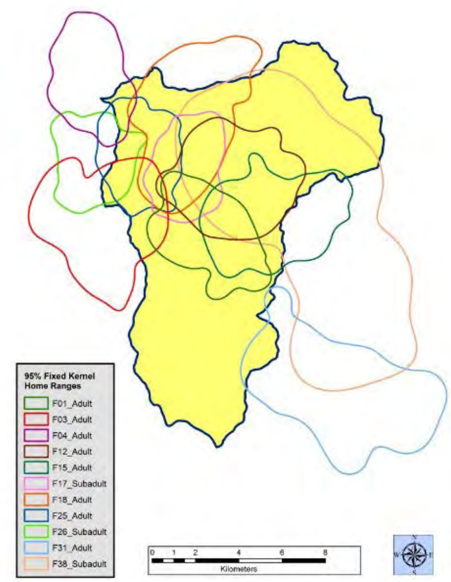


Figure D26: Index of fisher activity from repeat camera surveys completed in the Key Watersheds focal study area. The Index was calculated as the mean no. of days with fisher activity for years that the grid cell was surveyed/1 + proportion of surveyed years with fishers detections in the grid cell.

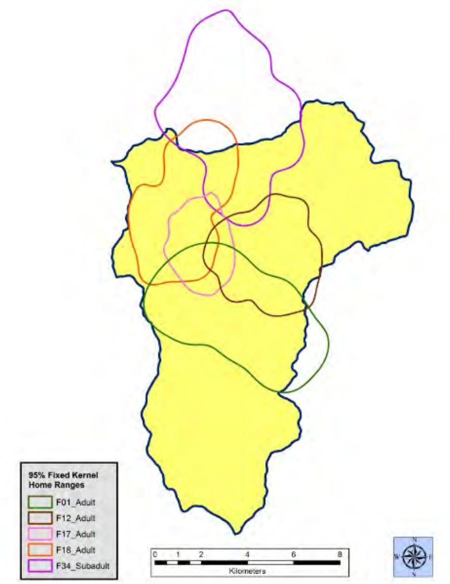
Population Year 2: *5.6 resident females*



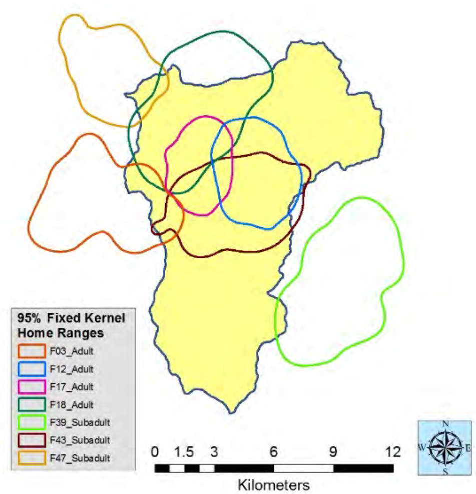
Population Year 3: *6.1 resident females*



Population Year 4: 4.*1 resident females*



Population Year 5: *4.0 resident females*



Population Year 6: *5.0 resident females*

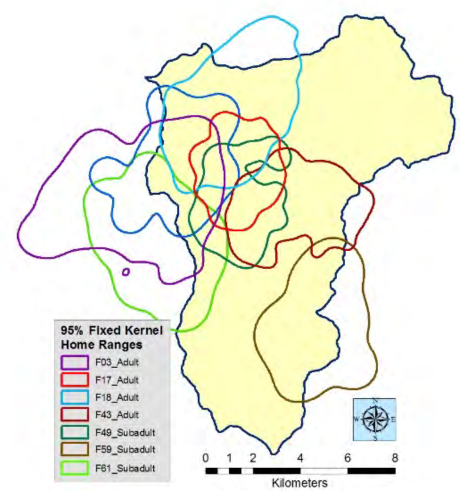


Figure D27: Estimated number of subadult and adult female fishers (resident females) with home ranges including portions of the Key Watersheds focal study area. Polylines are individual 95% fixed kernel home ranges based on location records during the Sep 1 to Mar 15 period during each population year (Apr 1 to Mar 31).

The original Management Indicator 3 was recast to estimate survival for adult female fishers for a sequence of 2-year groups of demographic data (data combined for Kaplan-Meier models of survival). For the first 2-year group, we included data for the small number of fishers (*n*=7) that were captured and radiocollared from mid December 2007 to March 31, 2008. We further summarized data on Juvenile and subadult female survival, and calculated point estimates of weaning reproduction and weaning litter size for each of the five 2-year groups (Table D18). Expanded Management Indicator 3 identified that adult female survival ranged from a low of 0.69 in Year group 3 to a high of 0.86 in Year group 4 (Table D29). Corresponding data on survival for juvenile and subadult females and data on reproduction identified that relatively low levels of survival and reproduction suggested the population was in decline ($\lambda < 1.0$) between 2008 and 2010, stable between 2010 and 2012, and increasing by 3-4%/year during 2012 to 2014 (Table D29). However the fact that 95% CI for λ overlapped 1.0 in all years indicates that these values should be interpreted carefully.

Table D29: Expanded Management Indicator 3 for adult female survival, including Leslie Matrix population growth rates for two year running average starting in 2008 and ending in spring 2014. Population years start April 1 and end March 31. Numbers in parentheses for survival are the 95% CIs based on Kaplan-Meier staggered entry survival analyses for the group of years identified.

Year group, Demographic rate	Juvenile	Subadult	Adult	λ[a]
1. 2007-08, 2008-09, 2009-10 [b]				
Survival, s(*t*)	0.76 (0.53-0.99)	0.47 (0.28-0.67)	0.81 (0.66-0.96)	0.87 (0.65-1.08)
2. 2009-10, 2010-11				
Survival, s(*t*)	0.8 (0.59-1.01)	0.67 (0.42-0.92)	0.70 (0.54-0.86)	0.88 (0.63-1.12)
3. 2010-11, 2011-12				
Survival, s(*t*)	0.74 (0.54-0.94)	0.89 (0.71-1.07)	0.69 (0.53-0.86)	1.00 (0.77-1.22)
4. 2011-12, 2012-13				
Survival, s(*t*)	0.80 (0.55-1.05)	0.73 (0.52-0.94)	0.86 (0.71-1.00)	1.04 (0.81-1.26)
5. 2012-13, 2013-14				
Survival, s(*t*)	1.0	0.73 (0.48-0.98)	0.74 (0.56-0.93)	1.03 (0.77-1.22)

[a] Population growth rate was estimated using the demographic parameters developed for each Year group in a Leslie-Matrix model formulation described previously. The range in values for λ was based on the 95% CIs for survival for each age class when producing fertility (F_i) rates using the equation $F_i = b_i Pi$, where *b(i)* was fecundity, and P_i was the age-specific survival rate (see Table D17).
[b] Year group 1 includes information for a small number fishers monitored for survival from late December to March 2008. All other year groups include two population years of data.

Fisher response to fuel management

Management disturbances and wildfire

Our analyses of FACTS and other extractive and restorative management activities revealed that the estimated area of forest disturbing activities that occurred in the study area was highest for restorative fuel reduction, moderate for logging, and lowest for managed burning and natural or human caused wildfires (Table D30). We estimated that there was an annual average 1.9% (SD 0.70) of the study area treated for restorative fuel reduction each year from 2002-03 to 2012-13, and 20.6% of the study area was disturbed by these activities in all 11 years. We estimated that there was an annual average of 1.1% (SD 0.70) of the study area with extractive fuel reduction each year from 2002-03 to 2012-13, and an estimated 12.1% of the study area was disturbed by logging in all 11 years. We estimated that there was an annual average of 0.25% (SD 0.28) of the study area with managed burning each year from 2002-03 to 2012-13, and an estimated 2.8% of the study area was disturbed by managed burns in all 11 years. Also, the combined area disturbed by all 3 management activities averaged 36.3 km^2 /year from 2002-03 to 2012-13, which represented an annual disturbance of 3.2%/year from SPLATS in the overall study area. Our fire variables included managed burns+forest fires, and we estimated that the annual average portion of the study area with managed burns+wildfires was 0.56%/year (SD, 0.83) from 2002-03 to 2012-13, and 6.2% of the overall study area was exposed to those disturbances in the 11 years. Also, in the 44 years from 1957 to 2001, we estimated that 130.2 km^2 (11.6%) of the overall study area was burned by wildfires.

Multi-season occupancy

The mean detection probability for fishers per 8-10 day survey period in the 361 multi-season survey grid cells was 0.31 (95% CI: 0.28, 0.37). Naïve inital occupancy among the multi-season grid cells was 0.66, whereas our modeled estimate for intial occupancy averaged across survey sites was 0.75 (95% CI: 0.59, 0.87). Mean annual persistence (1-extinction) was 0.87 (95% CI: 0.82, 0.91), whereas the annual colonization rate was 0.34 (95% CI 0.28, 0.42).

Our multi-season occupancy modeling identified a single best model for local colonization that included the intercept only (Table D31). Covariates *hazfuels.5*, *log.5*, and *burn.1.50* were included in 3 lower ranking colonization models with support, but the relative importance for each individual variable was≤ 0.35. We therefore fit an intercept-only colonization component in our subsequent evaluation of extinction covariates.

Table D30: Estimates of the areas (km^2) disturbed by logging activities, fuel reduction treatments, and managed burns in the Bass Lake District, Sierra National Forest, and southwestern Yosemite National Park in 11 camera survey years (Oct 15 to Oct 14) from 2002 to 2013 as well as wildfire activity in 5-year periods from 1957 through 2001.

	Restorative fuel reduction		Extractive fuel reduction		Managed burns + forest fire	
5 yr period or survey year	Area	Study area (%)	Area	Study area (%)	Area	Study area (%)
1957 to 1961					36.40	7.28
1962 to 1966					5.30	1.06
1967 to 1971					6.05	1.21
1972 to 1976					3.43	0.69
1977 to 1981					4.65	0.93
1982 to 1986					11.46	2.29
1987 to 1991					41.91	8.38
1992 to 1996					0.99	0.20
1997 to 2001					20.05	4.01
2002-03	23.7	2.10	11.6	1.03	3.5	0.31
2003-04	13.7	1.21	2.9	0.26	3.7	0.33
2004-05	13	1.15	7	0.62	4.3	0.38
2005-06	26	2.31	6.8	0.60	2.4	0.21
2006-07	34.5	3.06	13.1	1.16	5.3	0.47
2007-08	15.8	1.40	2.1	0.19	34.0	3.02
2008-09	29.1	2.58	11.4	1.01	3.8	0.34
2009-10	27.4	2.43	27	2.39	1.0	0.09
2010-11	12.4	1.10	13.8	1.22	6.1	0.54
2011-12	12.6	1.12	24.3	2.16	0.1	0.01
2012-13	23.9	2.12	16.1	1.43	5.7	0.50
Total area	*232.1*		*136.1*		*69.87*	

Our multi-season models evaluating local extinction identified a single top model including covariate *hazfuels.5* only (*hazfuel.5* relative importance = 0.98) (Table D31). There were 2 models with support that included the covariates *log.5* and *burn.1.50,* but the individual relative importance metrics for both were low. We found that fisher persistence (1 - extinction) was negatively associated with *hazfuels.5;* probability of persistence decreased by 27% as the proportion of the grid cell treated for cumulative restorative fuel reduction increased from 0 (occupancy = 0.89, 95%CI 0.85, 0.92) to 1.0 (occupancy = 0.65, 95%CI 0.46, 0.81).

Table D31: Candidate models for multi-season occupancy evaluations of colonization and local patch extinction for camera surveys for fishers in the Bass Lake District, and southwestern Yosemite National Park, California from Oct 2007 to Oct 2014.

Model, covariate	AIC	ΔAIC	AIC_{wt}	Cumulative AIC_{wt}	Covariate importance
Colonization					
intercept only	4211.96	0.00	0.34	0.34	
hazfuels.5	4213.15	1.19	0.19	0.53	0.35
log.5	4213.87	1.91	0.13	0.66	0.27
burn.1.50	4213.95	2.00	0.13	0.79	0.27
hazfuels.5 + log.5	4215.14	3.19	0.07	0.86	
hazfuels.5 + burn.1.50	4215.15	3.19	0.07	0.93	
burn.1.50 + log.5	4215.87	3.91	0.05	0.97	
hazfuels.5 + burn.1.50 + log.5	4217.14	5.19	0.03	1.00	
Extinction					
hazfuels.5	4205.26	0.00	0.50	0.50	0.98
hazfuels.5 + log5	4207.08	1.82	0.20	0.70	
hazfuels.5 + burn.1.50	4207.11	1.85	0.20	0.90	
hazfuels.5 + burn.1.50 + log.5	4208.96	3.70	0.08	0.98	
intercept only	4212.67	7.42	0.01	0.99	
log.5	4214.16	8.90	0.01	0.99	0.29
burn.1.50	4214.61	9.36	0.00	1.00	0.28
burn.1.50 + log.5	4216.05	10.80	0.00	1.00	

Integration

Fire modeling

Fuels treatments reduced the intensity of the simulated fire, as evidenced by the predicted flame lengths (Fig. D28). On the untreated landscape, 68.6%, 18.4%, 11.2%, and 1.8% of the study area experienced flame lengths of <2, 2-4, 4-8, and >8 m, respectively. In comparison, on the treated landscape, 75.1%, 16.4%, 7.5%, and 1.0% of the study area burned at these flame lengths. Collins et al. (2011) noted that flame lengths >2 m often corresponded to areas with crown fire initiation (i.e., torching). Thus, a greater proportion of the untreated landscape was exposed to potential crown fire (31.4%) than for the untreated landscape (24.9%).

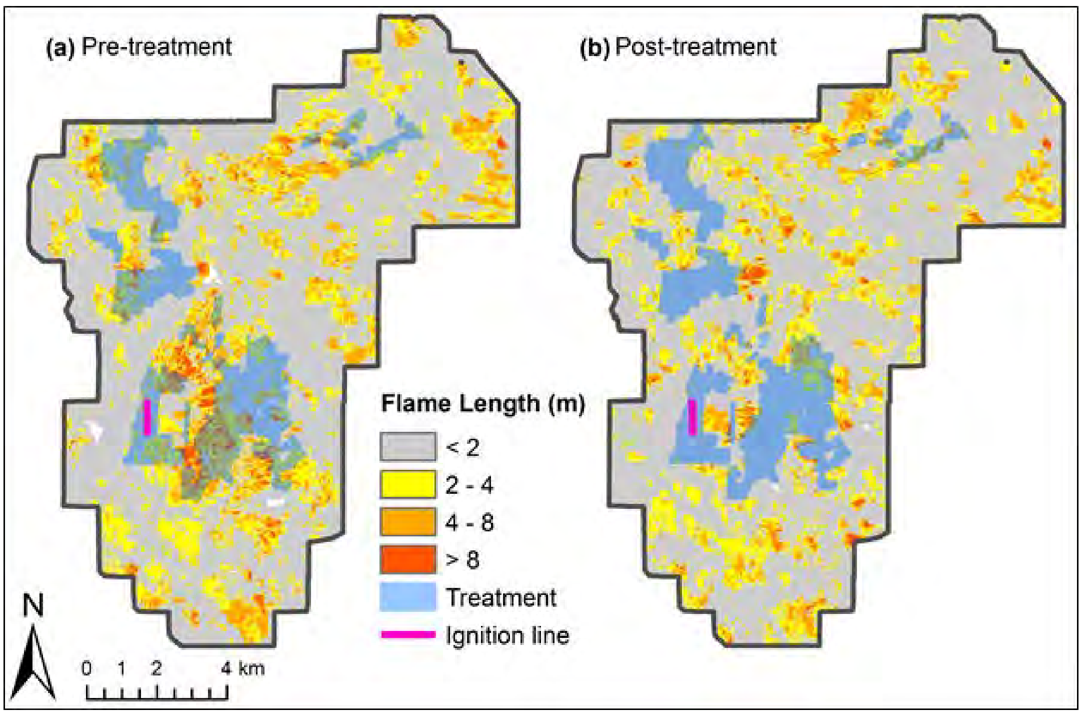


Figure D28: Flame lengths (m) of simulated fires at Sugar Pine on (a) untreated and (b) treated landscapes. We show the location of treatment polygons in (a) for ease of comparison, but treatments were not implemented in (a).

Assessing the effects of fire and SPLATs on fisher habitat

We found that SPLATs caused an immediate, slight reduction in potential fisher habitat. The entire area of the four watersheds was 35,103 ac (14,206 ha), and in year 0, there were 16,013 ac (6,480 ha) of potential fisher habitat on the untreated landscape compared to 13,938 ac

(5,641 ha) on the treated landscape (Fig. D29). In the absence of simulated fire, the amount of habitat steadily increased over time and was actually slightly greater on the treated landscape in years 10 and 30 (Fig. D2). When fire was simulated, SPLATs had a slight, positive effect on the amount of potential fisher habitat up to 30 years later. In year 30, there were 14,653 ac (5,930 ha) of potential fisher habitat on the untreated landscape compared to 15,254 ac (6,173 ha) on the treated landscape (Fig. D2).

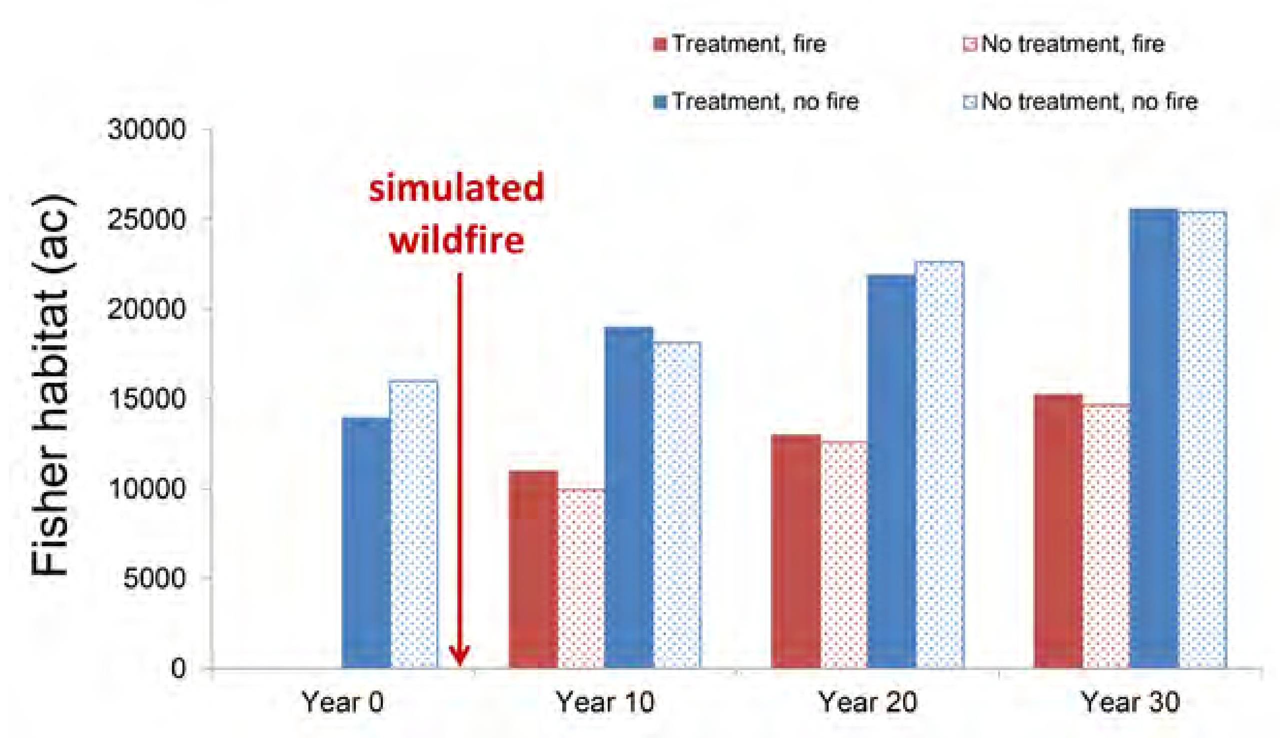


Figure D29: The amount of potential fisher habitat on the 35,103-ac Sugar Pine study area under four scenarios: 1) no SPLATs and no wildfire; 2) SPLATs and no wildfire; 3) no SPLATs and wildfire; and 4) SPLATs and wildfire. Year 0 for the “no treatment” scenarios was 2008, and year 0 for the “treatment” scenarios was 2013 (i.e., after SPLATs were implemented). Simulated fires occurred in year 0 for both the “no treatment” and “treatment” scenarios, and post-fire effects were first assessed in year 10.

Discussion

Reproduction and Basic Demography

Empirical data on reproductive rates and litter sizes are important for understanding the ability of a population to withstand challenges to survival, and to produce realistic estimates of population size in landscape level population models being developed for conservation planning (Lofroth et al. 2010, Spencer et al. 2011). The basic life history of fishers with regards reproduction is generally well known. Fishers have a long gestation period due to the reproductive strategy of delayed implantation (Powell 1993). Once the blastocyst implants in the uterine wall 10-11 months after fertilization of the egg, embryonic development resumes and ≈ 36 days later 1-4 kits are typically born.

Parturition for fishers in northern California typically occurs in mid to late March (Matthews et al. 2013a), and female fishers in the SNAMP Fisher population were no exception based on initiation of denning around March 22-31 (Table D7). Also, duration of denning for fishers in our study (≈ 70-75 days; Table D7), and cessation of localization to den trees in early to mid-June was typical of elsewhere in the western United States (Matthews et al 2013*a*, Aubry and Raley 2006). The mean denning rate for female fishers in the SNAMP Fisher study was 0.85 (Table D9), which was slightly lower than for fishers in the Hoopa Fisher Study in northern California (0.88; Matthews et al. 2013a), similar to in the Kings River Fisher Project area (0.86; R. Green, unpublished), and higher than in southern Oregon (0.59; Aubry and Raley 2006). The average weaning rate from SNAMP females in our study area (0.74; Table D9) was higher compared to the Hoopa Fisher Study (0.65; Matthews et al. 2013a), and in southern Oregon (0.44; Aubry and Raley 2006). However, as Matthews et al. (2013*a*) noted, reports of low weaning rates from some studies may be due to the difficulty in differentiating between subadult and adult females at first capture. We closely tracked most animals in the population from when they were juveniles until death, and ages for nine female fishers that were captured early in the study were determined by cementum annuli (Mattson's Laboratory, Milltown, MT; Poole et al. 1994).

Average litter sizes are larger for female fishers in eastern North America (2-4 kits/litter; Paragi et al. 1994, York 1996) compared to in the western United States where litter sizes are most commonly 1 or 2 kits (Aubry and Raley 2006, Matthews et al. 2013). The mean litter size from SNAMP Fisher (1.5 kits/litter, Table D10) was similar to reports from the Kings River Fisher Project (1.6; R. Green, unpublished), but lower than 1.8 kits/litter reported for the Sequoia National Forest, California (Truex et al 1988), 1.9 kits/litter from the Hoopa Fisher Study in northern California (Matthews et al. 2013a), or 1.8 kits/litter in southern Oregon (Aubry and Raley 2006).

Close monitoring of denning behavior by several current studies including SNAMP Fisher is providing insight on the risks female fishers encounter while attempting to reproduce. In the course of five denning seasons, we documented eight cases when females died or were killed with dependent kits in den cavities (Tables D15 & D16). Death of denning female fishers appears fairly common, based on reports from the Hoopa Fisher Study (*n* = 5; Matthews et al. 2013a), the USFS Kings River Study (*n* = 3; C. Thompson, unpublished data), the ongoing California Department of Fish and Wildlife, U.S. Fish and Wildlife, and Sierra Pacific Industries "Stirling Fisher Reintroduction Project" (*n* = 5; Powell et al. 2013), and the Olympic Fisher Reintroduction Project (*n* = 2; Lewis et al. 2012). Evidence that a significant number of females exhibiting denning behavior may die before weaning is important because weaning rates may be biased high unless estimates are based on complete monitoring through the duration of the denning period (Facka et al. 2013).

Denning Structures and Denning Habitats

Across their range in North America female fishers give birth to kits in cavities in live trees or snags (Paragi et al. 1996, York 1996, Weir et al. 2012, Zhao et al. 2012, Matthews et al. 2013a). Cavities provide protection from predators and inclement weather during the early spring to late spring when females are rearing their young (Weir et al. 2012). Most female fishers use more than one denning structure during a den season (range 1-6; Matthews et al. 2013a), and female fishers on the SNAMP Fisher study used an average of 2.4 different denning structures per den season (range 1-5), compared to 3.4 on the Kings River Fisher Study (R. Green, unpublished data), and 3.1 in northwestern California (Matthews et al. 2013). Female fishers may use more than one denning structure in a season for several reasons: to accommodate kit growth by moving to larger cavities, to reduce predation risk, as bobcats and mountain lions may discover a den location due to odors from the accumulation of urine and feces, to move closer to unexploited foraging areas, and to avoid exposure to feces and parasites that may accumulate in den cavities.

The lower mean number of den trees used by female fishers on the SNAMP Fisher study area compared to on the KRFP or the Hoopa Fisher Study may be related to disturbance by researchers. Biologists on both the KRFP and Hoopa Fisher studies climb den structures of most known denning female fishers to obtain kit counts, and they also attempt to extract kits from den cavities to measure body size, collect tissue samples, and to insert PIT tags for later identification (Thompson et al. 2011, Matthews et al. 2013*a,b*). This process requires presence of multiple biologists at the den tree for periods of 60 to 180 minutes. Although we occasionally ascended den trees in the SNAMP study area to obtain kit counts (n = 9 total den tree climbs during six denning seasons), most kit counts (≈ 90%) were obtained using images from 2-4 motion-sensing cameras placed around denning structures to monitor and chronicle denning activities remotely. Moreover, we noticed that some individual female fishers were sensitive to presence of technicians setting up den cameras (the process requires 30 to 60 min), based on short duration use of their denning structures after the first visit. Our den camera protocol was adjusted to minimize time needed to setup and service den cameras by quickly switching out memory cards and reviewing images away from the denning structure. Also, whenever possible, we did not approach den trees to service cameras when radiotelemetry identified presence of the denning female.

On the nearby Kings River Fisher Project where habitats are similar to the SNAMP Fisher study area, denning structures used by female fishers were most commonly black oaks (54%: 50% live, 4% snags). Overall, 91% of denning structures used on the Kings River Fisher Project were live trees. When repeat use den trees were counted just once, 43% of the unique denning structures used in the SNAMP Fisher study area were black oak trees (Table D11; 25%

live, 18% snags), and the remaining unique den trees were primarily incense cedar (33%) or white fir (15%). Only 56% of the denning structures used by female fishers in the SNAMP study area were live trees.

Weir et al. (2012) noted that trees need to have two very specific features for female fishers to use them for denning; some form of physical damage to the tree bole to provide access for decay organisms, and the damage must be of particular dimensions to provide females access to the interior of the tree while excluding predators (Lofroth et al. 2010). McDonald (1990) noted that live black oaks are susceptible to internal decay and probably last longer on the landscape than conifer snags. However, 26% of 125 unique den structures used by fishers on the SNAMP study site were in conifer snags (Table D11), suggesting they are not especially uncommon on the landscape in our area. Also, our observations of incense cedars and white fir suggested these two tree types were susceptible to the types of damage identified by Weir et al. (2012), particularly with regard to fire scars for cedar trees. Many of the cedar trees selected for use as den trees had basal fire scars, and the actual den cavities in both cedar trees and white fir were commonly associated with large branch break points.

Habitat and site characteristics immediately surrounding the denning structures are likely important for appropriate thermal conditions, availability of prey, and avoidance of predators (escape cover and concealment cover). Denning structures used in the SNAMP Fisher study area were generally larger than available trees and snags; mean DBH was relatively large (larger for conifers than the hardwoods) and mean tree heights were taller for live conifers compared to conifer snags or oaks in general (Table D12, Fig. D11). Canopy cover was greater than 80% in the vicinity of many den trees (Table D13). Shrub cover near den trees was variable, as was aspect (Table D13, Fig. D12). Most den trees had multiple large down trees/logs nearby, and concealment cover to the base of den trees averaged more than 45%. Although detailed analyses of data from fixed radius habitat plots have not been completed, habitat characteristics were developed from high resolution Lidar data for many den trees within the Key Watersheds. As part of collaborative work with the Spatial Team, Zhao et al. (2012) identified that fishers selected den sites with tall trees and steep slopes within a 10-m radius of the den tree, high forest structural complexity within 20 m, large tree clusters within 30 m, and high canopy cover and larger mature trees within 50 m. Finally, at the larger landscape scale, the mean elevation for denning structures used in the SNAMP Fisher study was 1,591 m (Fig. D11).

Fisher Survival and Cause-specific Mortality

The SNAMP Fisher study uncovered a wider diversity of causes of mortality for fishers in the region than anticipated (Table D16). In the first five years of the study many newly deceased fishers were recovered before the pilot and biologist in the airplane landed back at the Mariposa Airport, and almost always within six hours of the first indication that an animal's radiocollar was pulsing inactive. Although the fixed-wing aerial telemetry effort was expensive, the SNAMP study identified the first known death for the species caused by active infection with Canine Distemper Virus (CDV). We also recovered the fresh carcass of a fisher in spring 2009 that was subsequently determined to have died from exposure to anticoagulant rodenticides. This discovery prompted testing of archived tissue samples of dead fishers throughout California and in the western United States, leading to two peer-reviewed papers focused on the problem of rodenticides and other poisons used at clandestine marijuana grow sites on California public lands (Gabriel et al. 2012, Thompson et al. 2013). Moreover, an important and very real benefit from the investment in an aviation program in support of SNAMP Fisher has been the discovery that survival and reproduction of fishers in the Sierra National Forest is challenged by multiple factors external to, and not directly linked to current forest management activities.

Well over half of the individual fishers captured and radiocollared during the study had perished as of April 2014. Known sources of mortality in the SNAMP Fisher study population included high numbers of attacks by predators (interspecific killing; Wengert et al. 2014), roadkill deaths on Highway 41, infection by canine distemper virus (CDV; Keller et al. 2012) and *Toxoplasma gondii*, injury-induced starvation or septicemia, entrapment in a water tank, and acute toxicosis and hemorraghing caused by exposure to rodenticides (Gabriel et al. 2013, Thompson et al. 2013). Males made up the large majority of fishers that died of infectious disease, roadkill, and rodenticide exposure. On other hand, a greater proportion of females than males were killed by predators (Fig. D8), and work with collaborators from UC Davis indicated that males were less susceptible to bobcat predation than females (Wengert et al. 2014).

The diverse threats to survival that impinge on population growth in our study population are not unique to the southern Sierra Nevada region. Fishers in the Hoopa Valley in northern California area also died as a result of predation (Wengert et al. 2014), disease (Gabriel 2013), and rodenticides and other toxicants (Gabriel et al. 2013). Also, fishers that were reintroduced in northern California as part of the Stirling Fisher Reintroduction Project site have succumbed to predation, disease, and trauma from collisions with vehicles (Powell et al. 2013).

Survival estimators generally assume that live-trapping and radiocollars do not influence survival of study animals. Based on necropsies and extensive pathological tests completed on carcass remains of 47 dead fishers, no mortalities on the SNAMP Fisher study site were *directly* attributable to capture-related injury or radiocollars (e.g., strangulation or infection from chafing on the neck). However, one adult female fisher failed to survive the capture process to recovery and release. We acknowledge that the stress of capture and anesthesia contributed to the death of this female, though detailed pathological examination revealed that she was extremely emaciated and suffering from systemic infection from serious injury (laceration to the rostrum, fractured mandible, partially disarticulated lower jaw) prior to capture, and was unlikely to survive regardless of capture and handling (Gabriel 2013).

Analyses of live/dead status of individual fishers from SNAMP Fisher indicated that survival rates for adult females were within the range observed for other areas in the western United States. Overall survival for adult female fishers was 0.74, compared to 0.77 at the KRFP site (Sweitzer et al., In revision), which was higher than the 0.61 rate reported for a smaller sample of radio-collared female fishers on the Sequoia National Forest south of our study region (Truex et al. 1998). Aubry and Raley (2006) reported an adult female survival rate of 0.78 from a study in southwestern Oregon, whereas Higley et al. (2012) estimated adult female survival at 0.77 to 0.79 in northwestern California based on two different analytical methods (Known-fate models and Capture-Mark-Recapture, respectively). Jordan et al. (2011) reported a combined male-female adult survival rate of 0.94 for research completed in the KRFP study area in 2002-2004, however, their survival estimate was based on camera detections rather than radio-collared individuals, and the values reported were considered to have low precision related to tag loss and other factors.

In general, survival of male fishers on the SNAMP Fisher study area was consistently lower among all age and sex classes compared to females (Table D16). All year survival for SNAMP Fisher males ranged from 0.57 to 0.64, which was lower than adult male survival for fishers in southwest Oregon (0.85; Aubry and Raley 2006), in the Sequoia National Forest, California (0.73; Truex et al. 1996) and in northwest California (0.75 to 0.72; J. M. Higley unpublished report).

At the outset of the study we anticipated that survival would be lower for juvenile and subadult fishers compared to adults, as is typical for several species of mesocarnivores (Farias et al. 2005, Murdoch et al. 2010). Although survival among subadults trended lower than for adults, juvenile survival by both male and female fishers was often very similar or trended higher than adult survival (Table D16). We believe this is unlikely and an artifact of our inability to monitor juvenile survival during their first six months of life. Juvenile fishers are small in size and body mass during summer, and in our study and for most prior studies attempting to ascertain survival, juveniles were not fitted with radiocollars until fall or winter when many individuals within the cohort may have already perished (Facka et al. 2013). Even less is known about survival of kits when they are being provisioned inside den cavities (Lofroth et al. 2010). This is important because modeling efforts using empirically derived demographic parameters identify that population size and likelihood of persistence are relatively insensitive to juvenile survival (Buskirk et al. 2012, Spencer et al. 2011), potentially because juvenile survival is biased high.

The all year estimate of female survival on the SNAMP Fisher site was higher for juveniles, similar for subadults, and lower for adults compared to parameter values used by

Spencer et al. (2011) to simulate fisher population dynamics under different management scenarios for the southern Sierra Nevada region. Our combined year estimates of survival for juvenile females was 0.75 (value used by Spencer et al. = 0.50), 0.71 for subadult females (value used by Spencer et al. = 0.70), and 0.74 for adult females (value used by Spencer et al. = 0.90). Spencer et al. (2011) reported their model was relatively insensitive to juvenile and subadult survival (and other demographic parameters), but highly sensitive to adult female survival. Our empirically derived estimate for adult female survival (Table D17) was 15% lower than 0.90, which is important because Spencer et al. (2011) noted that a 5% decrease in female survival produced an approximate 18% reduction in the ending population size 40 years after model initiation. Similarly, 10% and 25% reductions in female survival resulted in 37% to 72% reductions in the ending population size. The significantly higher survival rate we estimated for juvenile females might ameliorate the reduced end year population size associated with 15% lower adult female survival. A new modeling effort is underway that will integrate new information on demographic rates from the SNAMP and KRFP study sites (Spencer et al. 2015).

Wildlife populations are exposed to a variety of mortality factors, which vary in importance towards limiting or impinging on population growth. Predation was clearly identified as the most important source of mortality on the SNAMP Fisher study area (Table D15, Fig. D8). Data on percent deviation in survival described by Sweitzer et al. (In revision) indicated that predation was more important than disease processes and human-linked factors for limiting fisher survival.

Disease in the form of canine distemper, toxoplasmosis, or pleururitus+pneumonia caused death of five radiocollared fishers during the SNAMP Fisher study, and an additional four fishers died of septicemia or starvation due to puncture wounds or other injury (Table D16; Gabriel 2013). The death of four fishers on our study by infection or starvation after suffering wounds or debilitating injury was not unusual or surprising for an animal as active as the fisher. Other long term studies of radio-collared fishers have reported similar circumstances (Aubry and Raley 2006, Weir and Corbould 2008).

Infectious disease has been a conservation concern for the two isolated populations of fishers in California since exposure to CDV and other pathogens was first documented in northern California in the early 2000s based on serological testing (Brown et al. 2008). Canine distemper is of special concern because of the abundance and widespread extent of mortalities among multiple species of rare and endangered carnivores has been reported (Timm et al. 2009, Williams et al. 1998, Woodroffe 1999). An outbreak, or localized epizootic of CDV that likely originated on the SNAMP site in spring 2009, and then spread south into KRFP during summer 2009 resulted in death of four fishers (Keller et al. 2012, Table D2). This disease-related mortality event confirmed that exposure by fishers to CDV and other agents of disease is of conservation concern for fishers in the western United States in general (Gabriel et al. 2012*b*), but particularly for the small, isolated population of fishers in the southern Sierra Nevada (Gabriel 2013). One fisher on the SNAMP study site was also confirmed to have died by complications after parasitic infection by *Toxoplasma gondii* (Gabriel 2013). Although exposure of fishers to *Toxoplasma gondii* was previously documented for fishers in North America (Larkin et al. 2011), this was the first case where complications from toxoplasmosis resulted in death (Gabriel 2013).

Wildlife-vehicle collisions may be a locally-critical mortality factor. Highway 41 is a very busy road locally referred to as the Wawona Road once it enters Yosemite National Park near the small community of Fish Camp. During the study period six non-collared fishers were also known to have been killed by vehicle strikes on Highway 41. Nine uncollared fishers were known to have been killed by vehicles along a 42 km stretch of Highway 41 between January 2008 to March 2013 in Yosemite National Park. Chow (2009) previously reported 4 fisher roadkill deaths between 1992 and 2004 along the same section of Highway 41, identifying this roadway as problematic for fisher survival in the region. Roadkill deaths of fishers have been reported in northern California as well, including two near Trinity Lake, (Truex et al. 1998), eight along paved highways in Humboldt and Siskiyou County (Gabriel 2013), and one in Butte County (Powell et al. 2012). In total, we are aware of 34 documented cases of fisher mortality by vehicle-strikes in California from 1992 to 2013 (Table D15). Moreover, seven fisher deaths were reported in western Washington state in association with the Olympic Fisher Reintroduction Project (Lewis 2014).

Our original prediction was that survival would be lowest during winter among each sex and age class. Sweitzer et al. (In revision) found that this prediction was not supported by the data, and that a disproportionate number of fisher deaths occurred during spring and summer. Increased mortality of fishers in this period is potentially related to exposure to second generation anticoagulant rodenticides, which is typically applied most heavily in the spring growing season. Expanded testing for anticoagulant rodenticides in archived tissues for fishers that died on our study before 2009, and for fishers that died on the Hoopa fisher study in northern California revealed that the majority of the animals had been exposed to anticoagulant rodenticides (>80%) and other toxicants being used in and around illegal marijuana grow sites on California public and tribal lands (Gabriel et al. 2012*a*). Ongoing investigations indicate that use of anticoagulant rodenticides at illegal grow sites is focused during spring and early summer when the marijuana plants are small and vulnerable to herbivory by rodents and insects (Gabriel et al. 2012*a*, 2013, Thompson et al. 2013). A total of eight fishers (three from SNAMP Fisher, five from the Hoopa fisher study in northern California) have now been documented as dying from exposure to rodenticides or other toxicants associated with marijuana grow sites (Gabriel 2013).

Another human-linked source of death for fishers in our study was entrapment or drowning in water tank. At the SNAMP site in spring 2008 we recovered the carcass of a non-collared fisher on the ground next to an open water tank (the cover had been ajar) where maintenance crews servicing the tank deposited the animal. Truex et al. (1998) and Powell et al. (2012) both reported deaths of single radio-collared fishers in abandoned water tanks at research sites in north central California, whereas Folliard (1997) recovered skeletal remains of eight fishers from an abandoned water tank on private timberlands in northwestern California. Finally, L. Davis (personal communication, Sept 7, 2013) reported the death of a radio-collared fisher that became trapped in a relatively short section of an upright culvert during a study of fishers in the Cariboo-Chilcotin region of British Columbia, Canada (Davis 2008). It appears that death of fishers by entrapment in water tanks and other human structures may not be uncommon. Folliard's (1997) 15 year old recommendation that abandoned water tanks on private and public forests in California be covered, or modified by inserting branches or poles so that fishers and other wildlife can self-rescue should be applied whenever possible.

Population Size and Density

Prior to this study there was limited information on the distribution and abundance of fishers at the north margin of their extant range in the southern Sierra Nevada. Despite many years of surveys with cameras and track plates, the lack of evidence of fishers north of Yosemite Valley suggested that the population in the SNAMP Fisher study area was likely sparse (low density). Also, there had been no indication that surplus animals were dispersing northward into suitable, but unoccupied habitat north of the Merced River (Spencer et al. 2011, Spencer et al. 2015). Moreover, reports of multiple roadkill fishers along Highway 41/Wawona Road between the south boundary of the park and the tunnel just north of Yosemite Valley suggested that dispersal and the overall population was being limited by deaths on that highway (Chow 2009).

Federal and state agencies are currently developing strategies to manage for long term viable populations of fishers in the southern Sierra Nevada, and six years of intensive investigation as part of the SNAMP Fisher study has recently produced the first estimates of abundance for the region. We estimated the size of the fisher population in the overall SNAMP study population at 48 to 62 individuals (Table D2). Narrow confidence intervals for the population estimates were likely due to the combination of a relatively high probability of detection (0.4 to 0.75) for our camera protocol when cameras were within the home ranges of radiocollared fishers (Popescu et al. 2014) (Table D2).

Mean annual population density for the three Subregions of the overall study area ranged from 0.072 to 0.097 fishers fishers/km^2, which was consistent with data from two previous studies of fishers in the High Sierra District of the Sierra National Forest, located 50 km south of our study site. Jordan et al. (2011) used a similar CMR design to estimate a density of 0.063-0.109 fishers/km^2 for the Kings River study area in 2002-2004. Thompson et al. (2013) used scat detector dogs and genetic detections in a spatially explicit CMR framework modified for variable search intensity to estimate a fisher density of 0.065-0.28 fishers/km^2 for the Kings River Fisher Project area in fall 2007. Thompson et al. (2013) emphasized that a modal density of 0.104 fishers/km^2 was the most appropriate point estimate developed from their research. At a research site on the Hoopa Valley Indian Reservation (Hoopa Fisher Study) in northern California, Higley et al. (2013) used CMR methods to determine that the density of fishers increased from 0.12-0.29 fishers/km^2 over 9 years from 2005-2013. In central Massachusetts, USA, Fuller et al. (2001) applied CMR models to camera sightings and determined fisher densities of 0.19-0.25 fishers/km^2. Considering the subset of studies that used CMR methods, the densities we estimated for the SNAMP Fisher study area are the lowest reported (Table D2).

As previously detailed, conservation planning is underway for fishers in the southern Sierra Nevada, including new modeling to estimate areas of suitable habitat for fishers in occupied "core" regions within the southern Sierra Nevada (Spencer et al. 2015). Our study area is within Habitat Core and Connectivity Area 5, for which the area of suitable habitat was estimated as 1,096 km^2 (Table D2, Spencer et al. 2015). We calculated the mean density and 95% C.I. for 12 area- and year-specific densities developed by our CMR modeling (Table D2; 0.085 fishers/km^2, 95% C.I. 0.073-0.097), and estimated that there were 93 (range 80-107) fishers in the Southern Sierra Nevada Habitat Core and Connectivity area 5.

In the context of similar data from other studies, the population of fishers in the Bass Lake Ranger District extending into southern Yosemite National Park is small, genetically limited (Tucker et al. 2014), and exists at a density that is lower than has been reported for any part of California or North America with the exception of boreal forest regions of northern British Columbia, Canada (Weir and Corbould 2006). Moreover, there are important challenges to the long term viability of fishers in the southern Sierra Nevada region as a whole, including periodic epizootics of canine distemper (Keller et al. 2012), exposure to poisons and other toxicants that directly and indirectly increase mortality (Thompson et al. 2013), and large, catastrophic wildfires capable of eliminating thousands of hectares of foraging and denning habitat in short periods of time (days or weeks; Final Update on 2013 Rim Fire: http://inciweb.nwcg.gov/incident/article/3660/21586/).

Dispersal and Home Range Movements

Information on dispersal provides important insight on how far individuals of a species may move on their own, which is valuable for understanding the potential that unoccupied but otherwise suitable habitat will be colonized or recolonized by the species without management intervention. For their body size, fishers appear to be relatively poor dispersers and large scale genetic substructure analysis supports this observation (Kyle et al. 2001). Fisher movement behavior appears to vary by age, sex, season, and habitat characteristics. Juvenile dispersal may vary widely, depending on habitat availability and landscape permeability.

Intensive monitoring of individual fishers by fixed-wing aircraft, in combination with an expansive trapping effort across the entire SNAMP Fisher study area provided insight on dispersal that would have been difficult to acquire otherwise. Microsatellite DNA analyses to identify maternity for many juveniles and some subadults further extended our inference to larger numbers of potential dispersers (24 females, 19 males).

We found limited evidence that natal dispersal was male-biased according to any of the typical metrics reported in the literature for this life history phenomenon, however the small samples size and wide range in dispersal distances precluded any robust statistical comparisons. Dispersal distances were not significantly longer for males (mean = 8.46 km) compared to females (4.89 km) based on either Euclidean distances or for more realistic Least Cost movement paths (Table D23, Figs. D17). There was no significant difference in the proportion of each sex that dispersed, or that remained philopatric (Fig. D13, Table D23), and, similar numbers of males (n = 5) and females (n = 3) undertook long distance dispersal movements from their likely natal areas (Fig. D14). Timing of dispersal in the SNAMP Fisher study population was focused during mid-February to July, and the longest distance dispersal event a female fisher in the population undertook was 22.3 km (44.1 by the Least Cost Path), compared to 36.2 km for a male (69.8 by the Least Cost Path)(Tables D28, D29). We did document dispersal by several fishers across landscape features previously identified as restrictive based on population genetics (Tucker et al. 2012, Wisely et al. 2004). Four fishers regularly moved across the Chiquito Ridge (via Shuteye Pass), and two male fishers transitioned across the San Joaquin River canyon.

Our data on dispersal differed from reports from southern Oregon and northwestern California. Aubry and Raley (2006) reported that mean juvenile male dispersal distance was 29 km, while the mean dispersal for females was 6 km. Dispersal distance in the Hoopa area of Northern California averaged 4.0 km (range = 0.8-18.0 km) for 7 females, and was 1.3 km for one male (Matthews et al. 2013a), however the authors noted that their focus on capturing adult females limited their ability to estimate male dispersal.

The maximum known dispersal distance for fishers from the literature was 100 km (York 1996), while the maximum observed movement of a translocated individual in unoccupied habitat was 163 km (Roy 1991). The relatively small number of long distance dispersal events noted during the six year SNAMP Fisher study suggests that long distance movements are uncommon and that the effective dispersal distance may be less than maximum dispersal capacity (Tucker et al. 2013).

Population Growth and Threats to Population Persistence

Estimates of λ for fishers derived from empirical data specific to the area of inference are rare for California, and absent for the southern Sierra Nevada. The All Year survival and empirically derived demographic rates produced a λ of 0.90 (range 0.77-1.22). While this point estimate suggests a negative growth rate, it was encouraging that the range for the all year population growth rate extended above 1.0 (Table D28). Elsewhere in California, Higley et al. (2013) integrated data on apparent survival from CMR models and data on reproduction in a series of random effects models to evaluate λ for fishers in the Hoopa Fisher Study. Two models produced λ estimates close to or greater than 1 (Both sexes, Females only; see Higley et al. 2013). Swiers (2013) used Robust Design models, software program POPAN, and Pradel models to develop information on demographic rates and population size for assessing whether removal of adult fishers from a population in northern California/southern Oregon for translocation elsewhere negatively affected population growth. Swiers' (2013) top ranked Pradel model produced a population growth rate of 1.06 (95% CI = 0.97-1.15), suggesting a stable or slightly increasing population after nine 'prime breeding adult' fishers had been live-trapped and removed from the population for translocation.

We identified several sources of mortality in the study population, and the indication of an overall negative population growth rate was in accordance with the fact that 60% of the 110 fishers that were radiocollared died (Table D16). The matrix model we developed was realistic and based on current knowledge of fisher life histories in California, but some demographic parameters were less well known than others. Survival of juvenile fishers during the three month period from mid-June to October is poorly known for our study, and for all other detailed studies of fishers in California (Facka et al. 2013). The estimate for juvenile female survival used in the matrix model was based on the 6-7 month period from October to March, which likely overestimated the number of juveniles recruited into the population. However, a basic sensitivity analysis indicated that the population growth rate was insensitive to variation in fertility for all age classes, and least sensitive to juvenile survival compared to subadult and adult survival.

SNAMP Fisher Management Indicators

Three management indicators we developed in 2008-09 as a mechanism for interim reporting on the status of fishers in the study area appeared useful when considered in relation to data on population growth rates and population density. Naïve occupancy in the Key Watershed was lowest in Camera survey years 2007-08, 2008-09, and 2009-10 when population growth rates were negative, but then increased in the later years when the growth rate was stable or positive (Tables D33, D35). The number of resident female fishers using the Key Watersheds did not track changes in population growth rates as closely, but the difference in the metrics was smallest in Population years 4 and 5 when the growth rate was negative or at approximate stasis. Adult female survival tracked change in population growth rate closely, declining from 2-year group 1 to 3, and then increasing afterwards (Table D28). Also, population density was in decline from 2007 to 2009, but then increased during Camera survey years 3 (2010-11) and 4 (2011-12) (Fig. D9), coincident with improved survival among juvenile and adult female survival (Table D28). We recommend that future long term studies consider developing similar metrics as a monitoring tool, and for interim reporting to interested stakeholders.

Fisher response to fuel management

Concerns that initiation of focused management to reduce fuel levels in Sierra Nevada mixed-conifer forests to correct for 90 to 100 years of fire suppression might have negative effects on habitat use by fishers were only partly supported by results from our study. Fisher occupancy was not negatively associated with either extractive or restorative fuel reduction, though disturbances from restorative fuel reduction had a negative effect on local scale persistence. We believe that the lack of a relationship between extractive fuel reduction and occupancy by fishers was most likely due to the combination of related factors. First, the overall extent of logging in our study in the 11 years from 2002 to 2013 was likely much lower than historically, and was likely further diminished by poor market conditions for wood products when a severe recession began in 2008. Second, estimates of annual disturbance from extractive fuel reduction among occupancy survey grid cells was equivalent to levels known "tolerated" by fishers elsewhere in the Sierra NF (Zielinski et al. 2013). Among the 361 multi-season survey grid cells, 172 of them encompassed 51.9 km^2 of disturbance from extractive fuel reduction, representing disturbances of 2.7%/year to grid cells with disturbance, and 1.3%/year among all grid cells. Zielinski et al. (2013) investigated tolerance of fishers to forest management in the High Sierra District, Sierra NF, and reported that 14 km^2 patches of forest habitat with high use by fishers typically had 2.6% of the areas disturbed by forest management annually, whereas 14 km^2 patches of forest with low use by fishers averaged 3.5% disturbance/year. Thus, the areas of extractive fuel reduction in our study were comparable to the 2.6% disturbance in high fisher use forest patches in the High Sierra District, Sierra NF, and below some threshold of $\geq$ 3.5% management disturbance/year that would likely cause fishers to use a different area (Zielinski et al. 2013).

Our occupancy modeling supported the hypothesis that fishers would reduce their use of local patches of forest exposed to proportionally higher levels of cumulative restorative fuel reduction. Nevertheless, an important prediction from our multi-season model was that small patches of forest with 100% of the area treated for hazardous fuels over 5 years would maintain an occupancy rate between 0.46 and 0.81, assuming no threshold effect. Thus, even at what would be considered a very high level of disturbance, fishers were not predicted to completely cease using those areas. For context, an occupancy rate of 0.65 for fishers elsewhere in the southern Sierra Nevada would be considered high, and a positive observation with regard to long term continuation of occupancy (Zielinski et al. 2013).

Ladder fuels, surface fuels, and thick layers of duff targeted under SPLAT-based management provide important habitat for squirrels and rodents preyed on by fishers, owls, and other forest carnivores (Kelt et al. 2013). Therefore, if forest patches that were extensively treated for restorative fuel reduction harbored less abundant prey, fishers may have shifted to nearby less disturbed forest patches to forage. The possibility that thinning of trees and shrubs, and reduction in understory surface fuels (coarse woody debris) has a negative effect on rodent populations has been considered by several recent studies. Meyer et al. (2007) reported reduced captures of northern flying squirrels in forest stands that were thinned and underburned in the High Sierra District, Sierra NF. Treated stands had reduced canopy cover and relatively shallow litter depth, and Meyer et al. (2007) considered that reduced abundance of flying squirrels may have been due to reduced abundance of truffles (fruiting bodies of hypogeous fungi) when duff was removed or reduced in depth after fuel reduction. Amacher et al. (2008) reported a negative effect of fuel reduction treatments (without follow-on burning) on abundance of deer mice, a positive effect of managed burning for deer mice, but no detectable effects of thinning or burning treatments on long-eared chipmunks, California ground squirrel, or brush mouse (*Peromyscus boylei*) at a research site in the north-central Sierra Nevada. Amacher et al. (2008) suggested that scattered debris and wood shards from rotary mastication was associated with the negative treatment effect for deer mice, whereas follow-on burning removed residual woody debris and thinned the understory, thereby improving conditions for deer mice. Converse et al. (2006) reported lower density or a trend for lower density for gray-collared chipmunks (*Neotamias canipes*) and Mexican woodrats (*Neotoma mexicana*) in thinned+burned forest stands in Arizona, which was linked to reduced coarse woody debris and reduced density of shrubs. In that same study abundance of deer mice increased after thinning+burning, and there was no treatment-linked change in abundance for golden-mantled ground squirrel (*Spermophilus lateralis*) (Converse et al., 2006). In restoration-treated ponderosa pine forests in Arizona, Lobeerger et al. (2011) found that winter season home ranges of tassel-eared squirrels (*Sciurus aberti*) disproportionately encompassed areas that had not been treated, whereas in other seasons their home ranges included a subset of the treated stands that retained relatively high canopy cover.

Bull and Blumton (1999) indexed presence of small mammals from track surveys in lodgepole pine (*Pinus contorta*) and mixed-conifer forest stands treated for fuel reduction in northeastern Oregon. We were unable to identify studies that reported responses of Douglas squirrels or dusky footed woodrats (*Neotoma fuscipes*) to fuel reduction treatments, but, based on habitat associations for *Neotoma* (Innes et al., 2007; Kelt et al., 2013), understory thinning and removal of surface fuels and coarse woody debris may reduce habitat suitability for woodrats (Lehmkuhl et al., 2006), whereas Douglas squirrels are a habitat generalist and less likely to be negatively impacted by fuel reduction (Coppeto et al., 2006, Herbers and Klenner, 2007; Kelt et al., 2013). Kelt et al. (2013) suggested that small mammal assemblages in the Sierra Nevada showed relatively limited responses to canopy thinning under current forest management. Abundance of small mammals in the Sierra Nevada has been linked to variation in production of cones or hard mast by pines and oaks (Coppeto et al., 2006; Wilson et al., 2008), which is important because a general pattern in many studies we reviewed was that inter-annual variation in abundance of small mammals was evident, and either masked or was much more important than the smaller effects introduced by fuel reduction-induced change to habitats (Converse et al., 2006; Coppeto et al., 2006; Amacher et al., 2008, Wilson et al., 2008; Kelt et al., 2013). We therefore conclude that reduced local scale habitat use by fishers in grid cells with larger areas treated for restorative fuel reduction was not likely to have been caused by changes in abundance of rodent prey from the associated disturbance to their habitats.

We consider it likely that the predicted 27% decline in persistence of local scale habitat use when cumulative restorative fuel reduction in a 1-km^2 grid cell approached 1.0 (100%) was associated with fishers shifting to forage in adjacent areas with less disturbance. A 27% decline in persistence of occupancy coupled with an annual colonization rate of 34%, suggests that fishers are flexible with regards local scale habitat use, and they might resume use of treated areas after several years of ecological recovery. Modeling analyses by Thompson et al. (2011) applied to a fisher occupied area of the High Sierra District, Sierra NF (Bear Fen) suggested that tree thinning (≤ 89 cm DHB) in mixed-conifer forest did not significantly reduce habitat suitability or "displace" habitat components from reference conditions in home ranges of resident female fishers. Based on these results from a nearby area in the Sierra NF, we believe it likely that fishers in our study area are likely to resume using forest patches treated for restorative fuel reduction within a few years of extensive disturbance. Also, fishers are known to adjust space use to avoid disturbed areas within their home ranges. Garner (2013) reported that resident fishers included areas treated for extractive+restorative fuel reduction in their overall and core home ranges in proportion to availability on the overall landscape. At the finer scale of individual locations, Garner (2013) found that those same resident fishers avoided using areas within ≈ 200 m of fuel treatments. We interpret this result as consistent with ours; fishers were predicted to continue using 1-km^2 patches of forest with more extensive cumulative disturbance by fuel treatments, but at a reduced level compared to areas with less disturbance. Finally, our assessment of how fishers responded to forest management was at the scale of 1-km^2 patches of forest, which was small in relation to resident adult female (≈ 23 km^2) and resident adult male (≈ 86 km^2) home ranges in our study area. If a 1-km^2 patch of habitat within the home range of a resident female fisher was 100% treated for fuel reduction of any type, 95.7% of that animal's home range could remain available for normal levels of foraging, contingent on SPLATs being dispersed on the landscape and not locally concentrated as appears typical (Modhaddas et al., 2010).

Integration

We found that the SPLATs at Sugar Pine slightly reduced simulated fire behavior and resulted in greater amounts of projected fisher habitat up to 30 years after the fire. In the absence of simulated fire, we found that the SPLATs had an immediate, negative effect on the amount of fisher habitat, but SPLATs did not generally have a negative effect on fisher habitat when we modeled future forest growth for 30 years. In all scenarios, the differences between the treated and untreated landscapes were small.

Our results were in general agreement with prior findings. Thompson et al. (2011) performed an analogous study to ours, in which they modeled fire and forest growth under treatment and no treatment scenarios and assessed fisher habitat suitability in the southern Sierra Nevada. They projected that fuels treatments had slight, short-term negative effects on fisher habitat, but provided significant protection in the event of fire and also extended the lifespan of current functional habitat. Truex et al. (2013) suggested that less fisher resting habitat was present immediately after mechanical fuels treatments were implemented in the Sierra Nevada. However, fishers consistently used areas in the southern Sierra Nevada where some timber harvest had occurred, so it may be possible to implement fuels-reduction treatments at an extent and rate that achieves fire-hazard-reduction goals (Zielinski et al. 2013).

As we noted in Appendix C for the California spotted owl, the net benefits of SPLATs for the Pacific fisher will depend upon the true, but unknown, probability that high-severity fire effects will occur on a given portion of the landscape. However, future probabilities for specific fire behaviors (e.g., crown-fire initiation) are difficult to estimate, and it is therefore difficult to quantify trade-offs associated with SPLATs in absolute terms (Finney 2005). We further note that the SPLATs which were implemented at Sugar Pine appeared to have relatively modest impacts on forest structure and simulated fire behavior, and that it may be necessary to evaluate additional SPLATs of different intensities over a larger scale to fully assess the effects of SPLATs on fisher habitat. Nonetheless, we have no reason to believe that Forest Service managers should alter their current policy of avoiding the placement of SPLATs near known fisher denning sites (U.S. Forest Service 2004) because these sites have significant biological importance for this species.

Management Implications of Findings from SNAMP Fisher

Fishers have been the focus of systematic monitoring in the southern Sierra Nevada by track plates, hair snares, and cameras since the mid-1990s (Truex et al. 1998, Zielinski et at al. 2005, Jordan 2007). Analyses of baited track plate detection histories from 2002 to 2009 for the entire southern Sierra Nevada fisher population found no evidence that the population trajectory for fishers in the area has been significantly positive or negative, based on constant and positive persistent values (Zielinski et al. 2013). In contrast, Tucker et al. (2014) suggested that the fisher population in the SNAMP Fisher study area was produced by a significant post-1900s northward population expansion involving dispersal of animals from south of the Kings River. Tucker et al. (2014) reported evidence of 'strong genetic clustering' to the north of Little Shuteye Peak (part of a high elevation ridge that forms the east boundary of Subregion 2 in our study area; Fig. D5), which, along with evidence for other small genetic clusters, was suggestive of multiple founder events associated with contemporary population expansion. Data from track-plate surveys in the Sierra National Forest in the early 1990s rarely detected fishers (Zielinski et al. 1995, 2005), which suggested a very sparse population in the SNAMP Fisher study area, compared to the more recent surveys in 2002-2009 (Tucker et al. 2014). Tucker et al (2014) postulated that very few fishers were present in the SNAMP Fisher study area prior to the 1990s, and that an expansion that occurred only during the last 20-25 years produced the population in this region.

Genetic data are not typically used to make inferences about population processes operating over extremely short periods in evolutionary time. The genetic analyses of Tucker et al. (2014), and the large increase in fisher detections in the region encompassing our entire study area between the early 1990s and 2002-2009 (Zielinski et al. 2013), suggest that a significantly positive population growth rate would be a requirement for understanding the current distribution and abundance of fishers in the SNAMP Fisher study area. During the period from 2007 to 2014, our results suggest that the fisher population in this region has not been experiencing consistently positive or significant population growth (Table D18).

The suggestion of an overall negative population growth rate, the low density, and the relatively small estimated number of fishers in Fisher Core Habitat area 5 (n = 93, range 80-107), warrants concern for the long term viability of fishers in the region. Any small population will be at high risk to stochastic events such as disease and large perturbations to critical habitats (e.g., forest fires or drought; Noss et al. 2006), and genetic limitation resulting from genetic drift after founder events (Tucker et al. 2014) will hinder population recovery and expansion (Reed et al. 2003). Minimum viable population size has been under debate (Shoemaker et al. 2013, Reed and McCoy 2014), but at <500 total individuals (Spencer et al. 2004), the current southern Sierra Nevada fisher population will likely require active management and conservation measures to maintain a positive growth rate across its entire range. The observed variation in fisher abundance and rates of population growth in the SNAMP Fisher study area reaffirms the vulnerability of the small, isolated population to external threats (Spencer et al. 2015), especially wildfires that are likely to increase in frequency and intensity with climate change (Bonan 2008, Safford et al. 2012). Moreover, our study spanned a limited period of six years when multiple threats to fisher survival within the study area were identified and during which three large wildfires further isolated the population by significantly reducing the availability of suitable habitat immediately to the south and north of the study site. We recommend continuous monitoring of the status of fisher populations in the southern Sierra Nevada region. It will be necessary to mitigate for major threats to fisher survival while maintaining contiguous expanses of suitable fisher habitats, and detailed analyses using realistic and empirically developed data on population parameters are necessary for evaluating the long-term viability of fishers in the southern Sierra Nevada. Data developed from the SNAMP Fisher study have provided important new insights on the status of a fisher population at the northern margin of their current distribution in the southern Sierra Nevada Range, which will be useful towards developing a comprehensive conservation strategy for fishers in California.

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Literature Cited

Ager, A. A., B. Bahro, and K. Barber. 2006. Automating the fireshed assessment process with ArcGIS. Pages 163–168 *in* P. L. Andrews and B. W. Butler, editors. Fuels management–how to measure success: conference proceedings, March 28-30, 2006, Portland, Oregon. Proceedings RMRS-P-41. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA.

Amacher, A. J., Barrett, R. H., Moghaddas, J. J., Stephens, S. L., 2008. Preliminary effects of fire and mechanical fuel treatments on the abundance of small mammals in the mixed-conifer forest of the Sierra Nevada. Forest Ecology and Management, 255, 3193-3202.

Arthur, S. M., T. F. Paragi, and W. B. Krohn. 1993. Dispersal of juvenile fishers in Maine. The Journal of Wildlife Management 57:868-874.

Arthur, S. M., and W. B. Krohn. 1991. Activity patterns, movements, and reproductive ecology of fishers in southcentral Maine. Journal of Mammalogy 72(2):379-385.

Arthur, S. M. and T. E. Paragi. 1993. Dispersal of juvenile fishers in Maine. Journal of Wildlife Management 57: 868-874.

Aubry, K. B., and C. M. Raley. 2006. Ecological characteristics of fishers (*Martes pennanti*) in the southern Oregon Cascade Range. USDA Forest Service, Pacific Northwest Research Station, Olympia, Washington, USA.

Aubry, K. B., C. M. Raley, S. W. Buskirk, W. J. Zielinski, M. K. Schwartz, R. T. Golightly, K. L. Purcell, R. D. Weir, and J. S. Yaeger. 2013. Meta-analysis of habitat selection by fishers at resting sites in the Pacific coastal region. Journal of Wildlife Management 77:965-974.

Berger, K.M. and E.M. Gese. 2007. Does interference competition with wolvers limit the distribution and abundance of coyotes? Journal of Animal Ecology 76: 1075-1085.

Bingham, B. B. and B. R. Noon. 1997. Mitigation of habitat “take”: Application to habitat conservation planning. Conservation Biology 11: 127-139.

Bonan, G. B. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science 320: 1444-1449.

Bowman, J., Donovan, D., Rosatte, R.C., 2006. Numerical response of fishers to synchronous prey dynamics. Journal of Mammalogy, 87, 480-484.

Boroski, B.B., R.T. Golightly, A.K. Mazzoni, and K.A. Sager. 2002. Fisher research and the Kings River sustainable forest ecosystems project: current results and future efforts. Pp. 143-154 *In* USDA Forest Service, Pacific Southwest Research Station, Albany, CA. General Technical Report PSW-GTR-183.

Brown, R. N., M. W. Gabriel, G. M. Wengert, S. Matthews, J. M. Higley, and J. E. Foley. 2008. Pathogens associated with fishers. Pages 2-48 *in* Pathogens associated with fishers (*Martes pennanti*) and sympatric mesocarnivores in California. Final Report submitted to the USDI Fish and Wildlife Service, Yreka, California, USA.

Bull, E. L., Blumton, A. K., 1999. Effect of fuels reduction on American martens and their prey. USDA Forest Service Pacific Northwest Research Station, PNW-RN-539, Portland, OR, USA.

Burnham, K. P, and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, NY.

Buskirk, S. W., L. L. McDonald. 1989. Analysis of variability in home-range size of the American marten. Journal of Wildlife Management 53: 997-1004.

Buskirk, S. W., J. Bowman, and J. H. Gilbert. 2012. Population biology and matrix demographic modeling of American Martens and Fishers. Pages 138-135 *in* K. B. Aubry, W. J. Zielinski, M. G. Raphael, G. Proulx, and S. W. Buskirk, editors. Biology and Conservation of Martens, Sables, and Fishers: A New Synthesis. Cornell University Press, Ithaca, New York, USA.

California Department of Fish and Game. 2008. California Interagency Wildlife Task Group. CWHR version 8.2 personal computer program. Sacramento, CA. <http://www.dfg.ca.gov/biogeodata/cwhr/>.

Center for Biological Diversity (CBD) website. 2013. http://www.biologicaldiversity.org/programs/biodiversity/species_agreement/#timeline.

Chepko-Sade, D. B., and Z. T. Halpin. 1987. Mammalian dispersal patterns: the effects of social structure on population genetics. University of Chicago Press, Illinois.

Chow, L. 2009. A survey for fisher in Yosemite National Park 1992-1994. Transactions of the Western Section of the Wildlife Society 45:27-44.

Clobert, J., E. Danchin, A. A. Dhont, and J. Nichols. 2001. Dispersal—causes, consequences and mechanisms of dispersal at the individual, population and community level. In: Danchin, E, A. A. Etienne, A. A. Dhondt, and J. D. Nichols, editors. Dispersal. Oxford University Press, Oxford.

Collins, B. M., S. L. Stephens, G. B. Roller, and J. J. Battles. 2011. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. Forest Science 57:77–88.

Collins, B. M., S. L. Stephens, J. J. Moghaddas, and J. Battles. 2010. Challenges and approaches in planning fuel treatments across fire-excluded forested landscapes. Journal of Forestry 108:24-31.

Collins, B. M., H. A. Kramer, K. Menning, C. Dillingham, D. Saah, P. A. Stine, and S. L. Stephens. 2013. Modeling hazardous fire potential within a completed fuel treatment network in the northern Sierra Nevada. Forest Ecology and Management 310: 156-166.

Converse, S. J., Block, W. M., White, G. C., 2006. Small mammal population and habitat responses to forest thinning and prescribed fire. Forest Ecology and Management, 228, 263-273.

Coppeto, S. A., Kelt, D. A., Van Vuren, D. J., Wilson, J. A., Bigelow, S., 2006. Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada. Journal of Mammalogy, 87, 402-413.

Corlatti, L., K. Hacklander, and F. Frey-Roos. 2008. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. Conservation Biology 23: 548-556.

Coulter, M. W. 1966. Ecology and management of fishers in Maine. Dissertation, Syracuse

University, Syracuse, New York, USA.

Dallas, J. F., and S. B. Piertney. 1998. Microsatellite primers for the Eurasian otter. Molecular Ecology 7: 1248.

Davis, L. 2008. Management for fisher (*Martes pennanti*) reproductive denning habitat in the Cariboo-Chilcotin. Unpublished report. Davis Environmental Ltd., Williams Lake, British Columbia, Canada. report,t Folliard, L. 1994. Discovery of an accidental trap for Pacific fishers. The Marten 2:7.

Davis, C. S., and C. Strobeck. 1998. Isolation, variability, and cross-species amplification of polymorphic microsatellite loci in the family Mustelidae. Molecular Ecology 7: 1776-1778.

Dixon, G. E. 2002. Essential FVS: a user's guide to the Forest Vegetation Simulator. USDA Forest Service Internal Report, Fort Collins, CO, USA (revised on 19 November 2013).

Douglas C.W., and M. A. Stickland. 1987. Fisher. Pages 511-529 *in* M. Novak, J. A. Baker, M. E. Obbard, and B. Malloch, editors. Wild furbearer management and conservation in North America. Ontario Ministry of Natural Resources and the Ontario Trappers Association, Toronto, Ontario, Canada.

Driezen, K., F. Adriaensen, C. Rondinini, C. P. Doncaster, and E Matthysen. 2007. Evaluating least-cost model predictions with empirical dispersal data: A case-study using radiotracking data of hedgehogs (*Erinaceus europaeus*). Ecological Modelling 209: 314-322.

Facka, A. N., R. A. Sweitzer, S. Matthews, and R. A. Powell. 2013. A note on standardization of reproductive and survival rates for populations of *Martes*. Newsletter of The Martes Working Group 20: 10-14.

Farias V., T. K. Fuller, R. K. Wayne, and R. M. Sauvajot. 2005. Survival and cause-specific mortality of gray foxes (*Urocyon cinereoargenteus*) in southern California. Journal of Zoology (London) 266:249-254.

Finney, M. A. 1998. FARSITE: Fire area simulator-model development and evaluation. Research Paper RMRS-RP-4. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT, USA.

Folliard, L. 1997. Discovery of an accidental trap for Pacific fishers. The Marten 2:7.

Fuller, T. K., E. C. York, S. M. Powell, T. A. Decker, and R. M. DeGraaf. 2001. An evaluation of territory mapping to estimate fisher density. Canadian Journal of Zoology 79:1691-1696.

Gabriel, M.W. 2013. Population health of California fishers. Dissertation, University of California Davis. Davis, CA, USA.

Gabriel, M. W., L. W. Woods, R. Poppenga, R. A. Sweitzer, C.M. Thompson, S. M. Matthews, J. M. Higley, S.M. Keller, K. L. Purcell, R. H. Barrett, G. M. Wengert, B. N. Sacks, and D. L. Clifford. 2012*a*. Anticoagulant rodenticides on our public and community lands: spatial distribution of exposure and poisoning of a rare forest carnivore. *PLoS ONE* 7: e40163. doi:10.1371/journal.pone.0040163.

Gabriel, M. W., G. M. Wengert, R. N. Brown. 2012*b*. Pathogens and parasites of Martes species: Management and Conservation Implications. Pages 138-135 *in* K. B. Aubry, W. J. Zielinski, M. G. Raphael, G. Proulx, and S. W. Buskirk, editors. Biology and Conservation of Martens, Sables, and Fishers: A New Synthesis. Cornell University Press, Ithaca, New York, USA.

Gabriel, M. W., G. M. Wengert, J. M. Higley, S. Krogen, W. Sargent, and D. L. Clifford. 2013. Silent Forests? Rodenticides on illegal marijuana crops harm wildlife. Wildlife Professional 7: 46-50.

Gantz, G. F., L. C . Stoddart, F. F. Knowlton. 2006. Accuracy of Aerial Telemetry locations in mountainous terrain. Journal of Wildlife Management 70: 1809-1812.

Garner, J.D. 2013. Selection of disturbed habitat by fishers (*Martes pennanti*) in the Sierra National Forest. MS thesis, Humboldt State University, Arcata, CA. http://hdl.handle.net/2148/1483

Gaskill, M. 2013. Rise in roadkill requires new solutions. Scientific American, May 16, 2013.

Gitzen, R. A, and J. J. Millspaugh. 2003. Comparison of least-squares cross-validation bandwidth options for kernel home-range estimation. Wildlife Society Bulletin 31: 823-831.

Gompper, M. E., and J. L. Gittleman. 1991. Home range scaling: intraspecific and comparative trends. Oecologia 87: 343-348.

Gotelli, N. 2001. A Primer of Ecology, Third Edition. Sinauer Associates, Sunderland, MA.

Grinnell, J., J. S. Dixon, and J. M. Linsdale. 1937. Fur-bearing mammals of California: their natural history, systematic status, and relations to man. University of California Press, Berkeley, California, USA.

Harihar, A., M. Ghosh, M. Fernandes, B. Pandav, and S. Goyal. 2010. Use of photographic capture-recapture sampling to estimate density of striped hyena (Hyaena hyaena): implications for conservation. Mammalia 74: 83-87.

Herbers, J., Klenner, W., 2007. Effects of logging on squirrel demography. Journal of Wildlife Management, 71, 2655-2663.

Hines, J.E. (2006). PRESENCE2- Software to estimate patch occupancy and related parameters. USGS-PWRC. http://www.mbr-pwrc.usgs.gov/software/presence.html.

Higley, J. M., G. M. Wengert, S. M. Matthews, and K. M. Rennie. 2013. Bobcat ecology and relationship with and influence on fisher survival on the Hoopa Valley Indian Reservation, California. Final Report. U.S. Fish and Wildlife Service Tribal Wildlife Gran CA U-29-NA-1. Hoopa Valley Tribe, Hoopa, California, USA.

Innes, R.J., Van Vuren, D.H., Kelt, D.A., Johnson, M.L. Wilson, J.A., Stine, P.A., 2007. Habitat associations of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forest of the northern Sierra Nevada. Journal of Mammalogy, 88, 1523-1531.

Janecka, J. E., B. Munkhtsog, R. M. Jackson, G. Naranbaatar, D. P. Mallon, and W. J. Murphy. 2011. Comparison of noninvasive genetic and camera-trapping techniques for surveying snow leopards. Journal of Mammalogy: 92(4):771-783.

Jensen, P. G., C. L. Demers, S. A. McNulty, W. J. Jakubas, M. M. Humpries. 2012. Marten and fisher responses to fluctuations in prey populations and mast crops in the northern hardwood forest. Journal of Wildlife Management 76: 489-502.

Jordan, M.J. 2007. Fisher ecology in the Sierra National Forest, California. Dissertation, University of California, Berkeley, USA.

Jordan, M. J., J. Higley, S. M. Matthews, O. E. Rhodes, M. K. Schwartz, R. H. Barrett, and P. J. Palsbøll. 2007. Development of 22 new microsatellite loci for fishers (*Martes pennanti*) with variability results from across their range. Molecular Ecology Notes 7: 797-801.

Jordan, M. J., R. H. Barrett, and K. L. Purcell. 2011. Camera trapping estimates of survival of fishers Martes Pennanti. Wildlife Biology 17:266-276.

Keller, S. F., M. Gabriel, K. A. Terio, E. J. Dubovi, E. Van Wormer, R. A. Sweitzer, R. H. Barret, C. M. Thompson, K. L. Purcell, and L. Munson. 2012. Canine Distemper in an isolated population of fishers (*Martes pennanti*) from California. Journal of Wildlife Diseases 48:1035-1041.

Kelt, D. A., Van Vuren, D. H., Johnson, M.L., Wilson, J.A., Innes, R. J., Jesmer, B.R., Ingram, K.P., Smith, J. R., Bigelow, S. W., Burnett, R. D., Stine P. A., 2013. Small mammals exhibit limited spatiotemporal structure in Sierra Nevada forests. Journal of Mammalogy, 94, 1197-1213.

Kendall, W. L., K. H. Pollock, and C. Brownie. 1995. A likelihood-based approach to capture-recapture estimation of demographic parameters under robust design. Biometrics 51:293-308.

Kendall, W. L., J. D. Nichols, and J. E. Hines. 1997. Estimating temporary emigration using capture-recapture data with Pollock's robust design. Ecology 78:563-578.

Kie, J. G. 2013. A rule-based ad hoc method for selecting a bandwidth in kernel home-range analyses. Animal Biotelemetry 1-13.

Kie, J. G., J. Matthiopoulos, J. Fieberg, R. A. Powell, F.Cagnacci, M. S. Mitchell, J. M. Gaillard, and P. R. Moorcroft. 2010. The home-range concept: are traditional estimators still relevant with modern telemetry technology? Philosophical Transactions of the Royal Society B: Biological Sciences 365: 2221-2231.

Koen, E. 2005. Home range, population density, habitat preference, and survival of fishers *(Martes pennanti)* in eastern Ontario. Thesis. Ottawa – Carleton Institute of Biology. Ottawa, Ontario, Canada.

Koen, E. L., J. Bowman, C. S. Findlay. 2007. Fisher survival in eastern Ontario. Journal of Wildlife Management 71:1214-1219.

Knaus, B., R. Cronn, A. Liston, K. Pilgrim, and M. Schwartz. 2011. Mitochondrial genome sequences illuminate maternal lineages of conservation concern in a rare carnivore. BMC Ecology 11:14pp

Krohn, W. B., S. M. Arthur, and T. F. Paragi. 1994. Mortality and vulnerability of a heavily trapped fisher population. Pages 137-146 *in* S. W. Buskirk, A. S. Harestad, M. G. Raphael and R. A. Powell, editors. Martens, sables, and fishers: biology and conservation. Cornell University Press, Ithaca, New York, USA.

Krohn, W.B., K.D. Elowe, and R.B. Boone. 1995. Relations among fishers, snow, and martens: Development and evaluation of two hypotheses. The Forestry Chronicle 71(1):97-105.

Laake, J. 2013. R Code for MARK Analysis. http://www.phidot.org/software/mark/rmark/.

Lambin, X. 1994. Sex ratio variation in relation to female philopatry in Townsend's voles.

Journal of Animal Ecology 63: 945-953.

Lande, R. 1993. Risks of population extinction from demographic and environmental stochasticity and random catastrophes. American Naturalist 142, 911-927

Larkin, J. L., M. Gabriel, R. W. Gerhold, M. J. Yabsley, J. C. Wester, J. G. Humphreys, R. Beckstead, and J. P. Dubey. 2011. Prevalence to *Toxoplasma gondii* and *Sarcocystis* spp. in a reintroduced fisher (*Martes pennanti*) population in Pennsylvania. Journal of Parasitology 97:425–429.

Lehmkuhl, J.F., Kistler, K. D., Begley, J.S., 2006. Bushy-tailed woodrat abundance in dry forests of eastern Washington. Journal of Mammalogy, 87, 371-379.

Lewis, J. C., R. A. Powell, and W. J. Zielinski. 2012. Carnivore translocations and conservation: insights from population models and field data for fishers (*Martes pennanti*). PLoS ONE 7:e32726.

Lewis, J. C., P. J. Happe, K. J. Jenkins, and D. J. Manson. 2012. Olympic fisher reintroduction project: progress report 2008-2011. Washington Department of Fish and Wildlife and Olympic National Park. (http://wdfw.wa.gov/wlm/diversty/soc/fisher/; accessed Aug 30, 2013).

Lewis, J. C. 2014. Post-release movements, survival, and resource selection of fishers (*Pekania pennanti*) translocated to the Olympic Peninsula of Washington. PhD Dissertation, University of Washington, Seattle, WA.

Litvaitis, J. A., and J. P. Tash. 2008. A approach toward understanding wildlife-vehicle collisions. Environmental Management 42:688-697.

Loberger,C. D., Theimer,T.C., Rosenstock, S.S., Wightman, C.S., 2011. Use of restoration-treated ponderosa pine forest by tassel-eared squirrels. Journal of Mammalogy, 92, 2011, 1021-1027.

Long, R. A. 2008. Noninvasive survey methods for carnivores. Island Press, 2008.

Lofroth, E. C., C. M. Raley, J. M. Higley, R. L. Truex, J. S. Yaeger, J. C. Lewis, and P. J. Happe. 2010. Conservation of fishers (Martes pennanti) in South-Central British Columbia, Western Washington, Western Oregon, and California–Volume I: Conservation Assessment. USDI Bureau of Land Management, Denver, Colorado, USA.

Magle, S. B., B. T. McClintock, D. W. Tripp, G. C. White, M. F. Antolin, and K. R. Crooks. 2007. Mark-resight methodology for estimating population densities for prairie dogs. Journal of Wildlife Management 71:2067-2073.

Mallek, C.R., H.D. Safford, J.H. Viers, and J.D. Miller. 2013. Modern departures in fire severity and area vary by forest type, Sierra Nevada and southern Cascades, California, USA. Ecosphere 4:1-28.

Manning, T., Hagar, J.C., McComb, B.C., 2012. Thinning of young Douglas-fir forests decreases density of northern flying squirrels in the Oregon Cascades. Forest Ecology and Management, 264, 115-124.

Marshall, T. C., J. B. K. E Slate, L. E. B Kruuk, and J. M. Pemberton. 1998. Statistical confidence for likelihood-based paternity inference in natural populations. Molecular

Ecology 7: 639-655.

Matthews, S. M., J. M. Higley, K. M. Rennie, R. E. Green, C. A. Goddard, G. M. Wengert, M. W. Gabriel, and T. K. Fuller. 2013a. Reproduction, recruitment, and dispersal of fishers (*Martes pennanti*) in a managed Douglas-fir forest in California. Journal of Mammalogy 94:100-108.

Matthews, S. M., J. M. Higley, J. T. Finn, K. M. Rennie, C. M. Thompson, K. L. Purcell, R. A. Sweitzer, S. L. Haire, P. R. Sievert, and T. K. Fuller. 2013b. An evaluation of a weaning index for wild fishers (Pekania [Martes] pennanti) in California. Journal of Mammalogy 94: 1161-1168.

Mazzoni, A.K. 2002. Habitat use by fishers (*Martes pennanti*) in the southern Sierra Nevada, California. MS thesis, California State University, Fresno, CA.

McCann, N. P., P. A. Zollner, and J. H. Gilbert. 2010. Survival of adult marten in northern Wisconsin. Journal of Wildlife Management 74:1502-1507.

McRae, B.H. and D.M. Kavanagh. 2011. Linkage Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle WA. Available at: http://www.circuitscape.org/linkagemapper.

McClintock, B. T. and G. C. White. 2009. A less field-intensive robust design for estimating demographic parameters with mark-resight data. Ecology 90:313-320.

McDonald, P.M. 1990. *Quercus kelloggii* Newb. California black oak. Silvics of North America 2:661-671.

McKelvey, K. S., and M. K Schwartz. 2005. Dropout: a program to identify problem loci and samples for noninvasive genetic samples in a capture-mark-recapture framework. Molecular Ecology Notes 5: 716-718.

Mech, L.D. 1974. Current techniques in the study of elusive wilderness carnivores. Pp 315-322 *in* XI International Congress of Game Biologists, National Swedish Environmental Protection Board.

Meyer, M. D., Kelt, D. A., North, M. P. 2007. Microhabitat associations of northern flying squirrels in burned and thinned forest stands of the Sierra Nevada. The American Midland Naturalist, 157, 202-211.

Moghaddas, J. J., Collins, B. M., Menning, K., Modhaddas, E. E. Y., Stephens, S. L., 2010. Fuel treatment effects on modeled landscape-level fire behavior in the northern Sierra Nevada. Canadian Journal of Forest Research, 40,1751-1765.

Murdoch, J. D., T. Munkhzul, S. Buyandelger, and C. Sillero-Zubiri. 2010. Survival and cause-specific mortality of corsac and red foxes in Mongolia. Journal of Wildlife Management 74:59-64.

Naney, R.H., L.L Finley, E.C. Lofroth, P.J. Happe, A.L. Krause, C.M. Raley, R.L. Truex, L.J. Hale, J.M. Higley, A.D. Kosic, J.C. Lewis, S.A. Livingston, D.C. Macfarlane, A.M. Myers, and J.S. Yaeger. 2012. Conservation of fishers (Martes pennanti) in south-central British Columbia, western Washington, western Oregon, and California. Volume III: threat assessment. USDOI Bureau of Land Management, Denver, CO.

North, M., P. Stine, P. O'Hara, W. J. Zielinski, and S. Stephens. 2009. An ecosystem management strategy for Sierran mixed-conifer forests. General Technical Report 220. Albany, CA: USDA Forest Service, Pacific Southwest Research Station. 49 p.

Noss, R. F., J. F, Franklin, W. L. Baker, T. Schoennagel, and P. B. Moyle. 2006. Managing fire-prone forests in the western United States. Frontiers in Ecology and the Environment 4: 481-487.

O'Connell, A. F., J. D. Nichols, and K. U. Karanth. 2011. Camera traps in animal ecology. Tokyo: Springer, 2011.

Paragi, T. F., S. M. Arthur, and W. B. Krohn. 1994. Seasonal and circadian activity patterns of female fishers, Martes pennanti, with kits. The Canadian Field Naturalist 108:52-57.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

Poole, K. G., G. M. Matson, S. A. Strickland, A. J. Magoun, R. P. Graf, and L. M. Dix. 1994. Age and sex determination for American martens and fishers. Pp. 204–223 in Martens, sables, and fishers: biology and conservation (S. W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, eds.). Comstock Publishing Associates, Cornell University Press, Ithaca, New York.

Popescu, V. D., P. deValpine, D. Tempel, and M. Z. Peery. 2012. Estimating population impacts via dynamic occupancy analysis of Before-After Control-Impact studies. Ecological Applications 22:1389-1404.

Popescu, V.D., P. deValpine, and R. A. Sweitzer. 2014. Testing the consistency of wildlife data types before combining them: the case of camera traps and telemetry. Ecology and Evolution 4: 933-943.

Powell, R. A. 1979. Ecological energetics and foraging strategies of the fisher (*Martes pennanti*). Journal of Animal Ecology 48:195-212.

Powell, R. A. 1993. The fisher: life history, ecology, and behavior, 2nd ed. University of Minnesota Press, Minneapolis, Minnesota, USA.

Powell, R. A., and W. J. Zielinski. 1994. Fisher. In L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, andW. J. Zielinski, editors. The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, USA.

Powell R, S. Buskirk and W. Zielinski. 2003. Fisher and marten. *In* G. Feldhamer, B. Thompson, and J. Chapman, editors. Wild mammals of North American, Second edition. Johns Hopkins University Press, Baltimore, Maryland, USA.

Powell, R. A., A. N. Facka, D. Clifford, C. Beach, and K. Smith. 2013. Reintroduction of fishers into the northern Sierra Nevada of California: annual report for 2012. Annual report to US Fish and Wildlife Service, Yreka, CA, California Department of Fisher and Game, Redding, CA, and Sierra Pacific Industries, Anderson, CA. May 31, 2013. (https://r1.dfg.ca.gov/Portal/LinkClick.aspx?fileticket=DpX4VZ4WJUk%3d&tabid=832; accessed Apr 24, 2014).

Price, A. J., W. Estes-Zumpf, and J. Rachlow. 2010. Survival of juvenile pygmy rabbits. Journal of Wildlife Management 74:43-47.

Purcell, K. L., A. K. Mazzoni, S.R. Mori, and B.B. Boroski. 2009. Resting structure and resting habitat of fishers in the southern Sierra Nevada, California. Forest Ecology and Management 258 (12): 2696-2706.

Pusey, A. E. 1987. Sex-biased dispersal and inbreeding avoidance in birds and mammals. Trends in Ecology & Evolution 2: 295-299.

Raine, R. M. 1983. Winter habitat use and responses to snow cover of fisher (Martes pennanti) and marten (Martes americana) in southeastern Manitoba. Canadian Journal of Zoology 61:25-34.

Reed, D. H., J. J. O'Grady, B. W. Brook, J. D. Ballou, and R. Frankham. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. Biological Conservation 113:23–34.

Reed, J. M. and E. D. McCoy. 2014. Relation of Minimum Viable Population Size to Biology, Time Frame, and Objective. Conservation Biology, 28: 867–870.

Reinhardt, E., and N. L. Crookston. 2003. The Fire and Fuels Extension to the Forest Vegetation Simulator. General Technical Report RMRS-GTR-116. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA.

Rodgers, A. R., A. P. Carr, H. L. Beyer, L. Smith, and J. G. Kie. 2007. HRT: Home Range Tools for ArcGIS. Version 1.1. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada. Available at http://flash.lakeheadu.ca/~arodgers/hre/

Roemer, G. W., T. J. Coonan, D. K. Garcelon, J. Bascompte, and L. Laughrin. 2001. Feral pigs facilitate hyperpredation by golden eagles and indirectly cause the decline of the island fox. Animal Conservation 4:307–318.

Roy, K. D. 1991. Ecology of reintroduced fishers in the Cabinet Mountains of northwest Montana. MS Thesis, University of Montana, Missoula, MT.

R_Core_Team. 2013. R: A language and environment for statistical computing. Vienna, Austria. ISBN 3-900051-07-0. http://www.R-project.org/.

Safford, H.D., M.P. North, and M.D. Meyer. 2012. Climate change and the relevance of historical forest conditions. Pp. 23-46 In Managing Sierra Nevada forests (M.P. North, editor). USDA Forest Service, Pacific Southwest Research Station, Albany, CA. General Technical Report GTR-PSW-237.

Safford, H.D. 2013. Natural range of variation (NRV) for yellow pine and mixed conifer forests in the bioregional assessment area, including the Sierra Nevada, southern Cascades, and Modoc and Inyo national forests. USDA Forest Service, Pacific Southwest Region, Vallejo, CA. Internal report.

Scheller, R. M., W. D. Spencer, H. Rustigian-Romsos, A. D. Syphard, B. C. Ward., and J. R. Strittholt. 2011. Using stochastic simulation to evaluate competing risks of wildfires and fuels management on an isolated forest carnivore. Landscape Ecology 26:1491-1504.

Seddon P.J., and R.F. Maloney. 2004. Tracking wildlife radio-tag signals by light fixed-wing aircraft. Department of Conservation Technical Series, Department of Conservation, Wellington, vol 30, pp 1–23

Sikes, R. S., and W. L. Gannon and the Animal Care and Use Committee of the American Society of Mammalogists. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. Journal of Mammalogy 92:235-253.

Shoemaker, K. T., A. R. Breisch, J. W. Jaycox, and J. P. Gibbs. 2013. Reexamining the minimum viable population concept for long-lived species. Conservation Biology 27:443–452.

Slauson, K.M., J.A. Baldwin, W.J. Zielinski, T.A. Kirk. 2009. Status and Estimated Size of the Only Remnant Population of the Humboldt Subspecies of the American marten (*Martes americana humboldtensis*) in Northwestern California, final report. Unpublished report dated November 25, 2009. USDA FS, PSW, Redwood Sciences Laboratory, Arcata, California.

Slauson, K.M., J. Baldwin, W. J. Zielinski, and M. Schwartz, M. 2009. Estimating detection probabilities for fishers using non-invasive methods, and implications for survey protocols. pp. 68. Final Report. U.S. Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, CA.

Spencer, W. and H. Rustigian-Romsos. 2012. Fisher denning habitat distribution on and near Sierra National Forest, California. Unpublished report prepared for Sierra National Forest. July.

Spencer, W. D., H. Rustigian-Romsos, J. Strittholt, R. Scheller, W. Zielinski, and R. Truex. 2011. Using occupancy and population models to assess habitat conservation opportunities for an isolated carnivore population. Biological Conservation 144:788–803.

Spencer W., S. Sawyer, W. J. Zielinski, R. Sweitzer, C. Thompson, K. Purcell, D. Clifford, L. Cline, H. Safford, S. Britting, R. Powell, J. Sherlock, and J. Tucker. 2015. Draft Southern Sierra Nevada Fisher Conservation Assessment. Conservation Biology Institute, San Diego, CA.

Svagelj, W. S. and F. Quintana. 2007. Sexual size dimorphism and sex determination by morphometric measurements in breeding imperial shags (Phalacrocorax atriceps). Waterbirds 30(1): 97-102.

Swiers, R. C. 2012. Non-invasive genetic sampling and mark-recapture analysis of a fisher (Martes pennanti) population in northern California used as a reintroduction source. 2013. Thesis, North Carolina State University, Raleigh, NC.

Swihart, R. K., N. A. Slade. 1985. Influence of sampling interval on estimates of home-range size. The Journal of Wildlife Management 49: 1019-1025.

Swihart, R. K., N. A. Slade, and B. J. Bergstrom. 1988. Relating body size to the rate of home range use in mammals. Ecology 69: 393-399.

Thompson, C. M., W. J. Zielinski, and K. L. Purcell. 2011. Evaluating management risks using landscape trajectory analysis: a case study of California fisher. Journal of Wildlife Management 75:1164–1176.

Thompson, C.M., K. Purcell, J. Garner, and R. Green. 2011. Kings River Fisher Project Progress Report 2007-2010. USDA Forest Service Pacific Southwest Research Station Sierra Nevada Research Center. Unpublished report.

Thompson, C.M., J.A, Royle, and J.D. Garner. 2012. A framework for inference about carnivore density from unstructured spatial sampling of scat using detector dogs. The Journal of

Wildlife Management 76(4): 863-871.

Thompson, C.M., R.A. Green, J. Sauder, K.L. Purcell, R. A. Sweitzer, and J. Armeno. 2012. The use of radiotelemetry in research on Martes species, techniques and technologies. Pages 284-319 in K. B. Aubry, W. J. Zielinski, M. G. Raphael, G. Proulx, and S. W. Buskirk, editors. Biology and Conservation of Martens, Sables, and Fishers: A New Synthesis. Cornell University Press, Ithaca, New York, USA.

Thompson, C., R. Sweitzer, M. Gabriel, K. Purcell, R. Barrett, and R. Poppenga. 2013. Impacts of rodenticide and insecticide toxicants from marijuana cultivation sites of fisher survival rates in the Sierra National Forest, California. Conservation Letters 6:1-12.

Timm, S. F., L. Munson, B. A. Summers, K. A. Terio, E. J. Dubovi, C. E. Ruprecht, S. Kapil, and D. K. Garcelon. 2009. A suspected canine distemper epidemic as the cause of a catastrophic decline in Santa Catalina Island foxes (*Urocyon littoralis catalinae*). Journal of Wildlife Diseases 45: 333–343.

Truex, R. L., W. J. Zielinski, R. T. Golightly, R. H. Barrett, and S. M. Wisely. 1998. A meta-analysis of regional variation in fisher morphology, demography, and habitat ecology in California. Draft report submitted to California Department of Fish and Game, Wildlife Management Division, Nongame Bird and Mammal Section, Sacramento, California, USA.

Truex, R.L., and W.J. Zielinski. 2013. Short term effects of fuel treatments on fisher habitat in the Sierra Nevada, California. Forest Ecology and Management 293:85-91.

Tucker, J.M., M.K. Schwartz, K.L. Pilgrim, and F.W. Allendorf. 2012. Historical and contemporary DNA indicate fisher decline and isolation occurred prior to the European settlement of California. PLoS ONE 7(12): e52803. doi: 10.1371/journal.pone.0052803.

Tucker, J.M., Schwartz, M.K., Truex, R.L., Wisely, S.M., and F.W. Allendorf. 2014. Sampling affects the detection of genetic subdivision and conservation implications for fisher in the Sierra Nevada. Conservation Genetics. 15: 123-136. doi: 10/1007/s10592-013-0525-4.

United States Fish and Wildlife Service. 2004. 50 CFR part 17 Endangered and threatened wildlife and plants; 12 month finding for a petition to list the west coast distinct population segment of the fisher (*Martes pennanti*); proposed rule Federal Register.

United States Fish and Wildlife Service. 2004. 50 CFR part 17 Endangered and threatened wildlife and Gilmer, D. S., L. M. Cowardin, R. L. Duval, L. M. Mechlin, and C. W. Shaiffer. 1981. Procedures for the use of aircraft in wildlife biotelemetry studies. U.S. Fish and Wildlife Resource Publication 140.

U.S. Forest Service. 2004. Sierra Nevada forest plan amendment: final supplemental environmental impact statement. U.S. Forest Service, Pacific Southwest Region, Vallejo, California.

Vaillant, N. M., A. A. Ager, J. Anderson, and L. Miller. 2011. ArcFuels 10 system overview. General Technical Report PNW-GTR-875. USDA Forest Service, Pacific Northwest Research Station, Portland, OR, USA.

Vangen, K. M., J. Persson, A. Landa, R. Andersen, and P. Segerström. 2001. Characteristics of dispersal in wolverines. Canadian Journal of Zoology 79: 1641-1649.

Verner, J., and A.S. Boss. 1980. California wildlife and their habitats: western Sierra Nevada.

USDA Forest Service General Technical Report PSW-37.

Weir, R., F. Corbould, and A. Harestad. 2004. Chapter 9 – effect of ambient temperature on the selection of rest structures by fishers. Pages 187-197 in D. J. Harrison, A. K. Fuller, and G. Proulx, edtors. Martens and fishers (Martes) in human-altered environments: an international perspective Springer Science + Business Media, New York, USA.

Weir, R. D., and F. B. Corbould. 2006. Density of fishers in the sub-boreal spruce biogeoclimatic zone of British Columbia. Northwestern Naturalist 87:118-127.

Weir, R. F., and F. B. Corbould. 2007. Factors affecting diurnal activity of fishers in north-central British Columbia. Journal of Mammalogy 88(6): 1508-1514.

Weir, R., and F. Corbould. 2008. Ecology of fishers in the sub-boreal forests of north-central British Columbia: Final Report. Peace/Williston Fish and Wildlife Compensation Program Report No. 315.

Weir, R.D., and F.B. Corbould. 2010. Factors affecting landscape occupancy by fishers in north-central British Columbia. Journal of Wildlife Management 74(3):405-410. Wengert, G. M. 2013. Ecology of Intraguild Predation on Fishers (*Martes pennanti*) in California. Dissertation, University of California Davis. Davis, CA, USA.

Weir, R. D., M. Phinney, and E. C. Lofroth. 2012. Big, sick, and rotting: why tree size, damage, and decay are important to fisher reproductive habitat. Forest Ecology and Management, 265: 230-240.

Wengert, G. M., M. W. Gabriel, J. E. Foley, T. Kun, B. N. Sacks. 2013. Field and molecular techniques for identifying intraguild predators of fishers and other North American small carnivores. Wildlife Society Bulletin 37:659-663.

Wengert, G., M. Gabriel, S. Matthews, J. M. Higley, R. Sweitzer, C. Thompson, K. Purcell, R. Barrett, L. Woods, R. Green, S. Keller, P. Gaffney, M. Jones, and B. Sacks. 2014. Using DNA to describe and quantify interspecific killing of fishers in California. Journal of Wildlife Management 78: 603-611.

White, G. C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement, 120-138.

Wilbert, J. C. 1992. Spatial scale and seasonality of habitat selection by martens in southeastern Wyoming. Thesis, University of Wyoming, Laramie,Wyoming.

Williams, E., E. Thorne, M. Appel, and D. Belitsky. 1988. Canine distemper in black-footed ferrets (*Mustela nigripes*) from Wyoming. Journal of Wildlife Diseases 24: 385-398.

Wilson, J. A., Kelt, D.A., VanVuren, D.H., Johnson, M.L., 2008. Population dynamics of small mammals in relation to production of cones in 4 types of forests in the northern Sierra Nevada, California. The Southwestern Naturalist, 53, 346-356.

Wisely, S. M., S.W Buskirk, G. A Russell, K. B Aubry, and W. J. Zielinski. 2004. Genetic diversity and structure of the fisher (*Martes pennanti*) in a peninsular and peripheral metapopulation. Journal of Mammalogy 85: 640-648.

Wolff, J. O., K. I. Lundy, and R. Baccus. 1988. Dispersal, inbreeding avoidance and reproductive success in white-footed mice. Animal Behaviour 36: 456-465.

Woodroffe, R. 1999. Managing disease threats to wild mammals. Animal Conservation 2: 185–193.

York, E. 1996. Fisher population dynamics in north-central Massachusetts. Thesis, University of Massachusetts, Amherst, USA.

Zhao, F., R. A. Sweitzer, Q. Guo, and M. Kelly. 2012. Characterizing habitats associated with fisher den structures in the Southern Sierra Nevada, California using discrete return lidar. Forest Ecology and Management 280:112-119.

Zielinski, W.J., T. E. Kucera, and R.H. Barrett. 1995. Current Distribution of fishers (Martes pennanti) in California. California Fish and Game 81:104–112.

Zielinski, W.J., N.P. Duncan, E.C. Farmer, R.L. Truex, A.P. Clevenger, and R.H. Barrett. 1999. Diet of fishers (*Martes pennanti*) at the southernmost extent of their range. Journal of Mammalogy 80:961-971.

Zielinski, W. J., and N. P. Duncan. 2004. Diets of sympatric populations of American martens (*Martes Americana*) and fishers (*Martes pennanti*) in California. Journal of Mammalogy 85:470-477.

Zielinski, W. J., R. L. Truex, G. A. Schmidt, F. V. Schlexer, K. N. Schmidt, R. H. Barrett. 2004. Resting habitat selection by fishers in California. Journal of Wildlife Management 68: 475-492.

Zielinski, W. J., R. L. Truex, F. V. Schlexer, L.A. Campbell, and C. Carroll. 2005. Historic and contemporary distributions of carnivores in forests of the Sierra Nevada, California, USA. Journal of Biogeography 32:1385-1407.

Zielinski, W. J., J. A. Baldwin, R. L. Truex, J. M. Tucker, and P. A. Flebbe. 2013a. Estimating trend in occupancy for Southern Sierra Fisher Martes pennanti population. 2013. Journal of Fish and Wildlife Management 4:3-19.

Zielinski, W.J., C.M. Thompson, K.L. Purcell, and J.D. Garner. 2013b. An assessment of fisher (*Pekania pennanti*) tolerance to forest management intensity on the landscape. Forest Ecology and Management 310: 821–82.

Appendix D1: Important and Key Protocols for Pacific fisher

Live Trap Site Selection, Trap Setup, and Trap Checking Protocol

This protocol was developed to guide and help standardize site selection, placement and camouflaging of live traps for the SNAMP Fisher Project.

General Instructions on Trap Site Selection

1. Trapping methods
   a) Target Fisher Trapping – Collared fishers will occasionally "drop" their collars, requiring focused trapping for recollaring the animals. Also, radicollars have a limited battery life (16-24 months) and we will periodically need to recapture animals for replacing their radiocollars. Traplines will sometimes be designed to capture/recapture fishers for these purposes. In these cases we will use information on the most recent locations to target fishers for capture. A trapline consisting of 5-10 traps will typically be placed in areas where multiple locations have been logged during aerial telemetry, focused at the microhabitat scale in areas with large trees and snags, near steam courses, and in areas with relatively high canopy cover.
   b) Trapline trapping – Most of our trapping occurs along traplines of 6-12 traps, where the number of traps depends on the area being covered and the logistics of access for checking traps. Traplines are typically designed along roads or trails in likely fisher habitat that is designated from a map designed in ArcGIS. GIS produced maps will always be used to guide the placement of traps along traplines. Maps of traplines will usually include the "Estimated" UTM coordinates for where the traps should be placed; do not second guess the estimated UTM coordinates by ignoring them and placing traps in other, more convenient locations far from the actual waypoints (far = more than 500 m from the coordinate). When navigating to the estimated waypoint, look for likely fisher habitat (areas with large trees, moderate to steep slopes, near stream courses, areas with high canopy cover) when you get close to the suggested position.
2. For the safety/security of trapped animals, traps should be at least 50 meters from a road or trail. Depending on forest vegetation, a greater distance from roads/trails may be necessary.
3. Just as cameras are placed in areas believed to be good resting habitat for fishers (according to Zelinski et al. 2004), trap sites should also be placed in areas with the following forest characteristics: *high canopy closure, large DBH black oaks, large decayed logs, large DBH conifers, large DBH snags, moderate to steep slopes, and near or in drainages with running and/or pooled water.*

Guidelines and Procedures on Trap Placement and Setup

IMPORTANT: Do not place the trap in the middle of what you believe is poison oak!

1. Whenever possible place the trap on level ground/snow, preferably at the base of a tree or next to a downed log to provide stability and to prevent the trap from tipping over with animals inside. Use a shovel to clear the duff from the forest floor and place the trap on the hard ground. In cases where some slope is unavoidable, orient the door of the trap facing slightly downhill; animals are generally more comfortable walking up into something than feeling like they might slip down into it.

2. Use dirt and sticks or tree bark to level the trap side-to-side. Also, make sure the trap is stable when you press on each corner of the trap, and that the trap door is unimpeded by plants and debris. If necessary, insert a small stick or slab of bark under the front of the trap to elevate it above uneven ground that may block the door from closing.
3. Test the door mechanism to ensure the treadle does not require too much force to close the door. Adjust the metal bar along the inside of the trap attaching the treadle to the door release; bending it will create more treadle tension and make it easier to trigger, but could prevent difficulties for straightening. The best approach is to use a pair of needle-nose pliers to adjust the curvature of the metal catch piece.
4. Check that the trap opening is square so the trap door does not catch on the sides.
5. Fully inspect the wooden nest box; remove old scat, bait or debris, and clean the trap with a mild bleach/water solution before taking into the field – spray the trap with the scent masking solution once it has been cleaned/disinfected with bleach water.
6. Make sure the metal plate at the back of the nest box can be slid out and the fold is pointing toward the front of the trap. Also, check that the metal plate has a pin or ring to hold it in place.
7. Mark and average the trap location (min 25 positions) with your Garmin GPS and record the UTM coordinates on the Trap Setup Data form.
8. Place plastic flagging on a tree either directly above or near the trap, so that it can be seen when walking from the nearest and most likely parking spot.

Baiting/Prebaiting and Setting Traps

1. When the trap is to be pre-baited or "wired open," place a clip on the trap door and attach it to the roof of the trap. If an extra clip is not available, use the one from the metal door in the back of the cubby. Make sure to note this on the trapping sheet.
2. Smear Fisher Lure onto a chicken/venison-filled sock. Push the bait sock to the back roof of the wire trap, directly in front of the wooden nest box *(Tip: drape the top of the sock over the tip of a stick and use it as an extended arm)*. From the outside of the trap, grab the top of the sock and pull it through a hole in the wires, knotting it on itself so it is suspended in front of the nest box opening and cannot be pulled back into the trap.
3. Place Gusto on trees near the trap; somewhere in front of the trap as well as on trees/shrubs on either side of the trap. Avoid dabbing Gusto on trees/shrubs where someone might accidentally lean into it.
4. Whenever possible and depending on equipment availability, all traps should have a trapsite transmitter affixed onto the top of the trap. Attach the trapsite transmitter to the metal crossbar halfway along the outside of the trap roof. Loop the plunger wire through the wire loop at the bottom of the door and put a little oil on the plunger to ensure it will not freeze or stick inside the transmitter. Record the transmitter frequency on the trap setup datasheet. *Test the trap door to ensure the plunger pulls smoothly out of the transmitter and does not catch on trap wire; use a receiver to make sure the signal tempo increases (the rate should double) when the closing door pulls the plunger out of the sleeve. Double check that the plunger has been inserted back into the transmitter sleeve after testing the transmitter and the trap door mechanism.*

5. Once the trapsite transmitter is in place and after testing, place a canvas tarp over the body of the trap, tucking it close to the sides and placing small logs on the edges to hold it down. Place the tarp edge flush with the edge of the open trap door.
6. Fully cover/camouflage the top and sides of the trap with pieces of bark, sticks and green branches. Be careful not to place too much weight on the trap or it could be bent and not close properly; be sure not to place any heavy camouflage objects on the front of the trap that will prevent the door latch mechanism from working properly. Avoid placing any materials on the trap that could impede the path of the transmitter plunger as it is pulled out by the closing of the trap door. *The metal handled shovels have a saw inside of them and are very helpful to cut branches for trap camouflage.*
7. Before leaving the trap site, test that the trap door works. Then take several minutes to completely fill out the trap setup form.

Checking Traps

1. Begin in the morning by planning how to split up the traps if you're working with another person and who to call if you get a fisher. Make sure that you have all the trap site locations before heading out into the field. Print the Trap Location file located in Z:\SNAMP_Capture_Trapping\SNAMP_Trapping Files/Fisher_Trap_Locations.
2. Gather a GPS, receiver, camera, flashlight, extra bait and lure, a capture kit (if available), and a Forest Service radio for checking traps.
3. Head out to your nearest trap location. Upon the capture of an animal, use a flashlight to determine the species. If it is a fisher ("target"), look for a radio collar ("old target"). If it does not have a radio collar it is called a "new target". Call the predetermined personnel on the forest service radio and let them know what type of "target" you have and the "station" (trap) number. Be sure that you do not say you have a new or uncollared fisher, but rather a new target. Also, do not give any indication of your location or the trap location, especially the UTM's. If you have caught an old target, use the receiver to identify the individual. If this animal is in need of processing use the metal slat to block the fisher into the wooden cubby. If you do not have one, navigate to the nearest trap. If it is empty, borrow the metal plate and make sure you bring it back after the capture. Then finish checking your traps and head straight back to the trap to set up the capture gear for processing.
4. If you have caught a non-target, let the animal go and clean out the trap. Animals will usually defecate and/or urinate inside the trap and can keep fishers from entering the trap in the future. If the trap is to be set again, reset the trap with a new bait sock with fisher lure.
5. When checking traps, make sure to re-scent the traps with fisher and Gusto scent lures every three days. Bait should also be replaced after 4-5 days in the summer and every 7 days or so during winter. If you replace the bait, remove the bait sock and the bait from the sock. Burry the bait in the soft forest floor and throw the sock away back at the field station.
6. Check that the trap door closes after pressing on the treddle from outside. Cover the trap with the canvas tarp (if available) and camouflage. Then head to your next tra*p*.
7. Upon checking all your traps on your line, call the predetermined personnel and tell them that your "stations are all clear". If you haven't already done so, make sure that all of the trap forms all filled out.

8. Once you have returned to the office, pull up the Excel TRAP CHECK DATAFILE from the server (folder = “SNAMP_Trapping Files”) and enter the data from the trap forms into the computer database, save, and close the file.

FISHER CAPTURE AND PROCESSING PROTOCOL

This protocol was developed to guide and help organize the process and procedures to be followed during a fisher capture and processing event. A minimum two staff should be present at a capture event, but the preferred number of participants is three.

Outline of Protocol

1. When a fisher is captured
2. Capture Site Set-up
3. Using the capture cone
4. Sedation
5. Processing the fisher
    a. data recording
    b. head, tail processing
    c. PIT tag
    d. radio collar
    e. Collected samples
    f. Capture clean-up/wrap-up
6. Releasing the fisher
7. Label Samples
8. Data entry
9. Restocking the capture bags

1. When a fisher is captured

a) When a trap contains a fisher the first step is to identify whether the animal is a new capture, or recapture of a previously processed animal. Remove the tarp and camouflage from the trap. Use a strong flashlight to look into the cubby at the fisher. Move the trap around gently until you get a quality look at the fisher's neck to confirm the presence/absence of a radio collar. It is easier to confirm a collar presence, than an absence. Next, turn the receiver on to high volume. Slowly scroll through all the known telemetry frequencies for collared fishers.

b) If the receiver does not pick up a signal; skip this paragraph. If the receiver does pick up a signal; note the animal's id and use the *telemetry fisher data sheet* to ascertain the fisher's status. The fisher should be immediately released if we do not need to re-collar, or collect more information from this animal. To release the fisher: point the cubby end away from you & remove the metal plate. Some fishers will need encouragement to leave the cubby. First try remaining quiet to allow the fisher time to leave. If that does not work, a combination of the following will work: wait longer, walk farther away from trap, gently tap on the cubby to encourage the fisher to turn towards the opening, blow into the cubby from the trap side, use a plunger (stick w/ blunt object attached to end) to persuade fisher out back of cubby while plunger enters from front of trap. In a case where time is limited you can leave the trap w/ the plate removed, and return later in the same day (*leaving & returning later is not an acceptable release method for fishers that were just processed)*. After the fisher has left the cubby, clean the inside of cubby with a scent neutralizing agent.

c) If the fisher is a new capture or re-capture that needs to be processed, notify the other crew members of the capture and station number. Then cooperatively establish a time and place for all the capture participants to meet. Usually there will be other traps to check along the line, so check the remaining traps and then return to the capture. Before leaving the trapped fisher, place the second metal door (from capture kit) in the front slot of the cubby. If there is not a second door available in the capture kit, temporarily borrow one from another trap (be sure to return the door at the end of the capture). *DO NOT move a trap w/ a fisher in it unless the second door is in place.* Before leaving, make sure the trap is located in a spot that will be shaded until your return. However, if the ambient temp is extremely cold, the trap should be placed in the sun if there is no chance of overheating. Observe the immediate area to confirm there are no insect colonies nearby. Cover the trap with the tarp in case of inclement weather.

2. Setting up for Processing Target Captures

a) Background: During set-up and throughout the entire capture it is important to maintain a quiet environment to minimize the level of stress on the captured fisher. Preparing for a capture involves assigning capture roles, setting up all the equipment, and testing both the radio collar and PIT tag before sedating the fisher. There must be at least two people present to process a fisher, but three is ideal to allow for a recorder role.

b) Assign roles for the capture team:

1. Person processing the fisher from the head end
2. Person processing the fisher from the tail end
3. Recorder (if available): if a recorder is not available, the two staff present will tradeoff data entry as needed in the course of processing

b) Equipment Set-up:

- Find or create a nearly level tarp sized surface in the shade/sun (depending on season).
- Lay out the tarp with the insulated pad on top, in the center of the tarp.
- Lay out a clean towel on top of the insulated pad. If there is a slope; roll up the second towel and place it underneath the first towel. This creates a bump that cradles the fisher preventing the animal from sliding downhill.
- Determine which side of the tarp people will kneel on. Then decide which way the fisher's head will be oriented on the towel. Place the sock and collar kit above the towel near the head end, the drugs kit near the tail end, and the samples kit in between.
- Find/remove a pre-prepared fisher capture samples kit from the Capture Kit – the pre-prepared kit will be in 1 gallon Ziploc bag. Extract the Capture Datasheet from the capture sample kit, place on a data form holder, and begin filling out the top portion of Page 1 on the form. NOTE: the Capture Event Start time is the approximate time that all members of the capture team arrived at trap position and began setting up for the capture/processing. The Capture Event End time is when the fully recovered leaves the cubby
- Place the extra/empty Ziploc bag between the two processors for the completed samples. Label the hair sample envelopes "tail" and "nape". Label the three swabs "ocular", "nasal", and "fecal". Place the hair sample envelopes and the fecal swab

near the tail end, the PIT tag near the middle, and all other sampling supplies near the head end.

- Remove the Kestrel weather station device from the kit and turn it on for determining the ambient temperature for the capture/processing – record once temperature stabilizes
- Find the stopwatch, reset it, and give to the person assigned to record data.
- Open the Vaseline and thermometer sleeves and set them near the tail end. Insert thermometer in a sleeve and stick thermometer in Vaseline so it is lubricated and ready to use.
- Each capture generates two types of trash; biohazards and sharps (needles). Place the red biohazard bag where it will be accessible by both processors, place the sharps container near the head end of the tarp.
- Place the ocular ointment next to the ocular swab near the head end.
- Put the laminated foot pad sheet near the tail end.
- Remove the measuring tape and ruler from the samples kit and place near the head end.
- Remove the calipers from the case and place near the head end.
- Check the scale to confirm it is zeroed. Set the scale and sling on the tarp off to the side.
- Prepare the sedatives (see section 4)
- Choose the appropriate size rubber gloves and have a pair readily available for each processor.
- Don a pair of leather gloves and prepare to use the capture cone.

c) Testing the PIT tag and radio collar:

- Remove the PIT tag reader from the waterproof case and turn it on.
- The reader will take a moment to warm up and then display “ready”.
- Hold the button down continuously on the reader and scan over the PIT tag until it displays the PIT tag identification number.
- If the reader does not register the PIT, the display will say “No ID found”. Try scanning the PIT tag again and be sure the button is fully depressed continuously while scanning. If the PIT tag is still not registering, then do not use this tag. Mark the PIT tag package defective and test a different PIT tag from the capture kits.
- After successfully scanning the PIT tag, place the tag and reader near the middle of the set-up.

d) Radio Collar test:

- Update all receivers present with the capture team with the new animal’s radio frequency. This can be done before the capture event starts during preparations.

Receiver Background: The receiver has three swivel knobs on top. Turn on your receiver by turning the ‘Power/Volume’ knob located in the lower right corner to the right. Make sure the ‘Gain’ knob on the left is turned as far up (right) as possible. The third knob, ‘Dial’, allows you to scroll through the channels used for designating certain animal’s frequencies. Scrolling through channels can also be accomplished by using the up and down arrows on the buttons in the lower left corner of the receiver.

Channels: The receiver has 1000 different channels (0-999). Male fisher are assigned channels 1-200 while female fisher are assigned channels 201-400 and each fisher's ID is identical to the channel. (Ex. M01 = Channel 001, M02 = Channel 002, F01 = Channel 201, F25 = Channel 225, etc.) If you do not know the sex of the fisher yet, select a channel in the 500 range to test the collar's frequency.

1. Turn on the receiver.
2. Press the 'Program' button. The screen will show three lines: the top is the frequency, the middle the channel, and the bottom is text (Fisher ID).
3. Use the down arrow button to move the cursor to the channel row. (Note: You must always first select a channel you wish to use).
4. To test a new frequency, type in a channel in the 500 range if you do not yet know the sex of the animal.
5. Use the upward arrow button to move the cursor to the frequency row.
6. Type in the collar's frequency you wish to test. Press the 'Enter' button when finished. (Note: pressing enter a second time will save this information.) Since you are only testing, just press enter once.
7. Make sure the magnet on the collar is removed and listen for the beeps/tones emitting from the receiver.
8. Adjust the frequency by using the dial knob in the top right corner. New collars will usually drift down a few thousand decibels over a period of hours and days. If the radiocollar is functioning properly, remove the label tape with the frequency and place it in the box on Page 2 of the Capture Datasheet. Find the serial number for the collar (usually written in permanent ink on the inside of the leather strap of the collar.
9. Once the capture event has commenced and sex of the animal has been determined, enter the animal's ID.
10. Follow Steps 1-3 above.
11. Type in the appropriate channel. (Ex. New female capture # 28 = Channel 228.)
12. Use the upward arrow button to move the cursor to the frequency row.
13. Type in the collar's frequency. Adjust the frequency as in Step 8 above if the frequency has drifted.
14. Use the downward arrow button to move the cursor to the text or bottom row.
15. Turn the dial knob in the top right corner to scroll through the alphabet and numbers for the proper ID.
16. Press 'Enter' twice to save this information.

Most likely you will only be able to update the one or two receivers the capture group has with them, and you will have to update the others at the office when all work colleagues and gear return from the field. Don't forget to also update the receiver used for aerial telemetry flights

3. Using/setting up the capture cone

- Place trap in an area as flat as possible, and accessible by all capture participants.
- Orient the back of the trap upslope if there is an incline.

- Determine the size/gender of the fisher by opening the front plate and observing size. Choose the larger capture cone for males and the smaller cone for females.
- Attach the large end of the cloth funnel bag around the back of the cubby. After the bag is attached to the cubby, use a stick to twist the drawstring of the funnel bag tightly around the cubby.
- Attach the small end of the cloth funnel bag around the large end of the capture cone. Then use either a clamp or strap to cinch the funnel bag securely to the capture cone.
- Place the dowel rods and laundry bag close to the cone, but out of view of the exiting fisher.
- Have the Persuader hold the persuader dowel rod in hand.
- The people responsible for operating the dowel rods need to crouch/sit very close to the capture cone (but out of view of the exiting fisher) with two rods each ready for insertion.
- When all participants are ready and quiet, the Persuader removes the back panel & observes the fisher's position. The Persuader may need to coax the fisher into the funnel bag by simply waiting longer, blowing in the cubby by removing the front panel, or using a plunger.
- After the fisher has completely entered the cloth bag, the Persuader uses the Persuader rod (in a horizontal position pressing the cloth funnel against the ground) to prevent the fisher from entering the cubby. The Persuader quickly moves the persuader rod forward to move the animal forward into the capture cone.
- Once the base of the fisher's tail is visible in the cone, insert the dowel rods completely through the cone behind the fisher to create a web of rods that prevents the fisher from backing out. Then push the rods towards the nose of the cone until the fisher is unable to move further forward. Hold the rods in place throughout sedation until the fisher is unresponsive.
- As soon as the fisher is pushed forward in the cone, lay the laundry bag over the fisher's face to help calm the animal down.
- Sedate the fisher (refer to section 4-Sedation)
- After the fisher is completely sedated: remove the dowel rods, laundry bag & fabric funnel from the capture cone. Then, one person holds the capture cone at an angle to slide the fisher out the open end. Meanwhile the second person inserts their hands into the cone to guide the animal out the opening and hold the sedated fisher once it has been removed.
- Take the animal over to the tarp and begin processing the fisher.

4. Sedation

- Background: The drugs used to immobilize/sedate fishers for processing are Ketamine Hydrochloride and Diazepam (liquid Valium). The drugs are premixed in a 10ml vial kept in the capture kit. Both drugs are controlled substances and we are required to closely track the volume used at each capture. *Both capture kits have a Controlled Substances Log: it is imperative that the Controlled Substances Logs are filled out and by recording the drug amounts used during captures*
- Draw up appropriate volume of drugs using a 1 cc syringe
    - NOTE: Each capture kit will have a laminated sheet providing precise volume information based on the estimated body mass of the fisher in the cubby

- Working together with the capture team, encourage the fisher to exit the back of the cubby (after removing the aluminum plate) into the cone
- As quickly but as carefully as possible feel through the bars of the cone and locate soft but thick muscle tissue on the rump or one of the two hind limbs
- Slowly but firmly insert the needle into the muscle tissue, and gradually inject the drugs
- IMPORTANT: Do not jab the needle into the tissue, or quickly inject the entire volume of drugs by rapidly pushing the plunger of the syringe (this is painful to the animal).
- Remove the needle and start the stopwatch immediately; ideally, one member of the capture team will be observing the injection process, and will have started the stopwatch upon seeing the injection occur.

5. Processing the fisher

This process is broken down into two separate roles with one person working from the head end while the other works from the tail end. However, many of the tasks can be done by either person. Below the tasks are marked with either an "H" or "T" to represent the tasks typically done by the head or tail person respectively. Tasks that are often done by either person are unmarked. Before touching the fisher all capture participants will put on rubber gloves.

There is not a concrete order that has to be followed, but the crucial aspects of a capture are to weigh and sex the animal, collect samples, attach the radio collar, and insert a PIT tag.

1. Weigh the fisher
   - Place fisher centrally in the weighing sling and attach all the D rings to the scale hook.
   - Hold the handle loop on top of scale and lift until the fisher is elevated just above the ground.
   - The scale reading will vary if the weighing sling is swinging or bouncing, so wait until the sling stops moving to take a measurement.
   - Read the measurement to the nearest hundredth kilogram (ex: 3.35kg, 2.75kg)
   - Place the sling gently on the ground and move the fisher to the towel on the tarp.
2. Collect 3 swab samples- ocular, nasal & fecal
   - Check each swab label to confirm that the correct swab is used for each sample.
   - (H) Ocular- Carefully swab along the inner corner of one eye. Do not rub the eye. Re-cap swab and place in the collected samples bag. Squeeze a thin bead of ocular ointment into each eye so that it drops onto the eye starting at the inner corner. Softly massage the skin around each closed eye with two fingers to assure the ointment contacts the surface of the eye.
   - (H) Nasal- Insert just the tip of the swab inside each nostril and twirl swab around against the inside of each nostril. Re-cap swab and place in the collected samples bag.
   - (T) Fecal- Insert just the tip of the swab into the anus and twirl the swab. Re-cap swab and place in the collected samples bag.
3. Measure temperature and observe respirations
   - (T) Temperature- After collecting the fecal swab, insert the thermometer (w/ a plastic thermometer sleeve lubricated w/ Vaseline) into the anus and press the button on the thermometer to begin taking a reading. Record the temperature and the current time from the stopwatch. Remove the thermometer and place the used sleeve in the biohazard trash bag. Continue to take temperature readings throughout the capture every five to ten

minutes. Use a new lubricated thermometer sleeve for each reading. If the fisher's temperature is ›105°F cool the animal with ice packs along the abdomen. If the fisher's temperature is ‹98°F warm the animal w/ heat packs along the abdomen and cover the body with towels.

- (T) Respirations- Each time a temperature is taken, it should be followed by observing the fisher's respirations for 15 seconds. Multiply the number of respirations by 4 and record this number and the time found on the stopwatch.

4. Head and body measurements-
   - Use the flexible measuring tape to measure:
     1- (H) Tip of the nose to base of the skull
     2- (H) Tip of the nose to base of the tail. <u>After measurements 1 & 2 are done, put the sock over the fisher's face covering the eyes.</u>
     3- Dorsal body length from base of the tail to bony end of the tail
     4- (H) Head circumference around largest part of the skull (near the ears)
     5- Neck circumference
     6- Chest circumference- find the bottom ribs and measure slightly above bottom ribs where chest girth is the largest
   - Use the hard plastic or hard metal ruler to measure:
     1- Width from ear tip to ear tip at the widest point
     2- Front of ears ear tip to ear tip
5. Collect remaining biological samples & put in the collected samples bag
   - (T) Nape & tail hair- With fingers grasp several hairs near their base and pull them out with a quick jerking motion. Collect a hair sample from both the nape and at the base of the tail. Place hair in the appropriate envelopes.
   - (T) Ectoparasites- Use the thin toothed comb to comb key areas of the fisher's pelage (groin, anus area, abdomen, armpits, and nape) while carefully checking the comb for ectoparasites. Place ectoparasites in the small vial full of alcohol, and record the abundance and types.
   - (H) Ear tissue- Prepare the sample area of the ear by cleaning it with an alcohol wipe. Place the wooden tongue depressor behind the ear to provide a backdrop to push against. Line-up the punch slightly inward from the edge of the ear. Avoid puncturing the ear along the edge, because this may contribute to tearing after the animal is released. Press the punch firmly through the ear against the depressor, then rotate the punch in place to assure the punch went completely through the ear tissue. Find the straight wire in the collar kit, and disinfect it with an alcohol wipe. Use this wire to push the tissue sample out of the punch into the vial of blue desiccant. If the desiccant is any color other than blue, use a different vial because the quality of the desiccant has been compromised.
   - (H) Blood-
6. Insert the PIT tag
   - Remove the PIT tag syringe from the packaging and lubricate the needle with antibiotic ointment.
   - Locate the fisher's scapulas with one hand. Then move to a slightly posterior position where the skin is loose enough to grab a handful of skin pulled away from the spine area. Align the knuckles of the hand parallel with the fisher's spine and grasp the fisher's skin. Pull the skin away from the spine about two inches so that it makes a triangle where the pinched skin is the apex of the triangle. With the other hand (that will hold the syringe)

push the skin in the middle of the triangle towards the fisher's head to create an inward depression.

- Insert the PIT tag syringe into this depression, careful not to hit the body of the fisher or push the syringe out of the skin on the other side of the triangle.
- Once the syringe is completely inserted, use the three fingers that were previously holding the apex of the triangle to carefully locate the tip of the syringe through the skin.
- Hold three fingers around the tip of the syringe and depress the plunger of the syringe to insert the PIT tag.
- Hold the PIT tag in place with three fingers. Remove with syringe with a spinning motion out the same path as insertion.
- Massage/rotate the PIT tag in place to discourage it from accidentally slipping out the path of the syringe.
- Check the pelage in the immediate area of the tag insertion to verify the tag did not slip out.
- Re-check the PIT tag with the reader to confirm the PIT tag is still functioning properly.
- Affix one of the labels from the back of the PIT tag package onto the datasheet, and affix remaining labels onto other collected samples.

7. Age & Reproductive Condition
   - (H) Check the sagittal crest development and record whether it is:
     1- absent
     2- partially developed
     3- well developed- large & obvious
   - (T) Determine the gender & measure the genitals with the plastic ruler
     1- Females: observe the color and status of the teats whether they are nulliparous or enlarged.
     Then measure width and height of each teat. Look for swelling, hair matting around the nipples and lactation.
     2- Males: Determine if the testes have descended, and measure length and width of each teste.
   - Take up close photos of the genitals using the macro setting on the cameras.
   - Estimate the fisher's age based on weight, appearance, teeth wear (done later), sexual maturity, and sagittal crest development.
8. Measurements and overall condition of teeth
   - Count the number and condition of upper and lower incisors. Note whether they are discolored or worn.
   - Classify the upper/lower canines & cusps of molar teeth as: sharp/pointed, points rounded, flattened, broken, and/or discolored
   - Use the calipers to measure the teeth. First turn on the calipers. Move the tips completely together and press the zero button to calibrate the calipers. The display will continue to blink as you move the tips for measurements. Collect the following measurements for all four canines and note the general condition of each.
     1- Length of canine from tip of tooth to base (lateral gum line at lowest point)
     2-Width of canine at tip of tooth
     3-Width at base of tooth- measure base anterior to posterior at gum line

- Measure distance between tips of upper canines, and distance between tips of lower canines.
- Take pictures of teeth.

9. Attach the radio collar (H)
    - Determine if a breakaway collar is needed (directions for breakaway at end of section). If female neck circumference is ≤12.6 or ≥18.6; then use a breakaway collar. If male neck circumference is ≤18.5 or ≥24.5; then use a breakaway collar.
    - Remove the nut from the bolt on the radio collar and set nut in a safe place.
    - Trim the leather strap close to the bolt plate to remove excess strap length.
    - Put the radio collar around the fisher's neck with the antennae pointing down the spine.
    - Overlap the long leather strap against the bolt and adjust the size of the collar until two fingers fit loosely between the collar and the neck. Mark the leather strap with a permanent marker in the spot where the bolt will pierce the strap.
    - Use the leather punch to put a hole in the leather strap. Make sure the smallest punch size is selected.
    - Put the bolt through the new hole, screw on the nut, and test the collar size with two fingers.
    - If the size is too tight/loose, then adjust the size and mark a new spot for the hole.
    - If the size is appropriate, then completely tighten the nut down. Trim the excess leather strap so that it does not protrude beyond the radio/battery.
    - Take pictures of the collar from the nut/bolt perspective and a shot of the antennae displaying the reflective tape pattern.
    - Using a breakaway collar- Breakaway collars are the same as regular collars with the additional piece of glued leather strap that will break upon extended wear.
      1- Trim the leather strap (of the radio collar) close to the bolt plate.
      2- The breakaway collar is glued together with a rough side of glue and a smoother side. Identify the smoother side of the collar and face the smoother side towards the fisher.
      3- Lay the breakaway section in line with the collar strap and slide the breakaway towards the bolt plate until the seam of the glued sections butts up against the bolt plate.
      4- Mark the breakaway with a permanent marker for the bolt hole.
      5- Attach the breakaway to the radio collar in the same orientation as used to mark the breakaway. Make sure the rough glued side is facing out and that the nut is fastened tight.
      7- Now place the collar around the fisher's neck with the antennae facing down the spine.
      The two loose ends of the collar will be attached with an additional bolt plate/nut oriented with the nut on the outside of the collar. Adjust the collar until two fingers fit loosely between the collar and the neck. Mark both leather straps with a permanent marker observing approximately a 1cm margin from the end of both straps.
      8- Punch a hole in both straps. Push the bolt through the radio collar strap with the bolt facing out from the fisher's neck. Push the bolt through the breakaway strap and tighten the nut. Check for appropriate collar size. If the size is too large/small adjust accordingly and punch a new hole.

9- Take photos of both bolt/nut hardware sections of the collar, and a shot of the antennae.

10. Foot Measurements-
    - Use the plastic ruler to measure the following lengths on both right and left feet:
      3- Length of front foot- distance from the proximal edge of the I4 pad to the distal edge of the fourth toe pad.
      4- Length of front foot- distance from the proximal edge of the I4 pad to the tip of the 4th claw.
      5- Width of the front foot- measure the widest part of the foot dorsally while excluding the first toe.
      6- Length of front foot- measure dorsal distance from the wrist to the distal edge of the foot/digits.
      7- Length of hind foot- distance from proximal edge of heel to distal edge of toe pad.
      8- Length of hind foot- distance from proximal edge of heel to tip of claw.
11. Pelage Color/Markings, Injuries, and Body Condition
    - Overall Coat Condition-Choose prime, shedding, summer, mangy, or other
    - Color of Head & Back- choose blonde, pale brown, dark brown, black
    - Check for Markings on the Chin & Throat, Chest, Abdomen- if present choose blonde, pale brown, dark brown, or black
    - Describe any other markings found.
    - Take photos of the markings.
    - Note whether there are any visible injuries, capture related injuries, or old scars.
    - Rank the overall body condition as poor, average//good, or excellent/very healthy.

6. Releasing the fisher

- Before returning the fisher to the cubby, check and collect feces that may be present in the cubby. Deposit feces in a whirl pak and label with date, fisher ID, and contents. Place sample in the collected samples bag. Wear leather gloves to gently put fisher in cubby and replace metal door.
- Document stopwatch time fisher placed in cubby. If the fisher was very alert when placed in cubby, you can check their level of coordination with the tip test as soon as 15 minutes later. Watch the fisher's reaction and balance while you quickly lift the front of trap and tip the trap side to side. If the fisher successfully counters, keeping their footing and upright stance during the tip test, then they are ready to be safely released. If they tip or stumble; they should NOT be released. Wait another 15 minutes and re-assess fisher's status with another tip test. DO NOT release a fisher until it passed the test with controlled reactions of balance and coordination.
- Record the stopwatch time and real time when the fisher actually leaves the cubby.

7. Label Samples and Clean-up Processing Area:

- Place the labels from the PIT tag on each on the three swab samples so that the sample type can still be read. Place the remaining labels on the 2 hair sample envelopes, blood sample, and the ear tissue sample.
- Label the hair sample envelopes and fecal sample with date, fisher ID, and capture or recapture.

- Use alcohol wipes to sanitize the ear punch wire, thermometer, ectoparasite comb, and calipers.
- Clean up all of the equipment and replace in the appropriate bags. Place all dirty linens in the laundry bag to clean upon return to the office.
- IMPORTANT: Review the data form for completeness before departing the capture site

8. Data Entry: When you have returned to the office

1. Update the whiteboard with new fisher information
2. Create a new fisher folder
   - Navigate to SNAMP_Capture_Files found in SNAMP_Capture_Trapping
   - Create a new folder denoted by fisher ID last 5 digits of PIT tag identification #. For example: F34_12345 or M56_54643
   - Within this folder create two more folders for the scanned data sheet and capture photos
   - Label 1st folder "fisher id_Capture Photos_yyyymmdd" (ex: F34_Capture Photos_20081231)
   - Label 2nd folder "fisher id_Capture Sheets_yyyymmdd" (ex: F34_Capture Sheets_20081231)
3. Download capture photos to capture photo folder you just created
4. Scan data sheet and save to capture sheets folder you just created
   - Place side 1 of capture form (w/ top of page to the right) facedown in the HP PhotosmartC6180, Press "Scan Menu" button, then select "Scan to computer"
   - Choose to scan to the computer that you are working on and select "Save to file"
   - When the computer prompts you; flip the data sheet and scan side 2
   - The comp will ask if you want to scan again, chose "done"
   - Both pages will be saved as the latest JPEG file in "My Scans" in "My Documents"
   - Copy this file and drag it into the Capture Sheets folder you just created
   - Rename the file as "fisher id_Capture Sheets_yyyymmdd" (ex: F34_Capture Sheets_20081231)
5. Update all four receivers with the new animal's radio frequency.

   Receiver Background: The receiver has three swivel knobs on top. Turn on your receiver by turning the 'Power/Volume' knob located in the lower right corner to the right. Make sure the 'Gain' knob on the left is turned as far up (right) as possible. The third knob, 'Dial', allows you to scroll through the channels used for designating certain animal's frequencies. Scrolling through channels can also be accomplished by using the up and down arrows on the buttons in the lower left corner of the receiver.

   Channels: The receiver has 1000 different channels (0-999). Male fisher are assigned channels 1-200 while female fisher are assigned channels 201-400 and each fisher's ID is identical to the channel. (Ex. M01 = Channel 001, M02 = Channel 002, F01 = Channel 201, F25 = Channel 225, etc.) If you do not know the sex of the fisher yet, select a channel in the 500 range to test the collar's frequency.

   1. Turn on the receiver.
   2. Press the 'Program' button. The screen will show three lines: the top is the frequency, the middle the channel, and the bottom is text (Fisher ID).

3. Use the down arrow button to move the cursor to the channel row. (Note: You must always first select a channel you wish to use so the receiver).
4. To test a new frequency, type in a channel in the 500 range if you do not yet know the sex of the animal.
5. Use the upward arrow button to move the cursor to the frequency row.
6. Type in the collar's frequency you wish to test. Press the 'Enter' button when finished. (Note: pressing enter a second time will save this information.) Since you are only testing, just press enter once.
7. Make sure the magnet on the collar is removed and listen for the beeps emitting from the receiver.
8. Adjust the frequency by using the dial knob in the top right corner. New collars will usually drift down a few thousand decibels. Adjust the frequency for the ultimate audio signal and be sure to record both the original and 'actual' drifted frequency on the capture sheet.
9. Once the capture event has commenced and sex of the animal has been determined, enter the animal's ID.
10. Follow Steps 1-3 above.
11. Type in the appropriate channel. (Ex. New female capture # 28 = Channel 228.)
12. Use the upward arrow button to move the cursor to the frequency row.
13. Type in the collar's frequency. Adjust the frequency as in Step 8 above if the frequency has drifted.
14. Use the downward arrow button to move the cursor to the text or bottom row.
15. Turn the dial knob in the top right corner to scroll through the alphabet and numbers for the proper ID.
16. Press 'Enter' twice to save this information.

Most likely you will only be able to update the one or two receivers the capture group has with them, and you will have to update the others at the office when all work colleagues and gear return from the field. Don't forget to also update the receiver used for aerial telemetry flights.

9. Restocking the capture bags

- Upon returning to the office, launder the capture gear (denim cone, towels, washcloths, sock, and laundry bag). Put these items back in the capture bags once they have completely dried. Re-stock the capture bags with a new capture kit and radio collar. Check all capture supplies such as thermometer covers, heat packs, iodine, etc. and restock if low. If a metal plate from the capture bags was used, make sure this is returned at the end of the day to the capture bags.

CAMERA TRAP SETUP AND CHECK PROTOCOL

This protocol was developed to guide field procedures used to prepare and deploy camera traps in the field for surveying for fisher presence/absence in 1-km² grid cells.

Camera Trap Preparation

1) Load 8 "C" batteries in camera.
2) Connect battery cable to camera cable.
3) Format CF photo card for camera:
    - Open Silent Image- Mapview Professional program.
    - Go to "change camera settings" to format camera time, and name CF card.
    - Use default for most settings, except naming CF card, and setting time and date.
    - Go to "images" to name the CF card. Call it "UCB X." X corresponds to the number of the camera being used. A "b" card will also be used, as described later, but it does not need to be formatted.
    - Go to "set date and time" tab to set the camera time for the first use. Set the date. Set the time (24 hr) of the card ahead a few minutes, to give enough time to remove it from the computer and place it in the CF card location in the camera.
    - Set the temperature to Celsius.
    - Place CF card in Camera and switch camera to "on" at the exact time formatted on the computer. Now the camera is formatted with the correct time and is ready for use. New blank cards placed in the Reconyx camera after initial formatting do not need to be formatted at this point.
4) Heat 4 desiccant packages in oven for 3 hours, at 170°. Four desiccants can also be microwaved 30 seconds (not recommended to go longer than 2 minutes), but oven use is preferable. Use rubber band to secure packets to one of the cables. Camera is now ready to be placed in the field.

Site Selection and Field Setup of Camera Traps

1) Use center point grid coordinates (UTM: EEE500_NNNN500) as waypoint in Garmin GPS to drive as close as possible to the center point of the target 1 km² grid cell for positioning the camera trap
    a. *our goal is to site the camera in the best possible location in the grid area based on resting habitat selection by fishers* (review Zelinski et al. 2004)
    b. *ideal forest areas for camera traps will include high canopy closure, large dbh black oaks, large decayed logs, large dbh conifers, large dbh snags, moderate to steep slopes, and be near or in drainages with running and/or pooled water (do not place cameras in flat areas with an open canopy, or at elevations above 7000 ft. until further notice)*
    c. *identifying the best location for a camera trap will require an adequate survey of most of the grid area prior to settling on the final camera trap location. This is an*

optimization problem trading off between ease of access, security of site away from areas likely used by people, and high fisher habitat suitability

2) Survey the area identified for the camera trap for trees that will provide good mounting positions for both the camera trap and the bait sock: *camera traps must face in a northward direction (approx 320˚ N to 40˚ N) to avoid triggering by sunlight*
3) Plan to hang both the camera and bait on sturdy trees: *the distance between the tree with the camera and the bait tree must be between 3m and 5.5m, measured by a meter tape*. It is critical to find two trees where the bait tree is larger than the camera tree, ideally the camera tree is 25 to 40 cm dbh and the bait tree is 50cm+ dbh.
4) Use/Complete a Camera Trap Set Up form for recording detailed information on the GPS location, positioning/orientation of camera to bait, and other details on the camera station
5) Clear a visual path between camera and bait tree
    a. *The goal is to minimize situations where animals triggering events/photographs are obscured from view by litter, woody debris or other vegetation*
    b. *Use the small hand saws, lopping shears, or hatchet (backside of a hammer) during this process*
6) Center bait in upper third camera view, and leave approximately 1-2 m of ground view in front of bait tree
    a. *Perform a walk test to aid in correctly positioning the angle of the camera to the bait*
    b. *Use digital image viewer to verify camera is functioning properly, and that the angle and view are acceptable – reposition camera as needed*
7) Place bait (chicken, road kill venison, etc.) in sock, and secure the bait sock firmly to the tree at about eye level
    a. *Place one piece of bait in sock*
    b. *Nail one nail at the top of a folded sock into the tree in summer. During winter months, nail both the top and bottom of the sock to the tree, which will require a duration of effort by the fisher or other animals for removal = more photographs*
8) Hang a string of walnuts and/or pecans above bait sock. This consists of a wire threaded through ten nuts. Smear a tablespoon-size glob of peanut butter over nut bracelet. This particular bait is intended to provide an index to abundance of squirrels and other small mammals within the 1 km^2 grid area
9) Nail a pre-prepared "reflective tape wood slat" or yardstick on bait tree, high end at bait sock level. The reflective tape wood slat is used to determine body size and sex of any fisher that climb the tree to get at the bait.
10) Place Gusto on one end of a small stick and insert the "clean" end under the reflective slat/yardstick. Smear a small amount of Gusto near the base of the bait tree and on 1-2 trees or shrubs in the immediate vicinity. Dab a small amount of Fisher Scent lure on the bait sock itself. IMPORTANT: The field worker that sets out the Gusto, fisher lure, and bait sock, etc. should not set up the camera. Any scent from Gusto, etc. may cause bears

or other large predators to "investigate" the camera, damaging it, or knocking it off center from the bait tree. Before leaving the camera trap site, spray scent neutralizer on a paper towel, and rub over camera.

11) Use a Pentax camera to take "reference photos" of the site and camera. IMPORTANT: The first picture should use the "macro" function to photograph the ID scratched in the side of the camera. Other photos should include a shot of the bait tree (from the camera location), a shot of the camera and it's tree (from the bait tree location), and then a couple photos off to the side to show the general area, habitat type, notable features, etc.
12) After Reconyx camera is mounted on tree, turn it on. Once the cam has finished loading up and the yellow and green lights are on, enter the pass code. When the green light appears (approximately 5 seconds) press "A/1" button until green light flashes. Pass hand over camera image detector until red light appears inside camera body (a click will also be heard). The camera is now working. Pass hand over image detector again, and verify that pictures have been taken. The red light inside camera will flash three times if there is a high level of light. If it is sufficiently dark outside, the infrared light will flash on the outside body of the camera.
13) Take a few pictures of the bait tree, to verify if everything is centered. Use laptop or digital image viewer to verify this, and make necessary corrections.
14) If everything is centered well, turn camera back on, and repeat procedure listed in step 11. Leave site.

IMPORTANT: COMPLETE THE CAMERA STATION DURING CAMERA TRAP SETUP INCLUDING COMPLETE INFORMATION ON ALL ASPECTS OF THE CAMERA TRAP POSITION AND SITE

DATA ENTRY FOR NEW CAMERA TRAPS AND CAMERA TRAP CHECKS ONTO SERVER AT OFFICE

Folder Set-up for Camera Trap Data

1. Open file.
2. "Save as" immediately (so as to avoid messing up the Template) by clicking the ribbon button on the top left corner within Excel and click Save As or press F12. In the pop-up browser window, navigate to Camera_Monitoring_SetUp_Results_Archive and rename file as "SNAMP_Camera_Monitoring_SetUp_Results_YEARMODD_XXX.xls" for the day you are entering your data, with your three initials at the end. Save as type: Excel Workbook. Click Save to save the file in the Archive. You can also save it in the Data Entry Templates folder on the desktop of the computer you are working on and then cut and paste it into the Archive when you finish data entry.

Downloading Reference Photos

1. When setting up a grid survey camera in the field for the first time, you will take several "reference photos" with our Pentax cameras. When you are entering your data for

camera setup, be sure to use the camera cord to download these pictures to a new folder within the grid survey folder, clearly labeled with the grid, UCB camera ID, and "ref photos", for example: 267_4141_UCB050_Ref Photos. If a new camera has replaced the original, make sure to use the full name history in the data sheet, and to update the name for previous checks in the Master data file. For example, a station with original camera 014 replaced with new camera 028 should be entered as UCB_014_028 in the current data sheet and in all previous entries in the Master.

Data Entry

1. Enter all collected data into the template using the drop-down cells provided. Name the grid cell ID and camera ID cells in reference to the top row. If there is not an option within the drop-down box which describes your results, manually type it in. Be sure to name the grid cell and the camera used with the provided format.
2. Note: the monitoring period column will automatically calculate once the initial set-up date and check dates have been entered. If a camera was not taking pictures because it was disturbed or is malfunctioning make sure to count up the days it was inactive and enter into cell "AL". Make sure to describe the issue in the detailed notes column.
3. Continue to enter all your camera monitoring and/or setup data and save when finished.

Append your Data

1. Open Z:\SNAMP_Cameras\Master Data Files\SNAMP_Camera_Monitoring_Setup_Results_Master.xls.
2. Expand your data sheet. Select and copy the rows of the new data you have entered.
3. Expand the Monitoring SetUp Results Master worksheet and click on the next empty row. Right-click and hit Paste Special… Select Paste Values and click OK. Check to see that all your new data has appended to the Master worksheet.
4. Save and close the Monitoring Results Master worksheet within Excel.
5. Save and close your data entry worksheet within Excel and close Excel.

Update Active Camera Trap worksheet

1. Open Z:\SNAMP_Cameras \Master Data Files\SNAMP_Active_Camera_Traps.xls.
2. Select all cells by clicking the top left corner of the worksheet, or press CTRL+A. In the home tab, click Sort & Filter: Custom sort. Make sure the box "My data has headers" is marked. Click Sort by: Camera.
3. Update the worksheet to reflect the cameras you checked today. Enter the day you checked the camera on the next available CheckDate cell. Change the Next Check Date cell to seven days from the day you checked the camera. If the rows of the cameras you checked were highlighted, un-highlight them.
4. Select all cells by clicking the top left corner of the worksheet, or press CTRL+A. In the home tab, click Sort & Filter: Custom sort. Make sure the box "My data has headers" is marked. Click Sort by: Next Check Date. Highlight all rows of cameras the need to be checked in the immediate future.

5. Save, print and close this file. Close Excel. Attach printed worksheet to whiteboard for others to view.

IMPORTANT: When finished with all data entry, be sure to return the field version of the camera data sheet to its correct folder in the black file box labeled “Camera Monitoring”. This should be done quickly so that others can access the data.

CAMERA TRAP CHECKS AND SERVICE 8-10 DAYS LATER

1. 8 days later, return/navigate to Reconyx camera site using previously recorded coordinates as waypoints in handheld GPS.
2. Turn camera off and replace CF card “a” with “b” card. This new card does not need to be formatted, but does need to be labeled properly with a marker. If you do not have a spare card, see PhotoViewer downloading below.
3. Turn on the camera according to the above instructions (*Field Setup* #12). Trigger the camera and then view several images from the CF card with a digital image viewer to verify the camera remains angled properly.
4. Use the digital image viewer to screen through photos for the check period. Record the species present/detected in area for “notable species” sightings on the data form.
5. Remove old bait sock even if it is undisturbed. Nail a new bait sock to the tree and refresh Gusto and fisher lure. Add new nut bait if missing or mostly eaten. Refresh nut bait with more peanut butter.
6. Turn camera back on, verify that the battery level is sufficient (>30%, on new style Reconyx) and depart the site. Do not touch the camera after you have touched the gusto and fisher lure. It will attract bears to the camera. If you are the only technician, use sticks to turn on the camera and close it. Or, you can spray scent neutralizer on a paper towel, and rub over camera.
7. Check every 8-10 days, for a total of 4 checks and 32-40 days. If the camera is checked late and the 32 survey days are reached by check 3, the camera still needs to stay out for a fourth check.
8. If the camera was operating properly for all checks and was not disturbed by bears, remove the camera, bait, wood slat and all nails on check 4.

PhotoViewer Downloading

1. Insert CF card into Epson PhotoViewer and turn on.
2. Go to: Memory Card → Browse CF Memory Card. Press OK.
3. Press the Menu button. Go to: Copy/Move → Copy to Folder. Press OK.
4. Press the Menu button. Highlight Select All and press OK. Press OK.
5. Go to: My Photos → Create New folder and press OK.

6. Name the file by the Grid cell, camera being used, the date you're downloading and what monitoring check this is. For example 273_4144_UCB_005_20080108_Check1 corresponds to grid cell 273_4144, Camera UCB 005, downloaded on 8 January 2008 and it's the first check for this camera location. Navigate to Done and press OK.
7. Check to make sure your photos were copied to the PhotoViewer. Navigate to My Photos and find the folder you created and press OK.
8. Once you have confirmed the photos were copied press back until you reach the main menu screen. Eject the CF card and turn off the PhotoViewer.
9. Return CF card to the camera, refresh bait and lure, turn camera back on and depart site.

CAMERA TRAP IMAGE TAGGING PROTOCOL

This protocol was developed to help guide the summary process for camera trap images. Each camera records important metadata with each photo taken. Metadata includes date, time, moon phase and other conditions recorded at the time of image capture. After photos have been downloaded to a computer via CF card or a PhotoViewer and the camera has been removed from the field, we will use RECONYX MapView to view the photos and add keywords ("Tag Images") to the Metadata file. Our added keyword tags describe what the camera actually recorded in the image. The metadata for each monitoring session will then be appended to a Master data file, which can be used to investigate the efficacy of our camera trapping effort.

Loading Images into MapView

1. Open Mapview, located on the desktop, in the quick-launch taskbar, or in Start → All Programs → RECONYX → MapView.
2. Click on the drop down arrow under the heading 'Site' and 'Choose a site' to make sure the Grid Cell you are entering data for exists. If your location site is not there, click 'Create a new site.' Name the site by the Grid Cell you will be tagging.
3. Click on the down arrow to the right of the 'View/Load New Images' button located in the upper left hand corner of the program window. Click on 'From Another Folder.'
4. Navigate to the camera folder you want to summarize. The pathway should resemble the following: Z:\SNAMP_Cameras\Camera_Images_Survey_Year_04\Removed Camera Images\Removed_Images_Backed_Up\[Grid ID]\[CheckX]. Click 'OK.'
5. Click 'Check-All.' Click 'Next.'
6. Click 'Add a new location.' Name the location as the grid cell and CheckX (for example: 268_4144_Check1) and click 'OK.' Select your new location and click 'Next.' Click 'Next' again. Once the images have been copied, click 'Finish.'
7. MapView will revert back to the original screen. In 'Camera locations' select the images you want to summarize. Click on 'View Images.' This will load the images into the viewer. Select the view style that suits you. The default view style is Detail, which is preferable to Thumbnail because it is quicker to load.
8. If your images have not yet been flipped to Portrait, refer to *After uploading images to computer, flip photos right-side up and transfer photos to server*, located in: Z:\SNAMP_Protocols\SNAMP_Camera_Image_Download_Protocol.doc

Tagging Images with Keywords

1. First, tag all the images with the monitoring session (check) number. Click on the first image in the viewer. Press CTRL+A to select all. Right-click on the selected images and click on 'Image Data.', click 'Add a Keyword.',click 'Click to choose a keyword.', click on 'CHECK #' and select the appropriate check number. Click 'OK.'
2. Next, tag all of the images for camera type using the same process as above for check number. Refer to SNAMP_Active_Camera_Traps for the camera type for the grid you selected. Press CTRL+A to select all. Right-click on the selected images and click on 'Image Data.', click 'Add a Keyword', click 'Click to choose a keyword.', click on

‘CAM_TYPE’ and select either ‘KW_Survey’, ‘1k_Survey’, ‘HE_Marten’, ‘4k_Survey’, ‘Smammal’, or ‘YNP_1kSurvey’. Click ‘OK.’

3. Once all the images have been tagged with the check number and camera type, it’s time to tag images that contain pictures of animals. An important fact about these Reconyx cameras is that when the camera is triggered, it takes photos in bursts of three images at a time. Thus, an animal that triggers the camera will have a minimum of three photos, even if it runs out of the camera’s view before the 2nd or 3rd photos are taken.
4. Flip through the images loaded into the viewer. Often there will be setup photos of our colleagues in the beginning and end of each check. Select these and tag as ‘Setup’ under the SPECIES_EVENT keyword option.
5. Begin tagging blocks of images by species. An image should be tagged with a particular species if it contains an animal or a blur of an animal, or if it is part of an animal-triggered series of images even if the animal is no longer visible. Hold CTRL and SHIFT and click on the series of photos associated with the first species you wish to tag. Right-click on this selection and click on ‘Image Data.’
6. Click ‘Add a Keyword.’ Click ‘Click to choose a keyword.’ Click on ‘SPECIES_EVENT.’ From the dropdown menu, choose the species depicted in the selected images.
7. If you cannot identify an animal to species, try to identify to family. In the ‘SPECIES_EVENT’ dropdown menu, there are options for Canid_Unknown and Squirrel_Unknown. Birds must only be identified to class, i.e., should be tagged as Bird, but you are encouraged to identify to species in the Narrative tab. If you cannot place an animal in any taxonomic group, select Animal_Unknown.
8. If the images were triggered by a domestic dog, tag ‘SPECIES_EVENT’ as Dog, and make notes in the Narrative tab as appropriate. In particular, note the presence of multiple dogs.
9. If the images appear to have been triggered not by an animal but by environmental conditions, choose the ‘SPECIES_EVENT’ option that best fits your assessment of the situation. As follows is a list of options and when they should be used:

Shadows_Wind	Triggered by tree parts moving in the wind *during daytime.*
Weather_Wind	Triggered by tree parts moving in the wind *during nighttime.*
Weather_Precip	Triggered by rain or snow, including snow falling from tree branches.
Sunlight_Exposure	Use when bright sunlight obscures a good portion of the image and no movement is detectable.
Tree_Branch	Triggered by tree or large branch falling or pine cone rolling *independent of wind* **(uncommon)**.
Stream_Water	Triggered by a river or stream in the background (**uncommon)**.

10. If the images were triggered by a human or vehicle not affiliated with the SNAMP study, tag ‘SPECIES_EVENT’ as Human/Vehicle. Include any notes in the Narrative tab.

11. If the images do not appear to have been triggered by an animal, human, or environmental conditions, tag 'SPECIES_EVENT' as Unknown.
12. We may now affix the keyword, IMAGE QUALITY, to those images that require it. As follows is a list of IMAGE QUALITY options and when they should be used. If none of the following scenarios apply to an image, it should not be tagged for IMAGE QUALITY.

Poor	The image contains an animal, but the animal cannot be identified from that image alone.
Animal_Not Visible	The image is part of an animal-triggered series, but the animal is not visible.
Disturbed_Off View	The camera was previously disturbed, and is no longer focused on the bait tree.
Disturbing_Bear	The camera is in the process of being disturbed by a bear.
Disturbing_Fisher	The camera is in the process of being disturbed by a fisher.
Disturbing_Squirrel	The camera is in the process of being disturbed by a squirrel.
Disturbing_Unknown	The camera is in the process of being disturbed by an unknown animal.
Cam_Malfunction	The image is dark or blurry due to a problem with the camera.

13. When tagging bear images, there are two additional steps you may undertake. After tagging 'IMAGE_QUALITY', add the keywords 'BEAR' and 'BEAR COLOR.' 'BEAR' asks you to assign a size/sex category to the bear as follows:

Sub_Adult	Smaller than adult bear, but unaccompanied by mother.
Female_1	Female with one cub.
Female_2	Female with two cubs.
Female_3	Female with three cubs.
Female_4	Female with four cubs.
Large_Male	Large adult bear travelling alone.
Unknown	Unable to place into size/sex category.

14. 'BEAR COLOR' asks you to describe the bear's coat as Black, Dark_Brown, Light_Brown, Blonde, or Unknown.
15. At this point, the Add/Edit Image Data window associated with a particular image may have up to 6 keywords: CHECK #, CAM_TYPE, SPECIES_EVENT, IMAGE_QUALITY, BEAR, and BEAR COLOR.

****THE ORDER IN WHICH IMAGES ARE TAGGED SHOULD BE CHECK#, CAM_TYPE, SPECIES_EVENT, IMAGE QUALITY, BEAR (WHEN APPLICABLE), BEAR COLOR (WHEN APPLICABLE).*** IMAGES THAT ARE NOT TAGGED IN THIS ORDER WILL AFFECT THE CORRESPONDING CSV FILE.****

Exporting Image Data

1. Once you have gone through all the images, it's time to export the Metadata from all the images. Press Ctrl + A to select all images. Click on 'Image' → 'Export Image Data.'
2. Navigate to: Z:\SNAMP_Cameras\Camera_Master_Data_Files_Year_04\SNAMP_SilentImage_CSV_
   a. Summary_Files_SurveyYr_04\Created_from_Silent_Image_Unprocessed, and either find the folder for the camera you are summarizing, or make a new folder and save file name as: XXX_XXXX_CheckX. This name refers to the camera location grid cell and check number. Click Save.

Additional Notes:

- You can only view the information you tagged on an *individual* photo. If you are tagging several images simultaneously, the previously tagged information will not be visible although it is there (not lost or deleted.) Same for correcting data—although you can tag as a group, you can only correct an entry one at a time.
- Narrative: Use this tab in the Add/Edit Image Data box to explain any tagging that is unclear, or to provide information not generated through the tagging process. For example, you may get a rare species that is not listed in the SPECIES_EVENT dropdown menu. Select 'Unknown' under SPECIES_EVENT in this case, and use the 'Narrative' tab to illustrate the animal's identity (Mountain Beaver!)

Update Active Camera Sheet

1) When you've finished tagging your images update the active camera sheet located at Z:\SNAMP_Cameras\Camera_Master Data Files\SNAMP_Active_Camera_Traps.xls
2) Enter the date you tagged the images and your initials in Column N.

CAMERA IMAGE CSV FILE PROCESSING PROTOCOL

The following protocol is a description on how to use the CSV Template when creating CSV files. The protocol must be followed as described below to ensure run time errors are not encountered.

1. Create a temporary folder on the desktop labeled with your initials_CSV (JAM_CSV). You will use this folder for the duration of the time you will be creating and proofing CSV files. However, be sure to delete this folder once you have finished with CSV files for the day.

2. Unprocessed CSV files may be found in Z:\SNAMP_Cameras\Camera_Master_Data_Files_Year_##\SNAMP_SilentImage_CSV_Summary_Files_SurveyYr_##\Created_From_Silent_Image_Unprocessed.
   - Browse to the camera grid you will be creating the CSV files for and copy all checks. Paste the selected checks into the temporary folder you have created on the desktop.
   - Once the files have been pasted into your temporary folder on the desktop rename all files so that the file names consist simply of Check1, Check2, etc. **(IF THE FILES ARE NOT LABELED AS INSTRUCTED ABOVE YOU WILL ENCOUNTER A RUN TIME ERROR.)**

3. Once the files have been renamed open each check file.

4. Open the CSV_Template excel file, found in Z:\SNAMP_Cameras\CSV_Template.

   - Please note the template has been set as a read only file, this is to ensure the template is not accidentally over written. When prompted to work in the file as read only select yes.

5. The CSV_Template file opens to display the CSV format check options. These options consist of how many checks you will be formatting and range from a single check to seven checks.

6. Before proceeding confirm all checks you will be working with have been renamed correctly and all check files are open.

7. Choose the CSV format # Check button that corresponds with how many check files you have.

8. Once the format completes confirm all checks are present, open each tab, confirm that the file is complete with correct check # and all data are present, and add the visit #'s.
   - *PLEASE NOTE: IMAGES OF GOOD QUALITY ARE NOT LABELLED AS SUCH DURING THE TAGGING PROCESS AND ARE LEFT BLANK. IF AN ENTIRE CHECK HAS GOOD QUALITY PHOTOS YOU MUST MANUALLY ADD THE IMAGE_QUALITY COLUMN. (See below for proper column arrangement).*

9. In the visit# column will be NEW VISIT to indicate a new visit for that species. While previously we would manually change the NEW VISIT to visit number 1,2, etc. **we no longer need to do this**. Leave the visit column as is and the NEW VISIT tags in place. Visit numbers will be generated when the processed CSV is added to the CSV master.

10. WHAT THIS PROCESS DOES NOT DO IS ORGANIZE THE SPECIES, VISIT, QUALITY, NARRATIVE COLUMNS, BEAR, AND BEAR COLOR FOR YOU. ALSO, IT DOES NOT COPY THE CHECKS INTO THE PROCESSED FOR SUMMARY TAB. BE SURE THE ABOVE MENTIONED COLUMNS ARE SORTED CORRECTLY AND THEN COPY EACH CHECK INTO THE PROCESSED FOR SUMMARY TAB.
    The correct arrangement of the columns should be:
    1. Site
    2. Cam Type
    3. Image name
    4. Image path
    5. Moon phase
    6. Temp
    7. Check#
    8. Date
    9. Time
    10. Species Event
    11. Visit#
    12. Image quality
    13. Narrative
    14. Bear (When applicable)
    15. Bear Color (When applicable)

    - Note that the bear and bear color columns will only be present if a bear was present at the check.
    - If you encounter a situation where the columns are not sorted correctly be sure to follow the above column arrangement as well as RE-SORTING THE ENTIRE CHECK. This may be done by choosing on the excel tool bar, Home-Sort&Filter-Custom sort. When the sort dialog box opens choose my data has headers and then add a level. You will add several levels and first choose Species, then Date, and lastly Time to populate the column field. IF YOU FIND THE NEED TO RESORT BE SURE TO CONFIRM THE VISIT# COLUMN IS CORRECT.

11. Save the file as "###_####_CSV_Processed_For_Summary.xlsx" within the Z:\SNAMP_Cameras\Camera_Master_Data_Files_Year_03\SNAMP_SilentImage_CSV_Summary_Files_SurveyYr_03\Processed_For_Summary folder.

12. Please note that the check files you have opened for processing will close automatically once the template macro is finished formatting.

MEASUREABLE FISHER IMAGE J MEASUREMENT PROTOCOL

This protocol is used to measure/extract various physical (morphological) measurements from fishers photographed at camera trap stations surveyed with Reconyx automatic digital cameras. Based on body measurements taken from captured study animals, it is possible to determine the sex of individual fisher based on several of the measurements we obtain from the camera photos. It may also be possible to determine individual identification (individually discriminate) fisher from the measurements

Before we begin please familiarize with the list of standard measurements, measurable data entry files, and the ImageJ program, which may all be found below. Additional information for the ImageJ program may be found in Z:\SNAMP_Office\ImageJ.

Standard Morphological Measurements

There are up 9 standard measurements that will be taken for each "measureable fisher photo", although the number of measurements possible for each photo will often be fewer. IMPORTANT NOTE: *you do not need to obtain all of the listed measurements for each photo; only take the measures that are possible based on the orientation/view of the fisher in the photograph.*

<u>List of Standard Measurements:</u>

- Head length (Hd_Lgth): straight line tip of nose to base of skull
- Ear tip to ear tip (Ear_Ear): measure the widest distance between the ears
- Neck width (Neck_W): distance across neck immediately behind base of ears, measuring the width of fur (from hair edge to hair edge).
- Head+body length (Body): tip of nose to end of body at base of tail
- Tail length (Tail): top of tail to base of tail not including tuft of hair at very end of tail
- Length of right and left forefeet (RFt_L or LFt_L): base of "wrist" to tip of foot
- Width of right and left forefeet (RFt_W or LFt_W): distance across back of forefoot not including the pollex or "thumb" (will often be extended apart from the other digits for gripping the tree)
- Forward edge of ear to forward edge of ear (Inner_ear): measure distance between where the ears meet the front of the head.

Measureable Data Entry Files

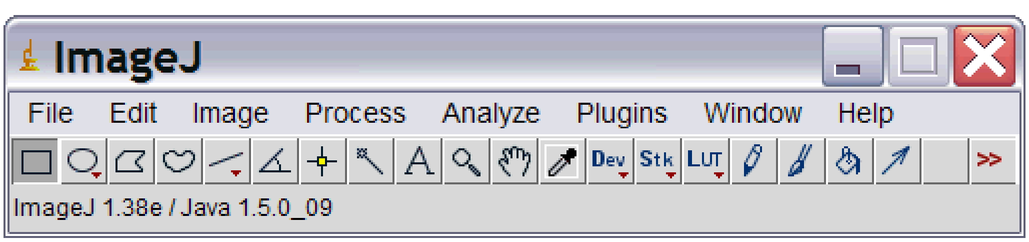
- To record the measurable results to the SNAMP database open the Excel SNAMP**_MeasureableFisher_Database file located in the Camera_Master_Data_Files_Survey_Year_03 folder** on the server.
- Begin by filling in ALL of the basic information for the photo(s) you will be measuring: Grid_ID, Check_No, Check_Date, F_Visit No, F_Type, Photo_No, Photo_Date, Photo_Time. Information on the fisher visit number (F_Visit_No) is available on the "Fisher_Visits_Detailed" worksheet in the SNAMP_Active_Camera_Traps_SurveyYr_0X file. Information on the date and time for the photo should be taken directly off the image – upper right corner, which may be obtained from the image you are working with.

- Move to the Excel program window with the already open file "SNAMP_MeasureableFisher_Database" and name and record your measurement.
- From this point you easily can proceed through all of the measurements that are possible for the photo you are measuring.

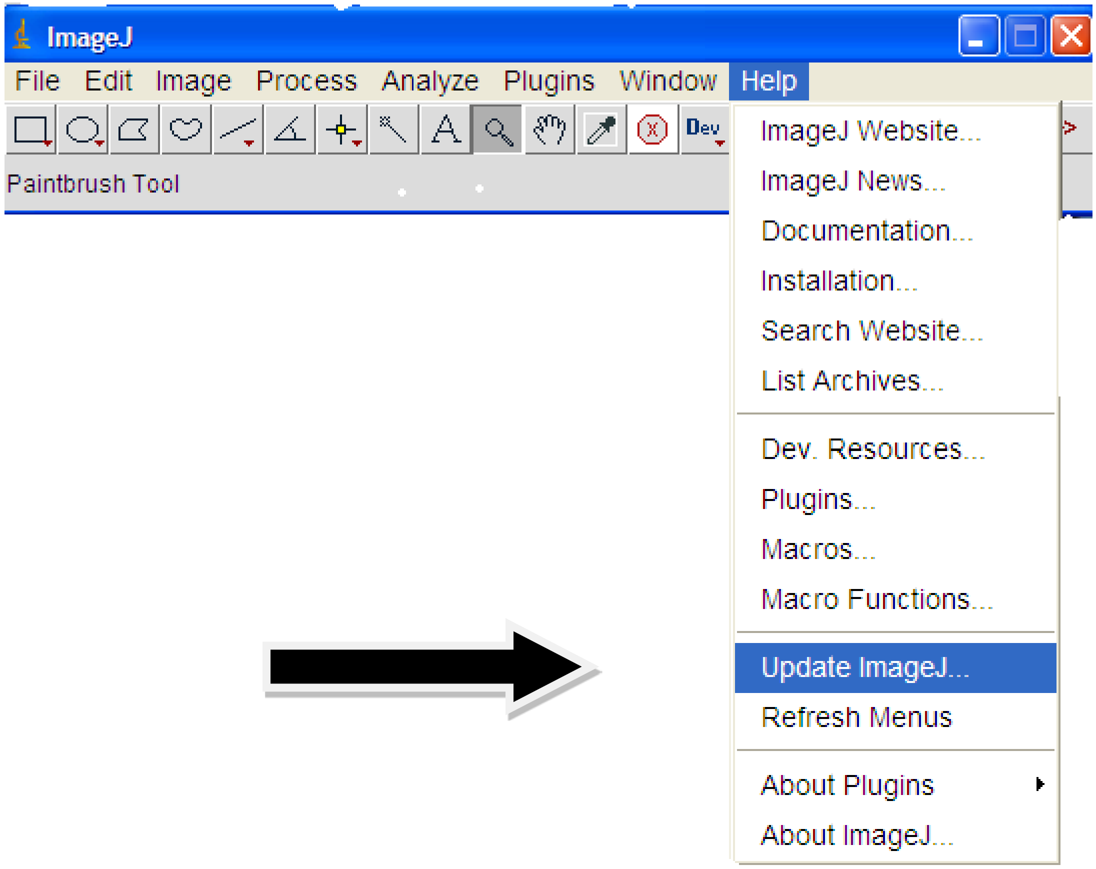
IMAGEJ Measureable Image Instructions

- We will have pre-selected the "Measureable Fisher Photos" from the fisher active grids during a given Camera SurveyYear. Please use the worksheet titled MeasurableFisher_Database_SurveyYr_0X" in the 'SNAMP_Active_Camera_Traps_SurveyYr_0X" file in the **"Camera_Images_Data_Survey_Year_0X"** folder on the server to track your contributions to measuring fisher body sizes.
- The camera images for all grids from a Camera Survey Year where fishers were detected should include a folder titled "XXX_XXXX_Measureable_Fisher_Photos." These photos are the only ones we will use for taking measurements from the fisher active survey grids.
- For your information and for future reference, fisher images that are considered measureable are those for which (a) the photo includes a wooden slat with at least two of the reflective tape markers easily visible, and (b) fishers are on the bait tree with back/body/head/tail oriented mostly towards the camera. Also, the best quality measurable fisher photos are those where the animal is stretched to its full length along the tree, not bunched up or twisted to the side. In instances where multiple photos are of quality to measure, select the best 5 photos, ensuring that as many of measurements listed below (page 1) are obtained. NOTE: Some images may be selected in order to obtain a good measure of one of just a few body features.
- <u>IMAGEJ</u>

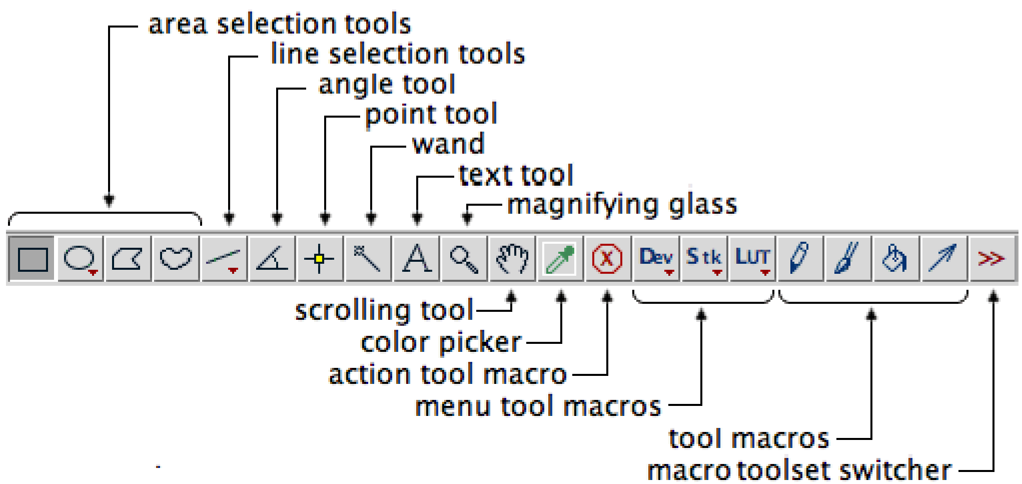
- Open "ImageJ" from its location on the desktop. The ImageJ program will open and consist simply of the ImageJ toolbar (File, Edit, Image, Process, etc.), illustrated below.



- **Before beginning any measurements be sure to update the Image J program to accommodate any upgrades that may be available.**
  a) On the toolbar navigate to Help - Update ImageJ.



- To open the image you will be measuring choose File/Open, and browse to the desired image using the path: Z:\SNAMP_Cameras\Camera_Images_Survey_Year_XX\Measurable_Fisher_Database.
- To open the desired image simply double click on it and a new, separate window will open. This new window containing the image will be the platform from which measurements will take place.
- **Before any measurements begin you must first set the scale for the measurable fisher image. (NOTE:*Scale must be set for each measurable image*)**
  a) To perform this operation we will be using the Zoom (magnifying glass icon), Line (straight icon), and Set scale feature, located on the ImageJ toolbar.

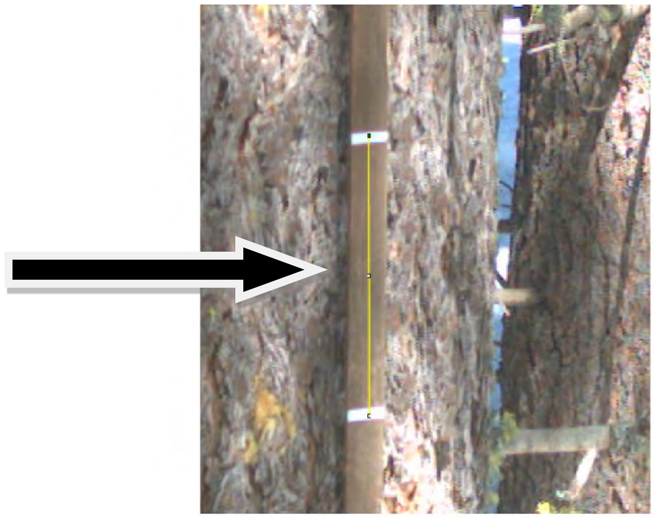


- **Before adjusting scale, first suggest to zoom into the slat, then enlarge the measurable image**, which may be done by either stretching the image vertically or horizontally.

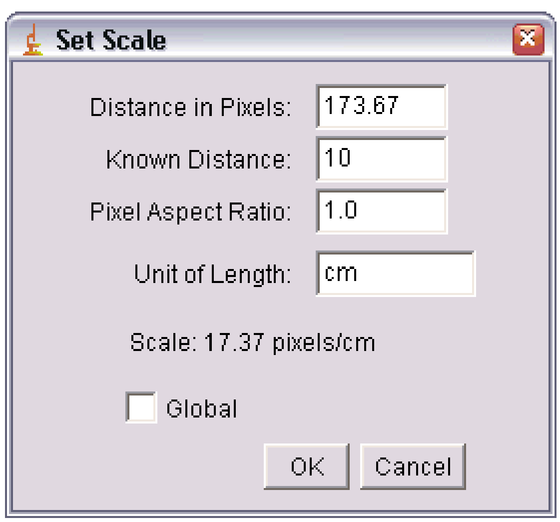
- To set the scale follow the steps below:
- ZOOM 
  1. Zoom into the woodslat by choosing the magnifying glass icon found on the ImageJ toolbar. Once the zoom feature has been chosen the cursor will appear as an “iron cross” once placed over the image. To zoom in, left click on the section of the image (wood slat) you want enlarged, right clicking on the image will zoom out.
     a. Note that hot keys are also available once zoom mode is activated
        ctrl + + (plus sign) zooms in
        ctrl + - (minus sign) zooms out.
- STRAIGHT LINE 
- During this step we will be creating a single line that stretches from the center of one piece of reflective tape to the center of the next consecutive piece of reflective tape.
  a) On The ImageJ toolbar choose the straight line icon. When your cursor has been placed over the image it will appear as a light gray + sign.

     By using the reflective strips that are most visible this will give you the most accurate measuring standard. Each reflective strip has a small amount of height, but the accurate measurement marking is in the middle of the strip’s height. Also, remember that the space between each reflective strip is 20 cm, or 0.2 m.

  b) Single left click in the desired area and drag the cursor to your destination point. This will create a single, straight, yellow line on the measurable image. Illustrated below.
     Please note that the line may appear staggered, if so, straighten the line by slightly dragging the endpoint either to the left or right.



- SET SCALE
- Once you have established your straight line on the slat set the scale for the image.
  - On the ImageJ toolbar choose Analyze/Set Scale.
  - The Set Scale dialog box will open in a separate window. Enter the known distance of 0.2 (this is only if you have placed your line between two pieces of consecutive reflective tape, see above for further explanation).
  - Enter unit of length as **m,** indicating the unit of measurement as meters.
  - Once the known distance and unit of length fields have been entered click OK.

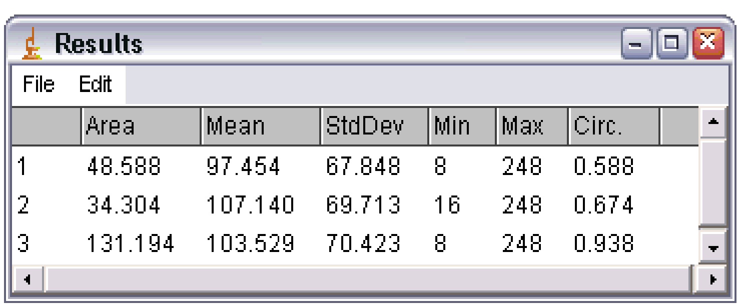


  - At this point the image is now ready to be measured and processed.
  - MEASURE
  - Measuring is accomplished by using the Straight Line  and Segmented Line  feature. The straight line will only measure from the beginning point of your measurement to a single end point, such as when measuring ear tip to ear tip. The

segmented line has the ability to measure from the beginning point of the measurement to multiple end points. This becomes helpful when taking the head and body measurement. ***Please note body length may be taken using the straight line feature by first measuring the head, record the measurement given, then by clicking on the lines point of origin, (tip of nose) then drag that point of origin to the base of the tail. The tail may be measured similarly by taking the point of the lines origin (base of tail) and dragging it to the tip of the tail.***

- The segmented line feature may be accessed by right clicking on the straight line icon, a drop down box will appear and from there you will be given several line options, including the segmented line.

- **NOTE: When measuring the head length, it may be helpful to position a line across the back of the head, from behind each ear. The middle of this line will usually be very close to the back of the skull, depending upon how the head is tilted.**
- Re-zoom  and pan  around the image as needed for obtaining all other measurements.
  - **The measurable results may be obtained from the ImageJ toolbar once you have placed your endpoint at the desired location. However, the cursor must not move once it is placed at the end location or the displayed results will no longer be available. You may also obtain the results by choosing ctrl + m, which will open the results dialog box. Once the data has been collected close the results box and do not save it.**


Results
File Edit

	Area	Mean	StdDev	Min	Max	Circ.
1	48.588	97.454	67.848	8	248	0.588
2	34.304	107.140	69.713	16	248	0.674
3	131.194	103.529	70.423	8	248	0.938

- The final step is to rename the original image file in the **Server** folder from which it was originally obtained. If the original file name was

M0001102 it should be renamed to include your initials (M0001102_RAS) indicating that the photo has been measured.

- Once you are done obtaining all possible/reasonable standard measurements, close the image, File/Close.

DEN SITE LOCATION AND DEN MONITORING PROTOCOL

The purpose of this protocol is to outline the methods we will use to search for and identify the den structures used by reproductive-aged female fishers. The methods primarily involve ground-based telemetry and "walk-ins" on female fisher in the early morning and, less frequently, early evening hours.

Equipment needed for Den Site Walk-ins:

a. Telemetry receiver + collapsible Yagi antenna + coaxial cable
b. Blue telemetry receiver headset
c. Garmin GPS unit
d. Pentax camera
e. Den site data forms: Den/Rest Site Form, Den Check and Walk-in Monitoring Form + Den Camera Check Form
f. Flagging
g. Truck omni (if travelling by truck)

Finding a new den or rest site

1. Individuals involved in performing aerial radio-telemetry will provide information on the locations of adult female fishers during the early morning period between 7:00 and 8:00 am. Adult females will be top priority for locations during late March and early April for all telemetry flights.

2. Once aerial locations are acquired for the targeted adult females for the day, the information will be communicated by radio to the ground crew waiting to perform walk-ins. It is critical that this location information is given as "Location reference" with no reference to a possible den structure. In addition, the numbers broadcast over the radio will be limited to the "LAT mm.mm" and "LONG mm.mm" without the degrees [always 37˚ (LAT) and 119˚ (LONG)]. To further protect the security of fisher den locations while broadcasting over the USFS radio, the last four digits of each Latitude and Longitude (minutes and fraction of minutes) should be transposed or reversed. (For example, the aerial readout is 37.42.18 and 119.54.68. The aerial technician should report these digits to the ground crew: 18.42 and 68.54.)

3. Ground crews will need to temporarily change the "Units" under the Setup menu for their Garmin GPS units for inputting the Lat/Long data as UTM waypoints. In the Units directory, highlight and open the drop-down menu for the "Position Format." Once this menu is visible, toggle down and select the "hddd˚ mm.mmm' format (This is degrees, minutes, and fraction of minutes.) Exit out of the menu and enter the LAT, LONG numbers provided from the airplane (remember that they are reversed!) (In the above example, the ground crew would enter 37.42.180 and 119.54.680. A zero is added on to the fraction of minutes.) Once the numbers have been entered, return to the Setup then Units menu and change the Position Format back to "UTM UPS".

4. The ground crew should now be in position to walk-in on the predetermined fisher, or can reach the location obtained via aerial-telemetry quickly. Once a strong signal is obtained on the ground (i.e., several bars flashing on the receiver), "walk-in" toward the animal.

Helpful Telemetry Hints:

- Make sure the gain is turned all the way up when first trying to listen for the animal. If the animal is far away and the gain is too low, you may miss it. Once you get a signal, adjust the gain lower (and volume louder) as you get closer. This will help in pinpointing the animal. **When you think you are getting close (within a few hundred meters), put on your blue headset to minimize noise disturbance to the animal.**
- Position of the yagi can greatly affect signal strength and direction. A vertical yagi is good for hearing a signal from a great distance (use this position if the animal seems far away (i.e., only one or very few bars flashing in the receiver). Again, make sure the gain is turned all the way up. A horizontal yagi is good for ascertaining direction, especially when getting close to the animal. Using both positions during a walk-in can greatly assist the speed and precision in which you locate the animal. Try to keep the yagi in the same plane when switching from vertical to horizontal positions (i.e., the yagi is not a magic wand.)
- Signal bounce can make ascertaining direction of a signal confusing. Try using both vertical and horizontal yagi positions. If this doesn't help, try changing position yourself. If you or the animal is near a large granite outcrop or steep canyon, you may have to do some walking around to get into a better position.

5. Once you think you have located the animal in a tree, confirm by circumnavigating the proposed tree using your telemetry gear. Flag a nearby tree (NOT the actual den tree) for future reference. Use your pentax camera to take several reference photos from differing angles. Take a waypoint with your GPS and fill out a new den/rest site data sheet. Although these data are important, completion of this form should be done quickly as to minimize further disturbance to the animal. If this is a new den or rest site and you are finding the animal for the first time at this location, the den/rest site form and the den check monitoring form are all the data forms that are needed.

Den Camera Set-Up and Checks

Confirmation of a new fisher den site usually happens the day after the initial location and is performed during an early morning walk-in. **Special circumstances**: Denning females that are logistically difficult to visit frequently are an exception to this rule. In addition to the telemetry equipment needed for Den Site Walk-ins (see page 1), a photoviewer, 2-3 Reconyx cameras, and the Den Camera Check Data Sheet are needed. Den camera checks and walk-ins are to be conducted every 3 days.

1. Before heading out, take a look at the reference photos your fellow technician took of the suspected den tree you will be confirming.
2. Set up 2-3 Reconyx cameras focusing on the base of the den tree. **NOTE****All denning female fisher are assigned 2-3 permanent Reconyx cameras that will remain with them throughout the denning season. Be sure to get adequate ground coverage at the base of the tree. Cameras should be placed 5-8 meters away. If using the new style Reconyx cameras, make sure the camera is programmed to "rapid fire." Double check to make sure date and time are correct.

3. When checking Den cameras, if the fisher is in the den tree or close by, you need to act swiftly and silently to minimize disturbance. Use your photoviewer to quickly download the photos. Save copies of the photos from each of the den tree cameras onto the photoviewer. Create new folders in the photoviewer and label with Fisher ID, UCB, and date. (Example: F01_UCB_056_20090406). Once you are a good distance away from the den tree or at your vehicle, scroll through the photos for each den camera and note date and times of fisher activity, if any.
4. (Quickly) fill out the Den Camera Check Data Sheet. Alternatively, complete the data form when you've gotten back to your vehicle, or somewhere away from the den tree to minimize disturbance.
5. Mating typically occurs about 1 week after females give birth (late March-early April), so male fishers will frequently be around natal den trees in early-mid April. When at natal den trees you should also scan through the frequencies for adult males and look around. If you hear or see any other fishers in/near natal den trees note this on the data form.
6. If the fisher is not in the suspected den tree, continue to locate her using telemetry to pinpoint her new location. Mark her new location with GPS and flagging. If the animal is located in a new tree, (quickly) fill out a new den/rest site data form. If it is suspected you have "bumped" her off her den tree or that her signal indicates she is active and on the move, take a general waypoint and leave the area. DO NOT continue searching for a fisher on the move. Fill out the Den Check Monitoring Log Data Sheet.

Naming Den Trees

A female fisher will change dens several times throughout the denning season. The female is thought to spend a longer period of time (2-3 weeks) at her first or 'natal' den. The Natal den is where her kits are born. Over the next two months, she'll very likely move her kits to a different den every 7-10 days. These secondary dens are 'maternal' dens. The female will spend more time foraging as the kits get older and have better thermoregulation while inhabiting the maternal dens. Label the dens Natal, Maternal 1, Maternal 2, Maternal 3 and so on.

Moving Den Cameras

Den cameras are to be moved ONLY after a den confirmation walk-in has been performed. A confirmation walk-in is performed the day after finding a suspected new den in the early morning hours. It is unlikely that new dens will be more than a kilometer from the old den as the female will have to transfer her kits over this distance. After confirming the new den site, return to the previous den site, remove the cameras, and set-up at the new site using the **Den Camera Set-Up** protocol above.

Office Data Entry:

- Update the **Fisher_Denning_Database_Master_20XX** (Z:\SNAMP_Fisher_Denning_Kit_Data\Denning Season 2011\Den_Season_2011_Master_Data_Files). There are three different worksheets in this spreadsheet that correspond to our three datasheets. If you found a new den site, enter your information into the "Fisher Den Site Data 2011" worksheet. For a walk-in, the "Den Check

Monitor Log 2011" will need to be updated. If you installed or checked cameras, open the "Den Cam Check Log 2011" worksheet and update your new information.

- If you installed or moved den cameras, open the "Den_Camera_Images_2011" folder located on the main server (Z:\SNAMP_Fisher_Denning_Kit_Data\Denning Season 2011). Open the folder for your denning female and create a folder for the den tree type (i.e., Natal, Maternal 1, Maternal 2, etc.). Within that folder create another folder named "Reference Photos" and upload your reference images there.
- If you checked den cameras, open "Den_Camera_Images_2011" folder and find the female's folder you have camera images of. Open the folder for your den tree type (i.e., Natal, Maternal 1, Maternal 2, etc.). Create a new folder for your check (simply Check 1_**Date**) and create a new folder for each UCB camera inside of this. Label it with UCB_XXX. Transfer the images to the new folders you have created.
- Even if your cameras did not have any photos during the check, make sure you still create an empty folder for each camera you visited and add "No photos" to the end of the label (Example: UCB_024_NoPhotos).
- Open the **Active Camera Traps Year 4** spreadsheet. There are two different worksheets that are present during the denning season only. Enter your walk-in information into the "Fisher Den Walk-in Schedule" worksheet. Add three days to the "Next Check Date". Open the "Den Cams" worksheet and enter the information from Reconyx den cams you setup, moved or checked. Den cams should be checked every 3 days as well.

PROTOCOL FOR ASSESSING HABITAT/VEGETATION CHARACTERISTICS AT FISHER DEN TREES

The purpose of this protocol is to begin to understand the combination of biotic and abiotic characteristics female fishers are likely selecting/using for denning habitats. Our goal is to collect similar types of data as those being recorded by the Forest Health Team on the Core Plots in the Sugar Pine area, while also capturing the same types of data being recorded by the Kings River Fisher Project at their den trees.

For each natal and maternal den tree we will define a circular plot centered on the den tree with a fixed radius of 18 meters (area ≈ 1 hectare), represented by the diagram below. Each circular plot will include four 18 meter transects, one each oriented N (0/360˚), E(90˚), S (180˚), and W (270˚), originating from small nails in the base of each den tree (removed at completion of plot). We will next define four 4m X 18m belt transects as the sampling space extending 2m from either side of each 18 meter line transect. Finally, within the circular plot centered on the den tree, we will also define 4 plot sections ordered A, B, C, and D clockwise from the N transect.

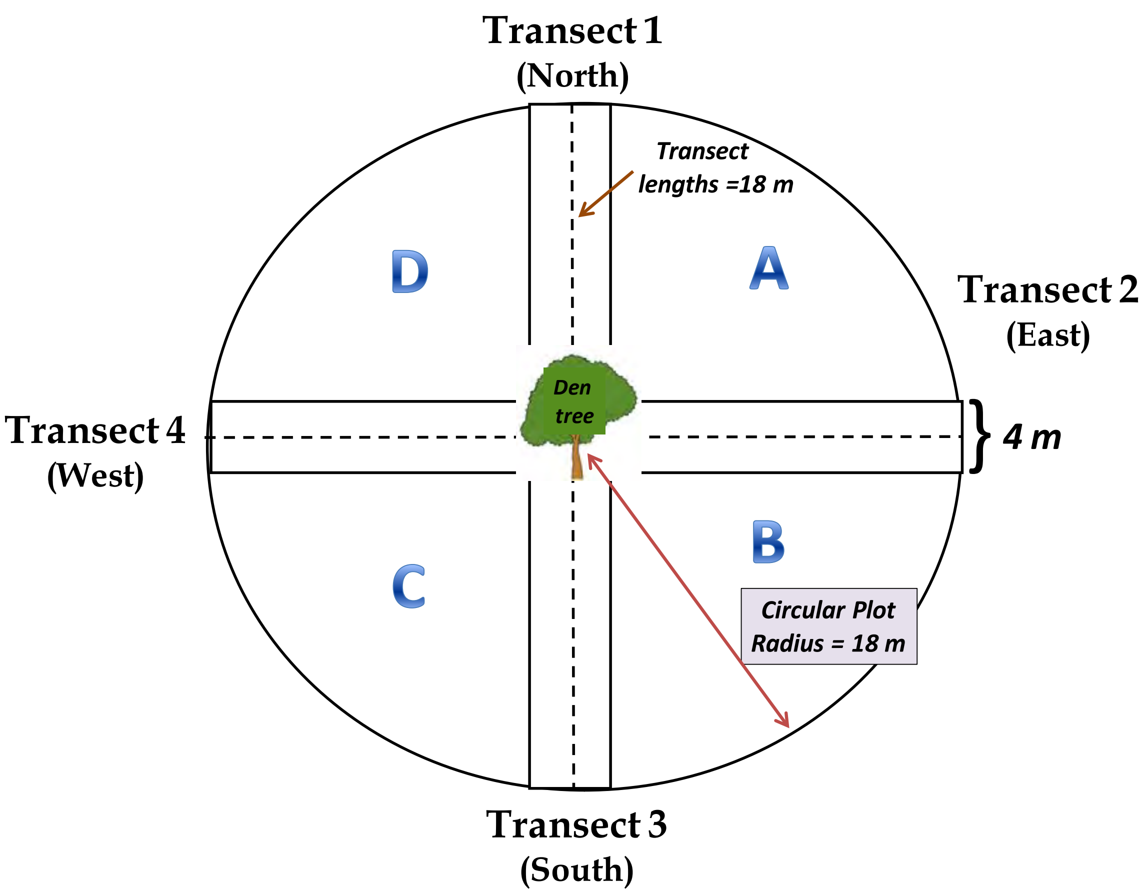


Figure D1.1: Diagram illustrating the layout of circular plots and associated measurement transects, including 4 quadrats A, B, C, and D.

Assessing/Measuring Canopy Cover: Canopy cover will be measured at the 2m, 6m, 10m, 14m, and 18m positions along each of the four 18 meter transects using a sighting tube device called a "moosehorn coverscope." At each sample point hold the coverscope to your eye, sighting as you would a periscope, center the bubble in the center of the bullseye level, then maintain the coverscope plumb and level while counting the number of line intersections on the grid obscured by forest canopy. NOTE: the grid is viewed as being crosshairs, and the number of squares that are open or obscured is unimportant. Also, there are a possible 25 possible hits or intersections, including the outside intersections at any one sampling point. See Figure D3.

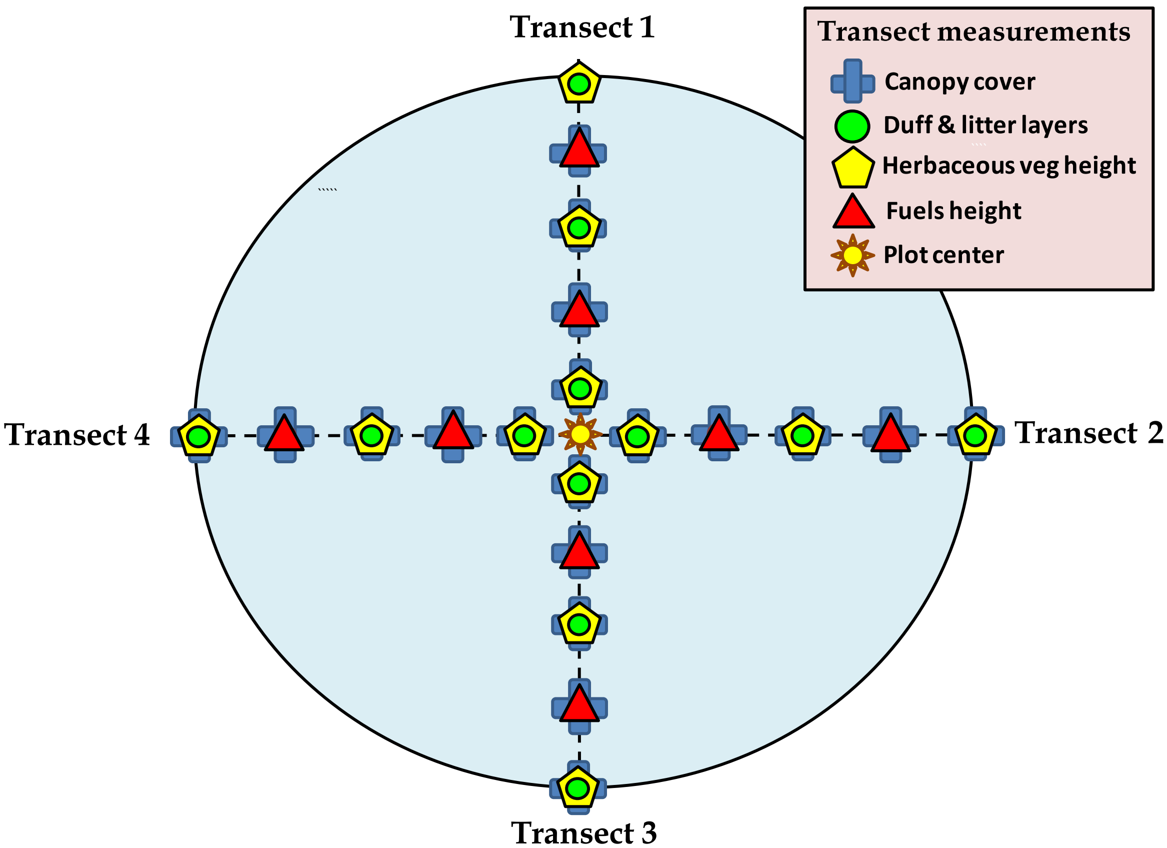


Figure D1.2: Diagram illustrating multiple types of measurements to be taken along the four 18 meter line transects.

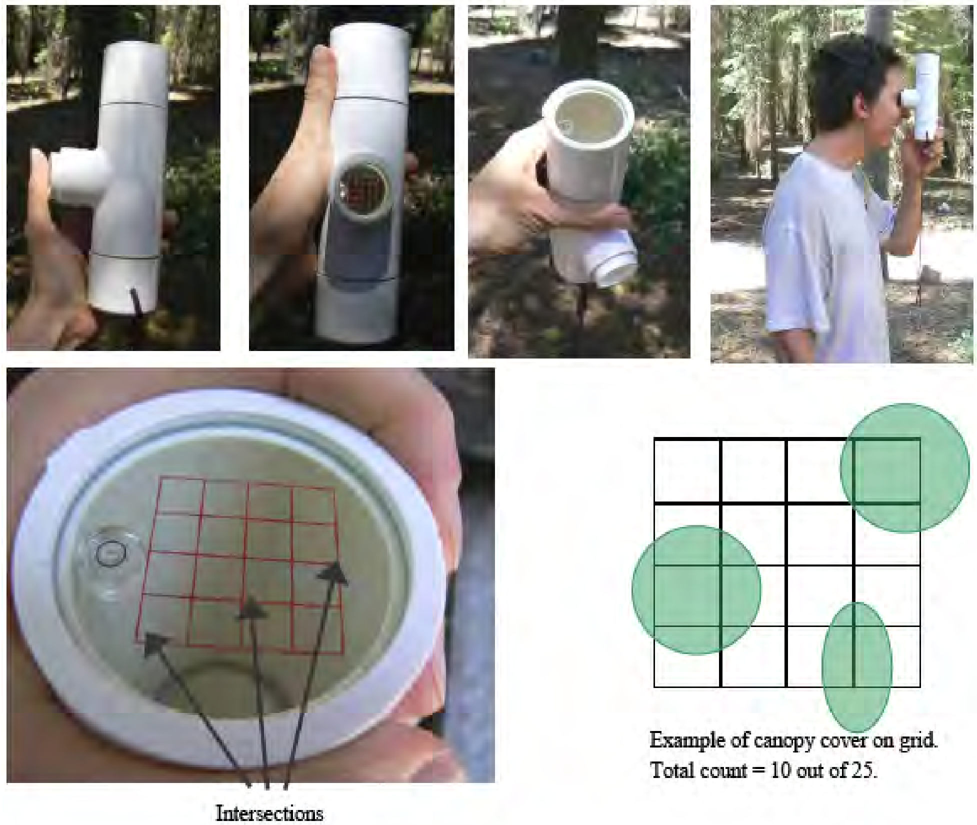
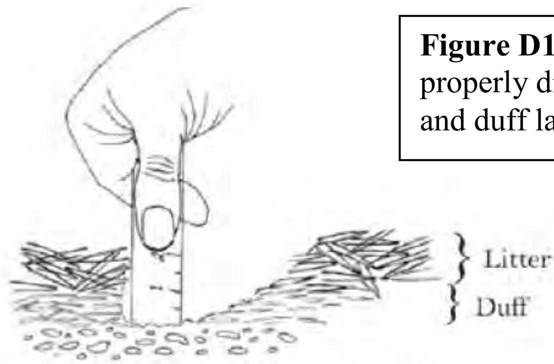


Figure D1.3: Overview of using the moosehorn coverscope; the coverscope should be held with the longest length perpendicular to the ground. The small side tube should be held up to the observer’s eye with the bubble level. The user will then count the number of intersections which are covered by canopy. The lower left photo points out what the intersections look like (corners, side intersections, middle intersections). The diagram on the lower right provides an example of what canopy cover might look like on the grid. In this example, the count would be 10 out of a total of 25.

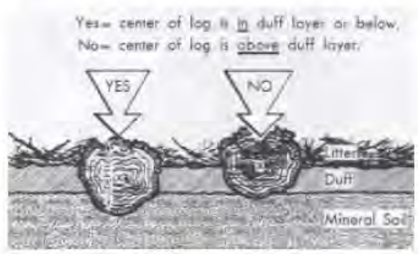
Assessment of Litter, Duff and Fuel Height: We will measure the thickness of the duff and litter layers and fuel height at several positions along each 18m transect. Measurements of the duff layer, litter layer, herbaceous vegetation, and fuel height will be done at the 2m, 10m, and 18m positions. Height of herbaceous vegetation (herbs or grasses), if present within a 10 cm radius of the point, should be measured first, prior to excavating holes for measuring the duff and litter layers.
Use a hand trowel to dig three small vertical holes down through the litter+duff to mineral soil at 2m and 10m and 18m along each 18m transect. If a tree of stump occurs at the position, offset your digging 30cm to the right. Measure the thickness of the duff (± 0.5cm) from the mineral soil to top of duff, and the litter layer (± 0.5cm) from the duff to top of litter, not including woody debris (branches/sticks/logs). Fuel measurements will start at the bottom of the litter layer and end at the top of the tallest fuel up to 1.83m (6 feet). Fuels are any woody twig (> 0.64 cm diameter), branch, or log that is severed from the original source of growth with its central axis lying above the duff layer

(excluding needles, grass, bark or pine cones). Basically, if the fuel object isn't more than 1/2 buried in the duff, its height up to 1.8 m/6 feet will be measured. If no fuel exists, record the height of the litter at the point.

Figure D1.4: Diagram illustrating how to properly discriminate between the litter and duff layers for taking measurements.



When stumps, logs, and trees occur at the point of measurement, offset 30 cm perpendicular to the right side of the sampling plane. Measure through rotten logs whose central axis is in the duff layer.



Duff depth is measured through a rotten log when its central axis lies in or below the duff.

- Duff thickness (mineral soil to top of duff;) (see diagram)
- Litter layer thickness (duff to top of litter; ± 0.5cm) (see diagram)
- Fuel height (bottom or litter layer to top of tallest fuel up to 1.8m/6 feet); if no fuel at point record the depth of the litter layer)
- Herbaceous/grass vegetation height (nearest 1 cm)

Shrub level vertical cover (i.e., concealment): Shrub level vertical cover will be measured using a cover-board/drop-cloth design. As we are concerned with concealment in general, not just shrub cover or foliage density, anything that provides potential cover to the fisher as it is coming or going from the tree should be counted (e.g., tree trunks, sapling foliage, shrub cover, boulders).The drop-cloth is 3 m x 0.5 m and is composed of 0.1 x 0.1 m squares separated into 4 categories: 0-0.3 m (15 squares, low ground), 0.3-1m (35 squares, high ground), 1-2m (50 squares, low shrub), and 2-3 m (50 squares, high shrub). One observer stands with their back to the den tree while a second person holds the cloth at the 10 m position along each transect. The observer counts the number of squares within each height interval at least 50% obscured by 'cover' and records this number. The observer should squat while reading the two lowest sections (low ground and high ground) and stand while reading the upper sections (low shrub and high shrub). The technician holding the cover-board should try to hold it as straight and steady as possible, taking care to make sure the bottom dowel is hitting the ground and that the cloth is taut in all directions.

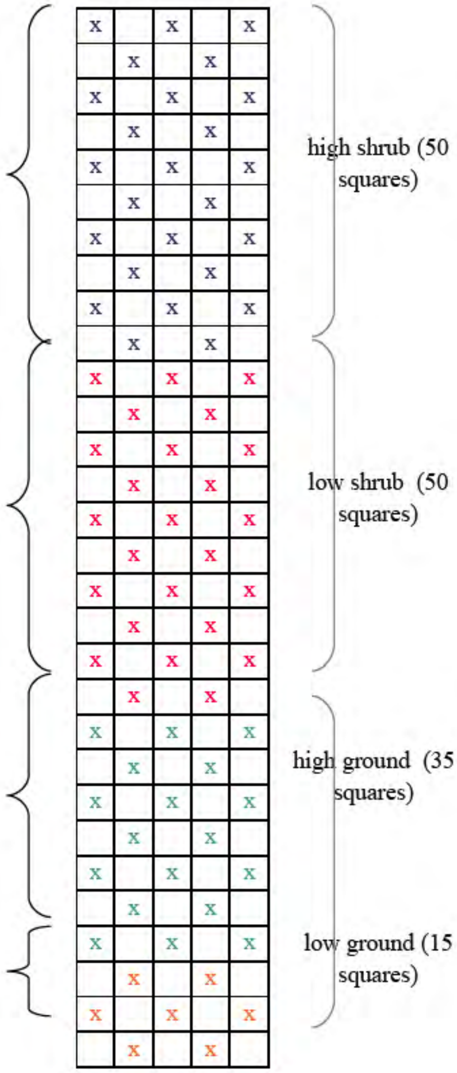


Figure D1.5: Design and use of coverboard for estimating concealment cover around the base of den trees. The coverboard is divided into four sections representing low ground cover, high ground cover, low shrub cover, and high shrub/small tree cover.

Measuring Topographical/Landscape Features: The prevailing aspect for the slope upon which the den tree is located will be measured using a clinometer. Walk to a position on the slope adjacent to the den tree with your back to the hillside behind you. Use the clinometer to estimate the prevailing aspect (*Hint: if you spilled your water, which way would it flow?*).
Slope will also be measured for the hillside upon which the tree is located. Use a clinometer to take two measures of slope, which will be averaged for the recorded measurement on the dataform. To obtain an appropriate measure of slope look directly uphill and locate a tree or object about 15-25 meters away. Estimate where your eye level would be on that tree/object (around 1.5 m), look through the viewfinder on the clinometer and read the % slope on the right hand side

Assessment of Sizes, Numbers of Trees and Snags Within Circular Plot): We will enumerate and measure all medium and large size trees and snags (see below) within each area of the circular plot. All medium and large size trees will be characterized by Vigor Class and Crown Class.

Trees and snags will be grouped into three size classes for measurements:

- Size class 1: greater than or equal to 19.5cm Dbh
- Size class 2: 5.0cm to 19.4cm dbh
- Size class 3: ≤ 5.0cm dbh

Live trees and snags are further be broken down into 6 vigor classes as follows:

Live trees:

- Class 1: healthy tree with no visible defects
- Class 2: healthy trees with minimal damage or defects (broken/dead tops, abnormal lean, etc.)
- Class 3: live trees that appear near death or likely to die within 5 years

Dead trees

- Class 4: a recently dead tree with little decay (retains bark, branches, top, even some needles)
- Class 5: Tree showing some decay including loss of some bark, broken off branches/top
- Class 6: tree shows extensive decay including loss of most bark, branches, broken top

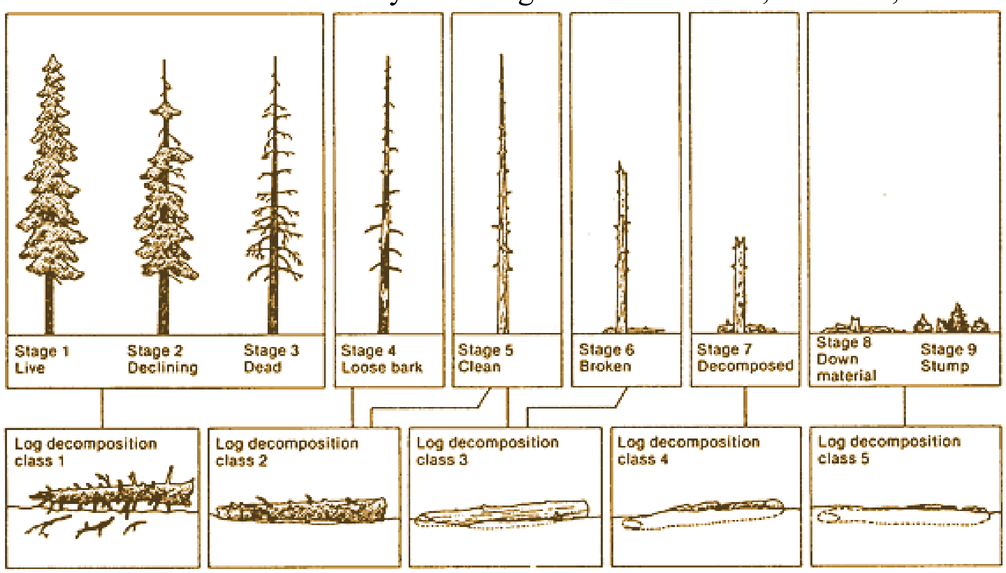


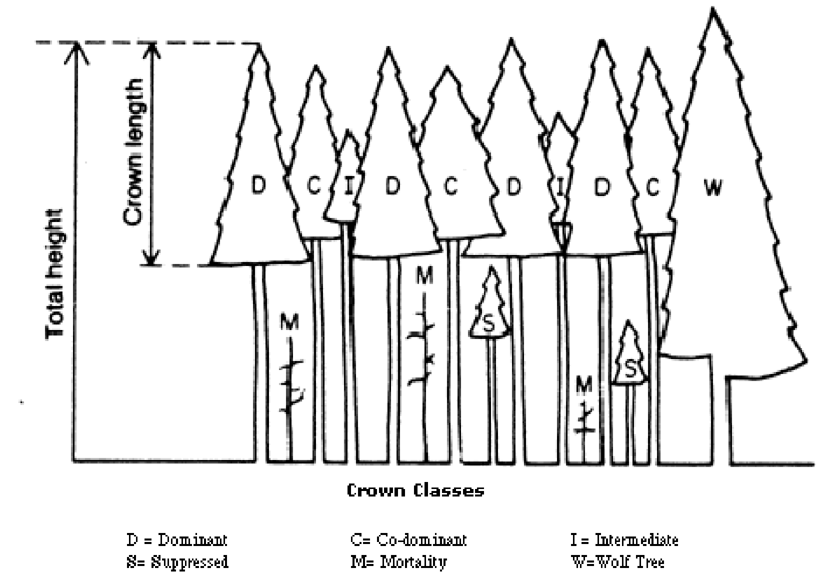
Figure D1.6: Illustration of multiple different possible vigor classes for trees and snags. For our habitat assessments, vigor class 3 will be trees that are near death, vigor class 4 will be recently dead snags, vigor class 5 snags are those with loss of limbs and loose bark (Figure stages 4-5), and vigor class 6 snags are those with broken tops, few if any limbs and visibly decomposed (Figure stages 6-7).

Live trees only will be characterized by Crown Class as follows:

- **D** (Dominate): trees with crowns extending above the general level of the crown cover and receiving full light from above and some from the sides
- **CD (Co-dominate):** trees with crowns forming the general level of the crown cover and receiving full light from above, but little light from the sides

- **I (Intermediate):** trees that are shorter than the class D and CD trees but with crowns either below or extending into the above crown cover and receiving little direct light from above or the sides
- **S (Suppressed):** trees with crowns entirely below the general level of the crown cover, receiving no direct light from above or the sides

Figure D1.7: Diagram illustrating trees of different crown classes, and associated crown height measurements.



Trees/Snags within Size Class 1 and 2: We will measure the straight line distance from the den tree to every tree or snag within Size Class 1 and 2 in each of the four quadrats (A, B, C. D) of the circular plot around the den tree. In addition, we will take a bearing from the den tree to each of the Size Class 1 and 2 trees in order to create a stem map once back in the office. After measuring the distance (± 5 cm) and bearing to each of these trees/snags, record/assess the vigor class, crown class (live trees only), height to live crown base (live trees only) and total tree/snag height for each of these trees/snags.
Small Trees/Snags (Tree Size Class 3): All live and standing dead trees less than 5.0cm dbh and a minimum height of 1.37 meters will be counted in each of the four quadrats around the den tree. Track on the dataform the live/dead status of these trees.
Assessment of Woody Shrubs: Woody shrubs will be sampled along each of the four 18m transects using the line-intersect technique. For all woody shrubs that occur along and intersect the transect line record/measure:

- Shrub species (see species list below)
- Length of shrub intersect (nearest 10cm)
- Average height (± 5cm)
- We will also record an ocular estimate of overall shrub cover by species within each of the 4 quadrats

Assessment of Cover by Herbaceous Plants: In addition to measuring the height of herbaceous cover (± 1cm) at the 2m, 10m, and 18m positions along the four line transects, we will also assess and record an ocular estimate of the percent cover of herbs and grasses combined in each of the four quadrats around the den tree.
Assessment of Course Woody Debris (CWD): Course woody debris is defined as dead tree boles, large limbs, and other large wood pieces either lying on the ground or elevated off the ground up to 45˚, but no longer supported by roots (i.e., dead trees hung up or leaning on other vegetation). CWD does not include live material, standing dead trees, stumps, dead foliage, separated bark, non-woody

pieces, roots, or the part of the bole below the root collar. We will assess/measure CWD along two of the four 4 X 18m belt transects, either transects 1 and 3, or transects 2 and 4. Use a coin flip to chose between Transects 1 and 2; if Transect 1 was selected then CWD will be assessed/measured along Transects 1 and 3, whereas if Transect 2 was selected then CWD will be assessed along Transects 2 and 4. Each piece of CWD sampled within the belt transects must have a large end diameter (LED) of 15cm and be at least 1m in length. Core variables to be measured include:

- Species (if determinable)
- Small end diameter (SED) in cm
- Large end diameter (LED) in cm
- Total length in meters to nearest cm
- Length of CWD within transect in meters to nearest cm
- Whether or not the midpoint of the CWD object fell within the belt transect
- Decay class of the CWD object (see Table below)

Other sampling rules for CWD pieces and logs:

- If a log is partially suspended by other logs or tipped against other trees, measure only the portion of the log that is within 2m of the ground.
- Pieces that are tipped must have an angle < 45˚with the ground to qualify as CWD.
- For logs with their root wad still attached, the large-end diameter (LED) is measured just above the butt swell, but the length is taken to extend into the mass of wood within root wad
- When a tree is forked or has a very large branch attached to the main bole and both segments intersect the transect, they are tallied as two separate pieces (see figure below), if each meets the required minimum dimensions. Forked trees are examined to identify one fork as the main bole by measuring both diameters at the fork location. The forked segment with the largest diameter is considered the main bole and the length is measured from the tip of the fork to the end of the log. The smaller segment is recorded as a second piece with a length measured from the fork tip down to the point where the fork joins the main bole.

Table D1.1: Overview and definitions of five Course Woody Debris (CWD) decay classes based on structure integrity, texture and overall condition.

Decay Class	Structural Integrity	Wood Texture	Condition of branches, twigs, and bark.
1	Sound	Intact, no rot.	Branches, twigs, and needles still attached with tight bark. Log solid.
2	Heartwood sound; sapwood somewhat decayed.	Mostly intact; sapwood soft-starting to decay. Wood cannot be pulled apart by hand.	Branches present, fine twigs or needles gone. Loose or peeling bark, 75-100% remaining.
3	Heartwood sound; log supports its weight. Sapwood decaying.	Large hard pieces of sapwood can be pulled apart by hand.	Branches not present; stubs will not pull out. Bark loose but 50-75% remaining.
4	Heartwood rotten; does not support its weight but shape maintained.	Soft, small blocky pieces can be pulled apart.	Branch stubs pull out easily. 0-50% of bark remaining.
5	No structural integrity. Log circumference flattened.	Soft and powdery when dry.	Bark gone.

Figure D1.8: Illustration for how to count and measure branched logs during CWD assessments.

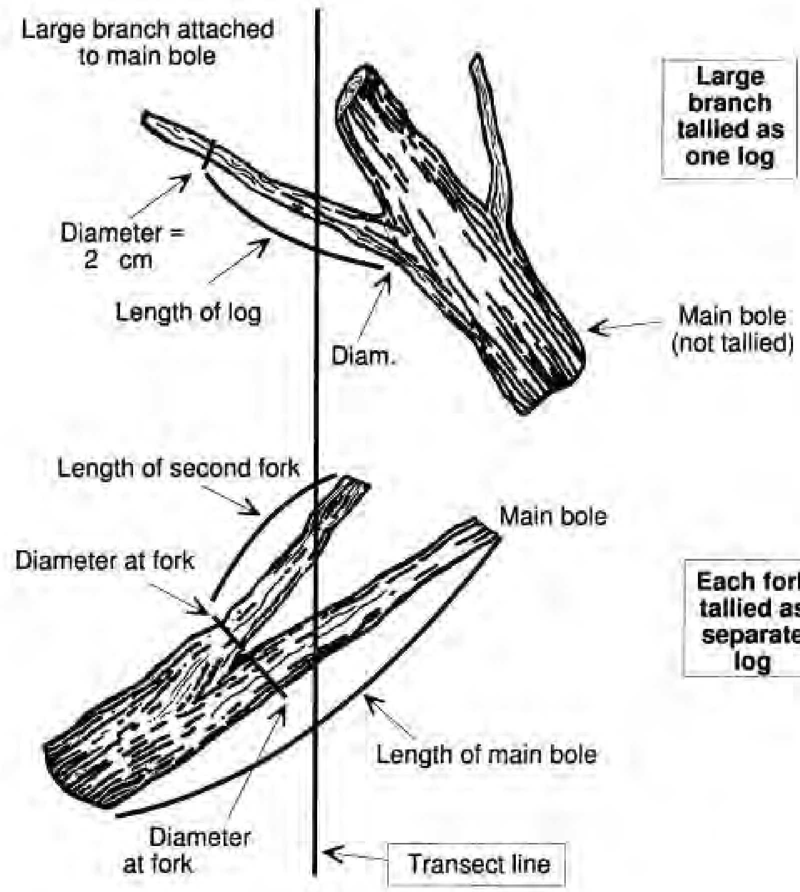


Table D1.2: List of the species of conifers, hardwoods, and woody shrubs present in our study area and around den tree structures.

Type and common name	Genus and species	Data code
Conifer trees		
White fir	*Abies concolor*	ABCO
Incense cedar	*Calocedrus decurrens*	CADE
Sugar pine	*Pinus lambertiana*	PILA
Douglas fir	*Pseudotsuga menziesii*	PSME
Jeffrey pine	*Pinus jeffreyi*	PIJE
Ponderosa pine	*Pinus ponderosa*	PIPO
Western white pine	*Pinus monticola*	PIMO
Giant sequoia	*Sequoiadendron giganteum*	SEGI
Red fir	*Abies magnifica*	ABMA
Lodgepole pine	*Pinus contorta*	PICO
Gray pine	*Pinus sabiniana*	PISA
Hardwood trees		
Black oak	*Quercus kelloggii*	QUKE
Canyon oak	*Quercus chrysolepis*	QUCH
Live oak (uncommon)	*Quercus spp.*	QUSP
Tan oak (uncommon)	*Lithocarpus densiflorus*	LIDE
White alder	*Alnus rhombifolia*	ALRH
Mountain dogwood	*Cornus nuttallii*	CONU
Woody shrubs		
Pine mad Manzanita	*Arctostaphylos nevadensis*	ARNE
Greenleaf Manzanita	*Arctostaphylos patula*	ARPA
Birchleaf mountain mahogany	*Cercocarpus betuloides*	CEBE
Mountain whitethorn	*Ceanothus cordulatus*	CEBE
Buckbrush	*Ceonothus cuneatus*	CECU
Deerbrush	*Ceanothus integerrimus*	CEIN
Mahala mat	*Ceanothus prostratus*	CEPR
Mountain misery	*Chamaebatia foliolosa*	CHFO
Bush chinquapin	*Chrysolepis sempervirens*	CHSE
Bitter cherry	*Prunus emarginata*	PREM
Huckleberry oak	*Quercus vaccinifolia*	QUVA
Western azalea	*Rhododendron occidentale*	RHOC
Currant	*Ribes* spp.	Ribes
California rose	*Rosa californica*	ROCA
Thimbleberry	*Rubus parviflorus*	RUPA
Blackberry	*Rubus ursinus*	RUUR
Willow	*Salix* spp.	Salix
Snowberry	*Symphoricarpos mollis*	SYMO

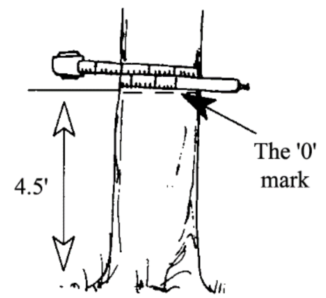
Definition/Details on how to measure Dbh (diameter at breast height) in different situations

Dbh is outside bark diameter at 4.5 feet above the forest floor on the uphill side of the tree. To determine breast height, the forest floor includes the duff layer that may be present, but does not include unincorporated woody debris that may rise above the ground line. If a dead tree (snag) is missing bark, measure the Dbh without the bark and record that measurement.

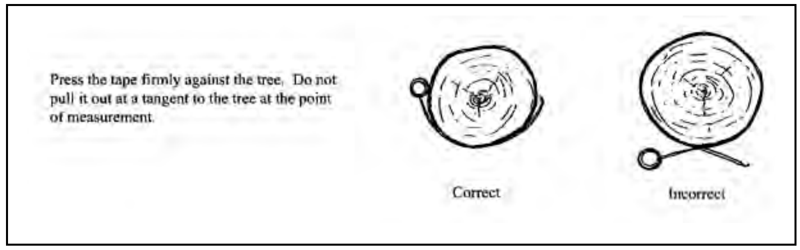
Forked tree: In order to qualify as a fork, the stem in question must be at least 1/3 the diameter of the main stem and must branch out from the main stem at an angle of 45 degrees or less. Forks originate at the point on the bole where the piths intersect. Forked trees are handled differently depending on whether the fork originates above or below 4.5 feet.
Trees forked below 4.5 feet are treated as distinctly separate trees. Dbh is measured for each stem at 4.5 ft above the ground.
Trees forked at or above 4.5 feet count as one tree. If a fork occurs at or immediately above 4.5 ft, measure diameter below the fork just beneath any swelling that would inflate Dbh.
Stump sprouts originate between ground level and 4.5 ft on the boles of trees that have died or been cut. Stump sprouts are handled the same as forked trees, with the exception that stump sprouts are not required to be 1/3 the diameter of the dead bole. Stump sprouts originating below 1.0 ft are measured at 4.5 ft from ground line. For multi-stemmed woodland species, treat all new sprouts as part of the same new tree.
Tree with irregularities at Dbh: On trees with swellings, bumps, depressions, and branches at DBH, diameter will be measured immediately above the irregularity at the place it ceases to affect normal stem form. If this is not possible, because of the vertical extent of the irregularity, then adjust the Dbh measurement to better reflect the diameter of a regular bole.
Tree on slope: Measure diameter at 4.5 ft from the ground along the bole on the uphill side of the tree.
Leaning tree: Measure diameter at 4.5 ft from the ground along the bole.
Independent trees that grow together: If two or more independent stems have grown together at or above the point of DBH, continue to treat them as separate trees.
Missing wood or bark: If 50% or more of the circumference of the bole is intact, reconstruct the diameter at Dbh.

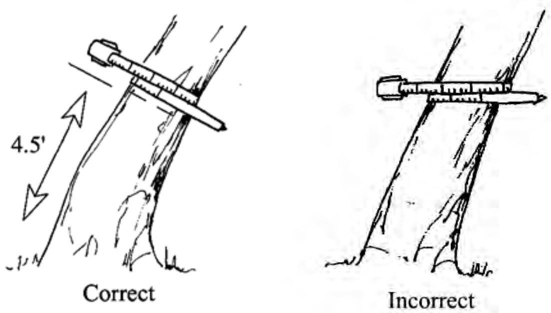
1.1.1 Figures Illustrating the Proper Use of a Diameter Tape

Correct Method

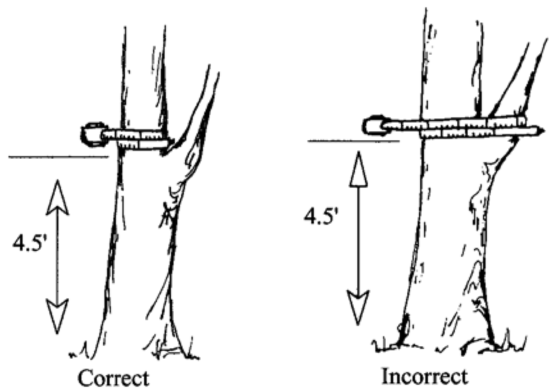


End of tape (with the '0' mark or hook) crossed under.


Press the tape firmly against the tree. Do not pull it out at a tangent to the tree at the point of measurement.

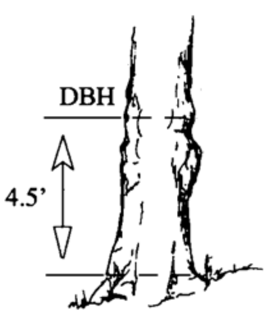


Tape must be at right angles to lean of tree.

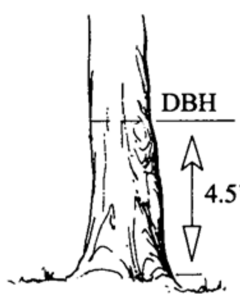


Do not place tape at abnormal location on bole of tree.

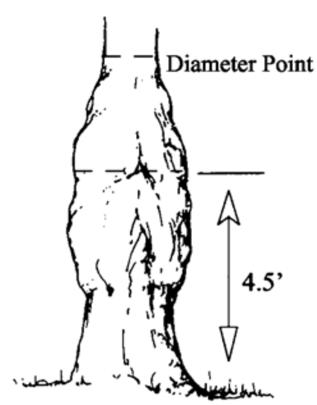
1.1.2 Point of Measurement for DBH



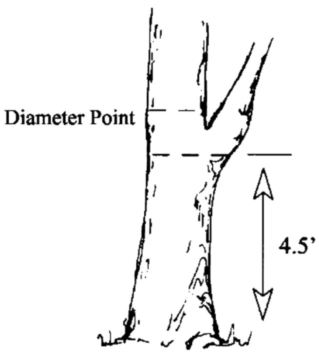
Tree on slope



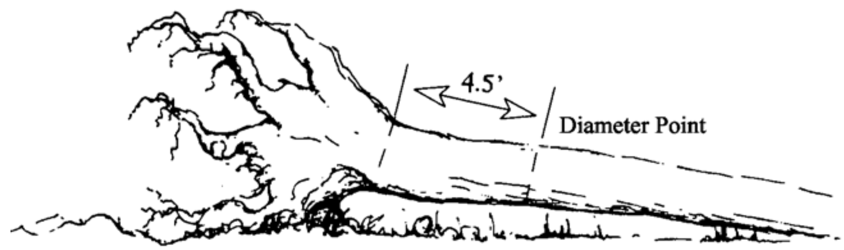
Tree on level ground



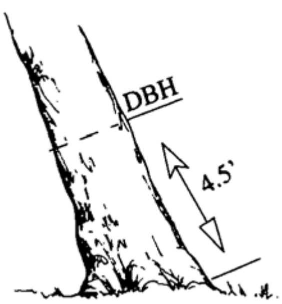
Tree deformed at DBH by swelling or crook. Take DBH above deformation.



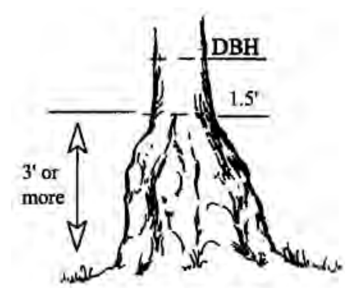
Tree with branch at 4.5 feet



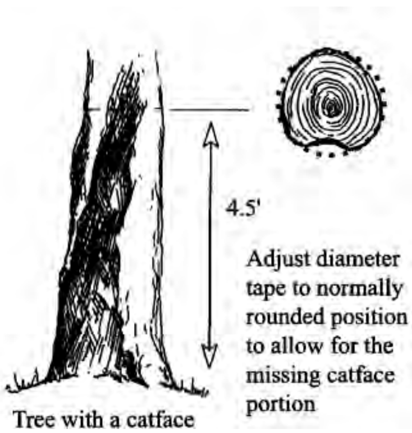
Windthrown tree



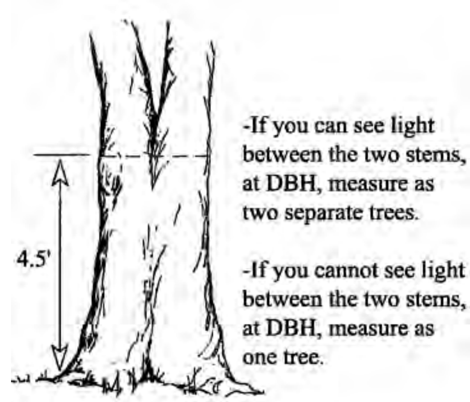
Leaning tree

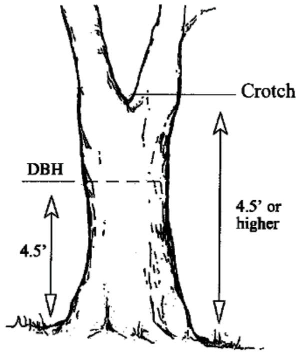


Bottleneck tree



Tree with a catface





Tree forked at 4.5 feet or higher. Record as one tree and consider only the main fork. Take DBH below the swell of the fork.

Appendix E: Water Team Final Report

DRAFT

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August 31, 2015

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Executive Summary

Part I of this chapter addresses water quantity measurement and modeling to determine the impacts of forest fuel treatments and wildfire on hydrologic fluxes. For this study, a spatially explicit hydro-ecological model, based on observed data, was used to scale from small to large catchments. The Regional Hydro-Ecological Simulation System (RHESSys) was calibrated using headwater catchment observations of climate, snow, soil moisture, and stream discharge for the three pre-treatment years (2010-2012), which encompassed wet, average, and dry precipitation conditions. The successful headwater calibrations were then transferred to the fireshed scale, based on geologic similarities between catchments. Changes in forest structure were determined by differences in Leaf Area Index (LAI), overstory canopy cover, and understory shrub cover.

Implementation of Strategically Placed Landscape Treatments (SPLATs) at Last Chance resulted in a vegetation decrease of 8% leading to runoff increases of at least 12% for the initial 20 years, falling to 9.8% by year 30, when compared to the no treatment scenario. Predicted vegetation growth following SPLATs showed the reduced biomass densities only lasted for about 10 years; after 10 years runoff decreased to pre-treatment levels. Two other modeled scenarios were also assessed: fire without SPLATs reduced vegetation by 49.8% while fire with SPLATs reduced vegetation by 38.1%, increasing runoff respectively by 66.7% and 54.9%.

SPLAT implementation at Sugar Pine resulted in a 7.5% decrease in vegetation, but increases in runoff were less than 3% compared to the no treatment scenario over 30 years. Predicted vegetation growth following SPLATs again showed the reduced biomass densities only lasted for about 10 years. Fire without SPLATs reduced vegetation by 42.5% while fire with SPLATs reduced vegetation by 39.5%, increasing runoff by 15.2% and 13.1% respectively.

Implementing SPLATs, both with and without wildfire, had a greater effect on annual runoff in Last Chance than in Sugar Pine. The difference in the two study area responses can largely be attributed to the differences in precipitation rates. Changes in vegetation at Sugar Pine had minimal effect on annual evapotranspiration (ET) rates, suggesting the forest is more water-limited than at Last Chance, where changes in ET were more closely linked to forest density. This response can be illustrated using the scenario of greatest vegetation change, wildfire without

SPLATs, where a 42.5% reduction in Sugar Pine vegetation led to a 2.9% decrease in ET. The 49.8% reduction in Last Chance vegetation resulted in a 22.8% decrease in evapotranspiration. Although the high-intensity fires can result in greater vegetation reductions and lead to increased runoff, these results did not specifically address water quality issues related to these wildfires such as soil erosion into the stream channel, hydrophobic soils, and elevated snowmelt rates.

Part II of this chapter addresses water quality measurements that were made to determine potential effects of treatments on water quality which could impact aquatic life and downstream water resources. Stream water temperature, conductivity, turbidity, and dissolved oxygen were recorded at 15-minute intervals using continuous recoding sensors from WY 2010 to WY 2013 in all four watersheds. Additional grab samples were collected and analyzed on a bi-weekly to bi-monthly basis for major ion chemistry and stable isotope chemistry. Movement of channel bed material was measuring using load cell pressure sensors and also recorded at 15-minute intervals for WY 2012-2014.

Water temperature, conductivity, and major ion concentrations were found to be higher in the 2012 and 2013 concurrent- and post-treatment water years respectively (referred hereafter in this chapter as the post-treatment period), however, these years were dry years and these patterns are typical of drought conditions. Dissolved oxygen remained fairly stable throughout the years of the study. Water chemistry parameters were found to all be within healthy ranges for aquatic life with the exception of low dissolve oxygen values during very low flows of dry years when stream flow was intermittent.

Much of the water quality measurement effort was focused on turbidity and bedload movement due to the healthy ranges for other water quality parameters and a lack of sources for chemical pollutants in these headwater systems. An analysis of seasonal turbidity patterns and sediment source areas has been published in a peer-reviewed journal (Martin et al. 2014) and we have summarized key findings here in this chapter.

The observed timing of turbidity verses discharge event peaks indicates that sediment is coming from localized in-channel sources that are easily transported. Data also indicate periods of accumulation and depletion tied to high and low flows. Because SPLATs were light and set far back from stream channels we hypothesized that any changes in water quality (namely turbidity) due to treatments would be due to changes in stream discharge. Mean peak turbidity values were compared for pre- and post- treatment periods in the treatment watersheds but no significant difference was found. This may have been due in part to small sample sizes and large standard deviations caused by the infrequent and episodic nature of sediment movement in these streams. Channel bed movement data indicated that the channel bed acts as temporary storage for sediment, but that it remains stable over the long term.

We found evidence of a drought signal in the water chemistry and turbidity data. In addition, the treatments were light and set far back from the active stream channel. The treatments as implemented were not intensive enough to show an increase in discharge during a low precipitation year and SPLATS as implemented in SNAMP had no detectable effect on turbidity.

I: Water Quantity Observations and Modeling

Introduction

The movement of water through mountainous catchments in the western United States is dependent on the interaction of climate, vegetation, and subsurface processes. Characterizing these components and their influence on snowpack and water supply is a priority for effective management of land and water resources. In the Sierra Nevada, winter and spring runoff from seasonal precipitation and snowmelt provides more than half of California's annual water supply (Kattelmann et al., 1983; Department of Water Resources, 2009) for use in hydropower, irrigation, and municipal water supplies throughout the state. Climate variability, vegetation management, and wildfire will collectively affect the water storage components and hydrologic fluxes in these mountain watersheds.

Reviewing numerous catchment studies of vegetation treatment effects on stream discharge, Stednick (1996) and Bosch and Hewlett (1982) show that removal of forest vegetation typically increases runoff and storm event discharge peaks, but the magnitude of change and period of impact depend upon the amount of vegetation removal, post-treatment precipitation levels, and the rate of vegetation re-growth. In seasonally snow-covered basins, tree removal not only impacts evapotranspiration, but also local energy balances that affect the patterns of snow ablation in a forest (Macdonald et al., 1987; Ellis et al., 2013) . Long-term experimental treatments implemented in the continental snowpack of the Rockies have shown some indication of increasing runoff. Harvesting 23.7% of the 16.7-km^2 Coon Creek Watershed in Wyoming resulted in a mean annual runoff increase of 7.6-cm (17%) for the 5 years following treatments (Troendle et al., 2001). Harvesting 25% of a 21.3-km^2 lodgepole forest in Utah revealed a 14.7-cm (52%) increase in annual runoff, after 20 years of post-treatment monitoring (Burton, 1997). Lastly, reviewing 28 years of post-treatment monitoring after harvesting 40% of the 8-km^2 Fool Creek Watershed in Colorado, Troendle and King (1985) observed a mean increase of 8.2-cm (28%) in annual runoff.

While a number of research catchments have already provided a wealth of information on mountain hydrology (Hicks et al., 1991; Swank et al., 2001; Troendle et al., 2001; Chauvin et al., 2011), there have been few initiatives in the Sierra Nevada for these types of long-term experimental watershed studies. Recently, the Southern Sierra site of the Critical Zone Observatory network has been developed to measure characteristics of forest hydrology, geomorphology, and ecology among other physical sciences (Lin et al., 2011). In the Sagehen Experimental Forest of the northern Sierra, the hydro-ecological model used in this study (RHESSys) was used to predict climate change effects of stream flow and temperature on trout in a 12-km^2 catchment (Meyers et al., 2010). Multiple regressions of runoff response to forest treatments, mean annual precipitation, mean annual runoff, and runoff fraction from 31 experimental catchments in the western United States were applied to model treatment effects in the Sierra Nevada (Marvin, 1996), and show that a 10% increase in mixed-conifer zone harvesting would have no statistical significance on annual runoff (-0.2 - 1.2 cm). Marvin (1996) notes that it is more difficult to determine effects of treatments on runoff in the arid west than the catchments used by Bosch and Hewlett (1982), although the model did not take into account any seasonality which may be significant in a Mediterranean climate, and treats less than 20% of the forest that Stednick (1996) suggests is generally required to detect changes in runoff. Using existing literature, Kattelmann et al. (1983) qualitatively hypothesize that removing all vegetation in the Sierra could increase runoff 30 - 40%, while managing National Forest land specifically for water production could increase runoff by 2 - 6%. Constraints of management, access, and economics lower this qualitative estimate to about 0.5 - 2% (0.3 - 1.2 cm), and Kattelmann et al. (1983) instead emphasize the benefit of treatments in delaying snowpack ablation.

There is an impetus to restore the resiliency of the forest to these pressures by applying localized integrated management (Stephens et al., 2013). Forest management to reduce fire risk requires the thinning of dense vegetation, removal of ladder fuels, and prescribed burning or mastication to reduce understory shrubs. This modification of the vegetated landscape has an impact on the energy inputs leading to snowpack melt (Black et al., 1991; Essery et al., 2008; Pomeroy et al., 2009; Lawler and Link, 2011) and the rate of water transferred to the atmosphere through evapotranspiration (Zhang et al., 2001; Moore et al., 2004; Biederman et al., 2014; Brown et al., 2014). Annual runoff and evapotranspiration rates in the Sierra Nevada are dependent on elevation and latitude. In the eight basins of the Kings River Experimental

Watershed, Hunsaker et al. (2012) calculated a mean annual runoff fraction ranging from 0.23 to 0.53, resulting in a loss term ranging from 47% to 77% of the annual precipitation. In a separate study, evapotranspiration loss in two Providence Creek sub-catchments was 76 cm (63%) of a 122 cm precipitation year, also estimated using a water balance calculation (Bales et al., 2011). Goulden et al. (2012) calculated a 44% ET loss from a mean 98.4 cm of precipitation in the larger watershed of the Upper Kings River using eddy covariance measurements expanded with remote sensing NDVI.

For the purpose of this study, a spatially explicit model was used to maximize available spatial data and to scale from small to large catchments. The Regional Hydrologic Simulation System (RHESSys; C. L. Tague and Band, 2004) was specifically chosen due to its use in research applications of forest and mountain hydrology over a range of geographical regions (Hartman et al., 1999; Mackay, 2001; Zierl et al., 2006; Hwang et al., 2008; Tague et al., 2009). Our objective was to first assess the characteristics of snow, soil moisture, and runoff in Sierra Nevada headwater catchments (approximately 1 km^2) over four water years (2010-2013). We then used these observations to constrain a hydro-ecological model to investigate forest thinning effects on hydrologic fluxes over a range of hydrologic conditions. We are then able to assess the effects of forest fuel treatment and wildfire effects at the fireshed-scale (> 40 km^2), leveraging the well-constrained headwater catchment models.

Study Sites

Two sets of paired headwater research catchments within two larger study areas have been instrumented with continuously recording observation equipment (Figure E1, Table E1). Big Sandy Creek (treatment) and Speckerman Creek (control) are the paired headwaters in the Sierra National Forest, both draining to the South Fork of the Merced River. Bear Trap Creek (treatment) and Frazier Creek (control) are the other set of paired headwaters in the Tahoe National Forest, draining to the Middle Fork of the American River. Frazier and Bear Trap catchments are underlain by upper elevation Miocene-Pliocene volcanic and lower elevation sedimentary bedrock of the Shoo Fly complex (Saucedo and Wagner, 1992). The bedrock underlying the Big Sandy and Speckerman catchments consists of plutonic Early Cretaceous

Bass Lake Tonalite (Bateman, 1989). Fireshed elevations range from 1600 ft to 7180 ft, transitioning from rain to snow dominated precipitation, and vegetation communities are mainly comprised of mixed-conifer forests (Tables E2-E4).

Soils in the northern sites are well drained with Bear Trap Creek having the Crozier-Cohasset, Crozier-McCarthy-Cohasset, and Hurlbut-Deadwood complexes and Frazier Creek having the Crozier-Cohasset, Crozier-McCarthy-Cohasset, and Crozier-Mariposa-Cryumbrepts complexes (Soil Survey Staff, 2011). Southern site soils are also well drained with Speckerman Creek having Ledford family-Entic-Xerumbrepts and Chaix-Chawanakee families with Big Sandy Creek having Ledford family-Entic Xerumbrepts and Umpa family soil series (Soil Survey Staff, 2011). Texture analysis from the 128 soil samples <1-m below the surface show the soils at the northern sites to be categorized as loam or sandy loam, with soils at the southern sites being categorized as sand or sandy loam. Mixed-conifer forest at Last Chance is dominated by White Fir (*Abies concolor*), Ponderosa Pine (*Pinus ponderosa*), Douglas Fir (*Pseudotsuga menziesii*), and Sugar Pine (*Pinus lambertiana*) with understory including Incense Cedar (*Calcedrous decrrens*), Huckleberry Oak (*Quercus vacciniifolia*) and Dwarf Rockcress (*Arabis parishii*). Mixed-conifer forest at Sugar Pine is dominated by Ponderosa Pine (*Pinus ponderosa*), Incense Cedar (*Calocedrous decurrens*), California Black Oak (*Quercus kelloggii*), White Fir (*Abies concolor*), and Sierra Live Oak (*Quercus wislizeni*) with understory including Mountain Misery (*Chamaebatia foliolosa*) and Dwarf Rockcress (*Arabis parishii*).

Methods

For the purposes of completing a water balance and constraining hydrologic model parameters, the following instruments were installed using the same methods at each site. One upper and one lower elevation meteorological station recording conditions of precipitation, temperature, wind speed/direction, and radiation close to the extremes of the headwater elevation ranges. Precipitation from the northern sites was input from the Blue Canyon meteorological station operated by the US Bureau of Reclamation, 14 mi (22 km) to the northeast. In the southern site, the Poison Ridge meteorological station also operated by the US Bureau of Reclamation, 5 mi (8 km) to the southeast, was used for precipitation input. Precipitation levels were assumed to be the same at upper and lower stations despite an approximate 1300-ft elevation difference. Distributed snow depth (15/site) and soil moisture (64/site) sensors recorded measurements at 15-minute intervals over a range of elevation, slope, aspect and forest cover, similar to Bales et al. (2011) and Pohl et al. (2014). Stream stage was recorded at each headwater catchment outlet by pressure-sensitive water depth recorders. Stream discharge was then measured at each location at multiple stages to develop the stage-discharge rating curve to calculate daily observed discharge for each stream.

Strategically Placed Landscape Treatments (SPLATs; Bahro and Barber, 2004) are designed to disrupt fire paths and reduce overall fire severity. SPLATs were implemented in the fall of 2012 in accordance with the record of decision for the Sierra Nevada Forest Plan Amendment (2004). Changes in forest vegetation were determined by differences in Leaf Area Index (LAI) and Canopy Cover (CC) calculated from LiDAR and vegetation plot data collected before and after treatments (Appendix A-FFEH in this report). Understory vegetation was incorporated into the model using a linear equation developed by the fire and forest health team, based on their forest plot measurements (Equations 1, 2); we assumed these relationships in overstory and understory structure were constant in all model scenarios. Shrub cover was calculated in each vegetation community type for Last Chance (Equation 1, R^2 = 0.16) and Sugar Pine (Equation 2, R^2=0.25) as

$$SC = 63.079 - 0.244 * BA - 0.257 * CC \qquad [1]$$

$$SC = 55.273 - 0.294 * BA - 0.256 * CC \qquad [1]$$

where SC is Shrub Cover, BA is Basal Area (m^2 ha^{-1}) and CC is Canopy Cover.

Leaf area index and vegetation cover modify transpiration rates by changing the total amount of vegetation, modify snowmelt rates by changing the amount of light that reaches the snowpack (Equations 2, 3), and on a smaller magnitude change interception and evaporation rates. Forest thinning in the treatment areas consisted of removing trees below 76.2-cm Diameter at Breast Height through a combination of cable and mechanical thinning. Mastication and prescribed ground burning were not specifically done in the headwater catchments, although they were used within the treated firesheds.

The RHESSys model (Tague and Band, 2004) combines a meteorological forcing model (MTN-CLM; Hungerford et al., 1989), biogeochemical cycling model (BIOME-BGC; Running and Hunt, 1993), and hydrological model (TOPMODEL; Beven and Kirkby, 1979) or DHSVM; Wigmosta et al., 1994). The spatial environment in the model is created using a 20-m DEM, soil layer from the SSURGO database (Soil Survey Staff, 2011), and a vegetation layer created from a combination of LiDAR canopy point clouds and forest plot data (Appendix A-FFEH in this report). Meteorological time-series data were input from the on-site met stations and closest-reference precipitation stations detailed above.

Modeling the impact of vegetation on catchment water balance is focused on the following equations. Vegetation density affects interception, transpiration, and the surface energy balance. Transpiration rates are impacted as LAI is used to scale up the rate of stomatal conductance to the landscape patch (Equation 3; Jarvis, 1976). The limitations of maximum stomatal conductance for sunlit and shaded canopy are calculated as linear scalars

$$gs = f(ppfd)f(CO_2)f(LWP)f(vpd)gs_{\max}(LAI) \quad [3]$$

where gs is stomatal conductance (m s^{-1}), $ppfd$ is photosynthetic flux density, CO_2 is carbon dioxide, LWP is Leaf Water Potential, vpd is vapor pressure deficit, and gs_{max} is maximum conductance. The surface energy balance for snowmelt is affected by a Beer's law approximation of the amount of incoming shortwave radiation (Equations 4,5), combined with longwave radiation (Equation 6). Incoming direct and diffuse shortwave radiation are calculated as

$$K_{direct} = (1 - \propto_{direct})K_{direct'}(1 - corr\ exp^{-ext_{coef}}) \quad [4]$$

$$K_{diffuse} = (1 - \alpha_{direct})K_{diffuse'}\{1 - exp^{-[(1-GF)PAI]^{0.7}} + S_c\} \quad [5]$$

where α_{direct} is the vegetation-specific albedo, K_{direct}' and $K_{diffuse}$' are the direct and diffuse solar radiation at the top of each vegetation layer, $corr$ is an option correction factor for low sunlight angles with sparse canopy, ext_{coef} is the Beer's Law extinction coefficient, GF is the canopy gap fraction, PAI is the Plant Area Index, and S_c is the scattering coefficient. Longwave radiation is calculated as

$$L = 41.868[ess_{atm}\sigma(T_{air} + 272)^4 - 663] \quad [6]$$

where ess_{atm} is the emissivity of the atmosphere , σ is the Stefan-Boltzmann constant, and T_{air} is the air temperature (K).

For each scenario, we used the four years of observed meteorological inputs (water years 2010-2013) to produce a mean annual value of runoff, evapotranspiration, and groundwater. Four vegetation scenarios were considered: an untreated forest, a forest with SPLATs implemented, a untreated forest following a simulated wildfire, and a forest with SPLATs implemented following a simulated wildfire. Vegetation growth in each scenario was projected for 30-years using the Forest Vegetation Simulator (FVS; Dixon, 2002), where a point-in-time snapshot of the vegetation conditions was captured at 0, 10, 20, and 30 years. The four years of meteorological observations were simulated for each vegetation condition to capture the range of dry to wet precipitation conditions that occurred during this study. Post-fire vegetation scenarios start at 10-years, allowing for a decade of growth following the simulated wildfire events, and avoid issues such as soil hydrophobicity, reduced soil infiltration capacity, and diminished litter cover that can occur immediately after fire. We differed from the exact FVS scenarios by adding in the shrub cover as outlined above, because understory vegetation can be an important additional source of transpiration loss following the disturbance events modeled in this study.

The stream outlets draining the study firesheds were not gaged due to the remote and steep terrain. The only monitored stream discharge site directly downstream from the firesheds drains the entire North Fork of the Middle Fork of the American River, an area of 230.2 km^2 of which 43.2% are the study firesheds. Initial comparison of flow duration curves for the two headwater streams and the North Fork of the Middle Fork of the American River (NFMF) showed that headwaters and downstream sites have differing distributions of flow probabilities (Figure E2). This suggests that during these conditions flow at different scales and between basins is controlled by different flow paths or paths with different flow lengths. However, as flow drops below the 20th percentile, the slope of the line representing the relationship between discharge and probability becomes more parallel between headwaters and the NFMF. This suggests that the behavior of these headwater basins is more similar to the hydrologic behavior of the NFMF at normalized discharges of less than 10 cm, until flow probabilities increases to above 90%, where discharge values for Frazier drop rapidly. This drop is due to the stream become ephemeral during extreme drought conditions in 2013. As flow decreases, the relative contribution of the two headwaters to discharge from the entire basin increases from approximately one percent to over four percent, showing the importance of these headwaters during low flow conditions (Figures E3, E4).

A direct comparison of area-normalized discharge between each headwater stream and the NFMF did not show a strong correlation between the headwaters and downstream sites (Figure E5). However, using the predictive format of linear regression models with the full discharge record for the headwater streams, the headwaters acted as predictors for downstream stream discharge and were highly significant for all three models tested (Table 5). Bear Trap discharge explained more of the variability in the North Fork of the Middle Fork of the American River than Frazier, however, the combination of the two basins was shown to be the best fit model using AIC (Table E5). This model explained 63.7% of the variability in the downstream discharge for the entire available data record.

When looking specifically at low flow conditions, a stronger relationship is seen between the basins. During low flow conditions, Frazier explains more of the variability in the downstream discharge than Bear Trap, however model selection again shows that the linear regression model using both headwater streams provided the best fit (Table E6). The combined regression model explains 93.2% of the variability seen in the NFMF area normalized discharge data. This suggests that during low flow and baseflow conditions, the headwaters and full basin have statistically similar behavior.

Flow Durations curves for the Sugar Pine sites show a similar relationship to those seen in the Last Chance sites (Figure E6). During high flow conditions, both headwater streams and the Lewis Fork of the Fresno show very different flow probabilities. However, as flow probability decreases below 20%, the slopes of the curves become more similar. The data for the Lewis Fork has a lower resolution and is likely affected by water withdrawals during the upper portions of the flow duration curve (California Environmental Protection Agency, 2014), which combined to reduce the similarity of the Lewis Fork to the headwater streams, although a relationship is still present. Additionally, a comparison of the hydrographs of the headwaters and the Lewis Fork show that peak discharge and subsequent recessions occurred at approximately the same time at both scales (Figure E7).

A direct comparison of area-normalized discharge between each headwater stream and the Lewis Fork did not show a strong correlation between the headwaters and downstream sites (Figure E8). However, these hydrograph comparisons between the headwater sites and the Lewis Fork of the Fresno River were complicated by a number of factors including (1) numerous active water withdrawals upstream of the gaged site on the Lewis Fork, (2) low resolution of the Lewis Fork data during low flow conditions (data was recorded in cubic feet per second with no decimal places), and (3) the headwater streams flow into the South Fork of the Merced River and are not hydrologically associated with the firesheds or the Lewis Fork of the Fresno River. These complications have likely resulted in lower correlations between headwater streams and the downstream discharge site. However, the regression analysis between discharge of the headwater streams (predictor variables) and discharge of the Lewis Fork (response) still show a similar pattern to those seen in the Last Chance sites. During the period of available data, the combined discharges of Big Sandy and Speckerman were seen to be the best fit model for discharge in the Lewis Fork (Table E7) and explained 43.5% of the variability in Lewis Fork Discharge.

During low flow conditions, the combined model is again the best fit and the ability of the headwater discharge values to predict Lewis Fork discharge increases and is able to explain 61% of the variability of the Lewis Fork of the Fresno River (Table E8). This model is not as good of a fit as in the Last Chance sites due to a combination of the low resolution of the data and the large number of water withdrawals upstream of the site. Using these methods, it was determined that Bear Trap Creek and Big Sandy Creek, both treated headwaters, would be the preferred catchments for transferring model parameters to the ungaged firesheds for flow storage and routing in the RHESSys model.

In addition to the fireshed comparisons, RHESSys was also tested in the Providence Creek catchments at the Kings River Experimental Watershed (KREW) using comparatively rich input datasets from the National Science Foundation's Southern Sierra Critical Zone Observatory (NSF-SSCZO), prior to running SNAMP study simulations. Providence Creek catchments are of similar elevation and area (Figure E9; (Stuemky, 2010)), but also have a longer period of discharge measurements (2003-2012), providing a better opportunity to evaluate model calibration. RHESSys was calibrated at P303 from 2003-2008 and evaluated for 2009-2012. Model results were also evaluated at P301 and P304 from 2003-2012 using the same soil and vegetation parameters from P303.

We used forcing datasets from two met stations (Upper and Lower Providence, USFS Pacific Southwest Research Station) at P303. RHESSys was calibrated at a daily time-step, using one optimal set for wet and dry years at P303 catchment in order to establish the best parameters for the region (Table E9, Figure E10). The timing of water availability in the soil is critical in the partitioning of precipitation into transpiration and runoff. Parameters controlling flow properties of hydraulic conductivity (k), decay of hydraulic conductivity with depth (m), and deep groundwater flow out of the basin (gw1) and groundwater flow to the stream (gw2) were calibrated with 500 random sets. Parameters controlling soil properties of pore size index (po) and air entry pressure (pa) were manually calibrated to match soil storage observations and held constant, however, groundwater inflow and outflow coefficients which vary with wet and dry soil and climate conditions, were modified annually. Calibration was completed for water years 2003-2008 to capture the range of wet to dry precipitation conditions, and evaluated for water years 2009-2012. Optimal calibration was determined by the highest combination of Nash-Sutcliffe Efficiency (NS_e; Nash and Sutcliffe, 1970) and log NS_e, which supports an improved statistical characterization of the seasonal periods of high and low flows (Table E10).

Snow accumulation and melt was also calibrated in RHESSys using the observed snow water equivalent (SWE) at P303. However, SWE was only directly observed in one place (a snow pillow) near the highest elevation of the catchment, and we found poor agreement between observed SWE at the point scale and modeled basin average SWE because there is more rainfall at lower elevations in the basin. Therefore, we calibrated model for SWE at the specific 10-m patch which overlapped with the snow pillow station (Figure E11), producing excellent agreement between observed and modeled SWE (NS_e = 0.92, Table E11). We then used the parameters for the temperature snow melt coefficient (SMc) and radiation melt coefficient that were calibrated at the snow pillow station for the entire watershed. The calibration parameters were. Using SMc = 0.0004 for wet years (2003-2006, 2008) and SMc=0.0001 for the dry years (2007, 2009), the radiation melt coefficient was reduced to 60% for the dry 2007 year.

Overall, the analysis shows very good agreement between observed and simulated stream discharge and SWE both for calibration and evaluation period at P303 (Figures E10, E11; Table E10). Similarly, we found very good agreements between observed and simulated discharge (2003-2012) at P301 and P304 using same soil and vegetation parameters used at P303 (NSe=0.82; Figure E12). SWE observations were not available within P301 and P304, so we could not evaluate modeled snow for those catchments. Bear Trap and Big Sandy watersheds also did not have continuous SWE measurements available within the basin. Instead, observed snow depth from the distributed sensors was converted to snow water equivalent using a linear relationship between the Day of Year and percent water from the nearest snow pillow at a similar elevation, following the methods of Liu et al. (2013). Daily mean SWE was calculated for the entire watershed using the converted snow water equivalent for each sensor and the average basin elevation.

Results

Precipitation observed over the four water years was highly variable. The first water year measured (2010) showed average precipitation, high levels of precipitation occurred in 2011, and low amounts of precipitation fell during 2012-2013 (Figure E13). Annual Precipitation in Last Chance ranged 57.5 to 98.4 in (146-250 cm, Table 11), which the California Department of Water Resources (DWR) 8-station Northern Sierra Precipitation Index shows was 60% – 140% of the long-term mean (1961-2010; California Department of Water Resources, 2014a). Sugar Pine had 35.8 to 79.1 in (91-201 cm, Table E11) over the same time period, with the DWR 5-

station San Joaquin Precipitation Index showing 61% – 160% of the long-term mean (1961-2010; California Department of Water Resources, 2014b).

At the higher elevation stations of Duncan Peak and Fresno Dome (elevation >6850 ft), snowfall consisted 69% and 52% of the precipitation over the four years, while at the lower elevation stations of Bear Trap and Big Sandy (4900 – 5900 ft elevation), snow fractions were at 41% and 40%. A grid survey of 119 points in the 0.4 mi^2 (1-km^2) around Duncan Peak was completed on March 23-26, 2009 and showed the 7 wired snow sensors represented 20% of the variability measured with the survey. A second survey on April 15 and 26, 2012 showed the wired sensors represented 24% of the variability, with 9 separate sensors from a new wireless network setup (Kerkez et al., 2012) improving that number to 61% (Figure E14). In both surveys, the snow-depth sensors represented the mean spatial value of snow depth over the 0.4 mi^2 (1 km^2) area surveyed.

Soil-moisture values increased with fall rain events, as early as the first few days of the water year. Moisture values typically showed sustained saturation through the winter season. Soils in the top 3.3-ft (1-m) stored 7.9 – 11.8 in (20 - 30 cm) of water during the wet winter season in Sugar Pine, while Last Chance soils stored 9.8 – 13.8 in (25 - 35 cm), possibly reflecting the lower sand content in Last Chance. Soil storage recession started as early as day 200 in the dry years, but as late as day 270 in the wet year.

Annual stream discharge rates varied greatly, revealing annual runoff that was 3-4 times in high precipitation years compared to low precipitation. Similarly, runoff fractions were lowest in dry years and highest in wet years, ranging from 0.24 – 0.56 for Sugar Pine and 0.28 – 0.67 for Last Chance, higher runoff fractions in the northern site reflected the elevated precipitation (Table E10, Figure E15). To determine if the forest thinning had an effect on observed discharge, F-tests ($p < 0.05$) were calculated to analyze differences in daily discharge between the paired streams on an annual basis. The results showed significant differences in the control-treatment stream discharge relationship, not only in the pre- and post-treatments years, but also for all four individual years (Figures E16, E17), masking any post-treatment specific signal in discharge.

Observed snow values were used to calibrate the daily snowpack output from RHESSys using a rain-snow temperature transition of -1°C   3°C, a radiation melt reduction of 0.4, and temperature snowmelt coefficient of 0.0005 and 0.001 for Bear Trap and Big Sandy respectively. The timing of water availability in the soil is critical in the partitioning of precipitation into transpiration and stream discharge. RHESSys was calibrated with 5000 normally distributed random parameters sets, of which 6 (Bear Trap, Last Chance site) and 17 (Big Sandy, Sugar Pine site) sets met the criteria described below (Table E12, Figure E18). Parameters controlling soil physical properties of pore size index (po) and air entry pressure (pa), along with parameters controlling flow properties of hydraulic conductivity (k), decay of hydraulic conductivity with depth (m), vertical hydraulic conductivity (svk), and deep groundwater flow (gw1, gw2) were modified.

Calibration was completed for water years 2010 - 2012, as all three years exhibited substantially different precipitation levels. Acceptable parameter sets were determined by comparing observed and modeled daily stream discharge using a Nash-Sutcliffe Efficiency (NS_e; Nash and Sutcliffe, 1970) and log NS_e greater than 0.60, and discharge within 20% of annual and 25% of August flows. These constraints support acceptable simulations of annual discharge, peak storm flow events, and the seasonal trends typical of a Mediterranean climate. Water year 2013 was post-treatment and could not be strictly considered an evaluation year, thus having an expected lower range of performance for Bear Trap (NS_e = 0.34 - 0.74, logNS_e = 0.68 - 0.79) and Big Sandy (NS_e = 0.2 7- 0.75, logNS_e = 0.29 - 0.81).

Model simulations show that implementation of SPLATs at Last Chance resulted in runoff increases of at least 12% for the initial 20 years, falling to 9.8% by year 30 when compared to the no treatment scenario (Table E13, Figure E19). Model scenarios included shrub cover, resulting in a LAI decrease of 8.0% due to SPLATs – slightly different from the fire and forest health team calculations (Table E13, Figure E20). Vegetation growth following SPLATs showed the reduced biomass densities only lasted for about 10 years, also returning runoff fractions to pre-treatment levels. Including shrub cover, fire without SPLATs reduced vegetation by 49.8% while fire with SPLATs reduced vegetation by 38.1%, increasing respective runoff fraction by 66.7% and 54.9%.

Model simulations of SPLAT implementation at Sugar Pine shows runoff increases of less than 3% compared to the no treatment scenario over 30 years (Table E13, Figure E21). With the inclusion of the shrub vegetation layer, SPLATs resulted in a 7.5% decrease in Sugar Pine LAI (Table E13, Figure E22), again slightly different from the forest team calculations (Appendix A-FFEH in this report). Vegetation growth following SPLATs again showed the reduced biomass densities only lasted for about 10 years. Differences in LAI and runoff were less than 3% and 1% respectively after 30 years. Including shrub cover, fire without SPLATs reduced vegetation by 42.5% while fire with SPLATs reduced vegetation by 39.5%, increasing respective runoff fractions by 15.2% and 13.1%.

Discussion

Compared to studies in the Kings River basin (Bales et al., 2011; Goulden et al., 2012; Hunsaker et al., 2012), the closely located Sugar Pine sites had similar annual runoff and evapotranspiration rates, but Last Chance showed high ET (48.4 in) resulting from high precipitation inputs (78.3 in). Although the annual precipitation measured in the Last Chance region was high, the Blue Canyon meteorological station (5280' elevation, 71.2 in yr^{-1} mean precipitation) was within the range of measurements reported by nearby stations including Drum Power House (3400', 62.7 in yr^{-1}), Hell Hole (4580', 47.7 in yr^{-1}), and Huysink (6600', 85.1 in yr^{-1}). Soil water storage and moisture patterns were similar to Bales et al. (Bales et al., 2011), where the coarser soils of Sugar Pine resulted in lower water content than Last Chance.

Model stream discharge calibration was heavily dependent on snow accumulation and melt timing, which was replicated using separate rain/snow inputs. The higher accuracy of Providence Creek modeled discharge compared to this study shows the advantage of calibrating over longer time periods, when multiple years of similar precipitation conditions are available. Model results (Forest-BGC) from forested mountain catchments of Montana showed similar runoff levels, but approximately 25 inches less evapotranspiration in Last Chance because of an equivalent disparity in precipitation rates (Running et al., 1989).

Model results of SPLAT implementation, both with and without wildfire, had a greater effect on runoff in Last Chance than in Sugar Pine. The difference in the two study area responses can largely be attributed to the differences in precipitation rates. Changes in vegetation at Sugar Pine had minimal effect on annual evapotranspiration (ET) rates, suggesting the forest is more water-limited than at Last Chance, where changes in ET were more closely linked to forest density. This difference in responses can be illustrated using the range of vegetation changes, where a 7.5% - 42.5% reduction in Sugar Pine vegetation led to a 0.5% - 2.9% decrease in ET and a 2.7% – 15.2% increase in runoff (Figure E23). Alternatively, the 8.0% - 49.8% reduction in Last Chance vegetation resulted in a 4.1% - 22.8% decrease in evapotranspiration and a 12.0% - 66.7% increase in runoff (Figure E24). These results on the modeled effects on stream runoff are within the range reported from long-term studies in the continental climate of the Rockies, where a 25% harvest area led to a 52% increase in annual runoff (Burton, 1997) and a 40% harvest led to a 28% runoff increase (Troendle and King, 1985).

Management Implications

Headwater catchment observations were unable to specifically attribute changes in discharge to the implementation of SPLATs, in part due to high precipitation variability and in part due to low precipitation following treatments. However, model simulations suggest that treatments as implemented would increase runoff in the high precipitation region of Last Chance, but either treating a broader area or greater vegetation reductions over the same area may be necessary to measurably increase runoff in Sugar Pine. Although the stage-discharge relationship method we use is a common low-cost method used in hydrology research, more precise measurements may be necessary to better capture effects of vegetation change for the wide range of interannual precipitation and stream discharge conditions present in the Mediterranean climate of the Sierra Nevada. The high-intensity fires modeled in this study can result in greater vegetation reductions and lead to increased runoff, however these results did not address potentially adverse issues related to these wildfires such as soil erosion into the stream channel, hydrophobic soils, and elevated snowmelt rates.

References

Bahro, B., and K. Barber (2004), Fireshed Assessment: An Integrated Approach to Landscape Planning.

Bales, R. C., J. W. Hopmans, A. T. O'Geen, M. Meadows, P. C. Hartsough, P. Kirchner, C. T. Hunsaker, and D. Beaudette (2011), Soil Moisture Response to Snowmelt and Rainfall in a Sierra Nevada Mixed-Conifer Forest, Vadose Zo. J., 10(3), 786, doi:10.2136/vzj2011.0001.

Bateman, P. C. (1989), Geologic map of the Bass Lake quadrangle, west-central Sierra Nevada, California, Geologic Quandrangle Map GQ-1656.

Beven, K. J., and M. J. Kirkby (1979), A physically based, variable contributing area model of basin hydrology, Hydrol. Sci. Bull., 24(1), 43–69.

Biederman, J., A. Harpold, D. Gochis, B. Ewers, D. Reed, S. Papuga, and P. Brooks (2014), Increased evaporation following widespread tree mortality limits streamflow response, Water Resour. Res., 50, 5395–5409, doi:10.1002/2013WR014994.

Black, T., J.-M. Chen, X. Lee, and R. Sagar (1991), Characteristics of shortwave and longwave irrandiances under a Douglas-fir forest stand, Can. J. For. Res., 21, 1020–1028.

Bosch, J., and J. Hewlett (1982), A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration, J. Hydrol., 55, 3–23, doi:10.1016/0022-1694(82)90117-2.

Brown, M. G. et al. (2014), Evapotranspiration and canopy characteristics of two lodgepole pine stands following mountain pine beetle attack, Hydrol. Process., 28(8), 3326–3340, doi:10.1002/hyp.9870.

Burton, T. A. (1997), Effects of basin-scale timber harvest on water yield and peak streamflow, Water Resour. Res., 33(6), 1187–1196.

California Department of Water Resources (2014a), Northern Sierra 8 Station Chronological monthly precipitation [in], Available from: http://cdec.water.ca.gov/cgi-progs/iodir/8stationhist (Accessed 14 July 2015)

California Department of Water Resources (2014b), San Joaquin 5 Station Chronological monthly precipitation (in), , 4.

California Environmental Protection Agency (2014), EWRIMS: Electronic Water Rights Information System, State Water Resour. Control Board. Available from: http://www.waterboards.ca.gov/waterrights/water_issues/programs/ewrims/index.shtml (Accessed 10 June 2014)

Chauvin, G. M., G. N. Flerchinger, T. E. Link, D. Marks, a. H. Winstral, and M. S. Seyfried (2011), Long-term water balance and conceptual model of a semi-arid mountainous catchment, J. Hydrol., 400(1-2), 133–143, doi:10.1016/j.jhydrol.2011.01.031.

Dixon, G. E. (2002), A user's guide to the Forest Vegetation Simulator, Fort Collins, CO.

Ellis, C. R., J. W. Pomeroy, and T. E. Link (2013), Modeling increases in snowmelt yield and desynchronization resulting from forest gap-thinning treatments in a northern mountain headwater basin, Water Resour. Res., 49, n/a–n/a, doi:10.1002/wrcr.20089.

Essery, R., J. Pomeroy, C. Ellis, and T. Link (2008), Modelling longwave radiation to snow beneath forest canopies using hemispherical photography or linear regression, Hydrol. Process., 2800(June), 2788–2800, doi:10.1002/hyp.

Goulden, M. L., R. G. Anderson, R. C. Bales, a. E. Kelly, M. Meadows, and G. C. Winston (2012), Evapotranspiration along an elevation gradient in California's Sierra Nevada, J. Geophys. Res., 117(G3), G03028, doi:10.1029/2012JG002027.

Hartman, M. D., J. S. Baron, R. B. Lammers, D. W. Cline, L. E. Band, G. E. Liston, and C. Tague (1999), Simulations of snow distribution and hydrology in a mountain basin, Water Resour. Res., 35(5), 1587, doi:10.1029/1998WR900096.

Hicks, B. J., R. L. Beschta, and R. D. Harr (1991), Long-Term Changes in Streamflow Following Logging in Western Oregon and Associated Fisheries Implications, J. Am. Water Resour. Assoc., 27(2), 217–226, doi:10.1111/j.1752-1688.1991.tb03126.x.

Hungerford, R. D., R. R. Nemani, S. W. Running, and J. C. Coughlan (1989), MTCLIM : A Mountain Microclimate Simulation Model; INT-414, Ogden, UT.

Hunsaker, C. T., T. W. Whitaker, and R. C. Bales (2012), Snowmelt Runoff and Water Yield Along Elevation and Temperature Gradients in California's Southern Sierra Nevada1, J. Am. Water Resour. Assoc., 48(4), 667–678, doi:10.1111/j.1752-1688.2012.00641.x.

Hwang, T., S. Kang, J. Kim, Y. Kim, D. Lee, and L. Band (2008), Evaluating drought effect on MODIS Gross Primary Production (GPP) with an eco-hydrological model in the mountainous forest, East Asia, Glob. Chang. Biol., 14(5), 1037–1056, doi:10.1111/j.1365-2486.2008.01556.x.

Jarvis, P. (1976), The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field, Philos. Trans. R. Soc. London, 273(927), 593–640.

Kattelmann, R. C., N. H. Berg, and J. Rector (1983), the Potential for Increasing Streamflow From Sierra Nevada Watersheds, J. Am. Water Resour. Assoc., 19(3), 395–402, doi:10.1111/j.1752-1688.1983.tb04596.x.

Kerkez, B., S. D. Glaser, R. C. Bales, and M. W. Meadows (2012), Design and performance of a wireless sensor network for catchment-scale snow and soil moisture measurements, Water Resour. Res., 48(9), 1–18, doi:10.1029/2011WR011214.

Lawler, R. R., and T. E. Link (2011), Quantification of incoming all-wave radiation in discontinuous forest canopies with application to snowmelt prediction, Hydrol. Process., doi:10.1002/hyp.8150.

Lin, H., J. W. Hopmans, and D. deB. Richter (2011), Interdisciplinary Sciences in a Global Network of Critical Zone Observatories, Vadose Zo. J., 10(3), 781, doi:10.2136/vzj2011.0084.

Liu, F., C. Hunsaker, and R. C. Bales (2013), Controls of streamflow generation in small catchments across the snow-rain transition in the Southern Sierra Nevada, California, Hydrol. Process., 27(14), 1959–1972, doi:10.1002/hyp.9304.

Macdonald, L. H., P. S. Forest, E. Station, and F. Service (1987), Forest harvest , snowmelt and streamflow in the central Sierra Nevada une augmentation des debits ., Water, 273–284.

Mackay, D. (2001), Evaluation of hydrologic equilibrium in a mountainous watershed: incorporating forest canopy spatial adjustment to soil biogeochemical processes, Adv. Water Resour., 24(9-10), 1211–1227, doi:10.1016/S0309-1708(01)00040-9.

Marvin, S. (1996), Possible changes in water yield and peak flows in response to forest management, in Sierra Nevada Ecosystem Project: Final Report to Congress, vol. 101, pp. 154–199.

Meyers, E. M., B. Dobrowski, and C. L. Tague (2010), Climate Change Impacts on Flood Frequency , Intensity , and Timing May Affect Trout Species in Sagehen Creek , California, Trans. Am. Fish. Soc., 1657–1664, doi:10.1577/T09-192.1.

Moore, G. W., B. J. Bond, J. a Jones, N. Phillips, and F. C. Meinzer (2004), Structural and compositional controls on transpiration in 40- and 450-year-old riparian forests in western Oregon, USA., Tree Physiol., 24(5), 481–91.

Nash, J. E., and J. V Sutcliffe (1970), River flow forecasting through conceptual models part I --- A discussion of principles, J. Hydrol., 10(3), 282–290.

Pohl, S., J. Garvelmann, J. Wawerla, and M. Weiler (2014), Potential of a low-cost sensor network to understand the spatial and temporal dynamics of a mountain snow cover, Water Resour. Res., 50, doi:10.1002/2013WR014594.

Pomeroy, J., D. Marks, and T. Link (2009), The impact of coniferous forest temperature on incoming longwave radiation to melting snow, Hydrol. …, 2525(May), 2513–2525, doi:10.1002/hyp.

Resources, D. of W. (2009), California Water Plan, Update 2009, Sacramento, CA.

Running, S. W., and E. R. Hunt (1993), Generalization of a forest ecosystem process model for other biomes, BIOME-BGC, and an application for global-scale models, in Scaling physiological processes: leaf to globe, edited by J. R. Ehleringer and C. B. Field, pp. 141–158, Academic Press, San Diego.

Running, S. W., R. R. Nemani, D. L. Peterson, L. E. Band, D. F. Potts, L. L. Pierce, and M. a Spanner (1989), Mapping Regional Forest Evapotranspiration and Photosynthesis by Coupling Satellite Data with Ecosystem Simulation, Ecology, 70(4), 1090–1101.

Saucedo, G. J., and D. L. Wagner (1992), Geologic Map of the Chico quadrangle, Regional Geologic Map 7A.

Soil Survey Staff, . (2011), Soil Survey Geographic (SSURGO) Database.

Stednick, J. (1996), Monitoring the effects of timber harvest on annual water yield, J. Hydrol., 176(1-4), 79–95, doi:10.1016/0022-1694(95)02780-7.

Stephens, S., J. Agee, P. Fule, M. P. North, W. Romme, T. Swetnam, and M. Turner (2013), Managing Forest and Fire in Changing Climates, Science (80-.)., 342, 41–42.

Stuemky, M. (2010), Kings River Experimental Watersheds (KREW): Providence - Instruments, USDA For. Serv., (March). Available from: http://www.fs.fed.us/psw/topics/water/kingsriver/documents/maps/krew_providence_instruments.pdf

Swank, W., J. Vose, and K. Elliott (2001), Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment, For. Ecol. Manage., 143, 163–178, doi:10.1016/S0378-1127(00)00515-6.

Tague, C., K. Heyn, and L. Christensen (2009), Topographic controls on spatial patterns of conifer transpiration and net primary productivity under climate warming in mountain ecosystems, October, 554(October), 541–554, doi:10.1002/eco.

Tague, C. L., and L. E. Band (2004), RHESSys: Regional Hydro-Ecologic Simulation System—An Object-Oriented Approach to Spatially Distributed Modeling of Carbon, Water, and Nutrient Cycling, Earth Interact., 8(19), doi:http://dx.doi.org/10.1175/1087-3562(2004)8<1:RRHSSO>2.0.CO;2.

Troendle, C. A., and R. M. King (1985), The effect of timber harvest on the Fool Creek watershed, 30 years later, Water Resour. Res, 21(12), 1915–1922.

Troendle, C. A., M. S. Wilcox, G. S. Bevenger, and L. S. Porth (2001), The Coon Creek Water Yield Augmentation Project: implementation of timber harvesting technology to increase streamflow, For. Ecol. Manage., 143, 179–187, doi:10.1016/S0378-1127(00)00516-8.

USDA, N. F. S. R. 5 (2004), Sierra Nevada Forest Plan Amendment, Record of Decision.

Wigmosta, M. S., L. W. Vail, and D. P. Lettenmaier (1994), A distributed hydrology-vegetation model for complex terrain, Water Resour. Res., 30(6), 1665, doi:10.1029/94WR00436.

Zhang, L., W. R. Dawes, and G. R. Walker (2001), Response of mean annual evapotranspiration to vegetation changes at catchment scale, Water Resour. Res., 37(3), 701–708.

Zierl, B., H. Bugmann, and C. L. Tague (2006), Water and carbon fluxes of European ecosystems: an evaluation of the ecohydrological model RHESSys, Hydrol. Process., 21(24), 3328–3339, doi:10.1002/hyp.

Table E1: Physiographic features of the four headwater research catchments.

Catchment	Area (ac)	Outlet Elev (ft)	Drainage Basin	Type
Bear Trap	345	5120	American R.	Treatment
Frazier	449	5265	American R.	Control
Big Sandy	552	5830	Merced R.	Treatment
Speckerman	479	5640	Merced R.	Control

Table E2: Physiographic features of the fireshed catchments.

Study Area	Catchment	Area (ac)	Elevation (ft)	Type
Last Chance	Screwauger	8532	3830 – 6620	Control
	Deep	5348	2160 – 7180	Treatment
	Grouse	5251	2160 – 6060	Treatment
	Peavine	5488	1600 – 6060	Control
Sugar Pine	Lewis	6033	3850 – 6850	Treatment
	Nelder	4373	4560 – 7150	Control

Table E3: The vegetation composition of Last Chance firesheds.

Vegetation Community	Lewis (%)	Nelder (%)
Open Pine-Oak Woodland	345	5120
Live Oak-Pine Forest	449	5265
Mature Mixed Conifer Forest	552	5830
Closed-canopy Mixed Conifer Forest	479	5640

Table E4: The vegetation composition of Sugar Pine firesheds.

Vegetation Community	Screwauger (%)	Deep (%)	Peavine (%)	Grouse (%)
Low Shrubs	0.0	0.1	0.0	0.0
High Shrubs	0.2	0.0	0.0	0.0
Open True Fir	4.3	3.2	1.1	0.1
Pine Forests	6.1	2.9	2.6	2.4
Cedar Forests	14.3	7.0	6.0	3.8
Young Mixed Conifer	13.6	8.9	6.0	2.8
Mature Mixed Conifer	61.5	77.9	84.3	90.9

Table E5: Results of AIC analysis of regression model between listed variables and discharge of the North Fork of the Middle Fork of the American River.

Variables	K	AIC	Akaike Weight	r^2
Bear Trap	3	6973.33	4.4×10^{-16}	0.618
Frazier	3	7393.36	2.7×10^{-107}	0.491
Bear Trap + Frazier	4	6902.602	0.999	0.637

Table E6: Results of the AIC analysis of the regression model between listed variables and discharge of the North Fork of the Middle Fork of the American River during low flow conditions.

Variables	K	AIC	Akaike Weight	r^2
Bear Trap	3	-914.15	9.1×10^{-100}	0.835
Frazier	3	-1307.62	2.5×10^{-14}	0.919
Bear Trap + Frazier	4	-1370.25	1	0.932

Table E7: Results of AIC analysis of regression model between listed variables and discharge of the Lewis Fork of the Fresno River.

Variables	K	AIC	Akaike Weight	r^2
Big Sandy	3	404.76	0.002	0.425
Speckerman	3	496.01	3.3×10^{-23}	0.352
Big Sandy + Speckerman	4	392.49	0.997	0.435

Table E8: Results of AIC analysis of regression model between listed variables and discharge of the North Fork of the Middle Fork of the American River during low flow conditions.

Variables	**K**	**AIC**	**Akaike Weight**	r^2
Big Sandy	3	-955.50	6.3×10^{-15}	0.593
Speckerman	3	-1005.93	5.6×10^{-4}	0.528
Big Sandy + Speckerman	4	-1020.91	0.999	0.610

Table E9: Calibration parameters for Providence Creek catchments. The highest combination of Nash-Sutcliffe Efficiency (NS_e) and log-transformed NS_e ($logNS_e$) were used to determine optimal parameters.

Site	SMc	m	k	po	pa	gw1	gw2
P301	0.0004	0.18	4.5	0.3855	0.528	0.05-0.35	0
P303	0.0004	0.18	4.5	0.3855	0.528	0.05-0.35	0
P304	0.0004	0.18	4.5	0.3855	0.528	0.23-0.45	0.00005 -0.0001

Note: For dry years (2007,2009) m=0.12, po=0.2455, SMc=0.0001

Table E10: Calibration results for Providence catchment 303 (P303). Streamflow statistics of Nash-Sutcliffe Efficiency (NS_e) and log-transformed NS_e ($logNS_e$) were used to determine optimal parameters.

Providence 303	**Snow NS_e**	**Stream NS_e**	**Stream $logNS_e$**
Calibration (2003-2008)	0.92	0.84	0.87
Evaluation (2009-2012)	0.92	0.75	0.85
Overall (2003-2012)	0.92	0.81	0.86

Table E11: Inter-annual variability of precipitation and runoff observed in the study watersheds.

Site	Catchment	Year	Precipitation, in	Runoff, in	Runoff Coefficient*
Last Chance	Bear Trap	2010	68.5	26.4	0.39
		2011	98.4	52.8	0.54
		2012	57.5	16.1	0.29
		2013	60.6	16.9	0.28
	Frazier	2010	68.5	34.6	0.51
		2011	98.4	167	0.67
		2012	57.5	65.7	0.42
		2013	60.6	17.3	0.29
Sugar Pine	Big Sandy	2010	50.4	20.5	0.41
		2011	79.1	30.3	0.38
		2012	35.8	9.1	0.24
		2013	46.5	11.4	0.25
	Speckerman	2010	50.4	15.4	0.30
		2011	79.1	44.1	0.56
		2012	35.8	14.1	0.25
		2013	46.5	12.2	0.26

*Runoff Coefficient is Water Yield divided by Precipitation

Table E12: Calibrated parameter ranges for Bear Trap and Big Sandy catchments, used for fireshed simulations. Streamflow statistics of Nash-Sutcliffe Efficiency (NS_e) and log-transformed NS_e ($logNS_e$) were used to determine acceptable parameter sets.

Site	m	k	svk	po	pa	gw1	gw2	NS_e	$logNS_e$
Bear Trap	5.6-12.3	2.0-6.6	7.0-249.9	1.4-3.0	0.6-2.6	0.0-0.15	0.0-0.01	0.60-0.64	0.75-0.84
Big Sandy	0.6-19.9	4.8-293.8	2.8-293.4	0.1-3.0	0.2-2.9	0.2-0.4	0.1-0.4	0.67-0.78	0.62-0.70

Table E13: Model results of treatment scenarios for Leaf Area Index (LAI), Groundwater loss (GW), Evapotranspiration loss (ET), and Water Yield (WY) in the Last Chance and Sugar Pine study sites, with the relative fraction of precipitation in parentheses. Precipitation listed for each study site was the mean annual precipitation over the four years of observation, water years 2010-2013.

Study Area	Treatment	Year	LAI	ET, in	GW, in	WY, in
Last Chance (Precip = 78.3in)	Control	0	7.0	48.3 (0.62)	8.2 (0.11)	21.7 (0.28)
		10	8.6	49.6 (0.63)	9.4 (0.12)	19.4 (0.25)
		20	10.0	50.3 (0.64)	10.3 (0.13)	17.8 (0.23)
		30	11.1	50.3 (0.64)	10.8 (0.14)	17.2 (0.22)
	Treatment	0	6.4	46.4 (0.59)	7.5 (0.10)	24.4 (0.31)
		10	7.7	47.9 (0.61)	8.5 (0.11)	22.0 (0.28)
		20	9.0	49.0 (0.63)	9.4 (0.12)	20.0 (0.26)
		30	10.1	49.4 (0.63)	9.9 (0.13)	19.0 (0.24)
	Treatment + Fire	0	6.4	46.4 (0.59)	7.5 (0.10)	24.4 (0.31)
		10	4.3	39.3 (0.50)	5.6 (0.07)	33.5 (0.43)
		20	5.1	41.8 (0.53)	6.1 (0.08)	30.4 (0.39)
		30	5.9	43.9 (0.56)	6.7 (0.09)	27.7 (0.35)
	Control + Fire	0	7.0	48.3 (0.52)	8.2 (0.11)	21.7 (0.28)
		10	3.5	37.3 (0.48)	5.0 (0.06)	35.9 (0.46)
		20	4.2	40.0 (0.51)	5.5 (0.07)	32.8 (0.42)
		30	4.9	42.5 (0.54)	6.1 (0.08)	29.7 (0.38)
Sugar Pine (Precip = 51.3in)	Control	0	9.0	25.6 (0.50)	9.5 (0.18)	16.3 (0.32)
		10	9.3	25.5 (0.50)	9.6 (0.19)	16.1 (0.31)
		20	10.0	25.4 (0.50)	9.9 (0.19)	16.0 (0.31)
		30	10.5	25.3 (0.49)	10.1 (0.20)	15.9 (0.31)
	Treatment	0	8.4	25.5 (0.50)	9.2 (0.18)	16.7 (0.33)
		10	8.8	25.5 (0.50)	9.5 (0.18)	16.4 (0.32)
		20	9.6	25.4 (0.50)	9.8 (0.19)	16.1 (0.31)
		30	10.2	25.4 (0.49)	10.0 (0.19)	16.0 (0.31)
	Treatment + Fire	0	8.4	25.5 (0.50)	9.2 (0.18)	16.7 (0.33)
		10	5.5	25.1 (0.49)	7.8 (0.15)	18.4 (0.36)
		20	6.2	25.5 (0.50)	8.2 (0.16)	17.6 (0.34)
		30	6.9	25.7 (0.50)	8.5 (0.17)	17.1 (0.33)
	Control + Fire	0	9.0	25.6 (0.50)	9.5 (0.18)	16.3 (0.32)
		10	5.2	24.9 (0.48)	7.7 (0.15)	18.7 (0.36)
		20	5.9	25.3 (0.49)	8.1 (0.16)	17.9 (0.35)
		30	6.6	25.6 (0.50)	8.4 (0.16)	17.3 (0.34)

II: Water Quality

Introduction

An understanding of water quality parameters in mountain catchments is important as they are a main water source and often a dominant sediment source area (State of California Sierra Nevada Conservancy). This is especially true in California where many major river systems contain dams with storage areas that can be greatly reduced by accumulating sediment (State of California Sierra Nevada Conservancy). Poor water quality can be harmful to aquatic organisms and have adverse effects on water supply systems, downstream hydropower plants and industries, and water-related recreation. With the concern of overgrown forests and the increasing frequency of catastrophic fires (Miller et al., 2009), it is vital to understand water quality and sediment transport in forested mountain catchments so that we know how factors such as fire, grazing, timber harvesting, road construction, and climate change can impact downstream resources.

In undisturbed small, headwater, mountain catchments, sediment tends to be the primary water quality concern, as these systems typically lack significant sources of chemical pollutants. Sediment and sediment transport play a key role in aquatic-habitat quality, flood-control and water-supply infrastructure, nutrient cycling, contaminant transport, channel morphology, and overall channel stability (Dunne and Leopold, 2002). Information on sediment sources and transport can help policy makers and land/water managers target erosion prone areas or erosion prone time periods with control efforts such as Best Management Practices. Finally, an understanding of how sediment production and transport is affected by seasonal conditions (i.e. snow cover) is key to planning for seasonal precipitation changes associated with climate change.

Sediment yields in streams are controlled not only by discharge but also by erosion and transport. Sediment can come from hillslope or in-channel sources. On hillslopes and floodplains, the relevant sediment production processes may include soil creep, rain splash, overland flow, bioturbation, and snow creep. In-channel processes that can act on banks include: mass failure, freeze thaw cycles, and drying and crumbling, fluvial erosion during high flows

(Leopold et al., 1995). In-channel erosion processes that act on the channel bed are generally a form of fluvial erosion (i.e., re-suspension or vertical incision). Previous work in stream systems similar to those in this study has suggested that under normal conditions the hillslopes are not very connected to the channels and that in-channel erosion of the bed and banks are the more important processes in forested mountain headwater catchments (Stafford, 2011). However, this assumption may not hold with land use changes such as road construction, extensive grazing, logging, or wildfire where moderate to severe impacts to the landscape occur.

Despite forested mountain catchments being an important water source world-wide, the majority of sediment transport theory has been developed on lowland systems and with flume work (Traylor and Wohl 2000). Over the past several decades, most of the research on the relationships between precipitation, discharge, and sediment transport has been focused on single events (e.g., Sadeghi et al., 2008), or has been in predominately agricultural areas (e.g., Doomen et al., 2008; Rodriguez-Blanco et al., 2010; Gao and Josefson, 2012; Wilson et al., 2012; Soler et al., 2008), in small hillslope plots (e.g., Granger et al., 2011) or in areas with drastically different physiographic and climatic regimes from that of the Sierra Nevada (Gao and Josefson, 2012; Fang et al., 2011; McDonald and Lamoureux, 2009). The wide variety of land use, topography, and climate across the existing studies has yielded mixed results. Several longer studies looking at multiple time scales have shown considerable temporal variation in sediment patterns. McDonald and Lamoureux (2009) found significant temporal variation in suspended sediment transport in High Arctic catchments that was linked to snow melt. For a medium sized basin in Central New York, Gao and Josefson (2012) found event and seasonal patterns to be too complex to identify sources or processes but that their system was generally supply limited. Iida et al. (2012) looked at hysteresis patterns associated with snow melt in a temperate mountain catchment in Japan. They found more sediment moved during the snow melt season than the rest of the year and that sediment depletion or a shift to more distant sediment sources occurred as the snow melt season progressed. Fang et al. (2011) found evidence of a hillslope source area in the Loess Plateau of China. Headwater and larger order basins in southeast Australia were studied by Smith and Dragovich (2009), who suggested that differences in sediment patterns were due to rates of sediment transfer to larger order basins.

Work in small, forested mountain catchments with a Mediterranean climate has been limited. Seeger et al. (2004) showed for a basin in the central Spanish Pyrenees that seasonal differences in the sediment - discharge relationship were tied to antecedent conditions within the basin. In their work in the Lake Tahoe region, Langolis et al. (2005) showed that suspended sediment peaked fairly consistently on the rising limb of the hydrograph for the snow melt season, but they did not look at other seasons.

Impacts of fire on water quality may be due to increased hillslope erosion, increased in-channel erosion from greater discharges, increased availability and rapid transport of nutrients to streams, and loss of riparian vegetation impacting water temperatures (Lane et al., 2006; Shakesby and Doerr, 2006; Shakesby, 2011; Smith et al., 2011). Lane et al. (2006) linked increased sediment exports for two basins in Australia to increased post-fire discharges. In a review of fire effects on water quality for forested catchments, Smith et al. (2011) reported first year post-fire suspended sediment exports varied from 1 to 1459 times unburned exports. Similarly, they reported wide ranges in total N and total P exports that represented 0.3 to 431 times unburned levels, but found that there was a low risk of N constitutients exceeding drinking water guidelines (Smith et al., 2011).

Sediment production and movement in small mountain catchments locally impacts aquatic organisms, plants, wildlife. It also affects downstream water supply, hydroelectric operations, recreation, and downstream ecosystem services such as fisheries. Increased sediment production and transport following heavy or clear cut logging has been well studied (Beschta, 1978; Grant and Wolff, 1991; Croke et al., 1999). However, the impacts of current lighter forest management strategies, such as SPLATS, on sediment production and transport in the Sierra Nevada is less understood. The Sierra Nevada Adaptive Management Project helps to fill some of these knowledge gaps. Our working hypothesis is that the light proposed treatments will not alter the timing or magnitude of flows. Likewise, no changes are expected to be seen in water quality due to no increased discharges. No catastrophic fires affected our field sites while we collected data.

Methods

Water quality instrumentation was installed and data collection began over the 2009-2010 winter and continued to water year 2014. Bi-weekly to bi-monthly manual sampling began around the same time. Instrumentation and manual sampling sites were co-located with the stream node instrumentation in all watersheds except Frazer Creek, where water quality was measured approximately 50 meters downstream of the snow and soil moisture nodes. A detailed description of instrumentation and site configurations can be found in (CA Department of Water Resources, 2012; CA Department of Water Resources, 2014).

In Situ Continuous Water Quality

Water temperature, conductivity, dissolved oxygen, and turbidity were collected in all study catchments using multi-parameter continuously running sondes. Starting in WY 2012 a second multiparameter sonde, co-located with the original sondes, was installed in all catchments except Frazier Creek. The additional sondes measured water temperature, conductivity, and turbidity for data redundancy. Anti-fouling wipers were installed on the turbidity and dissolved oxygen optical sensors to prevent buildup of sediment or algae that could interfere with measurements. Water-quality attributes and stream stage are reported in 15-minute time intervals. The meteorological attributes of air temperature, precipitation, and snow depth, plotted on the water quality figures for reference to the water-quality data, are reported in daily time intervals. Air temperature was recorded at the study-site met stations. Because the study-site rain gages were unheated and unshielded, these measurements were not used for quantity – just as a confirmation of precipitation events. Precipitation, reported for reference to the water quality data from WY 2012 and on, is from the nearby stations Blue Canyon (for Last Chance) and Westfall (for Sugar Pine). The snow-depth values plotted with the water quality data represent means of all snow-depth measurements at a given site.

Separate manual measurements of temperature, discharge, conductivity, and dissolved oxygen were made on a bi-weekly to bi-monthly basis to check data accuracy. Discharge was measured using the salt-dilution slug method. Temperature, conductivity and dissolved-oxygen measurements were made with a separately calibrated multi-parameter sonde identical to the continuous running sondes.

Data from all the multiparameter sondes were manually checked to remove any erroneous spikes due to maintenance of sensors, sampling in the stream, or (for optical measurements of turbidity and dissolved oxygen) periods when the sonde was buried in sediment. To reduce sensor background noise, the turbidity data were filtered to remove any values less than 5 NTU. The remaining values were considered actual turbidity events and were used in analysis. Gaps after the WY 2012 installation were filled using the secondary sonde. When data from the secondary sonde were unavailable, only water temperature and stage could be gap filled using data from the stand alone stage recorders.

Turbidity events were classified according to seasons, with fall defined as first fall rain event to before the beginning of snow accumulation, early/mid-winter as beginning of snow accumulation to peak accumulation, snowmelt as peak accumulation to complete melt out, and baseflow as full melt out to first fall rains. Intensity values of storm events for the turbidity and load cell pressure sensor analysis were found by subtracting peak discharge values from background discharge values defined by a 15-day running average.

The offset of turbidity or suspended sediment peaks from discharge peaks, termed hysteresis effect, can provide insight into sediment movement within watersheds. Fifteen-minute turbidity data was plotted against discharge to analyze hysteresis loop shapes. Hysteresis analysis has long been established as a technique for examining sediment source areas or processes in a wide range of watershed sizes and types based on the shape of discharge-sediment hysteresis loops. The temporal relationship between the turbidity peak and the discharge peak can indicate the proximity of the sediment source and whether or not sediment depletion is occurring. Early papers by Wood (1977) and Williams (1989) identified a hysteresis effect and related each hysteresis type to physical processes in the streams. Hysteresis loops are classified into five types (Williams, 1989). Clockwise patterns are produced when turbidity peaks occur before discharge peaks indicating a localized sediment source and/or depletion of the source. Counterclockwise patterns occur when turbidity peaks occur after discharge peaks, indicating a more distant sediment source, a discharge threshold that must be reached to entrain consolidated bank sediments, or a rainfall threshold required to initiate overland flow. Linear patterns, where peaks occur simultaneously, imply a sediment source at an intermediate distance, a lower entrainment threshold, or a continuous supply of sediment. Figure eight and complex patterns typically occur when there are multiple sediment source locations or multiple erosion processes acting concurrently.

Manual Samples

Water chemistry in stream and precipitation water can help to identify sources and flow paths of water in that system. Water chemistry samples were collected at stream sites year round at biweekly to bimonthly intervals. Samples were taken at or near the location of the water-quality instrumentation at each stream site in order to correlate sample results to continuous water quality data. Stream samples were analyzed for major ions, and isotopes. Bottles and lids used during sampling were cleaned, triple rinsed with DI water prior to field work and then triple rinsed at the site with stream water. All samples were taken in the center of flow and bed sediment disturbance was avoided.

Major Ions

Grab samples of 500 mL of stream water were collected for major cation and anion analysis. Samples were filtered using a vacuum-filtration system with a 0.45-μm filter then split in half for ion-chromatography analysis of major cation and anions as well as titration analysis for acid neutralization capacity (ANC). If samples could not be filtered immediately, they were frozen to preserve the samples until they could be processed. Cations measured included Na^{+}, NH_4^{+}, K^{+}, Mg^{+2}, and Ca^{+2}. Anions measured included F^{-}, Cl^{-}, SO_4^{-2}, and NO_3^{-}.

Isotopes

Isotope samples were collected in 30-mL glass vials with septum lids. Bottles were capped such that no air was present in the bottle. Samples were stored refrigerated until they could be analyzed to prevent algae growth. Isotope samples were processed using integrated-cavity laser spectroscopy to determine the δ D and $\delta\ ^{18}O$ of samples.

Channel Bed Scour

Load cell pressure sensors were installed to monitor sediment movement through the stream system. Two Rickly Hydrological load cell pressure sensors were buried 30 to 50-cm below the stream bed at each stream reach. The sensors operate by measuring the pressure of the water column and the pressure exerted on a water-filled pan buried in the sediment at the same depth. The difference between the two readings is the weight of the sediment on top of the pan. Sensors were co-located at Bear Trap, Frazier, and Speckerman Creeks to provide redundant measurements. At Big Sandy Creek, one sensor was installed adjacent to the water quality instrumentation and the other was installed approximately 15-m downstream. Cross-sections at the scour-pan locations were completed several times throughout the study, typically during late-summer/early-fall low flows.

Results

In Situ Continuous Water Quality

The water-quality parameters of water temperature, conductivity, dissolved oxygen, and turbidity were collected in all study catchments using multi-parameter, continuously-running sondes (Figures E25-E32).

Temperature

Water temperature ranged for the period of record from 0 to 13.0 ^{o}C in Speckerman, 0 to 18.0^{o}C in Big Sandy, 0 to 15.0 ^{o}C in Frazier and 0 to 13.6 ^{o}C in Bear Trap (Figures E25-E32). WY 2013 showed the warmest water temperatures in all catchments except Big Sandy, where WY 2012 had roughly 1 ^{o}C higher maximum water temperature. For all four catchments, water temperatures in WY 2010 were lowest in early winter and gradually rose through the season. In WY 2011, temperatures stayed steady for much of the winter. Water temperature patterns were similar in both water year 2012 and 2013, trending with air temperature, reaching lowest values in early winter and gradually rising through the season.

Conductivity

At both the Sugar Pine catchments, manual and continuous measurements of conductivity showed low, relatively stable values with little seasonal variation. Mean values for WY 2010 and WY 2011 were 12.5 µS and 12.4 µS at Speckerman (Figure E25). Continuous conductivity and dissolved oxygen values at Big Sandy are not shown for WY 2010 and WY 2011 due to frequent battery failures and sediment burial. Mean specific conductivity values for WY 2012 and WY 2013 were 18 µS and 17 µS at Speckerman, and 45 µS and 44 µS at Big Sandy respectively (Figures E26, E28).

Mean conductivity values for the Last Chance catchments were 33.3 µS and 28.8 µS for Frazier for WY 2010 and WY 2011 (Figure E29). For Bear Trap, the mean value for WY 2010 was 27.8 µS (Figure E31). Bear Trap's WY 2011 mean was not calculated due to the amount of missing data. Mean conductivity values for the Last Chance catchments were 46 µS and 44 µS for Frazier for WY 2012 and WY 2013 (Figure E30). For Bear Trap, the mean value for WY 2012 was 48 µS. Bear Trap's WY 2013 mean was found to be 43 µS (Figure E32).

Dissolved Oxygen

Dissolved oxygen data in both the Last Chance catchments showed percent saturation values that were fairly stable from year to year ranging between 75% and 95% saturation, with annual means for Frazier being 86%, 84%, and 83% for water years 2010, 2011 and 2012 respectively. Frazier had too many data gaps in 2013 to allow calculation of a mean (Figures 29, 30). For Bear Trap, annual means were 89%, 86%, 86%, and 85% saturation for water years 2010, 2011, 2012, and 2013 respectively (Figures E31, E32).

Sugar Pine catchments also ranged between 75% and 95% for WY 2010 and WY 2011 with annual means of 88% and 87% saturation for Speckerman, 91% and 87% saturation for Big Sandy (Figures E25, E27). In water years 2012 and 2013, Speckerman's dissolved oxygen values dipped much lower ranging from 50% to 95% with annual means of 85% and 77% respectively (Figure E26). Big Sandy had values ranging between 70% and 90% for water years 2012 and 2013, but due to data gaps during baseflow, may have dipped even lower than the recorded data showed (Figure E28). Annual means were not calculated for Big Sandy due to the large data gaps.

Turbidity

Seasonal turbidity patterns were analyzed for WY's 2010 through 2012. The highest turbidity values tended to occur during fall rains and during the snowmelt period (Figure E33).

These large turbidity spikes often, but not always occurred with the largest discharge events. When events were divided up by season, fall had the most turbidity-producing discharge events, with 84% of the events producing a signal (Table E14; Martin et al., 2014). However, these results did not seem to be tied to the size of the discharge events. When the three largest discharge events per year were tallied by season, none of the largest events occurred in fall (Table E14). Large storm data for WY 2011 in Bear Trap were not included in this analysis due to an extensive gap in turbidity data during the high-flow season. When intensity values (peak discharge minus 15-day running average discharge) of events were compared by season, fall had the highest average intensities (3.9 cfs), early to mid-winter had the second highest (3.5 cfs), with snowmelt and baseflow having the lowest (both 2.1 cfs).

Turbidity-discharge hysteresis patterns showed a dominance of clockwise patterns for all seasons except baseflow (Table E15; Martin et al., 2014). Fall and early/mid winter had the highest proportions of clockwise events. Snow melt had the third highest proportion of clockwise hysteresis event patterns, and baseflow had the lowest proportion.

A depletion of sediment was seen at the seasonal and at the event scale (for multi-rise events). Figure E34 shows a series of discharge and turbidity events during the fall 2011 season at Speckerman Creek. The largest turbidity signal was seen early in the season, with a gradual decrease in turbidity signal values, even though the peak discharges for events increased. Multi-rise events also showed a shift in hysteresis patterns indicative of depletion of sediments. Figure E35 shows a multi-rise discharge event in Big Sandy Creek that progressed from strongly clock-wise to a weakly clock-wise pattern and finally, to a linear pattern.

Mean peak turbidity event values were calculated for the pre- and post-treatment periods (Table E16). Data was aggregated separately for the control watersheds and the treatment watersheds. Due to lack of consistent flow during drier years and concerns with turbidity due to algae at extremely low flows, baseflow turbidity data was not included in the analysis. A comparison of mean peak turbidity between pre-treatment water years 2010 and 2011 and post-treatment water years 2012 and 2013 showed no significant difference within both the control catchments ($p = 0.38$) and the treatment catchments ($p = 0.11$) . The percentage of turbidity events occurring during the fall, early/mid-winter, and spring melt seasons for pre- and post-treatment periods are shown in Table E16.

Manual Samples

Major Ions

Analysis of major cation and anions from streamwater samples, and comparison of those ion concentrations with stream conductivity, showed Speckerman having the lowest concentrations and conductivities of the four watersheds (Figure E36). Big Sandy had intermediary concentrations and conductivities, while Frazier and Bear Trap showed the highest concentrations and/or conductivity depending on the ion in question. The Last Chance samples had a much larger spread of sample points than did the Sugar Pine sites.

For the cations Na^+ and K^+, Speckerman, Big Sandy, and Frazier had increases in concentration that were proportional to increases in conductivity, while Bear Trap did not exhibit an increase in concentration with increasing conductivity (Figure E36). For Mg^{+2}, Speckerman did not show a concentration increase with increased conductivity and Bear Trap had only a slight increase (less steep slope) in concentration with increased conductivity. Big Sandy and Frazier had proportional increases similar to that for Na^+ and K^+. For Ca^{+2} all streams except Speckerman showed higher concentrations associated with increased conductivities. The F^- anion showed considerable spread in the data along with relatively low concentrations. For Cl^- and $SO4^{-2}$, Bear Trap showed increasing ion concentrations with increasing conductivity, but the other three streams had relatively stable ion concentrations even with increased conductivity. All four streams had proportional increases between ion concentration and conductivity for HCO_3^-.

Stable Isotopes

Stable isotopes from stream samples showed slightly more negative δ D and δ ^{18}O values for the Big Sandy and Speckerman samples (Figure E37). Paired catchments showed similar values with the northern catchments showing a smaller range than the southern catchments. The isotopic signatures of the samples form a local meteoric water line (LMWL) that sits slightly to the left of the global meteoric water line (GMWL).

Baseflow Comparison

Conductivity, Ca^{+2} ion concentrations, and stable isotopes during the baseflow season were compared for each water year. Water years 2010 and 2011 were average to wet years and the post treatment water years 2012 and 2013 were both dry years. There was a general trend of increasing conductivity and increasing Ca^{+2} ion concentrations throughout the baseflow season (Figures E38, E39). For all four catchments, baseflow conductivity was higher for WY 2012 and WY 2013 than in the previous two water years with WY 2013 values slightly elevated over WY 2012 values. Ca^{+2} ion concentrations during baseflow showed similar elevated values in WY 2012 and WY 2013. Stable isotopes generally plotted along the local meteoric water line (LMWL) for all water years with the exception of a cluster of points slightly to the right of the LMWL from WY 2010 (Figure E40).

Channel Bed Movement

Data from load cell pressure sensors placed in the thalweg of the four study catchments, showed patterns of abrupt channel bed disturbance (scour and/or fill) associated with discharge events. These events were overlain on a broad annual pattern of accumulation of channel bed material during fall and early/mid-winter, followed by gradual scour of material back to a stable equilibrium bed surface elevation during spring and baseflow (Figure E41).

Discussion

In Situ Continuous Water Quality

Temperature

Water temperature trends in the four study catchments followed the trend in air temperature and were as expected with lowest values around freezing in early winter and rising to their peak in late summer. The higher summer temperatures at Big Sandy compared to Speckerman may be due to Big Sandy having less groundwater input and/or less shading of the stream by vegetation.

Conductivity

For all streams, the highest conductivity values were seen during baseflow conditions and the lowest during peak spring snowmelt. This was to be expected, because baseflow consists of a higher proportion of higher conductivity groundwater. In the spring, this groundwater input is diluted by relatively low conductivity snowmelt. The dilution effect could also be seen on a storm-by-storm basis. A good example was the large discharge spike from early season snowmelt centered on WY 2011 day 80 for Frazier Creek (Figure E29). The addition of low-conductivity melt water caused a dilution of the stream, and a corresponding dip in conductivity was seen.

The higher mean conductivities and high seasonal variation imply that the groundwater input at Big Sandy and the Last Chance catchments may be older or that the soil/rock the water it is in contact with is more easily reacted. Both explanations are plausible for the Last Chance sites, given that the Last Chance catchments have a mixture of granitic and metamorphic rock types. The relatively low amount of seasonal variation in the Speckerman catchment suggests that the water in this catchment is relatively new. The roughly double conductivity values at Big Sandy compared to Speckerman implies that Big Sandy either has some older/higher conductivity water or there are differences between the catchments in soils and rock that the event water comes in contact with.

The higher mean conductivity values for WY 2012 and WY 2013, compared with those in WY 2010 and WY 2011, were as expected due to WY 2012 and WY 2013 being low water years with proportionally less low-conductivity rain/snow entering the stream.

Dissolved Oxygen

The annual means for dissolved oxygen did not change much from WY’s 2010-2011 to WY’s 2012-2013 for the Last Chance catchments. This was likely due to their more-stable baseflow. These streams maintained a flow during baseflow in even in the latter, drier water years. The annual mean for Speckerman for WY 2012 did not change much from the previous two water years, however WY 2013 was slightly lower. The lower minimum values at

Speckerman were likely due to this catchment having very little late summer baseflow in the drier water years (with the stream becoming intermittent in the study reach).

The concentration values in all catchments showed a slight seasonal trend as would be expected with higher values in winter/spring when water temperatures are lower. For 85% saturation at sea level, dissolved oxygen values ranged from 12.2 mg L^{-1} at 0^{o}C to 8.5 mg L^{-1} at 15^{o}C. Values of 7.0 mg L^{-1} or higher are recommended for streams. With the exception of some brief time periods in water years of 2012 and 2013 in Speckerman Creek, where diurnal fluxuations in dissolved oxygen dipped to around 5 mg/L during very low/intermittent flows, all four streams stayed above the 7 mg/L dissolved oxygen level recommended for healthy aquatic life.

Turbidity

Fall likely had the most turbidity producing events without having the largest discharges due to the high intensity of fall rain events combined with the high availability of easily transported sediment that accumulated during the preceding low-flow baseflow season. Significant spikes in turbidity were sometimes observed during baseflows for all four streams, when no discharge events were occurring. The exact reason for these spikes is unknown, but possible explanations may be wildlife using the stream or algae growth in the water column. Because the turbidity sensors are equipped with automatic wipers, biofilm buildup on the sensor is not a likely explanation for these spikes.

As established by the work of Wood (1977) and Williams (1989), clockwise patterns indicate a localized, easy-to-transport sediment source that can be entrained and transported quickly during the early part of the discharge event. The dominance of this hysteresis pattern suggests localized in-channel sediment stores, likely at the toe of channel banks. Bank-pin surveys during the low-flow season in the Sugar Pine catchments confirm the existence of material accumulated at the toe of channel banks and support this interpretation (Martin et al., 2014).

The seasonal decreases in turbidity values suggest that there may have been stores of sediment that had accumulated during the previous low-flow season and that were gradually depleted as the season progressed. Mechanisms for low-flow sediment accumulation may be physical weathering of channel banks as they dry and crumble, or bioturbation.

The shift away from a clock-wise hysteresis pattern during multi-rise events indicates a progressive lag in sediment transport that likely results from a depletion in localized stores and a shift from nearby, easy-to-transport sediments to more distant sediment sources or to more consolidated sources (consolidated banks or armored beds) that require greater flow energy to entrain. Snow cover did not appear to factor into fall having higher turbidity values than winter and spring due to the sediment sources being localized, and no differences in turbidity patterns observed between the seasons (Martin et al., 2014).

The observed hysteresis shapes and patterns within the turbidity signal suggest that the catchment undergoes phases of accumulation and depletion of localized sediment stores. It is thought that during low-flow periods, sediment accumulates at the toe of banks. This accumulation period is thought to occur at the seasonal time scale (*i.e.*, summer baseflows) as well as event scale (*i.e.*, low flows between discharge peaks). Sediment is entrained and transported downstream during high-flow events, with multiple events in short succession depleting sediment stores (Martin et al., 2014).

The lack of significant difference seen between the pre-and post-treatment turbidity event means in the treatment watersheds is likely due to the light treatments performed and the dry conditions in the post-treatment years. It should also be noted that the infrequency of events resulted in a relatively small sample size compared to large standard deviations for turbidity. This may have also contributed to the lack of significance. The post-treatment period showed a higher percentage of turbidity peaks during winter rather than fall for the pre-treatment, however this is more likely due to timing of precipitation/melt events in wet versus dry years than to treatment effects.

Manual Samples

Major Ions

The values and trends in major ion chemistry indicate that for Speckerman Na^+, K^+, and HCO_3^- were important constituents affecting stream conductivity, while Mg^{+2}, Ca^{+2}, and SO_4^{-2} contributed little to that streams conductivity. The same constituent make-up seemed to be the case for Big Sandy, however there was more scatter in the data. The similarities are likely due to very similar rock types and source waters between the two paired watersheds.

The Last Chance sites have very different constituent make-ups between the two watersheds. Ca^{+2}, Cl^-, and SO_4^{-2}, and HCO_3^- seem to be the most important constituents for stream conductivity (Mg^{+2} to a lesser degree) for Bear Trap, while Na^+ and K^+ seem to be unimportant. Frazier has a nearly opposite trend, with Na^+, K^+, Mg^{+2}, and HCO_3^- being the more important constituents (Ca^{+2} to a lesser degree) and Cl^- and SO_4^{-2} not contributing significantly to conductivity. These differences are likely due to variations in the bedrock chemistry between these two streams. Bedrock in Frazier consists of mainly andesitic pyroclastic flow deposits with a small amount of the ShooFly Complex, a metasedimentary sandstone, siltstone, and slate (USGS 2014). Bear Trap is the opposite consisting mostly of the ShooFly Complex with very limited andesitic pyroclastic flow deposits.

Stable Isotopes

More negative isotopic values at the Sugar Pine sites were as expected due to the southern catchment's higher altitudes. The existence and position of the local meteoric water line (LMWL) were also expected and fit well with other Sierra Nevada sites.

That baseflow isotope samples plotted on this LMWL, indicates minimal evaporation was occurring. The lack of an evaporation signal during dry years, suggests that the increases in conductivity and ion concentrations were due to increased amount of dissolved solids. Dissolved solids are picked up in the water through contact with subsurface materials. Lengthened contact of water with subsurface materials and less dilution by low conductivity rain/snow results in increased conductivity or concentration.

Baseflow Comparison

The similarity of baseflow conductivity and ion concentrations trends for control and treatment catchments in this study suggests that there was not a measureable change in water chemistry signals due to treatments. Instead, the difference between pre-and post-treatment year data was likely due to factors that affected both treatment and control watersheds. The increased post-treatment conductivity and ion concentrations seen in WYs 2012 and 2013 were typical of drought conditions. Any potential post-treatment water chemistry signal was not distinguishable over the coinciding drought signal.

The general trend of increasing conductivity and ion concentrations during baseflow seasons were as expected due to one of two reasons: 1) as the baseflow season progresses there was an increasing proportion of sub-surface flow that had picked up dissolved materials while in contact with rock and soil, or 2) evaporation was occurring, increasing the concentration of dissolved material in the stream water throughout the summer baseflow season. The higher conductivity and ion concentration during drier water years was likely due to a greater reliance on subsurface water for maintaining stream flow, or earlier snow melt and a longer drier baseflow period where increased evaporation can occur (Figures E38, E39).

Baseflow stable isotope data helps to distinguish the mechanism causing higher concentration and conductivity. Isotope values are based on the isotopic signature of precipitation falling on the watershed. These values vary considerably by storm, but contact with the subsurface does not typically alter the isotopic signature of the water, so even non-event water will plot along a localized meteoric waterline. Evaporation, however, will alter the isotopic signature as samples diverge from the LMWL at a shallow angle with increasingly less negative δ D and $\delta\ ^{18}O$ values with increasing evaporation. The baseflow data for WY 2012 and WY 2013 did not show this evaporation signal in the stable isotope data so it can be concluded that increased conductivity and ion concentrations were due to a greater proportion of sub-surface water in the stream (Figure E40).

The anomalous cluster of points in WY 2010 that plot to the right of the LMWL were all samples from the two Last Chance watersheds and were from June and early July of that year (Figure E40). Due to these samples being from a fairly wet water year and early in the baseflow season this divergence is not likely due to evaporation within the stream.

Channel Bed Movement

The observed disturbance and recovery patterns over both event and annual time periods are consistent with the bed acting as a short term source or sink for sediment, but being roughly sediment neutral over longer time periods. This implies that the changes in bed elevation are reflective of fluctuations in storage rather than the bed being a true source or sink and that channel beds are relatively stable interannually.

Management Implications

Given that monitored water chemistry parameters (DO, temperature and turbidity) are within healthy ranges for the SNAMP watersheds, we expected the biggest potential risk to water quality in these systems to be from increased sediment movement. Analysis of turbidity hysteresis loops indicate that in-channel erosion is main sediment source with sediment accumulation and depletion cycles tied to low and high flows. These results fit with those from previous work in the King's River Experimental Watershed, which is analogous to the SNAMP watersheds, showing very low connectivity between the hillslopes and stream channels. Channel bed movement patterns suggest that under normal conditions (no treatment, no fire) the stream channels experience seasonal changes in storage of bed material, but remain stable on an interannual basis. Because in-channel sources dominate sediment supply, it is thought that any increases in sediment transport from treatments will be due to increases in discharge. The post-treatment monitoring period was following the second year of draught. Additionally, the implemented treatments were light and located a significant distance from stream channels. These light treatments were not intensive enough to show an increase in discharge during a low precipitation year and SPLATS as implemented in SNAMP had no detectable effect on turbidity.

References

Beschta, Robert L. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. *Water Resources Research.***1978**, 14.6, 1011-1016.

CA Department of Water Resources. Sierra Nevada Adaptive Management Project Water-Team Field Activities, Methods and Results. by Martha Conklin, Roger Bales, Ram Ray, Sarah Martin, Phil Saksa, and Patrick Womble. 2012. Print. Task Order #UC 10-6 Deliverable #4.3.2.

CA Department of Water Resources. Sierra Nevada Adaptive Management Project Water-Team Update. By Martha Conklin, Roger Bales, Phil Saksa, Sarah Martin, Ram Ray, Benjamin Tobin, and Patrick Womble. 2014. Print. Task Order #UC 10-6 Deliverable #4.3.2.

Croke, Jacky, Peter Hairsine, and Peter Fogarty. Sediment transport, redistribution and storage on logged forest hillslopes in south-eastern Australia. *Hydrological Processes.* **1999**, 13.17, 2705-2720.

Doomen, A.M.C.; Wijma, E.; Zwolsman, J.J.G.; Middelkoop, H. Predicting Suspended Sediment Concentrations in the Meuse River using a Supply-Based Rating Curve. *Hydrol*. *Process*. **2008**, *22*, 1846–1856.

Dunne, T.; Leopold, L.B. *Water in Environmental Planning*, 16th ed.; W.H. Freeman and Company: New York, NY, USA, 2002; pp. 713–777.

Fang, H.; Li, Q.; Cai, Q.; Liao, Y. Spatial Scale Dependence of Sediment Dynamics in a Gullied Rolling Loess Region on the Loess Plateau in China. *Environ*. *Earth Sci*. **2011**, *64*, 693–705.

Gao, P.; Josefson, M. Event-Based Suspended Sediment Dynamics in a Central New York Watershed. *Geomorphology* **2012**, *139*, 425–437.

Granger, S.J.; Bol, R.; Hawkins, J.M.B.; White, S.M.; Naden, P.S.; Old, G.H.; Marsh, J.K. Using Artificial Fluorescent Particles as Tracers of Livestock Wastes within an Agricultural Catchment. *Sci*. *Total Environ*. **2011**, *409*, 1095–1103.

Grant, G. E., and A. L. Wolff. Long-term patterns of sediment transport after timber harvest, western Cascade Mountains, Oregon, USA. *Sediment and Stream Water Quality in a Changing Environment: Trends and Explanation*. **1991**, 203, 31-40.

Iida, T.; Kajihara, A.; Okubo, H.; Okajima, K. Effect of Seasonal Snow Cover on Suspended Sediment Runoff in a Mountainous Catchment. *J. Hydrol*. **2012**, *428*, 116–128.

Lane, P.N.J.; Sheridan, G.J.; Noske, P.J. Changes in sediment loads and discharge from small mountain catchments following wildfire in south eastern Australia. *Journal of Hydrology.* **2006**, 331, 495-510.

Langlois, J.L.; Johnson, D.W.; Mehuys, G.R. Suspended Sediment Dynamics Associated with Snowmelt Runoff in a Small Mountain Stream of Lake Tahoe (Nevada). *Hydrol*. *Process*. **2005**, *19*, 3569–3580.

Leopold, L.B.; Wolman, M.G.; Miller, J.P. *Fluvial Processes in Geomorphology*, 2nd ed.; Dover Publications: Mineola, NY, USA, 1995; pp. 27–372.

Martin, S. E., Conklin, M. H., Bales, R. C., Seasonal accumulation and depletion of localized sediment stores of four headwater catchments. *Water.* **2014**, 6(7), 2144-2163.

Miller, J.D.; Safford, H.D.; Crimmins, M.; Thode, A.E. Quantitative Evidence for Increasing Forest Fire Severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA. *Ecosystems.* 2009, 12, 16-32. DOI: 10.1007/s10021-008-9201-9.

McDonald, D.M.; Lamoureux, S.F. Hydroclimatic and Channel Snowpack Controls over Suspended Sediment and Grain Size Transport in a High Arctic Catchment. *Earth Surf*. *Process*. *Landf*. **2009**, *34*, 424–436.

Rodriguez-Blanco, M.L.; Taboada-Castro, M.M.; Palleiro, L.; Taboada-Castro, M.T. Temporal Changes in Suspended Sediment Transport in an Atlantic Catchment, NW Spain. *Geomorphology* **2010**, *123*, 181–188.

Sadeghi, S.H.R.; Mizuyama, T.; Miyata, S.; Gomi, T.; Kosugi, K.; Fukushima, T.; Mizugaki, S.; Onda, Y. Determinant Factors of Sediment Graphs and Rating Loops in a Reforested Watershed. *J*. *Hydrol*. **2008**, *356*, 271–282.

Seeger, M.; Errea, M.P.; Begueria, S.; Arnaez, J.; Marti, C.; Garcia-Ruiz, J.M. Catchment Soil Moisture and Rainfall Characteristics as Determinant Factors for discharge/suspended Sediment Hysteretic Loops in a Small Headwater Catchment in the Spanish Pyrenees. *J*. *Hydrol*. **2004**, *288*, 299–311.

Shakesby, R.A.; Doerr, S.H., Wildfire as a hydrological and geomorphological agent. *Earth-Science Reviews.* **2006**, 74, 269-307.

Shakesby, R.A., Post-wildfire soil erosion in the Mediterranean: Review and future research directions. *Earth-Science Reviews.* **2011**, 105, 71-100.

Smith, H.G.; Dragovich, D. Interpreting Sediment Delivery Processes using Suspended Sediment-Discharge Hysteresis Patterns from Nested Upland Catchments, South-Eastern Australia. *Hydrol*. *Process*. **2009**, *23*, 2415–2426.

Smith, H.G.; Sheridan, G.J.; Lane, P.N.J.; Nyman, P.; Haydon, S., Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology.* **2011**, 396, 170-192.

Soler, M.; Latron, G.; Gallart, F. Relationships Between Suspended Sediment Concentrations and Discharge in two Small Research Basins in a Mountainous Mediterranean Area (Vallcebre, Eastern Pyrenees). *Geomorphology* **2008**, *98*, 143–152.

Stafford, A.K. Sediment Production and Delivery from Hillslopes and Forest Roads in the Southern Sierra Nevada, California. Master's Thesis, Colorado State University, Fort Collins, CO, USA, 2011.

State of California Sierra Nevada Conservancy. Available online: http://www.sierranevada.ca.gov/our-region/sierra-water-supply-connection (accessed on 23 June 2014).

Traylor, C. R., Wohl, E.E, Seasonal Changes in Bed Elevation in a Step-Pool Channel, Rocky Mountains, Colorado, U.S.A. *Arctic, Antarctic, and Alpine Research*. **2000**, 32(1), 95-103.

United States Geological Survey, 2014, National Geologic Map Database. (web database) http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

Williams, G.P. Sediment Concentration *Versus* Water Discharge during Single Hydrologic Events in Rivers. *J. Hydrol*. **1989**, *111*, 89–106.

Wilson, C.G.; Thanos Papanicolaou, A.N.; Denn, K.D. Partitioning Fine Sediment Loads in a Headwater System with Intensive Agriculture. *J. Soils Sedim*. **2012**, *12*, 966–981.

Wood, P.A. Controls of Variation in Suspended Sediment Concentration in the River Rother, West Sussex, England. *Sedimentology* **1977**, *24*, 437–445.

Table E14: Percentage of flow events producing turbidity and number of flow events by season for all catchments**.

Season	Percentage of flow events that produce a turbidity signal	Number of large flow events *
Fall	84.2%	0
Early/Mid winter	55.6%	11
Snow melt	49.0%	18
Baseflow	44.4%	4

*Large flow events consist of the three largest discharge events of each water year for each stream.
**from Martin et al., 2014

Table E15: Number of turbidity event hysteresis loop patterns by season at all study catchments*.

Hysteresis shape	Fall	Early/Mid winter	Snow melt	Baseflow
Clockwise	18	19	8	1
Counterclockwise	2	2	1	3
Linear	3	0	0	1
Figure Eight	0	2	2	2
Complex	1	3	2	0

*(from Martin et al., 2014)

Table E16: Mean turbidity event peak values, standard deviations, and percentage of events for the fall, early/mid-winter, and spring melt seasons for the pre- and post-treatment periods*.

	Mean of turbidity event peaks	Standard Deviation	Fall	Early/Mid-Winter	Spring Melt
Control pre-treatment	48	115	38%	35%	27%
Control post-treatment	57	128	18%	49%	33%
Treatment pre-treatment	118	255	44%	12%	44%
Treatment post-treatment	59	124	31%	39%	30%

* Baseflow events were not included in analysis.

Figures 1-24 go with water quantity (part I), figures 25-41 go with water quality (part II).

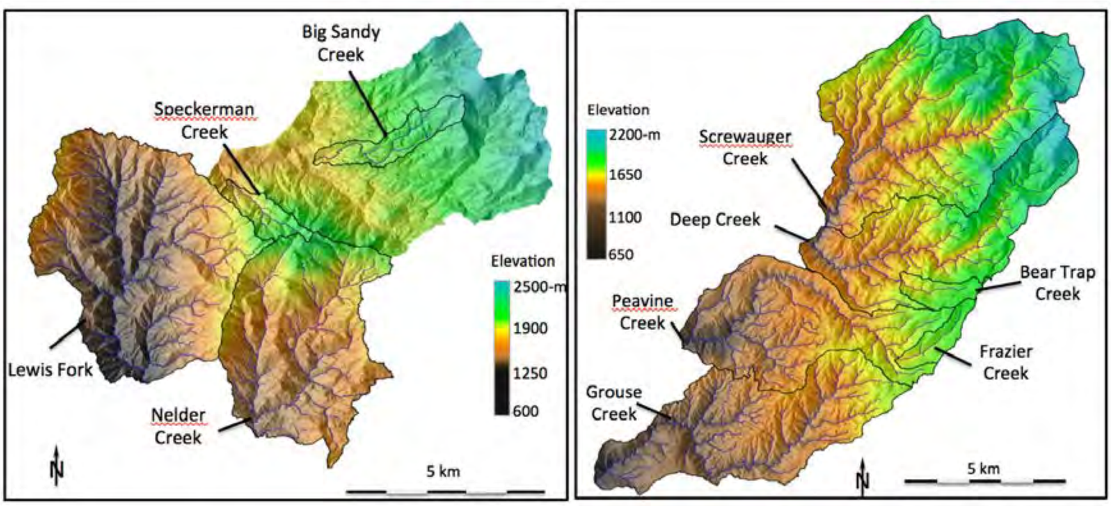


Figure E1: Location of the research catchments, Sugar Pine (left) in Sierra National Forest and Last Chance (right) in Tahoe National Forest.

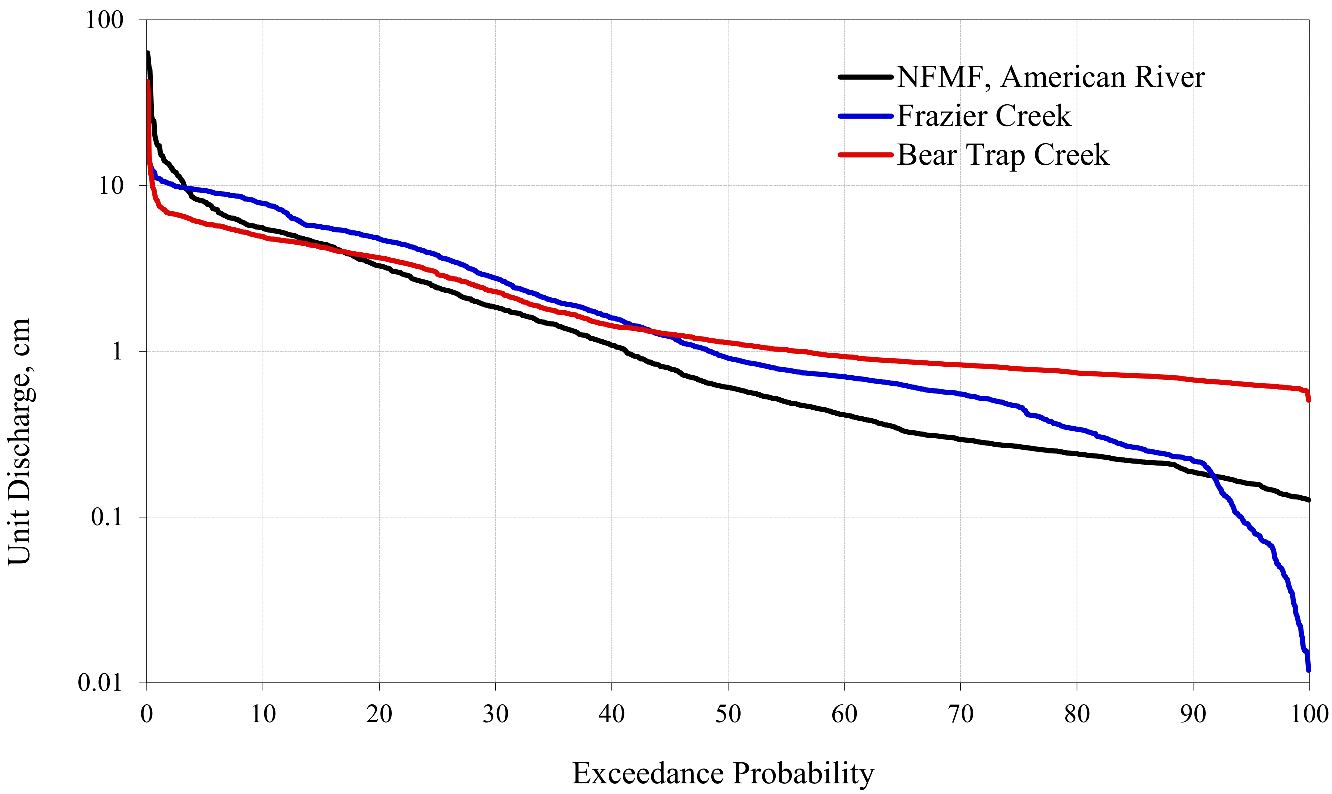


Figure E2: Last Chance flow duration curves for the North Fork of the Middle Fork (NFMF) of the American River, Frazier Creek, and Bear Trap Creek. Discharge is normalized over the watershed area.

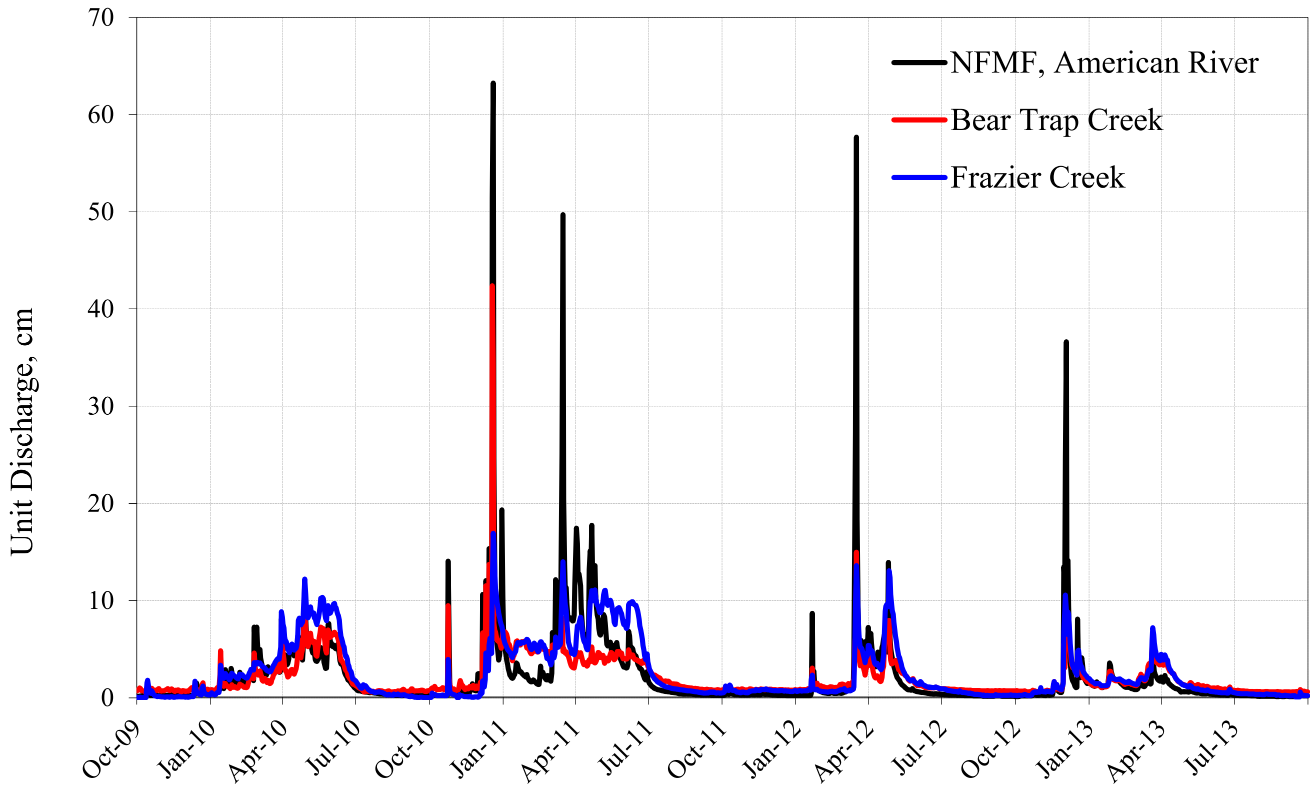


Figure E3: Last Chance discharge for the North Fork of the Middle Fork (NFMF) of the American River, Frazier Creek, and Bear Trap Creek. Discharge is normalized over the watershed area.

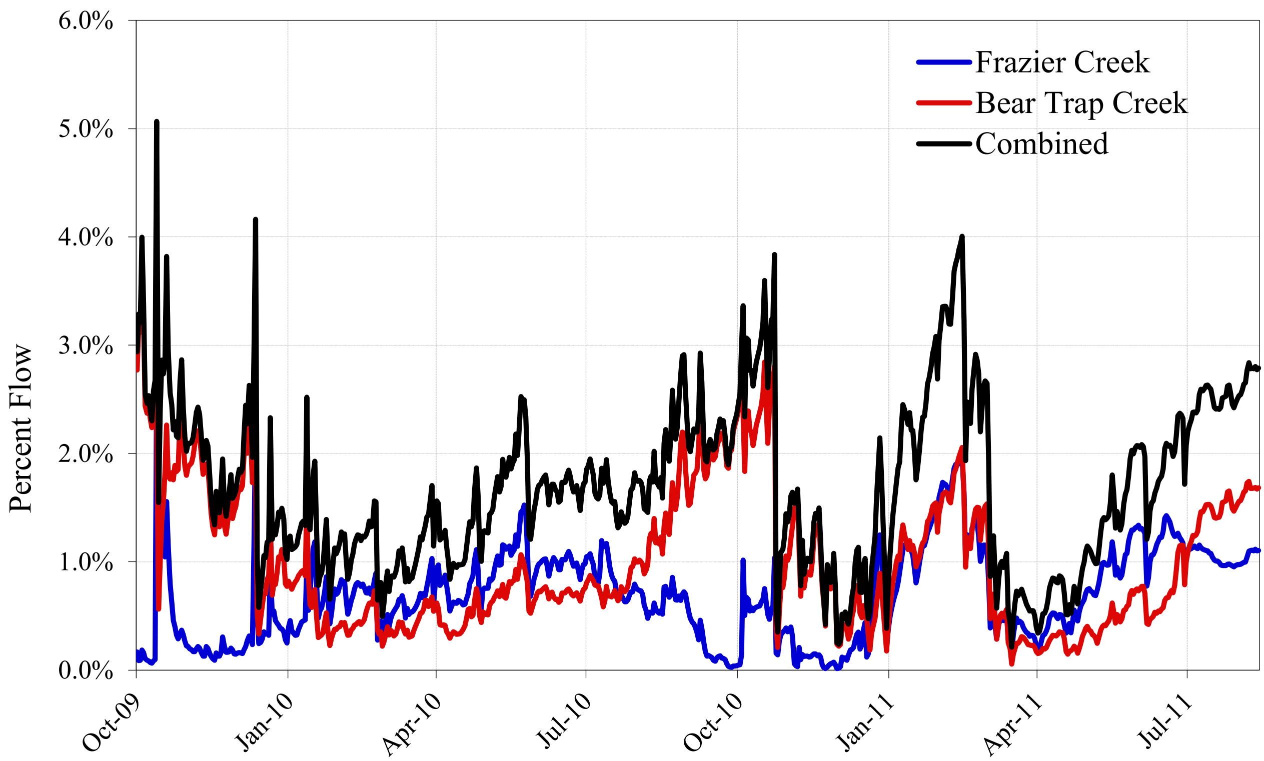


Figure E4: Percent contribution of headwater catchments to flow in the North Fork of the Middle Fork of the American River.

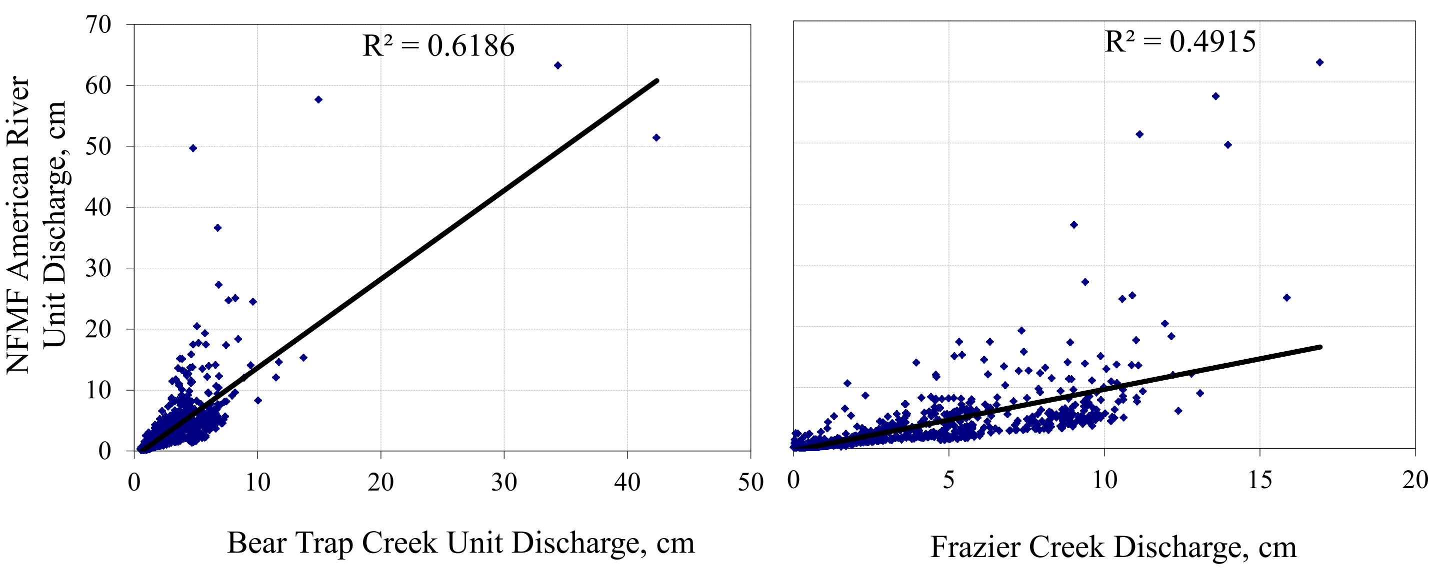


Figure E5: Linear relationships of area-normalized discharge for Bear Trap and Frazier Creek headwater catchments to the North Fork of the Middle Fork (NFMF) of the American River.

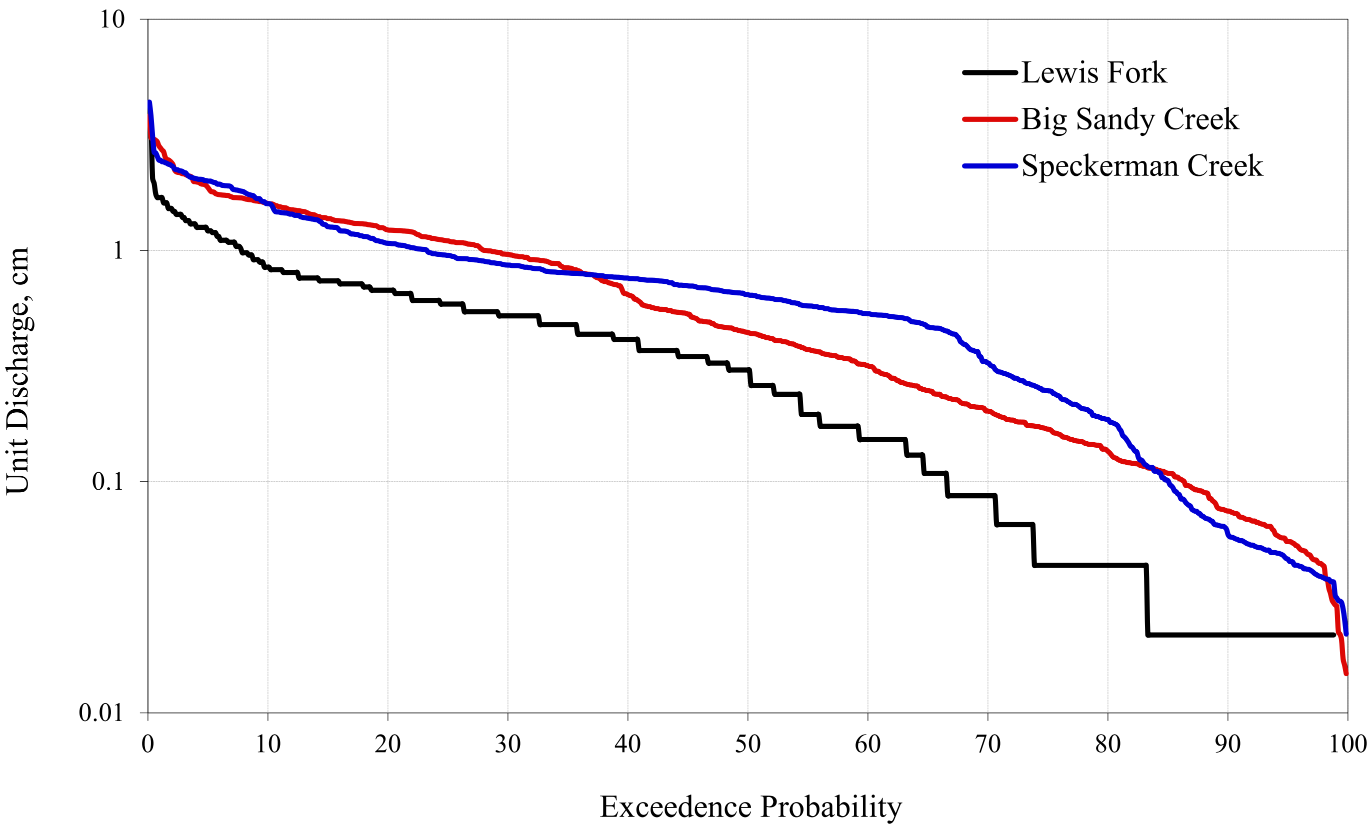


Figure E6: Flow Duration Curves of the Lewis Fork of the Fresno River, Big Sandy Creek, and Speckerman Creek. Discharge is normalized over the watershed area.

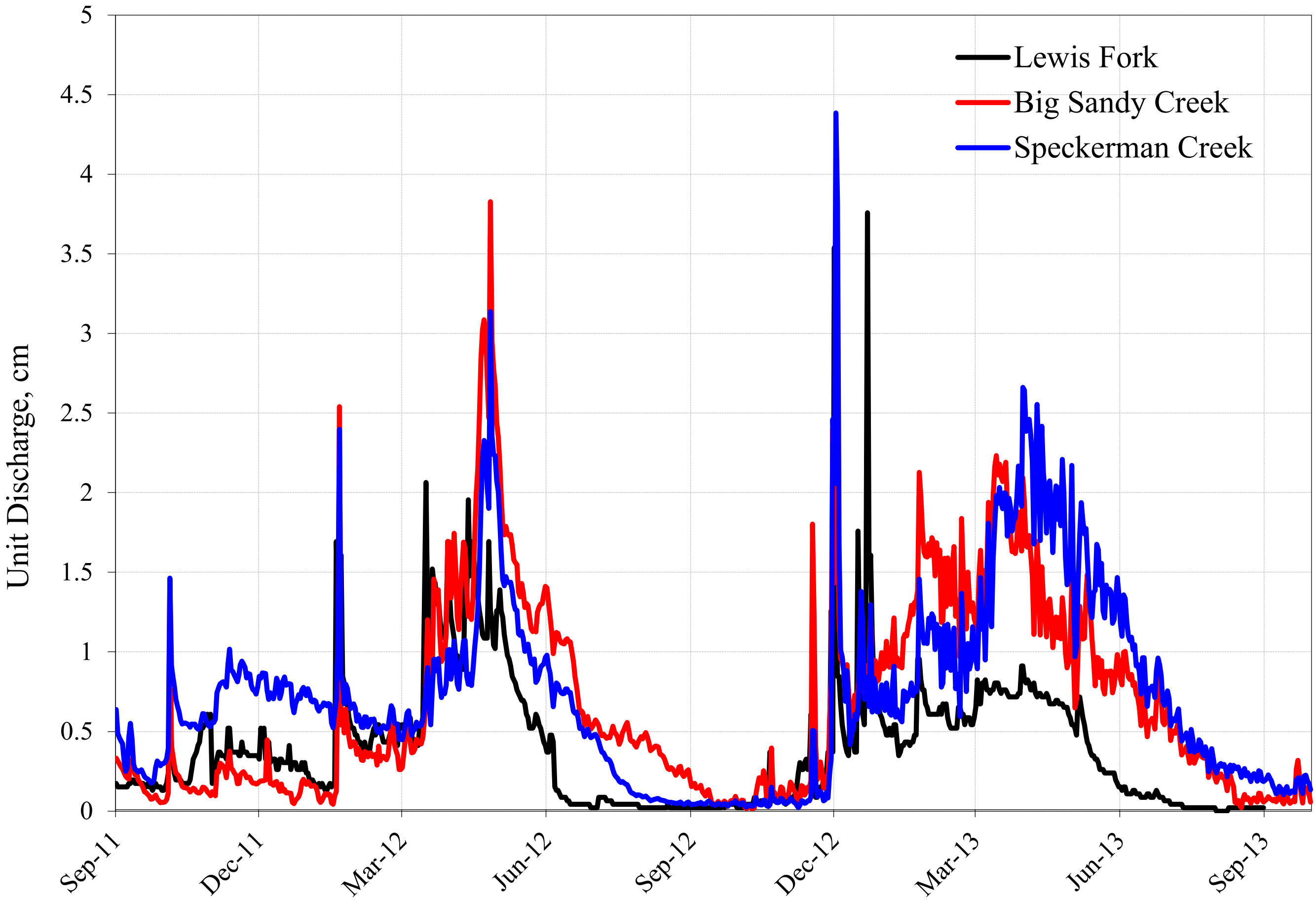


Figure E7: A comparison of area-normalized discharge for the headwater sites and the Lewis Fork of the Fresno River. Note: headwater sites do not flow into the Lewis Fork and thus a relative contribution plot was not created.

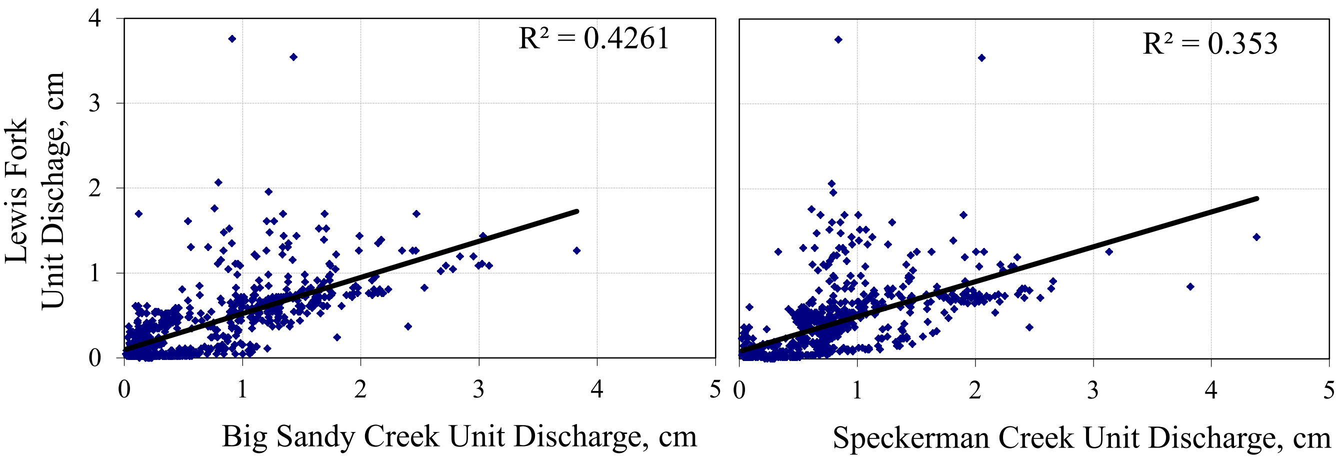


Figure E8: Linear relationships area-normalized discharge (cm) of Big Sandy and Speckerman Creeks to Lewis Fork Creek.

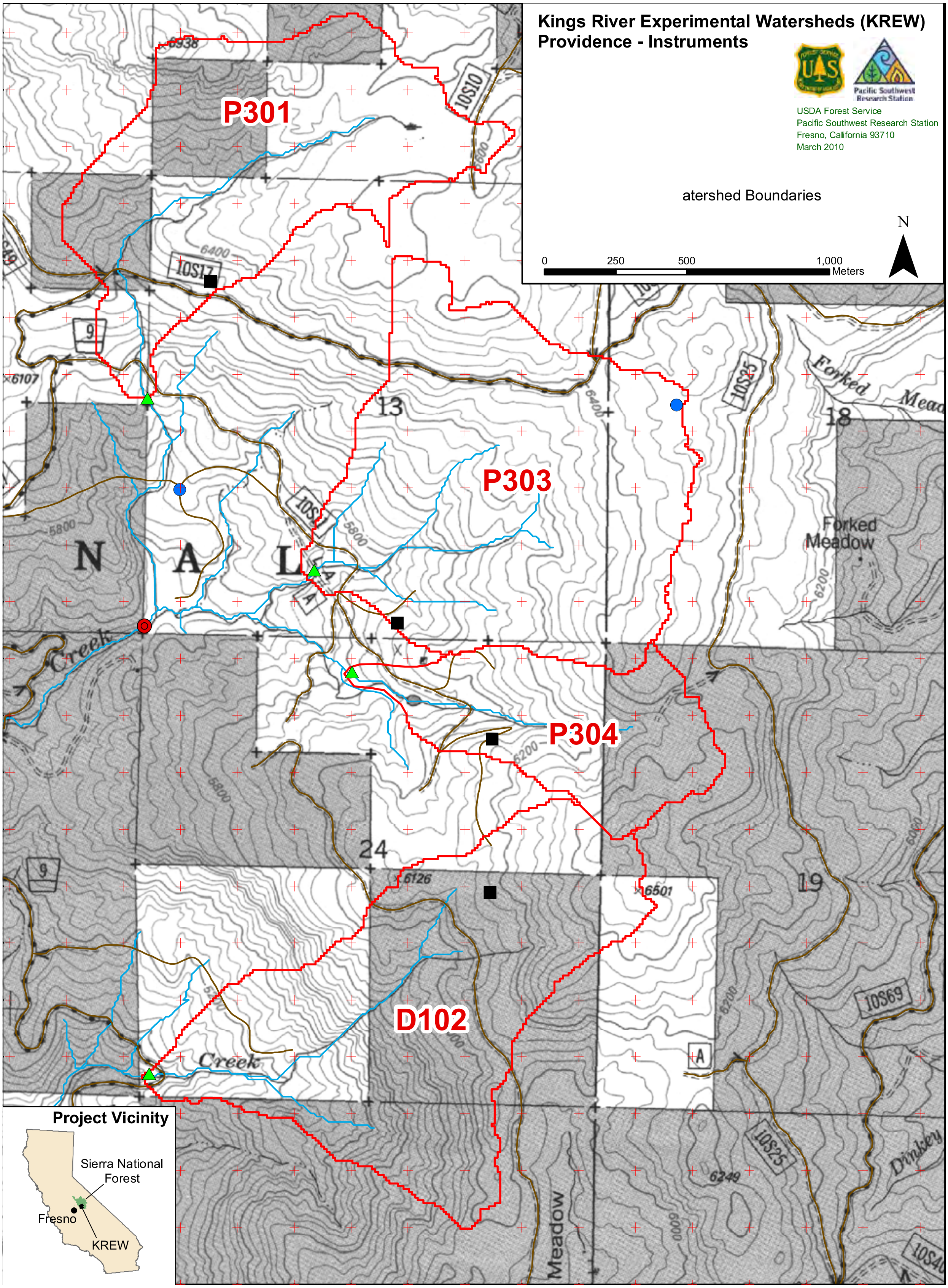


Figure E9: Providence Creek Catchments within the Kings River Experimental Watershed (KREW), Sierra National Forest (Map replicated from Stuemky 2010).

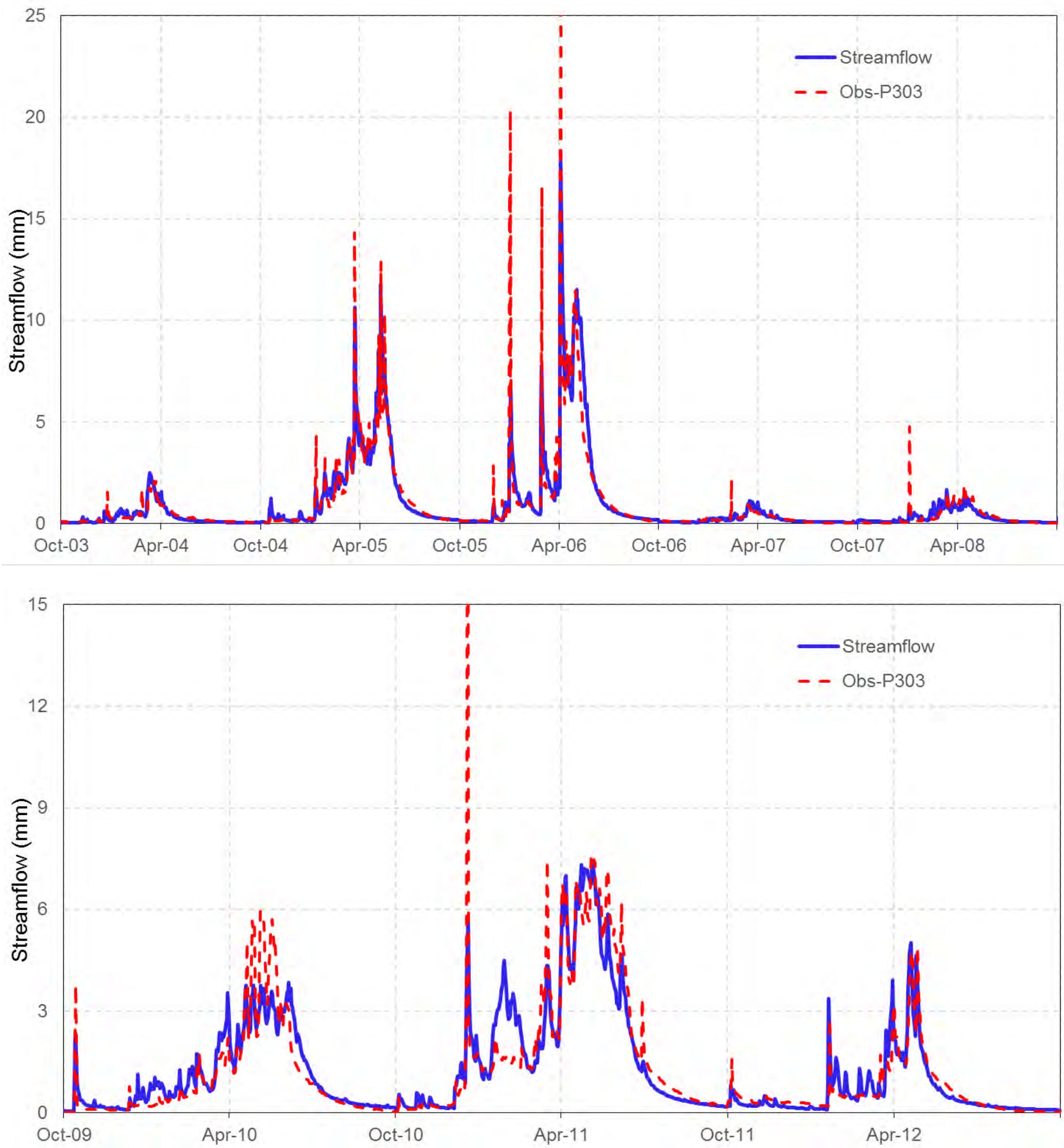


Figure E10: Model stream discharge calibration (2003-2008, top panel) and evaluation (2009-2012, bottom panel) for Providence Creek, catchment 303 (P303). Discharge is normalized over the watershed area.

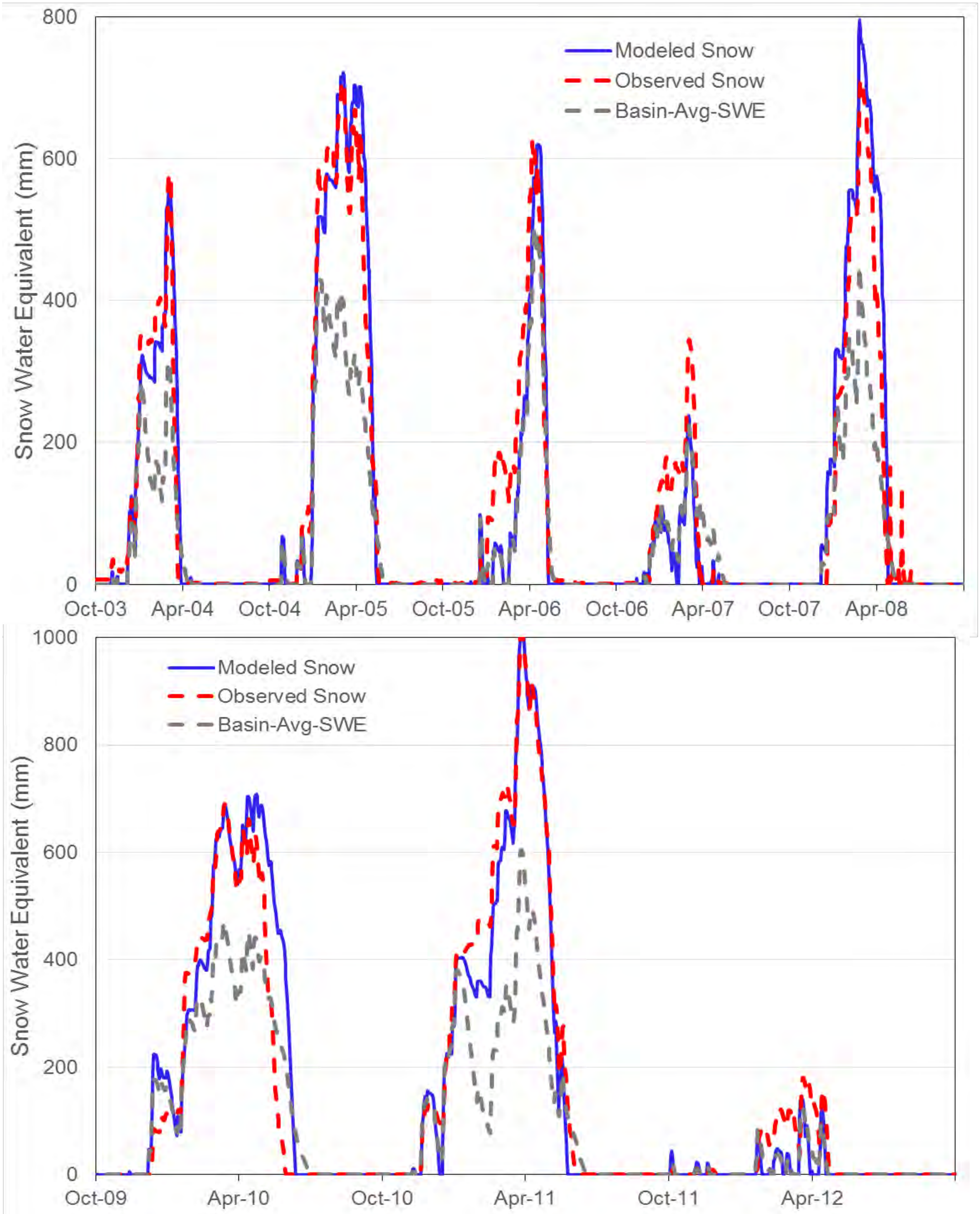


Figure E11: Model snow calibration (2003-2008, top panel) and evaluation (2009-2012, bottom panel) for Providence Creek, catchment 303 (P303).

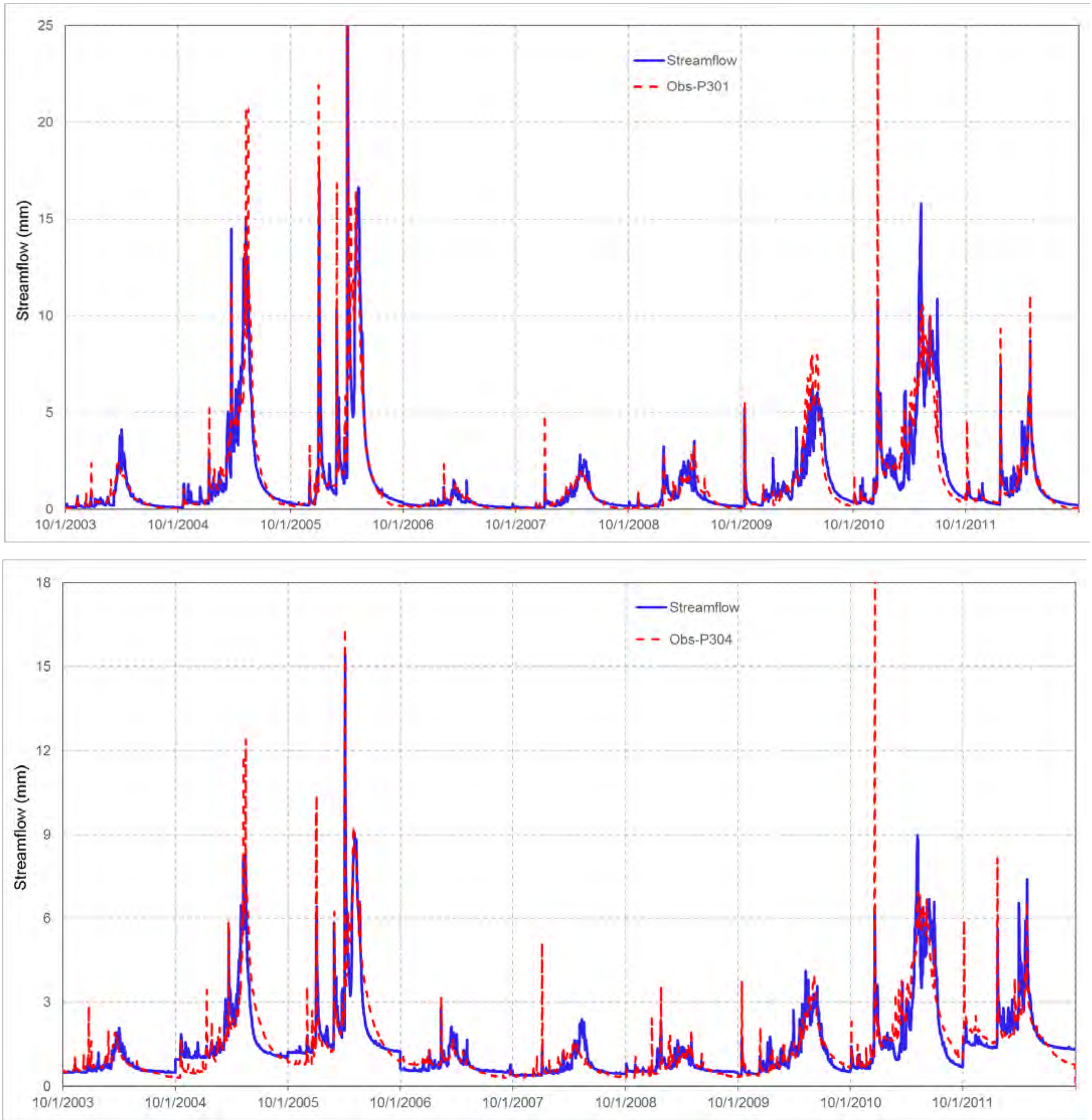


Figure E12: Model stream discharge evaluation for Providence Creek using parameters calibrated at P303 for catchment 301 (P301, top panel) and catchment 304 (P304, bottom panel). Nash Sutcliffe Efficiencies for both catchments were 0.82 (2003-2012). Discharge is normalized over the watershed area.

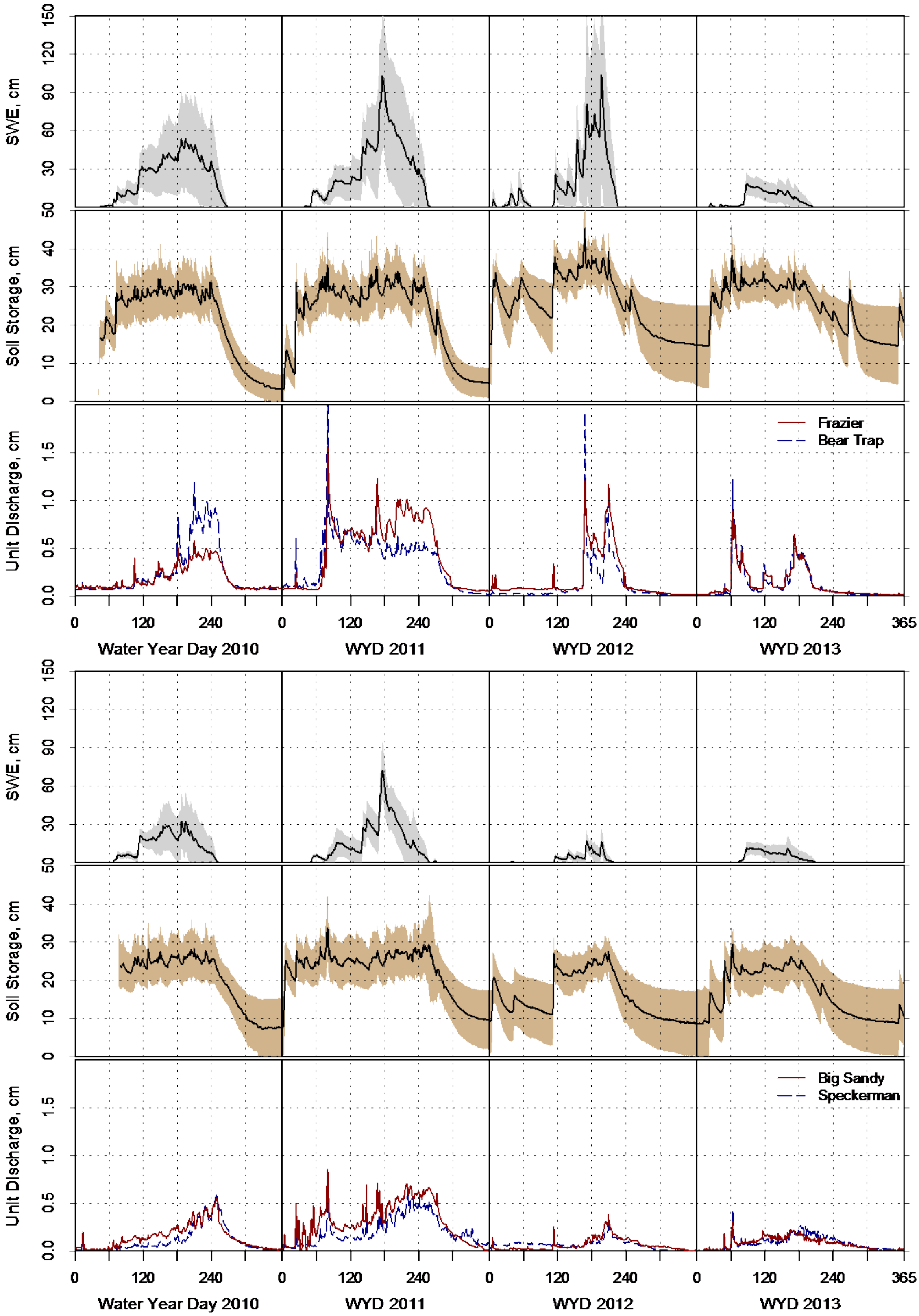
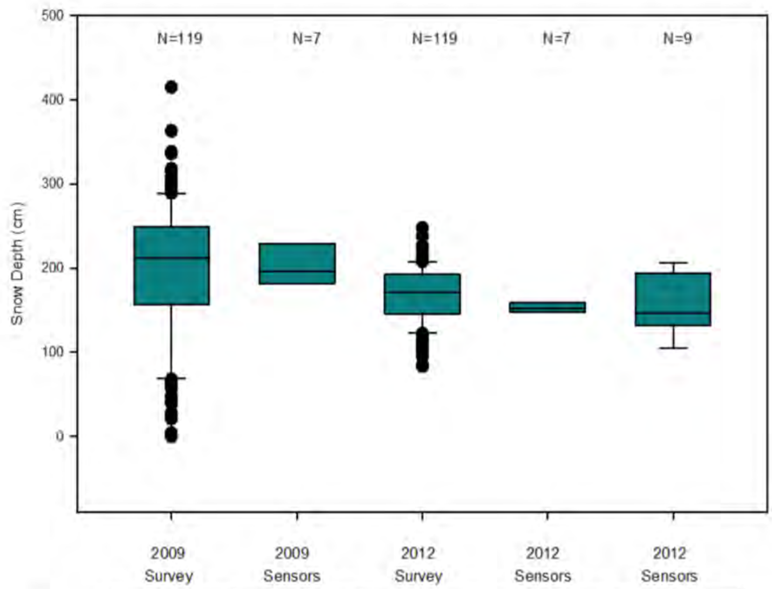


Figure E13: Snow, soil moisture, and stream discharge observations for Last Chance (top panel) and Sugar Pine (bottom panel) over water years 2010-2013. Black lines show mean of distributed observations, shaded area shows one standard deviation, and stream discharge is area-normalized.



Max	405	257	248	180	206
Mean	212	208	168	155	160
Median	226	196	172	152	146
Min	0	176	83	141	105

Figure E14: Snow depths recorded during surveys around Duncan Peak in 2009 and 2012. The wireless sensors (N=9) show an improved ability to capture snow variability over the original wired sensors. The boxes bound the 25th and 75th percentiles with a line for the median value in the middle. Error bars represent the 10th and 90th percentiles, with outliers shown as points.

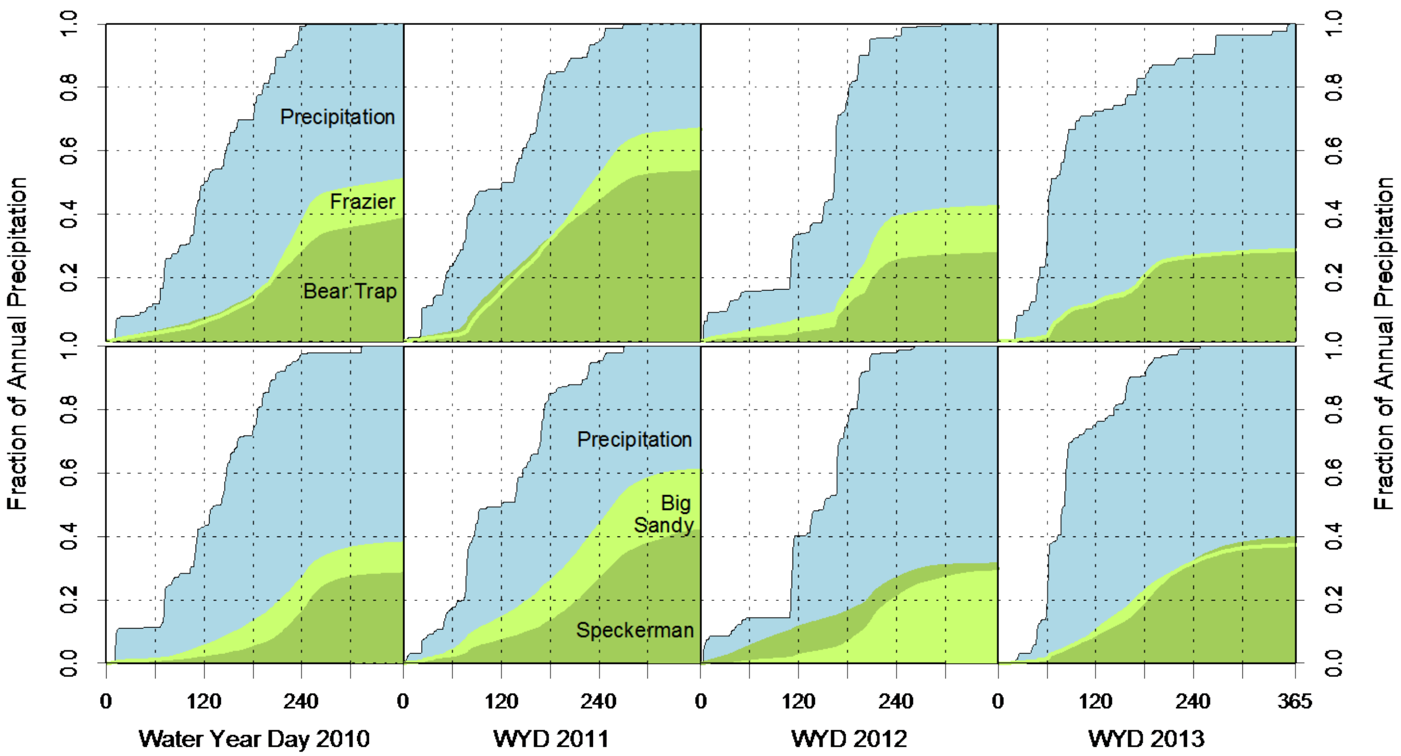


Figure E15: Cumulative precipitation and stream runoff as a fraction of precipitation during 2010-2013. The water year starts on October 1 of the previous year and ends on September 30 of each year labeled.

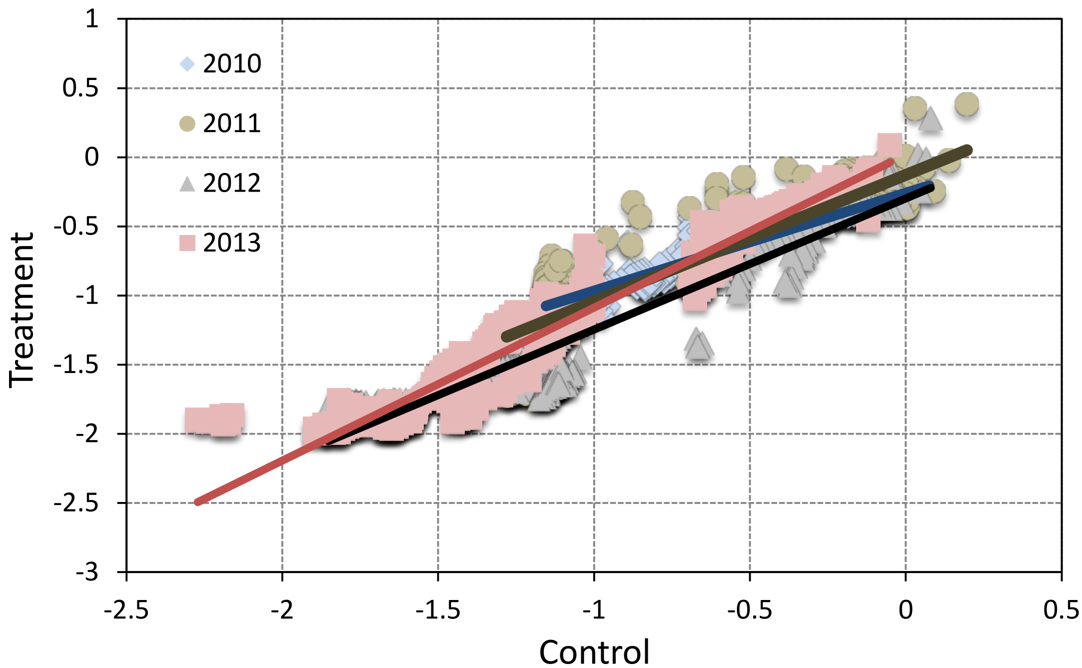


Figure E16: Log-transformed daily stream discharge relationships in Last Chance. All four years tested significantly different (F-test, $p<0.05$).

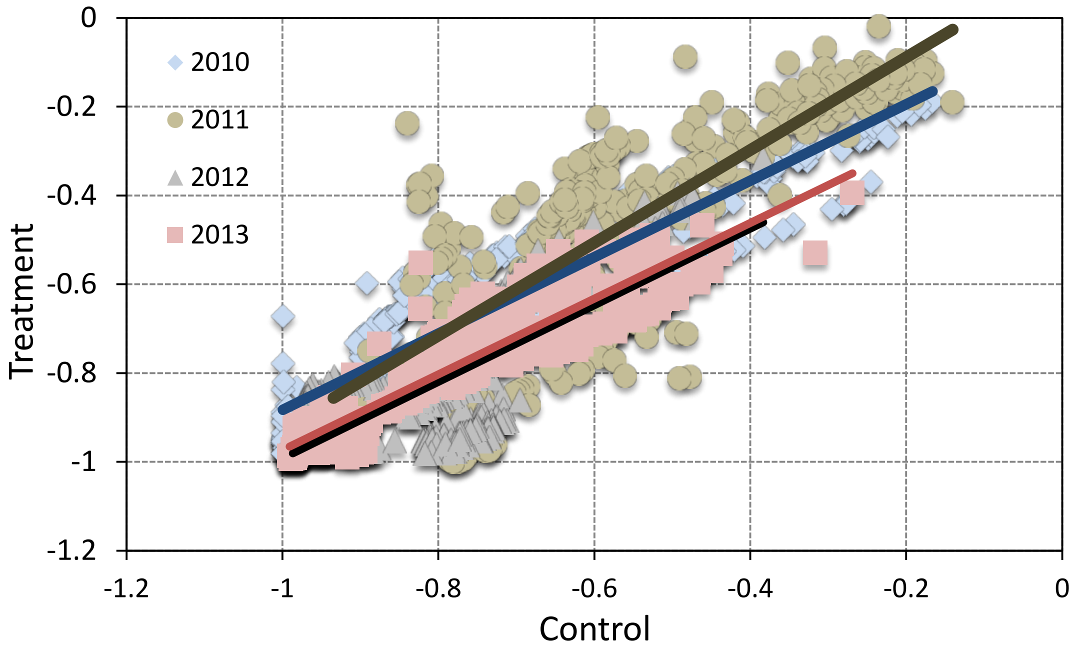
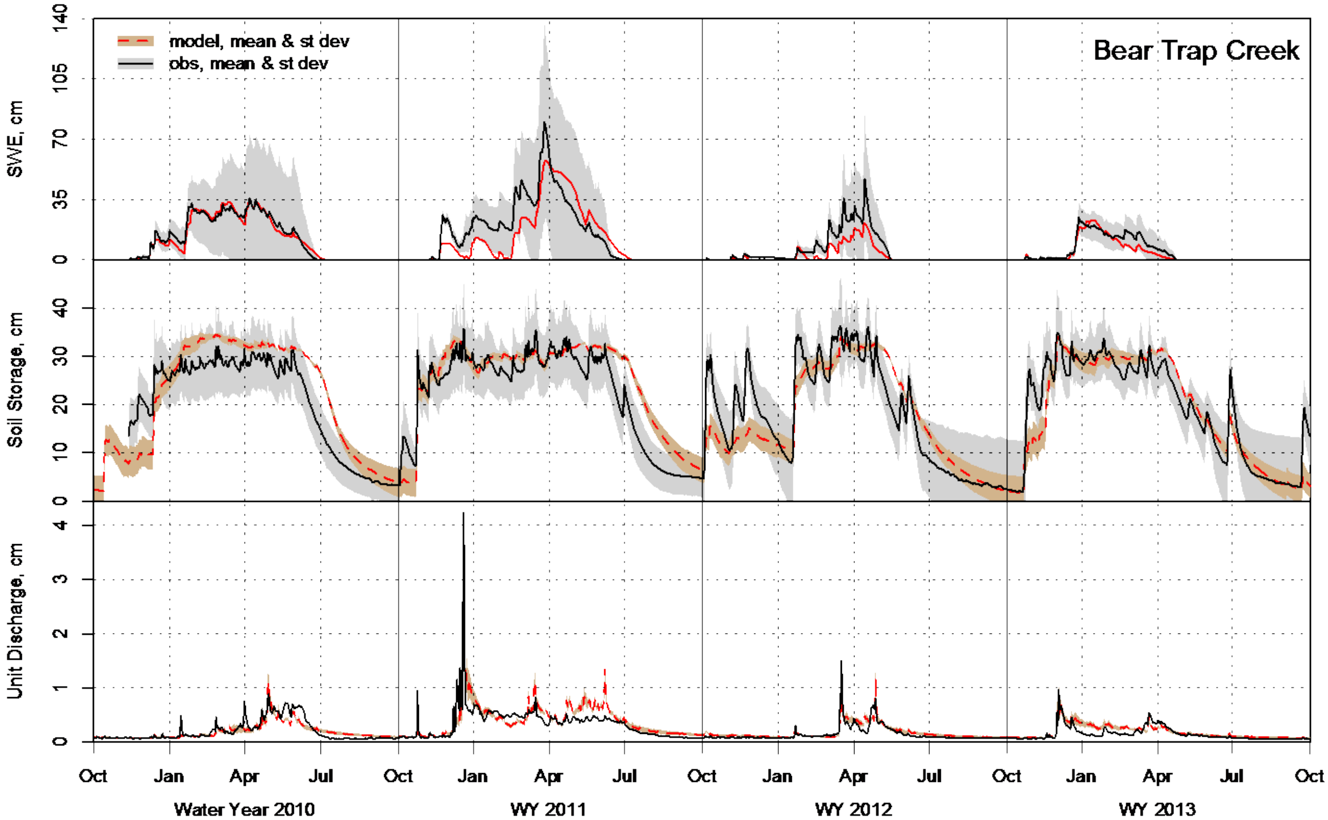


Figure E17: Log-transformed daily stream discharge relationships in Sugar Pine. All relationships tested significantly different (F-test, $p<0.05$).



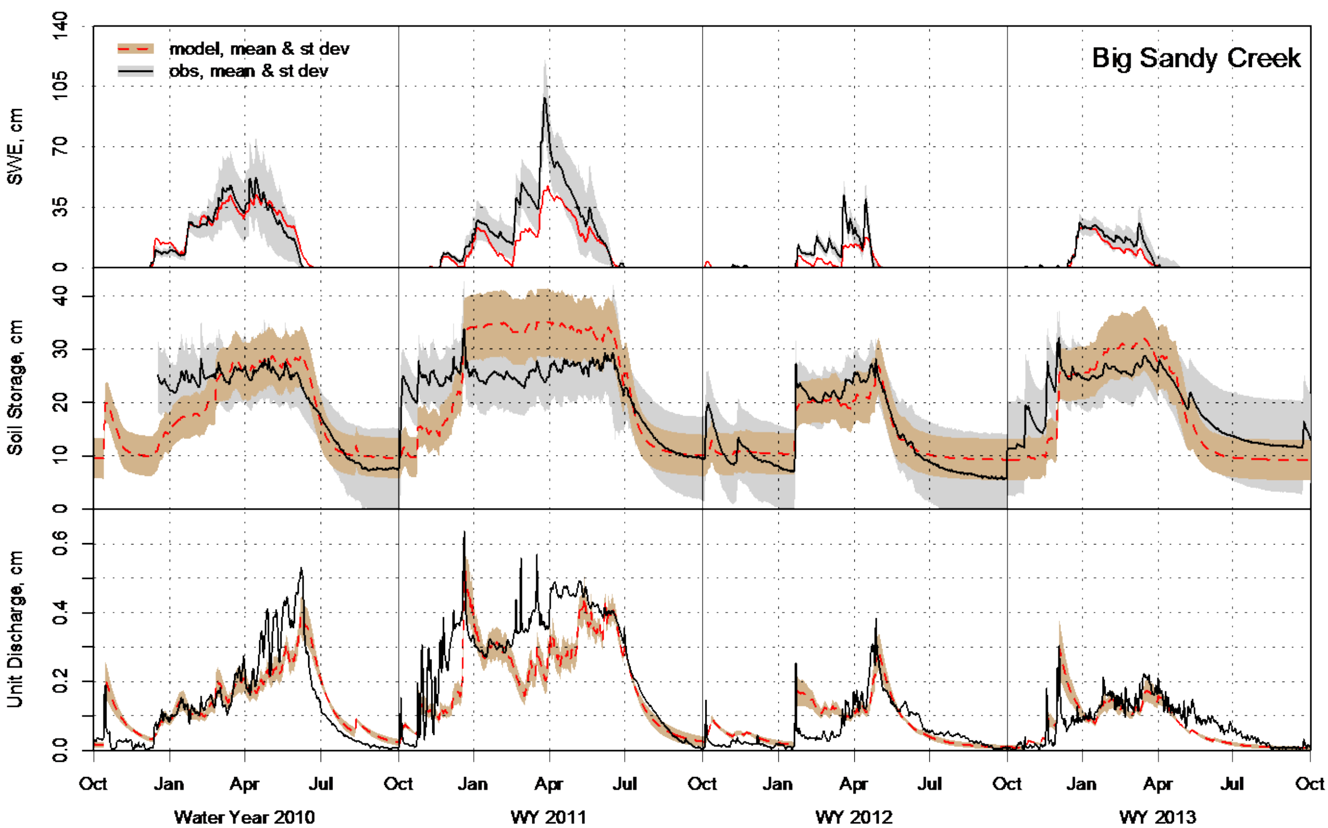


Figure E18: RHESSys daily snow water equivalent, root zone soil storage, and stream discharge calibrations (2010-2013) to mean observation values in Bear Trap (top panel) and Big Sandy (bottom panel) catchments. Discharge is normalized over the watershed area.

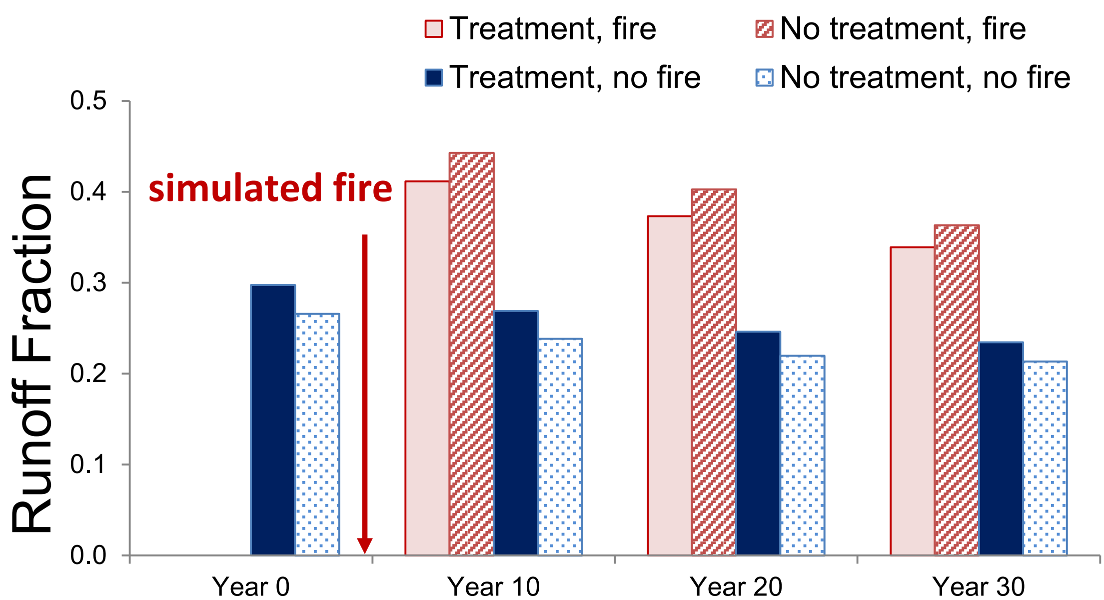


Figure E19: Changes in the runoff fraction of precipitation by treatment and time at Last Chance. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

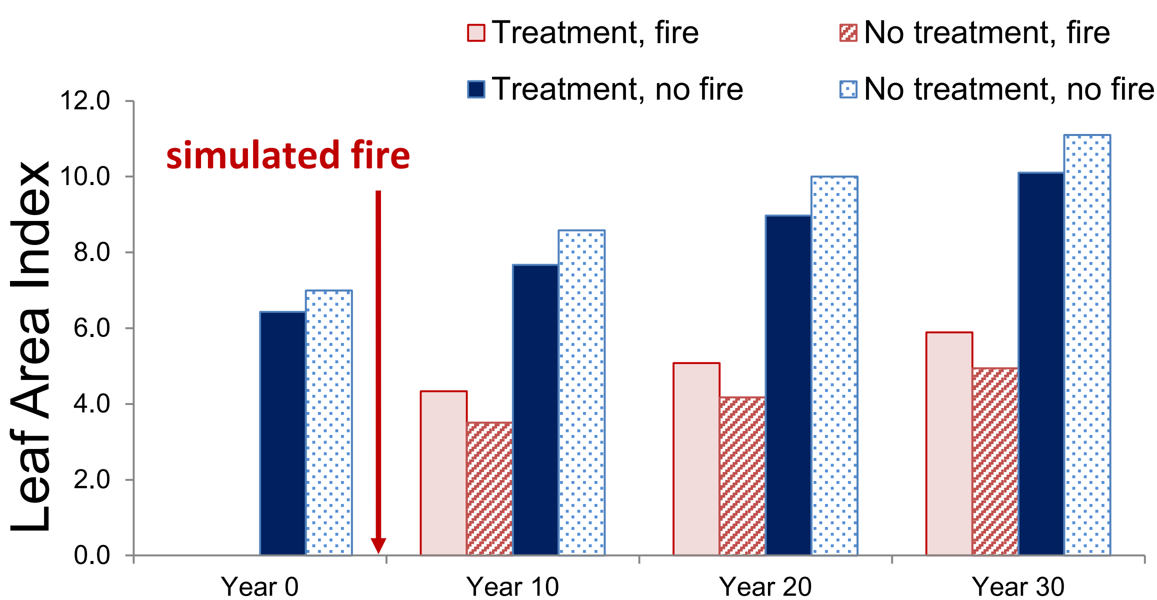


Figure E20: Changes in leaf area index by treatment and time at Last Chance. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

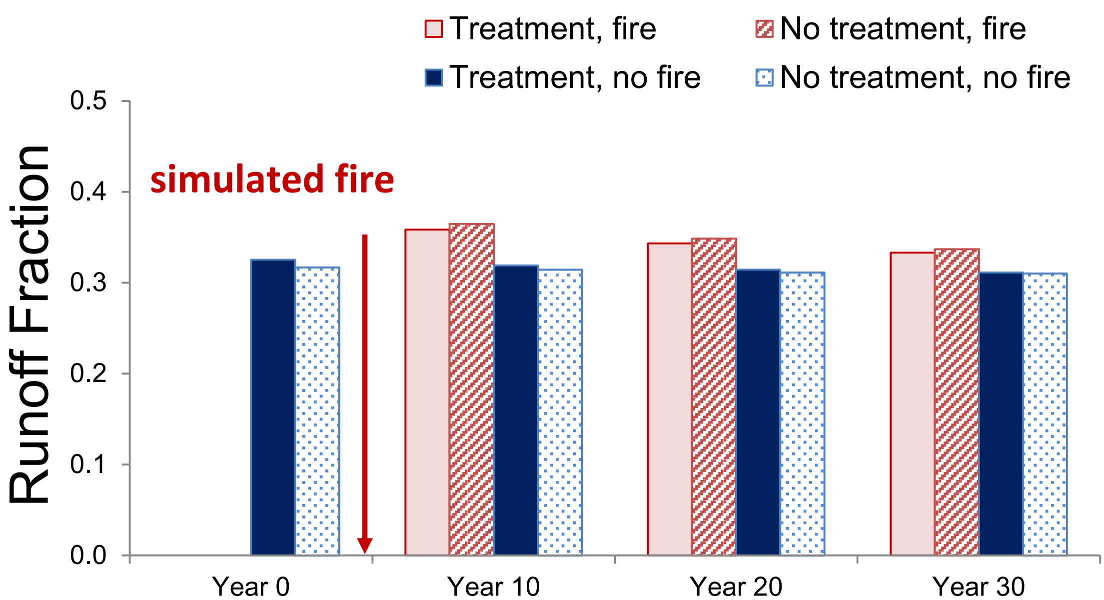


Figure E21: Changes in the runoff fraction of precipitation by treatment and time at Sugar Pine. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

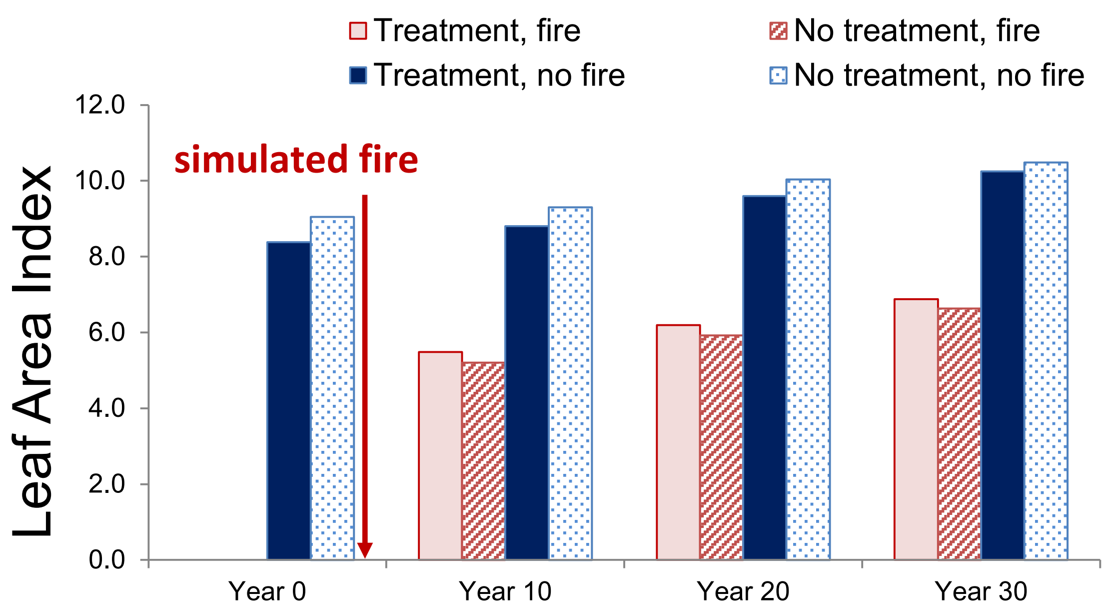


Figure E22: Changes in leaf area index by treatment and time at Sugar Pine. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

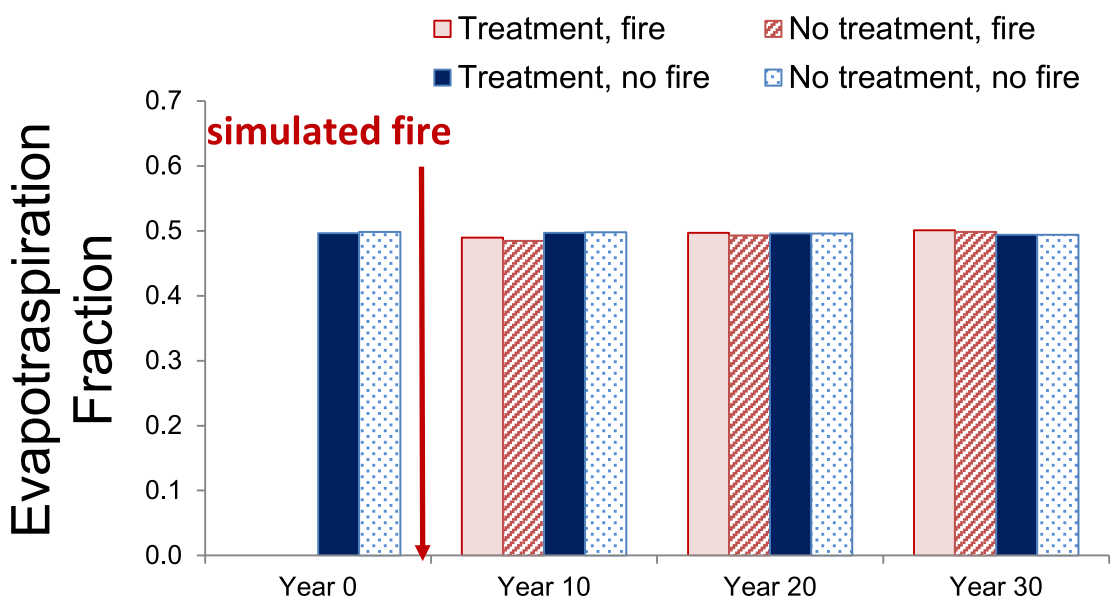


Figure E23: Changes in the evapotranspiration fraction of precipitation by treatment and time at Sugar Pine. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.

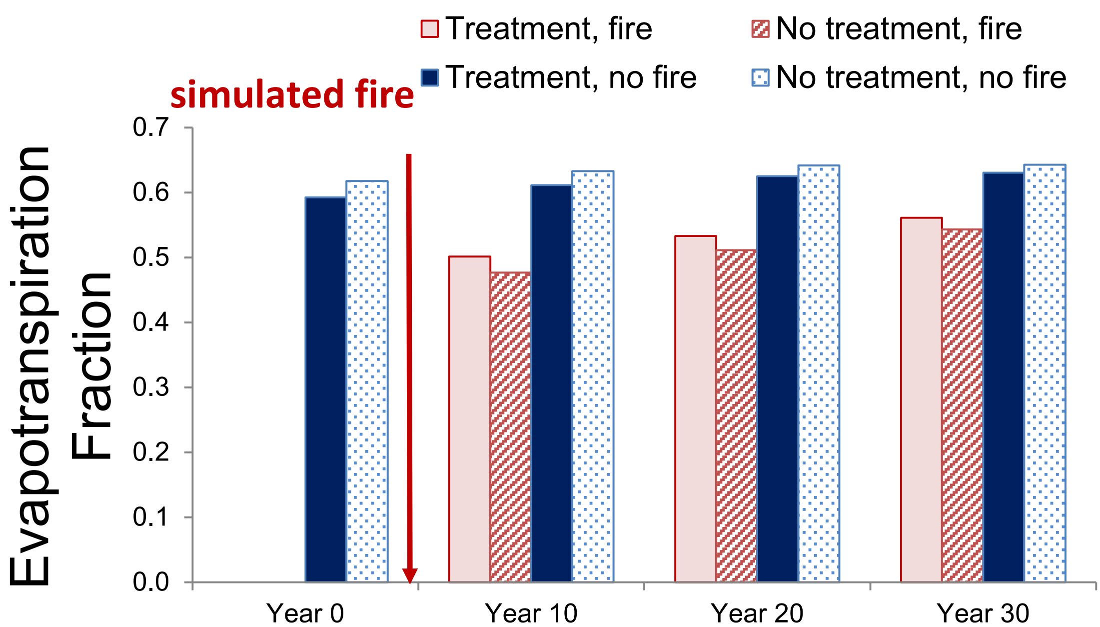
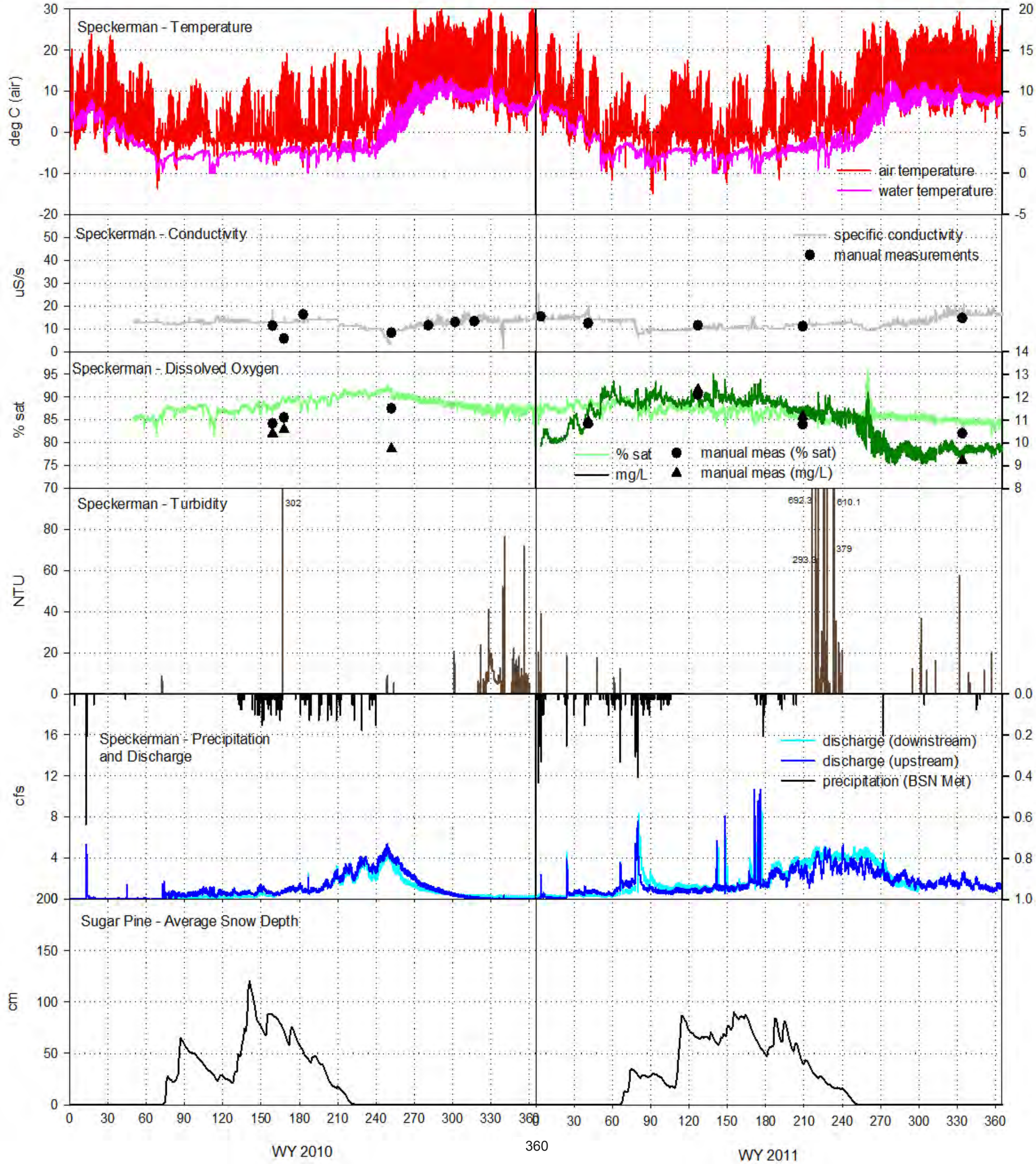


Figure E24: Changes in the evapotranspiration fraction of precipitation by treatment and time at Last Chance. Results based on fire and forest growth simulations. Models were parameterized with plot-level tree lists and scaled to the fireshed using remote sensing. The simulated fire burns immediately after Year 0 is measured. Results for the treated fireshed only.



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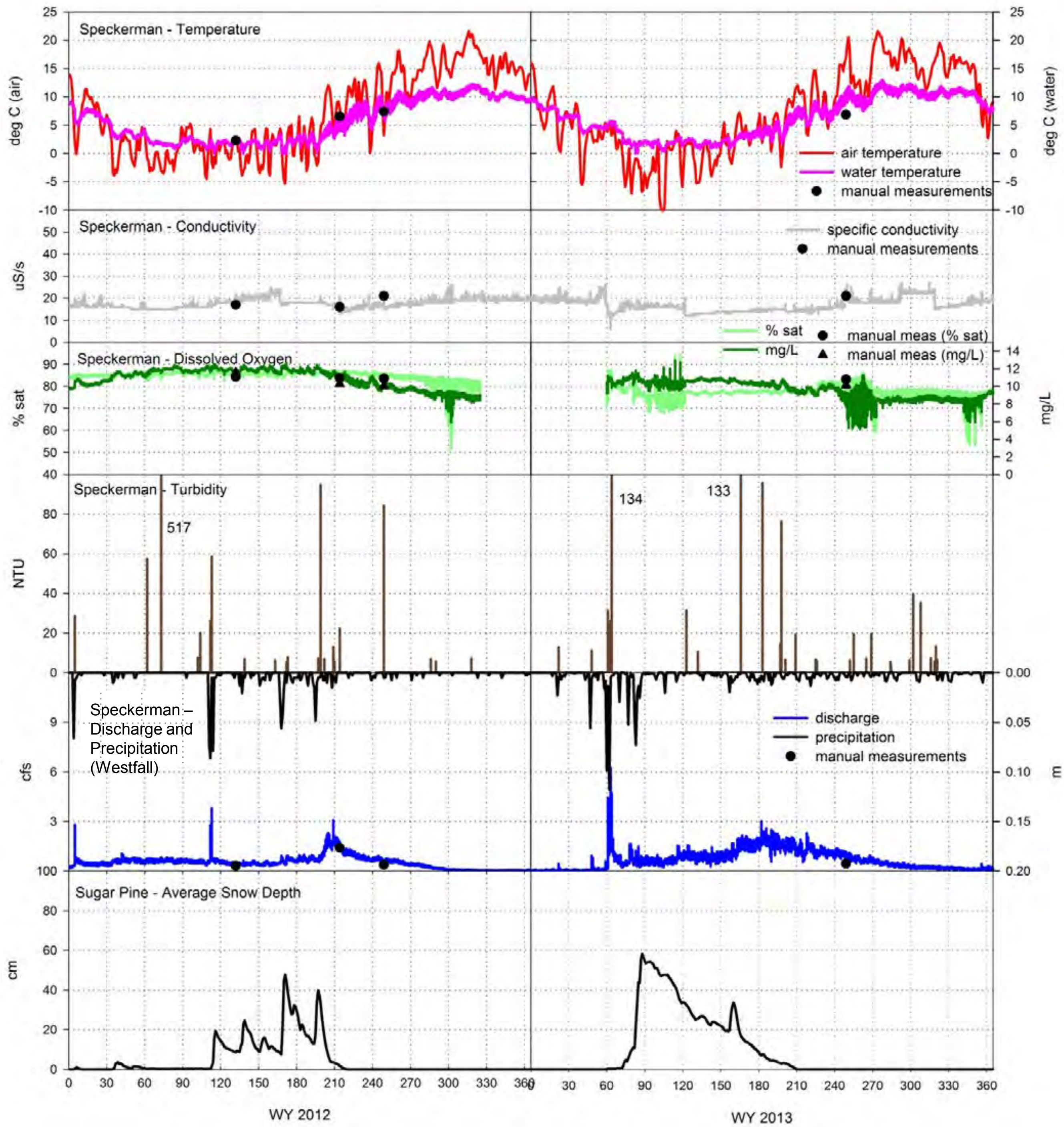

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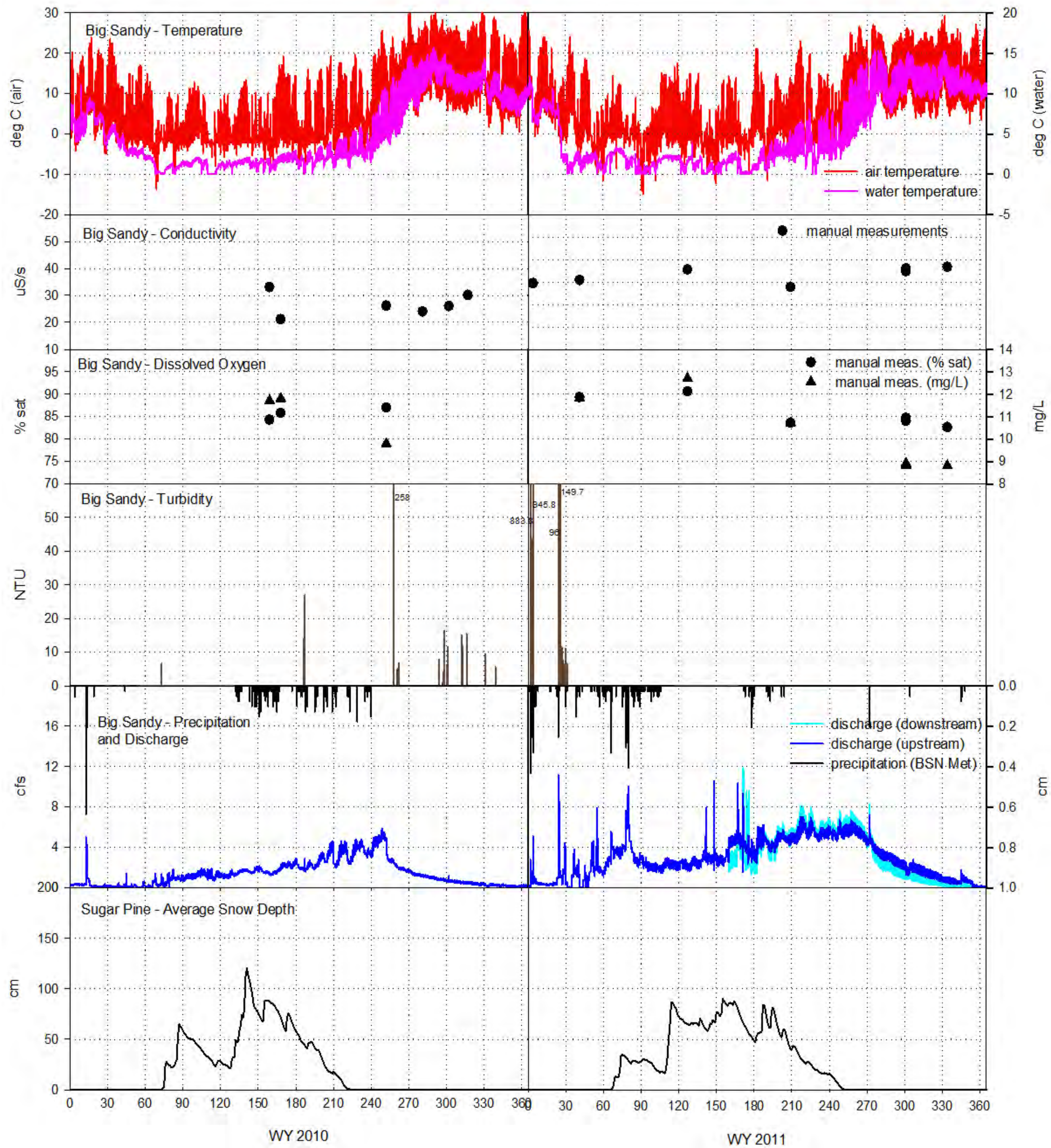

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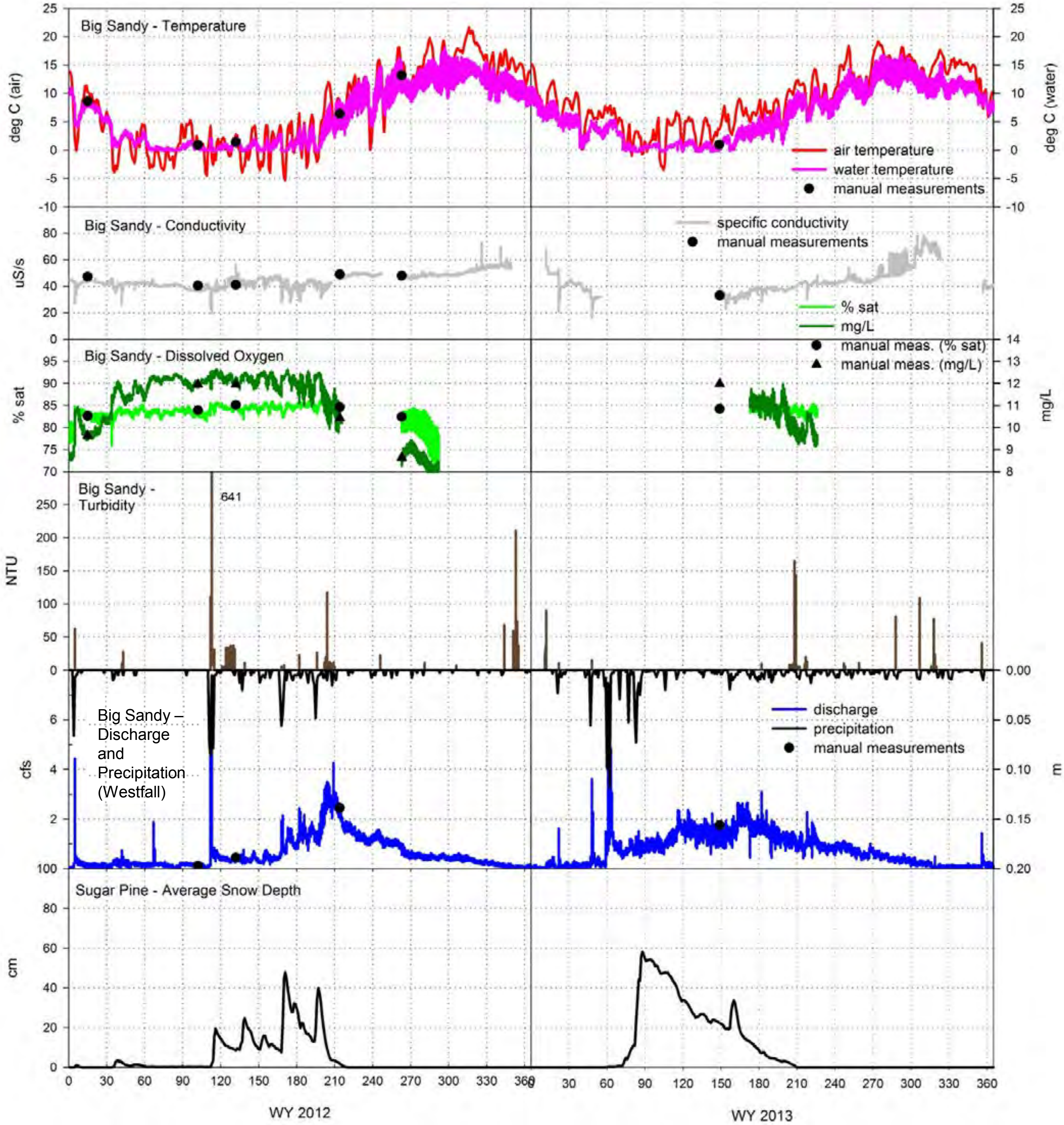

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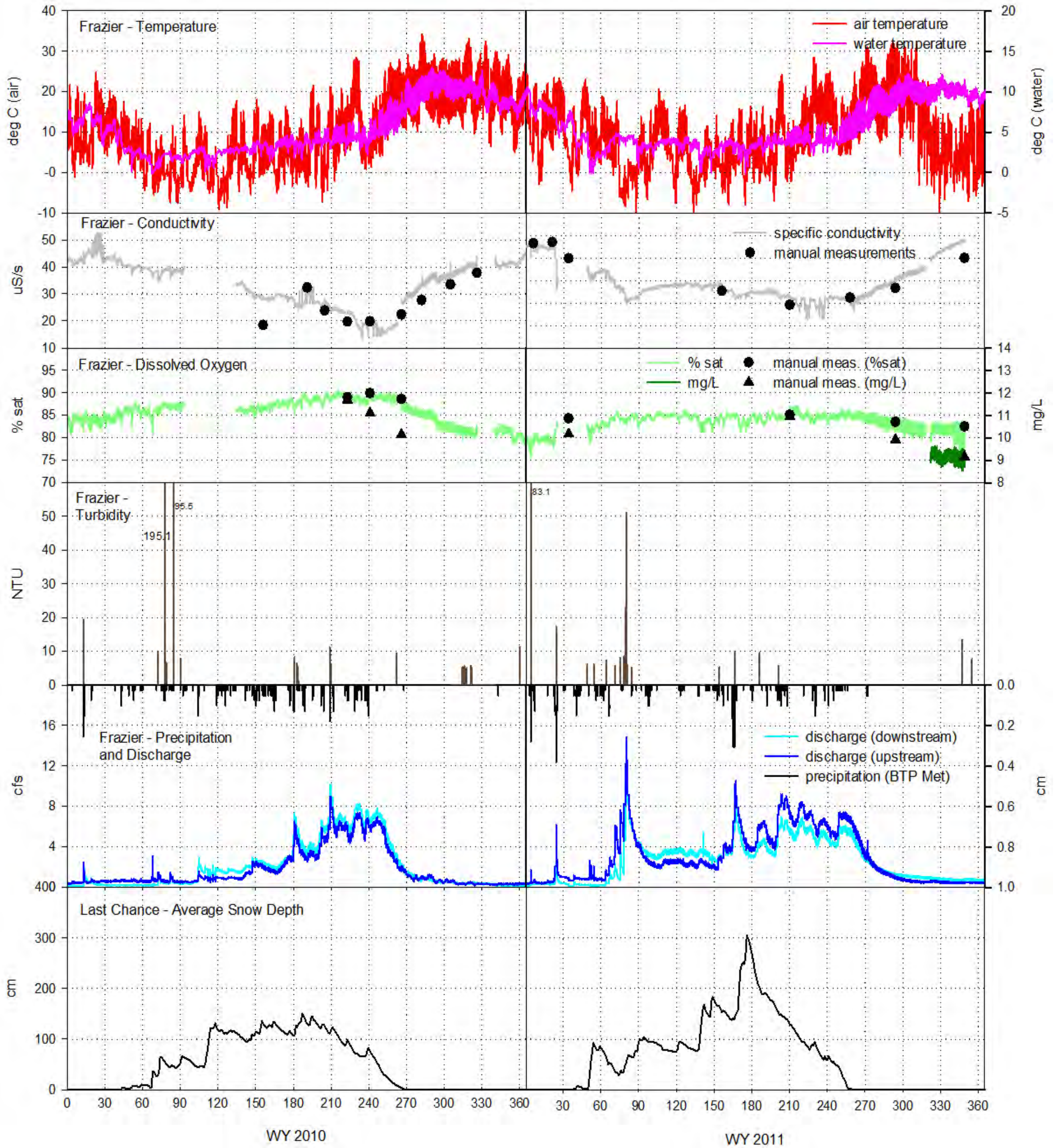

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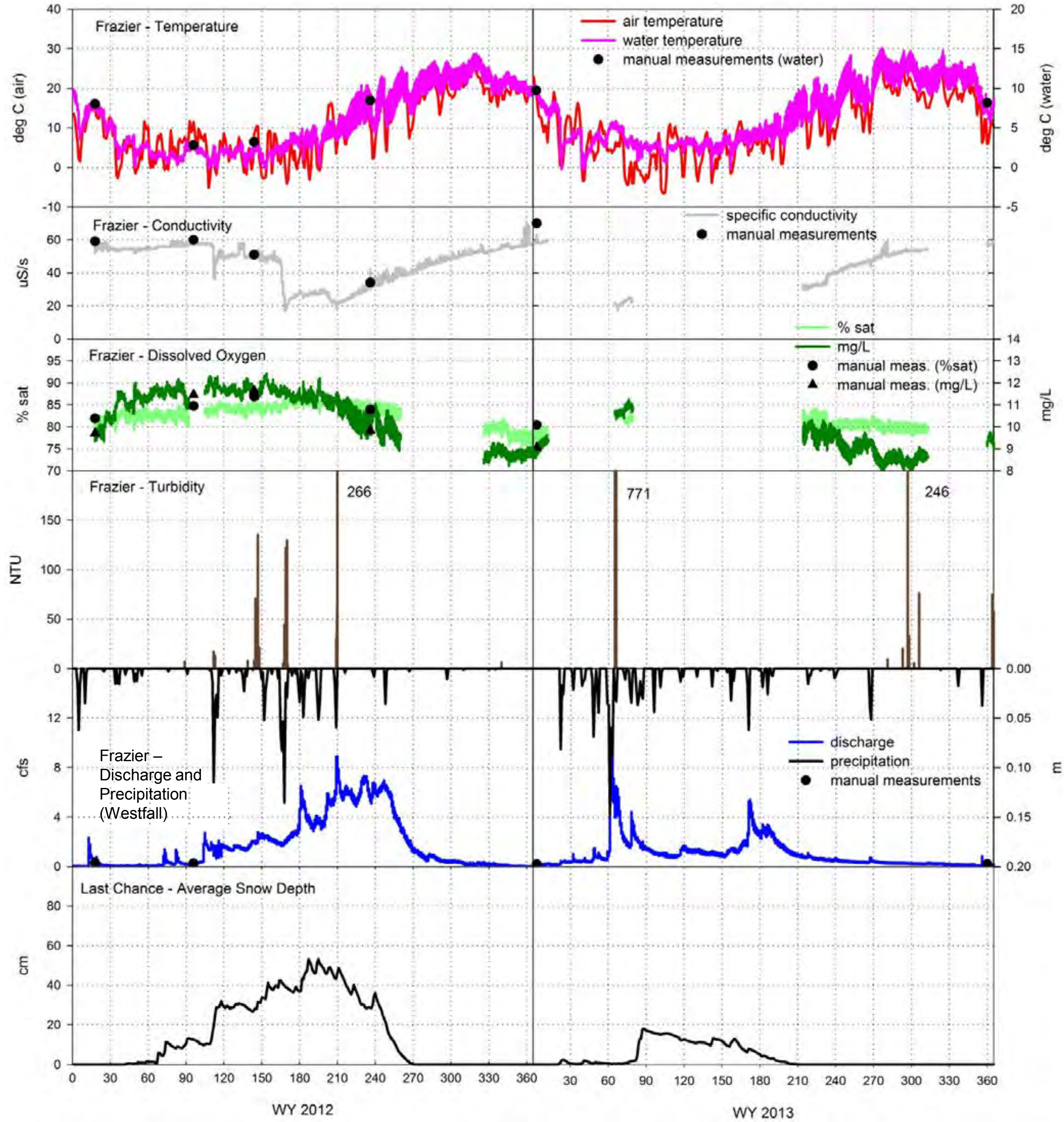

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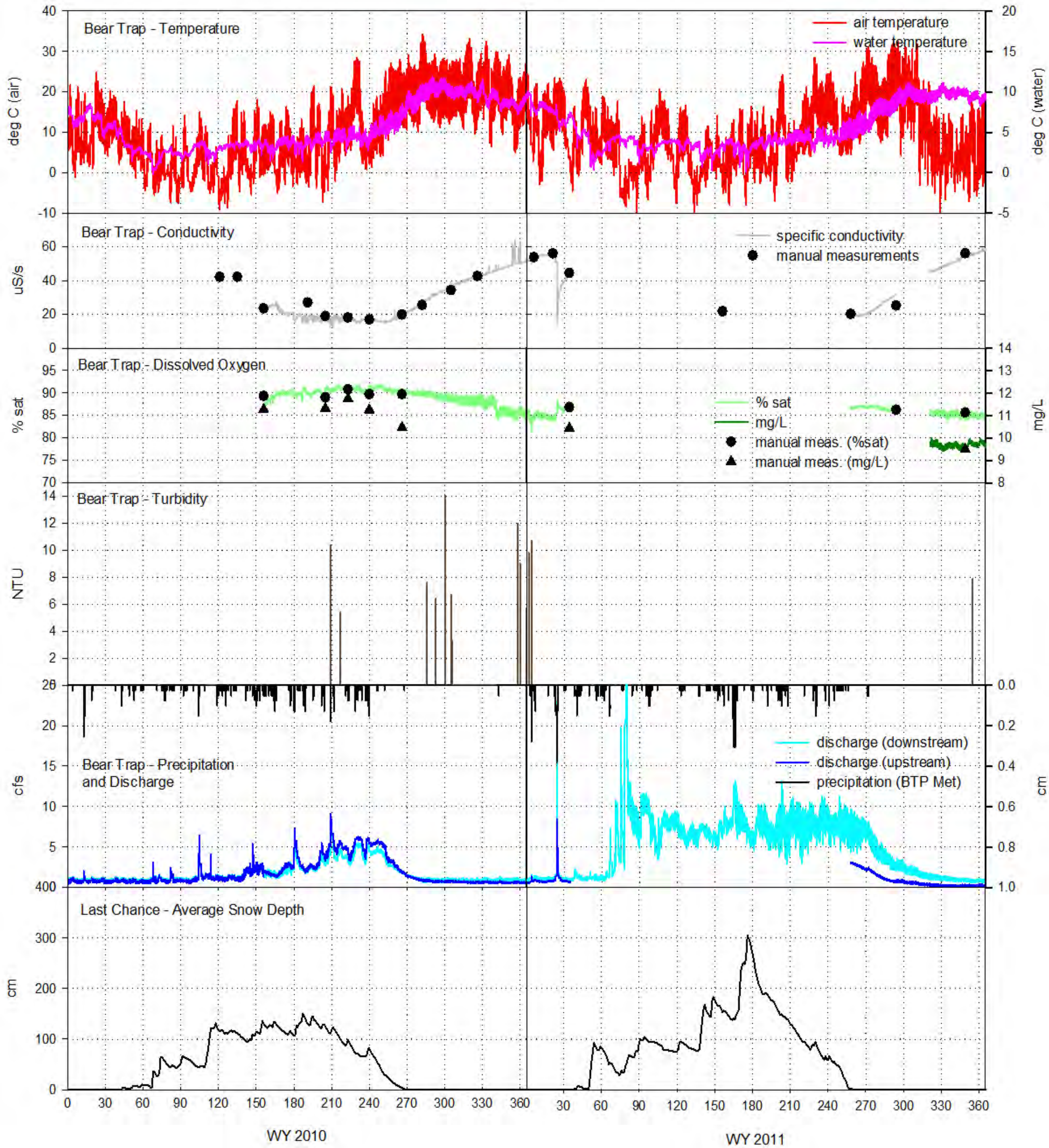

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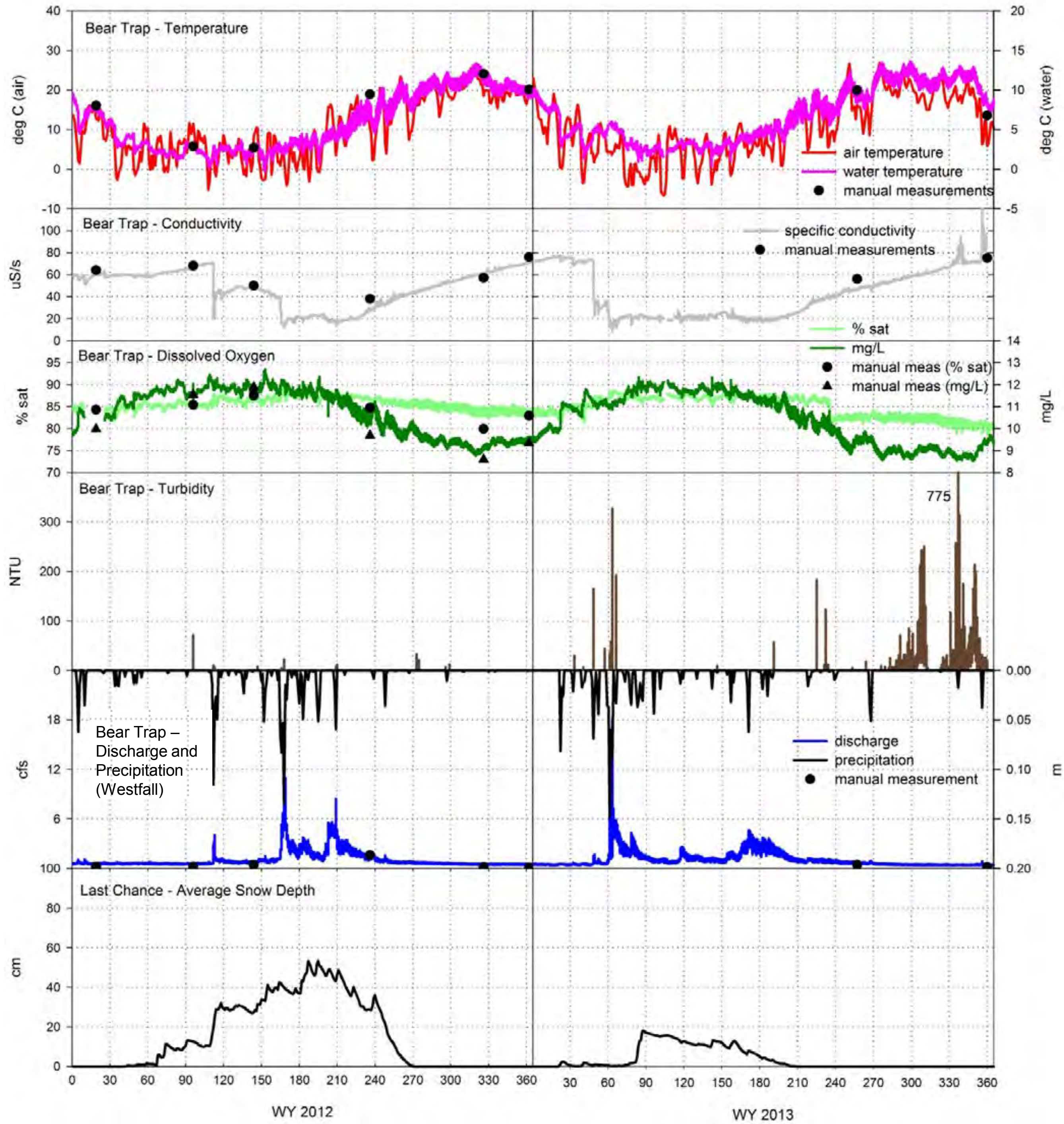

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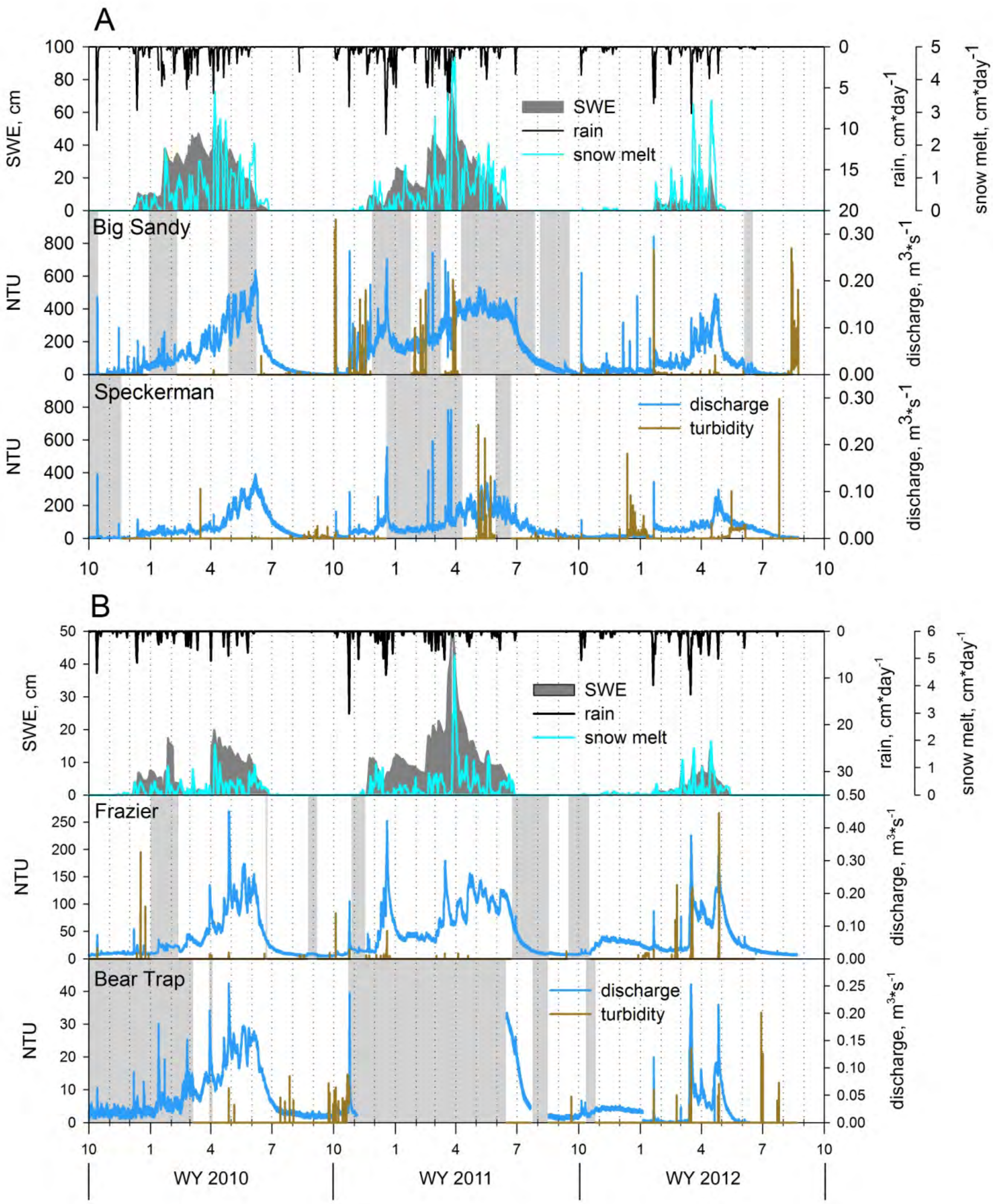

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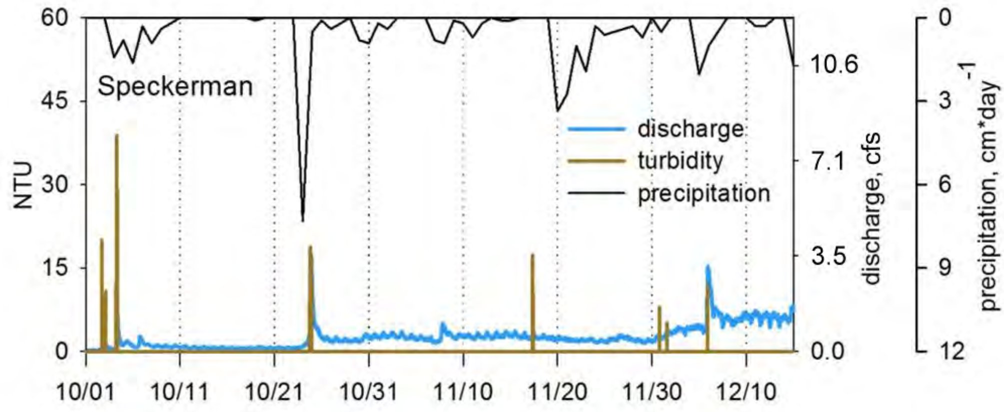

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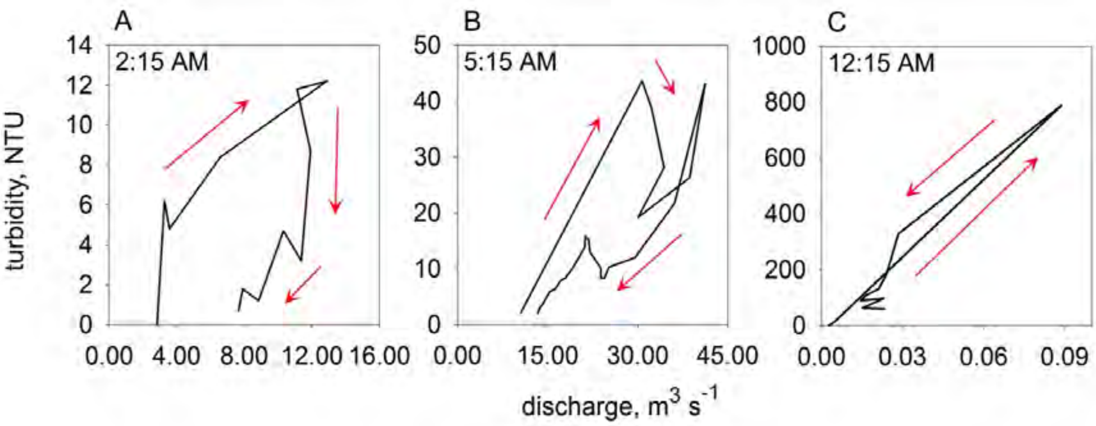

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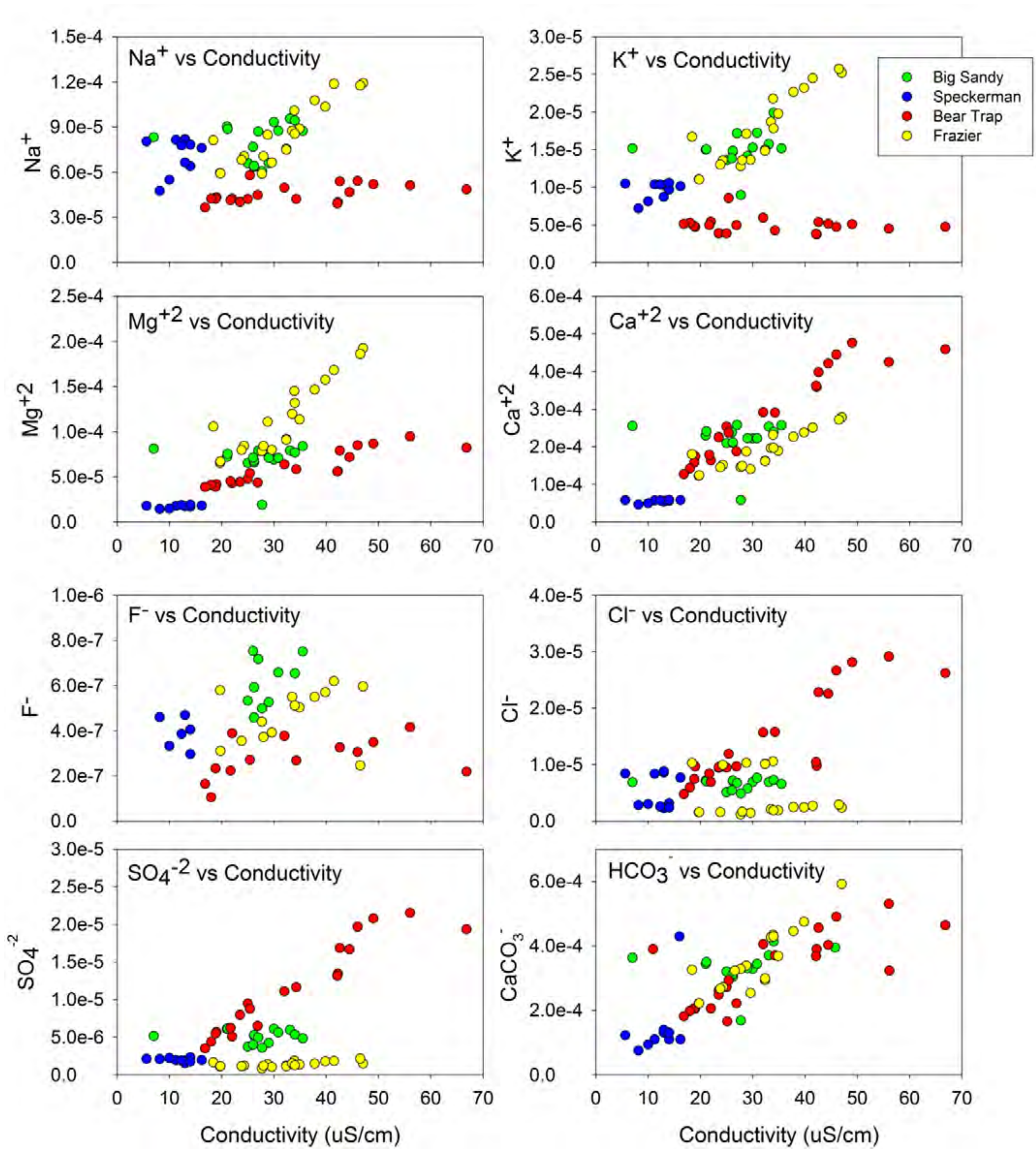

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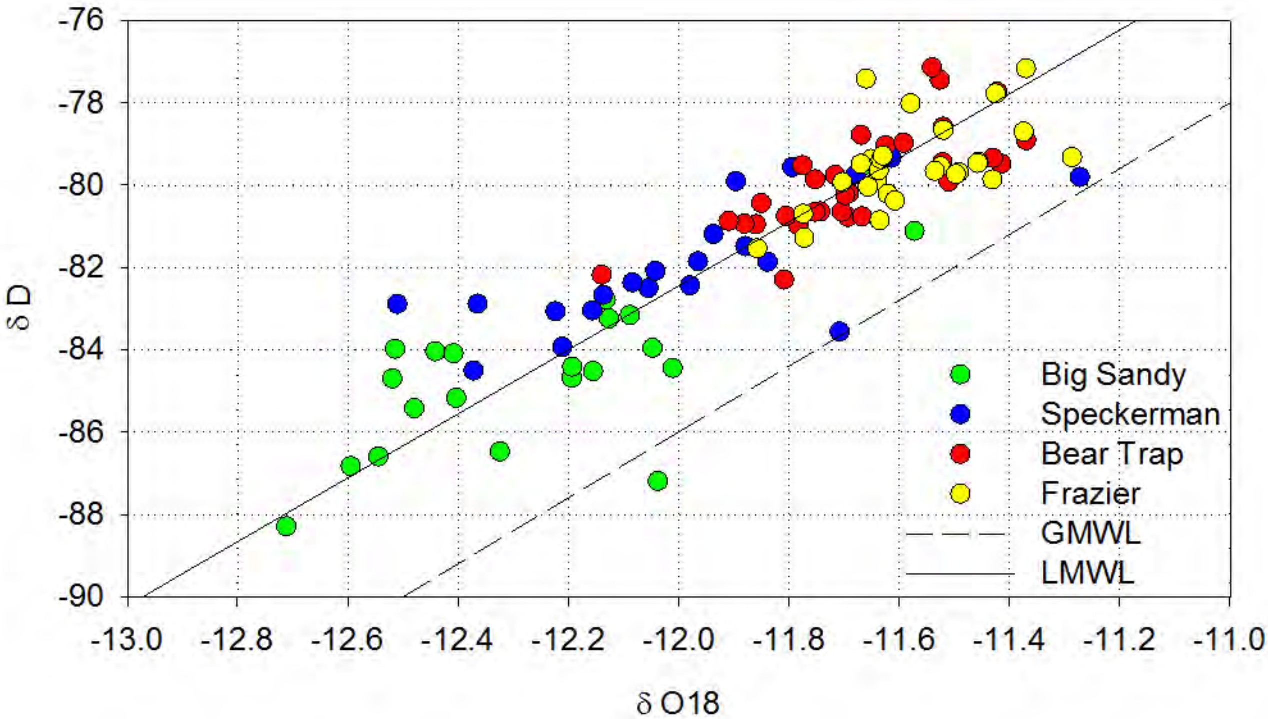

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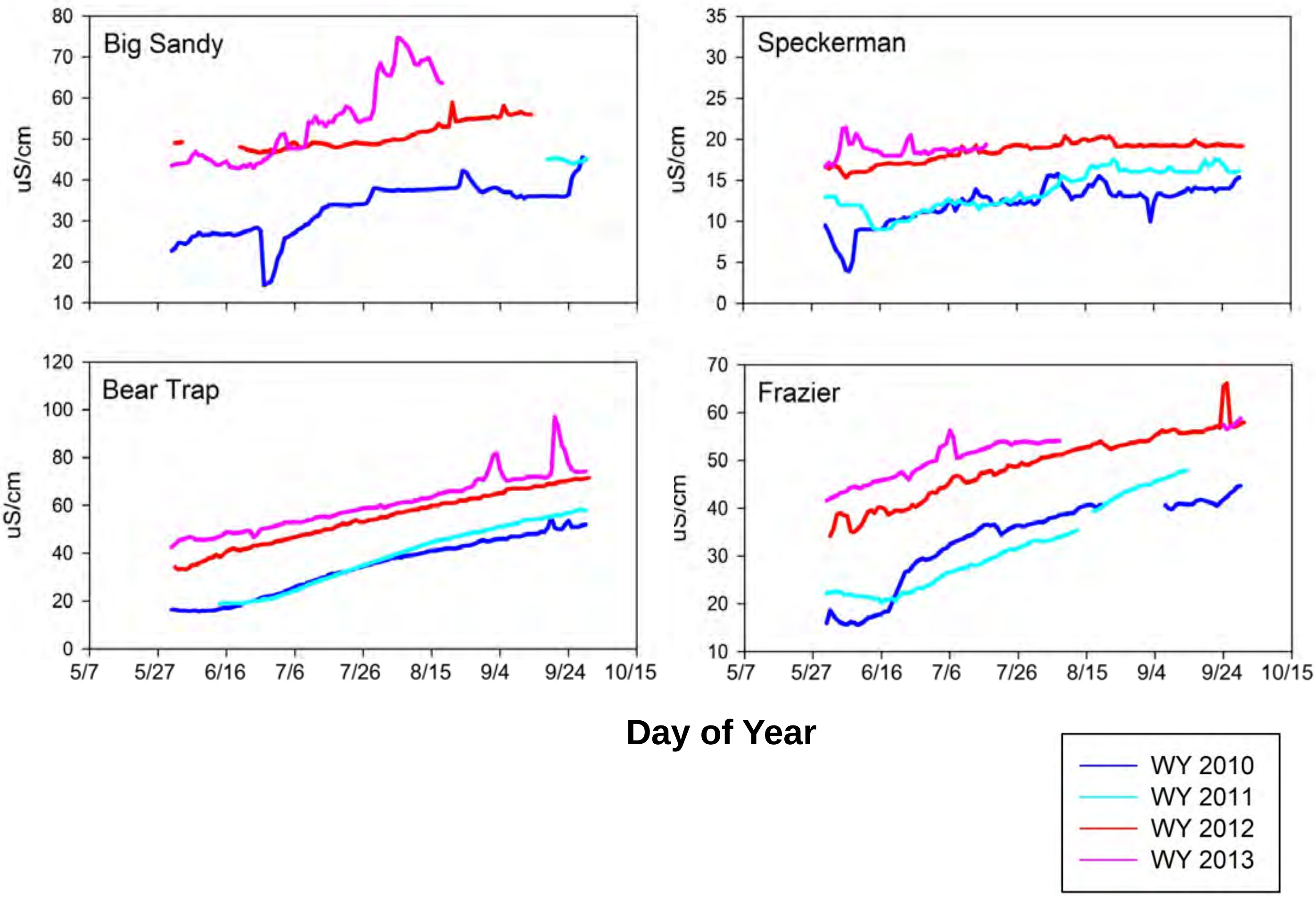

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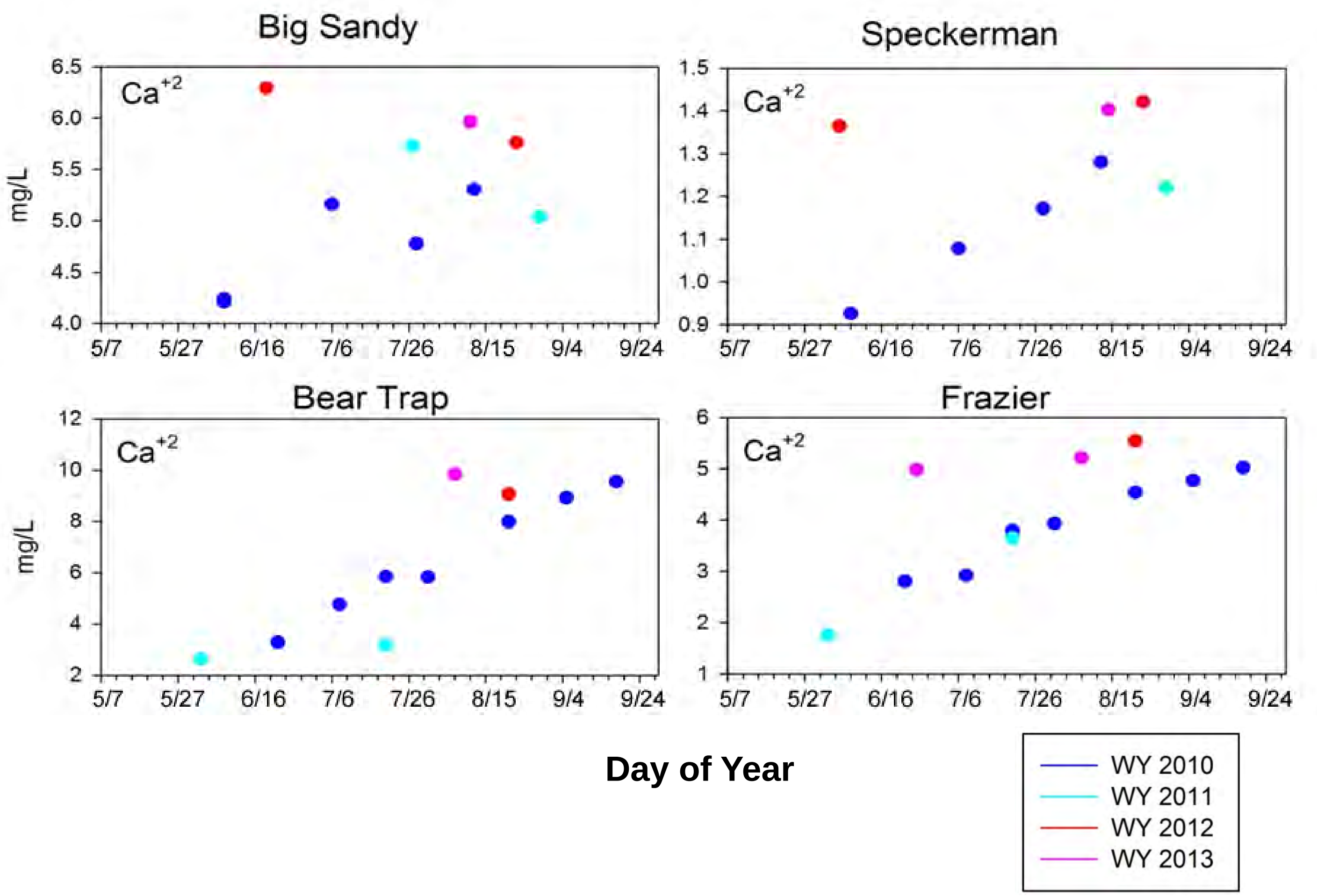

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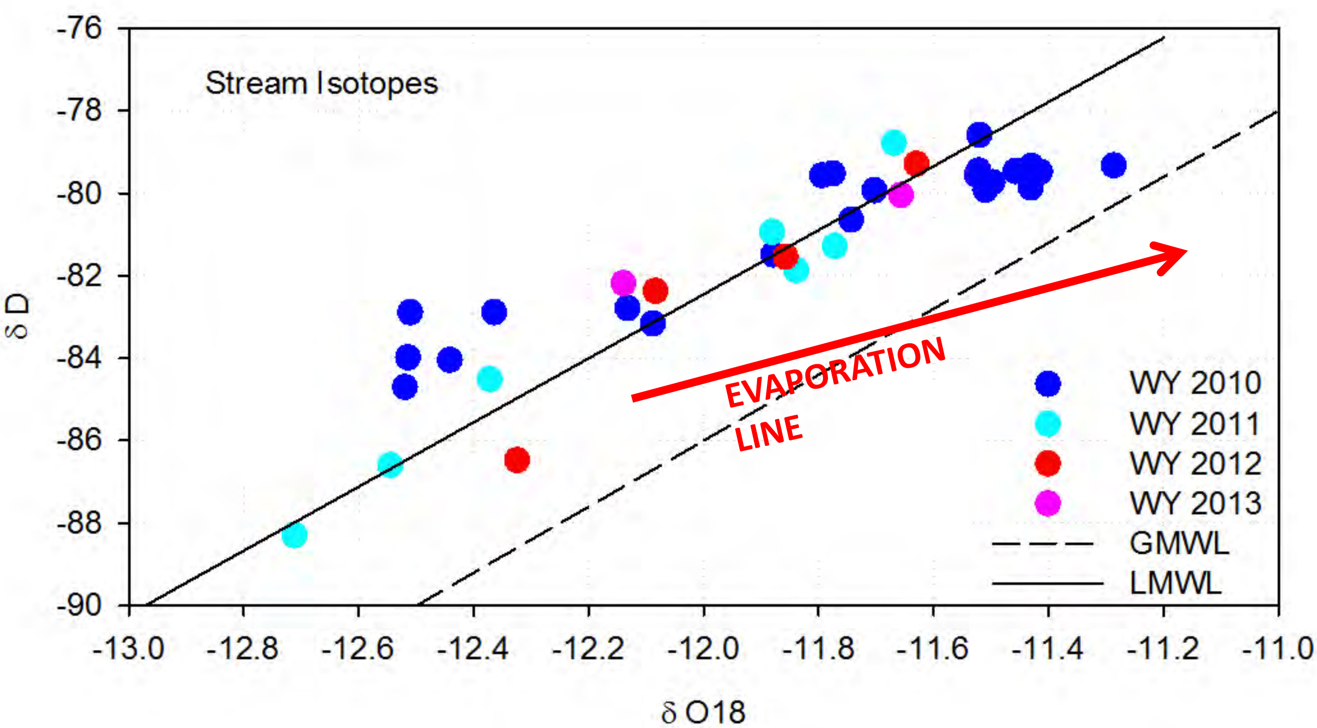

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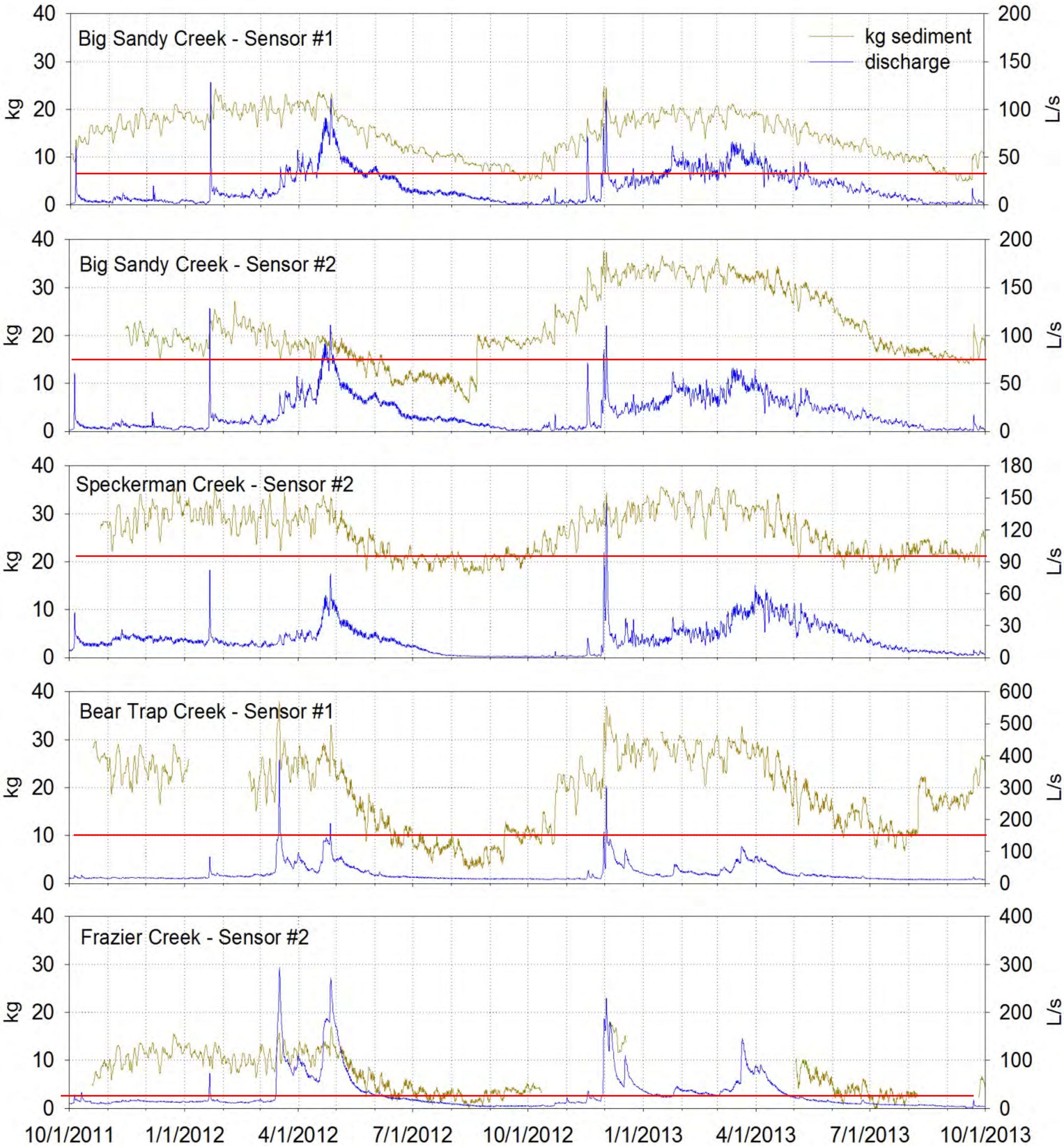

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Appendix F: Participation Team Final Report

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August 31, 2015

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Executive Summary

This Appendix is a report on the diverse activities carried out by the Participation Team to assess participation in SNAMP, improve our methods of outreach, and contribute to the integrated chapters (chapters 3, 4 and 5 of this report).

The Sierra Nevada Adaptive Management Project (SNAMP) was developed to incorporate stakeholders into an adaptive management framework where the University of California (UC) used scientific experiments to assess the impacts of Forest Service fuels reduction projects. The first pillar of the UC 2007 SNAMP workplan was that adaptive management involved "deliberate experimentation" and this dictated the way the UC Science Team structured the science conducted in SNAMP (in addition to the Participation Team, SNAMP teams studied the following subjects: fire and forest ecosystem health, Pacific fisher, California spotted owl, and water quality and quantity, and spatial analysis). The workplan's second pillar was "...that adaptive management must be a participatory process that engages scientists, stakeholders, and managers in a long term relationship grounded in shared learning about the ecosystem and society." We considered the Participation Team role to be two-fold: a demonstration of a model of participatory, or collaborative, adaptive management and an analysis of the participant experience in SNAMP. While the primary mode of stakeholder interaction with scientists and the Forest Service was necessarily consultative rather than the power-sharing of a full collaboration, the participatory adaptive management process used by SNAMP was defined for the project as "collaborative adaptive management" or CAM. For this reason the participatory process as implemented in SNAMP has the following stated definition of collaborative adaptive management (CAM):

> CAM is a science-driven, stakeholder-based process for decision-making while dealing with the scientific unknowns inherent in many physical and biological systems. In the SNAMP process, adaptive management incorporates stakeholder participation in order to improve the amount and breadth of information for decision-making, create meaningful engagement and build mutual understanding, learning, and trust.

Over the last century the Forest Service has shifted from an emphasis on management based solely on technical expertise to models using more participatory methods. Increasing litigation in the 1980s reflected continued frustrations and conflict as stakeholders demanded more input into the decision-making process. The third party model that SNAMP used, in which an agency, the public and an outside science and outreach provider in a sense act as checks and balances to each other was derived out of the concept of shared, multi-party, or joint monitoring, and to some extent, citizen science. Both increase the participation of stakeholders in the science that drives management decisions. As true co-management, where power is shared equally, is not legally possible for the Forest Service or for scientists adhering to strict experimental protocols, projects like SNAMP can be seen to allow for more transparency in the decision-making process by opening up the science and planning processes, and providing additional pathways for input and feedback. An unforeseen benefit was the stakeholder enthusiasm for increased participation in and understanding of the science that became apparent over the course of the project. SNAMP provided some direct communication channels between scientists and the public, and this turned out to be one of the most appreciated aspects of SNAMP.

To address our focal question and engage stakeholders in the adaptive management process, the Participation Team conducted outreach based on long evolved University of California Cooperative Extension principles, and produced extensive assessments of the participant experience in SNAMP. We developed a participation process and analysis framework based on our best practices for collaboration expertise as well as an extensive review of the literature. The five core elements of our effort were inclusivity, transparency, learning, relationship building and effectiveness. We collected input from both SNAMP participants and non-participants with regard to these core elements in SNAMP via written surveys immediately at the end of meetings as well as through two online email surveys of the SNAMP listserv and three separate rounds of in-depth interviews. Our team employed the following varied outreach methods to address these elements.

The Team focused on both in-person events and presentations as well as at-a-distance methods that were web based. Each type of participation event had its advantages and limitations and each allowed certain kinds of learning to occur or relationships to be fostered (Tables F3 and F4). Face-to-face interactions with scientists and managers were a focal point of the in-person outreach program. Our large public meetings gave broad access to the project, though with little time for details, and provided a forum for interest group positions to be shared. The smaller technical integration team meetings were focused on individual topics. These provided in-depth data sharing with advanced discussions and were incredible learning opportunities based on the presentations of the lecturers but also as participants learned from each other's less formal questions and comments. Field trips, where participants could "kick the dirt" together and actually see the forest, were touted as most valuable for learning about management context, scientific methods and findings as well as for building relationships through intimate and casual conversations. Subject matter workshops, which conveyed all the most relevant science on managing a resource including findings beyond the scope of SNAMP, were highly appreciated by managers. Taking SNAMP to targeted audiences by going to their meetings and events proved to be a powerful way to spread the scientific outcomes of SNAMP as well as increase project inclusiveness and transparency.

The project's at-a-distance methods such as the website and its document archive, science briefs, newsletters, and blogs provided the basis for all other SNAMP contacts because of their accessibility and transparency. The email list was invaluable for getting information out to interested parties, though it is not particularly interactive. Webinars were found to be useful at the end of the project (they saved time and money) but none of the online interactions could replace the importance of face-to-face connections with scientists, managers or other stakeholders. We observed that our webinars were mainly successful because they occurred at the end of the project when relationships were solidified and there was a group comfort level that could overcome the impersonal nature of the webinar.

To transfer the SNAMP collaborative lessons and to train stakeholders and the agencies to conduct or participate in future collaborative adaptive management projects, we created and implemented a multi-day workshop curriculum and companion workbook. Participants in these trainings gained a clearer understanding of adaptive management and how to include the public in the process, how and when to use an independent third party, and how participants can utilize facilitation tools to help defuse conflict. Evidence from the post-workshop surveys suggests that these trainings increased participant commitment to collaboration and it is these key stakeholders and agency participants that could help ultimately complete the SNAMP adaptive management cycle.

A review of our participation model by core element starts with the two most basic and primary elements: transparency and inclusivity. We attempted to attract and reach out to the broadest extent possible by varying our events, presenting at other groups' events and extending our contact through online and traditional media. Our goal was to include as many voices and perspectives as possible to foster the strongest buy-in for the final results as well as input during the process. Transparency was a focal point from the beginning, starting with the SNAMP website. Within its contractual constraints, SNAMP strove to be as open and transparent in its processes and decision-making as it could be. Our surveys showed that the strong effort put in by the Science Team to focus on inclusivity and transparency was recognized by participants.

Learning was the next goal of the SNAMP Participation Team and was also the overall purpose of SNAMP, as reflected in the title of the project: "Learning how to apply adaptive management…" Each of the science teams produced copious amounts of novel data with regard to their subjects and presented these findings to the public multiple times a year. We found that learning in these kinds of social settings helped SNAMP produce shared understandings about basic biological and ecological conditions as well as larger concepts about forest health and adaptive management.

The other crucial outcome of shared learning and understandings was new and improved relationships between the participants in SNAMP. Our results show that over the long life of the project, in which there were many and varied opportunities to interact or observe other participants, relationships improved even among those historically opposed to each other such as environmental and forest products groups. Unfortunately some relationships in the project were strained not because of the shared learning experience but due to limitations of the project such as funding. Though not an explicit goal of SNAMP, participants also learned about the Forest Service and the constraints faced in Sierran forest management that could help improve collaboration with the agency in the future. The shared scientific understandings and the hybrid culture they fostered, combined with the improved relationships between participants and familiarity with the Forest Service, could be the foundation for more productive and continued collaborations in the future. The Forest Service will need to continue to engage intensely with the public in order for the positive trends to continue.

We interpreted our goal of effectiveness as encompassing the collaboration's process or structure as well as the project's ability to accomplish the goals that the literature suggested and participants felt were important for the project to be interpreted as successful. Much of the basic communication structure of the project worked well: the project invested in trained outreach and facilitation staff, meetings were set up to encourage productive discussions, events were evaluated and continually adapted to meet participant suggestions, and a large variety of outreach strategies were implemented and supported for the duration of the project. In addition, the Forest Service treatments were implemented, the academic experiments were completed and this report was drafted, reviewed by peers and the public, and published; those were milestones that were not always assured of completion during the project and now can also be considered examples of SNAMP's effectiveness.

Ultimately, participants in collaborations like SNAMP intend for the project to have far-reaching and broader impacts past the study areas, timeframes, and agencies involved. One agency participant suggested that the most important goal of SNAMP was to create a group of stakeholders prepared to collaborate with the Forest Service and reduce conflict around forest management in the Sierra. The Participation Team worked to exemplify a model process for conducting collaborative adaptive management and training that could be implemented by agencies to hopefully reduce conflict. Though there was almost complete turnover of the Forest Service participants in SNAMP, many of the public, environmental group, forest products, and other agency representatives were able to stick with the project all the way through. A group of stakeholders had formed at the end of the project who had developed long-term relationships with each other, shared common understandings about the resources, and had similar expectations about the process of adaptive management. This modeling and training, combined with the shared understandings and improved relationships between participants, bodes well for future collaboration in the Sierra.

But was SNAMP effective at reducing conflict? A large majority of our email survey participants felt that SNAMP increased trust within the three party model. Yet both email survey respondents and interviewee participants were ambivalent as to the project's ability to reduce conflict over forest management in the Sierra. The dominant sentiment was that appeals and litigation were inevitable because they are driven by the entrenched philosophies and agendas of interest groups. The two solutions offered by email survey respondents were the cornerstones of the SNAMP three party effort: independent science and increased stakeholder participation.

SNAMP's three party model structure was effective in a most critical aspect – the university and its science were seen as independent, unbiased and responsive to stakeholder input. But with this new model came miscommunications and disappointed expectations. The two biggest issues were the separation between management and science, and financial constraints. Initially there were disagreements as to what subjects would be studied in SNAMP. Next some stakeholders and managers hoped that SNAMP would bring university experts into the Forest Service's planning processes but this was the opposite of what the Science Team imagined due to their interpretation of how to conduct a controlled experiment. A related misinterpretation was connected to definitions of monitoring. Some stakeholders expected the university to "blow the whistle" on the Forest Service if it implemented the treatments differently than planned. This also was not the role of the university as interpreted by the Science Team. A Neutrality Agreement was created by the Science Team to clarify some of these concerns.

The financial structure of the project was a serious challenge to our effectiveness though not surprising given the dollar amounts and years of commitment. For large scale adaptive management projects, sizeable and consistent funding over many years is vital yet very difficult to achieve (Gregory et al., 2006). The difficulties of carrying out long term projects with federal agencies under an annual funding regime have been well documented (Nelson 1995). In addition, the recession that started in August of 2008, just a few years into the project, caused havoc with state and federal budgets and threw the project into years of financial stress and uncertainty. Throughout the interviews there were many comments about the tensions within the MOU Partner funding agencies with regard to how much each contributed, staff turnover, as well as a perception that the university did not understand the financial constraints and had unrealistic expectations. Eventually the project was completed but with less funding and over a longer period of time than originally planned.

In 2015, UC completed its role in SNAMP. It is left to the Forest Service to work directly with stakeholders to use SNAMP's products, results and recommendations, and to adapt them to future needs. How and whether UC Science Team results and public input are used in the next and future forest treatment plans will determine how SNAMP's effectiveness is ultimately seen. Throughout this project we have considered this a crucial step that is outside of the funded and UC Science Team part of SNAMP (Figure F1). The SNAMP collaborative adaptive management workshop teachings offer tools for both the public and the agencies to improve their communication to complete the cycle of adaptive management and begin the next cycle of learning.

Participants from all three sides of the three party model concluded the project with positive aspirations for the future. The third party science provider model was well demonstrated and should be transferable in parts or in whole to other situations or places given adequate attention and funding. It is now up to the Forest Service to close the adaptive management loop and for all of us to use the lessons learned from SNAMP to improve collaboration and management of the forests of the Sierra.

> "… we are the beneficiaries of the work and I think that the investments that we made, no one has groused about them. That wasn't the motivator for us. Benefits to the landscape over the long term and over the entire Sierra landscape were our motivators." MOU Partner 2014

I. Introduction and approach

This Appendix is a report on the diverse activities carried out by the Participation Team to assess participation in SNAMP, improve our methods of outreach, and contribute to the integrated chapters (chapters 4 and 5 of this report).

Our introduction describes adaptive management and the Sierra Nevada Adaptive Management Project's (SNAMP) interpretation of that concept into a form of collaborative adaptive management. We present a short overview of the Participation Team, its approach, role and activities, describe the structure of the team, and provide a road map to the full Participation Team Appendix. The Participation Team is one of six science teams in SNAMP. In addition to its work in public participation, SNAMP teams studied the impact of Forest Service treatments on following: fire and forest ecosystem health, Pacific fisher, California spotted owl, and water quality and quantity. Within SNAMP, the Forest Service chose and carried out management prescriptions, while the Science Team designed and conducted assessments of management effects, reporting results back to the Forest Service and the public in order to improve future treatments.

SNAMP's collaborative adaptive management (CAM)

Adaptive management was first described by Holling (1978) and Walters (1986) as a systematic approach to learning about complex ecological systems through deliberate experimentation and improving management by learning from the results. This allows managers to act without complete information about a system (Morghan et al. 2006). The premise that adaptive management involves deliberate experimentation rather than passive trial and error provided the first conceptual pillar of the UC Science Team workplan.

Since first conceived, the definition of adaptive management has evolved to commonly include an emphasis on public participation, and SNAMP adopted this emphasis (Gregory et al. 2006; Stringer et al. 2006). The second pillar of the SNAMP workplan specifically defined adaptive management as a participatory process that engages scientists, managers and interested stakeholders, thus distinguishing SNAMP from adaptive management forms that engage managers and scientists, but not stakeholders. The Science Team's workplan states "…that adaptive management must be a participatory process that engages scientists, stakeholders, and managers in a long-term relationship grounded in shared learning about the ecosystem and society… Our working premise is that we need stakeholder participation and feedback during each phase of Science Team research for this adaptive management program. To encourage this exchange, we are committed to transparent decision-making. There will be ongoing analysis of the creation, adoption, and application of stakeholder and scientist information in the Forest Service adaptive management process" (UCST 2007 and Appendix H of this report).

Stakeholder participation was fitted to the adaptive management cycle such that participation was part of each phase (Figure F1). The Science Team's understanding of the processes that support adaptive management is perhaps most succinctly expressed by the following statement from a recent journal article, "Adaptive collaborative management emphasizes stakeholder engagement as a crucial component of resilient social-ecological systems. Collaboration among diverse stakeholders is expected to enhance learning, build social legitimacy for decision-making, and establish relationships that support learning and adaptation in the long term" (Arnold et al. 2012). The Participation Team was committed to modeling this kind of participatory adaptive management process. While the primary mode of interaction was consultative rather than the power-sharing of a full collaboration, the participatory adaptive management process used by SNAMP was defined for the project as "collaborative adaptive management" or CAM. The participatory process as implemented in SNAMP reflects SNAMP's stated definition of collaborative adaptive management (CAM):

> CAM is a science-driven, stakeholder-based process for decision-making while dealing with the scientific unknowns inherent in many physical and biological systems. In the SNAMP process, adaptive management incorporates stakeholder participation in order to improve the amount and breadth of information for decision-making, create meaningful engagement and build mutual understanding, learning, and trust.

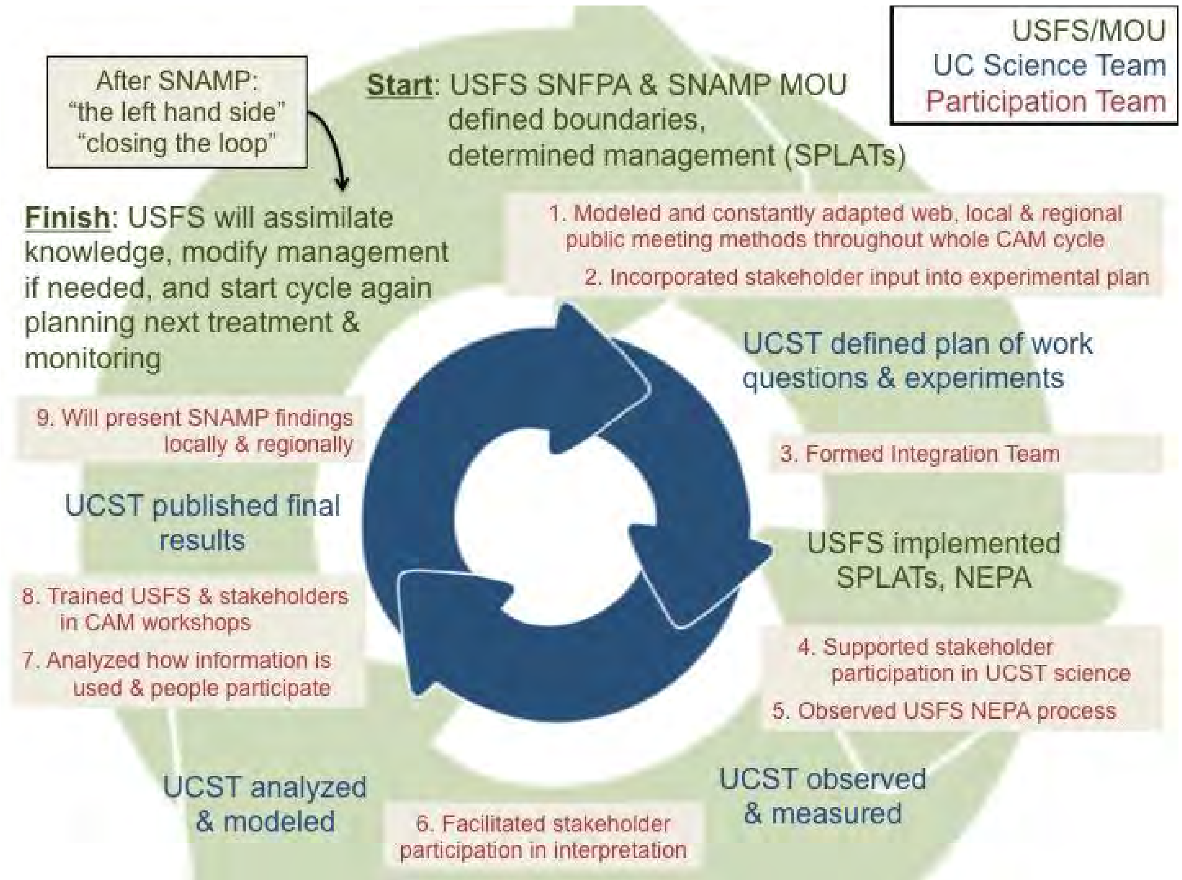


Figure F1: Depiction of SNAMP's collaborative adaptive management cycle including the roles of the United States Forest Service (USFS), the Memorandum of Understanding (MOU) Partners the UC Science Team and the Participation Team.

A complication of the collaborative adaptive management cycle that became apparent from the beginning was that completing full cycle was actually not part of the SNAMP workplan. The Forest Service planned and implemented the treatments, the UC Science Team conducted assessments and provided recommendations but the mechanism for feeding those findings back into Forest Service management was not incorporated into SNAMP. This crucial aspect of learning and utilizing that learning would occur on the "left hand side" of the collaborative adaptive management cycle and was also called "closing the loop" as it is the step just before the whole cycle would begin again (Figure F1). Participants sought assurance that SNAMP results and recommendations would be used in future management, but this could not go beyond a good faith statement by the Forest Service. Guarantees are not possible due to the legal responsibilities of the Forest Service, the difficulties in defining what "use" means in this context, and the need to continue to adapt as conditions change (described in Part II: Putting the

SNAMP Model into Context).

The SNAMP model can be seen as part of an evolving history of public participation in Forest Service decision-making. Efforts to include the public in decision-making for public lands can be generalized into two categories, “grass-roots,” or “top-down”, of course with the understanding that there is considerable territory between these two poles. The SNAMP project is a top-down project, initiated by public agencies to improve forest management in the Sierra and facilitate the implementation of fire hazard reduction treatments in accordance with the legally binding Sierra Nevada Adaptive Forest Plan Amendment (SNFPA) 2004. This controversial plan, also called the Framework, resulted in legal discussions between several agencies and groups, including the state of California Resources Agency and the federal Fish and Wildlife service, prompting the Forest Service to seek an alternative approach through this project and the request for UC to serve as a third party “neutral” entity within the SNFPA.

Defining the project boundaries, such as the fact that the Framework was law and that it would be implemented and tested rather than revised immediately, was critical to framing the dialogue. These set the limitations for the democratic forms of participation that could be facilitated to support mutual learning and to maximize information exchange between participants. Some stakeholders did not accept the SNFPA 2004 as a framework to begin with and could not accept the treatments associated with the project. The constraints the UC Science Team faced within the boundaries of SNAMP were many and diverse over this long term effort, including limited choices for treatment timing, maintaining neutrality despite the controversies surrounding forest management, vacillating funding levels, and a level of collaboration limited by the requirements of agency oversight and by scientific protocols. These required ongoing dialogue and resulted in key operational agreements. Maintaining open communication on all related changes over time to these boundaries, constraints and agreements became essential to maintaining stakeholder engagement and moving forward with the process.

Approach to participation

The University of California was chosen for the role of third party neutral science and outreach provider because of its perceived credibility with participants on both sides of Sierran forest management debates. Other factors were University of California Cooperative Extension's (Cooperative Extension or UCCE) extensive network of outreach professionals, and long history of working with stakeholders on collaborative projects. Cooperative Extension coordinated and facilitated all public, scientist, and manager involvement in SNAMP. The Participation Team integrated this engagement component with an extensive assessment piece emphasizing analysis of stakeholder response to and learning from, outreach, science, and treatments, and developing methods to allow greater participation in the program. This assessment effort included conducting and analyzing a variety of surveys of participants and non-participants at different periods over the 10 years of the project, and a series of three in-depth interview projects. The two scientific approaches were designed to complement each other: while the surveys provided quantitative measures of the proportion of participants experiencing various outcomes, the interviews provided a more nuanced understanding of the responses, allowing interviewees to frame problems, observations, and perceptions in their own terms.

A literature review of adaptive management and participation in natural resources management was conducted early in the project to provide the foundation for SNAMP participation work and evaluation (Appendix FI). It included what were identified as the core elements of collaborative adaptive management: inclusiveness, transparency, relationship building, learning, and the effectiveness of the process itself. From experimental design to interpretation of results, our outreach strategy emphasized these core elements using Cooperative Extension training and experience.

The Participation Team developed, managed and studied the participatory opportunities of the project. From the start, efforts to engage the public were part of SNAMP. The original UC workplan was peer reviewed by outside scientists and the reviews were shared with the public. The SNAMP ecological and outreach teams reported directly to the public, Memorandum of Understanding partner agencies (MOU or MOUP), and the Forest Service about the design, methods, and results of the effects of treatments. Results were published in peer-reviewed journals, and nontechnical briefs of each publication and a complete listing of all publications were readily available at the project website: http://snamp.cnr.berkeley.edu/. The Forest Service, from regional representatives and district managers to field technicians, attended, and frequently presented, at all SNAMP events, and carried out its National Environmental Policy Act (NEPA) public involvement process with UC attendance.

The Team managed the SNAMP website where all meetings were posted and documents were available, facilitated meetings among scientists and stakeholders, and led the development of a network of stakeholders that included the public, non-profit organizations, the state Resources Agency, the Forest Service, and others interested in forest management in the Sierra Nevada. Involvement included "integration team meetings" on specific scientific topics, field trips, lectures, annual meetings, presentations to local, state and regional groups including local high schools; and an interactive website for sharing meeting information, notes, reports and responding to comments and questions. Cooperative Extension also frequently represented SNAMP at Board of Supervisor's meetings, local interest group member meetings, and other venues.

Overall, SNAMP stakeholders included three broad groups: managers, scientists and the public. Managers were individuals from participating federal and state agencies (e.g. Forest Service, US Fish and Wildlife Service, CalFire, California Department of Fish and Wildlife, California Natural Resources Agency, California Department of Water Resources, and California Department of Food and Agriculture). Scientists came from UC Berkeley, UC Merced, UC Davis, UC Cooperative Extension, and the Universities of Minnesota and Wisconsin. Public stakeholders included a number of environmental advocacy groups, such as the Sierra Club, Sierra Forest Legacy, Defenders of Wildlife, and of a small group of vocal and concerned unaffiliated individual citizens from local communities, as well as of industry representation, such as Sierra Pacific Industries and the California Forestry Association (see Appendix F2: Affiliation of stakeholders contacted through SNAMP).

Participation Team structure: Outreach, facilitation, and analysis

The Participation Team was charged to facilitate public involvement and assess the response of stakeholders to the adaptive management experiment (Sulak et al. 2015). The Participation Team included three groups of UC scientists and UCCE professionals. The groups worked together and there was considerable overlap in the work and activities of each group.

Professor Lynn Huntsinger and Research Specialist Adriana Sulak led the effort to assess the kinds of learning and adaptation that took place as a result of project participation. Participation data was archived throughout the project and provided a database for digital and other assessments. In line with the "before and after" approach adopted by SNAMP overall, the use of qualitative interviews and quantitative email surveys of participants early and late in the project allowed examination of changing norms, what stakeholders learned about forest management treatments, and the response of stakeholders to different outreach and learning approaches.

Professor and Specialist Maggi Kelly of the Department of Environmental Science, Policy, and Management, and her graduate students including Shufei Lei and Shasta Ferranto, adapted the use of interactive web technology to create new means of engagement in the adaptive management process. This allowed participation from both near and far, overcoming the common barrier of distance to facilitate fuller participation. Using the long term data collection built into the project and the project archives, engagement could be explored using the latest in networking technology and assessment, and engagement levels and characteristics could be followed over the full duration of the project.

Kim Rodrigues of the Division of Agriculture and Natural Resources was one of the initiators of the project and led the outreach and facilitation effort with UC Cooperative Extension staff for most of the project. Natural Resources Advisor Susan Kocher transitioned from Team member to lead in the last 3 years of the project, after participating in SNAMP from early on. The team also included two outreach Community Education Specialists, Anne Lombardo and Kim Ingram who resided in the vicinity of the project sites in rural Foresthill and Oakhurst, California. Using the UC Cooperative Extension approach of bringing science based information to local communities with embedded local relationships, the UC Cooperative Extension outreach team facilitated local participation in science and adaptive management by conducting in-person events in the local community as well as with communities of interest. Adriana Sulak also assumed significant responsibilities in this group as the project progressed. In-person events were used to promote shared understandings of the science (both for results and how science is conducted) and emphasized direct communication with scientists. The in-person events were also important because they encouraged interactions between managers, scientists and the public to promote mutual learning, to foster stronger relationships that support adaptive management, and to strengthen confidence in the outcome of project. As was appropriate to the project, the major project investment was in outreach.

Outreach sought to engage the community of interest in Sierran forest management, rather than geographically bounded stakeholders, because in fact as Sierran urban populations grow, many local residents have less direct knowledge of forest management. Still, the majority of public stakeholders who participated in our email surveys as a sample from this community of interest, as defined by the Cooperative Extension's contact list for persons interested in Sierran forest management, were from the counties where the study sites were located (Figure F2). However, the online presence of SNAMP through the interactive website also meant that there were participating stakeholders from distant places. Email survey participants came from many different backgrounds (Figure F3), and the SNAMP email contact list grew steadily throughout the period of the project to 825 people in 2014.

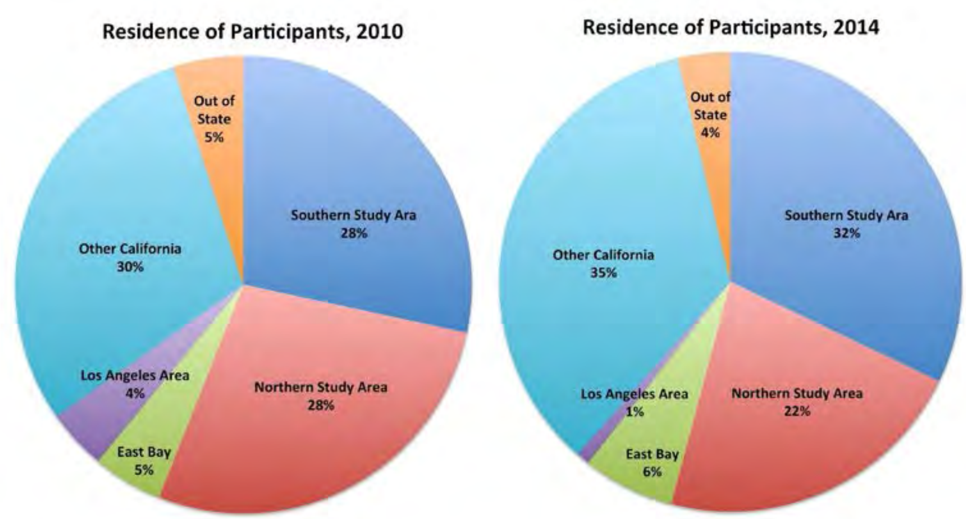


Figure F2: Residence of survey respondents in 2010 and 2014.

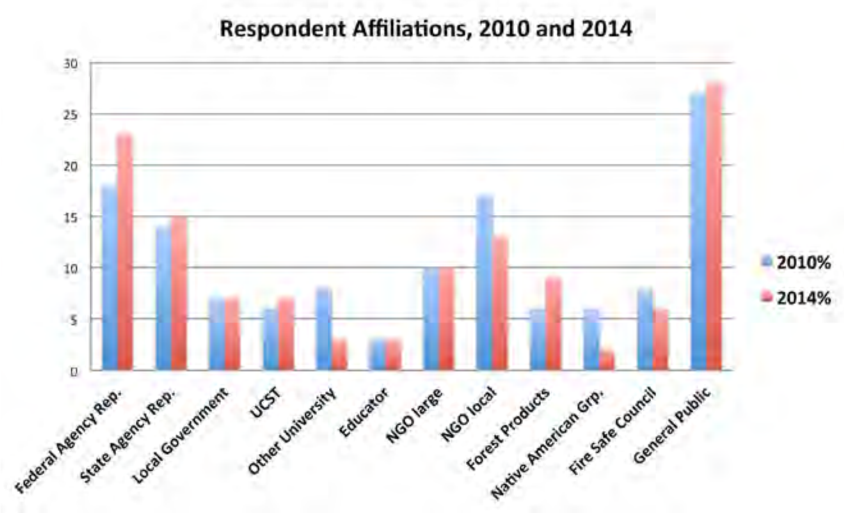


Figure F3: Respondent affiliations.

Organization of Appendix F

In Part II the collaborative adaptive management model used in SNAMP is placed within the context of the history of Forest Service efforts to create management and decision-making processes that meet the needs of the public and support sustainable forest management. It provides a brief background of the evolution of participation in forest management nationally. Over the last century the Forest Service has shifted from an emphasis on management based largely on technical expertise to models using more participatory methods.

The third party model that SNAMP used, in which an agency, the public and an outside science and outreach provider in a sense act as checks and balances to each other was derived out of the concept of shared, multi-party, or joint monitoring, and to some extent, citizen science. Both increase the participation of stakeholders in the science that drives management decisions. As true co-management, where power is shared equally, is not possible for the Forest Service because of legal doctrine, or for scientists following strict protocols, projects like SNAMP can be seen to allow for more transparency in the decision-making process by opening up monitoring and planning processes, and providing additional pathways for input and feedback. An unforeseen benefit was the stakeholder enthusiasm for increased participation in, and understanding of, the science that became apparent in the course of the project. SNAMP provided some direct communication channels between scientists and the public, and this turned out to be one of the most appreciated aspects of SNAMP.

Part III reviews in detail the outreach goals, methods, techniques, and systems the Participation Team created for SNAMP. The Team focused on both in-person events and presentations as well as "at-a-distance" methods that were web-based. Each type of participation event had its benefits and limitations and each allowed certain kinds of learning to occur or relationships to be fostered (Tables F3 and F4). Face-to-face interactions with scientists and managers were a focal point of the in-person outreach program. Our large public meetings gave broad access to the project, though with little time for details, and provided a forum for interest group positions to be shared. The smaller technical integration team meetings were focused on individual topics. These provided in-depth data sharing with advanced discussions, scientist presentations, and opportunities for participants to learn from each other's less formal questions and comments. Field trips, where participants could "kick the dirt" together and see forest conditions and treatments, provided opportunities to learn about management context, scientific methods and findings as well as to build relationships through conversation and shared experience. Participants emphasized that field trips were valuable learning experiences. Management workshops, which conveyed relevant science on managing a resource including findings beyond the scope of SNAMP, were appreciated by managers. Taking SNAMP to targeted audiences by going to their meetings and events proved to be a powerful way to spread the scientific outcomes of SNAMP as well increase project inclusiveness and transparency.

The project's at-a-distance methods such as the website and its document archive, science briefs, newsletters, and blogs provided the basis for additional SNAMP contacts because of their accessibility and transparency. The email list was invaluable for getting information out to interested parties though it was not particularly interactive. Webinars were found to be useful at the end of the project (they saved time and money), but none of the online interactions could replace the importance of face-to-face connections with scientists, managers or other stakeholders. We observed that our webinars were mainly successful because they occurred at the end of the project when relationships were solidified and there was a group comfort level that could overcome the impersonal nature of the webinar.

To transfer the SNAMP collaborative lessons and to train stakeholders and the agencies to conduct or participate in future collaborative adaptive management projects, we created and implemented a multi-day workshop curriculum and companion workbook described in Part IV. Participants in these trainings gained a clearer understanding of adaptive management and how to include the public in the process, how and when to use an independent third party, and how participants can utilize facilitation tools to help defuse conflict. Evidence from the post-workshop surveys suggests that these trainings should increase participant commitment to collaboration and it is these key stakeholders and agency participants that could help to assure that SNAMP results and processes are applied in the future.

Our overall assessment of the SNAMP project is described in Part V. In-depth interviews and email surveys were used during the project to collect participant views of SNAMP and all its varied components. The strong effort put in by the Science Team to focus on inclusivity and transparency was recognized by participants. The comments we collected during the SNAMP project tell us that SNAMP had a definite impact on the relationships between participants and created social capital that can be relied on in future collaborations. SNAMP's focus on shared learning did foster new and improved relationships (ex: environmental groups and forest products groups) but at the same time the constraints of the project caused some strained relationships (ex: MOU partner difficulties over funding, stakeholder and manager misunderstandings about roles and relationships). Years of large and small meetings, field trips, and webinars allowed participants the time in a consistently facilitated setting to build connections between stakeholders. These data were collected and analyzed before the final SNAMP results were presented and therefore we cannot say how relationships stood at the conclusion of the project. We can say that in 2014 environmental and forest products groups were working together, attendees learned a vast amount about the Forest Service that should improve interactions going forward, and some bridges have been built between agencies and participants. We believe the Forest Service will need to continue to engage intensely with the public in order to build on what has been created in SNAMP.

In addition to the evolution of relationships between participants, Parts VI and VII describe how the time spent together and learning together also created shared understandings about the scientific results and how science is done as well as larger more complex topics like adaptive management and forest health. These shared understandings and the hybrid culture they fostered, combined with the improved relationships between participants, could be the foundation for more productive and continued collaborations in the future.

The body of the Participation Team appendix concludes with a review of the project, its assets and limitations and presents a list of important lessons learned that should be helpful to anyone, agency or academic or public citizen, who intends to create or participate in a collaborative process.

Our Participation Team appendix also contains its own appendices that provide additional description or information about where our evaluation core elements were sourced (F1: Participation Team Evaluation Tables), the affiliations of all SNAMP participant contacts (F2: Affiliation of stakeholders contacted through SNAMP), and listings of all SNAMP newsletters (F3: SNAMP Newsletters), videos (F4: SNAMP Videos) and blog stories (F5: SNAMP UCANR Green Blog Stories). The full CAM workbook is included (F6: SNAMP Collaborative Adaptive Management Curriculum) and all our journal publications are also described (F7: Participation Team paper abstracts).

II. Putting the SNAMP model in context: Evolution of participatory management for national forests

The extent and process of public participation in US forest management transformed dramatically over the last century. Today, relationships between the land management agencies and the public are now considered key to making decisions and even conducting science for resource management. But is there a third phase on the horizon? SNAMP can be seen as part of the potential evolution of a three way model for natural resource management that includes the agency, the public, and a monitoring or scientific participant. SNAMP provided a demonstration of a neutral third party strategy and how the agency could foster a more open and transparent culture. The goals and ideologies of the Forest Service have changed over time, but the legacies of the past still cloud current options for participatory management. This section attempts to explain that historical context for SNAMP, shows how SNAMP fits into the development of collaborative management, and lays some of the groundwork for a future, more developed, publication.

SNAMP was created to address a specific problem at a particular point in time: the 2004 US Forest Service Sierra Nevada Forest Plan Amendment (Framework) that dictated management of the Sierra national forests was controversial and implementation was likely to be hindered by this conflict. The University's role was to study the impacts of the management strategies of the Framework in an open and transparent process that would allow the conflicting parties the space to learn together and, it was hoped, move forward from the impasse. The adaptive management process used in SNAMP emphasized public participation and was considered "collaborative adaptive management" within the project.

Three historical time periods can be used to characterize the major phases in the development of the public role in Forest Service decision-making processes: the early twentieth century, the post WWII period, and the post 1980's. After reviewing these periods we follow with a discussion of the current state of the collaboration field.

The early 20th century: A culture of expert management

In 1905 Gifford Pinchot, the first chief of the Forest Service, imbued the agency with his vision of conservation: "the greatest good for the greatest number for the longest time." Pinchot strove to create a cadre of professional forest managers, inculcated with the professional norms of the agency, to decide what was best for all (Hays 1960). Unfortunately, along with the assumption that only technical experts could make the right decisions, his philosophy seems to imply that what is best for the majority is best for all--leaving those not in the majority out in the cold. One of Pinchot's forest professionalism core beliefs was that the science developed by American and European institutions of higher learning was the only legitimate basis for making decisions for managing forests. Despite the fact that the U.S. timber supply was not then, and has never been, threatened, another core value was maximizing timber production and making it more efficient (Hays 1960).

According to the 1897 Organic Act that created the Forest Service as a federal agency, the intention of the forest reservations was "to improve and protect the forest within the reservation, ...securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States." In 1905 Gifford Pinchot sought to create a corps of educated resource professionals who would make decisions about managing the Forest Reservations for the "foresighted utilization, preservation and/or renewal of forests, waters, lands and minerals, for the greatest good of the greatest number for the longest time." The agency he created embodied Pinchot's progressive conservation ethic – professionalism, efficiency, use of science, and large-scale government management (Hays 1960). It was both a reaction against the impression that special interests were dominating and pillaging the public lands, and a commitment to the belief that science and technology could solve many societal issues including how to make public land management decisions (Culhane 1981). The Forest Service was organized to utilize "to the fullest extent the latest scientific knowledge and expert, disinterested personnel" (Hays 1960; Fortmann and Fairfax 1989). The founders felt so fervently about the conservation ethic that it was an issue of morality, of right and wrong (Wondolleck 1988). Fires set by Native Americans, herders, and farmers as part of traditional management practices were included among the many threats from which the forests needed protection. In 1895, Bernhard Fernow, a Prussian forester educated in Europe and Pinchot's mentor, opined that "the whole fire question in the United States is one of bad habits and loose morals. There is no other reason for these frequent and recurring conflagrations" (Bowers 1895).

These founding ideas created a decision-making model of expert management for the public good, where experts would decide what constituted the public good. Under the influence of Pinchot and his mentor Bernhard Fernow, the primary goal of forest management was determined to be sustainable timber production. Following a model of intensive forest management established in Germany, where the population was dense, timber was very limited, and wood was highly valued for domestic and military uses (Behan 1975), common silvicultural practices espoused by the Forest Service included clear-cutting to allow for "improved" forests and forest genetics, control of herbs, shrubs, and less desirable tree types to facilitate rapid forest re-growth, and harvest of mature, old-growth trees at least partly because they were considered “decadent”—no longer growing and adding to timber stocks (Nelson 1995). Worth noting is the contradiction between these “maximize timber production” practices and the low population density of the United States at the time, together with its vast stock of standing timber. In fact, timber prices remain low to this day.

Forest Service faith in the superiority of “science-based” knowledge and professional ethics went so far as to create a culture where the agency did not use information from other disciplines, only forestry: “Exalting expertise, the Service believed that it alone could master the requisite knowledge… Advice offered by scientists with backgrounds in related, if not more fundamental, disciplines frequently went unheeded” (Schiff 1962). Once hired by the Forest Service, the internal training each employee received was extensive (Kaufman 1960). This training, combined with immense amounts of detailed administrative requirements and prohibitions, created an agency where employees believed in agency policy wholeheartedly and usually disparaged or distrusted information sourced outside the forestry profession (Kaufman 1960). The public, especially those most affected by resource decisions, did not have the technical expertise to make correct decisions, and was too prone to self-serving intentions that would lead to abuse of the resource. To the Forest Service, “locals are in no way peers. Lacking professional expertise, they are, in terms of forestry orthodoxy, perforce political actors, seeking some kind of advantage, some distortion of the technically correct decision which would meet their own needs and preferences. It is the forester’s job to base decisions on science, hence to exclude such local influences from the process” (Fortmann and Fairfax 1989).

Concern about capture by local interest groups was the rationale behind the frequent transfer of Forest Service personnel and district rangers. The rangers were moved every few years to create a cohesive culture that trumped local needs: “By breaking rangers’ interpersonal ties to the communities in which they were stationed, the Service fostered identification with other agency officers as a peer group; by leaving rangers vulnerable to detection of departures from agency policies, transfers sharpened effectiveness of the Service’s formal control policies” (Kaufman, 1960). Changes in Forest Service personnel have at times frustrated long term collaborations and relationships (Kaufman 1960).

These founding qualities – professional expert management, belief in science and technology, a culture of conformity, and distrust of capture – are still with the Forest Service today. This model of decision-making for the national forests can be visualized in the top portion of Figure F-4, with the Forest Service responsible for determining the goals, activities, and outcomes of management. During this time, the “non-delegation” doctrine in U.S. legislation took shape. The doctrine forbids the delegation of federal agency decision-making or authority to private groups or other branches of the U.S. government, largely because agency authority comes from the responsibility of agencies to represent the will of Congress.

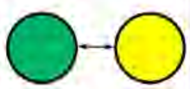
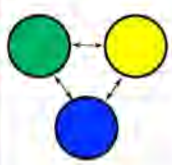
Model	Discourse	Legislation	Issues
[USFS: management+ monitoring+ representing the public interest] 	*Professional expertise.* Experts trusted and respected by the public. Experts are objective and use science. Experts decide the goals and methods, are responsible for the decisions. *Professional Management*	Organic Act, non-delegation doctrine	Experts not sensitive to local conditions, knowledge; agency "culture" takes precedence; clash with public, litigation, eventual rise of activism and "mistrust"
[USFS: management + monitoring] vs. [Groups and individuals: public interest] 	*Involving the public.* Communication, transparency Participation, USFS gets and uses feedback from diverse publics, earns trust Need for engaged stakeholders who are knowledgeable *Ecosystem Management, Community Forestry, Adaptive Management*	NEPA: public should be informed and comments taken; Clinton E.O.: Tribes must be consulted	Litigation, confusion about how comments are solicited and used, lack of trust Groups and individuals with resources/science/technology/ time/numbers get the most attention Rise in litigation Non-delegation doctrine constrains shared decision making.
[USFS manages] vs. [public interest] vs. [third party science] 	*Checks and balances.* Third party scientific monitoring separates management and research/monitoring functions, reports to public as well as USFS. Transparency critical; all-party and shared monitoring approaches, as well as other types of third party approaches *Shared science as mediator* *Third party monitoring* *Shared learning* *Participatory adaptive management*	SNAMP MOU	Assuring third party independence Maintaining transparency and public confidence in information gathering and decision-making processes Non-delegation doctrine constrains shared decision making.

Figure F4: Outline of major shifts in Forest Service (USFS) decision-making approaches and the SNAMP third party model. Figure developed for use in this discussion.

After the war: growing interest in alternative goals for the National Forests

Post World War II, recreation and wilderness gained prominence as management goals in both public consciousness and Forest Service rhetoric. "By the end of the Second World War, a growing population, combined with rising disposable income, longer paid vacations, retirement programs, and increased mobility ushered in an era of mass recreation" (Dana and Fairfax 1980). Previously, the Forest Service tolerated recreation and encouraged it in some places to justify expenditures (Dana and Fairfax 1980) but with increased interest in recreation during the 1950s this use could no longer be treated as an afterthought. Public pressure for better recreation facilities began to grow and this squarely pitted the Forest Service as a silvicultural organization against those who thought managing places to visit and enjoy should be a primary goal. The value of a "clear-cut" as a picnic ground was questionable. In fact, Bernhard Fernow lost his position as head of the nation's first forestry school when he applied the scientific harvest method of clear-cutting in the Adirondacks in the early 20th Century (Behan 1960).

By the end of the fifties, recreation was no longer a side benefit of the national forests; it was a purposefully funded part of the agency and hence began to compete with the agency's well-entrenched interests. Recreation and preservation lobbies were able to push the Forest Service to reconsider its priorities and policies. The agency emphasized recreation's importance in their newest agency wide plan for management – what turned out to be the Multiple Use Sustained Yield Act (MUSY 1960) – by listing is as one of four major uses (Dana and Fairfax 1980). Though the law was a start toward public involvement in Forest Service management, Congress continued to expand its appropriations for timber production more than any other use (Ruth 1996).

The wilderness and recreational movements took on steam in the 1960s with the growing environmental movement that was explicitly attempting to exclude the country's wild lands from management for commodity production. The Wilderness Act (1964), the Land and Water Conservation Fund Act (1964), the National Trails System Act (1968), and the National Wild and Scenic Rivers Act (1968) all direct the management of federal lands and began to reduce the discretionary power of the Forest Service. By the late 1960s, there was a strong distaste for industrial forest management. The Forest Service was perceived to be on the side of industry, and its inability to explain itself outside of technical jargon limited its ability to appeal to the public's good opinion.

The early 1970s also brought an array of environmental quality laws that added many layers of regulation to the Forest Service's job – the Endangered Species Act (1973) being an important example. Other laws specifically aimed at public land management and the Forest Service also added more layers to Forest Service management as well as started its public participation programs: The Forest and Range Renewable Resources Act (1974), the National Forest Management Act (1976), and to a lesser extent the Federal Land Policy and Management Act (FLPMA 1976 Pub.L. 94–579) all added Congressional expectations and subsequent rules and regulations to the Forest Service's work. These laws articulated processes and procedures for the agencies to follow but did not define priorities perpetuating multiple use conflicts. The agencies were directed to ask the public for help setting priorities.

Two laws were intended to specifically address the issue of public input in federal land management: The National Environmental Policy Act that affected all federal agencies, and the National Forest Management Act (NFMA) which was specific to the Forest Service. The National Environmental Policy Act (signed into law on January 1st 1970, NEPA) had a large impact on the public's interactions with the federal land management agencies. NEPA requires Federal agencies to analyze the short- and long-term adverse environmental consequences of a range of proposed management alternatives, including no action. Federal agencies were legally required to consult with the public, encouraging public values and goals to have greater representation in decisions about the forests. NEPA created a mechanism for participation in land management decisions but inadvertently opened the door for a dramatic increase in litigation against the Forest Service by setting up complicated and detailed procedural requirements (Kaiser 2006).

Through the National Forest Management Act of 1976, Congress reaffirmed the multiple use mandate and attempted to give the Forest Service clearer guidance on how to involve the public. Amongst other goals, "the law expanded opportunities for public involvement in the planning process, seeking to permit an unprecedented level of public participation in management decisions" (Ruth 1996). However, direction on how to incorporate public opinion was "less than definitive" at the time with the main emphasis being on attainment of input through the planning process (Ruth 1996).

Increasing litigation

The 1960s and 70s changed Forest Service management to include more mechanisms for public input. As part of NEPA and forest planning, the public can make suggestions and comment about forest management, and the agencies are required to listen and to consider them, but the agency is solely responsible for final decision-making and implementation. Public input is strictly on a "consultative" basis. There is little evidence that these approaches increased public confidence in the agencies or reduced conflict over forest management—in fact the opposite may be true in many cases, as is supported by the explosion in litigation in the following decades (Kaiser 2006; Broussard and Whittaker 2009; Henderson and Krahl 1996).

Through the 1960s, the Forest Service did not have more than one or two court cases about an administrative decision at a single time; in the 80s there were one to two dozen at a time (Wondolleck 1988). Litigation had become such a crucial tool that in the 1980s the Wilderness Society created a two volume manual explaining how to appeal national forest plans (Wondolleck 1988). Between 1970 and 2001 there were a little less than 300 cases brought against the Forest Service with regard to its NEPA compliance (Broussard and Whitaker 2009). Suits against the Forest Service for any type of transgression generally increased every year from 1989 till the year 2000 with a high of 76 cases in 1998 (Keele et al 2006). NEPA itself fed into this process, as the technical requirements of the law provided fertile ground for legal challenges.

The 1990s brought attempts at transformation for the Forest Service through many new social and ecological strategies to address this broad skepticism – conflict resolution, interest-based negotiation, alternative dispute resolution, community forestry, ecosystem management, adaptive management, and watershed councils (Leach 2006). Community forestry and other attempts at sharing decision-making have been constrained by an inability to fully share decision-making (Moote et al. 1997). Clarifying the limits of shared decision-making has been critical to participatory processes (Fernandez-Gimenez et al. 2008). Participatory management efforts that follow the two way model of an agency working with stakeholders have not proven to be the full answer to stakeholder distrust. For example, one comprehensive study of collaborative projects found that "collaboration experience was negatively associated with trust, indicating that participants with past experience in many collaborative groups were less trusting of other participants than participants with little previous collaborative experience" (Wagner and Fernandez-Gimenez 2009).

A review of these two historical approaches to forest management helps clarify how SNAMP can be distinguished from past efforts and what the SNAMP model might offer for future participatory management efforts. In the first model (Figure F4) the Forest Service determines the goals and management strategies, and then assesses the success of their own management. In the second model, the Forest Service has less discretion in goal setting due to a proliferation of legislation, and is required to consult the public on goals and practices, but at the same time, also assesses the effectiveness of their own management. The public has responded to this scenario with divergent and conflicting assessments of management outcomes and practices, delivered through multiple venues, including litigation. Other scientists have honed in on trust as the major problem—the public often does not trust the Forest Service, and there is a need to build more trust. However, given this second scenario, a lack of trust may be a reasonable response to a situation where the same entity carries out management in the public interest, and then assesses the success of its own management. No matter how well intentioned and sincere, the basic structural flaw remains, of the agency being primarily accountable to itself for monitoring the ecological and social outcomes of management.

2005: The Sierra Nevada Adaptive Management Project

In part, SNAMP arose out of the State of California's concerns that the implementation of fire hazard reduction treatments, as stipulated in the Sierra Nevada Framework of 2004 would be so controversial that they could not be implemented. Concerns of the California Resources Agency and the US Fish and Wildlife Service, as well as potential litigation was one of the major incentives for the Forest Service and others agencies to work with UC to develop an "adaptive management and monitoring process" between 2005 and 2007. The proposal for SNAMP came as a result of that collaboration, in an effort to provide a model for implementing forest health restoration and fuel reduction programs without litigation. An MOU was signed by state and federal agencies and the Forest Service initiating a diverse agency partnership based on the signatory agency representatives, as well as the role of the UC Science Team as a "third party" science and outreach provider in a forest management collaborative adaptive management program (MOU 2005, see also Appendix G of this document).

SNAMP continued the trajectory of increased public participation in forest management by emphasizing the participatory part of adaptive management, but perhaps even more importantly, by introducing a "third party" science provider and facilitator into the process (Figure F4), in the form of UCCE and the Science Team. Assessment was reported directly to stakeholders, as well as to the Forest Service, and stakeholders had many opportunities to interact directly with scientists and managers. The third model, with a third party participant that reports to the public as well as the agency, may be one way to address problems centering on "trust". The third party role of UC in SNAMP provides some insight into how such a scenario can work.

In SNAMP, the UC Science team carried out the science, and designed the way that ecological outcomes were assessed. For this reason the public was assured that a group outside the Forest Service was making the assessment. In addition, a principle of SNAMP was that, when not precluded by contractual arrangements, scientists reported directly to the public. Results were not filtered through the agency lens. Finally, stakeholders were given the opportunity to provide feedback throughout the scientific process, from goals, design, measurement of outcomes, and interpretation.

The last two decades have seen a trend towards opening up monitoring, particularly in collaborative projects. "Multi- party monitoring", "shared monitoring", and "joint monitoring" are all terms reflective of the desire to increase confidence in assessments of outcomes—public participants can witness and even participate in the gathering of data and ideally in its interpretation. This can contribute to collaboration within the bounds of the legal and scientific framework for participation, and help build trust, or rather "trust with verification" as some proponents have suggested. This could be seen as a form of third party monitoring, with the monitoring group as a third party. A third party approach has also begun to appear in a number of other ways. For example, the Bureau of Land Management (BLM), in the Department of Interior has called on the Natural Resources Conservation Service, an advisory agency in the

Department of Agriculture, to conduct monitoring on BLM lands, and to help devise monitoring strategies and databases. "Shared monitoring", or "all parties" monitoring can be seen as occurring along a continuum from monitoring taking place exclusively within and by the managing agency, to having a third party independent entity monitor management outcomes (Figure F4). Part of the assessment reported in this appendix describes some aspects of participant response to this model.

Early on in SNAMP, some stakeholders expressed skepticism of the process because of SNAMP's inability to guarantee the application of the science produced by SNAMP to future Forest Service management. There was no clear way to assure the public that the management recommendations made by the Science Team would be applied in future Forest Service management, or how they might be applied. It became clear that "co-management" in the sense of shared authority was an ideal for some participants. For this reason, this section explores the notion of co-management in forest management. The work was generated to clarify some of the boundaries of the SNAMP process.

SNAMP, consultation, and the co-management question

The literature of collaborative management programs tells us that transparency is crucial (Conley and Moote 2003, Laurian and Shaw 2009) and that it is imperative to provide opportunities for stakeholder input before agency decisions are made; that scientific information should come from sources credible to stakeholders, that studies should conducted in an open manner, ideally with stakeholder input; and that participation and management structures should be flexible and may need to change as new ideas and findings become available (Gregory et al 2006; Reed 2008; Rowe and Fewer 2000). To some extent, all of these things were possible in SNAMP. What was not possible was the kind of collaboration that relies on shared authority in decision-making.

Shared decision-making is logistically and legally problematic for the Forest Service (Moote and McClaran 1997). Sharing decision-making authority outside a federal public agency leaves Congress with no clear line of accountability or oversight (McClaran pers. comm. 2008). Legally, ultimate decision-making authority resides solely with the Forest Service and cannot be devolved or abdicated outside of Congress's reach (Coggins 1995/1996; Coggins 1999; Moote and McClaran 1997), as stated by Moote and McClaran, the "concept of shared decision-making is in direct conflict with federal officers' responsibilities to Congress" (Moote and McClaran 1997).

The extent to which authority for the management of public lands can be delegated to non-federal agencies and private organizations ultimately refers back to the separation of powers between Congress, the Executive Branch, and the Court. It is possible for agencies to sub-delegate some aspects of management to non-federal groups. This can be done through a direct act of Congress or through agency discretion. When the delegation is done by agency discretion it is looked at much more carefully by the courts. In either situation, however, the agency must have final review and control over decisions and this agency review must be specific and demonstrable. The Forest Service could not promise to SNAMP participants that it would abide by, or implement, all the SNAMP final recommendations because in addition to the need to adapt information to changing circumstances and future conditions, by doing so it would have delegated too much of its decision-making authority to SNAMP participants and the UC Science Team.

In fact, Congress has taken specific steps to limit the role of advisory groups in federal agency decision-making through the Federal Advisory Committee Act (FACA 1972). This was originally done to combat the backroom image and secrecy of many task forces by requiring federal advisory committees to be accessible to the public. FACA enables qualifying committees to give official advice to officers and agencies in the Executive branch. FACA committees must be made up of people representing a variety of perspectives and all work of these committees must be made public. However, the sponsor agency controls meeting agendas, meeting minutes are to be submitted to, and approved by, the sponsor agency, the agency can convene or dismisses meetings at its discretion, and the entire committee can have only a limited lifespan. There must also be an official agency representative at each committee meeting held. These types of cumbersome rules make forming FACA committees unappealing to many collaborative groups.

Before it could implement treatments at the two study sites the Forest Service conducted its NEPA process. NEPA encourages federal agencies to collect public input on the environmental consequences of proposed public activities. However, decision-making still resides with the agency: "Collaboration does not turn the NEPA process into a process where an agency's responsibility to make sound decisions is replaced by how many votes are cast for a particular option or alternative" (CEQ 2007). But, "Collaboration does enable decision makers to consider any consensus that may have been reached among the interested and affected stakeholders, furthering the lead agency's ability to make informed and timely decisions" (CEQ 2007). The Council on Environmental Quality (2007) considers the primary goal of the NEPA process is "to arrive at an alternative that can be implemented" (CEQ 2007); something that was crucial to SNAMP given the litigious nature of cutting trees.

At the request of the Forest Service, interviews were conducted with stakeholders in the SNAMP community of interest in 2008-2010 to explore their responses to the NEPA process, and results were discussed at a manager workshop. In general interviewees appreciated some opportunity to make their views known and also found it useful to meet other like-minded individuals at public hearings. However, as is typically revealed in studies of NEPA, stakeholders found the NEPA process frustrating, as it is purely consultative and there is no assurance that their input will be used.

Co-management, shared-management, and joint management are all phrases used to mean more or less the same thing: the sharing of power and responsibility between government and local resource users, affected communities or nongovernmental organizations (NGOs) (Treves et al 2006). None of these methods were used in SNAMP, and in fact as stated earlier their feasibility is arguably limited by the non-delegation doctrine in U.S. law: the Forest Service cannot delegate its responsibility for decisions. Figure F5 depicts increasing levels of shared decision-making in participatory programs. Full co-management, where all parties share decision-making power equitably, is located in the upper right corner. The SNAMP approach was closer to the middle, a more "consultative" approach. The Science Team was straightforward about this from the inception of the project, acknowledging that they could commit solely to a scientific and participatory process where the scientific results, and the processes of making experimental decisions, were shared as openly as possible. However, the Science Team believed that decisions needed to be bounded by the need to maintain the standards of the experimental methods and approach, and to fit topics to the realm of publishable interest and scientific peer review approval. The Science Team, and likely other scientific participants in future projects, therefore also have constraints that limit their ability to share power or decisions with other stakeholders, particularly when it comes to methods and the subjects of assessment. The Science Team did agree that if participant input was not used in a particular Science Team decision, the Science Team would provide a full explanation.

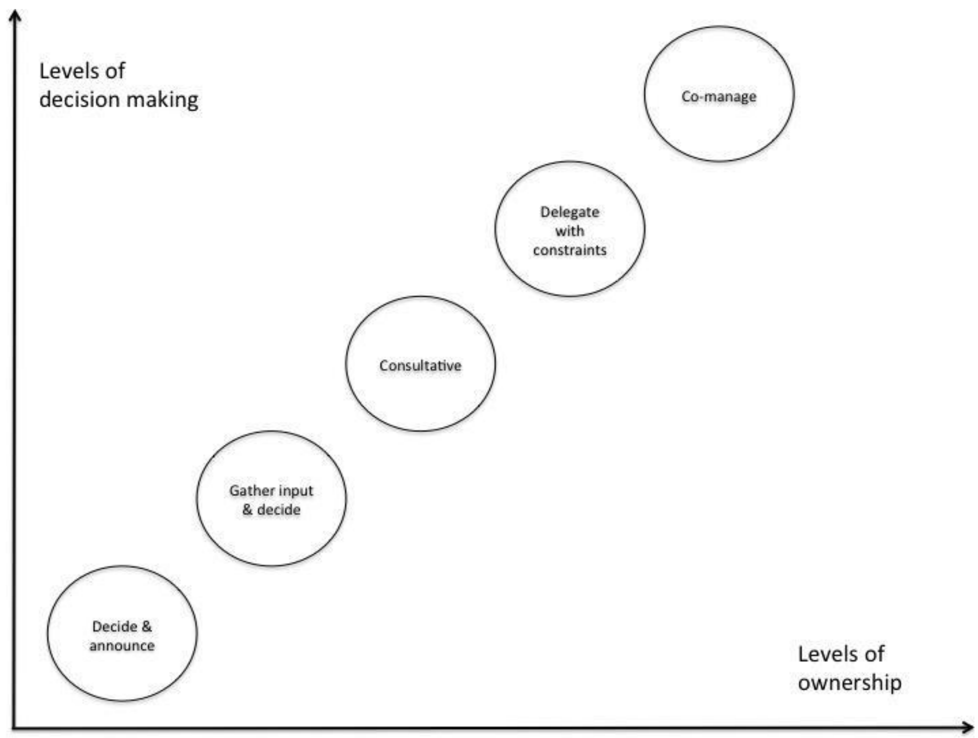


Figure F5: Levels of decision-making as related to levels of participant ownership of the process (originally from Interaction Associates 1997 and modified by Adriana Sulak).

Conclusions: A trajectory for participatory programs?

There are diverse ways of opening monitoring and science up to the public, and there is a growing trend to do so. These include all-parties monitoring, third party monitoring, sharing of monitoring data, and even citizen science, where research is conducted by unaffiliated citizens. One way to look at these kinds of models might be seeing them as similar to bringing in an external auditor. Another way to look at model three (Figure F4) is as a "checks and balances" approach. Shared monitoring and third party monitoring are the checks that may help to increase public confidence in agency management, especially if the process is transparent. A major innovation of the SNAMP project was the use of a form of a third party model, grounding it in principles of transparency and participation. A question for the future is how and if forms of third party monitoring can play a role in the future of adaptive and other participatory management programs, especially given the limitations on co-management and lessons learned from SNAMP. The Participation Team assessed some aspects of how a third party model might function, but it largely remains a hypothesis that we believe should be further tested.

III. SNAMP outreach: Goals, processes, and outcomes

To facilitate the engagement portion of the SNAMP project, the Participation Team's work was based around five core elements attributed to successful collaboration projects in the literature: inclusiveness, transparency and information exchange, learning, relationships, and effectiveness (Appendix F1). In this section we introduce these core elements and then describe in detail the outreach methods used, both in-person and distance strategies, as well as what we and our attendees thought of the methods' abilities to address our core engagement elements. Here the opinions of the meeting attendees were collected via written or online evaluation forms immediately after the event. This is different than our overall assessment of the SNAMP process, discussed in section V, where the results reported were from interviews and email surveys conducted at different times during the project, not connected to specific events. Evaluations were used to develop and improve SNAMP outreach strategies.

For SNAMP's results to be long lasting and widely known, the project needed buy-in from as large a group as possible. Our goal was to be inclusive with a broad and diverse group of participants. The Participation Team worked to engage participants from all sides of the forest management debate and also to create a project that was accessible at many levels of understanding of the topics discussed. Participation by people local to the project areas as well as national or regional groups was important. We valued consistency in participation but also encouraged new participants at any stage of the project.

Building positive relationships can be considered an outcome while also being the foundation of successful collaboration projects. Consistency in participation can influence the ability of a project to foster these kinds of productive relationships. Transparency and effectiveness, as well as going through the mutual learning process together, also sets the stage for building relationships.

Transparency is crucial to building trust and fostering collaboration around a contentious issue. The Participation Team tried to plan meetings that were located in the local study areas as well as in the regional center where many agency and other participants worked. Meetings always had a UC Cooperative Extension facilitator and we eventually developed trainings aimed at teaching participants how to engage in collaborations. The project was designed to share information, both scientific and administrative, as quickly as possible via email, phone calls or the SNAMP website, and also through in person meetings when time was less pressing. An extensive repository of documents was maintained on the project website including all meeting notes and questions and answers from scientists.

Learning together is a crucial part of collaboration and was a main focus of the SNAMP effort. The Participation Team tried to increase awareness of the variety of viewpoints active in the project and worked to help all participants feel "heard." The individual resource focused meetings and the annual meetings were intended to facilitate shared learning among the participants: meetings presented SNAMP findings and collected participant input. A data sharing server was created to promote information transfer. Ultimately it was hoped that shared understandings would develop regarding the results of the project forming a group of stakeholders with common collaboration skills and ecological knowledge who could continue to work together in the future.

Measures of effectiveness were: 1) participant response to the outreach and communication structure of the project, and 2) the project's ability to complete the basic project milestones and goals as described in the workplan and as compared to the collaborative and adaptive management literature. The Participation Team embodied SNAMP's communication people and processes and conducted all SNAMP sponsored events. The UC Science Team needed to effectively produce results and complete its assigned tasks in a way that was viewed as unbiased. Simply getting the treatments implemented and allowing the science to move forward with post project data collection was not always assured. Continuing the project until results could be determined was also not something all participants believed was likely. More audacious hopes for SNAMP were to reduce conflict and to create a group of stakeholders with shared understandings of the science of forest management. With this final report, the UC Science Team portion is complete. It was then left to the Forest Service to continue with the lessons learned and apply the Science Team's recommendations, and so to close the adaptive management loop where findings will be incorporated into future management.

SNAMP participation goals and methods

A first focus of SNAMP outreach was to promote and facilitate involvement by managers and the public in forest science development and use. In order to develop an active participatory project, substantial resource and time commitments had to be made at the very beginning of the project. Collaboration requires input of "labor" – time (of all stakeholders), money, and expertise – and should not be taken lightly. SNAMP was innovative in that the commitment to collaboration was made at the beginning of the project and continued for the project's duration.

The first and primary commitment was that SNAMP partners had to agree to a participatory approach. Project scientists made a commitment to work with the public, including allocating the time to develop at least one in-depth public science meeting or field trip per year. Forest Service managers made the commitment to host field trips, attend meetings, and integrate UC Science Team experimental activities into their management projects. Stakeholders from local communities and interest groups invested their time into on-going involvement (through meetings, field trips and workshops) with a long-term project.

Funding was planned to initiate and maintain a locally based outreach program through the whole project. At the beginning of the project this amounted to the equivalent of two full time staff. Funding consistently declined through the project years affecting the outreach effort. Staff that began as full-time saw their positions reduced to half time, leaving the equivalent of just one full time staff allocated to outreach by the end of the project.

Other studies have demonstrated the multiple benefits of having the local community involved in collaboration so outreach personnel were "embedded" in the local community (Conley and Moote 2003). To reach the participation team goals of transparency, inclusiveness, accessibility, and learning, staff were needed in the local study site as well as regionally. Outreach staff were hired in 2007 and 2008 by Cooperative Extension in each of the two study area communities, Oakhurst and Foresthill, California, as well as a central coordinator for outreach. Together with the rest of the Science Team, they organized, hosted or developed over 287 participation and outreach events during the life of the project, from 2005 to 2014. There were more than 8,455 attendees at these events, with duplications. Attendance numbers reported here sum up the total number attending each event, and so count many people more than once. They do not represent the number of individual people involved.

Public participation in SNAMP was fostered through both in-person and at-a-distance methods. With staff time and participant commitments as inputs, activities were developed to reach our core collaborative goals (inclusiveness, transparency, relationship building, and learning) as well as less quantifiable long term goals and indicators of effectiveness such as reduced conflict and increased equity. In general, in-person participation methods were focused on increasing learning and building relationships while distance methods were used to create awareness of the project, convey information and keep people updated. Both were used to increase inclusion and transparency within the project.

Overview of SNAMP in-person participation methods

In-person events and face-to-face interactions within a local community as well as with communities of interest were at the foundation of SNAMP participation. Our participation events were successful at drawing a broad and inclusive set of managers and stakeholders. Organizations with staff attending SNAMP meetings included a wide variety of federal, state, and local government agencies as well as local water and fire safe councils, districts and conservation organizations. Participants also represented local, regional and national conservation and industry organizations (Appendix F2, Figure F3).

SNAMP participation events were a significant investment in time and effort for all. Some agency and stakeholder participants came and went over the duration of the ten year project due to normal staff turnover. One study site had three different District Rangers during the project period. However, a number of participants were able to maintain involvement throughout the project. The UC Science Team showed very little turnover.

SNAMP's most dedicated non-Science Team participants were an environmental NGO participant and a Forest Service representative. We estimate that they each put in a minimum 170 and 150 hours respectively in meetings (again not including travel or preparation time). Of the ten most frequent non-UC Science Team attendees there were three environmental NGO participants, three Forest Service representatives, one forest industry group representative, one local water district representative and two unaffiliated public citizens. To us this shows that SNAMP was successful at attracting and obtaining serious commitment from a few people from the key stakeholder categories. This also exemplifies the challenge to obtaining more actively engaged participants because time requirements limit who is able to participate at that level.

The time invested in attending these events by all attendees combined was almost 8,300 hours by the end of the project (Table F1). This does not include the time of the UC Science and the Participation Team who facilitated all the events.

Table F1: Hours spent at SNAMP organized participation events. Hours spent is a calculation of the number of hours the event lasted multiplied by the number of people present at each event. Preparation and travel time was not known and so not calculated.

Event Type (2005 to 2014)	**Total Events**	**Total attendance**	**Hours spent by non-Science Team participants**
UCST Public / Quarterly / Annual meetings	14	745	1,874
Integration Team (science) meetings	23	811	3,077
Field Trips / Scientist talks	29	920	1,938
Workshops	29	472	1,407
TOTAL	**95**	**2,678**	**8,296**

In-person participation events included public/annual meetings, integration team (science) meetings, field trips and workshops. Each type of event was designed with somewhat different goals, formats and content. To investigate progress toward the goals of relationship building, learning, and transparency, participants completed evaluation forms at most of our meetings. Each type of participation event and how participants rated it is described below.

Public/annual meetings

At the beginning of the project (2005-2007), large public meetings were held quarterly to design the workplan and develop the experimental efforts. These were reduced to one annual meeting after public feedback indicated preference for more intensive modes of interaction. In 2008, the first of seven annual project wide annual meetings was held. These typically involved about 70 scientists, managers, regulators and stakeholders. The goal of these meetings was to update all participants on the status of the project. Typically the agenda included short science updates from each of the six science teams, updates from the Forest Service on the implementation of the treatments, time for discussion about next steps, and time for small group interactions with each science team so that participants could ask their specific questions of the scientists. All meetings were facilitated by the Participation Team. Fourteen of these meetings were held between 2005 and 2014 with a cumulative (not individual) attendance of 745. All participants (excluding science team members) logged over 1,800 total hours in these types of meetings (Table F1).

Participants completed at least 238 written evaluation questionnaires at the six annual meetings between 2008 and 2013. Evaluation forms asked for input and also quantitative ratings of the event, with participants agreeing with or disagreeing with statements about it (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree). Scores reported for responses are averages.

Annual meeting participants strongly agreed that the Science Team had clearly articulated study findings and issues (4.7), that collaborative discussion was encouraged (4.6), and that there was encouragement of public participation (4.6). The latter two findings were particularly rewarding to us given that these types of meetings were more difficult to facilitate due to the large venues and popularity. Participants' lowest ratings were for having adequate time for questions and answers (4.1) and for clearly articulating next steps (3.8).

Since they summarized the state of a very large and complex project, these meetings necessarily covered a lot of information in a small amount of time. Initial meetings included extensive technical information from each team. A variety of meeting formats and strategies were explored to allow for increased dialog. The solution was to reduce the amount of science content of these meetings so that each science team had only eight to ten minutes to summarize their findings for the year. This allowed for more time to ask questions using a small group breakout format so participants could converse with the scientists. Even though the settings were large, we wanted to promote relationship building so we also emphasized networking during breaks and lunches.

Annual meetings were designed to allow a less frequent participant to catch up on the project's accomplishments and challenges over the year in one meeting. Some stakeholders, especially those affiliated with Sacramento based agencies or organizations, attended only these SNAMP meetings. In order to have time for in-depth conversations about each of the scientific topics being pursued with those that were interested, we developed an additional format for participation, the integration meeting.

Lesson learned: Design participation events for participants with varying levels of interest and time, including those who only want an occasional briefing on the status of the project. Hold these events in the regional capital to draw agency and regional stakeholder representatives.

Integration meetings

To focus more on the specific information being developed by each science team, the Participation Team instituted science "integration meetings" in the third year of the project. Each of the six teams typically held one of these meetings each year attended by agency, Science Team, and interested public participants. The goal was to collaboratively address the interpretation of results and the potential applications of what had been learned to forest management. We hoped this would foster shared understandings about the project from start to finish, so that participants would have some common knowledge base at the end of the project on which to base individual conclusions and recommendations. The agenda typically involved an overview of the study plan, an in-depth presentation of data and findings at that stage of the project, and time for input into design, analysis, and the interpretation of results.

Meetings were a form of shared science learning. The long term goal was to enable participants to be able to evaluate impacts on forest resources from Forest Service fuels reduction treatments and to develop a knowledge base to facilitate participation in future natural resource management. Depending on the topic, attendance ranged from 10 to 100 persons.

Each integration meeting provided time for discussion and interaction between the Science Team and other participants so that learning could be mutual. In other words, learning by the Science Team from stakeholder and agency insights, knowledge, preferences, and constraints was also desired. The intention was to encourage detailed two-way conversations with the Science Team, to develop a committed core membership and allow for development of long-term, constructive, ways of working together.

The mission statement for this process was:

> "...to engage the public, the University of California, and natural resource agencies in a process of mutual learning as we proceed through the adaptive management cycle. Part of the work is to learn about UC research and data, as well as Forest Service treatments, so that the Integration Team can evaluate and understand the tradeoffs as research information is integrated within the adaptive management project and into Forest Service management. Ultimately, the goal is to address the part of the adaptive management cycle where scientific information and public input is integrated into future management decisions."

Stakeholders most interested in the resource being studied attended integration meetings. For example, Water Team meetings drew stakeholders that represented water purveyors, irrigation districts, agency hydrologists and conservation groups most interested in aquatic habitat. Many of these participants did not attend other integration team meetings with other science teams because understanding the science behind managing for forest health or the California spotted owl were not necessarily part of their job description or interest. Relationships between scientists and professionals in their disciplines within the agencies and stakeholder groups were fostered.

In the last year of the project, half of the integration meetings were held as webinars rather than in-person meetings. The final integration meetings were planned to occur in a short amount of time which would have burdened many stakeholders with extensive travel. In addition, we felt that SNAMP relationships were strong enough to overcome the detractions of webinars (disjointed discussion, reduced ability for feedback and engagement, lack of face-to-face interactions) after so many hours together in an assortment of settings.

A total of 23 integration meetings were held between 2005 and 2014 with a cumulative attendance of 811. Participants (excluding Science Team members) spent almost 3,100 total hours in these meetings. Participants completed at least 351 evaluations of the 17 meetings held between 2008 and 2014, showing agreement or disagreement with statements about the meeting (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree). They strongly agreed that collaborative discussion was encouraged (4.6), the events were well organized (4.5) and that they learned something new (4.6). Participants agreed there was encouragement of public participation (4.5) and their comments were heard by UC scientists (4.4). Participants still agreed though less strongly that there was adequate time for questions and answers (4.1) and that the meetings met their goals (4.1). Evaluation results for the webinars were consistently positive and not substantially different from ratings of the in-person meetings.

These meetings required a significant amount of investment by the Science Team as well as agencies and stakeholders in that they amounted to a 'yearly review' of their project. Principal investigators and staff spent significant amounts of time preparing for and presenting at these meetings. The benefit for the Science Team was the ability to get input and prioritization on study topics from stakeholders and to better understand the context in which the science would be used, with the goal of creating a more useful product.

Lesson Learned: Participants possess a wide variety of expertise in science methods and topics. It's important to design participation events for those from diverse backgrounds and to facilitate involvement of those who want to be immersed in the details of the science.

Field trips

Field trips were popular events with project participants including a wide variety of stakeholders, community members, and students. Each Science Team held at least one day-long field trip, while most teams held three or four over the course of the project. Pre and post treatment implementation field trips were held at each study site as well. At the northern site, additional field trips were held to view treatment in action and then later to see the results of a wildfire that burned through the treated area. Several Science Teams also made short presentations about their work to local community groups most interested in the topic such as local conservation and school groups. These types of talks were substituted for field trips by the Fisher Team due to concerns about confidentiality and location of individuals of this rare species. A total of 29 field trips or Science Team talks were held over the life of the project with over 920 (duplicated) in attendance. Participants (excluding Science Team members) spent at least 1,938 total hours in these events.

Field trips typically started at the local Forest Service office with a short safety briefing, a description of SNAMP and the agenda for the day. Participants then carpooled out to the treatment area in mixed groups. The distance to the northern study site from the Forest Service office was 45 minutes, while at the southern site it was only about 15 minutes. Scientists and Forest Service staff usually made presentations at 3 to 4 different stops on the field trip to give a broad overview of forest conditions, treatment and findings. Several field trips were attended by three UC Science subject teams so the broad effects of the treatments could be discussed. Several field trips were held at affiliated sites including the Forest Service's Kings River Experimental Watershed with the Water Team and UC Berkeley's Blodgett Research Forest with the Owl Team.

The Science teams gave demonstrations of their data collection techniques. These involved hands-on demonstrations of the equipment used and viewing of experimental plots and stations in the field. Participants were able to core trees, examine fire scars, measure vegetation on transects, hold fisher tracking sensors, watch spotted owls respond to calls and take the offered bait of live mice, see a carbon dioxide flux tower and wireless sensor network, and examine stream monitoring equipment. On the treatment oriented field trips they were able to look at the results of prescribed burning, see a cable yarder, feller bunchers, skidders, log loaders and trucks in action, and examine treatment units before and after thinning and before and after wildfire.

Field trips were a substantial time commitment on the part of the Science Team and the Forest Service. All these field trips were on national forest land and so collaboration with Forest Service staff was critical to holding the field trips. The District Ranger and other staff attended nearly all field trips. Implementation field trips were hosted primarily by the Forest Service themselves. Most field trips were 6 to 7 hours long.

Field trip goals were to increase inclusiveness and provide for relationship building and mutual learning. Seeing the forest, treatments and resources of concern made for a very productive mutual learning environment in which scientists could learn about management challenges while managers could learn about the most current science methods and results. Being together in the field and carpooling with new people was also extremely conducive to relationship building.

Participant (including the Science Team) evaluation of 12 of the 13 field trips held between 2009 and 2014 showed the trips were good for learning and for opportunities to give input. Participants filled out 262 evaluation surveys which showed that field trips allowed adequate time for questions and answers (4.9), encouraged public participation (4.8), were well organized (4.7) and encouraged collaborative discussion (4.7). Participants also agreed that goals of the meetings were met (4.6) and they learned something new at the event (4.6). As at other events, the lowest rated aspect of the field trip was that there was a clear plan of action for the future, though participants still agreed (4.0).

Lesson Learned: Field trips are excellent venues for learning about how science is done and how the forest is managed including constraints on management and science institutions. Field discussions allow scientists and managers to better understand each other's points of view. They also allow participants to visualize and discuss conceptual terms such as "resiliency" and "forest health" in tangible ways that cannot readily be done in other meetings – they are ideal settings for shared understandings to develop. Field trips draw the broadest audience of participants including unaffiliated citizens such as local community members, teachers and students. They are a critical part of a third party monitoring effort.

Subject matter workshops

These events featured the Science Teams' management advice about their resource of concern, often at the request of forest managers. Some workshops were not open to the public, while some were advertised broadly and brought in new participants who had not been involved in SNAMP. Typically these workshops provided a synthesis of information on the team's topic, beyond the information being produced for SNAMP. Science Team members compiled and drew on their experiences and practice in their field of expertise to summarize the state of knowledge on the topic and recommend management actions (which was explicitly not part of the Science Team's role in SNAMP). The California Spotted Owl Team was asked to give two full day workshops on management of owl habitat by the Forest Service (which was not open to the public as other SNAMP events were). The Spatial Team organized four workshops on use of lidar in forest management that involved some regular SNAMP participants but also diverse participants from many agencies and organizations who wanted to learn the latest science on this evolving technology. These lidar workshops included hands-on sessions where participants could manipulate lidar data and explore applications. The Participation Team held a workshop with the Forest Service that presented feedback on their NEPA processes in a private setting. In addition, the Participation Team initiated a series of public workshops on their own initiative (not in response to managers' requests) on how to facilitate collaboration in forest management which involved developing facilitation and meeting planning skills as well as role playing conflict resolution. A total of 17 collaboration workshops were held.

Participation Team goals were to increase mutual learning, build positive relationships, and increase effectiveness of the project. These workshops were excellent venues for scientists to learn about the everyday context that managers face and how their studies could address these problems. A total of 29 subject matter workshops were held between 2005 and 2014. Cumulative attendance was 472 people. Participants (excluding Science Team members) spent over 1,400 hours in workshops.

Participants at the four Spatial Team workshops on Lidar in 2009 and 2012 filled out 65 evaluations and strongly agreed (5- strongly agree, 4-agree, 3-neutral, 2-disagree, 1-strongly disagree) that workshops were a great place to have comments heard by UC scientists (4.9), learn something new (4.9), and hear a clear articulation of study issues (4.9) and participate in the project (4.9). Participants filled out 178 evaluation forms for the Participation Team's 17 collaboration workshops and rated them as excellent (64%) or very good (35%). They said their expectations for the workshop were met (53%) or exceeded (46%) and agreed strongly that workshops were timely and relevant (4.4), provided practical and useful knowledge and skills that are applicable to their jobs (4.5), and provided new information, ideas, methods and techniques (4.5). They agreed even more strongly that they were satisfied with the instructors (4.9) who were knowledgeable about the subject (4.9), and generated active discussion and involvement (4.8). Evaluation of the collaboration workshops is done in a separate section below.

Lesson Learned: Subject matter workshops that covered the latest science on a topic and allowed for hands-on practice and or role playing with new concepts allowed for an excellent learning environment. Topic focused workshops that went beyond the confines of SNAMP data and methods and focused on participants' own management contexts were highly appreciated by participants.

Special projects

Six different special SNAMP-related outreach projects were done to include people in SNAMP science. These projects focused on developing ways for participants to be included in investigation of SNAMP topics without directly participating in the SNAMP experiments. One project was to site wildlife cameras around the fisher study site to help the team identify occupancy of fishers on surrounding private lands where willing landowners wanted to be involved. Several other projects were carried out with students around the Oakhurst area to help them participate in appropriate levels of related study including conducting acorn counts (an important food to rodents, the prey base for fisher) and macro-invertebrate sampling in nearby streams (an example of an alternative way to monitor water quality). Over 160 people (duplicated) participated in these special projects. The format was not conducive to evaluation forms so evaluative data was not collected.

Reaching out from SNAMP (in-person)

Although SNAMP developed a core of committed and involved stakeholders, the Participation Team felt they also needed a strategy to involve people who were not attending in-person SNAMP events. Outreach goals were focused on increasing transparency, accessibility, and inclusiveness by keeping community members and interested groups up to date on study progress. Outreach to groups about SNAMP was also intended to encourage attendance at SNAMP meetings and events. This greatly broadened the amount and diversity of participants knowledgeable about the project and helped keep the local community in the loop. We conducted two main types of outreach: presentations at other groups' regularly scheduled meetings and attendance at other events to promote SNAMP through casual conversations, presentations and posters.

Outreach presentations

Local outreach staff made presentations about SNAMP to local groups at their meetings to keep members of the public informed that were less likely to participate in more technical science meetings or field trips. These presentations were typically a 20 to 30 minute overview about the project at the group's own regularly scheduled meeting. Presentations to groups with more of a special interest (such as the California Native Plant Society) focused on the aspect of the study most relevant to them. Presentations were made to members of:

- local civic clubs such as Rotary, Lions, and Elks;
- local conservation groups such as Audubon, Sierra Club and local conservancies;
- local governments such as county supervisors, resource conservation districts and chambers of commerce;
- local interest groups such as fire safe councils, Society of American Forester chapters, and watershed councils; and
- local schools, colleges, and universities.

Participation Team staff made a total of 167 of these presentations during the project period leading to over 4,100 contacts in total. For a list of all organizations reached through outreach presentations, see Appendix F2.

Representing SNAMP at other events

Participation Team members gave talks, brought SNAMP posters and displays to a total of 19 events held by others including conferences, professional society meetings and local Earth Day celebrations making over 1,200 contacts. This was a good way to keep the project visible and make new contacts from groups and stakeholders that were not already participating in SNAMP. This type of outreach led to personal contacts that then led to invitations to outreach staff to make SNAMP presentations to new groups not previously contacted. Therefore this outreach method primarily helped us meet inclusiveness goals.

Summary of SNAMP in-person outreach program

Inclusiveness

To achieve inclusiveness, we worked toward broad and diverse participation in terms of affiliations, locations and focal interests, as well as location and accessibility. SNAMP outreach staff hosted or attended a total of 287 participation events using the different in-person participation methods from the start of the project until December 2014. The types and frequency of outreach events and attendance increased greatly once outreach staff were hired in 2007 (Figure F6). This type of outreach is time consuming and could not have been accomplished without the commitment to staffing and outreach made at the outset of the project. It is also a product of the incorporation of place-based relationships developed by UC Cooperative Extension staff who lived and worked in the local communities and then used their connections and relationships to bridge to the Science Team who were generally located on campuses at least three to four hours away.

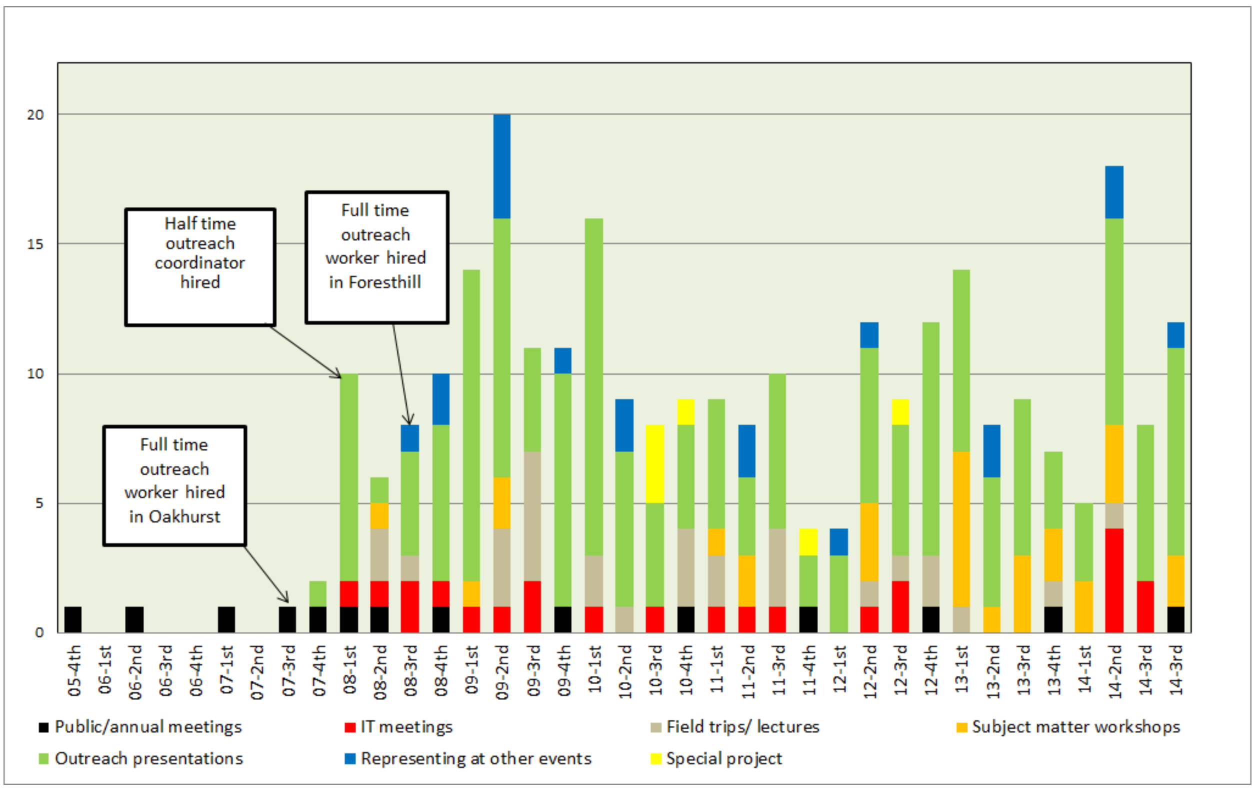


Figure F6: Number of public involvement events organized by SNAMP (public/annual meetings, field trips/lectures, subject matter workshops, integration meetings and special projects) and organized by others but attended by outreach staff (outreach presentations and representing SNAMP at other events) per quarter between 2005 and 2014 (287 total).

Almost two-thirds of the public involvement events were as a result of members of the Participation Team presenting SNAMP to people at meetings held by others, including outreach presentations (58%) and representing SNAMP at other events (7%) (Figures F7 and F8). More than half the total contacts made by the Participation and Science Teams were also made at these events [outreach presentations (49%) and representing SNAMP at other events (15%)].

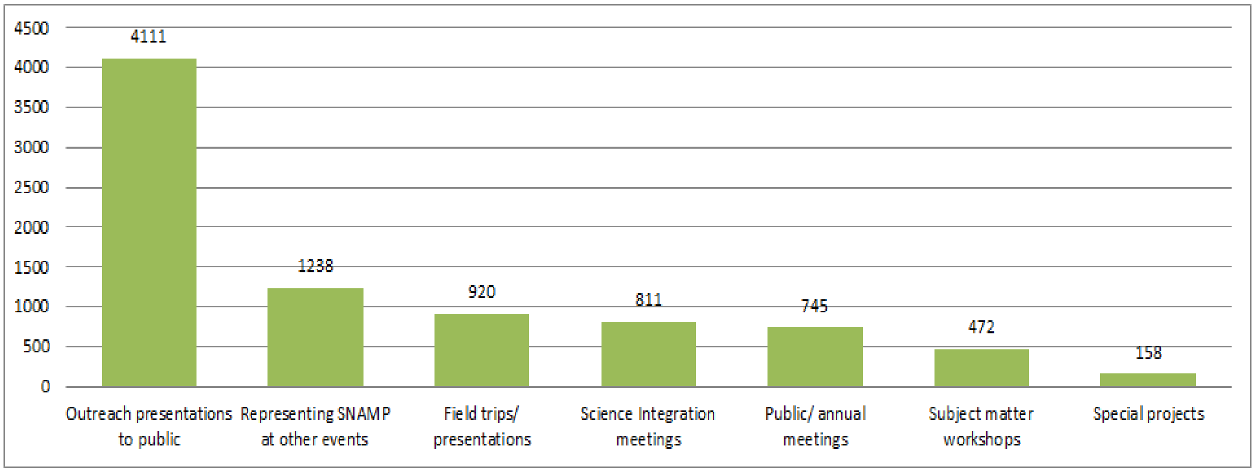


Figure F7: Total contacts made at all in-person SNAMP participation events. Contacts are the total attendance at events, including participants that attended multiple events and so not the total number of people involved. 8,455 contacts were made at 287 events.

These figures highlight the importance SNAMP put on inclusiveness by showing the commitment and effort expended to bring out information about SNAMP to interested groups and people rather than relying on those people coming to us to find out about the project.

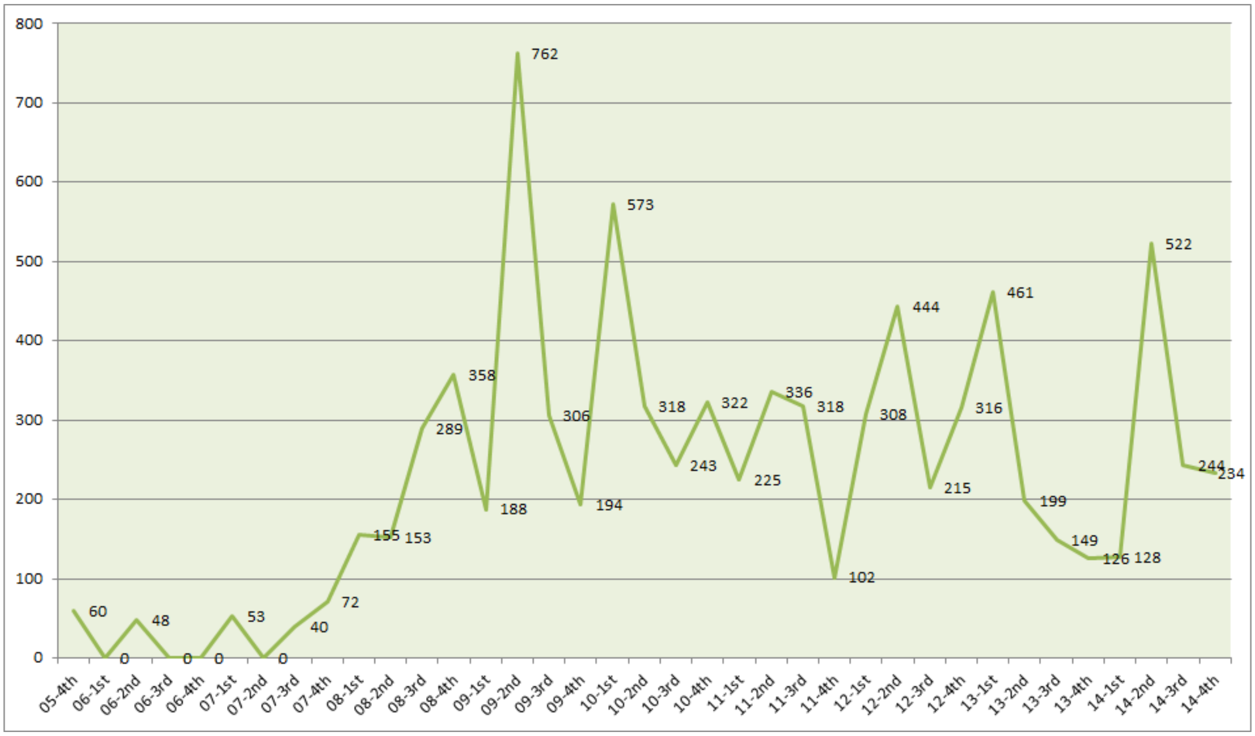


Figure F8: Personal contacts per month by SNAMP Participation Team from 2005 to 2014 by quarter (8,455 contacts).

Lesson Learned: To achieve inclusiveness it is important to keep local communities and communities of interest updated on the project by reaching out to them, rather than expecting them to come to you.

In-person events were spread over a wide area of the Sierra Nevada and Central Valley (Figure F9). Events were concentrated around the two study sites in Foresthill and Oakhurst (where outreach staff were stationed) and the state capitol area of Sacramento where many land management and regulatory agencies as well as regional and national conservation and advocacy groups are headquartered.

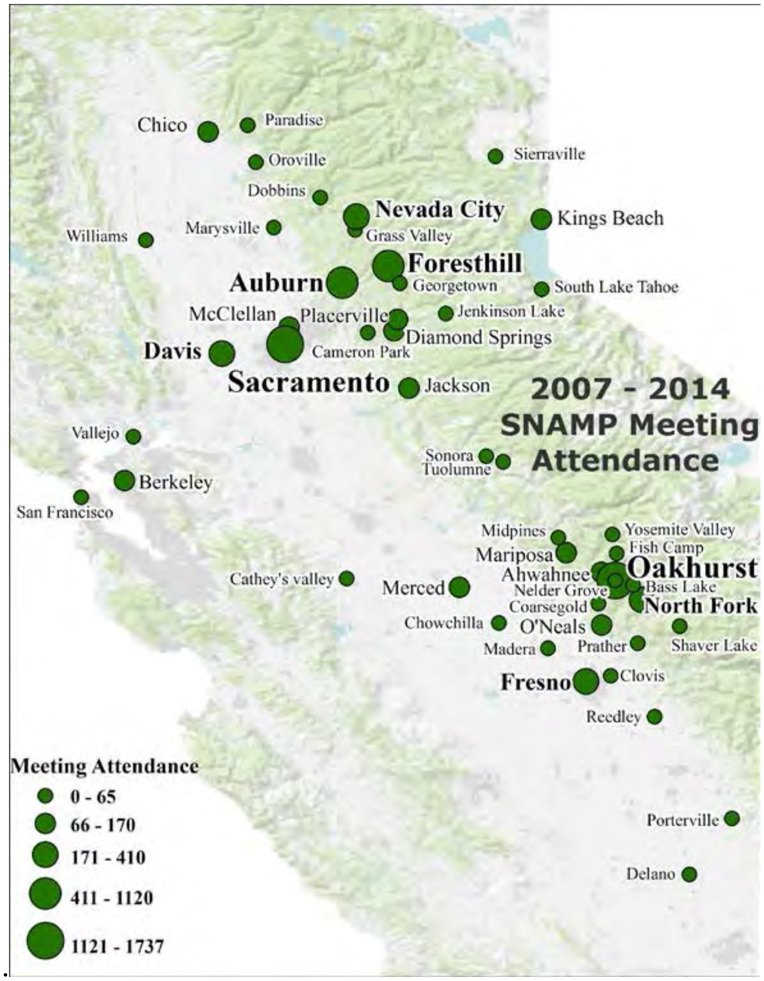


Figure F9: Attendance at SNAMP events by meeting location from 2007-2014. Map created by Kelly Easterday.

Overall SNAMP's outreach program attracted a broad and diverse set of participants, some of whom only wanted to be kept informed about the project, while also maintaining a core of dedicated participants who wanted to be involved in the details throughout the life of the project. The geographic dispersal of outreach staff embedded in the local communities was key to implementing this strategy. The evolution of different outreach methods tailored to different stakeholders was also crucial. However, we were less successful at reaching some specific targeted audiences we had specifically sought out, such as recreation groups and Native Americans. There were also several environmental groups that choose not to participate despite repeated invitations though participation by many other conservation groups was substantial.

We hoped that the broad and inclusive participation in SNAMP would provide a foundation for collaboration in developing the adaptive management strategies to be put in place by the Forest Service as a result of the recommendations made by the UC Science Team in this report. However, whether or not this inclusive process has led to reduced conflict in national forest management is not known at the time of this writing.

Transparency and information exchange

Topics covered at SNAMP meetings varied over time according to the focus of the meeting and the progression of the project. In addition to science content, annual and integration meetings covered contentious and critical issues to the welfare of the project including funding curtailment and occasional lapses in agreed-upon project protocol such as the neutrality agreement.

We used an additional method to inquire about the ways in which our public meetings succeeded in advancing dialogues and transparency for the project. We analyzed the meeting notes from the public meetings using self-organizing maps (SOM), which is a machine-learning textual analysis tool (Lei and Kelly 2015).

The self-organizing maps project textual data (in our case, this was all the questions and answers from public meetings through 2012) onto a two-dimensional space based on word frequencies and connections between words. The resulting textual map can be visualized in a variety of ways, such as word clustering, mapping through time, and histogram/frequencies (Figure F10).

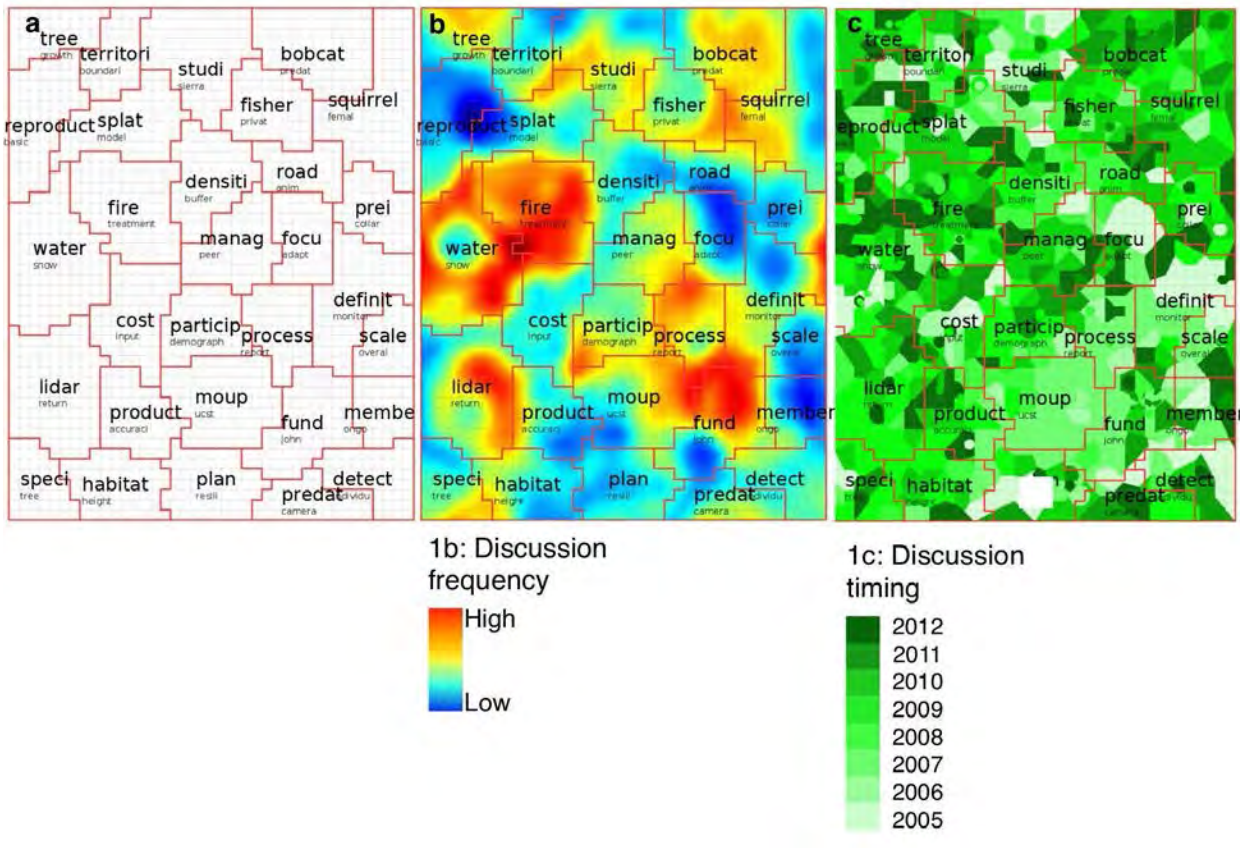


Figure F10: These three self-organizing maps visualize SNAMP public meeting discussions based on extensive annual meeting notes recorded and archived by the Participation Team. Sections are labeled by the 2 most prominent words in the discussions that occurred. The maps are as follows:

a) The basic, mapped clustering of discussion topics;

b) A smoothed data histogram map showing the frequency of the most consistently discussed topics. High discussion frequency topics are those items that were discussed often: the MOUP, funding, and process make one red cluster; and Lidar and fire make two other clusters that were discussed frequently; and

c) A thematic class map showing timing of topic discussion. The year is the year that those discussion points were emphasized through the discussion in a meeting. The color of each cell indicates when the subject was discussed. For example, MOUP was largely discussed earlier in the process, whereas fire was discussed throughout the process. The topics are determined by the discussion that occurred.

As you can see in Figure F10-1b, funding, the process and the role of the MOU Partners were high frequency topics of discussion at SNAMP event, as were lidar, fire, and water. Figure F10-1c shows that the emphasis of topics changed over time, though a number of high frequency topics such as funding, lidar, fire and management were consistently discussed over time.

By interpreting the various visualizations, we found that public discussion remained focused on the project content, yet the more contentious and critical issues dominated the discussions through time. Self-organizing maps were an effective and efficient unsupervised machine-learning tool for organizing, distilling and tracking content of meeting notes through time, and can be explored more often for this kind of analysis.

Lesson learned: Regular project meetings are important in order to facilitate discussion of critical project issues and increase transparency.

Lesson learned: The self-organizing map method helped us to see what topics were discussed more frequently, and when they were discussed over the course of the project.

Relationship building

We examined 7 years of attendance data at all public meetings associated with SNAMP and constructed an “affiliation social network” which is a diagram showing collections of individuals and how they are affiliated with collections of events. This network allowed us to ask questions about SNAMP project cohesiveness, relationships among participants, and patterns of participation. The affiliation network reveals patterns of geographic preference among meetings, the importance of particular individuals and particular public meetings, and the dynamics of social network (Figure F11).

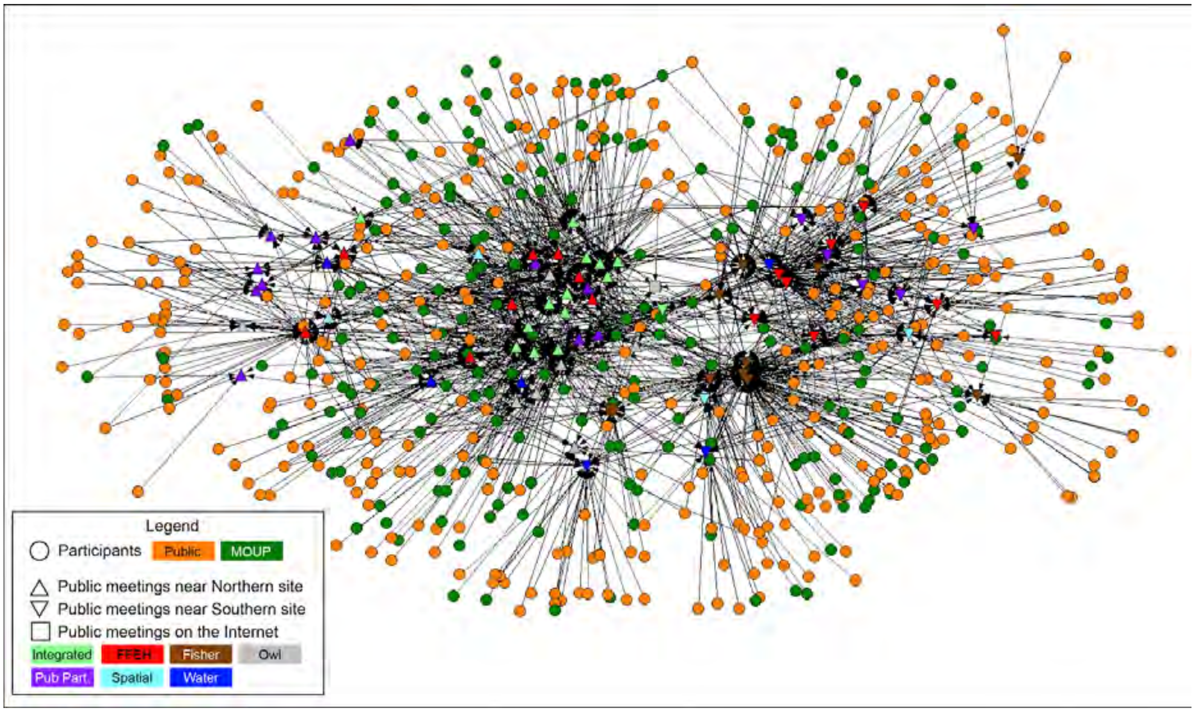


Figure F11: Affiliation network based on public meeting attendance data: participants are symbolized as orange (public) or green circles (MOU partners); meetings are symbolized as squares (webinars), or triangles of various colors (see legend) for in-person meetings. Science Team members were excluded from this analysis.

The social network analysis diagram shows clear clustering around the northern and southern meetings locations. Meetings focusing on fire and forest ecosystem health (red triangles), fisher science (brown triangles) and integration meetings (green triangles) were key elements of the SNAMP social network, bringing participants together. Meetings of the Participation Team reached the most stakeholders. There are several key stakeholders, both from the public and the MOU Partners that provide cohesion to the network. These are people who are connected well in the network by virtue of their consistent attendance at all types of meetings.

Lesson learned: Affiliation network analysis is a useful tool to characterize the social dynamics of the SNAMP network.

Comprehensive evaluation of SNAMP in-person outreach methods

There is ample evidence that SNAMP participation events allowed for learning and transparency about the project. Overall, participants rated in-person SNAMP sponsored participation events highly for the opportunity they provided for learning and interaction. Here we present the comparative evaluation results from the events described above (Table F2). Data are, again, from the evaluation forms filled out at the end of each event which involved agreeing or disagreeing with a series of statements about the event: 5- strongly agree, 4-agree, 3-neutral, 2-disagree, 1-strongly disagree. Overall, workshops and field trips were rated the most highly. Participants strongly agreed that these encouraged public participation, collaborative discussion, and left plenty of time for questions and answers. Therefore they were excellent venues for mutual learning.

Table F2: Summary of evaluation ratings for all SNAMP in-person participant events (Strongest agreement = 5, on a scale of 1 to 5).

Event type **Number of evaluations analyzed**	**Workshop s** **(243)**	**Field trips** **(262)**	**Annual meeting** **(238)**	**Integ-ration (351)**	**All events** **(1094)**
There was encouragement and acceptance of public participation	4.9	4.7	4.6	4.5	4.6
I learned something new at this event	4.9	4.6	4.5	4.6	4.6
There was clear articulation by presenters of study findings.	4.9	4.6	4.7	4	4.6
Collaborative discussion was encouraged/ I felt my comments were heard.	4.8	4.7	4.6	4.6	4.6
I felt my comments were heard by the UC scientists.	4.9	4.5	4.4	4.4	4.5
I felt my comments were heard by USFS attendees.	4.2	4.5	4.3	4.3	4.4
The goals and objectives of the meeting were met.	--	4.6	4.5	4.1	4.3
There was adequate time for questions and answers.	--	4.9	4.1	4.1	4.2
There is a clear plan of action for the future.	4.2	4.0	3.8	3.8	3.9
This workshop provided practical and useful knowledge immediately applicable to my job.	4.5	--	--	--	4.5
This workshop provided me new information, ideas, methods and techniques.	4.5	--	--	--	4.5
This workshop was timely and relevant-it dealt with issues with which I am currently dealing.	4.4	--	--	--	4.4

Least highly ranked at all the events was the statement that there was a clear plan of action for the future of the project or individual team. In general, most participation events summarized what had transpired so far in the project and asked for input about next steps. This is no doubt why this item did not show strong agreement from participants, as many events were actively seeking ideas from stakeholders about how to move forward. As a response to these ratings, the Participation Team made an effort to summarize next steps at the end of every event although some next steps were not well known or fleshed out at the end of the event.

Each of the participation event types described above had its specific focus, targeted audience, and strengths and weaknesses. These are summarized in Table F3.

Table F3: Comparison of different in-person participation methods used by SNAMP.

Event Type	Focus	Participants	Strengths	Weaknesses
Annual meeting	Overall status of project; Brief science summary; Done in regional center near agency headquarters	Management and agency leaders, committed and occasional participants	Conveyed a lot of information; Allowed participants to check in on the project annually	No time for in depth science information; Little time for relationship building
Integration meeting	In depth status report of science by each team	Committed participants, disciplinary professionals in agencies and organizations	Allowed for in depth learning about topic and input into experimental questions and design; Allowed for relationship building between scientists and disciplinary colleagues in agencies and organizations	Very technical, effort needed to include participants less current in topic
Field trips	Viewing treatment and scientific methods at study and affiliated sites	Committed participants, local community members, students	Allowed for in depth learning, relationship building and inclusiveness	Significant time commitment for forest managers and science teams
Subject matter workshops	Overall state of science on individual topics, beyond SNAMP work	Committed participants, local agency /organization staff, non-SNAMP participants	Excellent for mutual learning and relationship building; Some were very inclusive with many non-SNAMP participants some were private	SNAMP not the major focus so was additional work for the science teams
Special projects	Affiliated data collection with students, camera sitting on private lands	Students and teachers interested in SNAMP science, local landowners	Extended SNAMP science without time investment by Science Team; Produced some information for Science Team	Small numbers reached for extensive time expended
Outreach presentations	Short overall presentations to community and interest groups	Local civic, conservation, and interest groups, local government, students and teachers	Drastically increased inclusiveness and transparency about the project in local and professional communities	Built relationships with Participation Team, but not rest of Science Team
Representing SNAMP	Posters and displays about SNAMP at conferences and events	Non-participants, communities, professional and academic communities	Increased transparency, encouraged inclusiveness by making contacts for outreach presentations or other events	Most removed from targeted participants

It is important to note that these methods were designed to work together to increase project inclusiveness, transparency and information exchange, learning, and relationship building. In other words, the methods were additive with participants contacted through outreach presentations sometimes becoming committed participants and attending science meetings. Conversely, participants who typically attended only an annual meeting could drop in on an in-depth management workshop if they needed additional background and information on a topic.

Despite the multiple methods used for in-person participation, the time and resources of the Participation Team were necessarily limited to engaging local and regional participants who had more than a casual interest in their communities, national forest management and natural resource science. However, because public forest management takes place within a regional, state and national context, the Participation Team felt it was also important to convey the essence of SNAMP to a larger audience than could be reached through in-person events. To meet this need, we developed a number of distance outreach methods described below.

Distance outreach

The five factors that we have focused on that can contribute to the success of adaptive management – learning, transparency, inclusiveness, building relationships, and effectiveness - require open exchange of information about science and management among all participants. To facilitate this, the Participation Team developed a SNAMP website, science briefs for published journal articles, newsletters, web digests, and webinars. These methods specifically addressed three of our four goals by focusing on inclusiveness, transparency, and learning, with less emphasis on relationship building. This effort involved spreading information through both traditional and social media. Most of these efforts were created and maintained by the Participation Team and hosted by the SNAMP website.

Using these methods, we hoped to disseminate the highest quality science and make it accessible to all, increase awareness beyond the more traditional or accessible participant, transmit information to current participants, allow for some limited interaction and to develop a repository of SNAMP information.

Peer reviewed publications

Peer reviewed journal articles published in journals of good standing are those that have successfully passed review by other respected scientists working in a similar area. They are an important source of credibility for scientists, and help those seeking information to have confidence in the results. The Science Team remains committed to putting the results of SNAMP science through this review process. As of August 1, 2015, the Science Team has published a total of 39 journal articles on studies funded by SNAMP. These were posted on the website as allowed (some journals do not allow this to protect copyright).

We used citation analysis to track how fast and how far the SNAMP science publications were cited in other publications, including journal publications, dissertations, and resource management reports. We found that the average time it takes for a SNAMP publication to be cited in another peer-reviewed journal is about 7 months. And they have been cited all over the world, but they primarily travel within academia (Figure F12).

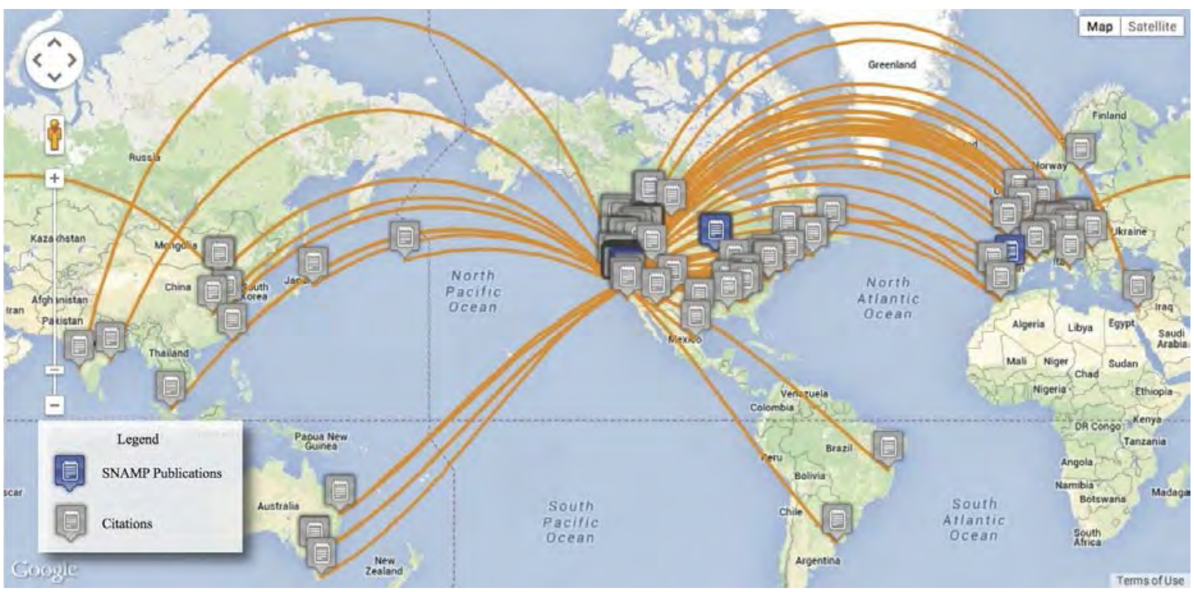


Figure F12: Map showing locations of citations of SNAMP science publications, as of December 2013.

Science briefs

Science briefs were developed to 'translate' all technical peer reviewed articles developed by the UC Science Team to a non-technical audience. These increased inclusiveness, learning and effectiveness by reaching a broader audience that might not have the expertise, time or access to read the journal articles produced by scientists for the project. Also, peer review articles are sometimes copyrighted by journals and so are not easily distributed to in-person or online audiences. Science briefs could instead be disseminated to any audience without concern for copyright infringement.

Usually briefs were developed by the Participation Team and reviewed by the author, or paper authors took the lead on developing the brief. These were posted on the SNAMP website. There were 1,518 pageviews of the science brief webpage as of December 31, 2014.

Newsletters

Newsletters were developed to introduce and explain the progress of the whole SNAMP project and newsletters specific to each Science Team were written to give overviews of the methods and findings. Newsletters were distributed as widely as possible. They were posted on the SNAMP website, handed out at project meetings, and distributed at outreach presentations to a variety of audiences. Ideally these were developed close in time to each team's annual integration meeting in order to capture the most interesting results. The goal was to increase inclusiveness and transparency about the status of the project and learning about the efforts of the individual science teams.

A total of 16 newsletters were developed through December 2014. The website listing the newsletters was viewed 3,464 times as of December 31, 2014, and the newsletters were also printed and handed out at meetings and outreach events. For a list of all newsletters, see Appendix F3.

SNAMP website

The SNAMP website (Figure F13) was built in 2007 using open source web technologies and database, which allowed us to utilize the latest, community- supported technologies and reduce development cost. The SNAMP website was a tool used by the Science Team to directly address our goals of inclusiveness, transparency, and learning. Use of the SNAMP website was strong - nearly 80% of our 2014 email survey respondents reported having accessed the site.

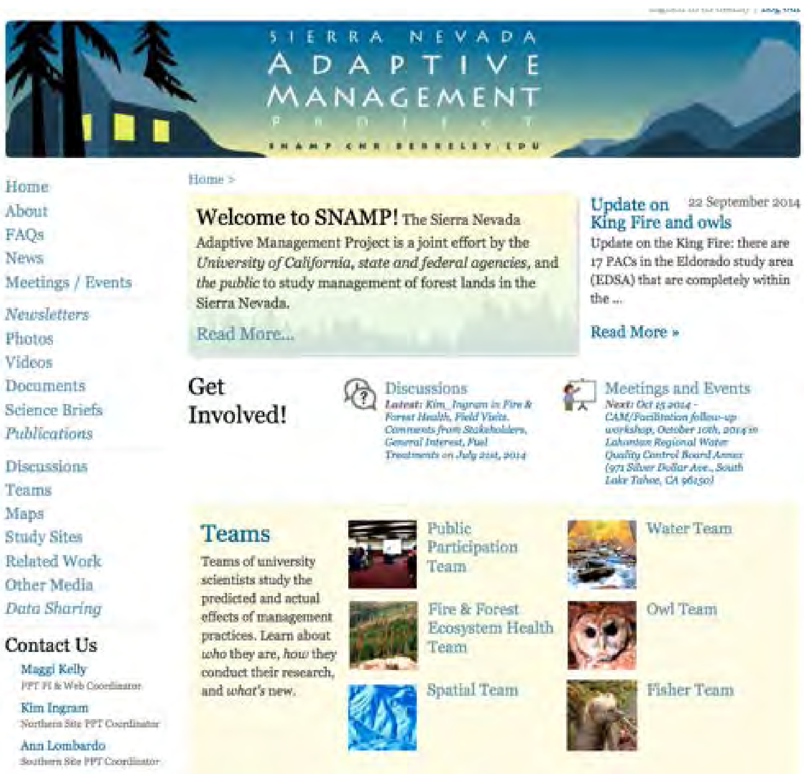


Figure F13: Screenshot of the SNAMP website home page from September 2014.

The aesthetic design of the SNAMP website was carefully considered with regard to appeal and ease of access to SNAMP information was paramount. The distinctive SNAMP logo and feel of the site were created to increase recognition of the project and were carried throughout all SNAMP products - all presentations, posters, newsletters, anything printed or web published. This continuity was important for recognition of the project as well as for projecting a professional image. The site had a news section where project status updates were posted. It hosted information generated by the Participation Team such as newsletters, science briefs, photos and videos along with a calendar of information and materials from all participation events (agendas, minutes, presentations). By the end of the project, the website had become a repository of all SNAMP generated documents, including foundational documents like the Neutrality Agreement, workplan, and project and team descriptions, as well as all papers published by the Science Teams.

Over the lifetime of the website, we had nearly 200,000 views, 83% of these were from within the US. Peaks in website activity tended to coincide with public events such as meetings (Figure F14). Our audience was concentrated in California, but we also had strong viewing from other parts of the US (Figure F15). The website was therefore key to increasing inclusiveness in the project to distant audiences.

Figure F14: Monthly summary of page views of the SNAMP website over the duration of the project, as of December 31, 2014.

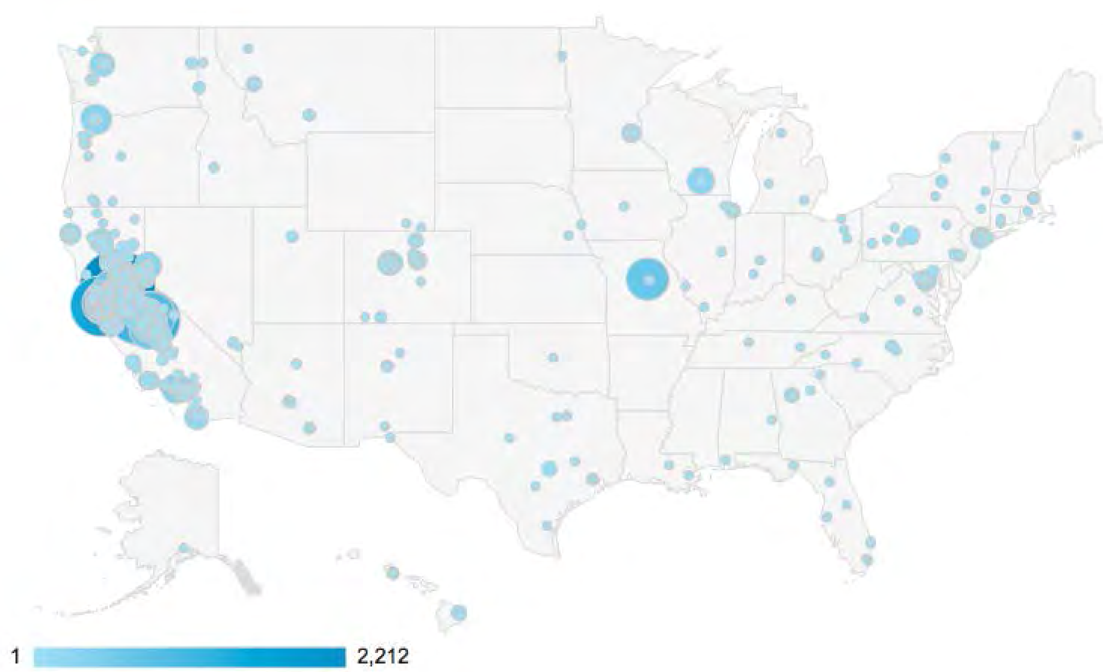


Figure F15: Spatial distribution of visitors to the SNAMP website for the duration of the project, as of December 31, 2014.

In email surveys in 2010 and 2014, more than 80% of respondents agreed that the SNAMP website helped them keep up with events, was a good place to get answers to questions about SNAMP, was easy to use, made SNAMP more transparent to the public, was the first place they looked for documents or information related to SNAMP, and offered online meetings by webinar that help them attend meetings they could not otherwise attend. It has often been pointed out that members of the general public have a harder time attending participatory management events than professionals or organization representatives paid to be there. It seems that the webinar approach may help more of the public participate. This shows that the website was effective at increasing project inclusiveness, learning, and transparency.

The recent proliferation of Internet communities and web-based participation tools raises the question of how the Internet might help facilitate information exchange in adaptive management. SNAMP provides a useful case study for the role of Internet technologies in facilitating the flow of transparent and useful information. The dataset used for this analysis was the content of the entire SNAMP website. Three evaluation methods were used: analysis of web usage and content, a survey of active participants, and a review of comments posted to the project website.

Results suggest that the web played an important role throughout the adaptive management cycle by supporting communication through disseminating information to the public and increasing the transparency of the scientific process. The Internet played a small, but important role in public consultation, by providing a forum for targeted questions and feedback from the public. We found however, that Internet technology did not actively support the two-way flow of information necessary for mutual learning. Internet technology complements face-to-face interactions and public meetings, rather than replacing them (Kelly et al. 2012).

Lesson Learned: Internet technology complements face-to-face interactions and public meetings, rather than replacing them.

In addition to the main SNAMP website (http://snamp.cnr.berkeley.edu), UC Cooperative Extension developed several websites to collect and maintain information that was not part of SNAMP for the Pacific fisher (http://ucanr.edu/sites/pacificfisher/) and California spotted owl (http://ucanr.edu/sites/spottedowl/). These sites contain collections of owl and Pacific fisher photos, news, scientific papers and information about Science Teams. These sites were developed separately from the SNAMP website to reduce any confusion that might arise regarding what was SNAMP information versus other science and news on these important species. The goal was to spread learning about these species to a wider audience than those involved in the project. The Pacific Fisher Information Repository and the California Spotted Owl Information Repository were visited by 3,651 and 1,183 unique visitors respectively between development in 2009 and the end of December 2014.

Email list

An email list with the email addresses of all participants and interested parties was maintained for routine communications. Over 825 people were on the email list by the end of 2014. A total of 184 email messages were sent between 2007 and December 2014. The list was used primarily to keep participants notified of upcoming events or important project news. In the second half of the project, we developed a web digest sent out quarterly that listed all new additions to the website such as papers, newsletters, photos, event notes, etc., with a link for the participant to visit the website and retrieve the information. After this innovation, we sent out many fewer emails.

Social media

The Participation Team maintained a Facebook page with 184 likes by the end of the project and contributed to 11 short videos about the project which have been viewed over 5,800 times (for a list of videos see Appendix F4). Almost 2/3rds of those views were on YouTube, which directed about 30% of the traffic to the videos. 740 photos were posted on Flickr, which were viewed 37,768 times as of November 20, 2014. These methods were used to increase inclusiveness and learning and the viewership of online videos increased dramatically during the lifetime of the project.

Blogs

The Participation Team also worked to broaden inclusiveness of the SNAMP audience by writing blogs and news articles on the project and information it was producing. This increased access, transparency, and learning about the specific blog topics. We wrote 19 blog stories on the project for the UCANR Green Blog http://ucanr.edu/blogs/Green by December 2014. Of these, seven were about the Pacific fisher, two were about Lidar, two were on the spotted owl, six on forest and wildfire mitigation, and one each was on public participation and water (for a list of all blogs see Appendix F5). Blog stories were also tweeted by UC public information staff (not affiliated with SNAMP). This outreach method was wildly successful. Hits on the SNAMP Green Blog stories totaled over 137,000 during the life of the project, including 46,000 direct and mobile hits. Almost half the hits were for fisher blogs and another quarter were views of the Lidar blogs.

The appeal of one particular blog entry about the Pacific fisher is particularly instructive (Kocher et al. 2012). The UC public information staff posted the blog *UC wildlife research team looking for single socks* on December 14, 2011 http://ucanr.org/sockdrive (as well as being tweeted and posted on the UCANR news page and Facebook page). The goal of the post was to increase inclusiveness in the project to more distant audiences. Another goal was to solicit donations of materials to help support fisher work. Socks are used by scientists to hold bait that is attached to trees. Then motion activated sensors take photos of animals taking the bait. This is part of the protocol used to determine fisher occupancy in an area.

The social media campaign was extremely successful. The blog received over 10,000 hits in the first six weeks, the most of any story posted on the Green Blog at the time. UC scientists were interviewed for statewide radio stations and newspapers. We received over 300 packages of socks in the mail in the first few months, more than the fisher team could use over the duration of the project (Figure F16). Excess socks were provided to other scientists and philanthropic organizations.

Figure F16: Anne Lombardo – University of California Cooperative Extension and Rick Sweitzer - University of California Berkeley processing donated socks.

Most packages were received from California and from urban areas, however, people in 20 other states and Canada also sent socks (Figure F17).

Figure F17: Location of donors sending in packages of socks with legible return addresses within first 6 weeks of blog story. Map by Sarah Lewis.

The success of this campaign shows that social media can increase inclusiveness through participation by new audiences and from distant locations. The campaign asked for items most people have readily at hand and used humor to capture people's attention. Online comments on the blog and associated articles made a lot of jokes about used socks.

SNAMP distance outreach summary

Each of the distance methods used to spread SNAMP findings, information and outcomes to a broader audience had its own content, targeted audience, advantages and disadvantages (Table F4).

As with the in-person participation methods, the distance methods used to spread SNAMP information each had its own audience but can be considered additive. The website was a place where all materials developed by the project could be posted and accessed over time. This included written products like news posts, newsletters and journal articles and science briefs that were targeted at participants and land managers. To keep up with the information age we also developed more ‘social’ type media including blogs, videos, and social networking. These were extremely effective at reaching broad audiences and increasing awareness of the project and its findings. Blogs developed by SNAMP were promoted through the UCANR Green Blog and so increased the reach of the effort.

Lesson Learned: Using multiple forms of electronic media including websites, emails, blogs and social media can extend awareness of projects beyond the local and regional scale.

Lesson learned: Information technologies greatly facilitate the flow and use of digital information. Especially for scientific publications, science knowledge was transferred quickly and widely from SNAMP to other environmental scientists.

Lesson Learned: Powerful new information monitoring tools can be used to characterize the flow of information products through their production, transport, use, and monitoring. There are a variety of metrics and measuring mechanisms available to track the usage of information products.

Table F4: Overview of SNAMP distance outreach methods.

Outreach Type	Content	Users	Strengths	Challenges
Journal articles	Peer reviewed findings produced by Science Team	Academics, committed participants, land managers	Highest quality of information needed for environmental planning and management	Often not read by managers and lay people
Science briefs	'Translation' of peer reviewed articles for non-scientist audience	Committed participants, land managers	Makes findings more accessible	Requires editing expertise and scientist review
Newsletters	Status updates on project, individual team study design and findings	Committed and casual participants, general audience, used at outreach events	Highlighted project and findings for a general audience	Not much room for details about the science
Websites	Repository of SNAMP information, news posts, calendar, discussion	Committed and casual participants, regional and national audience	Unified location for all materials; Archive for long term project; Easy to use	Discussion board under-utilized
Email list	Notifications about project status and events	All participants that have attended a SNAMP sponsored event or asked to be on list	Makes communication to large groups feasible and easy	Communication is only one way from the project out to participants
Social media	Notification about project status and events	All, local, regional and national audience	Increases reach of other materials to wide audience for minimal effort	Time consuming; Some participants do not engage with social media
Videos	Overviews of SNAMP and findings	All, local, regional and national audience	Reaches audiences not likely to read scientific materials	Time consuming and requires specialized skills; Easy to look unprofessional
Blogs	Overviews of SNAMP findings	All, local, regional and national audience	Can be focused around outcomes of SNAMP events; Reaches media and a very broad audience; Does not require editing skills as videos do	Benefits from an on-going dedicated effort

IV. Transferring collaboration skills: Review, summary, and evaluation

SNAMP participation goals were to increase inclusiveness and transparency about agency actions and the science being done, to build relationships, and to promote learning about forest management science and issues. These goals were developed to serve the larger project purpose of learning how to effectively implement collaborative adaptive management in Sierra Nevada national forests. However, achievement of adaptive management necessarily came after delivery of this final SNAMP report by the UC Science Team that reported on the effects of fuels reduction treatments and made recommendations about the next round of management actions by the Forest Service. The application of SNAMP findings and recommendations in the next series of Forest Service plans would be the final step in the adaptive management process but occurred after the UC Science Team and the Participation Team were no longer funded to be part of the dialog process.

The need to continue a productive dialog after UC involvement in SNAMP ended spurred the Participation Team to hold management workshops to pass along the skills needed to maintain inclusion, transparency, relationships and learning. Training staff to develop the skills needed to establish and maintain this kind of participation has not necessarily been a priority within land management agencies or organizations participating in SNAMP. This lack of training in collaboration skills has been noted nationwide in an assessment of the Forest Service (Burns and Cheng 2005). Scientists assessing the readiness of the Forest Service to collaborate identified the need for training staff on many national forests: *"The work of collaboration requires specific skills in and a commitment to relationship building, communication, and facilitated dialogue. Some staff has evolved these skills through previous experiences or training, while others may need some additional amount of orientation and preparation"* (Burns and Cheng 2005). In this section we report on a series of workshops conducted by the Participation Team that attempted to address this gap by training stakeholders in the adaptive management process so that the Forest Service and the public might partner to complete the SNAMP adaptive management cycle and go on to foster more productive future collaborations.

Development of facilitation and collaboration curriculum

To share collaboration lessons with our SNAMP partners, UCCE developed curriculum that became a free downloadable workbook entitled: *Facilitation Skills for a Collaborative Adaptive Management Process: A workbook to train natural resource managers and stakeholders in facilitation of collaborative projects* (UCCE 2014, http://snamp.cnr.berkeley.edu/documents/574/, Appendix F6). It includes 17 modules written in a 'train-the-trainer' style. Lessons focused on framing a collaborative process by identifying project boundaries and constraints, analyzing stakeholders and developing specific desired outcomes. Modules on methods to hold effective meetings included content on developing effective agendas, process rules, decision-making, note taking, evaluation and follow through. Group dynamics were addressed through identifying stages of discussion, thinking and learning styles and group development. Managing conflict was described through development of key agreements, dealing with difficult behaviors, and prevention and intervention methods.

Collaborative adaptive management workshops

In 2013 and 2014, UCCE staff held five separate 12 hour training series, each followed by a 6 hour long follow up workshop about 6 months after the initial workshops totaling 18 hours of instruction. Workshops were held in 2013 in Auburn (Placer County), Oakhurst (Madera County), and Jackson (Amador County). 2014 workshops were held in South Lake Tahoe (El Dorado County) and Marysville (Yuba County). Workshops were structured around participant input but also covered the standard curriculum, including the 17 modules. Initial workshops included lecture, group discussion, group exercises, and role playing. Follow up workshops reviewed previous content, included a guest speaker and focused on role playing.

A total of 115 staff from federal and state forestry, fire, wildlife and research agencies, local agencies and conservation and non-profit organizations attended the trainings. About 15% of those beginning the training were from federal agencies, 35% were from state agencies and 25% were from local agencies. 80% completing the training were female. About 90% of participants had facilitated some sort of meeting before the training although 64% had never had formal training before the workshop to do so.

Of those 115 participants, 72% attended only these workshops and no other event organized by SNAMP. Another 7% attended only one other SNAMP events while 21% also attended two or more other SNAMP type events. For comparison, the email survey results showed that of all SNAMP participants, 56% attended only one SNAMP event, 18% attended only two events, while 26% attended 3 or more events.

Participant hopes for collaboration

Participants were asked at registration to define successful collaboration. They gave a variety of answers that were then used in workshop discussions. Overall these comments show that participants had high hopes about collaboration and what it can achieve if done well. However, they also had many valid concerns about the potential pitfalls of collaborative processes.

Participant definitions of successful collaborations are described below as a set of composite opinions about their effects on relationships, process and results.

· *Relationships* - Participants described the relationship aspects of a successful collaboration in terms of how stakeholders feel about the process. They said stakeholders should leave the meeting (and the process) feeling heard, respected, and that their interests have been adequately considered. Stakeholders should feel they have been empowered with decision-making and that the process was a valuable use of their time. Participants should feel a sense of accomplishment, buy-in and forward movement.

· *Process* – Participants described a successful process as involving broad stakeholder participation and engagement allowing stakeholders to take ownership of the problem being addressed. It should be open, inclusive and have a commitment to dialogue with genuine give and take where all viewpoints are considered in making decisions and participants are willing to make compromises to meet the common goal. It should be structured to meet the goals of the group not one person or organization.

· *Results* – The results of a successful collaboration should be a win-win for all stakeholders leading to decisions that are transparent and built on participant and collective interests. It should move a project forward through a sustainable agreement/decision supported by enthusiasm and commitment from all participants. The task should be completed on schedule leading to a usable end product that is used to influence management decisions. Participants should learn about the problem and walk away with a common understanding of the problem while appreciating various perspectives.

Participant concerns about collaboration

Participant concerns were substantial. Attendees were worried about the time it takes to collaborate effectively, how to run an efficient process and ensure that there is follow through, having appropriate participation and expertise, dealing with conflict and producing a useful product. Here are quotes from participants about each of these concerns that they provided at registration:

· *Participation - I am concerned about…*

- "…working with people with different goals and values and staying positive while enduring our slow and expensive governing process so commonly stalled by special interests."
- "…how to strike the balance between including the right people and keeping the group to a productive and manageable size, without upsetting stakeholders who might feel excluded."
- "…about not having as much technical knowledge as your collaborators/stakeholders; and feeling that the void between groups is insurmountable."

· *Process - I am concerned…*

- "…about having the process of defining a project, or the project itself, disrupted by a small group who isn't interested in collaboration but instead just getting their way and they make meetings and progress difficult, not having enough time to dedicate to getting all stakeholders in agreement to the collaborative process and completing the project within the financial constraints and construction timelines."
- "…that [collaboration] is used as window dressing with limited follow through on considering opposing opinions."

· *Dealing with conflict - I am concerned about…*

- "…getting a stakeholder who does not believe in compromise. And that his solution is the only solution to the problem or issue we are attempting to collaborate on."

· *Emotion and conflict - I am concerned about…*

- "…not knowing what to say when a tense situation arises, or personal dogma interrupts the flow."

· *Results - I am concerned…*

- "…about getting a watered down product that does not achieve the original goal."

Eliciting these concerns during registration allowed the workshops to be structured to address them when applicable. Curriculum that dealt with the stated concerns was stressed during the workshops as were exercises and role playing.

Participant learning outcomes

In addition to commenting on their hopes and concerns about collaboration at registration, participants were asked to complete a written pre-test at the beginning of their first workshop to assess their knowledge and attitudes about facilitation of collaboration. They then took the same assessment at the end of the first 12 hours of instruction (Table F5). Scores were compared to evaluate changes in knowledge and attitudes. Of the 115 total participants, 42% attended only one of the collaboration workshops, 38% attended two workshops, and 20% attended three or more. A total of 82 participants took the pre-test, while 47 took the post-test. Paired data are described below.

Both before and after the workshops, participants were asked to agree or disagree with a series of outcome statements, choosing whether they strongly agreed, agreed, somewhat agreed or did not agree (scored 4, 3, 2, or 1). The biggest increases in agreement after the workshops were in participants agreeing that they had a clear idea of what adaptive management is (+0.8 from 2.4 to 3.2) and that stakeholder participation is critical to it (up +0.5 from 3.1 to 3.6).

Strong agreement became nearly unanimous that participants would be able to use what they learned in the workshops (agreement grew +0.5 from 3.3 to 3.8).

Table F5: Results of pre- and post- surveys of collaborative adaptive management workshop participants.

Do not agree = 1, Agree somewhat = 2, Agree = 3, Strongly agree = 4	**All**			**Pairs**		
	Pre N=82	**Post N=47**	**Diff**	**Pre N=47**	**Post N=47**	**Diff**
I have a clear idea of what adaptive management is	2.5	3.2	+.7	2.4	3.2	+.8
I will use what I learn here in my profession	3.4	3.8	+.4	3.3	3.8	+.5
Stakeholder participation is critical to the adaptive management process	3.2	3.6	+.4	3.1	3.6	+.5
In controversial management processes, it is useful to have an independent third party to do facilitation	3.3	3.7	+.4	3.3	3.7	+.4
The Forest Service is ultimately responsible for forest management decisions on Forest Service lands	2.6	2.9	+.3	2.5	2.9	+.4
I am comfortable managing conflict	2.1	2.4	+.3	2.0	2.4	+.4
Facilitation is not usually needed in meetings between stakeholders and agencies about forest management	1.1	1.4	+.3	1.1	1.4	+.3
I think that better facilitation can improve forest management	3.4	3.6	+.2	3.3	3.6	+.3

Increases of +0.4 were seen in understanding how to manage and frame collaborative processes. After the workshop, participants more strongly agreed that it is useful to have an independent third party to do facilitation in controversial management processes (from 3.3 to 3.7) though the Forest Service is ultimately responsible for forest management decisions on Forest Service lands (from 2.5 to 2.9). Participants' comfort level with managing conflict grew (from 2.0 to 2.4). There was also growth in agreement (+.3) that better facilitation, when needed, can improve forest management (from 3.3 to 3.6) though facilitation is not usually needed in all meetings between stakeholders and agencies about forest management (from 1.1 to 1.4).

Discussion

Participant hopes about collaboration collected at registration were quite high, though they listed many concerns that could jeopardize effective collaboration. They defined success as project participants feeling heard, respected, and empowered. The processes used should be open, inclusive and with a commitment to dialogue and learning where all issues and viewpoints are understood and considered in making decisions. Decisions should be transparent, built on participant and collective interests and supported by all participants. The project should be completed on schedule leading to a usable end product used for management.

Participant concerns about collaboration highlight some of the anxieties provoked by the prospect of conducting natural resource management in a different way, especially when almost half had had no training in collaboration or facilitation. Participants have valid concerns about *"having enough time to dedicate to getting all stakeholders in agreement to the collaborative process and completing the project within the financial constraints and construction timelines."* They also articulated concerns about dealing with difficult stakeholders that may not have enough expertise or open mindedness to participate fully, leading to a *"watered-down product."*

SNAMP collaboration workshops did seem to both increase the commitment to collaboration and also help ease concerns of participants. Participant learning outcomes were highest in areas that seemed to increase their comfort with the collaborative process, with strongest growth in understanding what adaptive management is and that stakeholder participation is critical to it. There was also growth in understanding how to manage a collaborative process including the importance of having an independent third party to do facilitation in controversial management processes though the Forest Service is ultimately responsible for forest management decisions on Forest Service lands. Participants' comfort level with managing conflict grew along with the belief that better facilitation can improve forest management though it is not needed in many situations.

Results also show that participants are glad to be receiving training in collaboration techniques. Participants said they would be able to use what they learned in the workshops and rated the collaboration and facilitation content as providing new information, ideas, methods and techniques practical and useful knowledge and skills that are applicable to their jobs.

Recommendations for collaboration skills training

Information collected as part of this workshop series shows that natural resource managers, scientists and stakeholders share many hopes and concerns about collaborative adaptive management. Most have not been trained in collaboration and facilitation techniques and so have concerns that increased collaboration will lead to time consuming and confusing interactions with potentially difficult participants that will lead to less effective outcomes.

Whether or not the management workshops held will assist participants in the post-UC phase of collaboration around UC Science Team forest management recommendations remains to be seen. However, available evidence suggests that the trainings held both increased commitment to collaboration and allayed some collaboration concerns for SNAMP participants. Workshops did this by giving specific instruction on how to frame and conduct collaborative processes, sharing collaboration success stories and developing skills to manage collaborative processes. These skills should increase participants' ability to be inclusive and transparent about agency actions, build relationships, and promote learning about forest management science and issues.

Lesson learned: Skills training can increase commitment to, and skill in, conducting collaboration when it focuses on how to frame collaborative processes including defining success, setting up the project's boundaries and constraints and, clarifying the roles and responsibilities of agency staff, scientists and participants. Trainings should also teach how to encourage positive interactions through a better understanding of group discussion, dynamics, learning styles, and tools to deal with difficult behaviors, including identifying when facilitation is needed.

Lesson learned: The SNAMP Collaborative Adaptive Management workshops allowed the community to build the capacity to continue this effort without the presence of the Science Team or active facilitative leadership from UCCE. A rigorous environmental decision-making framework, clearly outlining the roles for the public and the accountability of the agency(s) would also assist future efforts.

V. Assessment of the SNAMP process: Pre-and post-program results

Interviews and email surveys were used to assess the impact of the project on participants and their assessment of the adaptive management process. In this section we look at SNAMP's progress toward our core elements of inclusivity, transparency, learning, building relationships and effectiveness but from different vantage points: we report on views at three points in time over the course of the project and from participant and non-participant views unconnected to a particular event or meeting as was reported in section III and IV. This data helped us understand some of the larger and more elusive concepts such as how effective UC was in its third party role of facilitating public participation and assessing impacts of management practices; who was able to participate in the adaptive management program and why or why not, whether participants felt decision-making was adequately transparent, and what and how participants learned over the course of the project. An ultimate goal of the SNAMP process was reducing conflict, and survey and interview results give us some insight into this and prospects for the future.

Learning is critical to the adaptation needed to manage complex adaptive systems. Sierra Nevada forest management and the adaptive management process of SNAMP are parts of a social ecological system that has both social and ecological dynamics. As ecosystems change, management must learn and use what is learned to adapt--the studies conducted by the wildlife, water, and forest health teams were aimed at learning new things about ecological response to changes brought about by management within the context of the many other ecological changes affecting forests today. The Participation Team focused on understanding the social processes of adaptation and change: how people learn about a system, how they work together to use the knowledge they have gained to improve current management, and how to build a process to transmit what has been learned into the future for future management.

Methods

To gather thoughts, opinions and reflections directly from participants in the SNAMP process about learning and working together in SNAMP we used a variety of quantitative and qualitative social science methods. There are five sources of survey data, and two types of surveys, all separately conducted between 2008 and 2014, that informed our analysis of the collaborative adaptive management process in SNAMP (Table F6). In addition, meeting notes, matrices of attendee characteristics, and all written products were archived in a database that facilitated the network analyses reported in the previous section and remains a rich source of data for future use in understanding the adaptive management process. This "mixed methods" approach allowed us to take advantage of the benefits of qualitative and qualitative methods by using the two types of data to complement each other. Quantitative data allow us to understand the proportion of a population that responds in certain ways, while qualitative data take us out of the realm of pre-formed and limited questions and into an analysis where the respondent can frame ideas and responses in accordance with their own worldview. The qualitative data add nuance and depth to the quantitative information, and strives to assess the full spectrum of opinion, rather than the proportion of respondents agreeing with one prompt or another. For this reason, the two types of information are often presented together, while in some cases, one type of data is the only kind gathered. SNAMP results from both types have been published (Sulak and Huntsinger 2012; Sulak et al. 2015). All in all, we believe a robust and multifaceted presentation of respondent interactions with SNAMP is achieved.

Lengthy qualitative interviews, with protocols contextualized to the phase of the project, were conducted three times during the course of the project, toward the beginning, the middle and the end. Results were analyzed using NVivo software for qualitative data. The interviewees were purposely selected from an extensive interested parties list created from attendance at SNAMP meetings or Forest Service NEPA lists, contacts from SNAMP outreach team outside presentations, and key informant referrals from interviewees or team members. Selection from this group of around one thousand possibilities was based on participation level and affiliation category. Frequent, light and non-participants who were connected to the SNAMP forest sites or activities in some way, were chosen as well as Forest Service, representatives of agencies and local government, the UC Science Team, Native American Tribes, environmental organizations, forest industry, recreation groups, fire safe councils, ranchers, unaffiliated citizens and news reporters were all included in interviews.

Table F6: Program assessment methods.

Survey Data Source Name	Type of Data	Dates Collected	Number of Participants	Response Rate	Type of Participant
First interviews	Qualitative	2008-2010	42	NA	Both SNAMP participants (34) and non-participants
2010 Email survey	Web based, quantitative	Summer 2010	166	26%	Both SNAMP participants and non-participants
Midpoint interviews	Qualitative	2012	27	NA	SNAMP participants only
Final interviews	Qualitative	2013-2014	31	NA	Both SNAMP participants (26) and non-participants
2014 Email survey	Web based, quantitative	Summer 2014	258	32%	Both SNAMP participants and non-participants

In total, 100 interviews were conducted, lasting 45 minutes to 2 hours, and all but one was conducted by phone. For each round of interviews (“first”, “second” or “midpoint”, and “third” or “final”), interviewees were added or replaced “lost” or “declined” participants until we were confident that the majority of the relevant perspectives had been sampled (Auerbach and Silverstein 2003). The first and final interviews included non-SNAMP participants but the second round of interviews did not as we were focused on what participants were experiencing in, and learning from, SNAMP. A “response rate” is not included for interviews as all but one contacted potential interviewee agreed to be interviewed, and the qualitative data are in any case not appropriate for inferential statistics.

Interview questions ranged widely. The first and final interview questions focused on assessing the SNAMP program and its inclusivity, relationship building, transparency, learning, and efficacy. In the first interviews we also looked for preconceived sentiments toward the issues and participants in SNAMP: opinions on forest health, public land management, the Forest Service, the National Environmental Policy Act, the University of California, non-governmental organization (NGO) work in the Sierra and SNAMP. The second round of interviews was conducted mid-way through the project to collect participant experiences with learning in SNAMP. The final interviews aimed to assess perceptions of project outcomes and impacts. Most questions were different in each round of interviews but some questions were asked every time such as questions about forest health. Interview transcripts were imported into NVivo (NVivo QSR version 8.0, 9.0, 10 and for Mac, QSR International Pty, Victoria Australia, 1999-2014) and iteratively coded for emergent themes (Lofland and Lofland 1995).

The email contacts maintained by UC Cooperative Extension to promote SNAMP events and update stakeholders were invited to respond to a web-based survey in the summers of 2010 and 2014, in the middle and toward the end of the project. The list was comprised of individuals who wanted to keep informed about SNAMP progress, or who had attended SNAMP events, or who had a known interest in Sierran forest management. The email survey questions were left open to participants for 6-7 weeks. The 2010 survey was implemented with one initial invitation and three reminders while the 2014 survey had six reminders. The 2010 survey invitation ultimately went to 647 valid email addresses and the 2014 survey invitation went to 801 valid email addresses. Return rates were 26% in 2010 and 32% in 2014, similar to returns for other email surveys (Sheehan 2001). A wave analysis was used to check for non-response bias. Survey questions were on topics similar to those in the interviews. They were mostly multiple choice with the option for further comment, and were organized around the themes of who participates in SNAMP and how; what their different perspectives are on forest health, adaptive management, and the SNAMP process; and what they believe they are getting out of the project. In 2014, respondents were also asked their opinions about treatment effects, and how SNAMP influenced those opinions. These results form the core of the Participation Team integration report (see Part VII of this Appendix “An in-depth look at learning: Participant responses to treatments” and SNAMP Final Report Chapters 3 and 4).

The email surveys collected almost exclusively ordinal and categorical (interval) data. For this reason Chi-square analysis was used to compare results from 2010 to those from 2014, as the most straightforward method requiring the fewest assumptions for these types of data. (Planned future analysis will draw on logistic regression techniques and a more generalized analysis using the collected demographic data). Respondents were from the community of interest in Sierran forest management that wanted to maintain email contact with SNAMP. The listserv not only contained participants in SNAMP, but overall included a large spectrum of stakeholders some of whom were deeply involved in Sierra forest management and had instigated litigation with the Forest Service in the past, as well as those who had limited connection to the subject or project but still expressed enough interest to be on the mailing list.

While the interviews were designed to allow for in-depth conversation about the issues raised in SNAMP, the email survey provides an idea of the extent of various ideas and opinions among the SNAMP community of interest, and of the relationship between interest group affiliations and responses to the project. For the purpose of this report, because of the SNAMP emphasis on including different interest groups and to understand whether or not SNAMP brought those different interests together, our analysis of responses emphasizes comparison by interest group. In accordance with our mixed methods approach, interview and email responses are for the most part reported together. The interview statements are designed to shed light on and expand on the email responses.

Interviewee and survey respondent demographics

One hundred separate interviews were conducted with 58 different people. Of the 58 interviewees, 10 were interviewed because they had never attended a SNAMP meeting, and 4 were initially interviewed for their historical knowledge of the study areas. Much of the analysis focuses on the 47 participants who were involved in SNAMP at some level including both those who were very active as well as those who had only attended only one meeting.

Of the 47 interviewees who attended a SNAMP event of some sort, just over half of the participants were male and all were between the ages of 32 and 80 with an average age at first interview of 53 years old. All but one interviewee had attended some college and the vast majority had completed college, with almost half the group going on to postgraduate work. They had diverse income levels ranging from $19,000 or less up to $140,000 or more, though just over half the group had incomes over $100,000, and they ranged in experience with natural resource or forest management issues from a few years to over 50 years with most between 11 and 30 years. Most had grown up in suburban or rural settings that were not forested, but more than half lived in forested environments as of the interview. The vast majority was white, but people of American Indian and Asian ethnicities also participated.

The demographics of respondents to the 2010 survey were not significantly different from those in 2014, so we report the demographics of only the participants in the 2014 survey. While more than half of the survey respondents came from the two study areas, there were many respondents from other parts of California and some from other states (Figure F2). Respondents were from a wide range of affiliations (Figure F3). Respondents were 65% male, with the highest education level reached for 32% of interviewees being a Bachelor's degree, 40% a professional or graduate degree, 16% attended some professional or graduate school, and 9% attended some college or trade school. Less than 1% had never attended college or trade school. About 8% made less than $50,000 per year in household income, 51% made $50,000 to $100,000, and 41% made more than $100,000. Average age was 59 years. A little over 43% of our respondents grew up in a rural environment, 18% in a forested one, and 21% in an urban area, 38% in the suburbs. Slightly more than 65% lived in a forested environment when they participated in the survey.

Results: Participant views of SNAMP

Conducting three sets of interview surveys and two email surveys during SNAMP allowed general and in-depth information on the status of, and changes over time in, our approach to collaborative adaptive management. The goal was to find out what people learned, whether or not we were missing important stakeholders, if stakeholders had or developed relationships, whether information was produced and shared transparently, and how they responded to the adaptive management process, including the UC role. In this section we use both these sources of data to explore the impact the SNAMP science and process had on its participants and draw conclusions on SNAMP's future impact on forest management in the Sierra Nevada.

The UC role: Facilitating transparency

The 2014 survey data can be used to look at how respondents, toward the end of the project, viewed the SNAMP process and how it was facilitated by UC (Figure F18). Members of the UC Science Team were excluded from this analysis. Respondents were asked how much they agreed with statements about the way that the University of California shared its experimental questions, methods and progress with the public as part of SNAMP. When asked about the UC impact on the SNAMP process, the strongest levels of agreement were with the statements that UC took participation seriously, meetings were well organized and facilitated, participants could easily prepare using SNAMP agendas and other materials, and participants had adequate face-to-face contact with scientists and the Forest Service, similar to what was found through the meeting evaluations reported in Section III. This last statement is an indication of the importance of direct contact with managers and scientists. This kind of direct contact was an emphasis in SNAMP because we had previously observed that even in the most participatory projects the public often does not have direct contact with the scientists conducting the studies that are used in making management decisions.

High levels of agreement were achieved in the 2014 email survey with statements about understanding scientific results, having open discussions with the Forest Service, scientists, and other participants, and learning new things at SNAMP meetings. The SNAMP approach definitely increased the transparency of forest management for respondents, with 94% reporting that transparency was enhanced by the UC role in SNAMP. Two thirds agreed that because of the UC role in SNAMP, they were better able to participate in Forest Service planning processes overall (Figure F18).

Generally the email survey responses were similar in 2010 and 2014. The only significant ($p<.05$) changes were increased strong agreement that respondents "feel a part of the project" (7 to 16%), and "have had enough opportunities to provide input into UC research" (7 to

15%). There was significantly decreased overall agreement with the statement that SNAMP meetings are missing important stakeholders (49 to 37%, $p < .05$). In other words, almost 2/3rds of participants did not feel that stakeholders were missing by the end of the project. This improvement stakeholder participation in SNAMP was also brought up in the early interviews:

> "I think that [SNAMP events] have been pretty good – there have been a lot of discussions at the meetings, a lot of information presented and disseminated... The one comment that I would have is that some of the earlier meetings, there were a lot of stakeholder groups that were not there and their attendance would have been good. The last Integration Team meeting had a great diversity, I have never seen such a diverse group at a SNAMP meeting! And that was great. Just a really diverse group at that meeting – ideally I'd like to see that continue to have them interested enough to attend the meetings." UC Scientist 2008

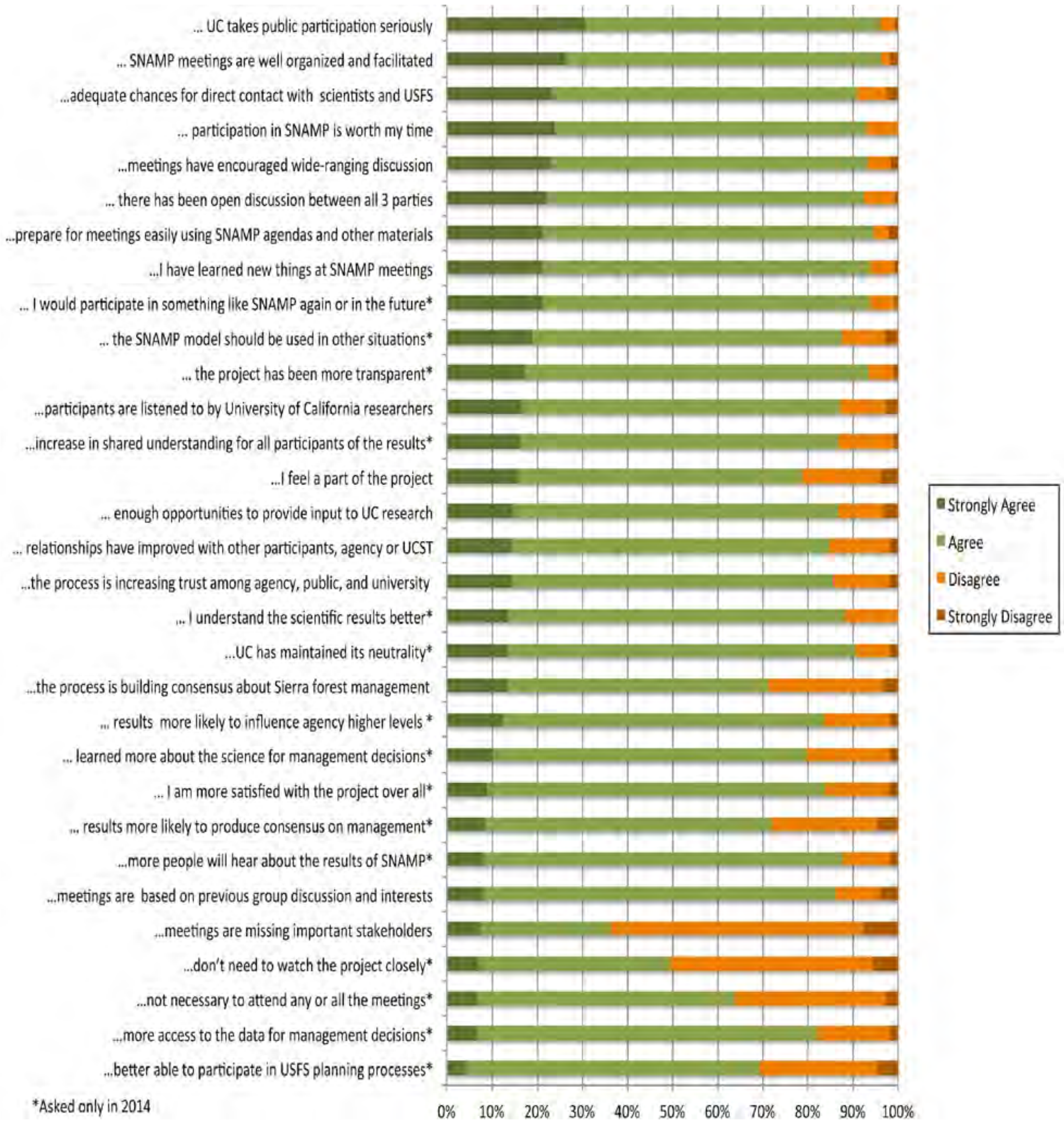


Figure F18: Results from 2014 email survey of people interested in Sierra forest management. Respondent agreement with statements that because of the UC role in the SNAMP process, they believe that…

Inclusiveness through participation

Respondents to the email survey did not feel that important stakeholders were missing from the process (Figure F18), but participation was affected by the ability and interest of stakeholders in attending events. SNAMP intentionally provided numerous ways of participating to allow the variety of interested parties to take part. The 2014 email data shows the SNAMP website served close to 80% of participants and that just over 70% also attended a UC led meeting of some sort (Figure F19, see section III of this appendix for more information about participation options and website use). Nearly half of the participants attended at least one integration meeting for in-depth study of SNAMP topics and face-to-face contact with scientists in particular topic areas. Of these, integration meetings on the owl and fisher drew the largest number of attendees. A little over a quarter of participants said they had attended one SNAMP event, another quarter attended 2-4 events, and another quarter had been to 5 or more events. About 3% did not participate in any way, and the remainder participated by other means.

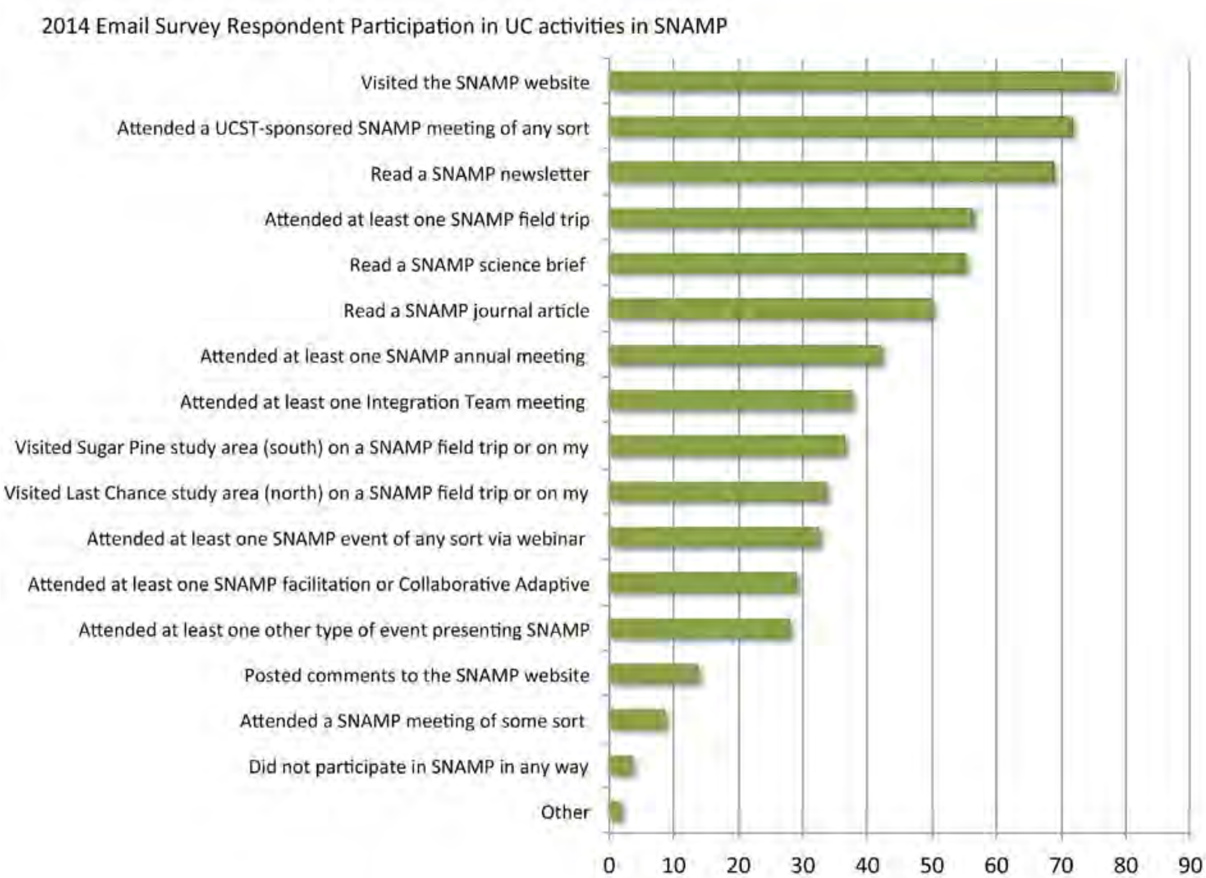


Figure F19: The percent of 2014 email survey respondents participating in various UC-sponsored SNAMP activities.

UC's transparency and multi-faceted outreach methods did help make it possible for more people to get information from SNAMP. Email survey volunteer comments included: "I was not actually involved in any part of the SNAMP project, but I have appreciated receiving the emails", and "I would have like to have taken a more active role in SNAMP, but it really requires $$ of support of some time. Just plain citizens could not afford time and travel...Remote hookups don't work out here in the boonies..." 2014 email respondents were asked about why they did or did not participate in SNAMP functions (Figure F20). Most stated that they simply did not have the time, but distance and cost were important too. It is also clear that participants picked the topics they were most interested in to follow. About 10% were dependent on web-based materials and webinars to participate.

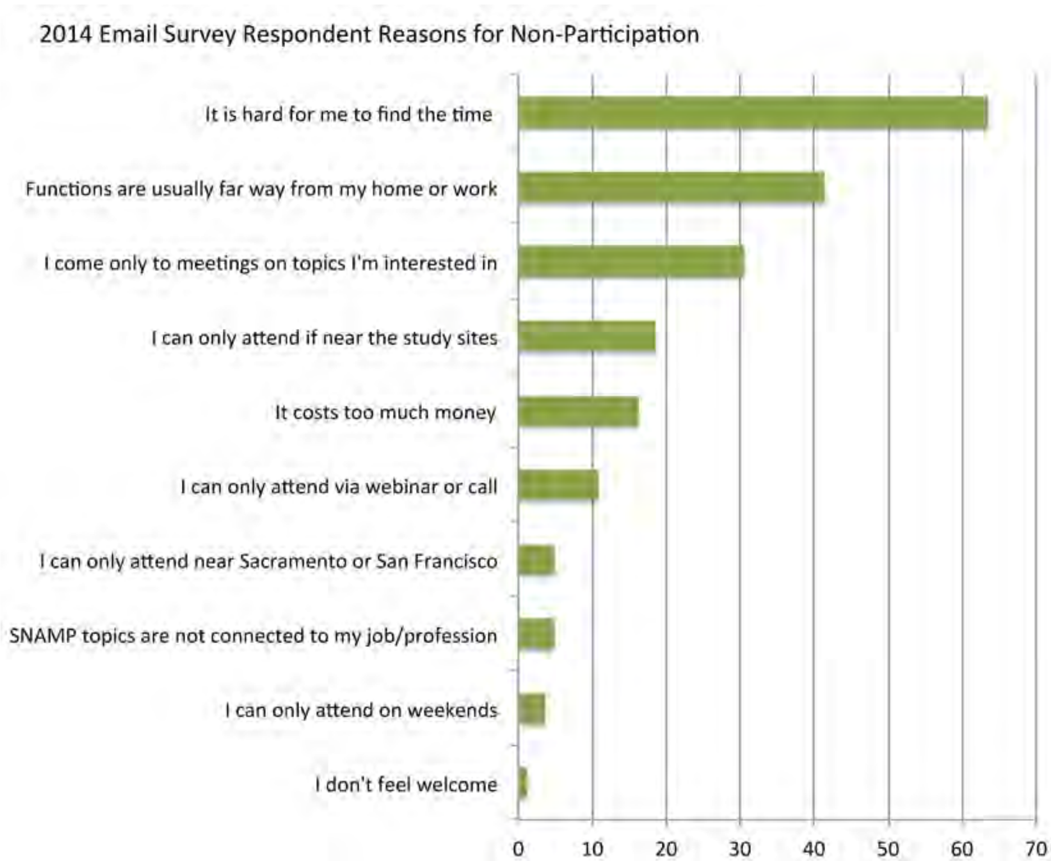


Figure F20: Reasons offered by 2014 email survey respondents for not participating in various UC-sponsored SNAMP activities, in percent.

Relationship building

Starting the project with a strong emphasis on project transparency and participant inclusiveness laid the foundation for what we hoped would be the lasting impacts of the project – improved relationships, shared understandings about the scientific basis for forest management, and ultimately reduced conflict. Our results show SNAMP had an impact on all of these aspirations. More than 85% of 2014 email survey respondents agreed that “relationships have improved among agencies, stakeholders, and the UC Science Team,” and that the process was “increasing trust” among them (Figure F18). One 2014 email survey respondent volunteered that “it has given a number of people with different backgrounds some common experiences, knowledge, and exposure to the science.”

We can look in detail and over time at the process of relationship building in SNAMP through the three rounds of interviews conducted throughout the project. When asked about the impact of SNAMP on relationships in general, the participants in the first interviews leaned toward slight improvements from SNAMP saying things like “I think so...” or “I hope so...” with a few saying “I don’t know” as well. Those participants who observed a tendency toward improved relationships felt it was based on increased transparency and communication opportunities as well as the facilitation conducted by UC Extension. Some thought relationships had not changed and that the stakeholders had not been convinced to change their preconceived adversarial positions based on SNAMP. Some also thought it was prudent to withhold judgment till treatments were complete or final results were released.

To explore these relationships further, in the first interviews we asked specifically about participant opinions of the dominant groups involved in the project, the SNAMP Memorandum of Understanding Partner agencies (MOUP or MOU Partners), NGO stakeholders, UC scientists, and the Forest Service. For the most part interviewee opinions of the SNAMP MOU Partners had not changed much. Many were unclear as to who they were and what their role was and others felt that there had not been enough interaction yet to cause a change in opinion. However, for those intimately involved in orchestrating and funding SNAMP, opinions of the MOU Partners had already developed. Some noted the difficulties associated with the state agencies and their involvement in SNAMP.

> "I don't know about my opinion of them but I have a better understanding of their interests and their fiscal struggles, but also how they think and what they are going to focus on. Helped me understand those groups much better. Especially with California State agencies – they have their own internal struggles themselves, fascinating." Forest Service 2008

Similarly, opinions of the environmental NGO and forest products participants were mainly unchanged. Some participants felt that their preconceived ideas (either positive or negative) had not been changed and others felt they had not had enough exposure to this group to have impact their opinion. Again, in this early phase, a few expressed the sentiment that they were waiting to see how other participant reactions might change once the treatments went in and results were shared.

Participant views of UC scientists were also unchanged but not due to lack of interactions. Many comments talked about the high regard interviewees already had for universities and that had either been enhanced or unaffected by SNAMP. For those who had improved images of UC scientists, participants mentioned the increased commitment this type of project required.

Where opinions about the MOU Partner agencies, UC and other stakeholders were unchanged, opinions of the Forest Service in these first interviews were "somewhat" improved by 2008 and 2009. Stronger sentiments came from some of those affiliated with the Forest Service who saw changes they were proud of within their own agency.

> "Maybe a little bit to the positive. They are now stepping out and engaging the periphery public, local communities, they are engaging people more. I think that will be able to be sustained once this is over because of the relationships being made." Environmental NGO 2008

> "The opinions of the people I am working with here has changed. They are working harder at making connections, facilitating, so on. I have a greater respect for my own employees." Forest Service 2008

In the midpoint interviews we asked about an individual's increased familiarity with other's perspectives and individual changes in opinions without prompting about who or what organizations. Most of the conversations about change focused on environmental NGOs and showed some dramatic improvements in relationships with, and opinions of, environmental NGOs. However, it was equally likely that interviewees felt their knowledge of other's perspectives, and their own opinions of other groups, did not change. Following these larger general tendencies were changing opinions about the Forest Service, both positive and negative.

> "...[two members of an environmental NGO] who sat next to me… you would think that someone who doesn't think like you, that they must be idiots, but I could tell that they were serious about doing something right. I think by working together we can get stuff done and make a healthy forest… I hadn't been around people like this till this project, probably didn't want to be… I am now willing to work with them. 10 years ago I was not. " Local government 2012

> "I have <u>a little more</u> faith in the Forest Service than I did at the beginning but underline 'a little more'. They are trying very hard to move in the right direction but, like making a ship turn around, it takes a long time." Unaffiliated citizen 2012

Our analysis of the first interviews showed a group that did not know each other well and so had limited knowledge of each other's perspectives and views but revealed a growing understanding of the Forest Service. The midpoint interviews uncovered a more comfortable group that had spent time together hearing each other's views in private conversations as well as in question and answer sessions in formal presentations. For some participants, these experiences increased participant knowledge of environmental group positions and improved participant opinions of those groups. To explore this in the final interviews conducted from 2013-2014, we specifically asked about changes in opinions about the Forest Service and the University of California and asked generally about relationships between stakeholder groups and opinions about other participant organizations.

Comments from the general questions in the final interviews elicited remarks about all the groups, not only focused on environmental or Forest Service groups, and fewer people felt that their opinions and relationships had not changed during SNAMP. Participants noted changes in the relationships between groups normally opposed to each other and comments demonstrate that the project also fostered extensive learning about the Forest Service, an important step toward improved relationships. Perceptions of the university were generally positive but many people learned about the politics and bureaucracy that exist in universities and some saw scientists as poor translators of science for a public audience. Fostering actual relationships with university scientists did not come up as a goal except for a few Forest Service participants. Many interviewees who were highly involved in SNAMP expressed “disappointment” with the MOU Partners citing unreliable attendance and lack of engagement due to staffing turnover. However, general SNAMP participants, and even those from agencies and the university who were not involved in the logistics behind SNAMP, did not portray the state and federal partner agencies in a negative light and instead, greatly appreciated their input and funding.

The new development in SNAMP’s NGO, industry and other non-agency relationships involved connections between groups normally opposed to one another. In 2013/2104, comments about stakeholder groups more often contained descriptions of environmental groups and forest products groups working together. Participants reported opinions and relationships that had grown past positive interactions into collaborating both inside and outside of SNAMP.

> “...the guys from…that saw mill, they were almost at everything I have been to lately, Dinkey Creek or SNAMP or whatever. I think that has really helped bridge the gap between the environmentalists and them. [I think it] really helped being in the same room, it made all the difference in the world.” Local government 2014

> “...life has changed a lot in the last 5 years. I have positive things to say about [one environmental NGO representative]. He has actually gotten pretty close to some of the researchers. The [SNAMP and Dinkey Creek] research has really helped build the trust level for some who formerly were adversaries to Forest Service management… And as far as [the environmental NGO representative] and ourselves we have actually a pretty close relationship compared to the past.” Forest products group 2014

In terms of opinions of the Forest Service, the dominant trend throughout the whole project was an increase in understanding about the agency and its constraints. Our final interviews showed that this increased familiarity with Forest Service limitations usually led to improvements in perception of the agency but not in all cases. Some participants continued with the same opinion of the agency though with more understanding for why it acts the way it does. However, there were also a very few voices who felt that what they learned in SNAMP caused them to have a less favorable opinion of the Forest Service at the end of the project. Increased understanding of the Forest Service through SNAMP, regardless of changes in opinion, will likely facilitate improved relationships for the Forest Service in its collaborations going forward.

The variety and types of comments about what participants learned with regard to the Forest Service is surprisingly large considering that educating the public about the Forest Service was not an explicit goal of SNAMP and time was not specifically dedicated to this in meetings or writings. Participants learned an immense amount about the agency's mission and how the agency conducts management, from the information that goes into decision-making, to goal setting, to processes and logistical constraints of all sorts. Funding, public participation and internal functioning constraints, the complexities of the timber market, and the differences in all these variables across national forests and even between Districts were all mentioned as learned by one or many more people. Learning about what capacities the agency does have for partnering and managing is also a crucial concept for collaboration going forward and recognizing how hard it is to change the agency is an important part of working together successfully. Some participants were pleased with changes they saw already in improved outreach and communication by the Forest Service. Continuing a trend that we saw in the earlier interviews, some Forest Service employees improved their opinions of their own agency. In the following quotes it is apparent that though these speakers said they did not change their opinions of the Forest Service, what they learned in SNAMP is representative of many other participant comments, and will impact their relationship and interactions with the agency in future collaborations.

> "I was encouraged that the Forest Service was very actively and engaged in the process… It was interesting to learn about many of the difficulties that they face, I hadn't thought… about thinning contracts and the need to be able to market those products to pay for that work and all the problems associated with that in trying to make it a viable undertaking... I am more sympathetic towards their problems in implementing forest management practices. [My opinion is] not better or worse just better appreciation of all of the intricacies that are involved." MOU Partner 2013

> "[I have learned both] from SNAMP and Kings' River fisher project about timing and capacity for collaboration. Timing for treatments and capacity of the Forest Service to plan and implement: contract, administration, management and conclusion… As a general matter I think the agency staff tend to be a group of people who want to see good

> things happen... [But overall my opinion is] the same... As an agency as a whole [I see it as] not much different." Environmental NGO 2014

> "...we knew a lot of people in forestry [the Forest Service] prior to this. Our next door neighbor works for forestry. Just by being exposed to more people from forestry of course it is an opportunity to find out what they are doing, how forestry is organized, and stuff like that, what they are interested in and what they aren't interested in. So the SNAMP lectures sort of broadened our knowledge about how the forestry service works." Unaffiliated citizen 2014

With regard to the UC Science Team, most interviewees at the start of the project and the end of the project, held the university in high esteem as an "objective", "unbiased", "trustworthy", "independent", "credible", non-political source of science. Most participants also felt that the UC Science Team would produce information that would be useful to managers. Many strongly emphasized that the UC Science Team had better produce useful results given the large quantities of time and money that had been spent in SNAMP ("Sure in hell better [produce information that is useful to forest managers] for what they are getting paid!" Local government official 2014). Some noted that pieces of information have already traveled the loop and have been used by the Forest Service.

Nevertheless, notes of criticism were also apparent in the comments regarding a lack of real world experience in academia. Participants also learned about UC and its scientists' limitations and constraints such as interacting with agencies or the public and contracting for this kind of a project. Some MOU Partners expressed frustration with the university based on their behind-the-scenes experiences with the university system. UC scientists learned about their own organization as well - how it is hampered by internal politics and bureaucracy and how scientists limit themselves to the ivory tower and resist political involvement.

> "I have learned how strange structurally they are about contracts and how they don't, or that they are not used to, transmitting their research information to the public or outside parties. That it is awkward for them. That they don't integrate or have much interaction with many of the agencies that their research would be helping… As well as seeing how it was very uncomfortable to talk to the public at the open public meetings and how uncomfortable some of them were with that. It's a combination of not having the skills and not being used to it." MOU Partner 2013

When asked if experiences in SNAMP changed participant opinions of the university most respondents said no, their generally positive opinions had not changed. A few SNAMP MOU Partner and Forest Service participants disagreed and felt that their opinions of the university had worsened based on SNAMP. These participants generally declined to explain.

In the final interviews, frustration with the SNAMP MOU Partners came up again from those intimately involved in the inner workings of SNAMP. The dissatisfaction seemed to stem from the frequent changes in representatives on the part of the Forest Service as well as the state agencies. The changes in agency contacts made it hard to keep up the intensity, interest and engagement of those agencies and made building lasting relationships very difficult. Also, a few participants perceived the MOU Partners as entrenched in their views and unable to support topics outside their official agency interests. Positive comments came from a few active agency representatives and the rest of the participants who appreciated the agencies' input and were grateful for the funding.

> "I am not as confident in the MOUP relationships improved. They have changed so much over time and there have been no consistent representatives from the California Resources Agency or CALFIRE or Fish & Game so relationships aren't as well established but maybe the structure and processes and importance of those relationships will be remembered in another project." UC scientist 2013

Shared understandings

Social learning in the adaptive management context is reaching "an agreement on relevant knowledge necessary for addressing a problem" (Ansell and Gash 2007) and supports the progression of the adaptive management cycle. Facilitation of well-structured and organized meetings that respect diverse sources of knowledge can create an environment conducive to developing shared understandings (Arnold et al. 2012). The email surveys indicate general satisfaction with this in SNAMP. Multiple formats for sharing scientific plans and results and getting feedback were used as has been shown beneficial in other studies (Stringer et al. 2006; Arnold et al. 2012). Throughout the project the Participation Team worked to create new events and formats to address needs that came up as part of an iterative public participation process (Stringer et al. 2006).

More than 85% of 2014 email respondents agreed that there was an "increase in shared understandings" as a result of the UC role as a third party in the SNAMP process (Figure F18). In the midpoint interviews we focused on this concept of shared understandings and found support amongst our varied interviewees for the evolution of shared understandings within the SNAMP participants. Observations of shared understandings were frequently associated with the wildlife portions of SNAMP and attributed to the Integration Team meeting format and facilitation. The few who disagreed, felt it was due to the short project length or that other projects were more successful examples.

> "Yes, my views are getting closer to others. It's only natural to the extent that you all sit in a room and look at an issue evaluating monitoring data … and you are doing it together … there is convergence that can occur and has occurred in this case." MOU Partner 2012

The development of shared norms and understandings is argued to be key to successful teamwork among participants with divergent perspectives (Sulak and Huntsinger 2012). The goal is to deconstruct polarizing issues (Arnold et al. 2012) and create a hybrid culture with a shared language (Sulak and Huntsinger 2012). As an example of how this was addressed, SNAMP's Collaborative Adaptive Management workshops (see section IV of this appendix) helped participants learn communication strategies for productive meetings and to create a common language to help build the long-term relationships support learning and adaptation (Stringer et al. 2006). One focus of the meetings was discussion of the variety of definitions of "adaptive management" in Forest Service literature and comparing these to Science Team and stakeholder definitions.

A clear definition of adaptive management was also initially elusive in our interviews. Both in the initial interviews in 2008-2010 and in the final interviews 2013-2014, we asked for participants to share their definitions of adaptive management. In the early conversations, support for adaptive management and its use in the forests of the Sierra Nevada was widespread, but it was difficult for interviewees to describe the concept. Monitoring or learning from past management were concepts important to at least half the interviewees but usually came from those in agencies, the university or those very active in SNAMP with many years of natural resource work or advocacy. Other similar concepts were that adaptive management must be science based and that it entails "learning by doing." Some did not think of it as a process but an end point and mentioned ecological goals or required a certain kind of treatment. The inclusion of public input was added into definitions for a few participants. A small number admitted they did not know what adaptive management really was and some were skeptical of the term. The academics in the group mentioned experimentation as crucial to the process of adaptive management.

By 2014, shared understandings of adaptive management did seem to have developed. In the final interviews in 2013 and 2014 we heard more people talk about experimental, science based approaches with monitoring components and people started using terms like "cycles" and "loops" in their descriptions. The importance of learning was still strong and we saw the addition of many more comments about public participation being an essential aspect as well. The only skeptical voice was concerned that SNAMP recommendations could get ignored in the future under the guise of new information that may or may not be transparent and could be political rather than scientific. Another issue raised was based in experience with the Forest Service's rigid structure that leaves little room for the flexibility required to do adaptive management.

> "I look at it as a cyclical process of implementing management, testing it with monitoring, sometimes research but mostly monitoring, making evaluation and then learning from that and using what we learn to change our management if necessary – sometimes we learn we are doing ok." Forest Service 2013

> "I define it differently now with SNAMP and other things, because now it has to be a collaborative, called "CAM"... We have a pretty good model for it now. What we did with SNAMP we made it participatory." Forest Service 2013

When asked if participants thought adaptive management was a good strategy for the forests of the Sierra Nevada, the answer in the final interviews was again positive, but the answers were much more detailed than the simple "yes" answers from the 2008-2010 surveys. The 2103-2014 participant answers more clearly showed understanding of the complexity of the management, financial, and administrative setting.

Though we saw these shared understandings develop, consensus was difficult to achieve. A smaller 2014 email survey majority, a little over 72% of respondents, agreed that that because of the UC role in the SNAMP process, "project results are more likely to produce consensus on forest management" (Figure F18). A look at the 2014 email survey voluntary comments helps to explain why a smaller majority agreed with the statement about consensus. Comments include, "I seriously question the necessity for consensus", and "I am doubtful there will ever be consensus on forest management...too many perspectives." In fact, reaching consensus was not an explicit goal of the project. Arnold et al. (2012) in their review of adaptive management processes point out that "although consensus is often loosely equated to agreement by all parties, it more accurately reflects the perspective of stakeholders with the most power and a lack of active opposition by others."

Effectiveness: Reducing Conflict

Reducing conflict was referred to several times as a foundational goal of SNAMP, from the creation of the MOU onward. Trust between the public and the Forest Service is often espoused as a key to reducing conflict over forest management. More than 86% of 2014 email survey respondents agreed that the SNAMP process was increasing trust among agency, public, and university participants. A majority even agreed that they did not find it necessary to attend any or all the meetings as a result of the confidence in the process with UC participation (Figure 18). An email respondent volunteered that "The science on the effects on some of these management techniques has been really thin. Working alongside the scientists to understand the data, methods, and results, has really helped groups typically outside the process and lobbying lawsuits into the fray to become part of the process."

However, the final interviewees were lukewarm on SNAMP's progress toward the ultimate goal of reducing conflict over forest management in the Sierra. Some were positive, hoping that the relationships, partnerships and shared understandings developed during SNAMP would reduce conflict but many more resigned themselves to a perception of the inevitable nature of conflict over natural resources. One person suggested that environmental groups took a "wait and see approach" with SNAMP and may go back to litigation if they do not see the results they like. Basic philosophical differences were the source of many disheartening comments where people expressed opinions such as: one project cannot solve all the diverse opinions of the environmental and social issues in the Sierra; SNAMP cannot change someone's value system; preconceived notions are hard to overcome.

> "Maybe a tiny bit. I think there are just really some basic philosophical differences in the way some people think the forests should or should not be managed and some feel the forests should be managed like National Parks. SNAMP will have an impact on some individuals but certainly not all." Forest Service 2013

The idea that forest management is often gridlocked by controversy and litigation is widespread. Broussard and Whittaker (2009) found an increasing trend in the number of NEPA-Forest Service cases in the federal courts between 1970 and 2001. Environmental groups were the most common litigants and timber harvesting, management plans, and endangered species were the subject of the majority of cases in both the U.S. District Court and the U.S. Circuit Court of appeals. Litigation is costly and time consuming, and emphasizes and tends to reinforce conflicts rather than creating constructive relationships. In the 2014 email survey, respondents were asked if some of the innovations in the SNAMP adaptive management model would be helpful in reducing litigation (Figure F21). A majority of respondents believed that scientific learning, building relationships, adaptive management, and the involvement of university scientists helped to reduce the likelihood of litigation. Science team members were excluded from this analysis.

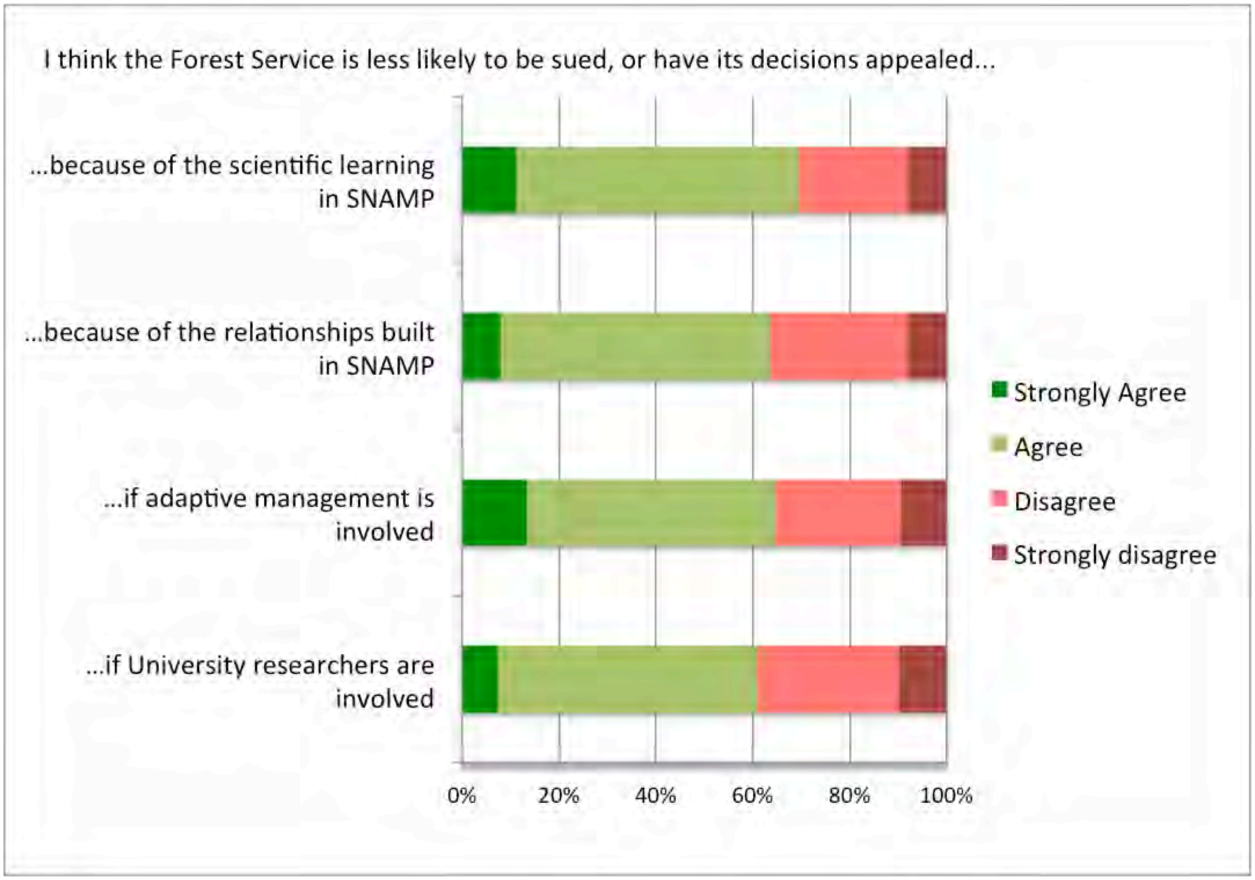


Figure F21: 2014 email survey respondents agreement with statements about SNAMP practices and their influence on the likelihood of litigation.

Many of the 2014 email survey respondents included comments explaining their responses, for example, saying that the Forest Service would be less likely to be sued if decisions and actions were based on any form of independent science--this supports the notion that a third party monitor may help defuse controversy. A comment was made that "having a third party that is reputable and knowledgeable and communication facilitation is the key to building trust" and another comment added that "science with monitoring must be present to balance politics and bad science"; possibly this person meant "to counter" rather than "to balance." Commenters mentioned an appreciation for the direct contact with scientists. There was also a general tone in the comments that lawsuits are not constructive, and in some cases, are instigated by people who will never be swayed by science, for example, "While SNAMP has seemed to have a positive impact on lessening controversy about forest management on public land, some entities commonly resorting to lawsuits to challenge Forest Service projects are simply dogmatically opposed to any commercial activities on public lands [and] are unlikely to be deterred simply because of SNAMP." Others commented that those who do not see the need to carry out fuel reduction should just "get out of the way" before the entire forest is lost, and that "if they don't like our product they will sue us regardless."

Overall, the 61 comments volunteered in the 2014 email survey fell along the following lines:

1. Lawsuits are agenda-driven, those suing do not listen and nothing will help
2. Science can help, especially if the Forest Service puts the results to good use
3. Shifting to community and stakeholder involvement, working together, adaptive management can build constructive decisions and reduce litigation

The first view is by far the most common among the email survey comments. There is a widespread belief that nothing can be done to prevent litigation, because the litigants are ill-informed, or have an agenda, or everything is decided by politics. Nonetheless, within this somewhat gloomy context, 2014 email respondents were still generally positive about the potential impact of SNAMP practices, with the possible exception of those affiliated with the forest products industry.

These 2014 email survey results are echoed in the final interview results. There was support for a neutral third party and relationship building but possibly more important is using the best available science.

> "For many it doesn't matter what the study outcomes are or the relationships… Some groups will sue regardless." Native American Tribe representative 2014

> "... it's really hard to sue when the best available science disagrees with your point of view. The more quality science comes out of our projects then the less likely we are to get sued." Forest Service 2013

The 2014 email survey respondents were categorized by whether they were primarily associated with the Forest Service, an environmental NGO, local government, an industry organization, or participating as a member of the general public. Responses for industry organization members did vary significantly ($p<.05$) from the averages presented in Figure F21. They more strongly disagreed with the others that the involvement of university scientists, adaptive management, scientific learning, or building relationships reduced the likelihood of litigation. The volunteer comments from this group uniformly expressed the opinion that litigation was capricious and not related to actual facts or responsive to science. As one commenter wrote, “it just takes one nut.” Those involved in forest products are clearly the most frustrated by the current conditions for forest management, and their opinions are somewhat isolated. In recent decades, the industry has undergone a steep decline, along with timber cutting on national forests in the Sierra Nevada.

Another example of the differences among groups is the responses to the statement about the involvement of university scientists reducing lawsuits, with Forest Service affiliates most strongly agreeing with the statement, and forest products industry affiliates most strongly disagreeing (Figure F22). Of the four statements, the Forest Service affiliates most strongly supported the statement about scientific learning. Local government representatives most strongly supported the statement about relationship building; NGO members most strongly agreed about adaptive management; general public members most often agreed with the statement about scientific learning; and the industry affiliates most strongly supported the statements about relationship building and scientific learning, although they were the least likely to agree with any statement.

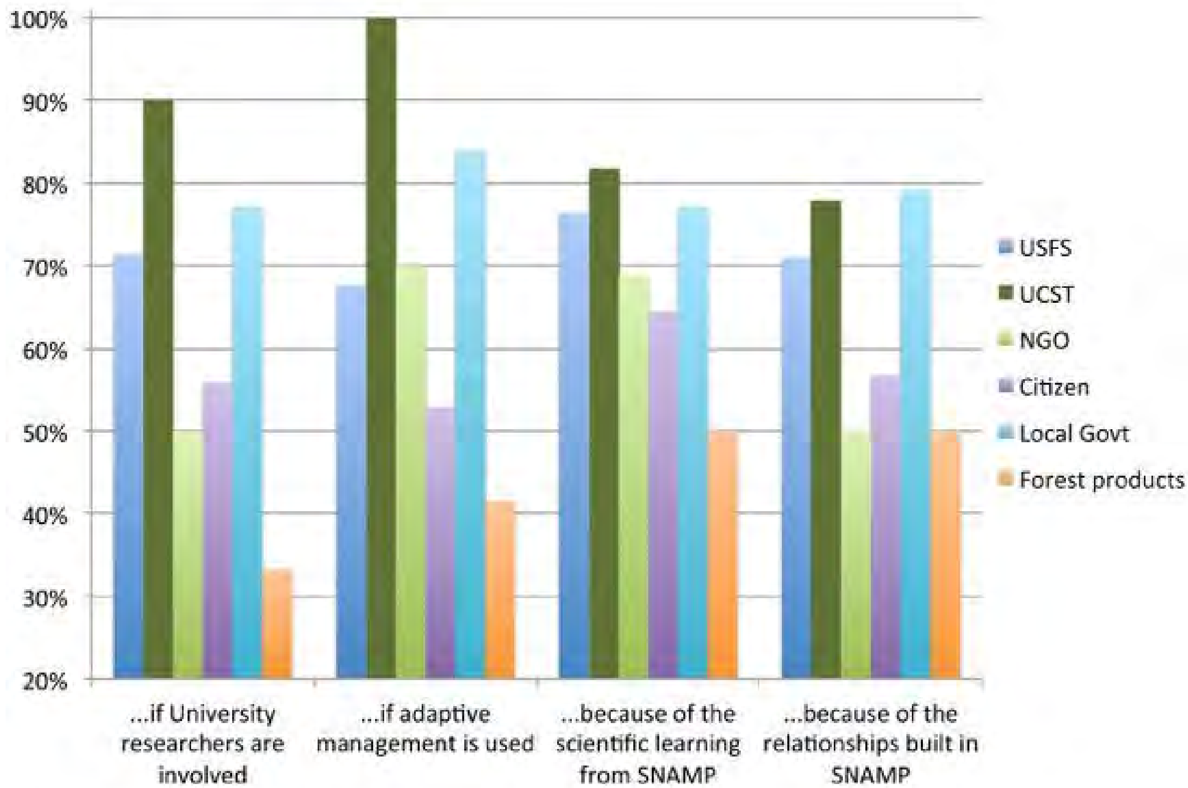


Figure F22: Percent of respondents agreeing that particular SNAMP activities reduced the risk of litigation: "I think the Forest Service is less likely to be sued, or to have its decisions appealed, if…"

SNAMP's third party model

SNAMP's collaborative adaptive management third party model (see section II of this report for more discussion of this model) was created at least to some extent to reduce conflict over forest management in the Sierra. It was thought that a partnership between agencies and stakeholders from all sides of the issue would be most fruitful with a "neutral third party" acting as the outreach and science provider in the adaptive management cycle. Here we present participant reactions to this model and their interpretations of its benefits and detractions. Because this collaborative adaptive management model is not simple or easy to interpret, expectations of UC function in the third party role were mixed and not all participants were satisfied. However, for the most part the neutral third party role was appreciated, UC was expected and seen to be independent and unbiased, and UC was perceived to have conducted itself credibly. This trust that the third party is unbiased and independent is essential for the third party model to function smoothly. One non-participant interviewee went as far as to say that UC's involvement allowed her not to participate since she trusted the university.

> "I think that the expectation is that their role is critical… because they are third party professional scientists that have the respect; if it was a Forest Service study it wouldn't have that respect." Forest Service 2008

> "I think when you have a university, if UC or some other university, it brings that presence of academia that really makes things feel more legitimate – science and research and intellectual behind it – give it more authority and credibility." MOU Partner 2014

As the third party science provider, the UC Science Team received high marks for being responsive to stakeholder input. This was an important part of the collaborative adaptive management process model but difficult to actualize at times. Scientists sometimes believe the scientific method cannot accommodate much public input but overall there was sentiment that the UC Science Team was responsive to stakeholder needs even if their scientific methods were not altered by stakeholder input.

Nevertheless, there were bumps in SNAMP's third party arrangement. One issue that was apparent immediately was the difference in expectations between UC scientists and the Forest Service managers and MOU Partners. There were strong differences of opinion as to the original subjects to be studied, biodiversity or specific species, as well as other debates over including water or economic impacts. Some managers hoped for direct UC input into the planning of the treatments, they saw this as a partnership with the university. The UC scientists were functioning under their interpretation of the scientific method where, in order to test the impacts of Forest Service treatments, the Forest Service had to do the treatments as normally as possible, meaning without additional scientific resources. This came as a surprise to some Forest Service managers and dislike of this "siloed" type of engagement was a problem for an environmental NGO and an unaffiliated citizen too. Even to UC scientists the line was vague at times. Some participants expressed frustration that the university was not 'monitoring' or not monitoring what was important. One participant thought that the university, based on its field data, should have told the public that neither study area project really looked like a SPLAT "a la Finney" and that the university should "blow the whistle" on the Forest Service.

> "On Monday I received a message from [the UC coordinator] about meetings this summer with the MOUP and I was a little taken aback – why wasn't I involved and asked about planning? Our connection with the scientists has been minimal – I really looked forward to a learning experience and working a lot with [UC Scientist] Scott Stevens but that hasn't happened at all – that has been disappointing." Forest Service 2008

> "Well the role [of the university] is to do the monitoring and the evaluation but I see backpedaling on that too. We know they won't recommend management but will they get us close enough that we can identify the management?" Forest Service 2013

> "I thought we weren't making management recommendations. I think they [the scientists] use good science but I don't think it is their place to make management recommendations. Well maybe recommendations but not… not terribly clear on what's happening for SNAMP for that, where the line is drawn. Do we present the science and they take it from there or do we make actual recommendations and they take it from there? I can't answer this one." UC Scientist 2014

Disconnects such as these created a need for the UC Science Team to create a Neutrality Agreement that helped describe the UC role and what scientists could or could not do with regard to the science involved in SNAMP. In our first and final interviews we asked about UC's performance and how it could have done better with regard to its neutrality. Most participants felt that the UC Science Team had performed well and followed its Neutrality Agreement. There were only a few suggestions of how the university could have done better and there were a few instances that participants cited where there had been conflicts – a scientist spoke to the press regarding opinions about the Forest Service and Forest Service management and there was one instance where UC's transparency was called into question.

The transparency of the scientific results and process was a very important tenet of the UC third party system. UC made a concerted effort to release SNAMP results and process updates to the MOU Partners and to the public directly and simultaneously. This ground rule as well as the idea that SNAMP science would not alter the normal way the Forest Service implemented treatments were both difficult to achieve in reality. After the study area expansion, the Owl Team had to share information with the Forest Service based on contracts that predated

SNAMP and the Fisher Team also had to share denning information with the Forest Service as required by law. The transparency issue with the Owl Team arose because the sharing of results was done in a way that looked to some like the Forest Service was able to alter the results of the report. In the case of the fisher, the sharing of that information was seen by some as a positive example of a small adaptive loop within the larger adaptive management cycle.

> "...one of the owl reports was modified by the Forest Service and they changed it... They may have had good reason to change it but the perception of influence, that the Forest Service reviewed it prior to the rest of the MOUP… I am not saying there is bias but there is the perception." MOU Partner 2013

Another complication of an outside entity performing in a third party role was the funding. The relationship building section above touched on the tensions within and between the MOU Partners and the university with regard to engagement and budget constraints as strains on building relationships. Interviewees commented that the conflicts over funding were extremely difficult hurdles for the three party model to grapple with when faced with annual funding cycles, a major international recession, and a 7-10 year expectation of consistent funding from the university and the stakeholders. Some participants felt that the state could have funded the project better, especially as the state was seen as the instigator of the project, while there was also an understanding that this project was given to the Department of Water Resources without much support. The UC Science Team was seen by some MOU Partners as always looking for "a handout" which was particularly frustrating as the country crashed into a recession and California was cutting "billions from state budgets." Many actively involved participants mentioned that multi-year projects like this need funding sources that can accommodate much longer commitments. The annual funding appropriation systems for these agencies was not a good fit for this decade long project.

The reliance of the project on multiple entities and the purposeful structure that separated the management from the science, created a lack of control over the implementation of the treatments. Participants mentioned that coordinating timing between many science teams as well as across a multiple universities and federal and state agencies was challenging and in the end culminated with parts of the project at vastly different stages of study as well as little to no post-project monitoring due to Forest Service treatment implementation delays.

> "They [UC] were an integrated player putting on the ground the objectives, very dedicated people who wanted to see the results. Unfortunately the Forest Service couldn't do the projects in a timely manner, that greatly compromised the work the university researchers were able to do and will grossly impact the quality of the university report in a negative way unfortunately. SNAMP doesn't have the post-project monitoring. Absolutely no fault of the researchers." Forest products group 2014

Though the third party model may have had its difficulties, most SNAMP participants welcomed the process and felt it could and should be transferable to other situations. Perhaps most important, in thinking about the future potential of collaborative adaptive management projects, one of the highest levels of agreement in the 2014 email survey was with the statement that "participation in SNAMP is worth my time" and "I would participate in something like SNAMP again or in the future." The large majority of respondents also agreed that "the SNAMP model should be used in other situations."

In the interviews, we also asked about these latter two concepts and found strong support for both. In the first round of interviews people said they wanted to stay engaged with the project either because they had to as part of their job or because they were interested in it. In the final round of interviews almost all participants said they would participate in something like SNAMP again. The only participants who expressed trepidation were SNAMP MOU Partners and UC scientists concerned about the funding for such a long project. Most interviewees also supported the application of the SNAMP model to other collaborative adaptive management situations with two common sticking points, the funding for an outside third party or the perception of bias for an internal one.

Learning

Inextricably linked to our fundamental principles of transparency, inclusiveness, relationship building, and effective adaptive management was learning. As a result of the UC role in assessment and facilitation of SNAMP, approximately 95% of 2014 email respondents agreed they learned new things at SNAMP meetings, 88% agreed that they understood the scientific results better, 90% agreed they learned more about the science behind forest management and decision-making, and we saw interview evidence for all this learning contributing to growing shared understandings throughout the project. Learning also played an important role in the relationships section of this appendix where increased understanding of Forest Service management led to a more sympathetic attitude toward the agency and learning about other stakeholder groups, environmental NGOs, other agencies or forest products groups, helped build relationships.

As part of learning, having face-to-face exposure to scientists was greatly appreciated by participants, with more than 90% agreeing they had "adequate opportunity for face-to-face contact with UC scientists and/or Forest Service representatives" and 87% agreeing that they had "enough opportunities to provide input into UC research." Volunteer comments included pointing out "how intimidating it was to query some of the scientists...and how much they needed someone to challenge their thinking." UC Science Team members also felt they gained from the contact, with one interviewee stating that they learned how important the terms used were, and how important it is to use descriptive rather than "normative" terms like "catastrophic."

> "I learned a lot from the UC Science Team and the Forest Service managers... about language around role of fire in a landscape. I had no problem talking about 'devastating' or 'catastrophic' when we started SNAMP and now I know those are terms to be avoided. We need to be more descriptive not value laden and define in terms of outcomes not values that differ between people and may disengaged some. Language is more important than we realize… I was aware of it but SNAMP has made me relearn it and be more aware of it." UC scientist 2013

These sentiments about the importance of face-to-face contact were echoed in our interview conversations. We did not specifically ask about this attribute of our meeting planning, it was mentioned unsolicited usually in conversations about SNAMP's impact on relationships between participants:

> "The field reviews provided opportunity for one-on-one discussions that would have not otherwise occurred and so from that aspect [they were] very positive. I would not have had much interaction with [environmental NGO group] except for the SNAMP field trips.

> Now we are on a first name basis and can talk about just about anything. Wouldn't have occurred without SNAMP field trips." Forest products group 2014

The value and importance of field trips, for both learning as well as changing opinions about other participants and building relationships, was clearly prominent in the interviews across all three rounds from 2008-2014. Physically being in the woods helps to clarify discussions reducing the likelihood of miscommunication, encourages more casual conversation that help participants understand differing points of view and learn from each other as well as the trip leaders and just simply sharing a ride can provide a great space for frank and honest conversation. "There is nothing better than staring at the woods and a tree and having a discussion" because "when you are there you don't have to visualize you can actually see it." Interviewees appreciated the "hands-on" nature of field trips and they said the trips "deepened my understanding." For some, field trips were crucial because "until I see the issue in the field I do not fully understand it…"

> "I have been on plenty of field trips outside of SNAMP that have been unpleasant – head banging - and that hasn't cropped up in the SNAMP trips. That makes for an easier and more productive learning environment. Either by the handy facilitation or a different social dynamic among the people involved and I think that is another sign of a learning environment that is shared and productive." Environmental NGO 2012

An extensive discussion of the final interview and 2014 email survey results on learning about the scientific topics in SNAMP is contained in the Participation Team contribution to the integration chapter (see chapters 3and 4 in this document and below in part VII). Conclusions from that analysis showed that participants learned from SNAMP and participant opinions were affected primarily in terms of forest health, fire behavior and fisher but also with regard to forest management, wildlife biology, and hydrology. In many cases participant opinions were bolstered and affirmed by SNAMP and some participants changed their preconceived opinions dramatically.

> "...others bring up, as well as me, the results of SNAMP… outside of SNAMP meetings so it is part of a larger conversation, signaling to me that it is a productive learning environment because people are taking it out of the environment." Environmental NGO 2012

Looking over the interviews broadly, the fisher part of the project stands out as a focal topic for participants. For example, the word "fisher" is more than twice as commonly uttered in our interviews as the word "owl." Some participants were not familiar with the fisher before their participation in SNAMP and so were excited to learn what they could about this new animal in their backyards. Participants were impressed with the project's basic biological discoveries and the remarkable findings about the harmful, and surprisingly common, impacts of rodenticide. The findings from the fisher study were also quickly able to feed back into management due to Forest Service regulations requiring use of the best science available.

Another important area of learning expressed by the interviewees was about the adaptive management process and the role of the public in forest management. When asked in 2012 about the most important, interesting or useful thing learned from SNAMP many answers focused on the public portion of the adaptive management process. Participants, especially some Forest Service, university and agency participants, appear to have learned the how and why of public involvement in forest management. This came up most frequently in the 2012 midpoint interviews and less so in the first or final interviews.

> "[I learned about the] participatory model – the word "collaboration" in adaptive management system. Adaptive management only works for public resource management if it is done in a participatory way." Forest Service 2012

VI. An in-depth look at learning: An evolving concept of "forest health"

Forest health is a topic that was originally a part of the SNAMP workplan but was ultimately only partially addressed through SNAMP science. Yet it was a term that was used frequently without much attention to the varied definitions commonly associated to it. This section looks in-depth at the term and tracks SNAMP participant definitions during the project to detect if SNAMP's emphasis on learning created a shared understanding of the term forest health.

The term "forest health" has long been used in forestry programs throughout the United States (Sulak and Huntsinger 2012). The phrase appears in national policy in the Healthy Forest Initiative (2002) and the Healthy Forests Restoration Act (2003), among others. The Sierra

Nevada Framework of 2004 calls for using adaptive management to implement Forest Service programs for creating healthier and more fire-resistant forests (USDA Forest Service 2004). There is, however, little consensus on what a healthy forest is. It has been suggested that this lack of definition can hinder public participation processes (Hull et al. 2003). Shared learning is an important component of adaptive management. Earley and Mosakowski (2000) found that developing shared agreements about the meaning of crucial terms could contribute to the development of a "hybrid culture" of shared norms that helped interdisciplinary teams work together on controversial problems. It may also be the case that in participatory adaptive management for forest management, shared agreement on terms like forest health might help develop a hybrid culture of shared norms that could lead to broader acceptance of what constitutes successful management action and outcomes.

The term "health" applied to ecosystems has been described as normative, because it is value-laden, implying that there is a healthy ecosystem state that is better than other states (Lackey 2001). In fact, conditions are seen as healthy through the lens of an individual's values and policy preferences, or through individual mental models shaped by experience and culture (Norman 1983). Deciding what ecosystem conditions are healthy is the product of political or social deliberations, not scientific results (Lackey 2001; Hull et al. 2003; Warren 2007). Yet the term forest health conveys, in non-technical terms, the message of a positive goal for the forest -- something that stakeholders can rally around, and defense of the term and attempts at definition are common (Ross et al. 1997; Rapport et al. 1999; Raffa et al. 2009).

An adaptive management program is often described in the scientific literature as management designed as a series of experiments to test and evaluate management alternatives, so that managers can learn from their management outcomes (Walters and Holling 1990; Gregory et al. 2006). Adaptive management, however, cannot set the goals for the forest, making a shared understanding and appreciation for these goals crucial to the perceived success of a management initiative. Participants will ultimately assess the success or failure of the project based on their understanding of the goals for the project. If forest health is the goal, different understandings of the term could cause different assessments of the results.

Data sources

In all three sets of interviews, 2008-2010, 2012, and 2013/2014, we started off our conversations with questions about perceptions of forest health. In the first round of interviews we asked questions like: "Have you heard people use the term forest health? What comes to mind when you think of the term forest health? Do you have a particular way that you think of forest health? What would you look for to determine if a forest was healthy?" We lead off the questioning in the later two rounds of interviews with "How would you define forest health?" but inevitably for all the interviews, the follow up questioning turned toward the more concrete "If you were standing in front of a forest what would you look for to determine if a forest was healthy?"

To look at causation for the observed changes in definitions of forest health, and to look more broadly at the impact of SNAMP on forest health definitions, we asked interviewees directly if SNAMP had affected them. In both the midpoint, 2012 interviews and the final 2013-2104 interviews, we asked: "Has your definition [of forest health] changed due to what you have learned from the UC Science Team through SNAMP? Could you share an example? If no, why not?"

The first email survey (2010) began with the question: "First, we would like to know what you think about forest health so that we can conduct outreach that is meaningful for you. Below is a list of statements different people have made about forest health. Please indicate how much you agree or disagree with each statement. A forest is healthy when…" This was followed by a list of 10 attributes collected from either interviewee responses or from scientific literature.

The final email survey (2014) also began with a question about forest health: "First, we would like to know what you think about forest health in the Sierra Nevada. We are seeking opinions here, there are no right or wrong answers. Below is a list of statements different people have made about forest health. Please indicate how much you agree or disagree with each statement. A forest is healthy when…" This time there were 20 forest health attributes to rate also based on either interviewee responses or on scientific literature (Figure F23).

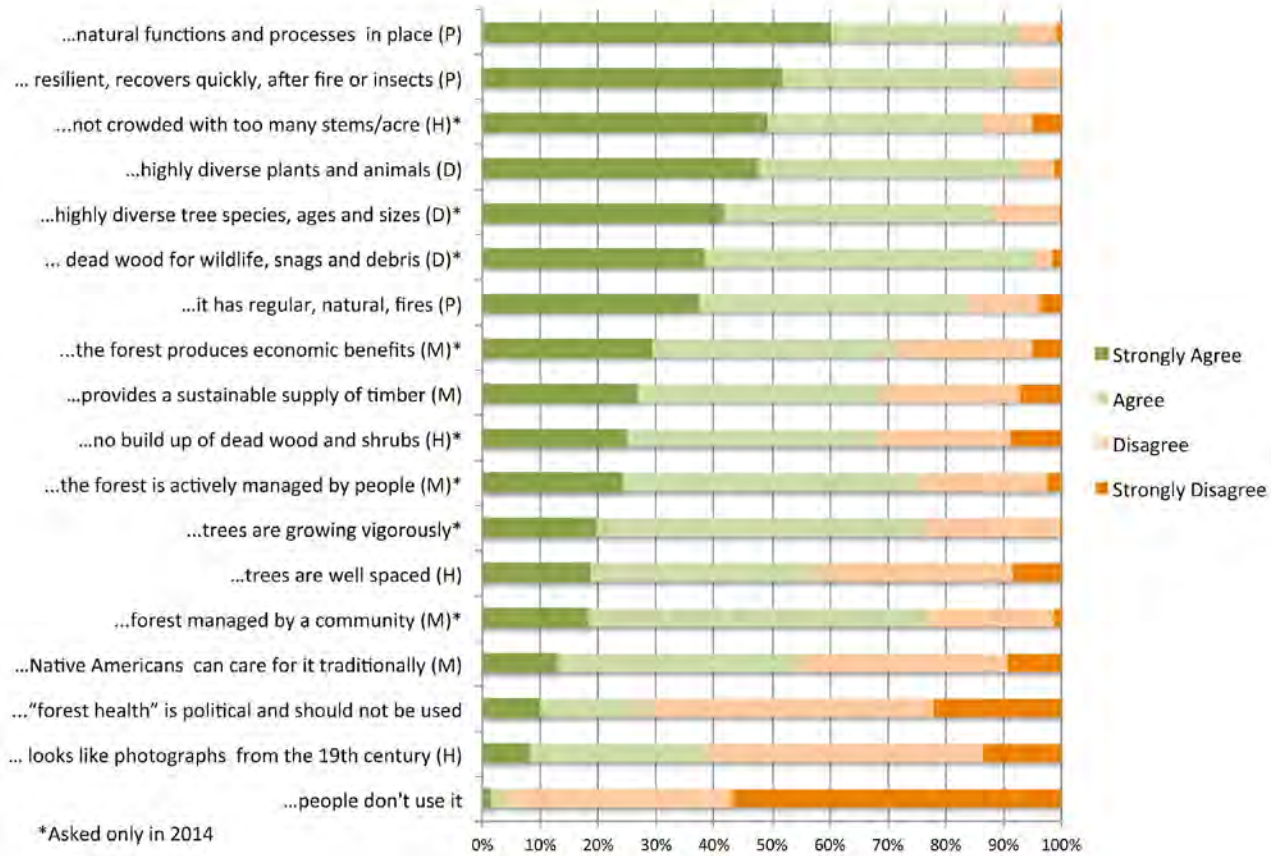


Figure F23: Respondent level of agreement with statements about what defines forest health, 2014 email survey. "A forest is healthy when…"

Four different ways of seeing of forest health

Four main forest health definition themes emerged from our analysis of the first interview responses (Sulak and Huntsinger 2012). Though interview participants typically made comments that fit more than one theme, they were categorized by their major emphasis when responding to questions about forest health. Each categorization was done without bias from knowledge of professional affiliations or previous categorizations for the later interviews.

Although we emphasize the differences, some common themes were apparent in all three rounds of interviews that formulated our forest health themes – fire was an important component to almost everyone, forest stand condition and structure were also popular components, and the condition of the trees was a part of many descriptions. Forest, water and wildlife components were broadly mentioned.

These four themes first emerged in the 2008-2010 interviews and represent views held by participants prior to the inception of the project. By looking at the tendency of our interview and email survey participants to incorporate these four original themes into their definitions, or create new themes, over the course of the project we hoped to see convergence showing the evolution of shared understandings for our participants (Sulak and Huntsinger 2012). The four distinguishing groups of forest health definitions were: Theme 1: Diversity, made up of those who related forest health most strongly to diversity or biodiversity; Theme 2: Process, populated by those who emphasized having functioning natural processes or resilience as indicative of forest health; Theme 3: Historical, comprised of participants who focused on historical conditions, often mentally comparing pictures of pre-suppression forests with those of today; and Theme 4: Management, involving respondents who were more focused on active human management as the determining factor for their definition of forest health.

Theme 1: Having diversity

A very common definition of forest health included *species diversity* or *biodiversity* as the crucial indicator of forest health. The diversity theme refers to descriptors such as the variety of tree species within a forest, diverse habitat structure and an emphasis on the myriad of other flora and fauna as well as water and watersheds. Commonly these definitions extended past diversity into ideas of process, resilience and balance but diversity was the primary component.

> "[To me, forest health is] biodiversity, maybe not too heavy a dying rate… Healthy forest equals a mature climax forest. [I would look for…] again, number of dead trees, large trees, bird poops, thickness of the duff for good water retention and little run off, lots of diversity all the way down to microscopic and then up to larger animals, the opposite being a forest clear-cut." 2008

Statements in the 2014 email survey that might be seen to correspond to a diversity theme were uniformly agreed to by a majority of participants (Figure F23, see "D" after statement). A third or more of the respondents strongly agreed to the three diversity related statements, and there was around 90% agreement overall on them.

Theme 2: Functioning processes

Ecological processes was also a popular way to define forest health. This theme's definitions commonly focused on the forest ecosystem as a whole and its resistance to change or resilience disturbances such as fire or insect outbreaks. Again, these definitions did have overlaps, and people with this mindset may have also used a pre-European setting as a benchmark, but their dominant focus was on the processes that created or maintained what they considered a healthy forest. There was a strong overlap between process definitions and diversity definitions due to the diverse set of species and relationships needed to foster an idealized resilience.

> "[To me forest health is] resilience in the face of change. Diversity in terms of stand structure, landscape makeup, species composition. Disturbance processes – are they active? Can I see that they are functioning? Successional processes – are they operating? They are really important." 2008

In the 2014 email survey, the two most strongly agreed to statements were about process, with more than half the participants strongly agreeing and more than 90% overall agreeing that an indicator of a healthy forest was "having all natural functions and processes in place." Respondents were a little less certain about the role of "regular, natural, fires," even though fires are often referred to as a crucial natural process. Still, more than 80% of respondents agree that a healthy forest has regular, natural fires (Figure F23, see "P" after statement.).

Theme 3: Looking like historical conditions

Those in this theme prioritized *historical conditions,* or looking like a pre-contact forest, in their descriptions of what forest health meant. Historical definitions generally focused on what most of us think the forests of pre-European times dating to 100-150 years ago in California looked like, with widely spaced trees and an open understory. The emphasis is on how the forest *looks*, rather than what is going on in it. This group wanted restoration efforts to recreate this earlier forest. Descriptions tended to reference snapshots or photographs, or a mental vision, of an earlier time, and frequently associated current conditions with a lack of fire in the Sierran forests. Water, diversity, ecological processes and wildlife were common secondary elements of these definitions.

> "I think of a healthy stand of a variety of species of trees that are appropriately spaced, what I mean by that is, when I go back and look at historical photos of Mark Twain or Teddy Roosevelt traveling the Sierra you see a landscape with fewer larger trees and a grassland mountain meadow vegetation type." 2008

From the email survey, the idea that an uncrowded forest was a healthy forest was strongly supported with close to 50% of respondents strongly agreeing and about 85% overall agreeing to it. On the other hand, "widely spaced trees," and "looks like a photograph" from the 19th century were not so strongly supported as indicators of forest health (Figure F23, see "H" after statement.).

Theme 4: Active management

Active human management was a prominent component of the definition of forest health for this group. This idea of active human management or intervention as part of what forest health entails was mentioned infrequently by interviewees in other categories.

> "Forest health is better management." 2009

> "…It is managed, not preserved, especially managed and not preserved." 2010

Email respondents almost unanimously did not espouse human exclusion from the forest. The least popular statement in the survey about forest health was that a forest was healthy when "people don't use it": 95% of respondents disagreed with that statement, and more than half strongly disagreed. More than 70% of respondents agreed that a forest should be actively managed, and that it should provide economic benefits. Email responses did indicate that by who and why management was carried out was a consideration that affected agreement with management related statements. Just under 70% thought a healthy forest should produce a sustainable supply of timber. While more than 75% agreed a healthy forest is one managed by a community, a bit more than 50% agreed a healthy forest was one managed by Native Americans in traditional ways (Figure F23, see "M" after statement).

Forest health definitions over time

As reported in the integration chapters (chapters 3 and 4 and in part VII below), two thirds of respondents to the 2014 email survey agreed that during the SNAMP project, their views of forest health had undergone change, and half agreed that their ideas about forest health changed because of their experience in SNAMP. In terms of participant agreement with statements about what constitutes forest health, there were significant changes over time in agreement with some statements between the 2010 and 2014 email surveys ($p<.05$). In the email survey, the proportion of those strongly agreeing that a healthy forest is one with natural functions and processes in place increased significantly, from 51 in 2010 to 60% in 2014. The proportion of respondents strongly agreeing a high diversity of plants and animals is important also increased significantly from 38 to 48%, as did the proportion strongly agreeing that a healthy forest is resilient (41 to 52%), and the proportion of those agreeing that a healthy forest should provide a sustainable supply of timber (18 to 28%). On the other hand, those agreeing that a healthy forest has well-spaced trees declined from 29 to 19%. Agreement with the remaining questions asked about in both years did not waver.

Unlike the email survey data that can be used to make inferences about those who had an interest in Sierra Nevada forest management, the interviews attempted to represent a diversity of views. The interview numbers reported here do not reflect proportions of a population but are used to show trends. The interview numbers support the email survey information and tell us that there are areas of forest health definition convergence even when a diversity of opinions is sought (Figure F24).

In the first round of interviews, there were 12 SNAMP participants categorized into the theme of diversity and 9 into the theme of process (n=34 SNAMP participants). The management and historical groupings respectively contained 7 and 6 participants. Interviewees were selected for their differing backgrounds, affiliations, and viewpoints and we did see some correlations between forest health definition and type of participant in the early interviews. Forest Service participants were the only group represented fairly evenly through all of the themes. The diversity and process themes were more likely to be composed of UC scientists, agency representatives and other active SNAMP participants. Not included in the analysis here, but the SNAMP non-participants tended to affiliate with the historical and management themes (Sulak and Huntsinger 2012).

When compared to the first set of interviews, we saw shifts in the tendency of our 2012 midpoint interviewees to affiliate with the different forest health categories (n=27 SNAMP participants). Process became dramatically more common (15 participants), diversity slightly less so (9 participants), and management (2 participants) and historical (1 participant) much less common. Most professional affiliations were spread throughout the forest health theme categories except Forest Service (4 participants) who were now all categorized into the process group. This is a distinct change from the first interviews where the Forest Service participants were spread pretty evenly across the four forest health themes.

The general categorical trends continued in the third and final round of interviews (n=26 SNAMP participants). Process continued to become dominant (17 participants), diversity lost ground (6 participants), and management (2 participants) and historical (1 participant) stayed steady though still much less common. One person defied categorization with a very vague answer and lots of honest “I don’t know” comments. In fact, many people throughout the three rounds of interviews began their comments with a qualification: “I am not a forester but…” Again in the final interviews, like in the 2012 interviews, most professional affiliations were found across the categories except Forest Service participants (5 participants) who were all categorized into the process group.

The only affiliation group that did not change its category was forest products. There were two forest products participants in each round of interviews (not always the same person) and they consistently affiliated with process definition.

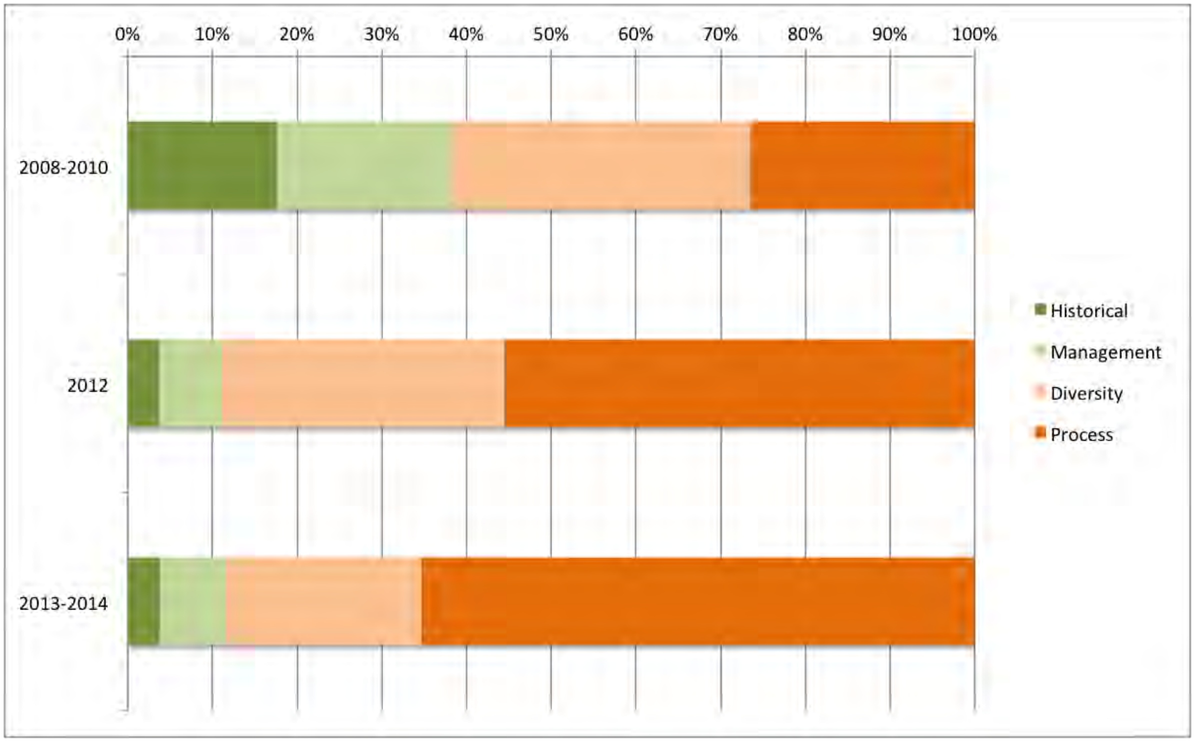


Figure F24: Proportion of interviewees by year of interview categorized into each forest health theme.

Evolution of category: Theme 1 - Diversity

The demographics of those from the first set of interviews who described forest health by the diversity theme reflected the overall interviewee pool and only differed in that they claimed slightly fewer years of experience in natural resources (mainly 30 years or less). In the second round of interviews the diversity participants lost numbers but set themselves apart by being composed of more women than any other group in relative and absolute numbers but this was not the case in the final interviews.

By the final interviews, diversity was a theme that, though not dominant in definitions, did appear in the majority of interview conversations about forest health. Frequently when asked for a formal definition of forest health, answers would be heavy in functioning ecosystems and processes but when asked what to look for if standing in front of a forest, the responses were about looking for signs of diversity as metrics for forest health.

> "...Personally I would look at it as one that is resilient to large scale insect and disease outbreaks and fires." What would you look for to determine if a forest was healthy? "Probably a combination of the diversity, species diversity, age class diversity, and size class diversity, density (stocking levels – if it appears to be under or over stocked), and just overall forest structure…" 2014 Process

Evolution of category: Theme 2 - Process

At the start, the characteristics of those who comprised the process group in the first round of interviews diverged the most from the overall interviewee demographics: only long-term active SNAMP participants, all college graduates mostly with graduate degrees, and slightly higher incomes. All of the participants in this category had been involved in SNAMP since inception or the start of active work in 2007. In fact, out of the interviewees as a whole, the term "resilience" tended to come from participants who were actively involved in SNAMP.

In the 2012 round of interviews, the process participants were similar in demographics to the first round but the addition of new interviewees did diversify the group slightly. (Six of the participants had been categorized into the process group in the first round of interviews and two each moved from diversity and historical into process with this round of interviews.) These participants were still dominated by long term SNAMP affiliations, many starting with the project before 2007. Even for those new to this round of interviews and this category, they also claimed long tenures with SNAMP starting in 2008 and 2010. Similar to the first round of interviews, mentions of the term "resilience" in these 2012 interviews also tended to come from active SNAMP participants. The term was mentioned by most of the process theme participants but also by two diversity theme participants.

Though the process group dominated the participants in the final round of interviews, the participants in this theme were still well educated (all but one completed college or a higher degree), had high incomes (half made $100,000 or more per year), and had been with the project for a few years (all started with the project in 2011 or before). In other ways, since the process group now claims most of the study's participants, they represent the group as a whole - they ranged in age from 30-69 years old, contained about half of the female participants, a little less than half grew up rural or forested or live in forested now, and they ranged up to 40 years in experience in natural resources. In this round of interviews, use of the term "resilience" came from the process group as well as one diversity and one historical participant. Overall mentions of the term "resilience" did increase in frequency over the three time periods with half of all the interviewees using the term in the final interview. The following is an example of a final interview process definition:

> "Forest health to me is the ability of the forest to be in a state to regenerate and evolve when subject to disturbance." 2013

Evolution of category: Theme 3 - Historical

In the first round of interviews the historical group of interviewees was different in that it contained the most non SNAMP participants (Sulak & Huntsinger 2012). However, the SNAMP participants in the historical category that we focused on for this analysis were not different than the group as a whole. In the midpoint and final rounds of interviews the historical theme still appeared within interviewee's definitions but not nearly as frequently and was almost non-existent as a dominant theme (1 person each for midpoint and final interviews). A UC scientist from the midpoint interviews and an (otherwise unaffiliated) fire safe council participant from the final interviews were categorized into the historical theme. They both had been categorized into other themes in previous interviews but in these two conversations they leaned on historical components in their forest health definitions.

These interviewees were not alone, historical reference points were still important to many participants in the learning and final interviews. Overall, 8 people categorized to forest health themes other than history mentioned historical reference points in their descriptions of forest health in the midpoint interviews. Participants made comments such as this one - it incorporates a historical reference point but places another theme higher in importance.

> "I define [forest health] as a desired condition in the forest that reflects both the historic conditions and current conditions being evaluated and measured with a measure of resilience or ability of a forest stand to come back after disturbance." 2012 Process

In the final interviews, historical reference points also came up in other interviewee descriptions of forest health from a variety of participant types. These people talked about aiming for “original or native” conditions, “alignment” with or “mimicking” historic patterns and bringing the forest “back to a resilient natural state." One person talked about protecting the post-European human features of a forest.

Evolution of category: Theme 4 - Management

In the first interviews, the management group diverged in that it contained no university or agency representatives. They also tended to be older, over 50 years old, and claimed either less than 10 or over 30 years of time in natural resource work. In the midpoint and final interviews, management as a theme was again less common but still strongly advocated by those in this category (2 participants each round of interviews).

In the midpoint interviews, the two participants in this category were a local government representative and an unaffiliated citizen. Their demographics are similar to the first round of interviews in that they were older, in their 60s and over 80 years old, one called himself a rancher and a logger and the other was with the Forest Service before he retired, neither graduated college and they both had 50 or more years of experience in natural resource work.

The management theme persisted in the last round of interviews and was advocated here by one person affiliated with an environmental organization and the only person, a local government representative, who was categorized to this theme in all three interviews. The quote below gives more depth to this person’s definition, showing an appreciation for Native American management. The other person, affiliated with an environmental NGO, was categorized in previous interviews into the process and diversity themes and that is apparent in the quote.

> “I describe it as a managed ecosystem – [now] it is not managed, white man has messed it up the last 100 years.” 2014

> “Forest health is smart management – it’s not just clearing its not just leaving things – it’s looking at the whole picture, plants, animals and the surrounding communities.” 2014

Humans, nature, and forest health

The interactions, connections, influence and impacts between humans and the environment have been subjects fraught with controversy for centuries. In our interviews we looked for strong opinions about this subject on either side. Those who see a necessary connection between humans and nature can be seen in our management group. As in the email surveys, those who see humans as having a negative impact on nature and forest health were few and far between in our interviews. The strongest sentiment found amongst our first interviewees is represented by this quote:

> "Depends on how much humans have inserted themselves into modifying the operation and function – where humans have a moderate influence say on fire regime, high elevations, [the forest is] probably pretty healthy." 2008

In the latter two interviews, 2012 and 2013 this person did not mention this idea of human influence again. In the midpoint interviews, the human-nature relationship was touched on by four participants outside the management theme. Some mentioned a sentiment implying that less human impact allowed a more natural and better forest, though difficult in this fire suppression era, and one leaned the other way, advocating for human use of the forest.

> "[A healthy forest is] ...not terribly impacted by human behavior – garbage or roads, and lumbering possibly, and things do need to be thinned out especially if we don't have fires. I would accept some human impact under the circumstances that exist now. We have too many people in the world now." 2012

> "Because we are next to all the forest areas it is important that we are able to access them but also to take care of them. ... it is good to have that usage." 2012

Similarly, in the final interviews, outside of those categorized into management, only two people mentioned anything related to nature being impacted positively or negatively by human influence. One person categorized to process talked about how it is important that these processes not be "... prevented by human intervention...." Whereas another participant specifically put human needs into her definition of process: "...and because we are people who need to build things, and need resources from the forest, there should be a little of that too but in a healthy sustainable way."

Recognizing forest health as a normative term

Some participants talked about the idea that the term forest health was subjective, or politically motivated and had negative connotations for them; to some the term really meant "cutting down trees." This sentiment was mentioned by interviewees across all the forest health categories.

> "I suppose it is first and foremost a political term – intended to be persuasive in one way or another." 2008 Historical

> "Forest health equals cutting timber with the excuse of making the forest healthier – [its] a con job." 2008 Process

In the midpoint interviews, a few participants also mentioned a skepticism of the term forest health. Unlike the earlier interviews, however, no participants mentioned a political or negative connotation for the word.

> "To me, it's an ambiguous term. It means different things to different people. There is not a clear consensus to exactly what it is. I don't personally like the term because it's kind of ambiguous." 2012 Process

> "It is a real subjective [term], it's in the eye of the beholder." 2012 Process

In the final interviews many participants mentioned a similar frustration with the term "forest health" calling it "a vague term", "nebulous", "subjective" and "...everyone's definition might differ…" or "...it means different things to different people…" One participant said she tried to avoid using the term due to the connotations connected with it. Two new ideas brought up in the final interviews were about the impact of agency affiliation on forest health definitions (mentioned by two people) and the importance of aesthetics.

> "...it's very complicated. I think it just depends on which agency you work for … or what kind of background you have." Process 2014

> "... I would ... add aesthetics--it appeals to my preconceived notions of what a healthy forest should look like. I wish there had been more discussion of this but probably

> because this is something that science can't put its hand on, the aesthetics of a sustainable forest." 2014 Diversity

In the email survey, around a quarter of participants agreed that "forest health" was a term with political connotations and should not be used (Figure F23).

Impact of SNAMP on forest health definitions

We looked for the influence of SNAMP on participants' definitions of forest health in a few different ways: how the definitions changed for individual interviewees across two or three interviews, what the participants said themselves about the influence of SNAMP on their own definitions of forest health, and how definitions changed over time within the email survey respondents from 2010 to 2014.

Forest health definition changes across time for the same individuals

Of the 47 people who participated in our interviews, 23 of them did only one interview. For those that did more than one interview (24 people did either 2 or 3 interviews), we saw changes in the category of their answers for 13 of them, a little over half. Obviously, since the process category ends up dominating the final interviewees and the historical group all but disappears, the biggest shifts are into process and out of historical. As of a person's last SNAMP interview, six people ended up being categorized into the process group, mainly moving out of the diversity group and two moving from the historical group. Four people moved into the diversity group from both historical and process. One anomaly is an environmental NGO participant whose definition was categorized into the process group to start, then moved to diversity and finally into the management group. These results do not show causation but they do show that participants in SNAMP tended to move toward forest health definitions that were increasingly process based while involved in SNAMP.

Self-reported impact of SNAMP on forest health definitions

A few participants mentioned important changes to their definitions of forest health based on what they experienced in SNAMP. Some of these participants mentioned adding an interdisciplinary aspect to forest health definitions, another moved his definition away from a historical perspective, and another changed her language and scale of analysis based on what she learned in SNAMP.

> "I have come to recognize that because of climate change for example, simply going back to a forest from 1850 or 1870 may not be the sole criteria...I had an overly romanticized idea of what an ideal Sierra forest should be..." 2012 Diversity

> "Mostly I thought at a watershed scale, so I never thought at a larger landscape scale and that helped me broaden my thinking…" 2013 Diversity

> "...it relates to a forest where the spacing or the density of the trees is unsustainable, I didn't really look at that prior to SNAMP…." 2013 Process

Overall, most SNAMP participants felt they learned to expand or extend their definitions or their preconceived definitions were reinforced. A few stated that their general definition of forest health did not change but the details did. Definitions evolved to be more holistic or include more aspects of forest health such as wildlife, water or the role of fire in the ecosystem. Some participant definitions did not change but they said they did learn from SNAMP about forest health, others learned about the forest management techniques to create forest health, a few were waiting for final SNAMP results, and others felt SNAMP had absolutely no impact on their thoughts about forest health.

> "I have become more knowledgeable, if you will, of what a healthy forest would consist of and what are the threats that face a healthy forest or a forest stand condition. … it definitely has strengthened my building blocks of forest management." 2013 Process

Regardless of whether a participant self-reported a perceived change in his or her personal forest health definition many of their answers did show how SNAMP influenced their definitions. The interdisciplinary format of SNAMP allowed many participants to learn outside their area of expertise broadening or expanding their definitions to include more aspects of forest health such as wildlife needs, water impacts and fire.

Through the interviews, both in actual definition changes, as seen in the increase of the popularity of the process theme definitions and decrease in historical definitions, and in self-reported changes to personal forest heath definitions, we saw changes during the many years of SNAMP as well as a direct influence of the results of the SNAMP science.

VII. An in-depth look at learning: Participant responses to treatments

Similar in premise to Part VI, this section addresses the impact of the SNAMP learning experience on participant opinions of the response of the studied resources to the treatments. Here we also found strong shared understandings based in the findings of SNAMP and this analysis provides the basis for the Participation Team contribution to the full SNAMP integration in chapters 3 and 4 of this report.

The integration framework created by the UC Science Team for the SNAMP project attempts to graphically present long and short term responses to fuels treatments as studied in SNAMP (Figure F25). For each team the question posed by this diagram is: "what are the short and long term responses of study subjects (participants, water, wildlife, forest and fire behavior) to the Forest Service fuels treatments examined by SNAMP, called SPLATs, and then, as a whole, how can these responses be understood and integrated to be of use to forest management decisions for the Sierra Nevada?" The Participation Team used information gathered up to 2014, prior to the final SNAMP results and report, to address these questions. Data from interviews and email surveys of SNAMP participants pertaining directly to perceptions of treatment outcomes, and about the role of SNAMP in shaping perceptions, was used in this analysis. The focal questions can be restated for the Participation Team as, "how do SNAMP participants perceive the short term and long term responses of the studied resources to fuels treatments conducted by the Forest Service, and did SNAMP help shape these perceptions?" Overall, results demonstrated public endorsement of the fuels treatments by participants, showed that participants learned from SNAMP, and revealed that most participants thought that long term treatment impacts would be positive.

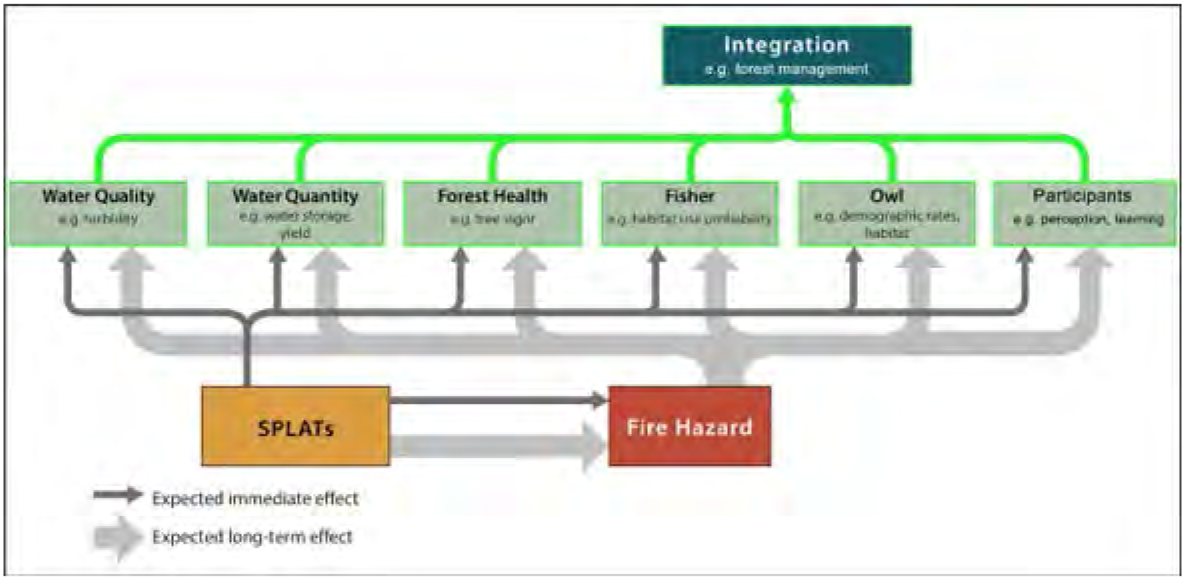


Figure F25: SNAMP integration framework.

Stakeholder opinions

Stakeholders were asked for their opinions about how SNAMP fuels reduction treatments influenced the resources studied in SNAMP, including forest health, Pacific fisher, California spotted owl, and water quantity and quality. Because the SNAMP process had a goal of improving relationships among groups, in some cases affiliations were used to differentiate respondents, breaking them into nine groups: UC Science Team, Forest Service, other state and federal agency participants, environmental NGOs (non-governmental organizations), forest products groups both for and not for profit, local governments, Native American Tribe representatives, and unaffiliated (including fire safe council members, local citizens and other types of interested parties) (Figure F26).

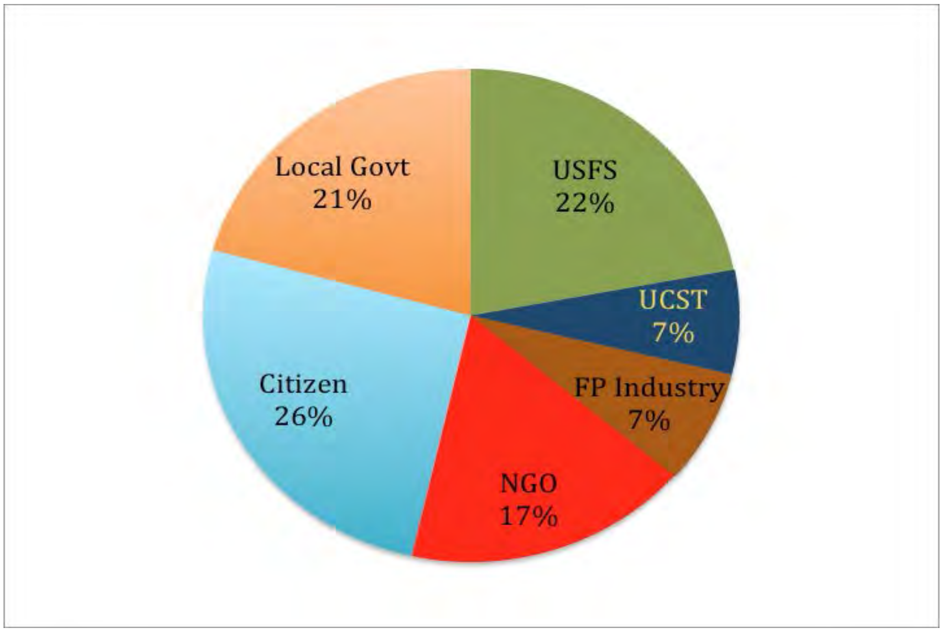


Figure F26: Respondent affiliations in 2014 email survey, N=258.

Fire and forest ecosystem health

Overall, email survey respondents felt that SNAMP fuels reduction treatments, and forest fuel clearing methods that reduce fire hazard in general, had the effect of improving forest health in the short term and long term (Table F7). Interviewees were also united in their opinions about the impact of treatments on fire behavior: all but one of the interviewees felt that the treatments would reduce the intensity of a fire in the treated areas. This was the dominant view across all interviewee categories. Concerns raised were that extreme weather and severe fires would likely overwhelm the treatments. It was also mentioned that some treatments still needed to be completed and cleared of debris piles. Several interviewees who spoke about the Last Chance site since the American Fire in 2013 felt that the treatments there did reduce fire damage, though it was difficult for some to tease out the impacts of treatment from the impacts of the back burning and fire-fighting. Some interviewees felt that the Sugar Pine treatments would likely have less of an influence on fire behavior because the treatments were implemented with a lighter touch, and others felt that neither treatment went far enough to actually create a fire-resilient landscape. The only interviewee who did not think that the treatments would have a "positive" impact on fire behavior answered "I don't know" and was an agency representative.

This person was not aware of any peer reviewed results where SPLATs had been tested by a fire, but also did not feel it was adequate to rely on modeling, and so felt unable to answer.

Table F7: Summary of SNAMP participant opinions of the impacts of fuels treatments on forest health.

Fuels treatment impact on…	**Respondents' Opinions** Email survey n=258 Interviews n=26
Forest health in general (email survey)	-Short term = 79% improved, 9% no change, 12% deteriorated -Long term = 72% improved, 19% no change, 9% deteriorated
Fire behavior (interviews)	-Fuels treatments could reduce intensity of fire -But could be overwhelmed by extreme weather and fires -Treatments needed to be complete and debris cleared
Sugar Pine project area forest health (email survey)	-Short term = 81% improved, 10% no change, 9% deteriorated -Long term = 63% improved, 26% no change, 11% deteriorated -Amount of material removed = 67% too little, 26% just right, 7% too much
Sugar Pine project area forest health (interviews)	-More healthy due to reductions in stand density and understory fuels -Treatments were possibly too light or not big enough
Last Chance project area forest health (email survey)	-Short term = 77% improved, 6% no change, 17% deteriorated -Long term = 65% improved, 23% no change, 12% deteriorated -Amount of material removed = 58% too little, 31% just right, 11% too much
Last Chance project area forest health (interviews)	-More healthy due to reductions in stand density and understory fuels, enhanced aesthetics and more similar to historical -Treatments were successful in reducing intensity of American fire (2013) -Treatments were possibly too light or not sure of opinion

The following are examples of interviewee responses to the question: "In your opinion, do you think the SNAMP forest fuel treatments in the Last Chance and Sugar Pine projects will affect fire behavior?" Some respondents addressed the effects of the American Fire in their responses:

> "I think it would reduce the chance of a high intensity fire. And reduce the risk that the fire would get into the crowns of the trees after the treatment." Native American Tribe representative

> "There was an interesting discussion about...the back burning that was intentionally done to control the fire once it got in there, how that is going to be teased out of the analysis to determine potential treatment versus fire impacts." UC Science Team

> "I want to say it's too early to say it has improved. I think the forest stand conditions [in Last Chance] were in a more resilient stand condition when that fire went through… We did have mortality but that mortality, I want to say, was much less than what it would have been if we didn't have any treatment before the fire." Forest Service

> "…hopefully it will but with the changing climate it's really hard to know what's going to happen. But it is really good ... that the Forest Service is taking this step to try to reduce that problem before we have another Rim fire for example…" Agency representative

SNAMP project areas

Given the interviewee agreement that fuels treatments could positively affect fire behavior it is not surprising that overall both the interviewees and email survey respondents saw the project areas as more healthy after treatments were implemented (Table F7). Of those interviewees who did not see the study areas as more healthy, some did not feel comfortable answering because they had not been to the study sites, a very few thought the treatments would have no impact, and only one person felt that the treatment areas are now less healthy. Similarly, email survey participants who had attended a field trip or visited the treatment sites were more likely to respond with an actual opinion, and less likely to say "I don't know."

Specific to the Sugar Pine project, the majority of respondents to the email survey agreed that forest health was improved by the treatments in the short term (Table F7). Environmental NGO respondents ("NGO" in the figures) were the most likely to be concerned about deterioration in forest health in the short term (Figure F27). Those in the forest products field and environmental NGOs were most concerned about deterioration in the long term – write in comments indicated that this was often because the forest products group thought the treatments did not remove enough material to have a lasting effect. The results were similar for email survey participant opinions of Last Chance, except that the UC Science Team was divided about the short term effects, split between improved and deteriorated, and more often agreed the long term health deteriorated. Interviews and comments indicate that this is also because they felt the treatments were too light to last (Figure F28).

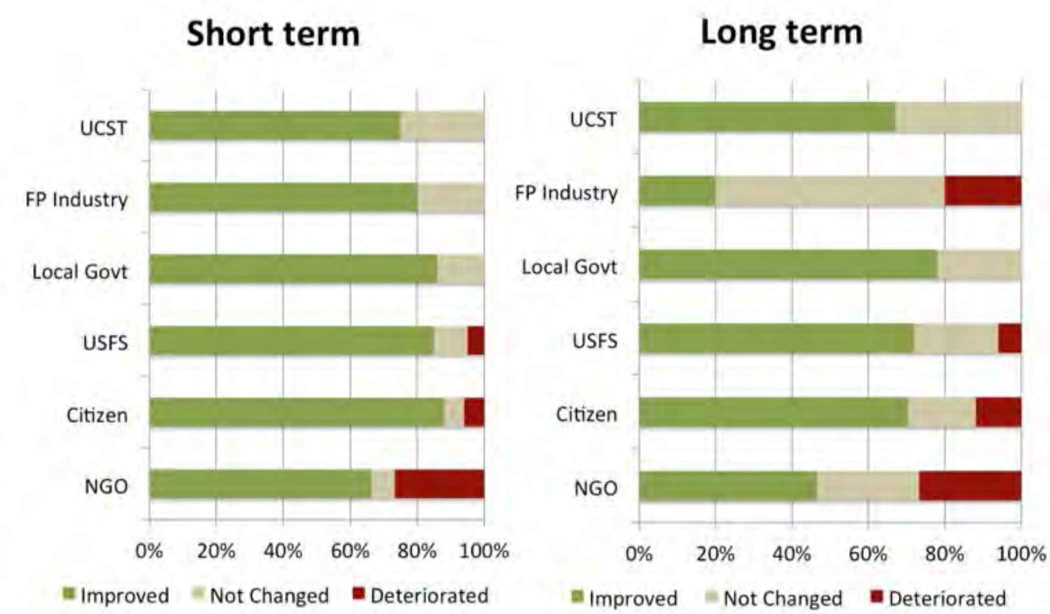


Figure F27: Perceptions of forest health after fuels reduction treatments at Sugar Pine, 2014 email survey, different affiliations. Altogether about 67% felt that the treatment removed too little, 26% just the right amount, and 7% too much material from the forest.

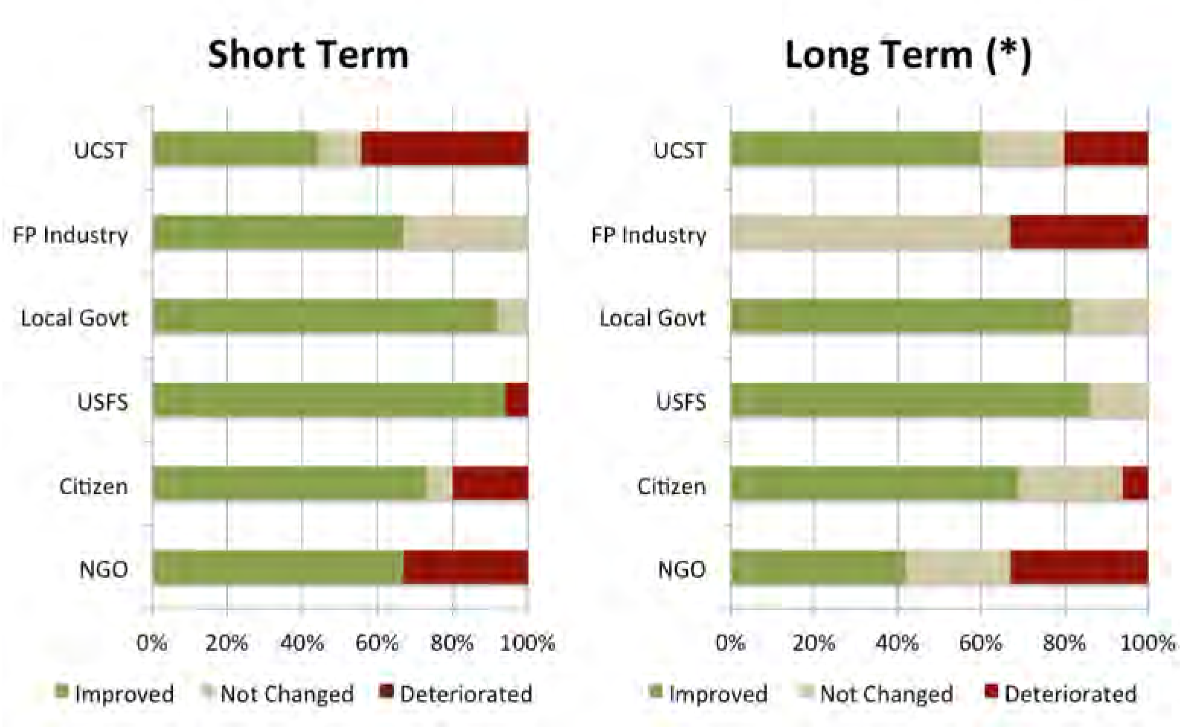


Figure F28: Perceptions of forest health after treatments at Last Chance, 2014 email survey, different affiliations (* = responses differ at p<.1, χ^2 by affiliation). Altogether about 58% felt that the treatment removed too little, 31% just the right amount, and 11% too much material from the forest.

For the Sugar Pine study area, those interviewees who answered from experience at the site after the treatments were implemented mostly felt the area was healthier (all groupings represented except agency participants, mostly because they had not been to the site) and attributed this to reductions in stand density and understory fuels increasing resiliency. However, some interviewees still felt an increased number, diversity and/or intensity of treatments needed to occur. For example, interviewees mentioned treatments could have poked holes in the canopy more like is described in Forest Service General Technical Reports # 220 and 227 (North et al 2009; González-Cabán 2009), should have increased heterogeneity more, and could have included more under-burning. Those interviewees who felt that there was “no change” in forest health after the treatments felt this way because not enough land was treated and the forest would subsequently not be able to withstand a wildfire.

Interviewees who had been to the Last Chance site and felt there had been improvement believed that the treatments created a more healthy landscape for the same reasons they did at Sugar Pine with the addition of enhanced aesthetics and increased similarity to historical forests. But compared to those who visited Sugar Pine, interviewees who visited the Last Chance site were more likely to say that they did not know if the forest health of the area had changed due to the treatments. All those who "didn't know" but had been to the Last Chance site were Forest Service, UC Science Team or agency participants and most are waiting for the final UC Science Team results to decide.

We pursued the emergent interviewee theme about the level, or intensity, of treatment through the email survey and found that about half the email participants felt that the two treatments removed "too little" material (Table F7). For the Sugar Pine treatment, those saying the treatments were "too light" were mainly US Forest Service, environmental NGO, local government, and industry participants. The UC Science Team respondents were more heavily represented in the "far too little" removed category and the general public was split between the "too little" and "just right" categories for the Sugar Pine treatment. At Last Chance, the US Forest Service, environmental NGO, UC Science Team, forest products, and general public participants were strongly in the "too little" category whereas local government participants felt more strongly that the treatment was "just right."

The following are examples of interviewee responses to the following question: "What is your opinion about forest health in the southern Sugar Pine project area now that the Forest Service's fuel reduction treatments have been implemented?"

> "I think that... it is probably closer to a reference condition and more within range… probably the biggest change may come through some increased resiliency to extreme fires." Environmental NGO

> "I'd say it has been... definitely improved. I think because the treatment areas have reduced density, they have opened more space for regeneration. And I think that those areas, when subjected to wildfire, inevitably will have a benefit to the areas that... have no treatments." UC Science Team

"...we are learning a lot about it. Most importantly we have been able to assist the community around it to learn more about what forest health is – not just going in and cutting things down or not just going in and leaving things alone either." Environmental NGO

"It's probably 100% better than it was 7-8 years ago when we started. Everything you guys have done, I drove up in there and looked at it, and had those field trips. I just love what is happening. I love the idea that they have environmentalists there to look at it and see what it takes to have that final healthy forest." Local government

"I recognize that not the entire areas were treated and that it varies from place to place. I would say that the fireshed as a whole is probably healthier, I think the treatments were done well and they tried to preserve biodiversity and tried to preserve multiple age stands and all the things I think are part of forest health." UC Science Team

"At extreme risk to wildfire. In my opinion in north and south sites, we aren't doing enough fuels reduction to do a difference if there is a wildfire." Forest products

"...part of the reasons that forest health didn't change significantly in the south is that there were a lot of other conditions that affected the potential to change the forest structure through treatment. Most of those are related to protecting stand density and larger trees and the heavier canopy even if it did pose potential fuel risks in order to protect the threatened species, the Pacific fisher." UC Science Team

The following are examples of interviewee responses to the following question: "What was your opinion about forest health in the northern Last Chance project area after the Forest Service's fuel reduction treatments were implemented but before the fire?"

"It didn't seem quite as overgrown but still pretty high vegetation density." Agency representative

"From what I saw, everything that I saw that was treated, looked aesthetically better to me and more likely to be a sustainable forest than what I remembered in the before condition." Unaffiliated citizen

"...looking at scientific data, I would expect it to be healthier because there had been a move to make it more like a historic forest with more open areas and less competition for nutrients and water…two years' time isn't enough time to really see what's going to happen…" Unaffiliated citizen/Fire Safe Council

> "I believe they were successful...I wish we had the opportunity to do more work out there but it was money dependent. Some of the treatments required additional funding which was a challenge to begin with to get as many acres treated that we did." Forest Service

Enjoyment

Enjoyment of the forest is another barometer of participant satisfaction with the treatments. The dominant sentiments of email survey participants were perceptions of improvements or no changes in their ability to enjoy the forests after treatments. The majority of participants in all the subgroups reported that their enjoyment of the area would be improved in the long term after the treatments or at least there would be no impact from treatments on their enjoyment. In the short and long terms, only a small group of email survey participants felt their enjoyment of the forests had decreased after treatment. Of the subgroups, the Forest Service, UC Science Team, and local government participants felt there was no change in their enjoyment of the forests in the short term after the treatments (Figure F29). The environmental NGO and public participants were the most positive of the effects of treatments on their enjoyment of the forest saying their enjoyment had improved in short term. In contrast, the forest products participants saw deterioration or no change in their enjoyment of the forests after treatment in the short term.

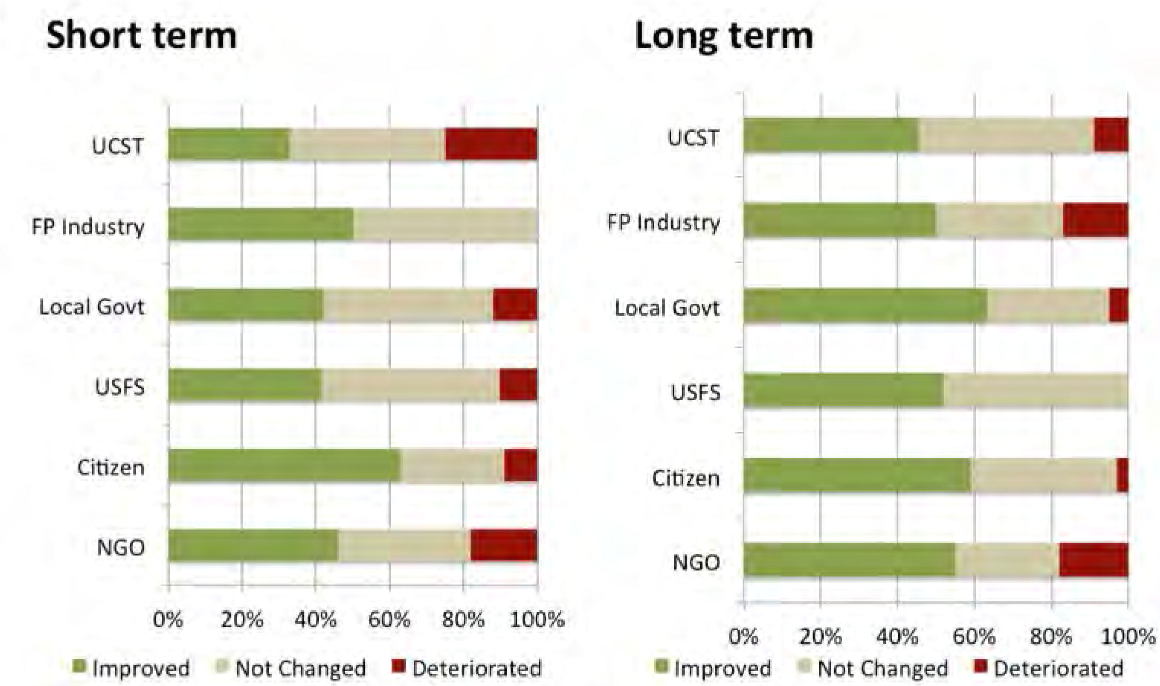


Figure F29: 2014 email survey: After treatment, my enjoyment of the area has increased in the short term (left); long term (right).

Wildlife species

The email survey respondents were not united in their opinions of the impacts of treatments on the two wildlife species in the short term – the Pacific fisher and the California spotted owl (Table F8). For both species the email survey respondents were split into thirds on the impact of the treatments in the short term – a third saw fisher and owl habitat as deteriorated, a third saw it as improved, and a third anticipated no change in the short term.

Table F8: Summary of SNAMP participant opinions of the impacts of fuels treatments on wildlife, water, and enjoyment (percents do not necessarily add to 100% due to rounding).

Fuels treatment impact on…	**Respondents' Opinions** Email survey n=258 Interviews n=26
Pacific fisher (email survey)	-Short term = 32% improved, 39% no change, 29% deteriorated -Long term = 73% improved, 15% no change, 12% deteriorated
Pacific fisher (interviews)	-Other issues may have been more important than treatments: rodenticide, road kill and predation
California spotted owl (email survey)	-Short term = 32% improved, 39% no change, 29% deteriorated -Long term = 67% improved, 20% no change, 14% deteriorated
California spotted owl (interviews)	-Will not see impact of treatments because there were too few owls in study area or treatment area too small
Water quality and quantity (email survey)	-Short term quality = 41% improved, 43% no change, 16% deteriorated -Long term quality = 63% improved, 31% no change, 5% deteriorated -Short term quantity = 56% improved, 34% no change, 10% deteriorated -Long term quantity = 57% improved, 36% no change, 8% deteriorated
Water quality and quantity (interviews)	-Treatments were positive compared to severe fire -Possibly minimal to no impact -If positive, might have increased yield

The email survey showed the detail behind the even split in opinions about the impacts of treatments especially in the short term (Figures 30 and 31). The US Forest Service and forest products groups saw no impact on the fisher or the owl in the short term. For the fisher, the UC Science Team and the environmental NGO participants felt that there could be negative impacts in the short term. For the owl, the environmental NGO participants felt the impacts would be negative whereas the UC Science Team participant answers were split between negative and no impact. The local government participants saw improvements for both species in the short term. The unaffiliated citizens felt there could be no impact on the owl and improvements for the fisher in the short term. There was much stronger support for habitat improvements in the long term for both species. In fact, a majority in all respondent subgroups groups agreed the impacts on fisher and spotted owl were likely to be positive in the long term.

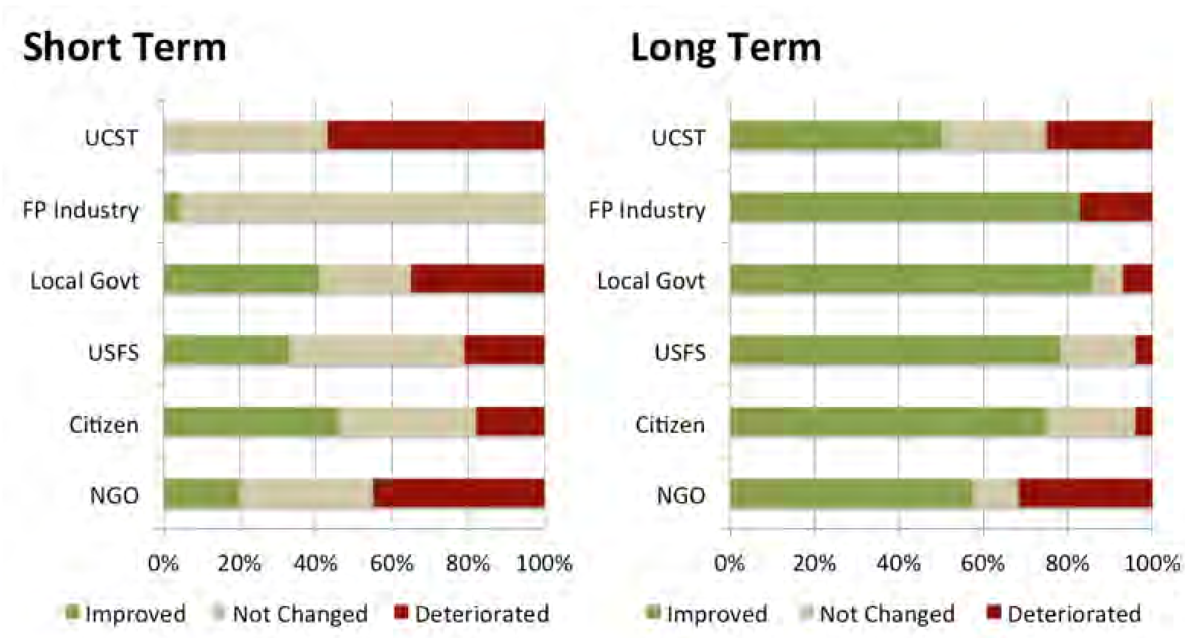


Figure F30: Perceptions of impacts on Pacific fisher habitat, 2014 email survey, short and long term.

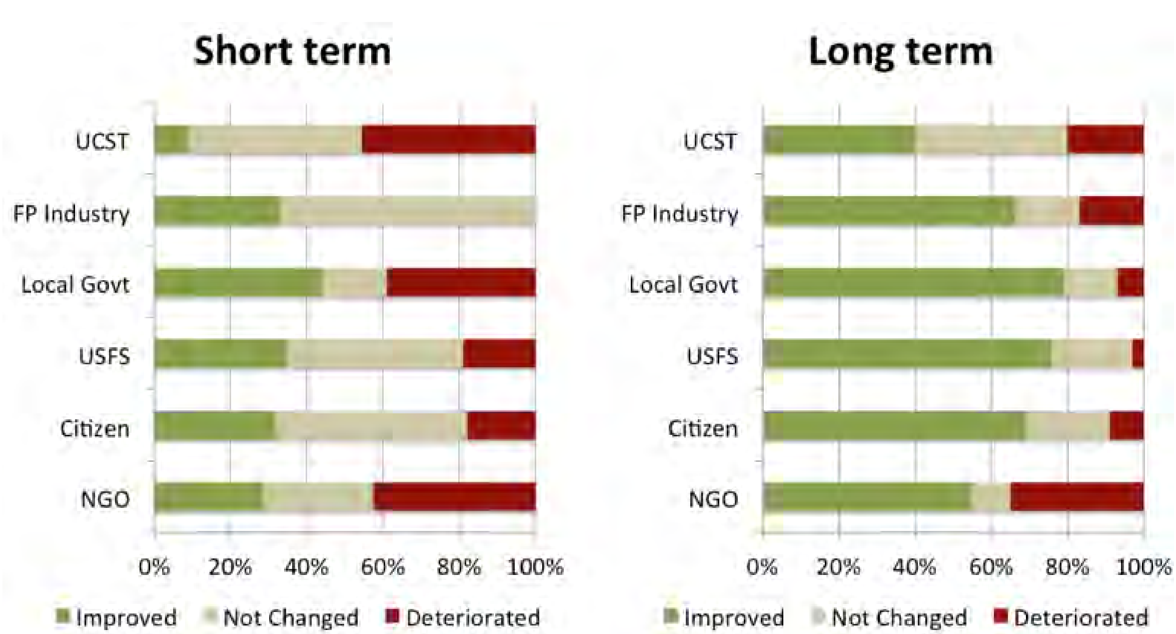


Figure F31: Perceptions of the influence of treatments on California spotted owl habitat, 2014 survey, short and long term.

Generalizing across all interviewees, for those with an opinion, there was also the perception that the treatments might have had a short term negative impact on the two wildlife species studied in SNAMP. But some felt that treatment planning should have taken into consideration wildlife needs and so possibly the impact would be decreased. In the long term, most interviewees talked about the positive impacts from reduced risk of severe fire except one participant (UC Science Team) who felt strongly that these treatments would lead toward listing for both species.

The perception of a long term positive trend for the fisher after fuels treatment implementation was broadly supported and mentioned by at least one person in all interviewee categories. However, interviewees also mentioned other issues reported in the SNAMP findings as possibly more important than treatments. They include fisher consumption of rodenticide from illegal marijuana farms, road kill and predation. The short term negative impacts cited by interviewees were based on the views that there would likely be direct impacts of the mechanized disturbance, alterations to fisher habitat and a possibility of increases in predators due to new roads.

There was also a large group of interviewees that felt that the actual impact of treatments on the fisher is still unclear – there may be no impact detected by the monitoring, there was not enough treatment to impact the animals, and there just is not enough information yet to make a determination. There is heavy representation of UC Science Team, agency participants and Forest Service interviewees in the group who had not yet made up their minds.

Yet treatments were strongly supported across all interviewee groups when compared to an interviewee-imagined scenario of severe fire, especially for UC Science Team, agency participants and Forest Service interviewees. Interviewees felt that a severe fire could kill fisher directly and could cause longer lasting negative impacts to fisher habitat. In addition, the drought conditions that could create intense fire would also stress the fisher causing an even greater threat to their survival. This dominant opinion was tempered with sentiments such as the treatments were too light to have an impact on the spread of a severe fire and that a lighter or moderate fire could have had beneficial impacts.

The following are examples of interviewee responses to the following question: "In your opinion, do you think the SNAMP forest fuel treatments will have an effect on fisher?"

> "Short term I don't know. So far the monitoring has shown that it really hasn't had much of a substantive effect on the fisher... In the long term I think it will have a beneficial effect [because of] risk of catastrophic fire being reduced. Fishers don't live well in forests that have been nuked." Forest Service

> "...hopefully it will give it a chance at living. There is always going to be the issue of the rodenticides due to illegal pot farms, ...and also going to be ...people, cars and so forth but I think, by taking their habitat into consideration, and how the area is treated for fires and such, if a fire goes through it may save their habitat and the people's habitat around it." Environmental NGO

> "It may but from reading the reports it looks like the cause of mortality doesn't have anything to do with habitat. They were hit by cars, they were killed by bobcats and they were poisoned by rodenticide... Treatments should ensure that they had both nesting denning and foraging areas...it takes quite a while to determine the effects on an animal that may live 5 years or more." Unaffiliated citizen

> "… hopefully the short term negative effects of all the treatments, you know machines being in there and their habitat kind of being ripped up in the short term, hopefully it does benefit fisher in the long term by reducing the large severe catastrophic wildfire potential which would be devastating to fisher habitat because then they would have no habitat at all." Agency representative

> "…these treatments should help the fisher [in] two ways: avoid catastrophic fires which would destroy too much habitat, but also create some of that heterogeneity that is important for fisher, they can use small patches and get a different prey base and burned areas." Agency representative

> "...they will be negative… it will reduce survival, reduce population size, and reduce the overall health of the fisher population and will lead toward listing." UC Science Team

> "None." Interviewer asked why? "They are not modifying the forest structure hardly at all with that particular project." Forest Products

> "...one of my areas of interest on the project, was the effects on the fisher. And I don't know. ... I don't know that they know the results yet or not..." Native American Tribe representative

Overall interviewee opinions about the impacts of fuels treatments on the owl were similar to those about the fisher – positive perception of treatment impact dominated, short term negative impacts were likely, low to moderate fire was beneficial, and many were waiting for more information. Differences apparent in responses focus on the perception that the study was unlikely to detect an impact of the treatment on the owl either because there were too few owls in study area or the treatment area was too small. Additionally, there are other changes that could influence the owl more than the treatments or it could be that it was the cumulative impact of many treatments over time that was most detrimental to the species. These comments were all made by agency representatives, UC Science Team or Forest Service participants. One environmental NGO representative interviewee cited studies that showed owls persisting in severely burned areas and so felt that the impact of severe fire on owls was still unclear.

The following are examples of interviewee responses to the question: "In your opinion, do you think the SNAMP forest fuel treatments will have an effect on the owl?"

> "...when I look at the data that the owl team has gathered ... teasing out treatment effects versus all those other cumulative effects at the landscape level that the owl team monitored, I think the treatments will become muddied." UC Science Team

> "I want to say that we, at minimum, maintained the requirements for managing for spotted owl and ... we hopefully improved stand conditions for them in the long term, making those stand conditions more fire resilient and so we hopefully have less risk of a catastrophic event that would harm spotted owl habitat." Forest Service

> "...I have a general perception that the owl utilizes a much larger area in the forest than where the treatments occur so would be surprised if treatments were extensive enough to change the conditions for the owl ..." Agency representative

> "The treatment units were not in a close connection with a lot of owls and so it will just be uncertain or indistinguishable." Environmental NGO

> "I think it will give the owl a better chance of surviving in that their habitat would be significantly less damaged by anything but a very high intensity fire, or severe greater than 100-year intensity fire." Unaffiliated citizen

Water

Most email survey respondents felt that that the treatments would have positive or no effects on water quality and quantity (Table F8), with long term impacts viewed the most positively (Figure F32). Looking at the email survey respondents by affiliation, the environmental NGOs, unaffiliated citizens, local governments and forest products groups actually all felt that water quality and quantity were improved post-treatment in the short and long terms. It is the Forest Service and UC Science Team that diverged from the norm. The Forest Service email survey respondents saw no change in water quality and quantity in the short term and improvements for both in the long term after treatments. The UC Science Team email survey respondents agreed with the Forest Service email survey respondents that there were likely to be no changes in water quality in the short term, but disagreed and saw water quantity improving in the short term, and in the long term they saw no changes in water quality or quantity from the treatments.

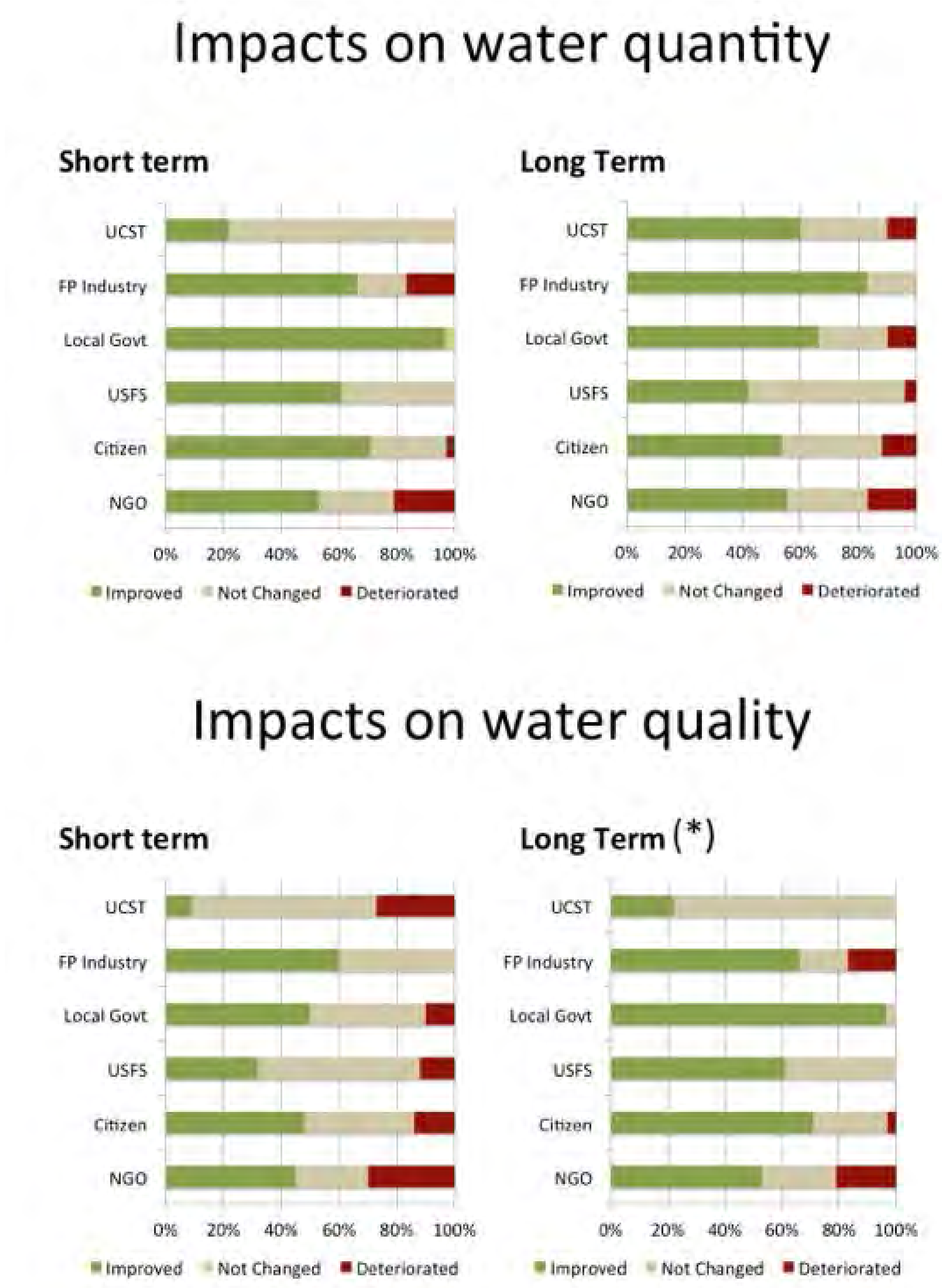


Figure F32: Perceptions of impacts of fuels treatments on water quality and quantity, 2014 email survey (* = responses differ at $p<.05$, χ^2 by affiliation).

The interviewee respondents reflected the email survey respondents' lack of agreement in terms of treatment effect on water quality and quantity. Many of the interview participants felt the treatments would have a positive impact on water quality and quantity especially when compared to severe fire. However, there was also support within the interviewees for the likelihood of a small to nonexistent treatment impacts on water. Treatments were perceived by interviewees to have minimal to no effect on water because best management practices were used, the treatments were too light to have an effect, or the study was too short to be able to detect an effect. This view of minimal to no treatment effect on water was supported by Forest Service, UC Science Team, and agency representatives as well as a forest products and an environmental NGO representative. Those that felt there would likely be positive consequences from treatment preferred treatment over severe fire and thought that increased water yield was an advantage of treatment (but the processes that would cause increased water yield varied). These positive outcomes for water were not mentioned by any UC Science Team interview participants.

The following are examples of interviewee responses to the following question: "In your opinion, do you think the SNAMP forest fuel treatments will have an effect on water quality and quantity?"

> "Yeah, I certainly hope so... some of the early work is showing we are right. Some of the most valuable work that will come out of SNAMP will be some of the basic information about the effects of vegetation removal on water quantity." Forest Service

> "Yes, it would have a beneficial effect in my opinion; if only by reducing the risk of intense fire." Unaffiliated citizen

> "...I think that it is more that the destructive effects of the fire would be reduced and that the actual treatments themselves, by themselves, will have relatively minimal effect on either quality or quantity…the long term treatment I don't think is going to be really probably measurable, particularly in terms of water quantity." Agency representative

> "Now I think that the treatments clearly demonstrate the benefits of healthy forests on watersheds... you are going to have stronger run offs, ...you are going to have greater storage capacity from snow pack...in my world they are very important." Agency representative

> "Minimal to none...because it's not doing anything on the landscape. ...you are not doing nearly enough thinning to affect water yield." Forest products

> "Possibly at the small scale, sort of the scientific watershed level, there may be some short term water quality effects to do with sediment. " UC Science Team

Impact of treatments summary

In sum (Table F9), email survey and interview respondents felt that the fuels treatments could impact fire behavior and that the forest health of the two study areas had improved after the treatments were implemented, but there were interviewee and email survey participant results suggesting that the fuels treatments might be too light to protect the landscape from severe fire and interviewees indicated that the studies may not be able to detect treatment impact due to study design limitations. For treatment impacts on wildlife, email survey participants were more divided in their assessment of the impacts, while there was more broad support for the idea that the treatments will benefit the animals in the long term. The interviewees also mentioned short term negative impacts on the animals from the fuels treatments, but that in the long run the treatments would have a positive influence and would be beneficial, or have little impact, compared to severe fire. Email survey results showed almost no support for a negative impact on water quality or quantity from the treatments in the short or long term. Interviewees projected minimal to no impact from the treatments on water as compared to the fisher and owl.

Table F9: Summary of interviewee comments on impacts of fuels treatments.

Summary for all resources	-Treatments were likely to be positive and are preferred compared to severe fire -Treatments improved forest health -But treatments might have been too light to protect from severe fire and study may not have been able to detect impacts -Treatments might have had short term negative impacts on wildlife but long term benefits -Treatments unlikely to have had negative effects on water in short or long term -Low intensity fire would create less negative impact and would be good for resources

Influence of SNAMP on stakeholder opinions

Forest health and fire behavior

Of those who participated in the email survey, most felt their ideas about fuels treatment impacts on forest health had changed over the last 7 years (7 years of the active assessment and treatment portion of the SNAMP project to one year before final results were published in 2014) and a little over half felt that their opinions were influenced by information they learned from SNAMP (Table F10). Most of the affiliation subgroups in the email survey show a majority agreeing that their ideas about the impacts of forest fuel treatments on forest health have changed over the last 7 years, and that SNAMP did influence that change (Figure F33). Those from the forest products group and unaffiliated citizens were split with about half agreeing and half disagreeing that SNAMP influenced their opinions.

Table F10: Impact of SNAMP on participant learning and on opinions about treatments.

Fuels treatment impact on…	**Has SNAMP changed your opinion?** Email survey n=258 Interviews n=26	**Have you learned about the topic from SNAMP?** Email survey n=258 Interviews n=26
Forest health and fire behavior (email survey)	- Changed = 69% - Not changed = 31%	- From SNAMP = 54% - Elsewhere = 46%
Forest health and fire behavior (interviews)	- Changed a little - Affirmed opinions - One strong change in opinion	- Mostly learned about forest management context: decision-making, fuels management - Field trips important for learning
Pacific fisher (email survey)	- Changed = 74% - Not changed = 26%	- From SNAMP = 73% - Elsewhere = 27%
Pacific fisher (interviews)	- Affirmed previously held opinions - Two strong changes in opinion	- Incredible amount of learning about basic fisher biology
California spotted owl (email survey)	- Changed = 56% - Not changed = 44%	- From SNAMP = 56% - Elsewhere = 44%
California spotted owl (interviews)	- Changed somewhat; affirmed previously held opinions - Two strong changes in opinion	- Learning about owls and habitat use
Water quality and quantity (email survey)	- Changed = 63% - Not changed = 37%	- From SNAMP = 54% - Elsewhere = 46%
Water quality and quantity (interviews)	- Affirmed previously held opinions - Three changes in opinion	- Learned about leaf area index, techniques/equipment - Study too small to detect change

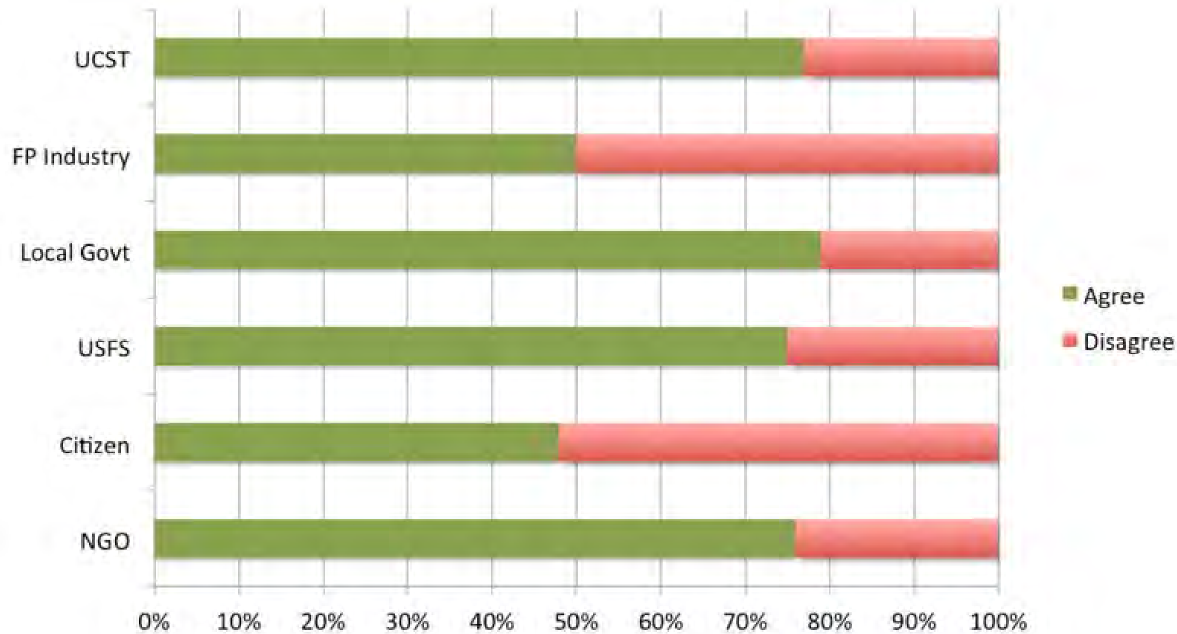


Figure F33: My opinion of the impact of fuels treatments on forest health has changed over last 7 years (responses differ at $p<.1$, χ^2 by affiliation).

Of those who answered "yes" to our interview question regarding opinion change with regard to fuels treatments and their impact on fire behavior, most felt their opinions changed only a little bit: "[SNAMP] helped me to be open to learning" or "I want to say yes but I am not sure how" and "No not really but probably just from conversations with [UC scientists] I am more confident that it is [going to have an effect] than I was before. Maybe a little." One interview participant mentioned that SNAMP did change his opinion about treatment impact on fire behavior because he did not have an opinion before SNAMP.

The following is an example of interviewee responses to the following question: "Did any information from SNAMP affect your opinions about forest fuels treatment effects on fire behavior?"

> "SNAMP has formed my opinions about fuel treatments… SNAMP has contributed enormously because I didn't have much knowledge about them before." UC Science Team

The dominant sentiment from interviewees about the influence of SNAMP on their opinions about treatment impacts on fire behavior was that participant opinions were strengthened, reinforced, validated or enhanced (Table 10). Participants learned about the context around Forest Service management, the techniques behind forest management, some were waiting for the final SNAMP report and others felt it would be a long time before there was reliable information about what happened out there. The comments below also pointed to the importance specifically of field trips as learning opportunities that helped to form or validate people's knowledge about the treatments.

The following are examples of interviewee responses to the following question: "Has your opinion of forest fuels treatment effect on fire behavior changed over the course of SNAMP?"

> "...it has solidified it because I knew things had to change… and just leaving things to nature, can't always be that way, we have learned that fire is necessary but also kind of directing it ourselves but clearing it and so forth is necessary too." Environmental NGO

> "I think it is very similar to what I thought would happen. The Forest Service did a nice job of implementing them." UC Science Team

> "...it is still really theoretical and I still think there needs to be more evidence and data collected to show that the fire models are performing the way they are assumed to be performing." UC Science Team

> "Didn't change the opinion but informed it about what the treatments were and how they looked on the ground. I saw the forest before the treatments and after – it looks pretty darn different … there is a lot less fuel to burn. I do know more about what that looks like now." Agency representative

> "I have followed other treatments in the area so I am not surprised by the results, most SNAMP results I am not surprised by." Forest products

> "...I would have probably advocated from my background that 'fuels treatments make sense and need to be moderate to heavy to have a significant impact on wildfire' but my sensitivity about public and land managers is higher… My bias as a forester would say heavier is better but maybe not." UC Science Team

> "I ... have a better understanding of how the different treatments are determined by the Forest Service based on the data the Science Team collected… I knew about in a general way but now I have a much more specific understanding of how they went about deciding what to do." Unaffiliated citizen

The following are examples of interviewee responses to the following question: "Did any information from SNAMP affect your opinions about SNAMP forest fuels treatment effect on fire behavior?"

> "It strengthened it, yeah. Well I think the main thing is the density, managing the density of the stocking levels... I believe on that trip they showed a couple of different treatments of surface fuels and that was educational too… it reinforced some of the things I had thought." Native American Tribe representative

> "Yes. Going on the field trips and listening to the UC Science Team and Forest Service talk about what they were doing and looking at what they were treating and post treatment areas and having an understating of why they were doing what they were doing and what outcomes they expected." Unaffiliated citizen

> "I think SNAMP probably taught me the most… it was SNAMP that opened my eyes to all of this [learning about fuels management]. Which was important for me as a state worker. We don't get much money to travel and get extra training." Agency

Wildlife species

Email survey participants changed their opinions about SNAMP forest fuels treatment impacts on both wildlife species and learned information from SNAMP that influenced their opinions (Table F10 and Figure F34). These sentiments were stronger for the Pacific fisher portion of SNAMP than they were for the California spotted owl. For all of the email survey affiliation subgroups, the majority agreed that their opinion about fuels treatment effects on the Pacific fisher had changed, and changed due to SNAMP, except those who were associated with the forest products industry. The industry email survey participants disagreed that their ideas had changed and disagreed that SNAMP affected them. The same lack of change was true for the forest product participant opinions and SNAMP influence with regard to the owl. For the owl, the unaffiliated citizen participants also reported no change in opinion and a lack of influence from SNAMP.

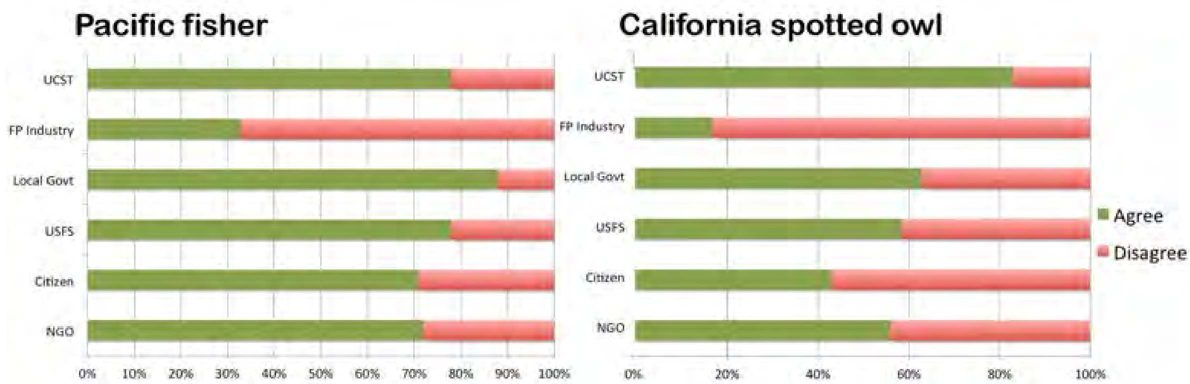


Figure F34: My opinion of the impact of fuels treatments on Pacific fisher and California spotted owl has been influenced over last 7 years by what I learned from SNAMP, 2014 email survey (responses differ at $p<.1$, χ^2 by affiliation).

Interviewees reported that the basic biological studies of fisher and spotted owl produced novel and interesting information that strongly influenced participant learning about the species (Table F10). The interviewees who attended to the fisher portion of the project mentioned that they learned about rodenticide issues, basic fisher biology, den trees, home ranges, and the impacts of fire on fisher. A Forest Service participant said that the "big news is...about the rodenticide and predation. That came out of SNAMP and we weren't thinking about that before." A forest products participant reflected the same sentiment when she said "...the fisher site is the most interesting…" One person felt that what he learned in SNAMP increased his concern about fisher vulnerability to fire. Another felt that she learned that light treatments are more spatially, politically and legally acceptable. Four interview participants admitted that they knew very little about the fisher before SNAMP and so learned quite a bit from the project. Two full changes in opinion about the impacts of forest treatments on the fisher were expressed by interviewees.

The following is an example of interviewee response to the following question: "In your opinion, do you think the SNAMP forest fuel treatments will have an effect on fisher?"

> "...before I was in SNAMP I would have said yes, what one thinks of as an old growth-associated species would be affected … probably negatively. Based on what I have learned as a participant in SNAMP I would now say that it's not clear – not sure there would be strong immediate effects." UC Science Team

The following is an example of interviewee response to the question: "Has your opinion of this [the effects of forest fuels treatments on the fisher] changed over the course of SNAMP?"

> "When SNAMP first started I thought we would see more of an impact on the fisher and now I think they have a wider variety of habitat that they choose to use than I initially thought." Forest Service

For those interviewees who did not feel their opinion changed about forest treatment impact on fisher, they commonly felt that what they learned in SNAMP affirmed, bolstered and reinforced previously held opinions or they were waiting for the final conclusions and recommendations.

The following are examples of interviewee responses to the question: "Did any information from SNAMP affect your opinions about this [the effects of SNAMP forest fuels treatment on the fisher]?"

> "SNAMP is helping me understand that the way I saw it is correct, that there won't be an effect. Helped solidify opinion that it won't affect the fisher." Forest Service

> "We have more information about the fisher but not how the fisher responds to disturbance." Environmental NGO

> "...active monitoring was a good thing and it showed the movement of the fisher under certain circumstances and good to have that ongoing. Fisher team did a great job on field trips and presentations. Interesting to see so many of the public attend those meetings...." Forest products

At the time of this project, the California spotted owl had been studied for decades and there were many sources outside of SNAMP for information on the species. Yet, for the owl portion of the project, many email survey participants and interviewees still felt that they learned about the owl from SNAMP and felt their opinion had changed during the 7 years of the project. Similar to the fisher, some interviewees knew little of the owl before SNAMP and so learned significantly from the project. Based on what they learned in SNAMP, some interview participants felt they now know more about owl habitat use and so feel more comfortable with conclusions that are the opposite of their preconceived opinions.

The following are examples of interviewee responses to the following question: “Has your opinion of the effects of forest fuels treatments on the owl changed over the course of SNAMP?”

> “...with both the fisher and the owl, ... now that I have had access to the science I think that the treatments probably are a wise idea compared to the risk of high severity fire.” UC Science Team

> “Because this was an area that I didn’t know a lot about when I went in, during the presentations I was reassured that the design was to protect the owl so yes I was significantly affected by SNAMP.” Unaffiliated citizen

> “...once the final data come out because I feel like this has been a much more complete large study of owls, but currently I don’t know that it has changed drastically but it may once we have the final data.” UC Science Team

Of interviewees who mentioned information sources outside of SNAMP affecting their opinions about the owl, some saw that information coming into SNAMP, some felt that SNAMP provided the context for learning about the owl, and others based their opinions on their own observations or other publications about the impacts of fire on the owl. Similar to the other resources studied in SNAMP, many interviewees felt that SNAMP studies of the owl supported the opinions they brought to the project.

The following is an example of interviewee response to the question: “Has your opinion of the effects of fuels treatments on the owl changed over the course of SNAMP?”

> “Before this it was a hypothesis more and now it is more “this should happen because I know” not just because “I think.” Learning in SNAMP solidified my concerns and what needs to happen.” Environmental NGO

Water

Email survey participant opinions of forest fuels treatments impacts on water quality and quantity changed during SNAMP and just over half reported an influence of SNAMP on their opinions (Table F10 and Figure F35). The two subgroups that did not fit this trend are, again, the forest products and unaffiliated participants. Few interviewees felt that they had changed their opinions about the impact of forest treatments on water quality or quantity over the last 7 years but many did feel they learned from the project and their preconceived opinions were supported. Interviewees mentioned learning from SNAMP about water assessment techniques and equipment, learning about the interactions of leaf area index and water, or, like the other subjects, some participants knew little of the topic before SNAMP and so the learning in SNAMP was significant for them.

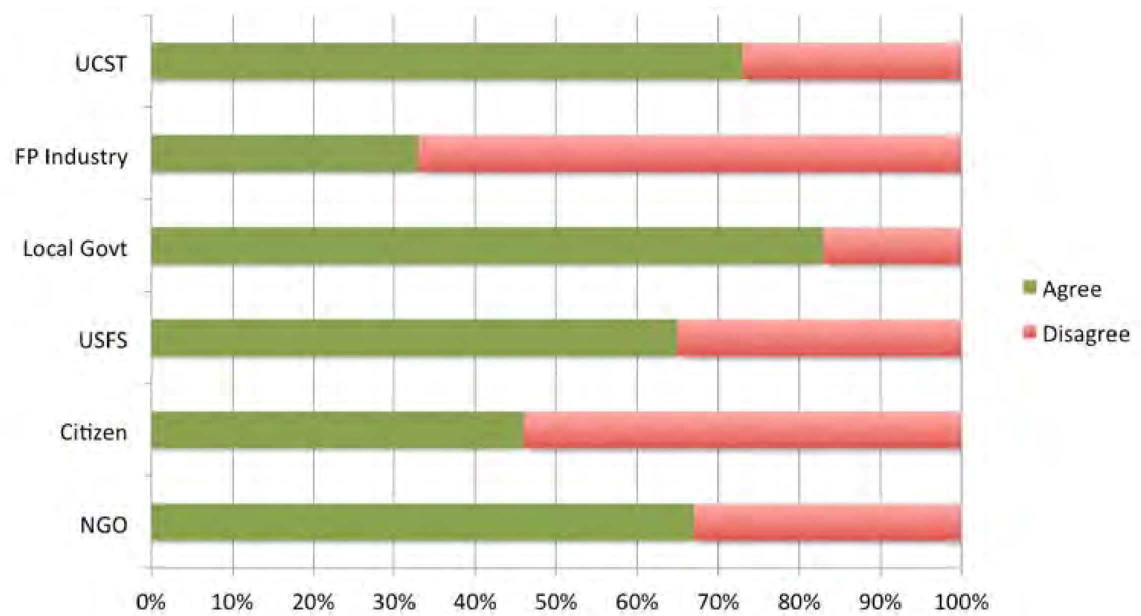


Figure F35: My opinion of the impact of fuels treatments on water quality and quantity has been influenced over last 7 years by what I learned from SNAMP, 2014 email survey (responses differ at $p<.1$, χ^2 by affiliation).

The following is an example of an interviewee response to the following question: "Has your opinion of forest fuels treatments on water quality and quantity changed over the course of SNAMP?"

> "Yes, that was ... where I learned the most from SNAMP." Unaffiliated citizen

> "I didn't know much about it beforehand so I got a lot of learning from the SNAMP project." UC Science Team

The following are examples of interviewee responses to the following question: “In your opinion, do you think the forest fuel treatments will have an effect on water quality and quantity?”

> “...I think they are on to something with the straight-line relationship between LAI (leaf area index) and water production... as you take photosynthetic capacity out of the forest more water results and it is more predictable than we would have thought.” Forest Service

> “...the presentations indicated to me that silt and debris and the water results of fire will be greatly reduced … if the intensity of the future fire that goes through that area is reduced.” Unaffiliated citizen

> “.... the effects were not anticipated to be that long on the landscape. But every little bit helps. To avoid catastrophic fires, which would really affect water quality, then some treatment is better than none.” Agency representative

For those who did not change their opinion, some felt their opinions were affirmed or refined through SNAMP but a large group felt that the study was too small to see an impact or that similar information already exists outside of SNAMP.

The following is an example of an interviewee response to the following question: “Has your opinion of the effects of forest fuels treatments on water quality and quantity changed over the course of SNAMP?”

> “For water quality it hasn’t changed too much, for water quantity what I learned was that the basics of spacing (where trees are removed, are they clumped together) really matter but where they are taken out on the landscape; there might be other things we learn too. I think that through the treatments, we may not see physical effects, with the modeling we will definitely be able to learn from it.” UC Science Team

The following are examples of interviewee responses to the question: “Did any information from SNAMP affect your opinions about the effects of SNAMP forest fuels treatment on water quality or quantity?”

> "They are going to see that this does help. They will reinforce what I already know from the college of hard knocks. Doing the science will make it significant and educate the public and the decision makers." Local government

> "Found it fascinating all the little monitors etc. Website field trips and meetings learned it. Especially from the field trip that I went on – I think I went on almost all hydrological team field trips." Unaffiliated citizen

SNAMP influence on opinions summary

Overall, during the lifetime of the SNAMP project, most email survey respondents reported changes in their opinions during SNAMP (Table F11). Just over half the email survey respondents felt that SNAMP influenced their opinions on forest health, water and the owl, but nearly three-quarters felt SNAMP impacted their opinions on the fisher. Interviewees reported a few significant changes in opinions about the subjects of SNAMP, with SNAMP playing a role in those changes. The dominant impact of the scientific portion of SNAMP is the vast amount of learning by participants about forest management, species biology and hydrology. This learning was novel for many and reaffirmed, confirmed and strengthened participant opinions. The completed SNAMP report is what many participants say they will base their opinions on.

Table F11: Summation of respondent responses on learning and changes in opinions.

	Has SNAMP changed your opinion?	**Have you learned about the topic from SNAMP?**
Summary	- SNAMP learning did alter some opinions, shows up more in email survey than interviews - Reaffirmed/ confirmed/ strengthened opinions - Need to wait and see with time and SNAMP results	- New subjects for some who then learned a considerable amount - Basic learning for most on forest management, species biology, hydrology

Opinions and change by affiliation

Our email survey affiliation analysis showed no statistical differences between affiliation group response about treatment impacts to the fisher and the owl; the majority of people in each group responded the same way. Most participant affiliations also had similar distributions of responses about the impacts on water quality and quantity but the UC scientist responses differed and tended to report an opinion of no impact on water quality in the long term whereas the local government participants were more likely to predict a positive impact on water quality in the long term. The forest products participants separated themselves from the group because they more often reported an opinion that, in the long term, forest health would not be improved—comments indicated that most felt that the treatments did not remove enough material to improve forest health over the long term.

The forest products email survey participants were also less likely to report they had learned or changed their opinions about any topic studied in SNAMP. Interviews revealed that forest products participants often referred to their own observations from working in the forest in preference to SNAMP information. Likewise, unaffiliated citizens in the email survey less frequently reported a change in opinion with regard to the impacts of the treatments on forest health and reported that SNAMP bolstered and reinforced their opinions on the impacts of treatments on forest health without changing them. The unaffiliated group from the email survey was in step with the group as a whole in terms of how frequently they reported experiencing a strong amount of learning about the fisher but was less likely to report that SNAMP had influenced their opinions about the owl or water quality or quantity. The unaffiliated citizens who participated in the email survey frequently selected "I do not know enough to have an opinion" about the impacts of the treatments and this could be why they were less likely to respond that they experienced a change in opinions and influence of SNAMP on their opinions. In contrast, the unaffiliated citizen interviewees who focused on the owl and the water portions of SNAMP, did report learning from SNAMP.

SNAMP fostered shared understandings

SNAMP's outreach program created an array of participation options to promote learning through in-person events and information sharing at a distance. Evaluation information showed that in-person events, most importantly field trips and management workshops were best for science learning. Overall, results demonstrated public endorsement of the fuels treatments by participants, showed that participants learned from SNAMP, and revealed that most participants thought that long-term treatment impacts would be positive. For all SNAMP focal areas, some participants changed opinions and most learned from the project. This was the case most strongly with forest health, fire behavior and fisher.

A focus on learning dominated every aspect of the SNAMP process from the original title of the work plan ("Learning how to apply adaptive management…") to the final public meeting and creation of the final report. The extensive outreach effort allowed participants to learn from the scientists and change or support their opinions. Shared understandings evolved around the impacts of treatments on the studied resources, as well as around the underlying assumptions of the project: what constitutes forest health and adaptive management process itself (Sulak and Huntsinger 2012; Sulak et al 2015).

VIII. Participation Team Conclusions

SNAMP fits into the category of top-down, rather than bottom-up or "grassroots", participatory processes. A top-down approach generally means a less organic set of relationships to begin with, making it harder to build and strengthen connections among participants, and a less democratic governance structure (Arnold et al. 2012). There are two major kinds of decision-making within SNAMP, decisions about scientific study made by the Science Team, and decisions about management made by the Forest Service. Both groups have strong constraints on sharing decision-making with stakeholders. Stringer et al. (2006) state that power sharing can remain elusive in settings dominated by scientists and managers. These limitations were made clear at the outset of the project, avoiding some of the misunderstandings that have been a problem in other participatory management efforts (Wagner and Fernandez-Gimenez 2009). The majority of respondents valued the learning opportunities, open discussions, and face-to-face interactions with scientists. Respondents felt "part of the project" (Figure F18).

Working with Cooperative Extension, the Science Team sought public and agency feedback on science decisions, and respondents agreed that the Science Team showed interest in stakeholder input. However, scientists held that they must keep to the scientific standards set by their peers, limiting their ability to use all suggestions. At the behest of the Participation Team, they agreed to make decisions transparent, and to provide a clear explanation when stakeholder input was not used. For example, there was an online discussion board post from a public participant who suggested study of a nearby severely burned area. A UC scientist explained that this could not fit the timeframe, budget, and objectives of SNAMP, or result in better management information, because there was no pre-fire data available from the site and it had a high severity burn, which is not comparable to the prescribed fires used in SNAMP. A Science Team principle was that public input leads to better science as well as management, but in fact a consultative approach is used, rather than the shared decision-making of a full collaboration.

As to the Forest Service, it has been argued that full decision-making authority cannot be devolved or abdicated outside of Congress's reach (Moote and McClaran 1997; Coggins 1999). This was raised at the beginning of the project in 2005, and again in April of 2008 by participants in SNAMP workshops because of the aspiration of many to have power sharing - based co-management, including shared decision-making, with the Forest Service. Some participants were concerned that their contribution over the many years of SNAMP might ultimately be "a waste of time" if they could not have more assurance that project results will be used by the agency. The perception that participants risk wasting resources and time is not specific to SNAMP, but has been expressed numerous times during agency-led participatory projects. Again, the Forest Service approach remains fundamentally consultative, with intention expressed to adhere to the results of the collaborative project.

However, different aspects of an adaptive management program may have different levels of public involvement (Stringer et al. 2006), and the diverse SNAMP formats allowed a more collaborative approach when possible. The SNAMP project emphasized transparency, created diverse and inclusive opportunities over several years for participants to join and to build relationships, and, using the adaptive management model of experimentation, provided material for shared learning. There was indication of the development of shared norms and values. Participants tended to agree that conflict was reduced, at least for those who participated in the project. Toward the end of UC's participation, in 2014, more than 80% of respondents felt that participation in SNAMP was worth their time.

The third party role

UC was strongly seen as neutral and unbiased in its third party role and most interviewees and survey respondents supported using the SNAMP model in other collaborative adaptive management situations, but cost and "scalability" are concerns. The SNAMP model is costly in time and money. In fact, the annual appropriations cycle of the Forest Service is not a good fit to the length to time needed to carry out an adaptive management project like SNAMP. Insecurities about funding, from time to time, cut into scientist commitment and upset stakeholders. The gradual but steady reduction in funding throughout the term of the project was also distressing, as pieces of the project were jettisoned along the way. In addition, changes in personnel in the agencies hampered long term learning and communication at times.

In fact there are gradations possible in a third party model, from stakeholder participation or implementation in monitoring, through bringing in another agency to do some of the monitoring and outreach, to collaborating with an entity like UC that conducts science and outreach as full partner to the public and the agency. One example is the role of the Natural Resources Conservation Service, an advisory service, in developing Ecological Site Descriptions for monitoring on BLM lands. These are the kinds of arrangements, conducted with utmost transparency, that engender what seems to be meant by hundreds of authors as "trust." The feeling that nothing is being ignored or kept secret, that parties are working together in good faith, and that the biases of each party are given an equitable chance at expression and then balanced using scientific information that all parties feel is credible. It is what a member of the public once characterized as "trust, but verify."

Closing the loop

To gauge participant thoughts on SNAMP's impact on future forest management in the Sierra, we collected participant assessments of SNAMP as a successful adaptive management project. Many answers included the phrase "time will tell…" because the final part of the process, the incorporation of final results into future management, as we have called it in this project, cannot occur during the project. The UC role ended in 2015, with the publication of the final report and results. What the Forest Service will do with that information was not able to be tracked as part of the project so the ultimate adaption will go unrecorded by the UC Science Team. For some this was less of an issue because they could point to adaptations that had already occurred and for others this was a sticking point.

The SNAMP legacy

Participants had many examples of why SNAMP was important and how it will impact forest management into the future. A few participants saw SNAMP as reaching past the local level to decision makers in the Forest Service Regional office (Region 5) and influencing the Forest Service's future collaboration intentions at a larger scale, whereas others did not. Other comments described SNAMP as a demonstration of better agency interaction with stakeholders that could be continued by the Forest Service. There were many hopeful remarks that the relationships built in SNAMP, with the public as well as between the agencies, would facilitate productive interactions in the future, but it is a question, it is not something participants are sure about. At the outset, a major goal was to create a group of knowledgeable stakeholders to work with the Forest Service--this has been accomplished, but the future hinges on the agency's ability to build on the relationships created thus far--to literally "keep stakeholders in the loop."

For the long term, participants hoped that SNAMP's scientific legacy would continue in improvements management of the study areas based in SNAMP's scientific findings – the list of SNAMP publications is extensive already (for a list of Participation Team journal articles see Appendix F7). Some of the scientific projects that have continued after the formal SNAMP project ended will continue outside the SNAMP framework. And, since the community of interest sampled by the email methodology is active in forest management issues, former SNAMP participants can continue to support using the lessons learned in future projects. Nearly 2/3rds of 2014 email survey respondents had attended other Forest Service NEPA-related meetings. About 70% reported participating in other collaborative projects. Survey respondents reported participation in the Sierra Cascade Dialog, Dinkey Creek CFLRP, fire safe councils and fuel management groups, and numerous other programs. About 42% of respondents said they knew that SNAMP had had an influence on other projects, and about a quarter reported that they knew of SNAMP results being used elsewhere. One typical comment volunteered on the email survey was that the “SNAMP collaborative process is being used for forest planning in Oregon and California. The facilitation workshops run by SNAMP have been attended by people from many different organizations so I imagine that is having an influence on collaborative projects.” Another comment was that “it has provided a model for cross-disciplinary collaboration and for modeling the importance of reaching stakeholders. I have been reaching out to community groups to explain our research at a level that I have not done beforehand.”

At the outset, the Forest Service expressed a desire to create a group of informed, committed stakeholders with which to work. We believe this has been accomplished, and hope that the relationships created will carry this constructive, learning based effort into the future. In fact, the creation of this group is a highly resilient way to continue what has been learned in SNAMP, as the group can work with the Forest Service to adapt the lessons learned to future conditions.

IX. Lessons Learned

Transparency, inclusiveness, learning, relationship building and effectiveness are the five main goals established for the SNAMP Participation Team. In their pursuit, we found value in the following:

1) **Transparency**:

Emphasize project openness and transparency. Communicate clearly and thoroughly. Report directly to the public.

- Maintain an up to date and accessible website with project document archive and meeting information. Make outreach staff contact information easily accessible.
- Maintain contact information for all participants for outreach purposes.
- Specifically address how decision making for the project will happen from the very beginning.

- Identify and record clear project boundaries and key agreements in shared notes. Clarify expectations at the start, and throughout the project, about what can and cannot be done especially with regard to funding.
- Use webinars to transfer information, increase access and enhance transparency.
- Evaluate project transparency on an ongoing basis through evaluation, conversations at meetings, or use of self-organizing map methods to help see sustained engagement between scientists, managers and stakeholders over time.
- Have a plan for bringing new participants up to speed on project progress, constraints and communication protocols in order to weather staff turnover while maintaining transparency.

2) **Inclusiveness**:

Maintain an atmosphere of inclusivity in all aspects of the project.

- Provide notice 6 weeks ahead (minimum) of gatherings and send reminders closer to the date.
- Design events for participants with varying levels of interest, availability and knowledge; provide background information for those who want more.
- Provide a variety of times for events.
- Hold events in the regional capital to draw agency and regional representatives and in the local area to connect with local stakeholders.
- Keep local communities and the broader communities of interest, including under-represented groups, updated on the project through notices to an email list and local outreach events. Do not expect them to come to the project, outreach must go to them.
- Use web technology, such as webinars, to complement face-to-face interactions and public meetings, allowing distant participants to be involved.
- Use multiple forms of electronic media including websites, emails, blogs and social media to extend awareness beyond the local and regional scale.
- Monitor the flow of information products through their production, transport, and use so that process corrections can be made if needed. Powerful new information monitoring tools may

be useful for monitoring.

3) **Learning**:

Learning together is critical for shared understandings and building relationships.

- Learning cannot occur without transparency and inclusivity.
- Design a variety of participation events that accommodate diverse backgrounds and knowledge levels – overview large meetings, technical detailed smaller meetings, hands-on workshops, field trips, and webinars or conference calls as needed.
- Conduct as many field trips as possible to draw the broadest audience of participants and clarify discussions in realities on the ground.
- Build in informal time at meetings, as it is important for people to network. Always include question and answer sessions to allow participants to get to know what others think.

4) **Relationship building**:

Put time and effort into allowing participants to build relationships between each other.

- Relationships cannot be built or improved without transparency and inclusivity. Learning together is also essential.
- Provide face-to-face meetings (large and small), especially field trips.
- Webinars are most effective after in-person relationships have been built.
- Monitor the status of participant relationships to ensure success of the project. This can be done through questions on event evaluations, group discussion or other more advanced tools such as affiliation network analysis.
- Continually brief new agency leaders in order to maintain agency commitment despite leadership turnover.

5) **Effectiveness**:

Structure the process for success. Specify roles, relationships, and responsibilities in the project's steering committee.

- Bring all partners at all relevant levels into the project as early as possible.
- Assign project staff and clarify roles and responsibilities for outreach and communication.
- Ensure that all participants, scientists, and agency staff understand expectations for communication throughout the project.
- Provide training for participating in collaborative efforts. Include facilitation skills and tools to deal with difficult behaviors.
- Use trained outreach professionals. Use a trained facilitator when difficult topics are anticipated.
- Provide many opportunities for feedback throughout the process including using on-going evaluation techniques.
- Be flexible. Continually adapt methods to match participant needs.
- Use in-person outreach methods for learning and relationships; at a distance methods for awareness and information transfers.
- Leadership is important – consistency and engagement are crucial. Choose leaders held in high esteem by project participants and with authority within their affiliated agency or organization.
- Develop the capacity to transfer leadership, as people change positions often in a long term project (agency contacts, managers, and scientists).
- Attend to project team relationships. Emphasize internal agency communication between field levels and management or administrative levels.
- Agency partnerships need to be fostered for effective collaboration.
- Secure long term funding for long-term projects.
- Develop the project at the time and spatial scale appropriate to the funding source.

X. Literature Cited

Ansell, C., and A. Gash. 2007. Collaborative Governance in Theory and Practice. Journal of Public Administration Research and Theory 18:543-571.

Arnold JS, Koro-Ljundberg M, Bartels W. 2012. Power and conflict in adaptive management: Analyzing the discourse of riparian management on public lands. Ecol Soc 17:19. http://dx.doi.org/10.5751/ES-04636-170119.

Auerbach, C. F., and L. B. Silverstein. 2003. Qualitative data: An introduction to coding and analysis. New York University Press, New York, NY. 202p.

Behan, R.W. 1975. Forestry and the end of innocence. American Forests May: 16-49.

Bowers, E. A., B. E. Fernow, F. L. Olmstead, J. F. Rothrock, V. Colvin, T. Roosevelt, G. Pinchot, N. S. Shaler, D. M. Riordan, J. Muir, C. Abbe, W. J. Palmer, and G. S. Anderson. 1895. Comments on Professor Charles S. Sargent's Scheme of Forest Preservation by Military Control. Century Magazine [Cornell University Library, Making of America Archive] 49:626-634.

Broussard, S. R. and B. D. Whitaker. 2009. The Magna Charta of environmental legislation: A historical look at 30 years of NEPA-Forest Service litigation. Forest Policy and Economics 11:134-40.

Burns and Cheng 2005. The Utilization of Collaborative Processes in Forest Planning. An Applied Research Project funded by the USDA Forest Service. 132 pages.

Coggins, G.C. 1995/1996. “Devolution” in federal land law. Environmental Law and Policy 3(2): 211-218.

Coggins, G.C. 1999. Regulating federal natural resources: A summary case against devolved collaboration. Ecology Law Quarterly 25:602.

Conley, A. and M.A. Moote 2003. Evaluating Collaborative Natural Resource Management. Society and Natural Resources 16:371–386.

Council on Environmental Quality (CEQ) 2007. Collaboration in NEPA: A handbook for practitioners. www.nepa.gov/ntf/Collaboration_in_NEPA_Oct_2007.pdf

Culhane, P. J. 1981. Public lands politics: Interest group influence on the Forest Service and the Bureau of Land Management. Baltimore, MD: Johns Hopkins University Press.

Dana, S. T. and S. K. Fairfax. 1980. Forest and Range Policy. McGraw-Hill Book Company, New York.

Earley, Christopher P., and Elaine Mosakowski. 2000. Creating hybrid team cultures: An empirical test of transnational team functioning. The Academy of Management Journal 43 (1):26-49.

Fernandez-Gimenez, M. E., H. L. Ballard, and V. E. Sturtevant. 2008. Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western USA. Ecology and Society 13(2):4.

Fortmann, L. P. and S. K. Fairfax. 1989. American forestry professionalism in the third world: some preliminary observations. Economic and Political Weekly August 12:18-24.

González-Cabán, A. 2009. Proceedings of the third international symposium on fire economics, planning, and policy: common problems and approaches. Gen. Tech Rep. PSW-GTR-227. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 395 p. http://www.fs.fed.us/psw/publications/documents/psw_gtr227en/psw_gtr227_en.pdf

Gregory, R., D. Ohlson, and J. L. Arvai. 2006. Deconstructing adaptive management: criteria for applications to environmental management. Ecological Applications 16(6):2411-2425.

Hays, Samuel P. 1960. Conservation and the Gospel of Efficiency, Cambridge, Harvard University Press.

Henderson, D. & Krahl, L. 1996. Public management of federal forest land in the United States. Unasylva, 47(184): 55-61.

Holling, C. S. 1978. Adaptive environmental assessment and management. New York: Wiley.

Hull, R. B., D. Richert, E. Seekamp, and G. Buhyoff. 2003. Understandings of environmental quality: Ambiguities and values held by environmental professionals. Environmental Management 31(1):1-13.

Interaction Associates. 1997. Facilitative Leadership: Tapping the Power of Participation. Boston.

Kaiser, B. A. 2006. The National Environmental Policy Act's influence on USDA Forest Service decision-making, 1974-1996. Journal of Forest Economics 12:109-130.

Kaufman, H. 1960. The forest ranger. Johns Hopkins Press, Baltimore, MD.

Keele, D. M., Malmsheimer, R. W., Floyd, D. W., Perez, J. E. (2006) Forest Service Land Management Litigation 1989–2002. Journal of Forestry 2006 (June), 196–202.

Kelly, N. Maggi, Shasta Ferranto, Shufei Lei, Ken-ichi Ueda, and Lynn Huntsinger. 2012. "Expanding the Table: The Web as a Tool for Participatory Adaptive Management in

California Forests." Journal of Environmental Management 109 (October): 1–11. doi:10.1016/j.jenvman.2012.04.035.

Kocher, S., Lombardo, A., and R.A. Sweitzer. 2012. Using Social Media to Involve the Public in Wildlife Research—the SNAMP Fisher Sock Collection Drive, February 2013. Volume 51(1).

Lackey, R. T. 2001. Values, policy and ecosystem health. BioScience 51(6):437-443.

Laurian, L. and M. M. Shaw 2009. Evaluation of Public Participation: The Practices of Certified Planners. Journal of Planning Education and Research March 2009 vol. 28 no. 3 293-309.

Leach, W. D., 2006. Public involvement in USDA Forest Service policymaking: A literature review. Journal of Forestry. 104 (1): 43-49.

Lei, S. and M. Kelly. (2015) Evaluating adaptive collaborative management in Sierra Nevada forests by exploring public meeting dialogues using Self-Organizing Maps. In press. Society and Natural Resources. DOI:10.1080/08941920.2015.1045645.

Lofland J. and L. H. Lofland. 1995. Analyzing social settings: A guide to qualitative observation and analysis. Wadsworth Publishing Company, Belmont, CA. 268 p.

McClaran, M. 2008. Personal communication April 22, 2008.

Moote, M.A. and M. P. McClaran 1997. Viewpoint: Implications of participatory democracy for public land planning. Journal of Range Management 50:473-481.

Morghan, K. J. R., R. L. Sheley, and T. J. Svejcar. 2006. Successful adaptive management - The integration of research and management. Rangeland Ecology & Management 59:216-219.

Norman, D.A. 1983. Some observations on mental models. Chapter 1, pgs. 7-14 In: , D. Gentner and A. L. Stevens (eds) Mental Models. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Nelson, R.H. 1995. Public lands and private rights: The failure of scientific management. Rowman & Littlefield Publishers, Landham, MD. 400 pgs.

North, M., Stine, P., O'Hara, K., Zielinski, W., Stephens, S. 2009. An ecosystem management strategy for Sierran mixed-conifer forests. Gen. Tech. Rep. PSW-GTR-220 (Second printing, with addendum). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 49 p. http://www.fs.fed.us/psw/publications/documents/psw_gtr220/psw_gtr220.pdf

Raffa, K. F., B. Aukema, B. J. Bentz, A. Carroll, N. Erbilgin, D. Herms, J. A. Hicke, R. W. Hofstetter, S. Katovich, B. S. Lindgren, J. Logan, W. Mattson, A. S. Munson, D. J. Robinson, D. L. Six, P. C. Tobin, P. A. Townsend, and K. F. Wallin. 2009. A literal use of "forest health" safeguards against misuse and misapplication. Journal of Forestry 107(5):276-277.

Rapport, D. J., G. Bohm, D. Buckingham, J. Cairns, R. Costanza, J. R. Karr, H. A. M. de Fruijf, R. Levins, A. J. McMichael, N. O. Nielsen, and W. G. Whitford. 1999. Ecosystem health: The concept, the ISEH, and the important tasks ahead. Ecosystem Health 5(2):82-90.

Reed, M. S. 2008. Stakeholder participation for environmental management: A literature review. Biological Conservation 141: 2417–2431.

Rowe, G., and L. J. Frewer. 2000. Public participation methods: a framework for evaluation. Science, Technology, & Human Values 25:3-29.

Ross, N., J. Eyles, D. Cole, and A. Innantuono. 1997. The ecosystem health metaphor in science and policy. The Canadian Geographer 41(2):114-127.

Ruth, L. 1996. Conservation and controversy: National Forest management, 1960-1995. P. 145-162 in Sierra Nevada Ecosystem Project: Final Report to Congress, Vol II. University of California Centers for Water and Wildland Resources, Davis, CA.

Schiff, A. 1962. Fire and Water: Scientific Heresy in the Forest Service. Harvard University Press, Cambridge, MA.

Sheehan K.B. 2001. E-mail survey response rates: A review. J Comput-Mediat Comm 6. doi:10.1111/j.1083-6101.2001.tb00117.x.

Stringer, L.C., A. J. Dougill, E. Fraser, K. Hubacek, C. Prell, and M. S. Reed. 2006. Unpacking "participation" in the adaptive management of social-ecological systems: a critical review. Ecology and Society 11:39.

Sulak, A. and L. Huntsinger. 2012. Perceptions of Forest Health among Stakeholders in an Adaptive Management Project in the Sierra Nevada of California. Journal of Forestry 110:312-317.

Sulak, A., L. Huntsinger, and S. Kocher. 2015. The Sierra Nevada Adaptive Management Project: Cooperative Extension and University Researchers Collaborate. California Agriculture 69(1):43-49.

Treves, A., R.B. Wallace, L. Naughton-Treves, and A. Morales. 2006. Co-managing human-wildlife conflicts: A review. Human Dimensions of Wildlife 11:383-396.

University of California Cooperative Extension (UCCE). 2014. Facilitation Skills for a Collaborative Adaptive Management Process: A workbook to train natural resource managers and stakeholders in facilitation of collaborative projects.170 page. Available on-line at: http://snamp.cnr.berkeley.edu/documents/574/.

University of California Science Team (UCST). 2007. Revision of the workplan: Learning how to apply adaptive management in the Sierra Nevada Forest Plan Amendment. 73 pages. http://snamp.cnr.berkeley.edu/workplan/

United States Department of Agriculture, Forest Service (USDA FS). 2004. Sierra Nevada Forest Plan Amendment - Final Supplemental Environmental Impact Statement Record of Decision. Pacific Southwest Region 5 p. 72.

Wagner C.L., Fernandez-Gimenez, M.E. 2009. Effects of community-based collaborative group characteristics on social capital. Environ Manage 44:632–45.Walters, C.J. 1986. Adaptive management of renewable resources. MacMillan Press, New York, N.Y. 374 pp.

Walters, C. J., and C. S. Holling. 1990. Large scale management experiments and learning by doing. Ecology 71(6):2060-2069.

Warren, W. A. 2007. What is a healthy forest?: Definitions, rationales, and the lifeworld. Society and Natural Resources 20(2):99

Wondolleck, J. M. 1988. Public Lands Conflict and Resolution: Managing National Forest Disputes. Plenum Press, New York, NY.

Appendix F1: Participation Team Evaluation Tables

CORE ELEMENT: Transparency - "Public understands decision-making (in the SNAMP) process. Information about issues and process is available" (Laurian & Shaw 2009). "Open, accessible, and transparent process" (Conley and Moote 2003).

Evaluation Criterion	Measures	Type of data	Analysis method	Accomplished?
Meetings are held in places/at times convenient for stakeholders (Smith & McDonough 2001).	SNAMP gives adequate notification of meetings and events: Number of days between first notification and event. Locations and times with most attendance. Choose a minimum attendance as acceptable.	Event records, interview results, compare to literature best practices, matrices, evaluations, observer notes	Quantitative	Yes
Presence of an effective facilitator and/or coordinator (Leach 2006, Reed 2008). Training for participants in collaborative skills (Leach 2006). Presence of a strong leader (Leach 2006). "External facilitator" (Twarkins et al 2001).	Presence/absence of facilitators at meetings and impact of that presence on participant experiences. Evidence of trainings and requests for trainings. Impressions of participants about leadership.	Event records, interview notes	Quantitative and qualitative	Yes
SNAMP meeting and engagement methods are "selected and tailored to the decision-making context" (Reed 2008 and Glicken 2000). Varied in time and place to encourage broad attendance; also structure as well as flexibility important (Twarkins et al 2001).	Meeting methods are appropriate for the meeting purpose.	Meeting evaluations, interview notes, internal evaluation of meetings	Qualitative	Yes
SNAMP makes current and relevant project and scientific information accessible and available to the public (Rowe & Fewer 2000). Information is "documented and communicated in a manner understandable to all stakeholders" (Gregory et al 2006; Beckley et al 2006). The process uses good science, science that is trusted by participants (Interview #2) "high quality information" (Innes 1999; Leach 2006). Scientists "employ clear language" and don't talk down to participants (Walker and Daniels 2001).	Plans, maps and other documents are updated, understandable and widely available to interested parties (Cote & Bouthillier 2002). Presentations are accessible to all levels and efforts are made to clarify definitions for the audience. Number of questions requesting explanation of meeting information. Currency of data used. Date documents uploaded to website prior or post meetings/events. Evaluation of SNAMP written documents for accessibility and timeliness. No jargon.	Interview results, meeting notes, website data, evaluations, meeting observation notes	Quantitative and qualitative	Yes except some critique of UCST communication with public
SNAMP promotes early and continued involvement - all participants are included in all phases of project. (Interviews #9, #13, #14, #19, #30; Reed 2008)	Percent of SNAMP meetings open to the public. Evidence of SNAMP encouragement of public attendance. Categories of people invited to events. Use of website for sharing of decisions/decision making events. Evidence of "sustained quality stakeholder interactions" (Bales et al 2004). Participants included as early as possible in design and implementation of project (Bales et al 2004; Sheppard 2005) - dates attendees first become involved. Website launch dates. Participants agree to ground rules for the process (Sheppard 2005). Evidence of stakeholder complaints about lack of transparency.	Invitee lists for events, attendance lists, interview results, website data, individual communications	Quantitative and qualitative	Yes except some critique that managers were not included as early as possible in design and implementation of project
SNAMP clearly defines and articulates reasons for public involvement.	There is clear and timely documentation of purpose, results and degree of public influence (Sheppard 2005). SNAMP includes rules and expectations for participants in meetings and publications (Leach 2006; Shindler & Neburka 1997). SNAMP meetings and the project overall have a clear purpose and endpoint and next steps are clear (Shindler & Neburka 1997). Mention of these topics in documents, publications, meeting agendas and notes.	SNAMP documents, publications, and meeting notes, matrices, evaluations, interview results, observer notes	Quantitative and qualitative	Yes - at beginning had to spend extra time on expectation; next steps were not always clear

CORE ELEMENT: Inclusiveness - SNAMP incorporates a wide range of public values (Beckley et al 2006; Rowe & Fewer 2000).

Evaluation Criterion	Measures	Type of data	Analysis method
SNAMP reaches a large number of people (Interview #9), "inclusiveness" (Conley & Moote 2003; Laurian & Shaw 2009; Leach 2006; Twarkins et al 2001) "accessibility" (Beckley et al 2006)	Number of contacts on outreach email list, attendance at SNAMP events, attendance at events where SNAMP was presented, numbers who comment on website, individual outreach contacts, affiliations for these people.	Names of participants, affiliations, for each event with type of event, interview results about who is missing, evaluation results, website data	Quantitative
SNAMP reaches a broad and diverse audience (Interviews #13, #14, #19, #30; Conley & Moote 2003; Leach 2006; Plummer and Armitage et al 2008; Wondolleck & Yaffee 2000)	Number of contacts from different affiliations: on outreach email list, attendance at SNAMP events, attendance at events where SNAMP was presented, who comment on website, individual outreach contacts. Connections to those beyond primary participants (Conley & Moote 2003)/ SNAMP engages more than the "usual suspects" who are already engaged in policy and research debates (Stringer et al 2006). Relevant stakeholders are analyzed and represented systematically (Reed 2008).	Names of participants, affiliations, for each event with type of event, interview results about who is missing, evaluation results, website data	Quantitative
SNAMP reaches all relevant and significant groups (Armitage et al 2007; Glicken 2000; Innes and Booher 1999, Innes 1999) including major NGOs from all sides. "Representation" (Moote & McClaran 1997)	All groups that are normally involved in forest management are participating in SNAMP. Those what are determined via stakeholder analysis and participant suggestions to have a stake in SNAMP are contacted and invited to join. All relevant and significant NGO groups from all sides participate in SNAMP regardless of size or influence (Keough & Blahna 2005). Those who frequently object and/or sue the USFS over management are involved in SNAMP. SNAMP is not missing any crucial groups/people.	Names of participants, affiliations, for each event with type of event, interview results about who is crucial to the process or missing, evaluation results, website data, lawsuit authors from USFS.	Quantitative and qualitative
SNAMP reaches local people (Moore 1996); specifically local government (Conley & Moote 2003). SNAMP reaches all scales - local, regional, watershed, etc (Armitage et al 2007; Plummer and Armitage et al 2008)	Local people and groups are participating in SNAMP. Numbers and kinds of events held in local study areas. Attendance at SNAMP events as well as outreach talks. [But at policy level collaboratives it is common to have organizations rather than individuals participate due to travel distance - two table problem - Margerum 2008.]	Names of participants, affiliations, for each event with type of event, interview results about who is crucial to the process or missing, evaluation results, website data	Quantitative
SNAMP incorporates a wide range of public values (Plummer and Armitage et al 2008; Rowe & Fewer 2000)	Number of contacts on outreach email list, attendance at SNAMP events, attendance at events where SNAMP was presented, numbers who comment on website, individual outreach contacts, affiliations for these people, number and diversity of comments received at meetings, outreach talks and on the website.	Names of participants, affiliations, for each event with type of event, interview results about diversity of views in SNAMP, evaluation results, website data	Quantitative and qualitative
SNAMP's attendance reflects renewal as well as consistency in participation (Interviews #9, #13, #14, #19, #30; Beckley et al 2006; Moote & McClaran 1997). Different groups are allowed to participate at different stages (Stringer et al 2006). The process "keeps participants at the table, interested and learning" (Innes 1999). "Comprehensive and sustained public involvement" and "continuity in participants" (Leach 2006).	"Evidence of sustained quality stakeholder interactions" (Bales et al 2004): SNAMP participant change and stability over time in both numbers, affiliations, and individuals. No major faction that has gone away mad and is litigating (Interview #20). The SNAMP participation process is flexible allowing people to change the way they participate (Stringer et al 2006). "New opportunities for interaction" (Wondolleck & Yaffee 2000). Accessible to all (Moote & McClaran 1997).	Event records and attendance, interview results to explain changes, meeting evaluation results	Quantitative and qualitative
SNAMP's website augments participation for existing participants and brings in new participants.	Number of people who use the website, comparison of those people to those who attend/are vocal at meetings.	Total number of website hits, reasons or timing for those hits, number of people using web, who using the web and how.	Quantitative and qualitative

CORE ELEMENT: Learning - Communication is ongoing and two way in SNAMP (Beckley et al 2006; Laurian & Shaw 2009); SNAMP "contributes to all participants' knowledge" (Beckley et al 2006)

Evaluation Criterion	Measures	Type of data	Analysis method	Accomplished?
SNAMP increases public awareness/increases agency awareness of public views (Laurian & Shaw 2009). "Joint or reciprocal learning" (Twarkins et al 2001)	Number of people aware of SNAMP, issues at stake, and decision making process (Laurian & Shaw 2009): number of contacts on outreach email list, attendance at SNAMP events, attendance at events where SNAMP was presented, numbers who comment on website, individual outreach contacts, diversity in affiliations for these people. Number of USFS people involved with SNAMP: on outreach email list, attendance at meetings, individual contacts between USFS and public, comments on their environmental docs, comments at their USFS NEPA events. UCST & USFS are aware of public views, concerns and preferences (Laurian & Shaw 2009): number of UCST and USFS attendance at meetings, face-to-face interactions with the public.	Names of participants, affiliations, for each event with type of event, interview results about interactions with the USFS and the public, comments on USFS documents.	Quantitative and qualitative	Yes for participants; unknown for non participants
SNAMP participants feel ownership of the process/plan (Moore 1996; Wondolleck & Yaffee 2000; Interview #2). Participants feel heard (Interview #9). SNAMP is learning from its participants.	SNAMP collects feedback from participants (Chess & Purcell 1999). Evidence that the participants' comments appear in meeting notes (Tuler & Webler 1999) or in environmental documents (McCool & Guthrie 2001). Or that they are clearly addressed in website interactions or emails. Evidence that changes are made in SNAMP in response to public input (Interview #9). If comments are not used, participants know why (Interview #9). SNAMP decision maker available to the public - generally and at meetings (Shindler & Neburka 1997). Number of participants who had face to face interaction with scientists/decision makers. Number of meetings that promoted individual conversations with PIs. Email/web interactions between participants and PIs. SNAMP participants feel that the events get more meaningful as time goes on in the project (Interview #9). "Active open minded listening" by scientists, scientists take notes on participant comments (Walkers and Daniels 2001).	Meeting notes, website data, archival data, environmental documents/publications, interview results, evaluations, observer notes, email interactions	Quantitative and qualitative	Yes but constrained by scientific method
Participants learn from SNAMP (Interview #21)/gain knowledge and understanding (Conley & Moote 2003, Innes 1999; Moote & McClaran 1997). The SNAMP process produces information that stakeholders can understand and accept (Innes and Booher 1999).	Availability of facilitator and UCCE representatives (Bales et al 2004) as well as UCST project scientists for translation of science (Glicken 2001). Structure promotes learning - room layout, agenda organization, facilitation. Researchers and agency people take participant knowledge seriously. The process engages participants in learning through discussion, drama, humor and informal interaction (Innes and Booher 1999). Educational aids provided where needed (Sheppard 2005). Evidence of "agreed upon data or scientific information"/mutual understanding (Innes & Booher 1999; Laurian & Shaw 2009).	Attendance, room evaluation and agenda analysis, evaluations, interview notes, observer notes	Quantitative and qualitative	Yes
SNAMP meetings are structured to promote full group interaction (Shindler & Neburka 1997) and deliberative dialogue (Beckley et al 2006; Interview #6). "Perspectives are exchanged and modified via discursive communication" (Plummer and Armitage 2007)	Room layouts, meeting goals, facilitation, interview comments, all crucial people in attendance. Participant discussions are frank and open (Beckley et al 2006).	Attendance, room evaluation and agenda analysis, interview data, observer notes	Quantitative and qualitative	Yes
Participants have power to influence the process and outcomes (Cote & Bouthillier 2002; Tuler & Webler 1999) Or they are able to share in collective decision making (Fiorino 1990, formal or informal - Keough & Blahna 2005). Process "encourages participants to challenge assumptions" (Innes 1999). "Equitable distribution of power and influence" (Leach 2006).	Analysis of participant legal or organizational structural power. Meeting notes that reflect sharing in decision making, and equitable interactions with PIs. Participants participate equitably with the experts and agency reps (Fiorino 1990). Evidence that meetings and meeting discussions focus on participants' interests/concerns (Cote & Bouthillier 2002); altered based on participant suggestion or request. Science is responsive to user needs and interests (Bales et al 2004).	Legal/structural analysis, meeting notes, email or website logs, meeting planning discussions, website data	Quantitative and qualitative	No - shared decision making not possible for UCST or USFS
Technology transfer - SNAMP/UC educates USFS and the public about the most current uses of technology used by the UCST teams. UCST is an active communicator of research (Gibbons et al 2008).	The SNAMP process incorporates high quality information for many types/levels of participant and assures agreement on meaning (Innes and Booher 1999). Variety of meeting and presentation types. Descriptions in meetings notes, meeting agendas, website.	Meeting notes, agendas and matrices, evaluations	Quantitative and qualitative	Yes
Data sharing - UCST shares research results/data to the best of their ability and in a clear and useful manner to the public and MOUP.	Amount of UCST data on data sharing site and speed of sharing, use of data sharing site by stakeholders, information shared at meetings, other methods of data sharing.	Data sharing website access log and uploading log, meeting notes	Quantitative and qualitative	Yes but data sharing website underutilized and eventually abandoned
Involving a third party increases vertical learning integration up to higher institutional levels (Stringer et al 2006).	Evidence that learning occurs at high levels within participating institutions - attendance of high level reps, appearance in environmental docs. Connections to UCST facilitation ("achieving such a feedback across institutional levels requires an agent or institution acceptable to all groups who can ensure that this sort of dialog does take place" Stringer et al 2006)	Interview notes, meeting notes, meeting attendance, individual communications	Qualitative	Yes to some extent
The public has a common understanding of the tradeoffs of implementing the studied fuels treatments (Interview #24).	Evidence that there is general agreement on the effects of SPLATs.	Interview notes, meeting notes, observer meeting notes, individual communications, web postings, key agreements	Qualitative	Yes
Shared understanding develops (Ansell and Gash 2007; Armitage et al 2007; Plummer and Armitage 2007)	Evidence that there is general agreement on the issues at stake in SNAMP - forest health? Adaptive management? State of Sierra forests? Strategies to manage forests?	Interview notes, meeting notes, observer meeting notes, individual communications, web postings, key agreements	Qualitative	Yes

CORE ELEMENT: Effectiveness - SNAMP improves the quality of decisions (Beckley et al 2006). SNAMP completes its contractual obligations.

Evaluation Criterion	Measures	Type of data	Analysis method	Accomplished?
The SNAMP process produces UC and USFS plans that are implemented. (McCool & Guthrie 2001; Moore 1996; Plummer and Armitage 2007; and Interviews #6, #11, #16, #19, #20, #24).	Implementation of individual parts of SNAMP - both UC research and USFS mgmt. All UCST team experiments conducted. USFS SP and LC treatments happen. Numbers of acres treated/studied.	Research completion, peer reviewed published papers and environmental docs, USFS records	Quantitative	Treatments were implemented but delayed and some experiments truncated
SNAMP generates acceptance of agency, legitimacy, (of USFS and UCST) and its actions (Moore 1996; Laurian & Shaw 2009; Plummer and Armitage 2007). There is broad support among the stakeholders for SNAMP (Interviews #3, #19). Stakeholder satisfaction is key (Interview #26). There are mutually beneficial outcomes (Moore 1996, Wondolleck & Yaffee 1994). SNAMP creates the basis for new agreements regarding forest management (Cote & Bouthillier 2002).	The USFS is an active participant; it listens to the public and UCST's findings (Interview #2). Number of meetings with USFS leadership present and actively participating. Participant attitudes towards agency actions and attitudes, either USFS or UCST. Participant understanding. The final plan/product agrees with public input (Interview #28, #30, #31). The agreement is supported through to implementation by stakeholders (Moore 1996). Stakeholders appear to be moving towards more collaboration post-SNAMP.	Conversations with participants, meeting notes, interview notes, observer meeting notes, web postings, email conversations	Qualitative	Somewhat accomplished and after SNAMP ends
SNAMP research results inform USFS management (Interview #23; Conley & Moote 2003). SNAMP and UCST research change the way USFS manages and studies forests in the future (Interviews #5, #13, #14) The USFS monitors after SNAMP is complete (Interview #10).	Examples of changes in Last Chance and Sugar Pine and future management plans for those forests and others in the Sierra (Interview #4). Examples of changes in USFS research or monitoring based on SNAMP. Should research show changes are needed in USFS, examples of everyone working together to change management (Interview #20).	Conversations with USFS, meeting notes, USFS environmental documents, interview notes, mention in any new Sierra Framework.	Qualitative	Some evidence of USFS use of SNAMP data, after SNAMP ends
SNAMP's AM framework/ parts of the AM framework are adopted by USFS. Quality of USFS decisions is improved (Laurian & Shaw 2009)	Examples of changes in future management plans or planning docs for forests in the Sierra. UCST monitors how SNAMP affects future management (Interview #6). Quality of decisions improved because based in broad knowledge base and public support (Laurian & Shaw 2009).	Conversations with USFS, meeting notes, environmental documents, interview notes.	Qualitative	After SNAMP ends
SNAMP creates new practices within participating institutions (Conley & Moote 2003). SNAMP results in flexible and networked institutions allowing more creativity in response to change and conflict/build institutional capacity and resilience (Laurian & Shaw 2009). New collaborations come out of SNAMP (Innes and Booher 1999). Improved capacity for dispute resolution (Conely & Moote 2003). "Second order effects" (Innes 1999).	Examples of changes within the USFS, changes in relationships with other MOUP based on SNAMP. New partnerships with stakeholders and within stakeholders. UCST and USFS are more efficient, effective, able to respond to input better (Interview #1). USFS and UCST relationships with stakeholders are improved. New collaborations are created out of SNAMP.	Conversations with USFS, meeting notes, environmental documents, interview notes	Qualitative	Some evidence of USFS use of SNAMP public participation methods, after SNAMP ends
SNAMP is successful and useful in the eyes of both the USFS and the participants (Interviews #7, #8). SNAMP was a good investment of time and energy (Interview #8). Participants satisfied (Laurian & Shaw 2009). SNAMP produces information that stakeholders accept as accurate (Innes 1999).	Discussions with USFS and other participants from interviews and meetings notes. Continued attendance at meetings and positive evaluations.	Interview notes, meeting notes, meeting evaluations, future survey?	Quantitative	Yes
A lasting data network is created and SNAMP measurements are continued (Interview #12).	Continuation of SNAMP study projects by USFS or UCST or a portion there of.	Future data collection protocols and data, environmental docs	Quantitative and qualitative	For some parts - fisher and water
The UCST completes its workplan and sees the research through to completion (Interview #13, #16). UCST produces a final report to the USFS.	Number of published peer reviewed papers (Interview #4, Gibbons et al 2008). Each team in SNAMP reaches its scientific research goals (Interview #11) and integrates research across disciplines - joint papers, collaborative field work, sustained participation in SNAMP meetings (Bales et al 2004). The UCST completes its contractual obligations. Factors that facilitated or hindered UCST's process. Specific team's progress and successes. The UCST remains a fully integrated team through the end of the project (Interview #13). All data is collected and the fisher are tracked (Interview #16). Final document reviewed by public and published.	SNAMP data records and documents, meeting notes, matrices	Quantitative and qualitative	Yes
SNAMP reaches consensus and answers the question of how to minimize fire danger and still have owls and fisher around (Interview #17; Laurian & Shaw 2009). Eventually SNAMP produces a real reduction in vulnerability to fire without environmental degradation (based on Bales et al 2004). SNAMP facilitates implementation of a solution (Laurian & Shaw 2009).	UCST makes useful recommendations to USFS that allow for fire danger mitigation as well as protection of environmental values. There is stakeholder and USFS agreement about next steps. Future research shows SNAMP research produced improved environmental conditions. Improved habitat and water quality; biological diversity preserved (Conely & Moote 2003).	SNAMP documents and meeting notes, matrices, peer reviewed research on Sierra forests	Quantitative and qualitative	After SNAMP ends
SNAMP compares favorably with other similar processes in terms of costs and benefits (Innes and Booher 1999).	Total cost of SNAMP compared to other AM processes of similar scale. Total benefits of SNAMP compared as well.	SNAMP records	Quantitative and qualitative	Unknown
SNAMP culminates in a written document of some sort that is acceptable to stakeholders and agencies. A "clear written plan" (Conely & Moote 2003) or a "high quality agreement" (Innes 1999).	The document has clear goals, expectations; is based in sound consensus science; integrated with socioeconomic considerations; approved by a consensus based process (all from Mandarano 2008).	SNAMP records, UCST workplan, meeting notes, final document review comments, final document	Quantitative and qualitative	Yes
SNAMP develops a clear 3rd party adaptive management process that can be applied elsewhere. It produces learning and change in and beyond this group (Innes and Booher 1999). SNAMP's results and conclusions are available to other groups and not lost in bureaucracy (Interview #18 and Innes 1999).	Review of SNAMP meeting information, processes and data, final documentation of SNAMP. Other projects that use SNAMP's lessons learned or are based on SNAMP in any way. SNAMP is able to be scaled up to regional or national level policies (Stringer et al 2006).	Meeting notes, agendas and matrices, evaluations, interview data, literature search	Quantitative and qualitative	Yes but after SNAMP ends
SNAMP produces a [mutually agreed upon] definition of adaptive management (Interview #2).	Mention of an agreement on a definition in any SNAMP documents or meeting notes in addition to the UCST workplan.	SNAMP records, UCST workplan, interview notes, meeting notes	Qualitative	Yes

CORE ELEMENT: Adaptive management components - Comparison to adaptive management criteria from literature

Evaluation Criterion	Measures	Type of data	Analysis method	Accomplished?
The AM circle is fully completed (Interviews #2, 4). SNAMP completes its legal requirements? (Laurian & Shaw 2009)	Explanation of the USFS constraints; its flexibility to adapt management based on UCST research (Interview #23). Information from public and USFS about implementation of next projects - the final step in SNAMP (the left hand side), check each step (Reever Morghan et al 2006). Delegation of power - Margerum 2008.	Conversations with USFS, future meeting notes, USFS environmental documents, interview results, meeting evaluations, key agreements.	Quantitative and qualitative	After SNAMP ends, USFS responsible, public to monitor
SNAMP "improves USFS managers' knowledge about a set of well defined ecological objectives through implementation of carefully designed quasi-experimental management interventions and monitoring programs" (Gregory et al 2006). UCST provides appropriate information at the level of detail needed for management (Interview #23). Does the UCST "recognize the need to provide information that can be directly used by decision makers"? (Gregory et al 2006)	USFS knowledge is improved. "The adaptive management design is paired down to focus on only those uncertainties most likely to influence management decisions" (Gregory et al 2006; Reever Morghan et al 2006) "Project timeline to obtain verified results is compatible with management decision making requirements" (Gregory et al 2006; Reever Morghan et al 2006). UCST provided enough information that the USFS can go forward with a science based plan for wildfire management (Interview #12). SNAMP experiments are designed to test managers' hypotheses about the effect of treatments on the ecosystem (Gregory et al 2006). How early were USFS managers included in SNAMP planning? Do SNAMP experiments change over time to increase or decrease the ability of the research to answer management questions? How does the UCST share information with MOUP? Does the MOUP agree with both the quantity and type of information shared? "The information collected through adaptive management has sufficient predictive ability to make a difference to managers" (Gregory et al 2006). The USFS uses UCST information in future wildfire management plans.	Interview data, meeting notes, communications between teams and USFS, appearance in USFS environmental documents, SNAMP final document, use of data sharing website, attendance at IT meetings where data/results are shared, communication between UCST and MOUP	Quantitative and qualitative	UCST aimed report at managers; managers were not included early enough and do not feel they had input. Use of SNAMP results occurred somewhat already, full use yet to be determined
SNAMP's "design and assessment of adaptive management plans explicitly address the multiple goals of stakeholders (rather than only scientists)" (Gregory et al 2006).	Description of who was involved in determining SNAMP research designs. Analysis of whether the science addresses the managers' and stakeholders' main questions or concerns.	Meeting attendance lists, email conversations, interview notes, meeting notes, observation notes	Quantitative and qualitative	Somewhat
The MOUP's responsibilities for implementing the adaptive management cycle are clear and acted upon (Gregory et al 2006). There is explicit policy guidance and leadership support for adaptive management.	Funding (Leach 2006), technological and coordination support are adequate (Keough & Blahna 2005; Habron 2003). MOUP professional support is adequate. MOUP time dedicated to SNAMP is adequate. Funding from a variety of sources (Wondolleck & Yaffee 2000).	Public, MOUP and internal UCST meeting notes, funding scares and improvements, interview notes	Quantitative and qualitative	No
Adequate attention is paid to stakeholder shared understanding and decision making for SNAMP over all and for each team (Gregory et al 2006).	Stakeholders are satisfied with SNAMP; participation is worthwhile. Stakeholders feel empowered. There are no lawsuits from within the active stakeholder group or from others/less management through the judiciary (Moore 1996; Interview #29).	Interview notes, legal proceedings of study areas or other entities post-SNAMP, meeting observation notes	Qualitative	Yes
SNAMP addresses "potential issues related to background trends and cumulative effects of management actions in the adaptive management design for SNAMP overall and for each team" (Gregory et al 2006).	Review of the workplan overall and for each team. Reviewed in both public meetings and internal meetings.	UCST and team workplans, public and internal meeting notes	Qualitative	Yes
SNAMP uses "stopping rules and clear thresholds [to] identify and/or minimize the perceived risks of failures to species and institutions for SNAMP overall and for each team" (Gregory et al 2006; Plummer and Armitage 2007)	Indicators and thresholds are jointly agreed upon for each team. How is agreement determined? The agreed upon thresholds are used by the USFS. The thresholds have clear meanings and implications to avoid misinterpretation.	Meeting notes (esp annual, internal UCST, and IT), USFS environmental docs	Qualitative	No - specifically not included
SNAMP and the USFS have "sufficient management flexibility and continuity to incorporate new information in revised experimental designs for SNAMP overall and for each team" (Gregory et al 2006)	Analysis of whether the USFS is able to change later prescriptions based on SNAMP lessons learned - Legally as well as procedurally. Can UCST incorporate new information during the project?	USFS environmental docs, SNAMP internal and external meeting notes	Qualitative	Somewhat for UCST and to be determined for USFS
The "proposed AM design does not involve any trade-offs that might be considered taboo by some stakeholders" (Gregory et al 2006).	Do stakeholders have lines already drawn in the sand? Are those who do (have lines drawn) participating or not participating in SNAMP? What are those taboos? Will this cause some groups/individuals to sue?	Interview notes, meeting notes, evaluations	Qualitative	No - specifically not included
Sufficient analytical skills are available (staff or contractors) to design, evaluate, and monitor adaptive management plans" (Gregory et al 2006).	Annual sufficient funding to have the personnel in place to complete workplan and monitoring. Peer review comments and approval of plans, final recommendations and interim publications.	Numbers of UCST employees, change over time, reasons for those changes, funding requests and actual funding levels	Qualitative	To occur after SNAMP ends
SNAMP researchers (ideally familiar with AM) and managers are engaged in the process from the planning stages. They worked together to create adaptive management plan (Reever Morghan et al 2006). SNAMP incorporates the right people and resources to achieve its goals (McGuire 2006).	When were researchers involved and when did managers become involved? How much did they work together to plan the project? Was the project adequately funded all the way through? Were the right people involved from the MOUP and UC to allow the project to move forward? Do the MOUP all bring critical components to the project?	Dates of meetings, attendance lists, meeting notes, interview notes	Quantitative and qualitative	No
Monitoring occurs either during SNAMP (UCST) or after (USFS)? (Keough & Blahna 2005).	Does UCST conduct final monitoring after the treatments are implemented? Does the USFS continue to monitor after SNAMP is complete?	SNAMP records, USFS records	Quantitative	After SNAMP ends, USFS responsible, public to monitor
"Ecological, social, and economic variables are included during data collection, analysis and monitoring" (Keough & Blahna 2005).	Confirmation that these components are included in workplan and occur throughout the project. If not why not?	SNAMP records, meeting notes, interview notes	Quantitative and qualitative	Yes but not economic
"Stakeholders see adaptive management as an effective way to deal with uncertainty" (Gregory et al 2006) .	Stakeholders support SNAMP and its conclusions via comments on final documents and lack of lawsuits.	Meeting notes, interview notes, USFS records, comments on final SNAMP docs	Qualitative	Yes
Decisions are reached through dialogue and diverse inputs are present in decision-making (Plummer and Armitage 2007).	Decisions are made transparent - either during or after deliberations. Diverse opinions are taken into consideration during decision making. Diverse interests are present during decision-making.	Meeting notes, interview notes, USFS records, comments on final SNAMP docs	Qualitative	Yes

Literature in SNAMP Evaluation Table

The table also includes input from participants via interviews conducted from 2008-2010.

Armitage, D., M. Marschke, and R. Plummer. 2008. Adaptive co-management and the paradox of learning. Global environmental change 18:86-98.

Bales, R.C., D.M. Liverman, and B.J. Morehouse. 2004. Integrated assessment as a step toward reducing climate vulnerability in the Southwestern United States. American Meteorological Society. November 2004: 1-8.

Beckley, T. M., Parkins, J. R., and Sheppard, S. R. J. 2006. Public Participation in Sustainable Forest Management: A Reference Guide., Sustainable Forest Management Network.

Chess, C. and K. Purcell. 1999. Public participation and the environment: do we know what works? Environmental Science & Technology 33:2685-2692.

Conely, A. and Moote, M.A. 2003. Evaluating collaborative natural resource management. Society and Natural Resources. 16:371-386.

Cote, M.A. and L. Bouthillier. 2002. Assessing the effect of public involvement processes in forest management in Quebec. Forest Policy and Economics 4:213-225.

Fiorino, D. J. 1990. Citizen participation and environmental risk: a survey of institutional mechanisms. Science, Technology, & Human Values 15:226-243.

Fischhoff, B. 1995. Risk perception and communication unplugged: twenty years of process. Risk Analysis 15:137-145.

Gibbons, P., Zammit, C., Youngentob, K., Possingham, H. P., Lindenmayer, D. B., Bekessy, S., Burgman, M., Colyvan, M., Considine, M., Felton, A., Hobbs, R. J., Hurley, K., McAlpine, C., McCarthy, M. A., Moore, J., Robinson, D., Salt, D. and Wintle, B. (2008), Some practical suggestions for improving engagement between researchers and policy-makers in natural resource management. Ecological Management & Restoration, 9: 182–186. doi: 10.1111/j.1442-8903.2008.00416.x

Glicken, J. 2001. Getting stakeholder participation ‘right’: a discussion of participatory processes and possible pitfalls. Environmental Science & Policy 3:305-310.

Gregory, R. Ohlson, D. and Arvai. J. 2006. "Deconstructing adaptive management: Criteria for applications to environmental management." Ecological Applications. 16(6) 2411-2425.

Habron, G. 2003. "Role of adaptive management for watershed councils" Environmental Management." 31(1) 29-41.

Innes, J.E. 1999. "Evaluating consensus building" in The Consensus Building Handbook: A Comprehensive Guide to Reaching Agreement. Eds. Lawrence Susskind, Sarah McKearnan, and Jennifer Thomas-Larmer. The Consensus Building Institute. Thousand Oaks, CA: Sage Publications.

Innes, J.E. and Booher, D.E. 1999. Consensus building and complex adaptive systems: A framework for evaluating collaborative planning. Journal of the American Planning Association; 65(4): 412-423.

Keough, H.L. and Blahna, D.L. 2005 Achieving integrative, collaborative ecosystem management. Conservation Biology. 20(5): 1373-1382.

Laurian, L. and M. M. Shaw 2009. Evaluation of Public Participation: The Practices of Certified Planners. Journal of Planning Education and Research March 2009 vol. 28 no. 3 293-309.

Leach, W.D. 2006. Public involvement in USDA Forest Service policymaking: A literature review. Journal of Forestry January/February 2006.

Margerum, R.D. 2008. A typology of collaboration efforts in environmental management. Environmental Management (2008) 41:487–500.

McCool, S. F., and K. Guthrie. 2001. Mapping the dimensions of successful public participation in messy natural resources management situations. Society and Natural Resources 14:309-323.

McGuire, M. 2006. Collaborative public management: Assessing what we know and how we know it. Public Administration Review Volume 66, Issue Supplement s1, pages 33–43, December 2006.

Moore, S. 1996. Defining "successful" environmental dispute resolution: case studies from public land planning in the United States and Australia. Environmental Impact Assessment Review 16:151-169.

Moote, M.A. and M.P. McClaran. 1997. Viewpoint: Implications of participatory democracy for public land planning. Journal of Range Management 50:473-481.

Plummer, R. and D. Armitage. 2007. A resilience-based framework for evaluating adaptive co-management: Linking ecology, economics, and society in a complex world. Ecological Economics 61:62-74.

Reed, M. S. 2008. Stakeholder participation for environmental management: A literature review. Biological Conservation 141: 2417–2431.

Reever Morghan, K. J., Sheley, R.L., Svejcar, T.J. "Successful adaptive management - the integration of research and management." Rangeland Ecology & Management. 59:216-219.

Rowe, G. and L. J. Frewer. 2000. Public participation methods: a framework for evaluation. Science, Technology, & Human Values 25:3-29.

Sheppard, S. R. J. 2005. Participatory decision support for sustainable forest management: a framework for planning with local communities at the landscape level in Canada. Canadian Journal of Forest Research 35:1515-1526.

Shindler, B. and J. Neburka. 1997. Public participation in forest planning: 8 attributes of success. Journal of Forestry 95:17-19.

Smith, P. D. and M. H. McDonough. 2001. Beyond public participation: fairness in natural resource decision making. Society and Natural Resources 14:239-249.

Stringer, L.C., Dougill, A.J., Fraser, E., Hubacek, K., Prell, C., Reed, M.S. 2006. "Unpacking 'participation' in the adaptive management of social-ecological systems: a critical review." Ecology and Society 11(2):39.

Tuler, S. and T. Webler. 1999. Voices from the forest: what participants expect of a public participation process. Society and Natural Resources 12:437-453.

Twarkins, M., L. Fisher, and T. Robertson. 2001. Public involvement in forest management planning: A view from the Northeast. Journal of Sustainable Forestry, 13(1-2), 237-251.

Walker, G.B. and S.E. Daniels. 2001. Natural resource policy and the paradox of public involvement: Bringing scientists and citizens together. Journal of Sustainable Forestry, 13(1-2), 253-269.

Wondolleck, J. and S.L. Yaffee. 1994. Building bridges across agency boundaries: In search of excellence in the U.S. Forest Service (Ann Arbor: University of Michigan, 1994), a research report to the USDA-Forest Service, Pacific Northwest Research Station.

Wondolleck, J.M. and S.L. Yaffee. 2000. Making collaboration work: Lessons from innovation in natural resource management. Island Press, Washington. 277pp.

Appendix F2: Affiliation of stakeholders contacted through SNAMP

<u>Affiliation of stakeholders attending SNAMP events:</u>

Federal Agencies

US Fish and Wildlife Service

United States Forest Service, Region 5

United States Forest Service, El Dorado National Forest

United States Forest Service, Sequoia National Forest

United States Forest Service, Sierra National Forest

United States Forest Service, Stanislaus National Forest

United States Forest Service, Tahoe National Forest

United States Forest Service, Pacific Southwest Research Station

United States Geological Survey

Natural Resources Conservation Service

National Park Service, Yosemite National Park

National Park Service, Sequoia/Kings Canyon National Park

Americorps (part of the Corporation for National and Community Service)

State Agencies:

California Air Resources Board

California Department of Fish and Wildlife

California Department of Food and Agriculture

California Department of Transportation

California Department of Water Resources

California Energy Commission

CalFire

California Regional Water Quality Board

California Resources Agency

California State Parks

California Tahoe Conservancy

Lahontan Regional Water Quality Board

San Francisco Regional Water Quality Board

Sierra Nevada Conservancy

Local Government/Collaboratives

Camptonville Community Partnership

Foresthill Forum

Fresno County Agricultural Commission

Madera County Board of Supervisors

Placer County

Placer County Agricultural Commission

Placer County Board of Supervisors

Sutter Yuba Mental Health

Trinity Collaborative

Yuba County Office of Education

Local Water Districts/Councils

Calaveras County Water District

Central Sierra Watershed Committee

El Dorado Water Agency

Fresno and Chowchilla Rivers Watershed Council

Mountain Counties Water Association

Placer County Water Agency

Plumas County Flood Control District

San Francisco Power and Water

Upper Merced River Watershed Council

Local Resource Conservation Districts

California Association of Resource Conservation Districts

Nevada County Resource Conservation District

Placer County Resource Conservation District

Tahoe Resource Conservation District

Tehama County Resource Conservation District

Local Fire Safe Councils/Fire Districts

Amador Fire Safe Council

Camptonville Valley Fire

Foresthill Fire Department

Georgetown Fire Department

Nevada County Fire Safe Council

Mariposa County Fire

Mariposa Fire Safe Council

North Lake Tahoe Fire Protection District

Plumas County Fire Safe Council

Tribes

Mono Rancheria

Tule River Tribe

Industry

California Forestry Association

Pacific Gas and Electric

Sierra Forest Products

Sierra Pacific Industries

Southern California Edison

TSS Consultants

WM Beaty and Associates

Universities/Research

University of California Berkeley

University of California Cooperative Extension

University of California Davis

University of California Merced

University of Minnesota

University of Wisconsin

University of California San Francisco

California Academy of Sciences

Conservation Biology Institute

Prescott College

Conservation organizations

American River Watershed Institute

Bear Yuba Land Trust
California Native Plant Society
Central Sierra Environmental Resource Center
Defenders of Wildlife
Ebbetts Pass Forest Watch
Environment Now
Environmental Defense Fund
Mariposans for Environment and Responsible Government
National Forest Foundation
Quincy Library Group
Pacific Rivers Council
Resources Legacy Fund
Sequoia Forest Keepers
Sierra Club
Sierra Forest Legacy
The Wilderness Society

Other

Bridges to Housing
Calvin Crest Outdoor Education School
Harmony Health
Indian Peak Ranch
Jim Nelson Facilitation
Sierra Business Council
Sierra Institute for Community and Environment
Sound Watershed Consulting
Salvation Army Yuba Sutter
Wildscape Engineering Services
Yosemite Mountain Ranch
Yuba Sutter Corporation

Additional organizations reached through outreach presentations at their events:

State Agencies

California Environmental Protection Agency

Local Government

Amador County Board of Supervisors
El Dorado County Board of Supervisors
Fresno County Board of Supervisors
Kern County Board of Supervisors
Madera County Board of Supervisors
Mariposa County Board of Supervisors
Nevada City Mayor
Placer County Board of Supervisors
Tuolumne County Board of Supervisors

Local Water Districts/Councils

Sierra County Watershed Council
Placer Watershed Forum
Statewide Watershed Forum
Yuba Watershed Protection Council

Local Resource Conservation Districts

Central Sierra Regional Resource Conservation District
Coarsegold Resource Conservation District
Mariposa Resource Conservation District

Tuolumne Resource Conservation District
Yosemite/Sequoia Resource Conservation and Development Council

Local Fire Safe Councils
Butte County Fire Safe Council
El Dorado County Fire Safe Council
Foresthill/Iowa Hill Fire Safe Council
NorCal Prescribed Fire Council
Prather Fire Safe Council
Sierra County Fire Safe Council
Yuba Fire Safe Council
Yuba Watershed Protection & Fire Safe Council

Industry/Business groups
Bass Lake Chamber of Commerce
The Divide Home & Business Show
Mariposa Chamber of Commerce
Oakhurst Board of Realtors
Yosemite Alpine Village Association

Civic groups
49er Rotary Club
Auburn Host Lions Club
Foresthill Lions Club
Oakhurst Rotary Club
Oakhurst Soroptomist Club

Civic /Political Forums
Amador-El Dorado Forest Forum
California Rangeland Conservation Coalition
Oakhurst Democratic Club
Fish Camp Advisory Council
Mountain Community Women
Sierra Dialog
Sierra Day at the Capital Reception
Yosemite Alpine Village Association
Yosemite Stanislaus Solutions Collaborative

Universities/Research
Association for Fire Ecology
Association of Natural Resource Extension Professionals

Conservation Organizations
Audubon Society, Sacramento, Sierra Foothills
California Native Plant Society, Sacramento and El Dorado Chapters
California Rangeland Conservation Association
Sierra Club, Tehipite Chapter
Sierra Foothills Conservancy
Sierra Nevada Alliance
Stewards of the Sierra
The Nature Conservancy
Trout Unlimited, Sac-Sierra chapter
Wilderness Society

Professional Societies

Ecological Society of America

Society of American Foresters Sac-Tahoe, High Sierra, San Joaquin chapters

Society of Range Management

Wildlife Society

Arts/Recreation Groups

Road Scholars

Tenaya Lodge Greenpath

Trailbike Sportsman Association

Yosemite Artists

Youth

Children's Museum of the Sierra

Foresthill High School

Mariposa 4H camp

Minarets High School

Mountain Home School

North Fork Elementary

Oakcreek Elementary School

Oakhurst Elementary School

Rio Americano High School

Yosemite High School

Other

Jack Boyd's Outdoor Education School

High Sierra Volunteer Trail Crew

IDRS Inc.

California Indian Partnership Fair

Appendix F3: SNAMP Newsletters

Fall 2007 - Welcome to SNAMP – The SNAMP project involves resource agencies, the public, and scientists to assess how vegetation treatments to prevent wildfire will affect fire risk, wildlife, forest health, and water quantity and quality. The Forest Service will plan and implement the treatments, while the Science team will independently monitor and study the effects of the projects. The public is invited to provide feedback on the entire process.

Spring 2008 - Forest and Fire Team - The Forest Team will investigate effects of fuel treatments on fire behavior and forest health. Crews are collecting pre-treatment data on forest structure and composition, shrubs and fuels in the 1^{st} 2 years.

Summer 2008 - Water Team - Water Team members will investigate impacts of strategic fuel treatments on water quality and quantity across SNAMP treatment and control catchments prior to and after treatments.

Fall 2008 - Fisher Team - The Pacific Fisher is a State and Federal Species of Special Concern. The fisher study will determine whether the population in the southern study area is stable or decreasing, which vital rate is most important in population change, and which environmental factors are correlated with these changes.

Fall 2008 - Spotted Owl Team - The California Spotted Owl is an uncommon resident in the mixed conifer belt of the west slope of the Sierra Nevada, and a State and Federal Species of Special Concern. This team will assess the impacts of forest fuel treatments on owl territory, occupancy rates and reproductive output.

Fall 2008 - Spatial Team - Geospatial data, or data linked to a place on the surface of the earth, is increasingly a part of our everyday lives and an important resource for environmental study. We are mapping the forest and forest habitat before and after treatments across our treatment and control sites.

Spring 2009 - Participation Team - The Participation Team is studying the Forest Service public participation processes and working to increase stakeholder involvement in SNAMP through regular public meetings and reporting, public outreach, and an interactive website. The Participation Team coordinates and facilitates all SNAMP meetings, field trips, and events. In addition, the Participation Team seeks to facilitate an open dialogue amongst scientists and interested members of the public.

Fall 2009 - Water Team - The Water Team is investigating impacts of strategic fuel treatments in SNAMP study areas on both water quantity and quality in headwater catchments of treatment and control firesheds. The goal is to better understand the water storage in and movement through the catchments: how the water begins as snow or rain, interacts with the landscape, and eventually exits the system as stream discharge.

Spring 2010 - Fire Integration Project- This study compares the performance of fuel management strategies currently being implemented on Forest Service lands in the Sierra Nevada using fire behavior modeling to better understand how fuel management treatments are implemented in real landscapes, and if these treatments perform as theory predicts.

Fall 2010 - Fisher Team - The Fisher Team goals include: (1) determining the population parameters and limiting factors for the Pacific fisher; and (2) evaluating the effects of fuel reduction treatments on resource use, survival, and population persistence of Pacific fisher. The fisher team has captured and radio collared 66 individual fishers since the start.

Spring 2011 - Owl Team - The Owl Team is studying the effects of treatments on spotted owl site occupancy, survival and reproduction. The owl team is collecting pre- and post-treatment data on vegetative structure within owl territories to estimate the effects of treatments on owl habitat. The owl team just finished their 4th field season and are currently analyzing the data.

Spring 2011 - Spatial Team - The Spatial Team is using Lidar data to map forests before and after vegetation treatments and measuring forest habitat characteristics across treatment and control sites. Airborne Lidar (light detection and ranging) works by bouncing light against a target in a similar way to sonar or radar.

Winter 2011- Forest Fuels Treatment Field Trip - The October 2011 SNAMP field trip to the Last Chance study site showed fuels treatment on the ground. Here we retrace our steps, review the stops of the field trip, and highlight some of the significant conversations and realizations made by participants. This field trip provided the opportunity to examine the fuel treatments for the first time and provide a forum for learning through discussion and dialogue.

Fall 2012 - Water Team - The Water Team is exploring: (1) What are the timing and amount of water storage and routing in forested Sierra Nevada catchments? (2) What effects do forest treatments have on water quality, quantity (yield), storage and routing through the catchments? And (3) What is the transferability of information from four intensively measured headwater streams to a larger area fireshed response?

Spring 2014 – Integration - The Public Participation team discusses the SNAMP integration effort, which will provide a comparative framework that examines the resources we are evaluating: water, wildlife, and forest health, and the role of public participation in collaborative adaptive management (CAM). The goal is to enable managers and other stakeholders to compare the effects of SPLATs across resources.

Fall 2014 - IT Meeting Wrap up - We are in the midst of a very busy final year as each team continues to work on data analysis, integration and final report writing. Part of our SNAMP commitment is to provide opportunities for all stakeholders to participate in meetings where information is shared and ideas exchanged. In this vein, each Science Team participated in either an in-person meeting or webinar to inform SNAMP participants of their current results and integration metrics. This newsletter is intended to provide one more link to the study and results, as well as to help better prepare participants for the Annual Meeting webinar on November 6, 2014.

Appendix F4: SNAMP Videos

Fisher Wildlife Team Webinar (October 2013): Dr. Craig Thompson of the SNAMP Pacific Fisher Team participated in a webinar today in which he presented an overview of the team's camera survey, reproduction, survival, and dispersal data for 2013. He also gave details about the metrics that will be used to integrate fisher data with the other SNAMP teams, including occupancy, intensity of use, and reproductive habitat quality, as well as the priorities for the Fisher Team in 2014

Pacific Fisher Survival vs. Predation (date): In our recent field trip with the Fisher Team, Dr. Rick Sweitzer shared some of the interesting findings regarding the survival and predation of Pacific Fishers in the Sierra Nevada forests. This field trip was organized by SNAMP.

Pacific Fisher Kits (date): In this video, Dr. Rick Sweitzer gives an explanation to why fishers would move their kits to different den trees?

California's Water Tower (date): This episode of Onward California follows Roger Bales, director of the Sierra Nevada Research Institute at UC Merced, into the mountains to measure the water and geochemical balance of the landscape. The impact of climate change on California's water supply is more than an environmental concern -- it's at the forefront of economic sustainability.

California Spotted Owl Science in the Sierra Nevada (March 2012): This video gives updates on the studies on California Spotted Owl done by the SNAMP Owl team and created by Participation Team.

Science on Forest Health (date): This video describes the science on forest health being done by the SNAMP Fire and Forest Ecosystem Health team.

SNAMP Picture Series - "What is SNAMP?" (March 2011): This short video created by Participation Team offers a brief introduction to SNAMP through a series of pictures and text.

Public Participation in Collaborative Adaptive Management (July 2010): This video created by Participation Team discusses the role of public participation in SNAMP and features SNAMP scientists / participants.

Spotted Owl Video (July 2010): This short video features SNAMPs Kim Ingram talking about a spotted Owl fieldtrip. It was created by Jeannette Warnert with UC Ag and Natural Resources.

Fisher Video (October 2008)**:** This video about the pacific Fisher features SNAMP scientist Rick Sweitzer. It was created by Jeannette Warnert with UC Ag and Natural Resources.

The Sierra Nevada Adaptive Management Project (October 2008): This overview video about SNAMP features several SNAMP scientists. It was created by Jeannette Warnert.

Appendix F5: SNAMP UCANR Green Blog Stories

Can be found at http://ucanr.edu/blogs/Green/

7/9/2010	Scientists track the California spotted owl
10/8/2010	Pacific fisher kits returned to the wild
12/15/2010	Wireless networks could improve state water forecasting
2/23/2011	Do CA Spotted Owls prefer to nest near forest edges? SNAMP scientists say No
6/15/2011	Scientists complete eventful fisher monitoring season
9/28/2011	US Forest Service and UC study ways to reduce wildfire
12/14/2011	UC Wildlife team looking for single socks
1/18/2012	You socked it to us!
2/29/2012	Using Lidar to map forest structure and characterize wildlife habitat
6/13/2012	Visualizing the forest
9/26/2012	Web-based tools' contribution to public participation and natural resource management
12/18/2012	Evidence of rodenticide poisoning of wildlife found in the Sierra
4/15/2013	Fire ecology - a "hot" career to attract students to science
7/25/2013	Roadkill is a serious threat to rare wildlife populations
11/8/2013	Generating energy from forest products
2/27/2014	What happens when a wildfire sweeps through your study area?
6/4/2014	Taming Sierra flames
9/19/2014	Calendar with rare Pacific fisher photos available from UC Cooperative Extension
11/13/2014	The effects of density and high severity fire on tree and forest health

Appendix F6: SNAMP Collaborative Adaptive Management Curriculum

Facilitation Skills for a Collaborative Adaptive Management Process: A workbook to train natural resource managers and stakeholders in facilitation of collaborative projects

By the University of California Cooperative Extension
January 2014

Collaborative Adaptive Management (CAM) is many things to different people. It is based on the premise that ecosystems are complex, dynamic and unpredictable. It involves deliberate experimentation that provides information to resource managers on appropriate spatial and temporal scales. CAM is a participatory process that engages scientists, stakeholders and managers in a relationship based on shared understanding and learning that assesses and evaluates the values and implicit assumptions that underline management goals.

A team of University of California Cooperative Extension (UCCE) professionals based on their experiences facilitating civic engagement in agriculture, natural resources, nutrition and youth development has developed a series of curriculum modules and workshops to help engage people with the CAM process.

The curriculum was refined through a series of workshops offered by UCCE to SNAMP scientists, managers and stakeholders in Winter, Spring and Summer 2013. Their CAM curriculum is available here as a download.

http://snamp.cnr.berkeley.edu/documents/574/

Appendix F7: Participation Team Paper Abstracts

Huntsinger, L. and A. Sulak. (in preparation) Third party monitoring and the evolution of National Forest Management

In 1905 Gifford Pinchot took the Division of Forestry and created the US Forest Service with his vision of conservation: “the greatest good for the greatest number for the longest time." His goal was to create a cadre of professional forest managers able to make the best decisions and develop the science needed to manage a resource crucial to the nation. Since then, and as vehement controversy persists, the management models for forests and rangelands have evolved to include multiple use, public participation, and now, adaptive management. Relationships between the land management agencies, and the public, are considered key to making decisions and even conducting science for resource management. But is there a third step on the horizon? The Sierra Nevada Adaptive Management Project can be seen as a case study for exploring the potential evolution of a three way model for natural resource management that includes the agency, the public, and a monitoring or science participant. Three historical periods can be used to represent three major phases in the development of the public role in Forest Service decision-making: the early 20th century, the post-war period, and beyond the 80’s.

Kelly, M., S. Ferranto, S. Lei, K. Ueda, and L. Huntsinger. 2012.. Expanding the table: the web as a tool for participatory adaptive management in California: a case study in the Sierra Nevada. Journal of Environmental Management 109:1 - 11. [http://dx.doi.org/10.1016/j.jenvman.2012.04.035]

Participatory adaptive management is widely promoted as the new paradigm in public lands management. It is grounded in two underlying principles e that management experiments and diverse sources of information should be used to continually refine management in complex ecological systems, and that the public must be included throughout the adaptive management process. Access to scientific results and exchange of information is at the core of both of these principles. The recent proliferation of Internet communities and web-based participation tools raises the question of how the Internet might help facilitate information exchange in participatory adaptive management. Using a case study approach, the role of web technologies in facilitating the flow of transparent and useful information was examined in a participatory adaptive management project focused on Forest Service vegetation management treatments in California's Sierra Nevada. Three evaluation methods were used: analysis of web usage and content, a survey of active participants, and a review of comments posted to the project website. Results suggest that the web played an important role throughout the adaptive management cycle by supporting communication through disseminating information to the public and increasing the transparency of the scientific process. The web played a small, but important role in public consultation, by providing a forum for targeted questions and feedback from the public. Internet technology did not actively support the two-way flow of information necessary for mutual learning. Web technology complements face-to-face interactions and public meetings, rather than replacing them.

Kocher, S., Lombardo, A., and R.A. Sweitzer. 2012. Using Social Media to Involve the Public in Wildlife Research—the SNAMP Fisher Sock Collection Drive, February 2013. Volume 51(1).

The University of California Cooperative Extension used social media to solicit donations to support studies on the Pacific fisher, a rare forest-dwelling weasel, conducted by UC scientists. The social media campaign included blog and Facebook postings, news releases, and tweets requesting donations of single socks. Socks were donated from around the state and nation, with 82% coming from urban areas. The drive was successful at securing resources to support wildlife studies while at the same time extending outreach to new non-local audiences. The major challenge was developing the local logistical support to deal with the overwhelming influx of donations.

Lei, Shufei , A. Iles, and M. Kelly. (2015) Characterizing the networks of digital information that support collaborative adaptive forest management in Sierra Nevada forests. Environmental Management 56(1): 94-109.

Some of the factors that can contribute to the success of adaptive co-management – such as social learning, open communication, and trust - are built upon a foundation of the open exchange of information about science and management between participants and the public. Despite the importance of information transparency, the use and flow of information in adaptive co-management is rarely characterized in detail in the literature, and there are opportunities to develop strategies for increasing the exchange of science and management information in such contexts. As digital information channels and networks have increased over the last decade, powerful new information monitoring tools have also evolved allowing for the complete characterization of information products through production, transport, use, and monitoring. This study uses these tools to characterize the use of various science and management information products in a case study - the Sierra Nevada Adaptive Management Project (SNAMP) - using a mixed methods (citation analysis, web analytics, and content analysis) approach borrowed from the information processing and management field. The results from our case study show that information technologies and systems greatly facilitate the flow and use of digital information, leading to multiparty collaborations such as knowledge transfer and public participation in science. We conclude with recommendations for increasing information exchange in ACM by taking advantage of available information technologies, systems and networks.

Lei, S. and M. Kelly. (2015) Evaluating adaptive collaborative management in Sierra Nevada forests by exploring public meeting dialogues using Self-Organizing Maps. Society and Natural Resources. DOI:10.1080/08941920.2015.1045645

Self-organizing maps (SOM) were used to explore multi-year public discussions associated with a forest management case study in the Sierra Nevada in order to understand whether and how adaptive co-management has facilitated discussion in a contentious environmental management setting. Input textual data consisted of the questions and responses from public meetings (2005-2012) in which scientific results, project progress, and other issues were discussed. We found that public discussion remained focused on the project content, yet the more contentious and critical issues dominated the discussions through time. Integration across topics could be improved. These results suggest that adaptive co-management in SNAMP has been successful in sustaining engagement and facilitating focused discussions among the contentious participants in the project. The SOM was an effective and efficient unsupervised machine-learning tool for organizing, distilling and making sense of unstructured and unorganized meeting notes, and might be explored more often for this kind of analysis.

Lei, S., and M. Kelly. (in preparation). Mapping the dynamics of social resilience in a forest management setting: Use of affiliation network analysis of public meetings and participants in the Sierra Nevada Adaptive Management Project. Environmental Management

Adaptive co-management is widely seen as the appropriate management regime for dealing with complex social-ecological systems, and to ensure ecological and social resiliency in these systems. More work has been devoted to understanding the ecological resilience of social-ecological systems; in this paper, we concentrated on the social resilience of a forest management system and modeled its social resilience framework using social network analysis. Our objectives were: 1) to quantitatively characterize aspects of social resiliency of adaptive co-management for a social-ecological system through affiliation network analysis of attendance data; and 2) to understand which factors in our project contributed to its social resilience. Our participants included managers from federal and state natural resource agencies and the public. We examined 7 years of attendance data at all public meetings associated with the Sierra Nevada Adaptive Management Project (SNAMP) and constructed a 2-mode affiliation social network that allowed us to ask questions about project cohesiveness, participation, and overall social resilience. Affiliation network analysis helped us evaluate critical aspects of the SNAMP social network, for example, the geographic and core-periphery patterns, the importance of individuals and particular public meetings were highlighted, and the dynamics of the network and its ability to withstand external perturbations were evaluated. In this case study, the SNAMP program showed aspects of social resiliency in the face of exogenous stressors. Important to the success of the SNAMP network were: 1) the ability of members of the management and public groups to become leaders; 2) the project norms of transparency and science integration; and 3) a flexible governance structure.

Sulak, A., Huntsinger, L. and S. Kocher. (2015). UC plays a crucial facilitating role in the Sierra Nevada Adaptive Management Project. California Agriculture. 69(1):43-49.

The Forest Service's 2004 Sierra Nevada Forest Plan Amendment calls for using participatory adaptive management to carry out treatments to improve forest health and reduce fire severity. The Sierra Nevada Adaptive Management Project began in 2005 and includes the University of California as a third party science and outreach provider in two Sierran national forests as part of a seven-year adaptive management project. University of California Cooperative Extension expertise in facilitating stakeholder participation is a crucial part of the project. Respondents to a 2010 email survey sent to an Extension outreach list valued the learning opportunities of the project, especially appreciating the open discussions, public input, and face-to-face contact with scientists. Despite the institutional and technical limits to power-sharing, an environment conducive to the social learning characteristic of democratic collaborative projects was created, and may lead to long term relationships that support use of project findings well after the University role in conducting the project has ended.

Sulak, A., and L. Huntsinger. 2012. Perceptions of forest health among stakeholders in an adaptive management project in the Sierra Nevada of California. Journal of Forestry 110:312-317.

"Forest health," a term broadly used in US forest management, has been described as a normative term that implies one ecological state is better than another and as a positive goal for forests that stakeholders can rally around. The definitions stakeholders brought to a participatory adaptive management program in central California may be thought of as reflective of mental models shaped by experience and culture. Perceptions of forest health and the potential link to ideas about management were assessed through 42 in-depth interviews of individuals concerned about forests in the study area. Four views of forest health emerged, characterized here as oriented to biodiversity, ecological processes, history, and management. These were not clearly linked to divergent opinions of what participants consider appropriate forest management tools. Definitions were not mutually exclusive or rigid, revealing opportunities for reconciliation and social learning. Working to establish unified ecological goals has been suggested as a first step for collaborative and participatory projects. Longer-term participants tended to espouse the process-oriented view of forest health, perhaps reflecting the development of a hybrid culture of shared meanings, norms, and expectations about team processes fostered through the social learning that is key to adaptive management.

MEMORANDUM OF UNDERSTANDING
among
UNITED STATES DEPARTMENT OF AGRICULTURE,
USDA FOREST SERVICE
PACIFIC SOUTHWEST REGION and RESEARCH STATION,
USDI FISH AND WILDLIFE SERVICE,
and STATE OF CALIFORNIA RESOURCES AGENCY

This **MEMORANDUM OF UNDERSTANDING** (this "**MOU**") is hereby entered into as of February ___, 2005 by and among the United States Department of Agriculture ("USDA") and the USDA Forest Service Pacific Southwest Region and Research Station, hereinafter referred to collectively as the "Forest Service," the United States Department of the Interior Fish and Wildlife Service, Pacific Region, California/Nevada Operations Office, hereinafter referred to as the "Fish and Wildlife Service," and the State of California, Resources Agency, hereinafter referred to as the "State." The Forest Service, Fish and Wildlife Service and the State may be referred to individually as a "Party" and collectively as the "Parties."

R E C I T A L S

A. The purpose of this MOU is to take the first step toward development of a framework for cooperation among the Parties and other stakeholders that builds upon the collaborative principles and goals of the Western Governors Association ("WGA") 10-Year Comprehensive Strategy and Implementation Plan to develop and apply a refined and active multiparty adaptive management and monitoring system consistent with the Sierra Nevada Forest Plan Amendment ("SNFPA"). This cooperation serves the mutual interest of the Parties and the public.

B. In January 2004, the Regional Forester, Pacific Southwest Region, issued the SNFPA Final Supplemental Environmental Impact Statement, Record of Decision ("ROD"). The ROD selected Alternative S2 for implementation and adopted and initiated an assessment of the Monitoring Plan contained in the 2001 SNFPA Final Environmental Impact Statement Adaptive Management Strategy (Appendix E). Adaptive management is the process of adjusting management in response to new information, knowledge or technologies.

C. In November 2004, the Chief of the Forest Service issued his SNFPA Appeal Decision affirming the Regional Forester's decision with instructions to fully develop the adaptive management and monitoring strategy of Alternative S2, to clarify how the timing of treatments and the feedback and adjustment loops will occur and to clarify how continued collaborative involvement of other government agencies, the science community, native tribes, local governments, and other interested stakeholders would be conducted by the Forest Service.

D. The Forest Service is interested in building stakeholder understanding and trust in the implementation of the ROD. The Forest Service and State recognize the value of using the University of California ("University") as a neutral third party with expertise in projects of this sort to assist in developing a process with the Forest Service and interested stakeholders to refine an active adaptive management and monitoring system. This refined adaptive management and monitoring process will inform and contribute to the improvement in implementation of land management practices, as prescribed, that will restore and protect valued natural resources and reduce the threats to them and communities at risk.

E. The Fish and Wildlife Service is interested in participating in the adaptive management process at both a technical and management level, in order to ensure that post-treatment and post-fire conditions offer multi-species habitat enhancement and the conservation of Federal threatened, endangered and candidate species. This process would include the development and review of individual project implementation monitoring and involve a feedback mechanism to ensure that appropriate changes are implemented when desired conditions and conservation goals are not being met at an individual project and landscape level.

F. The State is interested in increasing progress across the Sierra Nevada to reduce the risk of catastrophic wildfire to the communities, and associated destruction of wildlife habitat, water quality and adverse impacts on air quality in the region. The State is also interested in ensuring that the technical and management activities of the Forest Service, currently managing 11.5 million acres in the Sierra Nevada on behalf of the public, are effectively achieving broadly agreed upon goals weighing wildlife habitat needs with reducing expected wildfire losses, and improving overall forest health and structure and protecting municipal water supplies on a watershed basis. This objective is best achieved by full engagement by the Forest Service in a collaborative adaptive management and monitoring process with interested federal, state, local stakeholders, government agencies, Native American Tribal representatives and the scientific community as full partners directed previously by Congress and consistent with the WGA 10-Year Comprehensive Strategy and Implementation Plan. This adaptive management approach can improve forest management practices on lands owned and managed by other entities, both public and private.

G. There is mutual interest in understanding how various projects will look and function at the stand level as well as across larger landscapes. All Parties share the same general objective of balancing wildlife habitat needs and water quality considerations with reducing expected wildfire losses, and improving overall forest health and structure. A collaboratively developed and refined adaptive management strategy of annual monitoring, evaluation and accountability should inform management and interested stakeholders whether direction is being implemented as described, whether management practices are resulting in expected outcomes, and whether desired conditions are being met over appropriate timeframes. The adaptive management strategy should also offer a shared basis for designing and tracking changes or improvements at the stand and/or larger landscape levels. The refined SNFPA adaptive management and monitoring process will be coordinated with other monitoring processes under the Healthy Forests Initiative, the Wildland Fire Leadership Council, the December

23, 2004 NFMA planning regulations, and other ongoing SNFPA studies and research.

H. In light of the long history and debate over land and resource management planning on public and private lands in the Sierra Nevada, both stakeholder and expert deliberation throughout the process of developing and applying a refined and active multiparty adaptive management and monitoring system consistent with the SNFPA is necessary to enhance the Parties' collective ability to find lasting solutions to these inherently difficult management decisions. In addition, the Parties' ability to find such lasting solutions will be improved by working with a neutral third party to assist in the development of an adaptive management and monitoring system, implement the system, and then use the information obtained through this development and implementation process to inform the implementation of adaptive management and monitoring processes for future projects involving different areas. The third party must have impeccable scientific credentials as well as the skill and experience to sort through often apparently contradictory data and trends. In addition to their technical expertise, the party must also have the trust and respect of a wide variety of stakeholders. By virtue of its diverse teaching, research, and extension responsibilities, the University is both qualified to provide the depth of technical expertise and is highly regarded as an institution in its own right.

I. The Parties are entering into this MOU as a first step towards meeting the goals set forth above. The Parties contemplate that after the work required by this MOU is completed, the Parties will enter into two additional agreements. Specifically, the Parties desire to enter into a new agreement with the University by May 2, 2005, by which the Forest Service and University will agree that the University will start the process of developing the AMMP (as defined in Section I) and a work plan for implementing the AMMP. The Parties further contemplate that the University's report documenting the AMMP and the work plan for implementing the AMMP will be completed by September 23, 2005. Once the AMMP report and the work plan are completed, the Parties desire to enter into an agreement to implement the work plan by October 3, 2005.

I. Covenants of the Parties

In consideration of the above, the Parties agree as follows:

1) By February 23, 2005, the Forest Service and the University will jointly execute a brief statement of intent to participate in a process whereby the University will develop an adaptive management and project monitoring process designed to monitor the effects of a relevant range of ROD treatments (the "AMMP").

2) By April 15, 2005, the University will submit to the Parties a formal proposal outlining its role as third party in the AMMP. This proposal will include: (i) how stakeholder groups will be involved in the AMMP process; (ii) an overall explanation of how the University's recommended process will result in an AMMP that will meet the goals of the Parties set forth in the recitals; (iii) a timeline for completion of the

recommended process and a general work plan for the process; (iv) a description of a recommended phased approach for application of the AMMP to the Sierra Nevada Forest region covered by the ROD; and (v) the budget for completion of the recommended process. This proposal will be the basis for a written agreement (the "Agreement") between the Forest Service and the University, whereby the Forest Service and the University will agree that the University will implement a work plan that is based on the University's proposal and that is mutually acceptable to the Parties. .

3) The Agreement will be executed by the Forest Service and the University no later than May 2, 2005.

II. **Miscellaneous Agreements**

1. Freedom Of Information Act (FOIA) and Public Records Act . Any information furnished to the Forest Service and the Fish and Wildlife Service under this instrument is subject to the Freedom of Information Act (5 U.S.C. 552) and any information furnished to the State under this instrument is subject to the Public Records Act, California Government Code Sec. 6251 et seq.

2. Participation in Similar Activities. This instrument in no way restricts any of the parties from participating in similar activities with other public or private agencies, organizations, and individuals.

3. Commencement/Termination. This MOU takes effect upon the last date of any party to execute the MOU. This MOU will terminate thirty days after a Party sends a written termination notice to each of the other Parties.

4. Responsibilities of Parties. The parties and their respective agencies and office will handle their own activities and utilize their own resources, including the expenditure of their own funds, in pursuing these objectives, except as expressly set forth in this MOU.

5. Non-Fund Obligating Document. Nothing in this MOU shall require any of the parties to obligate or transfer any funds. Specific work projects or activities that involve the transfer of funds, services, or property among the various agencies and offices of the parties will require execution of separate agreements and be contingent upon the availability of appropriated funds. Such activities must be independently authorized by appropriate statutory authority. This MOU does not provide such authority. Negotiation, execution, and administration of each such agreement must comply with all applicable statues and regulations.

6. No Compensation to Participating Stakeholders. Nothing in this MOU includes or implies any payments or other compensation to participating non-governmental stakeholders by the signatory parties.

7. Establishment of Responsibility. This MOU is not intended to, and does not create, any right, benefit, or trust responsibility, substantive or procedural, enforceable at law or equity, by a party against the United States or the State, or any of their respective agencies, officers, or any person.

8. No Partnership Or Fiduciary Relationship. Nothing in this MOU shall be deemed to create a partnership or any other trust relationship among the Parties, it being expressly understood and agreed that the Parties' obligations hereunder are not fiduciary in nature.

9. Counterparts. This MOU and any amendment thereto may be executed in two or more counterparts, and by each Party on a separate counterpart, each of which, when executed and delivered, shall be an original and all of which together shall constitute one instrument, with the same force and effect as though all signatures appeared on a single document.

THE PARTIES HERETO have executed this instrument:

STATE OF CALIFORNIA
RESOURCES AGENCY

____
MIKE CHRISMAN
SECRETARY

UNITED STATES DEPARTMENT
OF AGRICULTURE

____
MARK E. REY
UNDERSECRETARY FOR NATURAL
RESOURCES AND ENVIRONMENT

USDI FISH AND WILDLIFE SERVICE
CALIFORNIA/NEVADA OPERATIONS

____
STEVE THOMPSON
MANAGER

USDA FOREST SERVICE

____
DALE BOSWORTH
CHIEF

USDA FOREST SERVICE
PACIFIC SOUTHWEST STATION

____
JAMES SEDELL
STATION DIRECTOR

USDA FOREST SERVICE
PACIFIC SOUTHWEST REGION

____
JACK BLACKWELL
REGIONAL FORESTER

Appendix H: SNAMP Revised Workplan, 2007

Revision of the workplan: Learning how to apply adaptive management in the Sierra Nevada Forest Plan Amendment

Submitted by the University of California Science Team*

Revised January 16, 2007

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*See Appendix 1 for biographical sketches of UC Research Team.

1.0 INTRODUCTION

The goal of the research proposed here is to learn how to use an adaptive management and monitoring system to understand ecosystem behavior, incorporate stakeholder participation, and inform the implementation of adaptive management for Forest Service lands in the Sierra Nevada of California. Nearly a century of fire management in the Sierra has had the unintended consequence of placing millions of hectares of forest at risk of catastrophic fire (Biswell 1989, van Wagtendonk 1998). This regional assessment of fire hazard and fuel loads is reflected in the Sierra Nevada Forest Plan Amendment (SNFPA 2004), in which modifying wildland fire behavior is a management priority. The preferred alternative is to apply strategic fuel management at the landscape level. The approach is based on the theory (Finney 2001) that disconnected fuel treatment patches that overlap in the direction of the head fire spread reduce the overall rate and intensity of the fire. Simulations have shown that with as little as 30% of the area in these strategically placed area treatments (SPLATs), fire risk can be decreased for the entire landscape. Despite the sound conceptual underpinning of strategic fuel treatments, there is uncertainty regarding their efficacy in modifying fire behavior and concern regarding potential impacts on wildlife and water resources. Moreover, given the history of debate over land and resource management in the Sierra Nevada, a lasting solution should engage stakeholders and promote active public participation in all phases of the process, including the development, interpretation, and incorporation of research-based information in the adaptive management process.

In February 2005, federal and state agencies responsible for the management of forest resources in California signed a Memorandum of Understanding (MOU 2005) in which the Parties agreed to begin the development of a framework for cooperation among the Parties and other stakeholders. The initial goal is to design and apply a multiparty adaptive management and monitoring system consistent with the Sierra Nevada Forest Plan Amendment (SNFPA 2004). The University of California was invited to serve as a neutral third party with expertise in this area to help the Forest Service achieve this end.

The fundamental mission of the University of California (UC) is to conduct basic research, educate University students, and provide public outreach. In consideration of this mission and the importance of the questions posed, we accepted the invitation in the Memorandum of Understanding (MOU 2005). Our charge was to develop an adaptive management and monitoring plan that informs and contributes to the improvement in implementation of land management practices, as prescribed in the Sierra Nevada Forest Plan Amendment. In this workplan, we describe a strategy to integrate stakeholder involvement into a research program measuring ecosystem responses to planned landscape prescriptions. To date, there is not enough information available to definitively assess the trade-offs implicit in this plan. Thus we propose to apply an adaptive management framework that describes how to collect and integrate information across scales, disciplines, and stakeholders in order to create a synthetic understanding of forest ecosystem responses to the proposed treatments and generate an inclusive appreciation of the inevitable trade-offs involved in forest management decisions. Critical to the success of this endeavor is adequate funding and timely execution of the strategic fuels management.

2.0 CONCEPTUAL FRAMEWORK

Adaptive resource management is an approach to management that acknowledges uncertainty about the resource to be managed and the need to learn (Walters 1986, 1993). This learning is produced by treating management as deliberate experimentation (Walters and Green 1997). Since the effects of any management activity are likely to be confounded by concurrent ecological and environmental changes, this confounding must be limited by the experimental design. The premise that adaptive management involves deliberate experimentation rather than a passive trial-and-error approach provides the first pillar of our conceptual foundation for this proposal.

Our second conceptual pillar is that adaptive management must be a participatory process that engages scientists, stakeholders, and managers in a long-term relationship grounded in shared learning about the ecosystem and society. We expect management and research objectives to change as society, environment, and knowledge change (Tear et al. 2005).

In this model of adaptive management, the products from the monitoring process are used to inform further experiments and should be used to shape management initiatives (Lee 1999). Adaptive management brings monitoring into the experimental process, using monitoring of outcomes to refine ecosystem understanding in a systematic way. Thus experimental design is a crucial part of management and monitoring because it ensures that outcomes are meaningful and provide feedback on a rigorous basis.

Box 1. Steps in Adaptive Management

1. Determine current management goals.
2. Gather and synthesize existing knowledge to develop working model(s) about how the ecosystem works in order to make first approximation predictions of management outcomes.
3. Design and implement management in accordance with principles of experimentation.
4. Monitor and evaluate the results of the management action.
5. Incorporate what is learned into the working model of how the ecosystem works, basing future management on improved understanding of ecological processes.
6. Adjust management as indicated by results, evaluation, and re-assessment of project goals.
7. Begin the process again.

Adaptive management in the context of our aspirations for collaborative and participatory management inherently requires a way of gathering information and incorporating it into an integrated model of how the ecosystem works that, ultimately, is accessible to all participants (Box 1). It is our premise that grounding collaborative and participatory processes in a common body of knowledge about the area to be managed, and the unfolding of the research process, supports more effective research and can inform decision-making. We believe this approach can provide for a shared understanding of the dynamic behavior of ecosystems and of the dramatic changes, both long- and short-term, that ecosystems have undergone.

In the case of the Sierra Nevada Adaptive Management Project, the management priorities have been decided by the Sierra Nevada Forest Plan itself. However, each project initiative will have local and

Illustration 1. Bahro and Barber 2004.

Sample Products from Fireshed Assessment

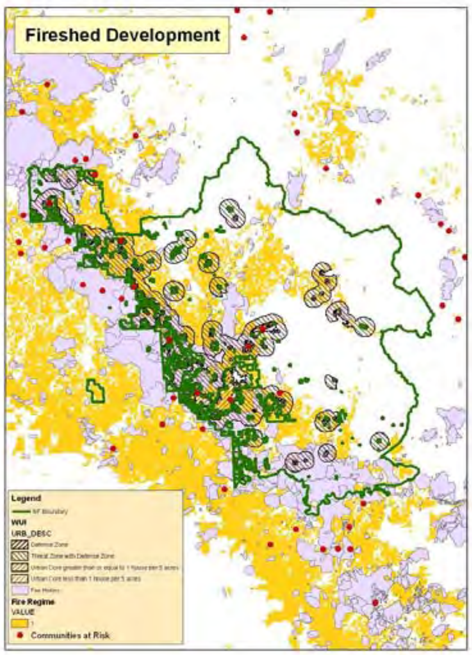

Figure 1. Fireshed delineation.

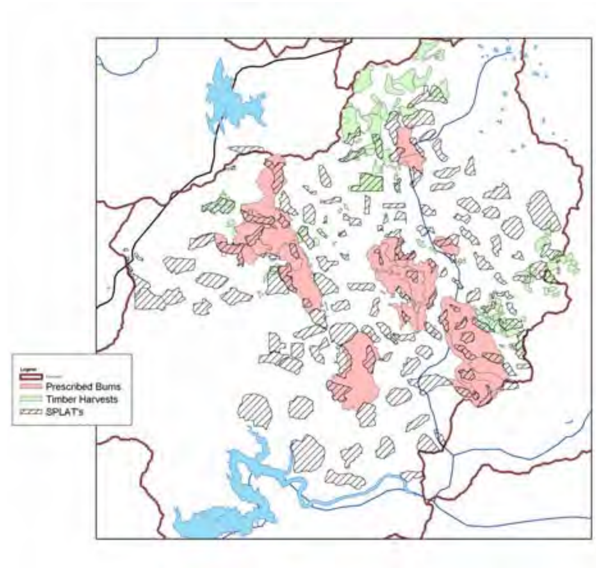

Figure 2. Treatment area opportunities.

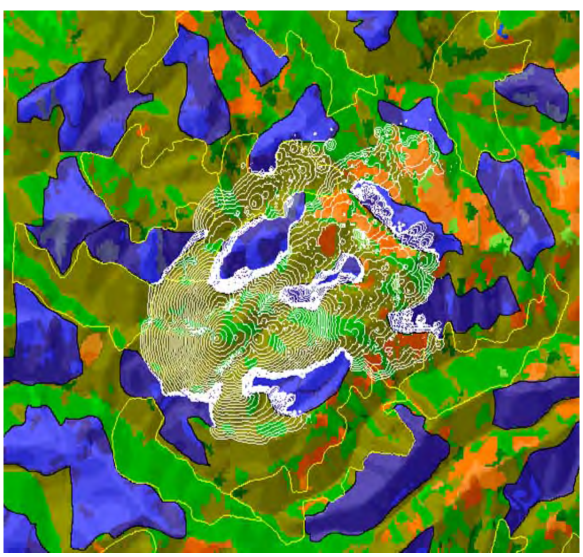

Figure 3. Potential wildland fire behavior in the treated landscape.

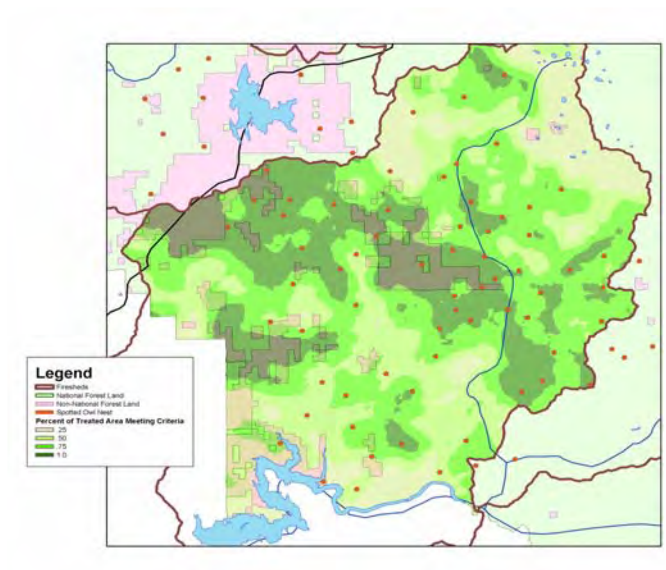

Figure 4. Focal mean analysis of California spotted owl habitat in the treated landscape.

Disclaimer: The views in this report (presentation) are these of the author(s) do not necessarily represent the views of the Forest Service.

multifaceted objectives that can be considered in the development of research approaches. Our working premise is that we need stakeholder participation and feedback during each phase of Science Team research for this adaptive management program. To encourage this exchange, we are committed to transparent decision-making. There will be ongoing analysis of the creation, adoption, and application of stakeholder and researcher information in the Forest Service adaptive management process.

3.0 USFS MANAGEMENT PLAN

The record of decision regarding the Sierra Nevada Forest Plan Amendment (SNFPA 2004) adopts "an integrated vegetation management strategy with the primary objective of protecting communities and modifying landscape-scale fire behavior to reduce the size and severity of wildfires." Under the approved plan (Alternative S2, SNFPA), Forest Service managers will use thinning, salvage, and prescribed and natural fires to make forests less susceptible to severe wildfires, as well as invasive pests and diseases. While goals previously established for the conservation of old-forest ecosystems and associated species will be retained, this plan also provides for other important elements, including the objectives of reducing stand density and regenerating shade-intolerant species (SNFPA 2004).

An innovative aspect of this plan is an explicit landscape planning approach epitomized by an emphasis on fireshed assessments. Firesheds are large landscapes (several to many thousands of acres) delineated by fire regime, condition class, fire history, fire hazard, and potential wildland fire behavior. Fireshed assessment is an interdisciplinary and collaborative process to change fuels and vegetation at the landscape scale. Within the context of the Sierra Nevada Forest Plan Amendment, these changes include the strategic placement of treatment (SPLAT) areas across the landscape to interrupt potential wildland fire spread, to reduce the extent and severity of these fires, and to improve the continuity and distribution of old forests across landscapes (Bahro and Barber 2004). See attached illustrations from Bahro and Barber (2004) of fireshed delineation and SPLAT arrangement (Illustration 1).

Our adaptive management plan is designed to address the uncertainties associated with the application of fireshed treatments. We have little experience by which to predict responses of wildlife, water, and forest health to the imposition of treatments distributed across 30% of a fireshed. Moreover, the concept of fireshed planning is new to the public. Thus an important goal is to learn how to engage stakeholders in this novel process to improve available information and to foster understanding and trust. As a team we are committed to an integrated, multimetric, adaptive management and monitoring plan. However, for project planning and management, we have identified four research themes: Fire and Forest Ecosystem Health, Participatory Processes, Water Quantity and Quality, and Wildlife. For each theme, we identify below the focal questions and our a priori expectations regarding the impact of the planned management regime.

4.0 FOCAL QUESTIONS

4.1 **Fire and Forest Ecosystem Health**

The three main questions we propose to address include modification of fire behavior across a fireshed, tree morbidity and mortality patterns associated with treatment design, and secondary effects of SPLATs on forest health through insect interactions. We expect that the strategic fuel manipulations will modify fire behavior in the treated fireshed as predicted by Finney's (2001) model. That is, if area treatments are placed strategically, the spread rate and intensity of the fire over the entire area burned will likely be reduced (Finney 2003). In terms of tree morbidity and mortality across the fireshed, we expect that the management regime will improve tree growth and survival within the treated areas and the immediate edge environments. The removal of some fraction of the vegetation will reduce competitive stress on the remaining trees. However, the extent of improvements of tree health across the landscape will depend on the specific spatial arrangements of the treatments. More numerous smaller treatment areas laid out in more linear shapes will maximize the edge to interior ratios and thereby reduce the effective neighborhood density of more trees in the fireshed. At the local level, there may be instances where insect interactions in the residual forest left after the creation of SPLATs have a negative effect on tree health. For example, if mechanical methods are used alone to reduce small tree density and the resultant activity fuels (i.e., slash) is left on site, it could provide habitat for *Ips* beetles to multiply. *Ips* beetles can seriously injure and kill trees under outbreak conditions. Alternatively, if prescribed fire is used to consume natural and activity fuels, we expect red turpentine beetles to attack residual pine trees (ponderosa, sugar, and Jeffrey pines). Such attacks may predispose these trees to the often lethal predation of mountain and western pine beetles. Our tree measurement and monitoring program is designed to capture both landscape and local impacts on tree health. This complexity related to issues of scale and ecological interactions further reinforces the need for a strong adaptive management program to reduce the uncertainty associated with the implementation of SPLATs.

4.2 **Participatory Processes**

How should an adaptive management process be structured to engage stakeholders in a way that encourages participation in science? A premise of the overall project is that UC, acting as a neutral third party, can make a significant contribution through scientific research conducted within an adaptive management framework. There has been progress thus far in developing the capacity for working with stakeholders in research development among members of the science team and the MOU partners (i.e., federal and state agencies that signed the MOU). As the project continues, stakeholders will be engaged at a deeper level, building relationships and networks that will facilitate mutual learning through the research process. Each research team is committed to identifying ways that stakeholders can be integrated into their parts of the research. In this way the stakeholders will be part of research development, implementation, and interpretation.

Part of this work will be examining local experience with science-based management. From the research perspective, the efficacy of various methods of stakeholder engagement in the research process will be analyzed. One method is the use of an interactive website and web-based tools to keep people informed and to provide a means for the public to give feedback and input directly to the science team. Another is public meetings and workshops, where attendees provide feedback and information. The application of SPLATs in two different sites provides an exceptional opportunity to learn from the experience of working with stakeholders. The strategic facilitation, coordination, and research demands of the project will require personnel trained in facilitation and community collaboration, connected to UC's faculty and research resources. Two new UC Cooperative Extension Advisors or equivalent personnel will coordinate stakeholder participation across the various research initiatives of this project, including stakeholder participation in research planning, monitoring, and interpretation. In addition, they will support team efforts to integrate stakeholder and research information into the adaptive management process and help to analyze how new information is incorporated into Forest Service decision-making. The decision-making flexibility, given the scientific research frame, at each juncture in the research process is a critical question. As a neutral third party, UC will work to identify how much influence stakeholders can have as part of the research at each step from research design through incorporating research results into management, and how stakeholder input is ultimately used. Public and stakeholder outreach as part of NEPA and other Forest Service public participation efforts will be conducted by the Forest Service.

4.3 **Water Quantity and Quality**

We expect that the catchment water cycles and the resulting stream water quality in Sierra Nevada forests will be directly affected by strategic fuel treatments in at least three ways. First, treatments may alter the partitioning of rain and snowmelt into runoff versus infiltration, affecting the timing and magnitude of both peak flows and the overall flow regime. This alteration is expected to be linked to canopy changes, which will affect interception, evapotranspiration, and soil moisture. Second, changes in the water cycle may affect water quality through effects on erosion and sedimentation and through changes in biogeochemical and nutrient cycling. Third, these changes, plus soil disturbance from roads/tracks may affect terrestrial and aquatic flora and fauna and the water resources serving downstream users. Effects of treatments on high flows vs. low flows vs. annual water yields may all differ in terms of magnitude, persistence, and relative impact to other resources. It is thus important to understand how different treatment strategies affect water quality (e.g. stream temperature, turbidity/sediment, dissolved oxygen), catchment water cycle (e.g. infiltration and soil moisture versus runoff and evapotranspiration), and ecological response (e.g. stream macroinvertebrates). We look forward to receiving comments from the stakeholders regarding these expected responses. We also note that in order to support an effective adaptive management plan for Sierra Nevada forests, information must be developed for representative areas and scaled across different hydroclimatic, physiographic, and forest regimes. Having a scaling strategy is important given the practical need to focus field measurements of treatment effects on the scale of a small headwater fireshed/watershed, versus the need to manage at the scales of a forest and bioregion. In this case, scaling refers to effects on lower-order catchments and streams throughout the forest rather than the cumulative effect on larger streams and catchments. Results should provide the basis for continuing operational assessments of how Framework treatments (SNFPA 2004) will impact streams, water cycle, water quality, and forest health.

4.4 **Wildlife**

Our focus is on the response of wildlife species dependent on attributes in late-seral forests to changes in habitat structure and composition at multiple geographic scales. We expect that SPLATs will reduce the viability of sensitive species (e.g., fisher, spotted owl, goshawk, and marten). However, we remain uncertain as to the extent and persistence of these impacts. Thus it is important to quantify changes in vital rates and population growth trends to make informed decisions about the trade-offs between reducing fire risk and the viability of sensitive wildlife species. Public input on the impacts of these tradeoffs is critical to the overall success of the decision making process.

5.0 RESEARCH DESIGN

As noted above, the challenge implicit in management as experimentation is to control for confounding influences (Walters and Green 1997). This control is particularly challenging when the experimental unit is a whole landscape (Hobbs 2003) and the inferential reference is an entire region. To meet our goal of providing credible scientific information (sensu Tear et al. 2005) we have identified three specific needs: 1) control for a host of ecosystem drivers in order to measure impact of SPLATs; 2) accommodate multiple measuring and monitoring objectives (e.g., fire behavior, fisher viability, water quality); 3) extend level of inference beyond research areas.

The management plan (SNFPA 2004) defines the experimental unit chosen for our study as a fireshed (Bahro and Barber 2004). While firesheds are a new concept, they share the scalability of watersheds in that large firesheds can be subdivided into smaller “catchment” firesheds. The largest experimental unit considered will be a fireshed on the order of 120 km^2 (30,000 acres) in size. We are focusing our efforts on the west side of the Sierra Nevada. In particular we are evaluating performance of strategic fuel reductions in relatively mature mixed conifer forests without a recent (last 50-100 years)

Table 1. Outlier analysis of top ranked candidate sites in the northern Sierra Nevada (Tahoe/El Dorado NF) and the southern Sierra Nevada (Sierra/Sequoia NF). Results based on GIS data layers provided by the USFS. For the quantitative variables (elevation, slope, and distance from urban areas), the means are reported with the standard deviation in parentheses. For the categorical variables, the top two ranked categories are reported followed by their fractional importance in parentheses. Majority categories are reported for the candidate sites.

Region Site	Elevation (m)	Slope (°)	Distance from urban area (km)	Aspect (N, E, S, W)		Canopy cover class (%)		Tree size distribution (size class)	
				1st Rank	2nd Rank	1st Rank	2nd Rank	1st Rank	2nd Rank
Tahoe/El Dorado National Forests	1511 (393)	5.5 (2.5)	21.4 (8.6)	W (0.36)	S (0.28)	>59 (0.40)	40-59 (0.30)	Small (0.44)	Medium (0.36)
Manila Canyon	1589 (260)	6.6 (3.6)	27.3 (3.5)	Majority: W		Majority: 40-59		Majority: Medium	
Sierra/Sequoia National Forests	2007 (311)	8.1 (3.3)	31.6 (12.9)	W (0.31)	S (0.27)	>59 (0.42)	40-59 (0.24)	Small (0.70)	Medium (0.17)
Fish Camp	1368 (316)	6.2 (2.8)	5.9 (3.1)	Majority: W		Majority: 40-59		Majority: Small	

major disturbance (e.g., natural fires, severe timber harvests). Region-wide these forests pose the greatest risk of catastrophic wildfire.

We cannot statistically sample the inherent heterogeneity present in firesheds throughout the Sierra Nevada. There are thousands of square kilometers of potential study areas that span a large range of conditions (Table 1). A random sample sufficiently large to capture this heterogeneity would be prohibitively expensive. As a feasible alternative, we have decided to select two sites that represent the major biogeographic gradient in the Sierra Nevada. We will locate one site in the northern half of the Sierra Nevada and one in the southern half. Using these two sites, we will look for consistent responses to SPLATs. In collaboration with our MOU partners, we identified 11 criteria for selecting our research sites. These criteria were unranked and represent management and policy priorities of the MOU partner agencies as well as ecological criteria that support the objectives of this study (Table 2). Statistically, our goal in the final site selection was to choose sites that were not outliers with respect to key ecological and management parameters (Table 1). The treatments in our management experiments will be the implementation of strategic fuel reductions within a small fireshed as outlined in the SNFPA (2004) and as implemented by the National Forests. Thus we anticipate treatments in approximately 30% of a fireshed distributed as patches across the entire landscape (Bahro and Barber 2004).

To control for potential confounding factors and to isolate the ecosystem impacts related to the forest management operation, we propose to use a Before After Control Impact (BACI) design. BACI compensates for the sparse replication (2 sites) and the non-random assignment of the treatments by providing robust longitudinal controls (Stewart-Oaten et al. 1986). BACI design defines two treatments, a control and an impact. In our case, we will subdivide our experimental unit into two subfiresheds. One subfireshed (on the order of 40 km^2 or 10,000 acres) will receive SPLATs and be defined as the impact site. The other subfireshed will be the control. Here we define control as a comparable subfireshed in terms of forest type, size, management history, fire history, and terrain features. Since these two sites are subfiresheds, they will also be in close spatial proximity. In terms of management, we expect that currently permitted use in the control fireshed will continue but there will be no major management intervention during the course of the study.

As Stewart-Oaten and Bence (2001) noted, the control site in the BACI design is not a true control but rather a measure of the existing natural variation in the ecosystem. The “before” measurements are crucial in that they provide a means to quantify the differences in ecosystem function between the control and impact sites not related to the management impact since these measurements occur before the imposition of any activity. We use the “after” measurements to estimate the effect of the management treatment at the impact site based on the divergence between the control and impact sites.

We propose a 2-2-1-2 schedule of research (total = 7-year research program). This will allow for public involvement in the monitoring as well as the research design. We plan and budget for 2 years of pre-treatment measurements. As described above, these before measurements are critical to the success of

Table 2. Criteria for site selection and evaluation of candidate sites with regard to these criteria. Note criteria were unranked.

Criteria	Manila Canyon (northern)	Fish Camp (southern)
Old forest habitat for species at risk	Yes	Yes
Potential for recruiting large tree structure	Yes	Yes
Proximity to wildland urban interface	No	Yes
Adjacent to significant amounts of private land eligible for State grants	Yes	Potential
Large enough to support fireshed scale research	Yes	Yes
Representative of typical Sierran landscape (i.e., not outliers)	Yes (see Table 1)	Yes (see Table 1)
Sufficient organizational capacity of National Forest to implement treatments	Yes	Yes
Presence of existing data/studies/infrastructure	Spotted owl study; Nearby watershed studies	Limited
History of land and resource management agencies involving community interest in forest management	To be determined	To be determined
Potential for positive and detectable changes leading to desired forest conditions	Yes	Yes
Costs of development and implementation of treatments	More remote; potentially more expensive	Yes. Extensive infrastructure available

the research design. An optimistic estimate from forest managers is that the treatments would be implemented during the course of 2 years to be followed by 1 year of ecosystem recovery. Finally, we acquire 2 years of after measurements to measure the effect of the management activity. This research schedule will result in an intense initial effort as we establish baseline conditions (i.e., before measurements) and install sensor clusters (years 1 and 2); a period in which we analyze/summarize baseline processes and monitor forest responses during SPLAT implementation (years 3, 4, and 5), and then another concentrated effort at the end (year 6 and 7) to quantify the trade-offs of the management regime in terms of public perception, fire and forest health, wildlife, and water quantity and quality.

Box 2. Complementary Research in the Sierra Nevada

1. Kings River Ecosystem Study
2. Quincy Library Group Administrative Study
3. Teakettle Experimental Forest
4. Fire and Fire Surrogate Study
   - Blodgett Forest Research Station
   - Sequoia/Kings Canyon NP
5. Sagehen Experimental Forest
   - SPLATS study
6. Spotted Owl demography research in the Sierra Nevada
7. Blacks Mountain fire research

In a recent paper, Johnson (2002b) argued for meta-replication. His view is that the best way to ensure credible results for management oriented research is to replicate the studies with different teams who make different sets of assumptions and use independent approaches. Holl et al. (2003) made a similar recommendation for studies on landscape restoration. They recommended a creative combination of data from multiple sources. The possibility for meta-replication already exists in the Sierra Nevada for several of the questions we are charged to address (Box 2). For example, The Pacific Southwest Research Station (PSW) and the Forest Service have ongoing studies across the Sierra Nevada that are producing relevant information (PSW Sierra Nevada Research Center 2006). There are also a number of participatory management programs being implemented in the Sierra. These opportunities for meta-replication present an excellent way to extend the limited inferential implications for our two study sites to other sites in the Sierra Nevada.

We will make meta-replication a priority and thereby take advantage of the ongoing adaptive management and participatory processes research conducted by the Forest Service and the PSW. One way to think about the challenge is that meta-replication approach is a proactive form of meta-analysis. There may be design or analytical changes that can be made while the studies are ongoing to improve the ability to draw more general conclusions.

In our formal estimates of management impact we intend to take a likelihood approach to evaluating our results (Edwards 1992). Instead of the traditional hypothesis testing, we will measure the support in the data for our a priori expectations (i.e., models). An advantage of this approach is the greater relevance of the information gained by evaluating the effect size with estimates of uncertainty rather than a test of null hypotheses. For example, rather than testing the uninformative null hypothesis -- SPLATs do not reduce the fire spread rates in the treated firesheds -- we plan to report the difference in the rates of fire

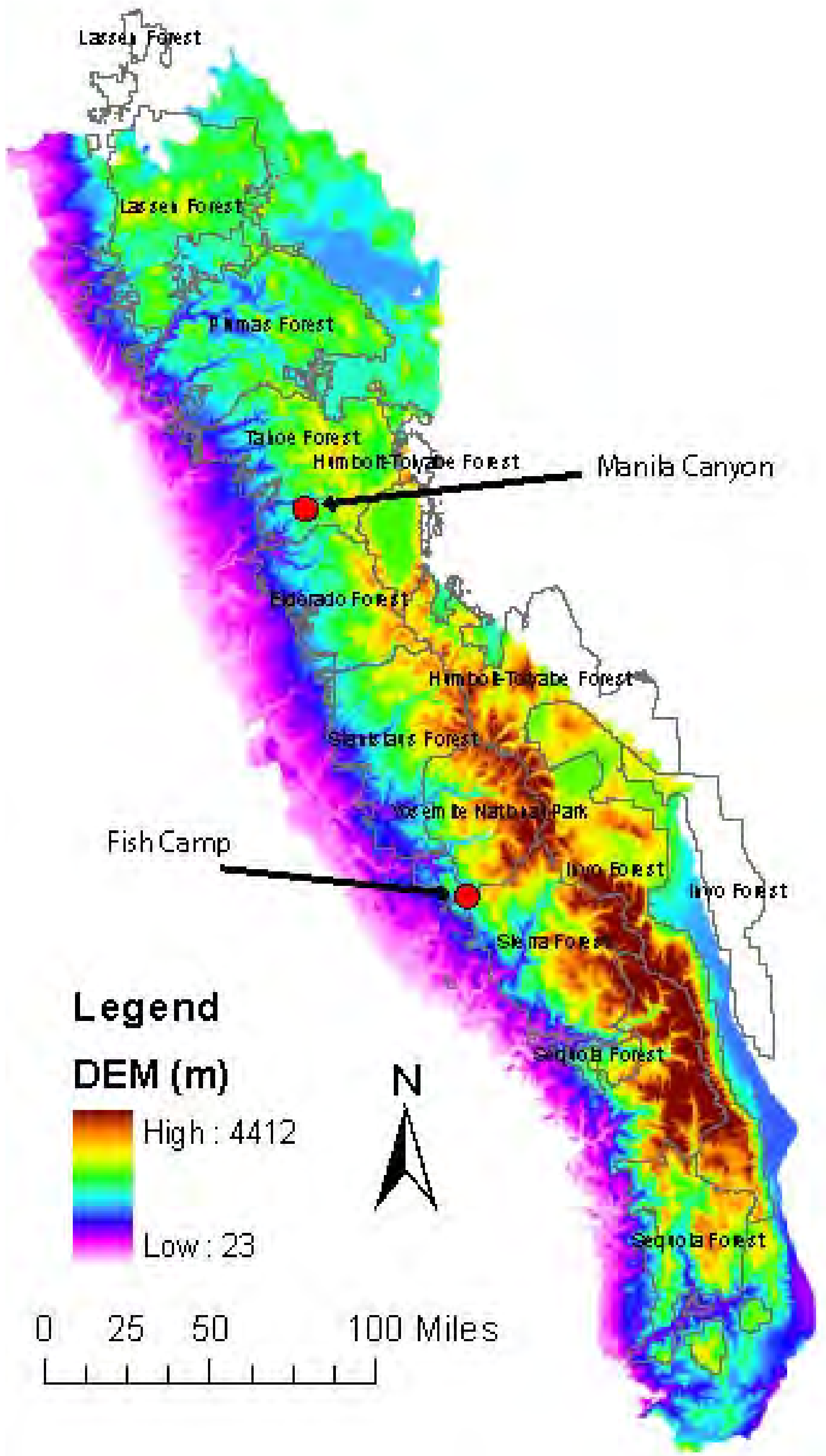

Figure 1. General location map of prospective research sites. Detailed maps are available at https://ucmeng.net/people/rbales/SNammp/Maps.

spread and quantify the uncertainty in these estimates. This approach is more conducive to an adaptive management framework (Johnson 2002b, Hobbs 2003, Bennett and Adams 2004) in part because it provides more intuitive answers to stakeholders' concerns. For cases where we have competing models to explain the observed responses, we will use approaches based on information theory (e.g., Akaike's information criterion) to quantify the strength of evidence for alternative models (Burnham and Anderson 2002).

[1]6.0 SITE DESCRIPTIONS

The site we are considering in the northern half of the Sierra Nevada is located in the upper Manila Canyon (39°10'31"N, 120°32'23" W) between the north and middle fork of the American River in Tahoe National Forest. The southern site is near Fish Camp (37°28'44" N, 119°38'19" W) in the upper Merced and Fresno River basins, in the Sierra National Forest (Figure 1). Both sites are accessible by forest roads. Other areas were screened, including in the Ruby area of the Tahoe National Forest, areas east of Blodgett Forest in the El Dorado National Forest, the Kings River Project in the Sierra National Forest, and Ponderosa area in the Sequoia National forest. Our process of site evaluations involved extensive consultation with Forest Service managers from all four National Forests. Manila Canyon and Fish Camp were identified as areas where there was active planning for fuels management and adequate institutional capacity to implement the treatments in a timely fashion.

Two treatment projects are under planning in the Manila Canyon and Secret Canyon area, namely the Manila and Whiskey projects (Figure 2). Together they involve 10-15 km^2 (2,400-3,600 acres) of mechanical treatment with mastication, plus thinning by tractor and helicopter. Elevations are about 1,500-2,000 m in the areas proposed for treatment. There are at least 3 options for adjacent subfiresheds (similar to 1st-order CalWater watersheds) that could serve as treatment and control areas, each with areas on the order of 30-40 km^2 (7,500-10,000 acres). While there is some private land in the area, most is under Forest Service ownership.

The Fish Camp area is in the proposed Fresno River Landscape Analysis project located along the Highway 41 corridor south of Yosemite National Park (Figure 3). Near Fish Camp and Sugar Pine, elevations are in the 1,500-1,800 m range for areas proposed for treatment. A few km south, near Cedar Valley, treatment areas are in the 1,100-1,500 m elevation range. Together they involve 10-15 km^2 (2,400-3,600 acres) of area identified for treatment. There are multiple options for subfiresheds that could serve as treatment and control areas.

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[1] In collaboration with the participating ranger districts in the Tahoe and Sierra National Forests we have more specifically defined the research sites. However this general description of the sites and their selection still holds.

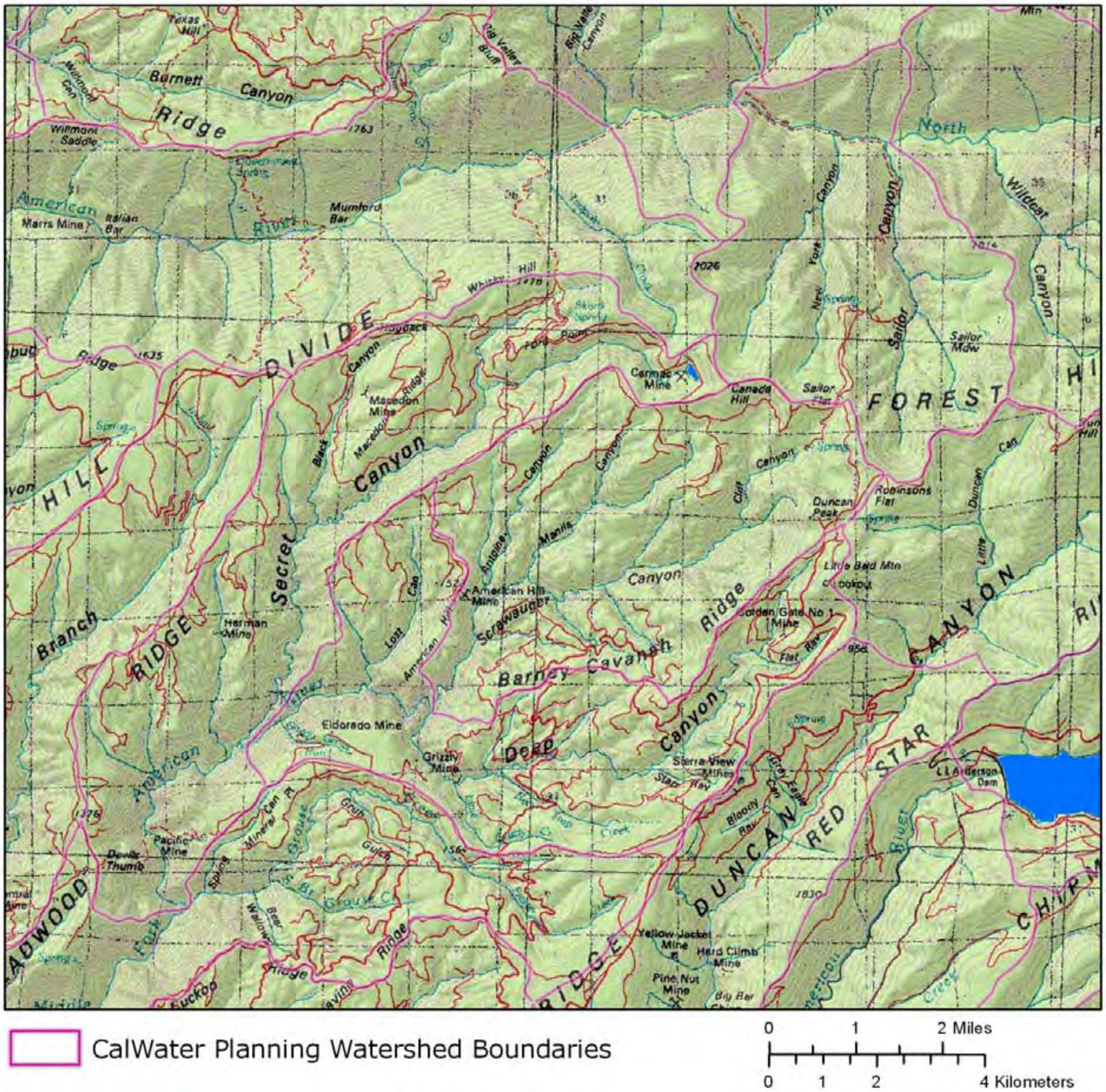

Figure 2. Detailed relief map of the proposed Manila Canyon research area in Tahoe National Forest.

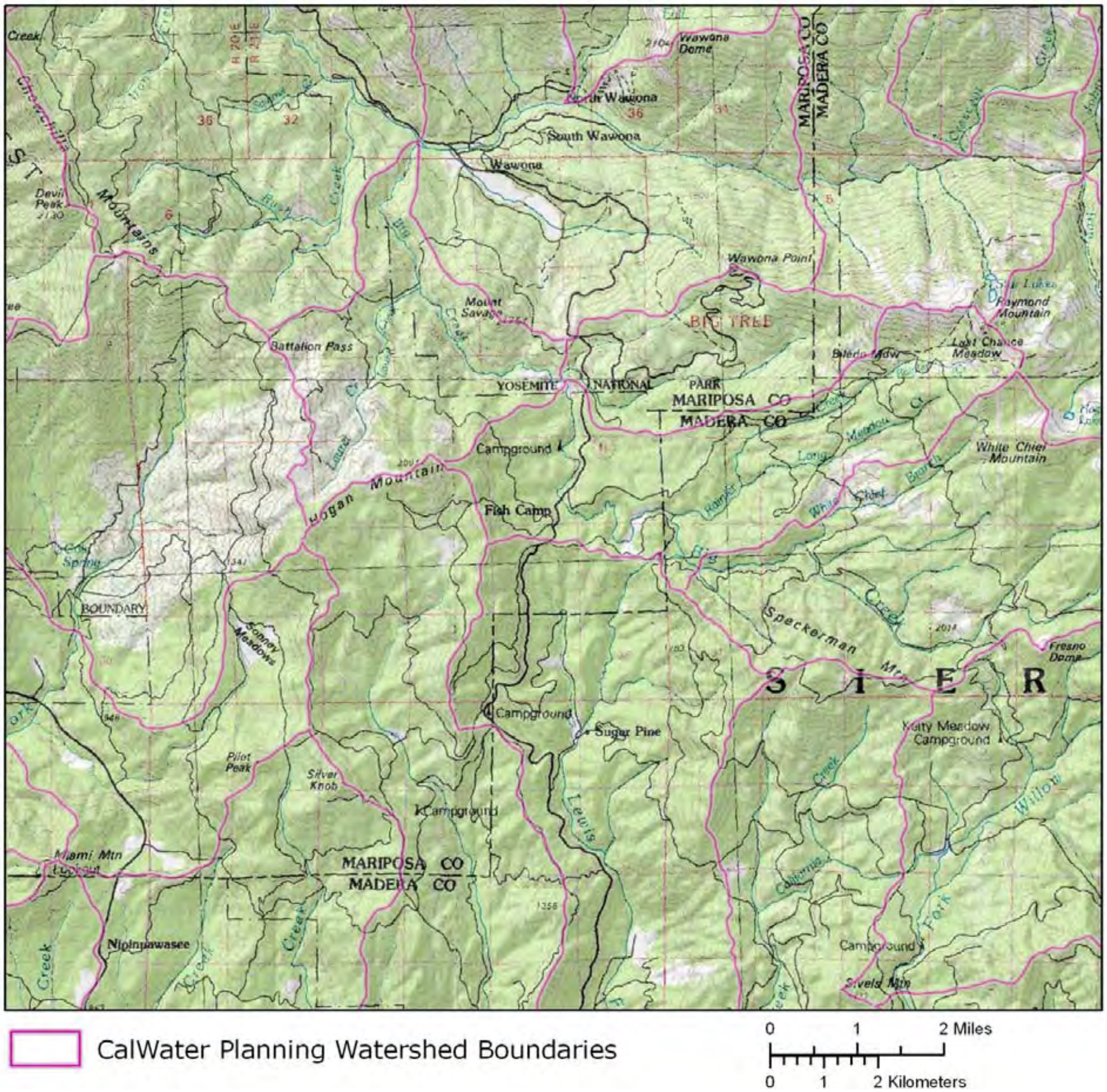

Figure 3. Detailed relief map of the proposed Fish Camp research area in the Sierra National Forest.

Based on existing spatial data, there is approximately 4,100 km^2 of potential study area (mixed conifer forests) in the Tahoe (west side only) and El Dorado National Forests. In the Sierra and Sequoia National Forests, the combined mixed conifer forest type covered 2,500 km^2. In regard to the selection criteria (Table 2), the Manila Canyon area meets at least 7 of the 11 criteria. The Fish Camp area meets at least 8 of the 11 criteria. The major difference between the sites is that Fish Camp includes more wildland urban interface in the fireshed while the Manila Canyon area is more remote. The results from our outlier analysis (Table 1) indicate that the candidate sites are within the range of variation present in their respective regions. In other words, they are not statistical outliers. The exception is the close proximity of Fish Camp to urban areas and its lower mean elevation (Table 1). It was intentionally chosen (selection criteria in Table 2) to include wildland urban interface.

7.0 SPECIFIC RESEARCH PLANS

7.1 **Fire and forest ecosystem health**

*Fire behavior modeling***.** Both sites that we have selected for study have an accumulation of forest fuels that has created a severe risk of catastrophic wildfire. The primary goal of this component of the study is to evaluate the effectiveness of SPLATs in reducing potential fire behavior and improving forest health. Our approach is first to build a field-parameterized version of the fire behavior model, FARSITE, and simulate SPLAT fuel management designs. The performance of this management technique will be evaluated in terms of slowing fire spread and reducing fire intensity and subsequent tree mortality. The data needed to develop the map layers for FARSITE will be obtained from a network of geo-referenced field plots where we will measure the fire-relevant attributes of the vegetation and the surface fuels. Since these attributes are heterogeneous and not amenable to measurement by satellite remote sensing alone, we will explore innovative, efficient field methods for assessing fuel loads. For example, we have developed protocols to rapidly assess ladder fuel continuity and to estimate ground fuels. We also plan on linking intensive, field-based, forest and fuel inventory techniques to remotely sensed data to allow us to populate the needed GIS data layers to perform the SPLAT simulations. We will repeat the field measurements and fire behavior analysis after the treatments have been completed. The differences in modeled fire behavior between the control and treated firesheds will provide the necessary information to quantify the efficacy of the SPLAT approach.

This module will be integrated with the water module by providing tree canopy cover and bare mineral soil exposure (percent) on a 30 x 30 m GIS grid after simulated wildfires for the entire area of interest. This information will be used in estimating perturbations to the hydrologic cycle after wildfires. We will use archived ignition locations for the last 25 years to determine where “simulated” wildfires will begin. Eightieth, 90^{th}, and 97.5^{th} percentile fire weather, representing moderate, severe, and extreme fire weather conditions, will be computed from archived data from RAW’s weather stations located near the study sites (http://www.wrcc.dri.edu). This fire weather information will include maximum and minimum temperatures and humidities, wind speeds, wind direction, 1, 10, and 100-hour fuel moistures, and herbaceous and live woody fuel moistures that will be used in the wildfire simulations. Linkages to the wildlife component of this study will occur by providing pre- and post-simulated wildfire effects on forest canopy cover, large woody debris, tree structure, and ground fuels on the 30 x 30 m grid. Linkages to the social component of this study will occur as we learn how the public perceives and reacts to one of the first implementations of a SPLAT strategy in any forested ecosystem. Input from stakeholders on what are the most important characteristics to determine the effects of SPLATs on potential fire behavior and forest health is also encouraged.

Documenting reference conditions. As noted above (Section 2.0), a common understanding of the long term changes that have occurred in the Sierran forests is thought to enhance effective decision-making. Towards this end, we propose to re-measure and analyze historic USFS inventory data collected in the early 1900's near the proposed research sites. In 1908, the Supervisor for the California 'District' (now Region 5) created a directive for each forest in California to begin a systematic plan for timber inventory that applied a standardized sampling protocol. Some forests, such as the Tahoe National Forest, had systems in place to assess timber sales and post-harvesting needs as early as 1908. Some of the inventories are accurately located and include stem maps and photographs. By capitalizing on the historic records available for our two study sites, we will quantify the changes in the composition and structure of forest for the last century. These results will provide informative biophysical references that will be integrated into the collective ecological histories being developed for the research sites (see Section 7.2).

Forest vulnerability assessment. The increased fire risk in the Sierra Nevada is related to fundamental changes in the structure and composition of the mixed conifer forest. As a result of relative increases in the density of shade-tolerant tree species (mostly white fir and to a lesser extent incense cedar), the forest is more homogeneous in terms of species distribution (Ansley and Battles 1998, Roy and Vankat 1999). Also, net increases in understory tree density have been reported in the literature (Kilgore 1973, Parsons and DeBenedetti 1979, Ansley and Battles 1998) and noted on forest health assessments conducted by the USFS. As a result, many trees are experiencing increased competition for resources that, in turn, reduces the vigor of individual trees. Under these circumstances, forest pests and pathogens spread faster and with more virulence (Maloney and Rizzo 2002). The biologically-driven feedback between competition and predation further acerbates hazardous fuel conditions by creating a large cohort of dead and dying stems. These changes have raised concerns about potential for increases in tree morbidity and mortality.

Radial stem growth in trees has proven to be a reliable indicator of mortality risk (e.g., Pacala et al. 1996). Typically, growth-mortality functions are based on the most recent five years of growth (Kobe et al. 1995, Wycoff and Clark 2000). However, recent work has documented a relationship between longer term growth characteristics and tree decline, including lifetime growth rates, long term growth trends, and abrupt changes in growth (Pedersen 1998; Cherubini et al. 2002; Suarez et al. 2004). Das et al. (in press) have demonstrated that incorporating these additional growth characteristics significantly improves the predictions of mortality for white fir and sugar pine trees in the Sierran mixed conifer forests. For example, internal validations of the growth mortality models had a correct classification rate of 81.6% for white fir and 81.6% for sugar pine.

These validated growth-mortality models can be used to develop robust forest-wide assessments of health for target species. For every tree sampled, a probability of mortality can be predicted. These predictions are then summarized in vulnerability profiles. These vulnerability profiles provide a general measure of tree vigor in the target population. See Appendix 2 for details on the development of vulnerability profiles and an example of their application.

Reducing understory tree density is one of the objectives of the strategic fuel modifications. Thus there will be areas in the fireshed where density is locally reduced. Our expectation is that reductions in tree density will lead to increases in growth and thus increase tree survivability. However, we are less certain of the impact beyond the borders of the treated areas. The implementation of SPLATs across the landscape will create a substantial amount of edge areas. Thus it is critical to know the extent of the impact of the individual SPLAT into the surrounding untreated forest.

We propose to use white fir and sugar pine as indicator species of tree health in the experimental firesheds. These two species represent the gradient in life-history strategies employed by the dominant tree species in the mixed conifer forests. White fir is a shade-tolerant, fire-sensitive species while sugar pine is less shade-tolerant but more resistant to fire damage (Burns and Honkala 1990). We will use stratified random sampling within the firesheds with the strata initially defined by forest type and by areas in and out of SPLATs to gather an unbiased sample of trees. We will collect samples before treatments are imposed (years 1 and 2) and after the treatments are in place (years 6 and 7). To estimate the probability of mortality, we will extract an increment core near the base of the tree and measure the relevant growth parameters. We will construct vulnerability profiles by species and strata and then compare the changes in the distributions that occur with the treatments. We also will collect comparable data from the control watershed to measure changes in tree mortality not associated with the management activity. Given the size of the firesheds, we anticipate sampling at least 50 trees per species and strata (a sampling strategy that will result in 750-1,250 individuals accessed per species and site). These trees will be tagged and geolocated so they can be resampled after the treatments are in place. We will also monitor the firesheds during the field sampling for evidence of major pest and pathogen occurrence.

The collection and processing of tree cores provides an exceptional educational and public participation opportunity. With minimal training and supervision, the community can help collect the cores. Immediate inspection of the cores provides an insight into the growth history of the individual tree. Comparing just a few cores will illustrate the variability among trees in a firesheds. Events in the core (e.g., low growth due to drought, high growth due to death of neighbor) tangibly demonstrate the processes that affect the growth and survival of trees and thus help to build the necessary common understanding of how these ecosystems function.

We will supplement this detailed tree vulnerability approach with a mortality assessment based on remotely sensed images of the entire fireshed. Before treatments, the team plans to obtain a set of high-resolution satellite-based photographs. A recent application in the tropics (Clark et al. 2004) has demonstrated the potential of using remotely sensed images to measure tree mortality across large regions. We will develop this approach for the challenges of conifer dominated forests. Our field based plots and vulnerability trees will provide the necessary ground-truthing to refine the detection routines. With a second, post-treatment set of images, we will be able to measure changes in the magnitude and distribution of tree mortality across the fireshed and relate any changes to the intensity and proximity of fuel modifications areas.

7.2 **Participatory Processes**

The participatory processes group will conduct strategic facilitation for stakeholders, MOU partners, UC science team, and Forest Service as part of an integrated participatory adaptive management approach for vegetation management on national forests in the Sierra Nevada. We will also evaluate the processes and outcomes of this inclusive participatory approach as well as the efficacy of having the UC science team function in a third party role. Our focus is on stakeholder and partner participation in the development, monitoring, analysis and incorporation of research as part of adaptive management.

The strategic facilitation that is at the core of our proposal will require considerable networking and the ability to build knowledge on the part of the facilitators. Consistent participation is crucial. Thus we plan to recruit two UC Cooperative Extension advisors to conduct the strategic facilitation and outreach processes that need to be implemented locally and regionally.

Part of facilitation is the development and documentation of boundaries, constraints, and triggers that emerge throughout and shape the adaptive management process. We will document how participation practices "adapt" over time as more is learned about and from local stakeholders, the UC Science Team, and MOU partner participants. Approaches include pre-scoping of stakeholder groups and development of local histories of stakeholder experience with science-based management initiatives.

A post-doctoral scholar will be recruited to research the development, analysis, and use of stakeholder information, and to document the methods used for participation and their efficacy. This position will analyze the use of stakeholder information, develop local histories of experience with scientific management, and integrate information from the two study sites and from various levels of stakeholder engagement in the adaptive management process. The position will be for a policy-oriented social scientist with experience in participatory processes.

Throughout the planning effort, participatory processes research has been informed by studies indicating that efforts at improving risk communication and community relations must come from within an organization as a whole (Chess et al. 1994). Organizational learning should occur at different levels. For this reason we have facilitated this learning within the UC Science Team and MOU Partners, as well as with those participating community stakeholders. Below we identify five objectives for the development of participatory research processes that we posit will lead to stakeholder, manager, and scientist engagement in mutual learning and that will inform future adaptive management programs.

Objective 1. Defining a participatory adaptive management model. Recent studies have suggested that adaptive management provides a useful framework for engaging stakeholder participation because of its emphasis on deliberate experimentation, potential for incorporating stakeholder knowledge, and flexibility in responding to changes in goals and knowledge (McDaniels and Gregory 2002; Clark 2002). Among the potential benefits are the opportunities to meet the public's increased expectation for having a voice in governance (Allen 1998; Baldassare 1994; Bishop and Davis 2002); to foster relationships that will endure beyond the specific project focused on (Shindler and Cheek 1999); to increase ownership and satisfaction with the outcomes of the adaptive management process (Margerum 2001; Shindler and Cheek 1999); to enhance trust of the managing agencies among the affected publics (Shindler and Cheek 1999); to establish a tendency to move towards collaboration and engagement in place of conflict (Innes and Booher 1999); and to improve biophysical outcomes (Selin, Schuett and Carr 2000). From the science team perspective, adaptive management incorporates stakeholder participation in order to improve the depth and breadth of information for research development, monitoring, and interpretation. We realize that participation takes time, and does not necessarily reduce conflict, but successful participation should create meaningful engagement and build mutual understanding, learning, and trust. Critical is a shared understanding of the limits of stakeholder influence on some aspects of the research process: many decisions will ultimately be made primarily by researchers on the basis of what they consider to be the demands of the scientific method and experimental design. This will be documented, and the basis for such decisions will be provided to stakeholders. Scientists on this project, however, are committed to carefully considering stakeholder input on all aspects of the project.

Objective 2. Facilitating researcher, stakeholder, and public meetings. As the project unfolds, more in-depth integration of stakeholders into research processes will occur, as research sites are established and methods are defined. Success will require a significant commitment from all parties to find ways of meaningful engagement. Continuity of engagement is critical, as relationships with stakeholders are fragile and can be rapidly undone by gaps in effort on the part of the research team (Bales et al. 2004).

Objective 3. Development and maintenance of interactive website. This adaptive management effort will confront the challenge of how dynamic communities with changing needs, aspirations, and technologies can maintain a non-destructive relationship (Geyer-Allely 1994, Meredith et al. 2002). Sharing and discussing information about the human and natural components of the system being managed are essential (Walters and Holling 1990; Haklay 2003). We will design and deploy web-based tools to facilitate this exchange. Place-based data access and content acquisition will be incorporated into the comment and response dialogue. A geographically enabled web-based commenting system can greatly enhance the public's ability to participate in the development of spatially relevant research approaches. The ability to easily incorporate maps depicting topics of discussion can help participants visualize the locations and scenarios under debate. The inclusion of spatial data used in the formation of research approaches, such as ecological or fire modeling results, will allow stakeholders to see precisely how the research under discussion might affect their specific locations of concern, or address specific questions. Additionally, a web-based map can be the interface to a commenting system. Instead of a traditional bulletin board-like interface, where each comment follows another in a chronological list and discussion threads are divided by subject matter, a spatial interface organizes discussions geographically. A user starts by viewing a map with icons indicating locations under discussion, and then clicks on a location to view all the discussion threads relating to that place. In addition, mixed media (maps, photos, and comments) can be uploaded and linked to specific locations.

Developing tools to gather new information, optimizing the use of available information, and ensuring that all parties can effectively participate in research decisions are critical components of a natural resource adaptive management process (Meredith et al. 2002). Modern tools (e.g., Internet message boarding, "counter-mapping" and Geographic Information Systems) have been used often separately as information gathering and sharing tools (Aberley 1993; Leitner et al. 2002; Sieber 2002; Crampton and Stewart 2004). Recently, the combination of these tools, often called webGIS, is being used for public participation and community monitoring. By merging Internet and GIS technologies, webGIS systems are a promising option for storing, indexing, and sharing complex datasets in a visual, dynamic, and interactive format (Kearns et al. 2003).

If successful, these tools can be replicated and scaled-up to meet the needs of a larger clientele and stakeholder group. Success will be evaluated based on stakeholder contributions to the website, evaluating how the Internet-GIS component of the public participation compares to the range of other participation options. The incorporation of the interactive website into a suite of collaborative opportunities helps broaden the range and modes of participation of various stakeholders and ensures that review notes and progress updates are easily accessible to a broad public.

Objective 4. Integrating new knowledge into research and management. One way to begin integrating USFS and stakeholder concerns and expertise into the adaptive management process is to hold small focused workshops to engage the UC research team with Forest Service decision-makers. Beyond information sharing, one goal is to better understand how new information can impact Forest Service adaptive management decisions. From the research perspective, the goal is to better understand how new information is used in an adaptive management process, and how it influences decision-making and management. This will provide vital information about the effectiveness of "feedback loops" in the adaptive management process, and contribute to general understanding of the capacity of adaptive management to improve forest management. Again, these workshops will be coordinated and facilitated by the UC Cooperative Extension Advisors.

Objective 5. Documentation and analysis of the use of information generated from the adaptive management. The use of the information and other inputs from stakeholders, as well as the information generated from the adaptive management research process and its interpretation and use must be documented and shared with participants and stakeholders.

Box 4. Water issues identified in SNFPA

Water quality: Clean Water Act & Safe Drinking Water Act
Species viability: habitat, native & invasive species
Plant & animal community diversity: riparian areas, wetlands & meadows
Special habitats: maintain & restore special aquatic habitats
Watershed connectivity: within and between watersheds
Floodplains & water tables: connections to distribute flood flows & sustain habitats
Watershed condition: infiltration characteristics, vegetative cover & stream flows
Streamflow patterns & sediment regimes: in-stream flows, sediment regimes, conditions of riparian, aquatic, wetland & meadow habitats
Stream banks & shorelines: physical structure & condition of stream banks & shorelines

7.3 **Water quality and quantity**

The Sierra Nevada Framework identifies at least nine water issues of concern that motivated development of this component of the research plan (SNFPA 2004, Box 4). Within this context, we expect the proposed fuel management treatments to have a measurable impact on at least six key features of the forest water cycle and associated aquatic ecosystems:

1. Treatment will alter soil moisture patterns in the areas treated, with effects dropping off in riparian areas and in untreated forest, and potentially in drier areas.
2. Treatment will affect the timing, duration, and magnitude of rainstorm and snowmelt flow in headwater streams. These responses will be linked to changes in soil moisture patterns, to canopy attenuation of rainfall/snowmelt, and to changes in the surface energy balance after thinning.
3. Stream turbidity and transport of suspended material will increase following treatment, but effects will diminish with subsequent runoff events. These effects will be reflected in stream macroinvertebrates.
4. Treatments will have a small, positive effect on summer stream baseflow, depending in part on proximity of treatments to streams; the first fall storms may induce a greater response in streamflow. These responses will be linked to changes in soil moisture and evapotranspiration.

5. Effects of treatments will be more significant in first and second order streams that drain treated headwater catchments (up to a few km^2) and will have modest, if any, effects on lower order streams that drain a mix of treated and untreated area.
6. In the context of the physiographic and hydroclimatic regimes, it will be possible to define thresholds linking area treated with both aquatic effects and impacts on the forest water cycle.

Research will consist of intensive field measurements in areas subject to treatment, data analysis, modeling to interpret observed watershed response, and spatial scaling to estimate responses across larger areas.

Field measurements and interpretation. Each of the four field study sites (two each, treatment and control) will include an instrument cluster within the study fireshed. Working with the fire and forest ecosystem health science team members, we will develop complementary, and if possible coincident, definitions for firesheds and watersheds in each of the study areas. For measuring stream impacts it will be important to choose areas where the entire watershed (fireshed) drains to a stream. Thus we expect to locate on lower-order streams. In each of the two forests one instrument cluster will be in a catchment subject to treatment and the second in an untreated control catchment. As noted in section 5.0, this sampling regime provides both a before and after set of measurements and a parallel control set of measurements. Each instrument cluster will have about a 1-km^2 footprint, will include a stream reach, and will consist of both aquatic and terrestrial measurements. It is desirable to choose a response reach of the stream, one that is not too steep and is subject to sediment deposition and scour.

Autonomous stream water quality measurements will include stream stage, temperature, electrical conductivity, and turbidity. A single, self-logging instrument package (Seabird SBE 52-MP) provides the first three. We will also evaluate continuous measurement of dissolved oxygen. For these continuous measurements we will choose a stream section with shallow bedrock so that most of the water flow is in the stream rather than subsurface. If feasible, we will install a control section (weir or flume) in the stream to enable making more accurate discharge measurements for both the higher flow events and the smallest flows. Otherwise, stream stage will be related to discharge by developing a site-specific rating curve. Temperature and electrical conductivity, together with discharge, will provide indications of stream response to runoff events, and facilitate inter-site comparisons. Measurable responses for turbidity will most likely be limited to periods during and immediately after storms, with interstorm periods having values below the detection limit.

Stream macroinvertebrates will be measured bi-annually at multiple sections along the response reach, following protocols in use in the Sierra Nevada (e.g. Herbst and Kane 2004). The biological integrity of stream environments can be estimated from an enumeration of the inhabitant organisms. Aquatic insects and other invertebrates are central to the functioning of stream ecosystems, consuming organic matter and algae, and providing food to fish and birds. Invertebrates also tolerate disturbance to varying degrees and integrate the impacts of disturbance. Their community composition can indicate water quality and habitat conditions. Monitoring relative to reference sites (having little or no impact but similar physical setting), and over time, permits impact problems to be estimated (Rosenberg and Resh 1993, Davis and Simon 1995, Karr and Chu 1999).

Sediment scour and deposition will be measured in the same reaches using autonomous, continuously recording scour pans (Hamblen 2003; Hamblen et al. in preparation) set into the bed of the stream. These will be limited to reaches with small-grained sediments in their beds and relatively flat slopes. A second indication of sediment scour and deposition will come from seasonal surveys of the stream profile and bed material (Bunte and Abt 2001). These latter data will link well with existing operational measurements by the Sierra Nevada Forests. Erosion will be measured by selecting a sensitive reach – "a reach that is likely to show change that relates to the monitoring objective and is uniform in terms of channel and valley form characteristics" (USFS Region 5 SCI Protocol) of 100-200 m in length. In this sensitive reach, a detailed longitudinal profile, riffle and pool cross sections, and Wolman particle size distribution measurements will be taken (we propose to count more than 100 particles, as per Bunte and Abt 2001). The longitudinal profile and cross sections will show erosion related changes in channel-form and bed-form due to scour and deposition. The particle size distribution will measure embeddedness of the channel substrate, and show changes in the deposition of fine particles associated with erosion. These measurements will be done multiple times during the year, with the goal of showing change due to precipitation and snowmelt patterns, and will be conducted before and after treatments.

We will evaluate two ways of measuring hillslope erosion. However, it is expected that a large rain/runoff event will be needed to elicit a measurable response. First, erosion pins will be placed across a hillside to measure the soil loss over the site. Alternatively, silt fences installed along the contour of a hillslope will collect eroded material and measure the amount of soil transported off the hillside (e.g. Benavides-Solorio and MacDonald 2005). These measurements will need to be done several times a year (in response to precipitation pattern variations – i.e. thunderstorms vs. snowmelt). In more rain-dominated areas, sediment fences will be cleaned out following large storms in order to get sediment production on a storm basis rather than annually; this will help generate and test more useful predictive models.

Soil moisture response to the stream will be measured using an embedded sensor network, which is a single "instrument" consisting of 10-15 nodes distributed over the landscape (Rice et al. 2005). These nodes will be placed to capture the physiographic and canopy variability across the site (Bales et al. submitted). Each node will be equipped with 3 levels of soil moisture/temperature (Decagon and Watermark), snow depth (Judd Communications), solar radiation, temperature, and relative humidity (built into wireless pods). A weather station providing precipitation, wind, and long-wave radiation will be integrated into each cluster. All measurements will be continuous over the study period, with each cluster being self logging (Bales et al. 2004). By using autonomous instruments, we can limit field campaigns to short visits for routine maintenance and downloading of data, and periodic visits for making sediment measurements. We also propose to add telemetry to the instruments, which will provide a real-time indication of operation and problems. Three options that have been used in other locations in the Sierra Nevada will be evaluated once sites are selected: 1) telemetry via Forest Service radio, 2) GOES satellite link, and 3) cellular phone link (ground or satellite).

Modeling and scaling of watershed response. Results from the hillslope-to-catchment scale field sites, supplemented with other ongoing measurements in the region, will be scaled up to the larger watershed and forest scales in order to evaluate the broader impacts of treatments. As most effects of treatments will be more significant in lower-order than higher-order streams, it is planned to focus most hydrologic and water-quality modeling on headwater catchments on the order of 1 km^2. Effects of treatments on water yield will be investigated at larger watershed scales, based on responses measured at the smaller scales, and using hydrologic models explicitly designed to use satellite remote sensing and other spatial inputs (Dressler et al. 2006; Molotch et al. 2004).

Public participation. The interested public can participate in the water research either through participation in field measurements or use of data and information produced from the research (or both). Over the past ten years, under the international GLOBE program (www.globe.gov) we have directly engaged dozens of schools in making water quality measurements, including aquatic macroinvertebrates, and have supported measurement protocols and quality control for thousands of more schools. We have also published papers using volunteer (GLOBE) data (Morrill et al. 2005). We will continue to engage volunteer groups under this project. We plan to make our data available via the internet, as described below, including analyses of results. Another aspect will be stakeholder partnerships. Since our data should also be of interest to water managers and other groups, we will pursue leveraging and partnerships to enhance the data and track field measurements.

7.4 **Wildlife**

Criteria for refining wildlife question. Given that there are more than 400 terrestrial vertebrates occurring in the Sierra Nevada bioregion, we support in general the Multiple Species Inventory and Monitoring approach (Manley et al. 2005). However, a primary goal of adaptive management is to focus monitoring and research effort on one or a few critical topics. Prioritization is a difficult but crucial first step determining *why* funds will be spent on monitoring and research (Walters 1986, Hanley 1994, Tear et al. 2005). We used the following criteria to decide on the wildlife species to include in this adaptive management program: 1) presence in detectable numbers in at least one study area; 2) likely negative response to the proposed forest management practices; 3) a history of impeding forest management activities because of insufficient ecological knowledge; and 4) should exhibit a relatively high "signal-to-noise-ratio" in that a negative response will be detectable despite the expected variability due biotic and abiotic factors unrelated to forest manipulations.

Prioritization. We considered two approaches to systematically review all 427 native vertebrate species that currently occur or previously occurred prior to European colonization of the Sierra Nevada bioregion. The first approach was that used by the Forest Service for its first Sierra Nevada Framework EIS (2001, Volume 4, Appendix R-1). Specific criteria used in this analysis emphasized extinction risk and included population size, population trend, and range change. The reliability of this information was not considered. Forty-two species were classified as "high vulnerability" species, including six species now likely to be extinct. Twenty-one of the high vulnerability species depend on riparian, meadow, or aquatic habitats that are important but quite restricted in their distribution, and therefore less likely to be directly affected by strategic fuel management. Thirteen of the high vulnerability species are dependent on western foothill (hardwood) environments, and therefore also less likely to be affected by management activity in mixed conifer stands. Only the fisher (*Martes pennanti*) was considered a high vulnerability species dependent on late seral (dense canopy) conifer forest habitat. Thus, this approach clearly places the fisher at the top of the priority list for this adaptive management program because the fisher also satisfies all of the inclusion criteria listed above. We note that this approach would list the following moderate vulnerability species in decreasing priority: northern goshawk (*Accipiter gentilis*), spotted owl (*Strix occidentalis*), marten (*Martes americana*), and northern flying squirrel (*Glaucomys sabrinus*).

The second approach to prioritizing species used the California Wildlife Habitat Relationships (CWHR) System (Airola 1988, Mayer and Laudenslayer 1988). The CWHR System was developed as a result of a Memorandum of Understanding signed in 1980 by all state and federal agencies with responsibilities for wildlife or wildlife habitat in California. It is now maintained by the California Department of Fish and Game. It represents the "best available science" as it is kept current based on published research. We queried the CWHR database (Version 8.0) to consider the relative response of wildlife to a change in forest structure from a dense (>60% canopy closure), small tree (quadratic mean diameter at breast height 11-24 in) Sierra Mixed Conifer (SMC 4D) stand to an open cover (25-39% canopy closure), medium/large tree (quadratic mean diameter >24 in) stand (SMC 5P). We focused on Sierra Mixed Conifer Habitat because this type is consistent with the focus of the study (see section 5.0). This approach indicates that of the 221 species potentially inhabiting Sierra Mixed Conifer Habitat in the Sierra bioregion, 121 (55%) would find habitat value increased, 65 (29%) would find habitat value unchanged, and 35 (16%) would find habitat value decreased. Of the last group, only the fisher and marten would find generally suitable habitat decreased to a low suitability, suggesting that the manipulated habitat would become a "sink" for these species. That is, the low quality habitat may allow individuals to survive there, but reproduction would not be sufficient to maintain population size without immigration from neighboring "source" habitat (i.e., habitat rated moderate to high suitability). Northern goshawk and spotted owl would be expected to have reduced habitat quality, but not to the extent indicated for fisher.

The results of both these approaches are similar in that the fisher is clearly the most important species for consideration in any adaptive management program that includes a wildlife species in its monitoring scheme. Therefore, the fisher should receive first priority. Of the sites being considered for study (see section 6.0), the fisher is currently present only in the southern site so it will be the focus of wildlife research there. For the northern site in the Tahoe National Forest, we will build on the ongoing research of forest management impacts on the spotted owl.

Fisher study design in the Sierra National Forest. In an active adaptive management context (Walters and Holling 1990, Lancia et al. 1996), the primary wildlife question to be evaluated is whether the fisher population in the treatment area will exhibit decreased viability over time as measured by population trend, reproductive performance, survival, and dispersal success as a result of lowered habitat quality. Because the fisher's large home range and low densities, only a few individuals are likely to be found in any one 30,000-acre study area. Therefore the adaptive management plan must involve intensive radio-telemetry and detailed vital rate analysis of all individuals in each study area. It is essential to go beyond presence-absence monitoring to determine the factor limiting a population (Schlaepfer et al. 2002).

Two types of models are being constructed for the fisher by the Conservation Biology Institute (http://www.consbio.org/cbi/projects/fisher/index.htm) prior to our field work. A fisher habitat relationships model will be applied to each study area to provide testable predictions as to the likely distribution of animal activity. Second, a fisher population dynamics model will be used to suggest a range of likely population trajectories given possible values for population size, reproduction, and age- and sex-specific survival and dispersal. The field monitoring will test predictions and allow refinement of the models' performance. Once validated, these models may prove to be useful management tools to assess the status of fisher populations across their range in the Sierra Nevada.

The rationale and basic approach to monitoring the fisher is as follows. Because there will be so few fishers inhabiting any study area, all individuals must be monitored. One can expect about 5 fishers (1 male, 4 females) per 40 km^2 (10,000 acres) of suitable habitat. Thus, the issue of statistical inference for point estimates about the local population does not arise. For inferences about the fisher population throughout the Sierra, our sample size is one because we are only looking at the fisher in one sample site, thus our study uses a case history approach.

We want to make it clear that we support the continued monitoring of the presence of fisher and other carnivores throughout the Sierra (Zielinski and Stauffer 1996, Zielinski et al. 2005). Presence-absence data are necessary to detect large changes in the range of these species, but they are insufficient to inform us as to which environmental factors are limiting a population (Stanley and Royle 2005, Vojta 2005).

The entire population in the study area will be monitored. As noted above, we expect to find about five adult fishers per fireshed. The only feasible way to ensure that all individuals in the study area are monitored daily is to carry out an intensive, year-round, radio-telemetry study (Braun 2005). This will necessitate initial and periodic live-trapping of all members of the population in the study area, and maintaining radio tags on each individual. We will expand our trapping grid until at lease 20 fisher are captured. Radios are likely to remain effective for only 8-10 months; therefore live-trapping must occur at least twice a year. Each tagged individual must be located daily to ensure that the cause of death can be determined if and when mortality occurs. With this intensity of monitoring, reproductive success will be relatively easy to detect. Video camera traps will be used to monitor den sites. Dispersal can be monitored with aerial support. Detecting mortality, quickly locating the carcass, and carrying out a detailed necropsy will be among the most difficult but most essential of activities.

A radio-telemetry study of this intensity will require at least three teams of two field technicians plus a light plane and pilot. The project leader will normally join the pilot to locate fisher from the air daily. To produce meaningful results given the likely high annual variation in vital rates due to weather patterns, monitoring will be continuous for the duration of the study. Analysis of vital rates and causes of their variation will follow the approaches used by Karanth et al. (2006) and Schwartz et al. (2006).

Spotted owl study design in the Tahoe National Forest. We propose to measure occupancy rates of owls in the northern study site. Because of limited funding levels allocated to this study, our design is contingent on continued funding of the Eldorado Population Monitoring Study. This contingency is required because the project leader (R. J. Gutiérrez) and assistant project leader (Douglas Tempel) of the Eldorado Project will serve the same role in the Sierra Nevada Adaptive Management Project.

We propose to band owls and examine the chronic effect of SPLATs on owl occupancy using banding and annual resighting of individually color-banded birds. These chronic effects include changes in reproduction, survival, and occupancy rates of owls. We do not know how many owls are present on the northern study site. However, we suspect that about 12 pairs will be present. Therefore, we propose to capture and band all owls within the study site. In addition, we will survey adjacent areas to locate and monitor any birds whose home ranges could conceivably overlap the selected watersheds. Regardless, the number of birds available for study will be relatively small, and it is conceivable that there may not be enough owls present to conduct a viable study of effects. We can compensate for a potential small sample size by assuming that the recapture probabilities would be the same for the experimental/control populations and the owls in Eldorado Population Monitoring Study. In addition, prior work on spotted owls has demonstrated that all territorial owls on a study area can be detected given adequate survey effort, which increases the probability of detection (Franklin et al. 2004, Anthony et al. 2006).

We have a reference group of owls that is experiencing the ongoing management regime in the central Sierra Nevada (i.e., the Eldorado Study Area), two treatment areas receiving a SPLAT prescription, and a control area receiving no treatment. We believe this approach allows us to examine the chronic effects of SPLATs on spotted owl occupancy. We believe that estimation of occupancy is the best way to examine the long-term effects of SPLATs on spotted owls given funding constraints (Seamans 2005).

We will test the predictions of models relating occupancy to habitat quality within owl territories (e.g., canopy cover and size class of dominant trees). Seamans (in preparation) has modeled the effects of habitat reduction in owl territories considered to contain good habitat versus those considered to contain poor habitat. Habitat quality was based on occupancy rates of owls on the Eldorado Study Area. The preliminary results suggest a greater relative impact of habitat reduction to owls located on better territories. Although one might expect that owls on better territories could better cope with habitat loss, the simulations suggest the existence of a threshold requirement for high-quality habitat, below which occupancy rates decrease greatly.

Barred owls (*Strix varia*) have colonized the entire range of northern spotted owls (*S. o. caurina*), and they are also invading the range of the California spotted owl (Gutiérrez et al. in Press). Currently they occur in low numbers in the Eldorado spotted owl study area (only a pair of hybrid individuals are known to occur on the entire study area). Thus, we do not think they will be a confounding issue in the short term for this study. Nevertheless, we will monitor presence of barred owls routinely as they often respond to spotted owl vocal imitations (Crozier et al. 2006). See Appendix 3 for a more detailed description of the research plan for spotted owls.

Opportunities for public participation. The interested public can participate in wildlife research in several ways. Incidental observations of species of concern can be provided to researchers using an interactive web site. Selected individuals willing to volunteer for intensive training and substantial time commitments can assist in camera trapping, live trapping, and radio-tracking subject animals. Individuals with special expertise such as veterinarians and aircraft pilots may be able to volunteer for certain jobs.

8.0 PROJECT MANAGEMENT AND INTEGRATION

Administration. The Center for Forestry at UC Berkeley will be the lead administrative unit for the Sierra Nevada Adaptive Management and Monitoring program. The Center will be responsible for the financial and logistical coordination of the program. Members of the UC Research Team have agreed to communicate results with one voice. Thus the goal for the team is to reach a consensus assessment of the impacts of the prescribed management regime. Uncertainties associated with these impacts will be identified and, to the best of our ability, quantified. If consensus cannot be reached, we will present the competing arguments and their supporting evidence. Project planning and decision making will be the responsibility of the PI and an executive committee consisting of the PI's leading each of the four research areas.

Spatial information and data support. Each of the research teams will require detailed maps of the study areas in order to plan and execute field visits, to inform the public and other stakeholders about the study sites, and to understand processes at the site-scale, and to upscale results to the forest scale in order to evaluate the broader impacts of treatments. Because spatial variability of vegetation and terrain features greatly influences forest health, wildlife habitat, water cycling, and fire behavior over a range of scales (Shen and Leclerc 1995; Cosh and Brutsaert 2003), we plan to extract the topography and vegetation information from numerous available existing and remotely sensed geodatasets augmented with field measures acquired using GPS, leaf area meters, and laser rangefinders. First, we propose to acquire high-resolution remote sensing images (e.g. IKONOS) and LiDAR data to map in detail the vegetation and topography of the sites, the change of the crown closure, leaf area index, and other vegetation parameters before and after the treatments. These data will improve our understanding of the spatial relationships between canopy and forest characteristics and changes in habitat, fire, and hydrologic responses (e.g. soil moisture and thus stream response). We also plan on scaling up these relationships from the catchment to the forest level using coarser resolution remotely sensed imagery (e.g. Landsat TM) and topography (e.g. NextMap Radar product at 5m spatial resolution).

Specifically, the wildlife team will require detailed spatially referenced biotic and abiotic data that can be associated with their field location of animals. Such information will be used to develop multivariate models of animal habitat and movement (Lim et al. 2002; Peterson et al. 2002; Illoldi-Rangel et al. 2004; Parra et al. 2004). One channel through which the public participation team will be interacting with stakeholders is via webGIS, and all data will be maintained on the webGIS site (Kearns et al. 2003). The fire and forest ecosystem health team will require tree mortality, tree canopy cover, average tree height, crown bulk density, and height to live crown base. Those attributes will be derived from LiDAR (Andersen et al. 2005) and high resolution images such as IKONOS (Clark et al. 2004a; Clark et al. 2004b). The water quantity and quality team will also need fine-scale information about canopy and vegetation indices to upscale their point measurements to the fireshed scale (Cosh and Brutsaert 2003). Used in combination, LiDAR and IKONOS results can generate the necessary vegetation characteristics (Shen and Leclerc 1995; Andersen et al. 2005). Meanwhile, Landsat TM data together with MODIS data will be used to upscale the results from the individual firesheds to a broader regional level.

Field data, spatial data, and other project data will be made available to team members via the Internet, using an existing digital library modified to accept and serve data and metadata from this project. Our goal is to have share data within the team as soon as it is available on our computers (i.e., both raw and processed data). We will make processed data available outside the team in as timely a manner as possible, following basic quality control.

Deliverables. Integration of team efforts across disciplines and with Forest Service decision-makers will receive explicit attention throughout the project. Feedback loops are essential to achieve the aim of adaptive management research – namely to inform Forest Service decision-makers in their use of an adaptive management process to meet their objective of protecting communities and modifying landscape-scale fire behavior to reduce the size and severity of wildfires. Working within constraints imposed by impacts on water, wildlife, and other response variables is critical. Small workshops will be used in the 1st year of the project to engage the UC research team with Forest Service decision-makers. The workshops will be theme-based with an emphasis on hands-on and field-based learning to keep them focused and productive. Beyond information sharing, one goal is to better understand how new information can impact Forest Service adaptive management decisions. These efforts will contribute to better defining the decision space available to stakeholders. Similar small workshops will be offered to the interested publics. Follow-up interviews will be used as needed to extend workshop results. Every two years, when there is new information to exchange, workshops will be repeated. Products from the workshops will then be integrated with those from broader stakeholder meetings, with information from each informing each. The timing, themes, and format of these workshops will be developed and adjusted over the course of the project, but we will start with themes equivalent to the modules in this workplan. Workshops and their analysis will be facilitated and conducted by the proposed Cooperative Extension personnel working in conjunction with UC researchers.

We propose a reporting schedule that includes quarterly updates and annual reports. These updates and reports will be written to make them as relevant as possible to the management questions. As is our practice, these updates and reports will be made available to all parties. We will invite public review and comment with our responses organized and presented in the subsequent communication. In conjunction with the summaries provided by the UC Research Team, groups of researchers will prepare their findings for the peer-reviewed academic literature. In short, we hope to build the organizational infrastructure that improves upon the "strategy of hope" (Rogers 1998) by making reliable scientific information relevant to the challenges faced by managers.

9.0 BUDGET

The total direct costs for the research described in this workplan is $16,576,311. As requested, we have divided the budget by research theme and year (Table 3). This budget has followed institutional guidelines for anticipating future costs and assessing fringe benefit rates on the various kinds of salaries (faculty, research scientists, technicians, and students). We have also excluded expenses (e.g., graduate student tuition costs) that are typically not covered by USDA contracts to land-grant universities like UC Berkeley. The indirect costs as well as cost-sharing expectations remain to be negotiated.

Table 3. Proposed budgets organized by research theme and year.

		2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Total**
Core Administration		167,724 $	172,756 $	177,939 $	183,277 $	188,775 $	194,438 $	200,272 $	**1,285,181 $**
Fire and Forest Health		238,164 $	253,133 $	197,033 $	174,172 $	179,391 $	268,138 $	273,066 $	**1,583,099 $**
Public Participation		286,904 $	308,693 $	313,782 $	318,522 $	323,916 $	333,472 $	338,187 $	**2,223,477 $**
Spatial Data/Support		172,384 $	77,922 $	80,365 $	96,654 $	85,488 $	182,224 $	90,947 $	**785,986 $**
Water Quantity/Quality		615,657 $	229,488 $	228,647 $	243,007 $	242,572 $	257,349 $	257,345 $	**2,074,064 $**
Wildlife: Spotted Owl		149,729 $	150,329 $	155,422 $	159,451 $	159,583 $	163,737 $	169,233 $	**1,107,485 $**
Wildlife: Fisher		1,168,670 $	992,572 $	1,022,790 $	1,053,882 $	1,137,143 $	1,118,800 $	1,152,674 $	**7,646,531 $**
Total		**2,799,234 $**	**2,184,893 $**	**2,175,979 $**	**2,228,966 $**	**2,316,869 $**	**2,518,159 $**	**2,481,724 $**	**16,705,823 $**

It is a challenge to project the costs of a workplan of such scope and scale. Many aspects of the expenses will need to be revised as we refine our priorities and confirm exact research areas. As expected, the wildlife component is the most expensive (~$9,000,000). The cost of quantifying fisher population dynamics at just the southern site accounts for half of the entire budget. However the expenses are in line with comparable similar comprehensive field studies of species with similar life histories.

10.0 REFERENCES

10.1 **References for Sections 1.0 – 6.0**

Bahro, B. and K. Barber. 2004. Fireshed assessment: An integrated approach to landscape planning. USDA Forest Service Pacific Southwest Region. RS-TP-017.

Bennett, L. T., and M. A. Adams. 2004. Assessment of ecological effects due to forest harvesting: approaches and statistical issues. Journal of Applied Ecology **41**:585-598.

Biswell, H. H. 1989. Prescribed burning in California wildlands vegetation management. University of California Press, Berkeley, CA 255 pp.

Burnham, K.P., and Anderson, D.R. 2002. Model selection and multimodel inference: A practical information-theoretic approach. New York: Springer-Verlag. 488 pp.

Edwards, A.W.F. 1992. Likelihood. Expanded edition. Baltimore: The John Hopkins University Press. 275 pp.

Finney, M.A. 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. Forest Science 47: 219-228.

Finney, M.A. 2003. Calculation of fire spread rates across random landscapes. International Journal of Wildland Fire 12: 167-174.

Hobbs, N. T. 2003. Challenges and opportunities in integrating ecological knowledge across scales. Forest Ecology and Management **181**:223-238.

Holl, K. D., E. E. Crone, and C. B. Schultz. 2003. Landscape restoration: Moving from generalities to methodologies. Bioscience **53**:491-502.

Johnson, D. H. 2002b. The role of hypothesis testing in wildlife science. Journal of Wildlife Management **66**:272-276.

Lee, K.N. 1999. Appraising Adaptive Management. *Conservation Ecology* 3(2):3. [online] URL: http://www.consecol.org/vol3/iss2/art3.

MOU. 2005. Memorandum of Understanding regarding the Sierra Nevada Adaptive Management and Monitoring plan. Available at http://kellylab.berkeley.edu/snamp/documents/.

PSW Sierra Nevada Research Center. 2006. Webpage accessed on 2/12/06. http://www.fs.fed.us/psw/programs/snrc/.

SNFPA. 2004. Sierra Nevada Forest Plan Ammendment. Available at http://www.fs.fed.us/r5/snfpa/.

Stewart-Oaten, A, W. W. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "Pseudoreplication" in time?. Ecology 67:929-940.

Stewart-Oaten, A., and J. R. Bence. 2001. Temporal and spatial variation in environmental impact assessment. Ecological Monographs **71**:305-339.

Tear, T., Kareiva, P, Angermeier, P.L., Comer, P., Czech, B., Kautz, R., Landon, L., Mehlman, D., Murphy, K., Ruckelshous, M., Scott, J.M., and Wilhere, G. 2005. How much is enough? The recurrent problem of setting measurable objectives in conservation.

van Wagtendonk J.W. 1998. Fire and fuel in a Sierra Nevada ecosystem. In; Status and trends of the nation's biological resource. USGS-BRD. http://biology.usgs.gov/s+t/SNT/index.htm/.

Walters, C.J. and R. Green. 1997. Valuation of experimental options for ecological systems. Journal of Wildlife Management 61: 987-1006.

Walters, C.J. 1993. Dynamic models and large scale field experiments in environmental impact assessment and management. Aust. J. Ecol. 18:53-62.

Walters, C.J. 1986. Adaptive management of renewable resources. MacMillan Press, New York, N.Y. 374 pp.

Walters, C. J., and C. S. Holling. 1990. Large scale management experiments and learning by doing. Ecology 71 (6): 2060-2069.

10.2 **References for Section 7.1 -- Fire and Forest Ecosystem Health**

Ansley, J.-A. S., and J. J. Battles. 1998. Forest composition, structure, and change in an old-growth mixed conifer forest in the northern Sierra Nevada. Journal of the Torrey Botanical Society **125**:297-308.

Burns, R.M. & Honkala, B.H. (1990) *Silvics of North America* U.S. Dept. of Agriculture, Forest Service, Washington, D.C.

Cherubini, P., Fontana, G., Rigling, D., Dobbertin, M., Brang, P., & Innes, J.L. (2002) Tree-life history prior to death: two fungal root pathogens affect tree-ring growth differently. *Journal of Ecology*, **90**, 839-85.

Clark, D. B., C. Soto Castro, L. D. Alfaro Alvarado, and J. M. Read. 2004. Quantifying mortality of tropical rain forest trees using high-spatial-resolution satellite data. Ecology Letters **7**:52-59.

Das, A., J. J. Battles, N.L. Stephenson, and P.J. van Mantgem. In press. A dendroecological approach to understanding tree mortality: A study of two tree species in the Sierra Nevada.

Kilgore, B. M. 1973. The ecological role of fire in Sierra conifer forests: its application to national park management. Quaternary Research **3**:496-513.

Kobe, R.K., Pacala, S.W., Silander, J.A., & Canham, C.D. (1995) Juvenile Tree Survivorship as a Component of Shade Tolerance. *Ecological Applications*, **5:** 517-532.

Maloney, P. E., and D. M. Rizzo. 2002. Pathogens and insects in a pristine forest ecosystem: The Sierra San Pedro Martir, Baja, Mexico. Canadian Journal of Forest Research **32**:448-457.

Pacala, S.W., Canham, C.D., Saponara, J., Silander, J.A., Kobe, R.K., & Ribbens, E. (1996) Forest models defined by field measurements: Estimation, error analysis and dynamics. *Ecological Monographs*, **66**, 1-43.

Parsons, D. J., and S. H. Debenedetti. 1979. Impact of Fire Suppression on a Mixed Conifer Forest. Forest Ecology and Management **2**:21-33.

Pedersen, B. S. 1998. The role of stress in the mortality of midwestern oaks as indicated by growth prior to death. *Ecology* 79: 79-93.

Roy, D. G., and J. L. Vankat. 1999. Reversal of human-induced vegetation changes in Sequoia National Park, California. Canadian Journal of Forest Research **29**:399-41.

Suarez, M.L., Ghermandi, L., & Kitzberger, T. (2004) Factors predisposing episodic drought-induced tree mortality in Nothofagus - site, climatic sensitivity and growth trends. *Journal of Ecology*, **92:**954-966.

Wyckoff, P. H., and J. S. Clark. 2000. Predicting tree mortality from diameter growth: A comparison of maximum likelihood and Bayesian approaches. *Canadian Journal of Forest Research.* 30: 156-167.

10.3 **References for Section 7.2 -- Participatory Processes**

Aberley, D., 1993. Boundaries of home. Mapping for local Empowerment. New Society Publishers, Gabriola Island, BC.

Allen, P.T. 1998. Public participation in resolving environmental disputes and the problem of representativeness. Risk: Health, Safety & Environment, Fall, 297-308.

Baldassare, M. 1994. Regional Variations in Support for Regional Governance. Urban Affairs Review 30:275-284.

Bales, R. C., D. M. Liverman and B. J. Morehouse. 2004. Integrated Assessment as a Step Toward Reducing Climate Vulnerability in the Southwestern United States. American Meteorological Society:85 1727.

Bishop, P. & Davis, G. 2002. Community consultation symposium: Mapping public participation in policy choices. Australian Journal of Public Administration, 61(1).

Chess, C., M. Tamuz, and M. Greenberg. 1994. Organizational learning about environmental risk communication: The case of Rohm and Haas' Bristol plant. Society and Natural Resources 8:57-66.

Clark, M. J. 2002. Dealing with uncertainty: Adaptive approaches to sustainable river management. . Aquatic Conservation: Marine and Freshwater Systems 12:347-363.

Crampton, J. W. and D. J. Stewart. 2004. Community mapping as a solution to digital equity. In: D.G. Janelle (Editor), WorldMinds: Geographical Perspectives on 100 Problems. Kluwer Academic Publishers, pp. 523-527.

Geyer-Allely, E. 1994. Towards sustainable agricultural production :cleaner technologies. Organisation for Economic Co-operation and Development, Paris.

Haklay, M. E. 2003. Public access to environmental information: past, present and future. Computers, Environment and Urban Systems 27:163-180.
Innes, J. E., and D. E. Booher. 1999. Consensus building and complex adaptive systems - A framework for evaluating collaborative planning. Journal of the American Planning Association 65:412-423.
Kearns, F. R., M. Kelly, and K. A. Tuxen. 2003. Everything happens somewhere: using webGIS as a tool for sustainable natural resource management. Frontiers in Ecology and the Environment 1:541-
Leitner, H., R. McMaster, S. Elwood, S. McMaster, and E. Sheppard. 2002. Models for making GIS available to community organizations: dimensions of difference and appropriateness. In: W.J. Craig, T.M. Harris and D. Weiner (Editors), Community Participation and Geographic Information Systems. Taylor and Francis, London and New York, pp. 37-52.
Margerum, R.D. 2001. Organizational commitment to integrated and collaborative management: Matching strategies to constraints. Environmental Management, 28(4), 421-431.
McDaniels, and R. Gregory. 2002. Exploring a structured decision making approach as a means of fostering participatory space policy making at NASA. Space Policy, pp. 221-231.
Meredith, T. C., G. G. Yetman, and G. Frias. 2002. Mexican and Canadian case studies of community-based spatial information management for biodiversity conservation. In: W.J. Craig, T.M. Harris and D. Weiner (Editors), Community Participation and Geographic Information Systems. Taylor and Francis, London, pp. 205-217.
Selin, S.W., Schuett, M.A. & Carr, D. 2000. Modeling stakeholder perceptions of collaborative initiative effectiveness. Society & Natural Resources, 13(8), 735-745.
Shindler, B. & Cheek, K.A. 1999. Integrating citizens in adaptive management: A prepositional analysis. Ecology and Society, 3(1).
Sieber, R. E. 2002. Geographic information systems in the environmental movement. In: W.J. Craig, T.M. Harris and D. Weiner (Editors), Community Participation and Geographic Information Systems. Taylor & Francis, London and New York, pp. 153-172.
Walters, C. J. and C. S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71:2060-2068.

10.4. **References for Section 7.3 -- Water Quantity and Quality**

Bales, R C; N.P. Molotch, D.G. Marks, E. E. Small. 2004. Integrated snow, soil and water-balance measurement strategy for multi-scale environmental observations in mountain areas. *Eos Trans. AGU, 86*(52), Fall Meet. Suppl., Abstract H34D-04.
Bales, R. C., N.P. Molotch, T. H. Painter, M. D. Dettinger, J. Dozier. Mountain hydrology of the Western U.S. submitted.
Benavides-Solorio, J. D. and L. H. MacDonald. 2005. Measurement and prediction of post-fire erosion at the hillslope scale, Colorado Front Range. International Journal of Wildland Fire 14:1-18.
Bunte, K. and S. R. Abt. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel-and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring**.** Gen. Tech. Rep. RMRS-GTR-74. Fort Collins,CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 p. available online at http://www.fs.fed.us/rm/pubs/rmrs_gtr74.html.
Davis, W.S. and T.P. Simon (editors). 1995. *Biological assessment and criteria – tools for water resource planning and decision making*. Lewis publishers, Boca Raton.
Dressler, K.A., G. H. Leavesley, R. C. Bales, R.C. and S. R. Fassnacht. 2006. Evaluation of gridded snow water equivalent and satellite snow cover products for mountain basins in a hydrologic model. Hydrological Processes. In press.
Hamblen, J., Temporal and spatial trends in sediment dynamics and potential aerobic microbial metabolism, Upper San Pedro River, southeastern Arizona, MS Thesis, Hydrology, University of Arizona, 2003.
Hamblen, J., I.S. Burns, and M.H. Conklin. Temporal and spatial trends in microbial metabolism and sediment dynamics in the San Pedro River, southeastern Arizona, in preparation.
Herbst, D.B. and J. M. Kane. 2004. Responses of Stream Channels, Riparian Habitat, and Aquatic Invertebrate Community Structure to Varied Livestock Grazing Exposure and Management in the

West Walker River Watershed (Mono County, California). Final Report to Lahontan Regional Water Quality Control Board 5 May 2004, 42 pp. Also paper presented at Rangeland Water Quality Conference February 23 & 24, 2005 at Heidrick Ag History Center, 1962 Hays Lane, Woodland CA 95776. Report available at http://forestry.berkeley.edu/rangelandwq/pdfs/West_Walker_Grazing_Report.pdf.

Karr, J.R. and E.W. Chu. 1999. *Restoring life in running waters – better biological monitoring*. Island Press, Washington, D.C.

Molotch, N. P., T. H. Painter, R. C. Bales and J. Dozier. 2004. Incorporating Remotely-Sensed Snow Albedo into a Spatially-Distributed Snowmelt Model,Geophysical Research etters,31(3): Art. No. L03501.

Morrill, J. C., R. C. Bales and M. H. Conklin. 2005. Estimating Stream Temperature from Air Temperature: Implications for Future Water Quality, *Journal of Environmental Engineering,131 (1): 139-146 JAN 2005.*

Rice, R, R. Bales, K. Delin, S. Jackson. 2005. Sensor Web technology: implications for a network design in an alpine environment of the Sierra Nevada Mountains of California, *Eos Trans. AGU, 86*(52), Fall Meet. Suppl., Abstract IN21B-1180.

Rosenberg, D.M. and V.H. Resh (editors). 1993. *Freshwater biomonitoring and benthic macroinvertebrates*. Chapman and Hall, New York.

SNFPA. 2004. Sierra Nevada Forest Plan Amendment. Available at http://www.fs.fed.us/r5/snfpa/.

10.5 **References for Section 7.4 -- Wildlife**

Airola, D.A. 1988. Guide to the California Wildlife Habitat Relationships System. California Department of Fish and Game, Sacramento. 74 pp.

Anthony, R.G., E.D. Forsman, A.B. Franklin, D.R. Anderson, K.P. Burnham, G.C. White, C.J. Schwarz, J. Nichols, J.E. Hines, G.S. Olson, S.H. Ackers, S. Andrews, B.L. Biswell, P.C. Carlson, L.V. Diller, K.M. Dugger, K.E. Fehring, T.L. Fleming, R.P. Gerhardt, S.A. Gremel, R.J. Gutiérrez, P.J. Happe, D.R. Herter, J.M. Higley, R.B. Horn, L.L. Irwin, P.J. Loschl, J.A. Reid, and S.G. Sovern. 2006. Status and trends in demography of Northern Spotted Owls, 1985-2003. Wildlife Monographs 163.

Braun, C.E. (ed.). 2005. Techniques for wildlife investigations and management. The Wildlife Society, Bethesda, MD. 974 pp.

Cozier, M. E. Seamans, R. J. Gutiérrez, P. J. Loschl, R. B. Horn, S. G. Sovern, and E. D. Forsman. 2006. The Presence of Barred Owls Suppress the Calling Behavior of Spotted Owls? Condor 108:760-769.

Gutiérrez, R. J., M. Cody, S. Courtney, and Alan B. Franklin. In Press. The invasion of barred owls and its potential effect on the spotted owl: a conservation conundrum. Biological Invasions.

Hanley, T.A. 1994. Interaction of wildlife research and forest management: The need for maturation of science and policy. The Forestry Chronicle 70(5):527-532.

Franklin, A. B., R. J. Gutiérrez, J. D. Nichols, M. E. Seamans, G. C. White, G. S. Zimmerman, J. E. Hines, T. E. Munton, W. S. LaHaye, J. A. Blakesley, G. N. Steger, B. R. Noon, D. W. H. Shaw, J. J. Keane, T. R. McDonald, and S. Britting. 2004. Population dynamics of California spotted owls: a meta-analysis. Ornithological Monographs 54.

Karanth, , K.U., J.D. Nichols, N.S. Kumar, and J.E. Hines. 2006. Assessing tiger population dynamics using photographic capture-recapture sampling. Ecology 87(11):2925-2937.

Lancia, R.A., C.E. Bra2005un, M.W. Collopy, R.D. Dueser, J.G. Kie, C.J. Martinka, J.D. Nichols, T.D. Nudds, W.R. Porath, and N.G. Tilghman. 1996. ARM! For the future: adaptive resource management in the wildlife profession. Wildlife Society Bulletin 24(3):436-442.

Manley, P.N., M.D. Schlesinger, J.K. Roth, and B. VanHorne. 2005. A field-based evaluation of a presence-absence protocol for monitoring ecoregional-scale biodiversity. Journal of Wildlife Management 69(3):950-966.

Mayer, K.E., and W.F. Laudenslayer (eds.). 1988. A guide to wildlife habitats of California. California Department of Forestry and Fire Protection, Sacramento. 166 pp.
Schlaepfer, M.A., M.C. Runge, and P.W. Sherman. 2002. Ecological and evolutionary traps. Trends in Ecology and Evolution 17(10):474-480.
Schwartz, C.C., M.A. Haroldson, G.C. White, R.B. Harris, S. Cherry, K.A. Deating, D. Moody, and C. Servheen. 2006. Temporal, spatial, and environmental influences on the demographics of grizzly bears in the Greater Yellowstone Ecosystem. Wildlife Monographs 161:1-68.
Seamans, M. E. 2005. Temporal and Spatial Variability in California Spotted Owl Demographic Rates as Related to Weather, Habitat, and Habitat Modification. Doctoral Dissertation, University of Minnesota, St. Paul, MN.
Seamans, M. E., and R. J. Gutiérrez. In Press. Sources of variability in spotted owl population growth rate: testing predictions using long-term mark-recapture data. Oecologia
Stanley, T.R., and J.A. Royle. 2005. Estimating site occupancy and abundance using indirect detection indices. Journal of Wildlife Management 69(3):874-883.
Tear, T., Kareiva, P, Angermeier, P.L., Comer, P., Czech, B., Kautz, R., Landon, L., Mehlman, D., Murphy, K., Ruckelshous, M., Scott, J.M., and Wilhere, G. 2005. How much is enough? The recurrent problem of setting measurable objectives in conservation.
Vojta, C.D. 2005. Old dog, new tricks: innovations with presence-absence information. Journal of Wildlife Management 69(3):845-848.
Walters, C.J. 1986. Adaptive management of renewable resources. MacMillan Press, New York, N.Y. 374 pp.
Walters, C. J., and C. S. Holling. 1990. Large scale management experiments and learning by doing. Ecology 71 (6): 2060-2069.
Zielinski, W.J., and H.B. Stauffer. 1996. Monitoring Martes populations in California: survey design and power analysis. Ecological Applications 6(4):1254-1267.
Zielinski, W.J., R.L. Truex, F.V. Schlexer, L.A. Campbell, and C. Carroll. 2005. Historical and contemporary distributions of carnivores in forests of the Sierra Nevada, California, USA. J. Biogeography 32(8):1385-1407.

10.6 **References for Section 8.0 -- Project Management and Integration**

Andersen, H.-E., R. J. McGaughey, and S. E. Reutebuch. 2005. Estimating forest canopy fuel parameters using LIDAR data. Remote Sensing of Environment 94:441-449.
Clark, D. B., C. S. Castro, L. D. A. Alvarado, and J. M. Read. 2004a. Quantifying mortality of tropical rain forest trees using high-spatial-resolution satellite data. Ecological Letters 7:52-59.
Clark, D. B., J. M. Read, M. L. Clark, A. M. Cruz, M. F. Dotti, and D. A. Clark. 2004b. Application of 1-m and 4-m resolution satellite data to ecological studies of tropical rain forests. Ecological Applications 14:61-74.
Cosh, M. H. and W. Brutsaert. 2003. Microscale structural aspects of vegetation density variability. Journal of Hydrology 276:128-136.
Illoldi-Rangel, P., V. Sanchez-Cordero, and A. T. Peterson. 2004. Predicting distributions of Mexican mammals using ecological niche modeling. Journal of Mammalogy 85:658-662.
Kearns, F. R., M. Kelly, and K. A. Tuxen. 2003. Everything happens somewhere: using webGIS as a tool for sustainable natural resource management. Frontiers in Ecology and the Environment 1:541-548.
Lim, B. K., A. T. Peterson, and M. D. Engstrom. 2002. Robustness of ecological niche modeling algorithms for mammals in Guyana. Biodiversity and Conservation 11:1237-1246.
Parra, J. L., C. C. Graham, and J. F. Freile. 2004. Evaluating alternative data sets for ecological niche models of birds in the Andes. Ecography 27:350-360.
Peterson, A. T., L. G. Ball, and K. P. Cohoon. 2002. Predicting distributions of Mexican birds using ecological niche modelling methods. Ibis 144:E27-E32.
Rogers, K. 1998. "Managing science/management partnerships: a challenge of adaptive management". Conservation Ecology [online] **2**(2): R1. http://www.consecol.org/vol2/iss2/resp1/.

Shen, S. and M. Leclerc. 1995. How large must surface inhomogeneities be before they influence the convective boundary layer structure: a case study. Quarterly Journal of the Royal Meteorological Society 121:1209-1228.

Appendix 1. Biographical sketch of the UC Science team.

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RESEARCH INTERESTS

Mountain hydrology and biogeochemistry, polar snow and ice, climate impacts and water resources.

EDUCATION

Ph.D. 1985 Environmental Engineering Science, California Institute of Technology
M.S. 1984 Social Science, California Institute of Technology
M.S. 1975 Civil Engineering, University of California, Berkeley
B.S. 1974 Civil Engineering, Purdue University

EMPLOYMENT

2003-present: School of Engineering, University of California, Merced (Professor and founding faculty member).
1984-2003: Department of Hydrology and Water Resources, University of Arizona, (Assistant Professor 1984-1989, Associate Professor 1989-1995, Professor 1995-2004).
1980-84: Graduate Research Assistant, California Institute of Technology.
1975-80: Project Manager and Project Engineer, Brown and Caldwell, Pasadena, California

REGISTRATION

Civil Engineer 27677, California

OTHER APPOINTMENTS

2004-present. Member, Hydrology Graduate Group, University of California, Davis.
2000-2003: Deputy Director NSF, Center for the Sustainability of Semi-Arid Hydrology and Riparian Areas, University of Arizona
2000-2003: Member, Committee on Remote Sensing and Spatial Analysis, University of Arizona.
1999-2003: Director, Regional Earth Science Applications Center, University of Arizona
1997-1999: Director, Institute for the Study of Planet Earth, University of Arizona
1994-2003: Member, Interdisciplinary Committee for Global Change, University of Arizona. Chair, 1994-1997.
1994-2000: Investigator, Center for Toxicology, University of Arizona.
1994-1995: Visiting Fellow, Udall Center for Studies in Public Policy, University of Arizona.
1989-93: Associate Researcher, Department of Geography, University of California, Santa Barbara.

PROFESSIONAL SOCIETIES

American Geophysical Union (Fellow), American Society for the Advancement of Science (Fellow), American Meteorological Society (Fellow), American Society of Civil Engineers, American Chemical Society, Association of Environmental Engineering Professors.

PROFESSIONAL ACTIVITIES

2004-present. Member, Committee on Integrated Hydrologic Observations, Water Science and Technology Board, National Research Council.
2003-2005: Member, Committee on Metrics for Global Change Research, National Research Council.
2002-2004: Member, Committee on Geophysical and Environmental Data, National Research Council.
2001-present: Member Representative, Consortium of Universities for the Advancement of Hydrologic Science, Inc. 2001-2004 Member, Board of Directors. 2001-2003 Member, Executive Committee. 2000-2001 Chair, steering committee to form consortium and PI on grant that funded the consortium.
2000-present: Steering Committee Chair and Science Coordination Office Director, Summit Greenland Environmental Observatory.
1999-2000, Chair, Steering Committee, Southwest Regional Assessment, U.C. Global Change Research Program; Member, Regional Assessment Team.
2000-2002: Member, Advisory Committee, Geosciences Directorate, National Science Foundation.
2000-2002, Steering Committee, Eos, Transactions, American Geophysical Union. Hydrology Editor, 1997-2001.
1999-2002: Member, Committee on Hydrologic Sciences, National Research Council.
1999-2001: Chair, Ice Core Working Group. Member, 1997-1999.
1999-2000: Member, Water Cycle Study Group, U.S. Global Change Research Program.
1994-1996: Hydrology section secretary, American Geophysical Union.
1992-1996: Associate editor, Water Resources Research.
1992-1996: Member, Committee on Glaciology, National Research Council.

1991-1996: U.S. representative, International Commission on Water Quality, International Association of Hydrologic Sciences.
1991-1995: Chair, Snow-Atmosphere Chemical Exchange Working Group, International Commission for Snow and Ice.
1990-1993: Fall meeting program chair, Hydrology Section, American Geophysical Union.
1987-1990: Steering Committee, Snow Chemistry Working Group, International Commission for Snow and Ice.
1985-1990: Water Quality Committee, Hydrology Section, American Geophysical Union.
1989-1991: Coagulation Research Committee, American Water Works Association.

PUBLICATIONS

Five relevant publications

N.P.Molotch,R.C. Bales, M. Colee, J. Dozier, Estimating the spatial distribution of snow water equivalent in an alpine basin using binary regression tree models: the impact of digital elevation data and independent variable selection, *Hydrol. Proc., 19: 1459-1479, 2005.*

R.C. Bales, D.M. Liverman, B.J. Morehouse. Integrated assessment as a step toward reducing climate vulnerability in the southwestern United States, *Bull. Am. Met. Society*, 85: 1727–1734, 2004.

T. Meixner, J.R. Shaw, R.C. Bales**,** Temporal and spatial variability of cation and silica export in an alpine watershed, Emerald Lake, California. *Hydrol. Proc.* 18(10): 1759-1776, 2004.

A.K. Huth, A. Leydecker, J.O. Sickman, R.C. Bales, A two-component hydrograph separation for three high-elevation catchments in the Sierra Nevada, California, *Hydrol. Proc.* 18 (9):1721-1733, 2004.

J.A. Rohrbough, D.R. Davis, R.C. Bales, Spatial variability of snow chemistry in an alpine snowpack, southern Wyoming, *Water Resour. Res.*, 39(7): 1190-1201,2003.

Five other publications

J.F. Burkhart, M.H. Hutterli, R.C. Bales J.R. McConnell, Seasonal accumulation timing and preservation of nitrate in firn at Summit, Greenland, *J. Geophys. Res*., D19302, 2004

M.A. Hutterli, J.R. McConnell, G. Chen, R.C. Bales, D.D. Davis, D.H. Lenschow, Formaldehyde and hydrogen peroxide in air, snow and interstitial air at South Pole, *Atmos. Environ*. 38:5439-5450, 2004.

H.W. Jacobi, R.C. Bales, R.E. Honrath, M.C. Peterson, J. E. Dibb, A.L. Swanson, M. R. Albert, Reactive trace gases measured in the interstitial air of surface snow at Summit,Greenland, *Atmos. Environ*., 38: 1687-97, 2004.

S.R. Fassnacht, K.A. Dressler, R.C. Bales, Snow water equivalent interpolation for the Colorado River Basin from snow telemetry (SNOTEL) data, *Water Resour. Res*., 39(8): 1208-1217, 2003.

T. Meixner, R.C. Bales, Hydrochemical modeling of coupled C and N cycling in high-elevation catchments: Importance of snow cover, *Biogeochemistry*, 62(3): 289-308, 2003.

CURRENT STUDENTS AND POSTDOCS

Ph.D. Ricardo Cisneros,
M.S. Sarah Martin.
Postdoctoral. F. Liu, R. Rice

FORMER STUDENTS AND POSTDOCS

M. S.: J. F. Burkhart, B. J. Cadle, S. M. Carroll, J. Clemmons, S. Hinkle, D. Hunter, A. Kramer-Huth, D. G. Kebler, T. Kinoshita, A. Klein, T. W. Kroeger, D. Lawler, P. W. Lawson, D. McCaulou, K. L. McClellen, P. A. Noppe, C. Peters, C. E. Petersen, J.A. Rohrbough, J.R. Shaw, D. A. Stanley, K. Stocking, P. Whitaker, T. W. Whitehead, J. R. Winterle, B. D. Wolaver.

Ph. D.: J. Burkhart, Z. K. Chowdhury, K. Dressler, M. Frey., R. Harrington, A. Kramer-Huth, S. Li, R. A. Matzner, J. R. McConnell, T. Meixner, N. Molotch, D. L. Pardieck, R. H. Galarraga-Sanchez, J. E. Szecsody, M. P. Valdez, R. A. Wolford.

Postdoctoral: M. Anklin, C. Brown-Mitic, D. W. Cline, S. R. Fassnacht, M. Glueck, M. Hutterli, H. W. Jacobi, J. Morrill, A. Seth,

OTHER INFORMATION

Current Research Collaborators*:* M. Albert, C. Anastasio, T. Cahill, J. Dibb, J. Dozier, J. Frew, G. Huey, J. Kahl, B. Lefer, J. McConnell, N. Miller, A. Nolin, T. Painter, R. Shetter, R. Stewart, D. Tanner.

Graduate Advisor*:* J. J. Morgan.

RESUME

REGINALD HAUGHTON BARRETT

OCCUPATION:

Goertz Distinguished Professor of Wildlife Management
Department of Environmental Science, Policy, and Management
151 Hilgard Hall, University of California
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EDUCATION:

B.S. Game Management, Humboldt State College, Arcata CA (1965)
M.S. Wildlife Management, University of Michigan, Ann Arbor MI (1966)
Ph.D. Zoology, University of California, Berkeley CA (1971)

RECENT HONORS AND AWARDS

Goertz Distinguished Professor of Wildlife Management (2003)
Fellow California Academy of Science (2004)
Fellow The Explorer's Club (2004)

MOST RELEVANT RECENT PUBLICATIONS (5):

Zielinski, W. J., R. L. Truex, G. A. Schmidt, R. V. Schlexer, K. N Schmidt, and R. H. Barrett. 2004. Resting habitat selection by fishers in California. Journal of Wildlife Management 68(3):475-492.

Zielinski, W. J., R. L. Truex, G. A. Schmidt, F. V. Schlexer, K. N. Schmidt, and R. H. Barrett. 2004. Home range characteristics of fishers in California. Journal of Mammalogy 85(4):649-657.

Jordan, M. J., K. L. Purcell, and R. H. Barrett. 2003. Fisher population monitoring in the southern Sierra Nevada. Martes Working Group Newsletter 11(1):6-7.

Jordan, M.J., A.K. Mazzoni, K.L. Purcell, R.H. Barrett, P.J. Palsboll, and B.B. Boroski. 2002. Fisher population monitoring in the Kings River Adaptive Management Area. (Abstract Only) Proceedings of the Sierra Summit, October 8-10, King's Beach, Lake Tahoe, CA.

Zielinski, W. J., N. P. Duncan, E. C. Farmer, R. L. Truex, A. P. Clevenger, and R. H. Barrett. 1999. Diet of fishers (*Martes pennanti*) at the southernmost extent of their range. Journal of Mammalogy 80(3):961-971.

OTHER SIGNIFICANT PUBLICATIONS (5):

Benson, J. F., J. D. Perrine, R. T. Golightly, and R. H. Barrett. 2005. Use of cover and response to cover type edges by female Sierra Nevada red foxes in winter. Western North American Naturalist 65:127-130.

Mitchell, B. R., M. M. Jaeger, and R. H. Barrett. 2005. Coyote depredation management: current methods and research needs. Wildlife Society Bulletin 32(4):1209-1218.

Casher, L., R. Lane, R.H. Barrett, and L. Eisen. 2002. Relative importance of lizards and mammals as hosts for ixodid ticks in northern California. Expeimental and Applied Acarology 26:127-143.

Battles, J. J., A. J. Schlisky, R. H. Barrett, R. C. Heald, and B. Allen-Diaz. 2001. The effects of forest management on plant species diversity in a Sierran conifer forest. Forest Ecology and Management 146:211-222.

Gogan, P. J. P., R. H. Barrett, W. W. Shook, and T. E. Kucera. 2001. Control of ungulate numbers in a protected area. Wildlife Society Bulletin 29(4):1075-1088.

BIOGRAPHICAL SKETCH

John J. Battles

PROFESSIONAL PREPARATION

Yale University:
B.S. in biology, May 1985.
Graduated with distinction in the major and summa cum laude.
Cornell University:
Ph.D. in forest science, May 1994.
Cornell University
Post-doctoral Associate, Forest Ecology, 1994-1995.

APPOINTMENTS

Co-Director, Center for Forestry, College of Natural Resource, UC Berkeley, December 2000 to present.
Associate professor of forest community ecology, Department of Environmental Science, Policy, and Management, UC Berkeley, July 2000 to present.
Assistant professor of forest community ecology, Department of Environmental Science, Policy, and Management, UC Berkeley, January 1995 to June 2000.

PUBLICATION LIST (5 most relevant manuscripts)

Eschtruth, A.K., N. L. Cleavitt, J. J. Battles, R. A. Evans, and T. J. Fahey. In press. Vegetation dynamics in declining hemlock stands: nine years of forest response to hemlock woolly adelgid infestation. Canadian Journal of Forest Research.

Stella, J.C., J. J. Battles, B. K. Orr, J.R. McBride. In press. Synchrony of seed dispersal, hydrology and local climate in a semi-arid river reach in California. Ecosystems.

Wenk, R. C., J. J. Battles, R. D. Jackson, J. W. Bartolome, and B. Allen-Diaz. In press. An accurate and efficient method for sorting root cores using point-intercept sampling. Soil Science Society of America Journal.

Fahey, T.J, T.G. Siccama, C.T. Driscoll, G.E. Likens, J. Campbell, C.E. Johnson, J.J. Battles, J.D. Aber, J.J. Cole, M.C. Fisk, P.M. Groffman, S.P. Hamburg, R.T. Holmes, P.A. Schwarz, and R.D. Yanai. 2005. The biogeochemistry of carbon at Hubbard Brook. Biogeochemistry 75:109-176.

Gersonde, R., J.J. Battles, and K. L. O'Hara. 2004. Characterizing the light environment in Sierra Nevada mixed-conifer forests using a spatially explicit light model. Canadian Journal of Forest Research 34:1332-1342.

OTHER SIGNIFICANT PUBLICATIONS (5 other**)**

Battles, J.J., T. J. Fahey, T. G. Siccama, and A. H. Johnson. 2003. Community and population dynamics of spruce-fir forests on Whiteface Mountain, New York: Recent trends, 1985-2000. Canadian Journal of Forest Research 33: 54-63.

Battles, J.J., J.J. Armesto, D.R. Vann, D.J. Zarin, J.C. Aravena, C. Perez and A.H. Johnson. 2002. Vegetation composition, structure, and biomass of two unpolluted watersheds in the Cordillera de Piuchué, Chiloé Island, Chile. Plant Ecology 158:5-19.

Battles, J.J., A.J. Shlisky, R.H. Barrett, R.C. Heald, and B.H. Allen-Diaz. 2001. The effects of forest management on plant species diversity in a Sierran conifer forest. Forest Ecology and Management 146: 211-222.

Battles, J.J. and T.J. Fahey. 2000. Gap dynamics following forest decline: A case study of red spruce forests. Ecological Applications 10: 760–774.

Fahey, T.J., J.J. Battles, G.F. Wilson. 1998. Responses of early successional northern hardwood forests to changes in nutrient availability. Ecological Monographs 68:183-212.

SYNERGISTIC ACTIVITIES

Maintain and share databases on long-term forest plots in the Sierran mixed conifer forest (see http://ecology.cnr.berkeley.edu/)

Lead PI of a multidisciplinary science team that is designing a comprehensive adaptive management and monitoring program for the National Forests in the Sierra Nevada. This effort is being used as a model for encouraging meaningful public participation in the science and management of National Forest lands.

Organizing member and current chair of the Global Environment Residential Theme Program on the Berkeley campus. Globe House provides a living and learning environment for students interested in social, economic, and scientific issues affecting our Earth's urban, rural, and global environments.

COLLABORATORS & OTHER AFFILIATIONS

Barbara Allen-Diaz – UC Berkeley
Greg Asner – Stanford University
Roger Bales – UC Merced
Reg Barrett – UC Berkeley
Tim Fahey – Cornell University
Patrick Gonzales – The Nature Conservancy
Lynn Huntsinger – UC Berkeley
Randal Jackson – U Wisconsin
Joe R McBride – UC Berkeley
Michael Lefsky – Colorado State University
Thomas Siccama – Yale University
Scott Stephens – UC Berkeley

Thesis advisor -- Tim Fahey, Cornell
Graduate students supervised –15

Post-doctoral advisor -- Tim Fahey, Cornell
Post-doctoral students supervised – 2
(Kristen Waring, John Stella)

Martha H. Conklin

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University of California, Merced
Merced, California 9530

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RESEARCH INTERESTS

Metal transport in natural waters, surface water/shallow groundwater interactions, biogeochemistry, organic chemical distribution in soil and ground water, chemical processes in snow, K-12 environmental education.

EDUCATION

Ph.D. 1986 Environmental Engineering Science, California Institute of Technology
M.S. 1980 Environmental Engineering Science, California Institute of Technology
A.B. 1976 Physics, Mount Holyoke College

EMPLOYMENT

2003-present: Professor, School of Engineering, University of California, Merced
1987-2003: Department of Hydrology and Water Resources, University of Arizona (Assistant Research Hydrologist 1987-89, Research Assistant Professor 1989-90, Assistant Professor 1990-1996, Associate Professor 1996-2002, Professor 2002-2003).
1986-87: Associate Engineer, Environ Corp., Washington, D.C.
1979-86: Graduate Research Assistant, California Institute of Technology.
1976-79: Air Quality Scientist, Environmental Research & Technology, Concord, Massachusetts.

OTHER APPOINTMENTS

1998-1999: Fellow, Udall Center for Studies in Public Policy, University of Arizona.
1994-2003: Investigator, Center for Toxicology, University of Arizona.
1994-2003: Member, Interdisciplinary Committee for Global Change, University of Arizona.

PROFESSIONAL SOCIETIES

American Geophysical Union, American Society of Limnology and Oceanography, Association of Enivironmental Engineering and Science Professors, American Chemical Society, American Society for the Advancement of Science, American Water Resources Association.

SELECTED PUBLICATIONS

Relevant and Recent Refereed Journal Papers

Morrill, J.C., R.C. Bales and M.H. Conklin, Estimating Stream Temperature from Air Temperature: Implications for Future Water Quality, *Journal of Environmental Engineering*, 131, 139, 2005.
J.W. Harvey, M.H. Conklin and R.S. Koelsch. Predicting changes in hydrologic retention in an evolving semi-arid alluvial stream, *Advances in Water Resources*, **26**, 939-950, 2003.
J.E. Villinski, J.E. Saiers and M.H. Conklin, The effects of reaction-product formation on the reductive dissolution of MnO_2 by Fe(II). *Environmental Science and Technology,* **37**, 5589-5596, 2003.
N. Melitas, M. Conklin and J. Farrell. Electrochemical study of arsenate and water reduction on iron

media used for arsenic removal from potable water. *Environmental Science and Technology,*36, 3188-3193, 2002.

J.A.K. Silva, R. G. Bruant and M.H. Conklin. Equilibrium partitioning of chlorinated solvents in vadose zone: Low f_{oc} geomedia, *Environmental Science and Technology*, 36, 1613-1619, 2002.

J. Villinski, P.A. O'Day, T.L. Corley and M.H. Conklin. In situ spectroscopic and solution analyses of the reductive dissolution of MnO_2 by Fe(II). *Environmental Science Technology*. 35, 1157-1163, 2001.

J.T. Kay, M. H. Conklin, C.C. Fuller and P.A. O'Day. Processes of nickel and cobalt uptake by a manganese oxide forming sediment in Pinal Creek, Globe Mining District, Arizona. *Environmental Science and Technology*, 35, 4719-4725, 2001.

J. Choi, J.W. Harvey and M.H. Conklin. Characterizing multiple timescales of stream and storage zone interaction that affect solute fate and transport in drainage basins. *Water Resources Research,* 36(6), 1511-1518, 2000.

R.G. Bruant, Jr., and M.H. Conklin. Adsorption of trichloroethene at the air/water interface. *Environmental Science & Technology*, 35(2), 362-364, 2001.

R.G. Bruant, Jr., and M.H. Conklin. Dynamic determination of vapor/water interface adsorption for volatile organic compounds (VHOCs) using axisymmetric drop shape analysis: Procedure and analysis of benzene adsorption. *The Journal of Physical Chemistry B*, 104(47), 11146-11152, 2000.

J. Choi, M.H. Conklin, R.C. Bales, R.A. Sommerfeld. Experimental investigation of SO_2 uptake in snow. *Atmospheric Environment,* 34: 793-801, 2000

CURRENT STUDENTS

Ph.D.: Glenn Shaw (University of California, Merced.

CURRENT POSTDOCTORAL FELLOWS

Sarah May, Fengjing Liu

FORMER POSTDOCTORAL FELLOWS

Jean Morrill, John Villinski

FORMER PHD STUDENTS

Robert Bruant, Chunming Yu, Ingrid Padilla, Jungyill Choi, David Quanrud, John Villinski.

COLLABORATORS

Michael Hoffman (dissertation advisor), Christopher Fuller (USGS), G. Bryant Hudson (LLNL), Jean Moran (LLNL), Gregory Nims (LLNL), Roger Bales (UCM), David Goodrich (USDA ARS)

Curriculum Vitæ

LYNN HUNTSINGER

Environmental Science, Policy, and Management,
137 Mulford Hall #3110
University of California
Berkeley, 94720-3110
(510) 642-1022; *buckaroo*@nature.berkeley.edu

Education

Ph.D. 1989. University of California at Berkeley. Wildland Resource Science, specializing in range ecology and management.

M.S. 1983. University of California at Berkeley. Range Management.

B.A. 1979. University of California at San Diego. Major in Chinese Studies: Modern History; Minors in Literature and Biology.

Dissertation Title: Grazing in California's Mixed Conifer Forests: Studies in the Central Sierra Nevada.

Professional Experience

November 15, 2002 to July 1, 2005t: Associate Dean, Instruction and Student Affairs, College of Natural Resources, UC Berkeley.

July 1, 1996 to present: Associate Professor, Department of Environmental Science, Policy, and Management, University of California, Berkeley.

July 1, 1989 to July 1, 1996. Assistant Professor, University of California, Berkeley, Department of Forestry and Resource Management.

September 1987 to June 30, 1989. Research Program Specialist for the Forest and Rangeland Resources Assessment Program, California Department of Forestry and Fire Protection, 1416 9th St., Sacramento, CA 94244-2460.

Licensed Certified Professional Rangeland Manager, State of California, #80

Selected Publications

Ballard, H. and Huntsinger, L. *in press.* Salal harvester local ecological knowledge, harvest practices, and understory management on the Olympic Peninsula, Washington. *Human Ecology.*

Campos, P.; Caparrós, A.; Cerdá, E., Huntsinger, L. and. Standiford, R. *in press*. Modeling multifunctional agroforestry systems with environmental values: dehesa in Spain and woodland ranches in California. In: A. Weintraub, T. Bjorndal, R. Epstein and C. Romero (Editors), Management of Natural Resources: A Handbook of Operations Research Models, Algorithms, and Implementations. Kluwer Academic Publishers.

Standiford, R. Huntsinger, L., Campos-Palacin, P., Chaparros, A. *in press.* Economic Considerations of Silvopastoralism in California Oak Woodlands. In: Silvopastoralism and Sustainable Management, CAB International.

Huntsinger, L. Sulak, A, Gwin, L. and Plieninger, T. 2004. Oak woodland ranchers in California and Spain: conservation and diversification. In: Schnabel, S. and Ferreira, A. (eds). Sustainability of Agrosilvopastoral Systems: Dehesas, Montados. Chapter 6. Advances in Geoecology 37:309-326.

Sulak, A., Huntsinger, L., Standiford R, Merenlender, A, Fairfax S. 2004. The agricultural conservation easement: a strategy for oak woodland conservation. In: Schnabel, S. and Goncalves, A. (eds). Sustainability of Agrosilvopastoral Systems: Dehesas, Montados. Chapter 6. Advances in Geoecology 37:353-364.

Fairfax, S.K., Gwin, L. and Huntsinger, L. 2004. Presidio and Valles Caldera: A Preliminary Assessment of Their Meaning for Public Resource Management. *Natural Resources Journal* 44(2): 445-473.

Merenlender, A., Huntsinger, L., Guthy, G. and Fairfax, S. 2004. Land Trusts & Conservation Easements: Who is Conserving What for Whom. Conservation Biology 18(1): 65-75.

L. Huntsinger and S. Barry. 2002. Will California's landscapes keep working? Rangelands 24(3):6-10.

Ballard, H., Kraetch, R., and Huntsinger, L. 2001. How collaboration can improve a monitoring program. In: Standiford, Richard B.; McCreary, Douglas; Purcell, Kathryn L., technical coordinators. 2002. Proceedings of the fifth symposium on oak woodlands: oaks in California's changing landscape, pgs.617-624. 2001 October 22-25; San Diego, CA. Gen. Tech. Rep. PSW-GTR-184. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 846 p.

L. Huntsinger and M. Fernandez-Gimenez. 2001. Spiritual pilgrimage at Mt. Shasta. *Geographical Review* 90(4):536-558

R. Liffmann, L. Huntsinger, and L. Forero. 2000. To ranch or not to ranch: home on the urban range? *J. Range Management* 53(4)362-370.

Lynn Huntsinger, Lita Buttolph, and Peter Hopkinson. 1997. Ownership and management changes on California's hardwood rangelands, 1985-1992. *Journal of Range Management* 50:423-430.

Sally K. Fairfax and Lynn Huntsinger. 1997. The new western history: an essay from the woods (and rangelands). *Arizona Quarterly* 53(2):191-210. (Winner of Modern Language Association "Best Special Issue" award, 1997).

Lynn Huntsinger. 1997. Managing nature: stories of dynamic equilibrium. Proceedings of the Sixth Biennial Watershed Management Conference, Watershed Management Council, October 23-25, Lake Tahoe, California/Nevada. University of California Water Resources Center Report No. 92: 3-8. ISBN 1-887192-06-9.

Awards/Honors

2005 Exceptional Contribution Award, College of Natural Resources, UCB
2003 Distinguished Teaching Award, College of Natural Resources, UCB
2002 Exceptional Contribution, California Section, Society for Range Management,
1993 Vice-Chancellor's Educational Initiatives Award (with Sally K. Fairfax, for the Department of Forestry and Resource Management)
Fellow, Center for the Study of American Cultures, UCB 1990-1, 1991-2 & 1997-8.
Fellow, Society of Women Geographers
Charles Lathrop Pack Essay Prize, 1983&4.
Distinguished Paper, World Forestry Congress 2003

Distinguished Service

Associate Dean, Instruction and Student Affairs, College of Natural Resources 2002-2005
Science Advisory Board, Malpai Borderlands Group (ongoing)
President, California Section, Society for Range Management
President, California Chapter, Society of Women Geographers
Distinguished Paper, World Forestry Congress 2003

Biographical Sketch – N. Maggi Kelly

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EDUCATION

University of California, Berkeley, California	Geography	B.A. 1988
University of North Carolina, Chapel Hill, NC	Geography	M.A. 1991
University of Colorado, Boulder, Colorado	Geography	Ph. D. 1996
National Research Council Postdoctoral Assoc. NOAA-NMFS Lab, Beaufort, NC	Ecology	1996-1998

APPOINTMENTS

2003-present	Associate Specialist in Cooperative Extension and Adjunct Associate Professor. Ecosystem Sciences Division of the Department of Environmental Sciences, Policy and Management. University of California, Berkeley
1999-2005	Co-Director. University of California College of Natural Resources' Center for the Assessment and Monitoring of Forest and Environmental Resources (CAMFER)
1999-2003	Assistant Specialist in Cooperative Extension and Adjunct Assistant Professor. Ecosystem Sciences Division of the Department of Environmental Sciences, Policy and Management. University of California, Berkeley
1998-1999	Lecturer. Department of Geography. San Diego State University
1996-1999	Visiting Scholar. San Diego Supercomputer Center
1996-1998	National Research Council Postdoctoral Associate. National Oceanic and Atmospheric Administration: National Marine Fisheries Service Southeast Fisheries Laboratory. Beaufort, North Carolina
1996	Physical Scientist. National Geophysical Data Center, National Oceanic and Atmospheric Administration. Boulder, Colorado

FIVE RELATED PUBLICATIONS

Guo, Q., M. Kelly, and C. Graham. 2005. Support vector machines for predicting distribution of Sudden Oak Death in California. *Ecological Modeling* 182(1):75-90.

Kelly, M., K. A. Tuxen, and F. R. Kearns. 2004. Geospatial informatics for management of a new forest disease: Sudden Oak Death. Photogrammetric Engineering and Remote Sensing 70(9): 1001-1004.

Kelly, M., D. Shaari, Q. Guo, and D. Liu. 2004. A comparison of standard and hybrid classifier methods for mapping hardwood mortality in areas affected by sudden oak death. *Photogrammetric Engineering and Remote Sensing* 70(11): 1229-1239.

Kelly, M., and R. Meentemeyer. 2002. Landscape dynamics of the spread of Sudden Oak Death. Photogrammetric Engineering and Remote Sensing 68(10): 1001-1009.

Kearns, F. R., M. Kelly, and K. A. Tuxen. 2003. Everything happens somewhere: using webGIS as a tool for sustainable natural resource management. Frontiers in Ecology and the Environment 1(10): 541-548.

FIVE ADDITIONAL PUBLICATIONS

Liu, D., M. Kelly, and P. Gong. A Spatial-temporal approach for monitoring forest disease dynamics using multi-temporal high spatial resolution imagery. Accepted in Remote Sensing of Environment.

Liu, D., P. Gong, Q. Guo, and M. Kelly. In Press. Automatic registration of airborne images by combining area-based methods with local transformation methods. Photogrammetric Engineering and Remote Sensing.

Chen, Q., D. Baldocchi, P. Gong, and M. Kelly. In Press. Isolating individual trees in a savanna woodland using small footprint LIDAR data. Photogrammetric Engineering and Remote Sensing

Kelly, N. M., and K. Tuxen. 2003. WebGIS for monitoring "sudden oak death" in coastal California. Computers, Environment and Urban Systems 27(5): 527-547.

Helly, J. H., N. M. Kelly, D. Sutton, and T. Elvins. 2001. Collaborative management of natural resources in San Diego Bay. Coastal Management 29(2): 117- 132

SYNERGISTIC ACTIVITIES

- President of the Northern California Branch of the American Society for Photogrammetry and Remote Sensing.
- 1999-present: UC Cooperative Extension activities delivering lectures and short-courses on remote sensing and Geographical Information Science applications.
- 1999-present: chair of the UC Division of Agriculture and Natural Resources "Monitoring Landscape Change Workgroup" (http://kellylab.berkeley.edu/MLC).
- Faculty Director of UC Berkeley's Geospatial Imaging and Informatics Facility.
- Developer of numerous web-GIS sites for community based monitoring and environmental education.

COLLABORATIONS

Collaborators and Co-Editors

- UC Berkeley: B. Allen-Diaz, D. Baldocchi, Q. Chen, N. Clinton, J. Battles, G. Biging, J. Fisher, P. Gong, S. Fairfax, L. Huntsinger, F. Kearns, N. Kobzina, D. Liu, B. McPherson, Merenlender, M. Moritz, R. Pu, V. Resh, J. Romm, S. Stephens, M. Wacker, D. Wood.
- UC Merced: R. Bales, Q. Guo
- NOAA-NOS, Beaufort, NC: D. Field, M. S. Fonseca, P. E. Whitfield
- San Diego Supercomputer Center: J. Helly
- San Francisco State University: Tom Parker, Trish Foschi
- University of San Francisco: J. Callaway
- University of Indiana: T. Evans
- University of North Carolina, Chapel Hill: S. Walsh
- University of Southern Illinois: W. Sun
- US Park Service: D. Schirokauer

Graduate and Postdoctoral Advisors

Ford Cross, NOAA-NMFS Lab; M. J. Hodgson, USC-South Carolina; Steve Walsh, University of North Carolina-Chapel Hill; Mark Kumler, University of Redlands; Carol Wessman, University of Colorado.

Recent graduate advisees (2 PhD and 1 MS)
Kristen Byrd, PhD UC Berkeley 2005; Qinghua Guo, PhD UC Berkeley 2004; Matt Wacker, MS UC Berkeley 2002.

Thesis advisor and graduate committee activity (4 current PhD students, 13 active student committees)
Qi Chen, ESPM-UCB. PhD Committee member; Brandon Collins, ESPM-UCB PhD Committee member; Tim DeChant, PhD advisor, ESPM-UCB; Josh Fisher, ESPM-UCB PhD committee member; Ashley Holt, ESPM-UCB PhD committee member; Desheng Liu, ESPM-UCB PhD advisor; Andy Lyons, ESPM-IB PhD committee member; Suzy McIlroy, ESPM-UCB PhD committee member; Xin Miao, ESPM-UCB PhD committee member; Marc Parisien, ESPM-UCB PhD committee member; Orien Richmond, ESPM-UCB PhD committee member; Kim Rodriguez, ESPM-UCB PhD committee member; Emily Rubridge. ESPM-UCB PhD committee member; Fernando Sedano. ESPM-UCB PhD committee member; Karin Tuxen, ESPM-UCB PhD advisor; Qian Yu, ESPM-UCB PhD committee member; Esther Zeledon, ESPM-UCB PhD advisor.

QINGHUA GUO

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EDUCATION

Institution	*Major*	*Degree & Year*
University of California at Berkeley	Environmental Sciences	Ph.D. 2005
Peking University, China	GIS and Remote Sensing	M.S. 1999
Peking University, China	Environmental Sciences	B.S. 1996

APPOINTMENTS

2005 - Present	Assistant professor, University of California at Merced
1999 - 2005	Research assistant, University of California at Berkeley
1996 - 1999	Research assistant, Peking University, China

PUBLICATIONS

Five Relevant Refereed Journal papers

Guo, Q., Kelly, M., Graham, C. 2005. Support vector machines for predicting distribution of Sudden Oak Death in California. *Ecological Modelling.* 182: 75-90.

Guo, Q., Kelly, M. 2004. Interpretation of scale in paired quadrat variance methods. *Journal of Vegetation Science*. 15: 763-770.

Kim, J., **Guo, Q.**, Baldocchi, D., Xu, L., Leclerc, M. In Press. Upscaling CO_2 fluxes from tower to landscape: overlaying tower flux footprint calculations on high resolution (IKONOS) vegetation density images. *Agricultural and Forest Meteorology*.

Piao, S., Fang, J., Ji, W., **Guo, Q.**, Ke, J., Tao, S. 2004. Variation in a satellite-based vegetation index in relation to climate in China. *Journal of Vegetation Science.* 15: 219-226.

Piao, S., Fang, J., Zhou, L., **Guo, Q.**, et. al. 2003. Interannual variation of monthly and seasonal normalized difference vegetation index (NDVI) in China from 1982 to 1999. *Journal of Geophysical Research*. 108(D14), 10.1029/2002JD002848.

Five Other Refereed Journal papers

Liu D., P. Gong, M. Kelly, **Q. Guo**, In press. Automatic registration of airborne images by combining area-based methods with local transformation models. *Photogrammetric Engineering and Remote Sensing*.

Wieczorek,J., **Guo, Q.**, Hijmans, R. 2004. The Point-Radius method for georeferencing locality and calculating associated uncertainty. *International Journal of Geographical Information Science*. 18: 745-767

Kelly, M., Sharri, D., **Guo, Q.**, Liu, D. 2004. A comparison of standard and hybrid classifier methods for mapping hardwood mortality in areas affected by "sudden oak death". *Photogrammetric Engineering and Remote Sensing*. 70: 1229-1239.

Guo, Q., Yu, H., Cao, Y., Zhang, Z. 1999. The remote sensing study on the characteristics of Forest-Steppe Ecotone. *Univesitatis Pekinensis* (in Chinese). 35: 550-557.

Zeng, H., Shao, N., **Guo, Q.** 1999. A Study of landscape heterogeneity in the Eastern Pearl River Delta. *Acta Geographica Sinica* (in Chinese). 54: 255-262.

AWARDS

2004	Student Honors Paper Competition (2^{nd} Place): Remote Sensing Specialty Group, 100^{th} Annual Meeting of the Association of American Geographers
2001-2002	Carolyn Meek Scholarship: UC Berkeley
2001	NASA-MSU Professional Enhancement Award: US-International Association for Landscape Ecology
1998-1999	Jiu Ding-Xuan Scholarship: Peking Univ.
1997-1998	Outstanding Youth Scientist Award: Peking Univ.
1994-1995	Excellent Academic Scholarship: Peking Univ.
1992-1993	Excellent Social Work Award: Peking Univ.

PROFESSIONAL SERVICE

Reviewer

International Journal of Remote Sensing, Remote Sensing of Environment
Data Knowledge and Engineering, ASPRS 2006 Annual Conference
Journal of Spatial Hydrology, Acta Ecological Sinica

Society Membership

Association of American Geographers (AAG)
American Geophysical Union (AGU)
American Society for Photogrammetry and Remote Sensing (ASPRS)

BIOGRAPHICAL SKETCH
RALPH J. GUTIÉRREZ

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PROFESSIONAL PREPARATION

Colorado State University	Wildlife Biology	B.S., 1971
University of New Mexico	Biology	M.S., 1973
University of California, Berkeley	Zoology	Ph.D., 1977

POSITIONS AND ACADEMIC APPOINTMENTS

Professor and Gordon Gullion Endowed Chair in Forest Wildlife Research (2001-Present), *Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, St. Paul, MN.*

Assistant to Professor (1979-2000), *Department of Wildlife, Humboldt State University, Arcata, CA.*

Assistant Professor, (1977-1979), *Department of Natural Resources, Cornell University, Ithaca, NY.*

PUBLICATIONS (115 TOTAL PEER REVIEWED PAPERS; 8 EDITORSHIPS; 1 BOOK)

Recent Papers Closely Related to the Project:

Anthony, R.G., E.D. Forsman, A.B. Franklin, D.R. Anderson, K.P. Burnham, G.C. White, C.J. Schwarz, J. Nichols, J.E. Hines, G.S. Olson, S.H. Ackers, S. Andrews, B.L. Biswell, P.C. Carlson, L.V. Diller, K.M. Dugger, K.E. Fehring, T.L. Fleming, R.P. Gerhardt, S.A. Gremel, R.J. Gutiérrez, P.J. Happe, D.R. Herter, J.M. Higley, R.B. Horn, L.L. Irwin, P.J. Loschl, J.A. Reid, and S.G. Sovern. 2006. Status and trends in demography of Northern Spotted Owls, 1985-2003. Wildlife Monographs 163.

Crozier, M. E. Seamans, R. J. Gutiérrez, P. J. Loschl, R. B. Horn, S. G. Sovern, and E. D. Forsman. 2006. Does the Presence of Barred Owls Suppress the Calling Behavior of Spotted Owls? Condor

Barrowclough, G. F., J. G. Groth, L. A. Mertz, and R. J. Gutiérrez. 2006 Genetic structure of Mexican spotted owl (*Stix occidentalis lucida*) populations. Auk

Franklin, A. B., R. J. Gutiérrez, J. D. Nichols, M. E. Seamans, G.C. White, G. S. Zimmerman, J. E. Hines, T. E. Munton, W. S. LaHaye, J. A. Blakesley, G. N. Steger, B. R. Noon, D. W. H. Shaw, J. J. Keane, T. L. McDonald, and S. Britting.

2004. Population dynamics of the California spotted owl (Strix occidentalis occidentalis): a meta-analysis. *Ornithological Monographs* 54:1-55.

Gutiérrez, R. J., M. Cody, S. Courtney, and Alan B. Franklin. 2006. The invasion of barred owls and its potential effect on the spotted owl: a conservation conumdrum. Biological Invasions

Nichols, J. D., J. E. Hines, D. I. Mackenzie, M. E. Seamans, and R. J. Gutiérrez. In Press. Occupancy Estimation and Modeling with Multiple States and State Uncertainty: Characterizing Occupied Sites by Productivity. Ecology

Seamans, M. E., and R. J. Gutiérrez. 2006. Spatial Dispersion of Spotted Owl Sites and the role of Conspecific Attraction on Settlement Patterns**.** Ecology, Ethology, and Evolution

Seamans, M. E., and R. J. Gutiérrez. In Press. Sources of variability in spotted owl population growth rate: testing predictions using long-term mark-recapture data. Oecologia.

Other Recent Significant Publications:

Barrowclough, G. F., R. J. Gutiérrez, and J. G. Groth. 1999. Phylogeography of spotted owl (Strix occidentalis) populations based on mitochondrial DNA sequences: gene flow, genetic structure, and a novel biogeographic pattern*. Evolution* 53:919-931.

Gutiérrez, R. J., and S. Harrison. 1996. Applying metapopulation theory to spotted owl management: a history and critique. Pp. 167-185. In McCullough, D. (ed.). *Metapopulations and Wildlife Conservation*. Island Press, Covelo, CA.

Gutiérrez, R. J., G. F. Barrowclough, and J. G. Groth. 2000. A classification of the grouse (Aves: Tetraoninae) based on 5 complete mitochondrial DNA gene sequences. *Wildlife Biology* 6:205-211.

Gutiérrez, R. J., G. S. Zimmerman, and G. W. Gullion. 2003. Daily breeding season survival rates of ruffed grouse. *Wildlife Biology* 9:351-356.

Tempel, D. J., and R. J. Gutiérrez. 2004. Estimating Fecal Corticosterone Levels in California Spotted Owls: Implications for Assessing Chronic Stress. *Conservation Biology* 18:1-11.

SYNERGISTIC ACTIVITIES

Workshops Organized to Integrate and Transfer Knowledge (1998-2001): Workshop on Analysis of Demographic Rates of California Spotted Owls (Colorado State University) and Northern Spotted Owls (Colorado State University; Oregon State University); Co-developed short course on "Applying remote sensing techniques to Wildlife Habitat analysis" (Humboldt State University).

Participation in Review Teams Applying Science to Conservation Problems: (1) Member, Scientific Review Panel for 5-year Review of Federal Listing Status of the Northern Spotted Owl (2003 - present), *Sustainable Ecosystem Institute, Portland, Oregon*; (2) Member, Federal Advisory Team to review U.S. Forest Service Sierra Nevada Forest Management Strategy (1997), *Congressional Appointment through USDA Forest Service [Received Conservation Award 1997]*; (3) Member, California Spotted Owl Technical Assessment Team (1990-1992). *U. S. Forest Service, Sacramento, California [Received 3*

Conservation Awards {1992, 1992, 1994} and 1 Publication Award {2001}]; (4) Member, Northern Spotted Owl Recovery Team (1990 – 1992), *U. S. Fish and Wildlife Service, Portland, Oregon [Received Citation for Exceptional Service in 1992 from the Secretary of the Interior]*.

Contributions to Minority Participation in Science and University Education: (1) NIH Minority Representative from U.C. Berkeley to a national workshop on minority participation in Science (1975); (2) Development of biology teaching module in the College Enrichment Program for underrepresented students preparing for University life (1972; University of New Mexico); (3) Co-Director, CORE Student Affirmative Action Program to enhance minority participation in University education, particularly science (1981; Humboldt State University).

Service to the Professional Scientific Organizations: (1) Humboldt Chapter of The Wildlife Society representative to the Western Section of the Wildlife Society (1981); (2) The Wildlife Society's Representative to The Nature Conservancy (1990-1998); (3) Associate Editor, *Wildlife Biology*; (4) Ad Hoc Associate Editor, Wildlife Monographs, Conservation Biology, (5) Rush Scholarship Committee, the Wildlife Society (2004-present).

COLLABORATORS & OTHER AFFILIATIONS

Collaborators During past 48 Months: David R. Anderson (Colorado State University), Beatrice E. Arroyo (Spain), George F. Barrowclough (American Museum of Natural History), William M. Block (Rocky Mountain Research Station), Alan Franklin (USDA, APHIS), Jeffery G. Groth (American Museum of Natural History), Joshua J. Milspaugh (University of Missouri), Darryl Mackenzie (New Zealand), James D. Nichols (Patuxent Wildlife Research Center), Steven M. Redpath (Institute of Ecology and Hydrology, Banchory, Scotland), Peter Stine (PSW), Gary C. White (Colorado State University).

Graduate and Postdoctoral Advisors: A. Starker Leopold (Ph.D.; University of California, Berkeley), J. David Ligon (M.S.; University of New Mexico).

Graduate Students Advised (University of Minnesota 8) : Lorelle Berkeley, PhD., Andrea Chatfield, M.S. (2005), Jeremy Rockweit, M. S., Mark Seamans, PhD. (2005), Jonathan Slaght, PhD., Douglas Tempel, M.S. (2002), Douglas Tempel, PhD., Perry Williams, M.S., Guthrie Zimmerman, PhD. (2006)
(*Humboldt State University* 32) – Individuals not listed, but all M.S. [no PhD program at Humboldt State]

Undergraduate Theses Advised (40+): not listed, all but one at Humboldt State University

Biographical Sketch

KIMBERLY A. RODRIGUES
REGIONAL DIRECTOR
DANR – NORTH COAST AND MOUNTAIN REGION

EDUCATION

1984	M.S.	Forest Genetics. Colorado State University, Fort Collins, CO.
1981	B.S.	Forest Management. University of California, Berkeley, CA.

Kimberly is pursuing her Ph.D. in Environmental Science and Management, at UC Berkeley, under the guidance of Dr. Lynn Huntsinger, integrating participatory research methods supportive of adaptive management goals. Ph.D. ABD 2005

WORK EXPERIENCE

1984 – 1985	Chief Forester, Applied Forest Genetics
1985 – 1991	Tree Improvement Specialist, Simpson Timber Company
1991 – 1999	Forest Advisor, University of California Cooperative Extension
1999 – Present	Regional Director, DANR – North Coast and Mountain Region

BIBLIOGRAPHY

Peer Reviewed

Libby, W.J. and K.A. Rodrigues. Revegetating the 1991 Oakland-Berkeley Hills Burn, Fremontia, Vol. 20, No. 1, 7 pages.

Rodrigues, K.A. Overcoming Obstacles to Bioregional Planning, Watershed Management Council Newsletter, Fall, 1992, Vol. 5, No. 1, 3 pages (Michael Furniss-Edition)

_____________. The History of Conflict over Managing Coast Redwood, Humboldt State University, Summer, 1996, 4 pages.

Dunne, T., Rodrigues, et al. A Scientific Basis for the Prediction of Cumulative Watershed Effects, June 2001, Report No. 46, Wildland Resources Center, 103 pages.

Related Extensions Publications

Wallace, L. Tim, Jerry Moles, and K.A. Rodrigues. Working Paper No. 678, Proceedings of the Panel Discussion on Property Rights, June 1993, 20 pages.

Rodrigues, K.A. Annual Report for Humboldt County Cooperative Extension, 1993, 1994, 1995, 1997.

Giusti, G.A. and K.A. Rodrigues. Marbled Murrelet and Timber Harvest Plans, June 1994, IHRMP Publication – UCB, 4 pages.

Rodrigues, K.A. and G.G. Markegard. Keeping Track of TMDLs in California, Forestland Steward, Fall 1998, 1 page.

Educational Videos

Rodrigues, K.A. 1-25-93. Panel Discussion on Property Rights, 2 hours, Humboldt County Office.

_____________, 1-18-94. Headwaters Forest Forum, 4 hours, Humboldt County Office.

_____________. 10-1-94. Bioregional Tour of Headwaters Area, Martin Gift's property, 60 minutes, Humboldt County Office.

_____________. 5-17-95. Road Restoration Training Video, 30 minutes, Humboldt County Office.

SYNERGISTIC ACTIVITIES

Chair – Education Committee – Save-the-Redwoods-League
Member of Professional Foresters Examining Committee – State Board of Forestry
Director for Renewable Resources Extension Act (RREA)

COLLABORATIONS

Member of Cultural Diversity Working Group – National Network of Forest Practitioners (NNFP)
Advisory Member to the Alliance of Forest Workers and Harvesters
Advisory Board Member – Common Ground – Center for Cooperative Solutions – UC Davis Extension
Partner with Center for Collaborative Policy, Sacramento State, to Develop Collaborative Strategic Planning process for the Sierra Conservancy
Partner with the University of Nevada in support of the Lake Tahoe Environmental Education Coalition (LTEEC)

Name: Scott Lewis Stephens
Title: Assistant Professor of Fire Science

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Education

Ph.D. Wildland Resource Science, *University of California, Berkeley,* 1995.
Graduate study, Departments of Land, Air and Water Resources and Biological and Agricultural Engineering, *University of California, Davis,* 1988-1991. (hydrology, soil science, plant sciences)
M.S. Bio-Engineering, *California State University, Sacramento*, 1988.
B.S. Electrical Engineering, *California State University, Sacramento*, 1985.

Positions held

Assistant Professor of Fire Science, University of California, Berkeley. 2000 – present.
Assistant Professor of Quantitative Plant Ecology, California Polytechnic State University, San Luis Obispo. 1997-2000
Research Forester, United States Forest Service Pacific Southwest Research Station, Albany, CA. 1995-1997

Selected Publications

Fry, D.L., and S.L. Stephens. 2005. Influence of humans and climate on the fire history of a Ponderosa pine-mixed conifer forest in the southeastern Klamath Mountains, California. Forest Ecology and Management (in press).

Stephens, S.L., and N.G. Sugihara. 2005. Fire management and policy since European settlement. In: Fire in California Ecosystems, N.G. Sugihara, J.W. van Wagtendonk, J. Fites-Kaufman, K.E. Shaffer, and A.E. Thode (eds.). University of California Press. Berkeley, CA. (in press)

Stuart, J., and S.L. Stephens. 2005. North coast California bioregion. In: Fire in California Ecosystems, N.G. Sugihara, J.W. van Wagtendonk, J. Fites-Kaufman, K.E. Shaffer, and A.E. Thode (eds.). University of California Press. Berkeley, CA. (in press)

Stephens, S.L., and W.J. Libby. 2005. Anthropogenic fire and bark thickness in coastal and island pine populations from Alta and Baja California. Journal of Biogeography (in press).

Apigian, K., D. Dahlsten, and S.L. Stephens. 2006. Fire and fire surrogate treatment effects on leaf litter arthropods in a western Sierra Nevada mixed-conifer forest. Forest Ecology and Management 221:110-122.

Stephens, S.L., and P.Z. Fule. 2005. Western pine forests with continuing frequent fire regimes: Possible reference sites for management. Journal of Forestry 103: 357-362.

Stephens, S.L., and D. R. Fry. 2005. Spatial distribution of regeneration patches in an old-growth Pinus jeffreyi-mixed conifer forest in northwestern Mexico. Journal of Vegetation Science 16:693-702.

Beche, L.A., S.L. Stephens, and V.H. Resh. 2005. Prescribed fire effects on a riparian and stream community in the Sierra Nevada: Dark Canyon Creek, California, USA. Forest Ecology and Management 218:37-59.

Stephens, S.L. and J.J Moghaddas. 2005. Silvicultural and reserve impacts on potential fire behavior and forest conservation: 25 years of experience from Sierra Nevada mixed conifer forests. Biological Conservation 25:369-379.

Stephens, S.L. and J.J. Moghaddas. 2005. Fuel treatment effects on snags and coarse woody debris in a Sierra Nevada mixed conifer forest. Forest Ecology and Management 214:53-64.

Stephens, S.L. and J.J. Moghaddas. 2005. Experimental fuel treatment impacts on forest structure, potential fire behavior, and predicted tree mortality in a mixed conifer forest. Forest Ecology and Management 215:21-36.

Hille, M.G., and S.L. Stephens. 2005. Mixed conifer forest duff consumption during prescribed fires: Tree crown impacts. Forest Science 51: 417-424.

Stephens, S.L. 2005. Forest fire causes and extent on United States Forest Service lands. International Journal of Wildland Fire 14: 213-222.

Purcell, K., and S.L. Stephens. 2005. Changing fire regimes and the avifauna of California oak woodlands. Studies in Avian Biology 30: 33-45.

Stephens, S.L., & D.L. Fry. 2005. Fire history in coast redwood stands in the Northeastern Santa Cruz Mountains, California. Fire Ecology 1:2-19.

Stephens, S.L. and Gill, S.J. 2005. Forest structure and mortality in an old-growth Jeffrey pine-mixed conifer forest in northwestern Mexico. Forest Ecology and Management. 205:15-28.

Stephens, S.L. and Ruth, L.W. 2005. Federal forest fire policy in the United States. Ecological Applications, 15:532-542.

Stephens, S.L. 2004. Fuel loads, snag density, and snag recruitment in an unmanaged Jeffrey pine-mixed conifer forest in northwestern Mexico. Forest Ecology and Management 199: 103-113.

Stephens, S.L., Meixner, T., Poth, M., McGurk, B, Payne, D. 2004. Prescribed fire, soils, and stream water chemistry in a watershed in the Lake Tahoe Basin. International Journal of Wildland Fire 13: 27-35.

Stephens, S.L., Skinner, C.N., Gill, S.J., 2003. Dendrochronology-based fire history of Jeffrey pine-mixed conifer forests in the Sierra San Pedro Martir, Mexico. Canadian Journal of Forest Research 33:1090-1101.

Stephens, S.L., and M.A. Finney, 2002. Prescribed Fire Mortality of Sierra Nevada Mixed Conifer Tree Species: Effects of Crown Damage and Forest Floor Combustion. Forest Ecology and Management 162: 261-271.

Stephens, S.L. 2001, Fire history of adjacent Jeffrey pine and upper montane forests in the Eastern Sierra Nevada. International Journal of Wildland Fire 10:161-176.

Stephens, S.L. 1998. Effects of fuels and silvicultural treatments on potential fire behavior in mixed conifer forests of the Sierra Nevada, CA. Forest Ecology and Management 105: 21-34.

Appendix 2. Quantifying forest health using vulnerability profiles.

Adrian Das and John Battles

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The relationship between tree diameter growth and tree death is well established (e.g. Kobe et al. 1995, Yao et al. 2001), with slower growing trees tending to be more susceptible to mortality than faster growing trees. This relationship has often been used in forest models to simulate mortality, using submodels that rely on theoretical relationships between growth and risk of death (Bugmann 2001, Keane et al. 2001). Other studies have utilized a more empirical approach (Pacala et. al 1996, Bigler and Bugmann 2003) and in some cases have demonstrated a marked improvement over strictly theoretical models (Bigler and Bugmann 2004).

Despite the fact that several studies have documented a relationship between longer term growth characteristics and tree decline (Phipps and Whiton 1988, Leblanc 1990, Pedersen 1998, Ogle et al. 2000, Cherubini et al. 2002, Duchesne et al. 2002, Duchesne et al. 2003, Suarez et al. 2004), most mortality models have relied on average recent growth (Pacala et al. 1996, Yao et al 2001, Bugmann 2001, Keane et al. 2001) to assess mortality risk, with only a few notable exceptions (Bigler and Bugmann 2003, 2004, Bigler et al. 2004, Das et al in review). It seems likely, at least for some species, that long-term growth measures as well as additional types of growth parameters will be important for assessing a given tree's vulnerability to mortality (Das et al. in review).

Regardless of the form most of these individual-based models, implicitly or explicitly, generate a survival probability for each tree. These survival probabilities are then used either to assess the effectiveness of the model (i.e. to classify trees in a validation set as live or dead) or to simulate tree mortality in theoretical stands (e.g, forest gap models and SORTIE).

We propose that these survival probabilities have additional value for use in assessing forest health. Given a representative sample of trees from a forest stand (or any larger unit), we can generate a distribution of survival probabilities that provides a profile of that stand's relative vulnerability. Stands that are more vulnerable will tend to have a distribution of survival probabilities shifted to the left, with a higher proportion of trees in more vulnerable categories.

These vulnerability profiles can then provide a quantitative assessment of a given stand's relative health. In addition, the distribution can be used to examine the proportion of trees in more vulnerable categories. In the Sierra Nevada mixed conifer forest, for instance, mortality rates are typically around 1% (Stephenson and van Mantgem 2005). Therefore trees with a survival probability of less than 99% can be considered to be relatively more vulnerable to mortality than the population at large.

For a further quantification, we can estimate the expected mortality rate via simulation: For each tree a random number between 0 and 1 is picked. If the number chosen is greater than the survival probability for that tree, then the tree dies. By repeating this process numerous times an average mortality rate can be estimated for that population.

An example of vulnerability profiles is provided in Fig. 1, which show the survival distributions for *Abies concolor* (white fir) sampled at two mixed-conifer stands in Sequoia National Park. The results in shown in Fig. 1a are for trees along Log Creek, and those for Fig 1b are for trees sampled along the Crystal Cave Road. The Log Creek stand is located at a higher elevation (~2100 m) than that at the Crystal Cave Road (~1600 m) and historically has a lower mortality rate (Stephenson and van Mantgem 2005).

As expected, the Log Creek stand shows a lower vulnerability than that the Crystal Cave stand. Its survival probabilities are relatively right shifted; it has a lower theoretical mortality rate; and it has lower proportion of trees in more vulnerable categories.

Please note that these results are provided merely as an example and some caution should be taken in their interpretation. The samples were not originally collected for the purpose of generating stand health assessments, and therefore the trees used do not provide an adequate representation of stand structure. Not surprisingly, while the mortality rates are correct in their relative ranking, they do not well match those found in mortality censuses. At least for the Log Creek stand, this bias can be corrected by a resampling procedure (Das et al. in review), but a simplier approach for health assessments would be to collect a more representative sample.

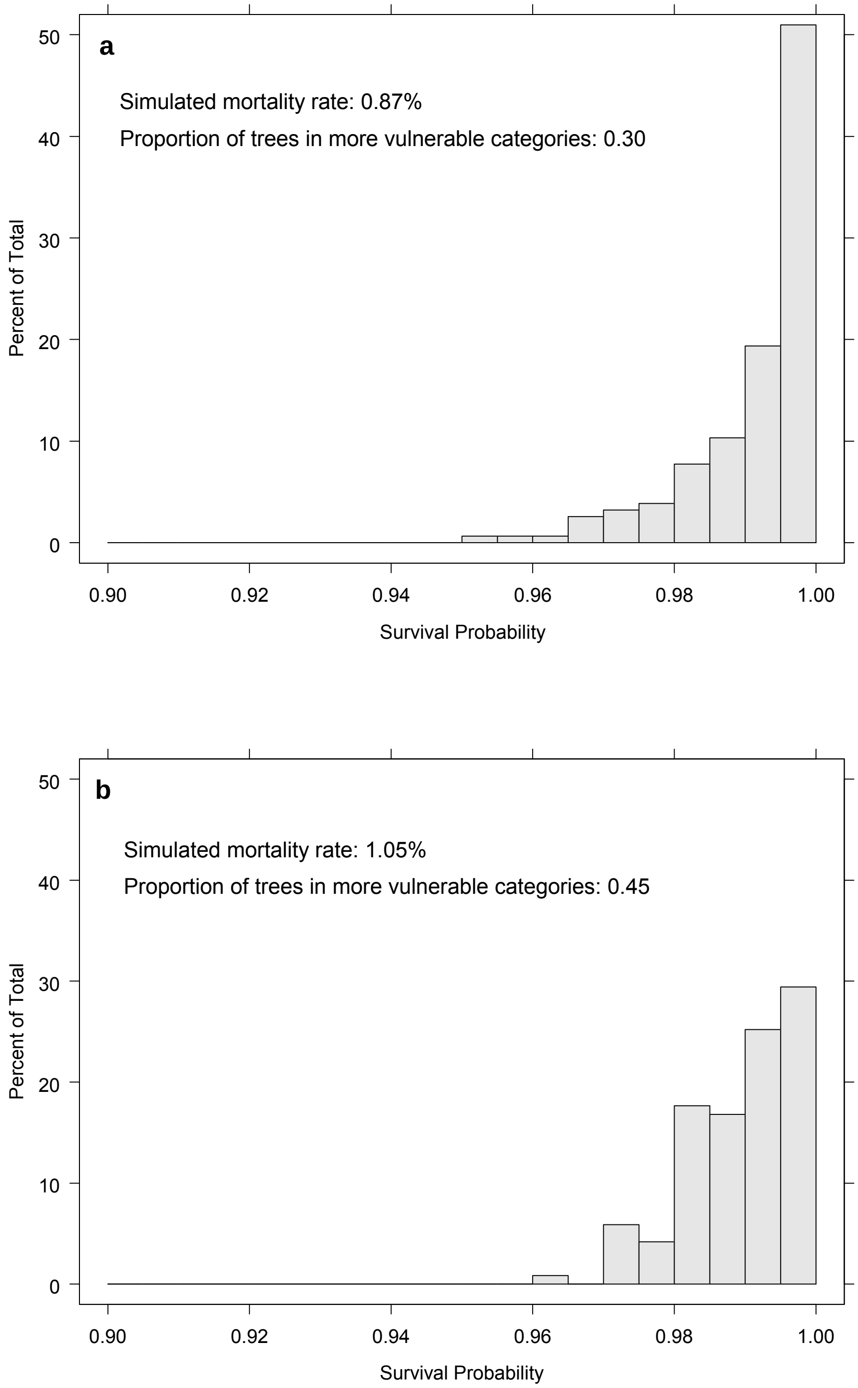

Fig. 1. a) Distribution of survival probabilities for 155 *Abies concolor* (white fir) sampled along Log Creek at Sequoia National Park. b) Distribution of survival probabilities for 119 *Abies concolor* (white fir) sampled along the Crystal Cave Road at Sequoia National Park. All survival probabilities were estimated using a logistic model developed in Das et al. (in review). Note: Samples were not collected for the purpose of generating stand health assessments, and therefore the trees used do not provide an adequate representation of stand structure. These distributions are meant merely to serve as examples of vulnerability profiles and should not be taken as accurate assessments of health for these two stands.

References

Das, A., Battles, J., Stephenson, N. L., and van Mantgem, P. J. In press. A Dendroecological Approach to Understanding Tree Mortality: A Study of Two Tree Species in the Sierra Nevada

Duchesne, L., Ouimet, R., and Houle, D. 2002. Basal area growth of sugar maple in relation to acid deposition, stand health, and soil nutrients. J. Environ. Qual. **31**:1676-1683.

Duchesne, L., Ouimet, R., and Morneau, C. 2003. Assessment of sugar maple health based on basal area growth pattern. Can. J. For. Res. **33**:2074-2080.

Bigler, C., and Bugmann, H. 2003. Growth-dependent tree mortality models based on tree rings. Can. J. For. Res. **33**:210-221.

Bigler, C., and Bugmann, H. 2004. Assessing the performance of theoretical and empirical tree mortality models using tree-ring series of Norway spruce. Ecol. Model. **174**:225-239.

Bugmann, H. 2001. A review of forest gap models. Clim. Change **51**:259-305.

Keane, R. E., Austin, M., Field, C., Huth, A., Lexer, M. J., Peters, D., Solomon, A., and Wyckoff, P. 2001. Tree mortality in gap models: Application to climate change. Clim. Change **51**:509-540.

Kobe, R. K., Pacala, S. W., Silander, J. A., and Canham, C. D. 1995. Juvenile Tree Survivorship as a Component of Shade Tolerance. Ecol. Appl. **5**:517-532.

Leblanc, D. C. 1990. Relationships between Breast-Height and Whole-Stem Growth Indexes for Red Spruce on Whiteface Mountain, New-York. Can. J. For. Res. **20**:1399-1407.

Ogle, K., Whitham, T. G., and Cobb, N. S. 2000. Tree-ring variation in pinyon predicts likelihood of death following severe drought. Ecology **81**:3237-3243.

Pacala, S. W., Canham, C. D., Saponara, J., Silander, J. A., Kobe, R. K., and Ribbens, E. 1996. Forest models defined by field measurements: Estimation, error analysis and dynamics. Ecol. Monogr. **66**:1-43.

Pedersen, B. S. 1998. The role of stress in the mortality of midwestern oaks as indicated by growth prior to death. Ecology **79**:79-93.

Phipps, R. L., and Whiton, J. C. 1988. Decline in Long-Term Growth Trends of White Oak. Can. J. For. Res. **18**:24-32.

Stephenson, N. L., and van Mantgem, P. J. 2005. Forest turnover rates follow global and regional patterns of productivity. Ecol. Lett. **8**:524-531.

Suarez, M. L., Ghermandi, L., and Kitzberger, T. 2004. Factors predisposing episodic drought-induced tree mortality in Nothofagus - site, climatic sensitivity and growth trends. J. Ecol. **92**:954-966.

Yao, X. H., Titus, S. J., and MacDonald, S. E. 2001. A generalized logistic model of individual tree mortality for aspen, white spruce, and lodgepole pine in Alberta mixedwood forests. Can. J. For. Res. **31**:283-291.

Appendix 3. EFFECTS OF SPLAT DISTRIBUTION ON SPOTTED OWL SURVIAL AND REPRODUCTION

R. J. Gutiérrez, Principle Investigator
University of Minnesota

Douglas Tempel, Research Fellow
University of Minnesota

Introduction:

The Sierra Framework has a central management proposal to distribute an array of Strategically Placed Land Allocation Treatments (SPLATS) across the landscape. The purpose of these SPLATS is to reduce the rate of spread of wildfire. Because SPLATS are fuel reduction measures, they are a function of tree removal, which affects ground vegetation, canopy closure, tree diameter distributions, and tree density. Thus, they could have an impact on spotted owls and other forest wildlife.

Currently, we are conducting an adaptive management study under the auspices of the U.S. Forest Service in the central Sierra Nevada on the effect of canopy reduction on the movement patterns and habitat use of spotted owls. This study is based on monitoring radio-marked owls before and after applying SPLATS within owl territories. This is a true experiment where both treatment and control birds have been randomly selected from the owl population following appropriate local control (e. g., birds must have at least sufficient suitable habitat within their territory to allow treatment). The results of this study will be limited to examining the short-term responses of owls to canopy reduction, which is an important aspect of measuring disturbance effects. However, chronic effects of disturbance are more important when assessing the long-term impacts of SPLATS on spotted owl populations. Chronic effects could be measured as changes in reproduction, survival, and occupancy rates of owls.

We propose to measure chronic effects (changes in reproduction, survival, and occupancy rates of owls) as part of the University of California's Sierra Nevada Adaptive Management Research Proposal. Because of limited sample sizes (see methods and discussion below) and funding levels allocated to this study, our study design is contingent on continued funding of the Eldorado Population Monitoring Study. This contingency is required because both the project leader and assistant project leader of the Eldorado Project will serve the same role in the Adaptive Management Research.

Methods:

There are two ways to examine the effect of SPLATS on spotted owls. The first is through radio marking and tracking of individual owls. However, we believe that radio telemetry of owls is best suited to examining acute effects of disturbance rather than examining chronic effects. From our recent and past experiences, we believe that radio-telemetry monitoring of the same individuals is difficult to conduct on a long-term basis, particularly where road access is limited as it is on most national forests. Additionally, the repeated capture of owls (necessary to periodically replace radios) makes the birds exceedingly wary over time, and therefore difficult to capture. In areas where road access is good and birds can be easily found on a daily basis, recapture of birds becomes primarily a matter of probability. But in areas where access is difficult, the probability of repeated recapture goes down dramatically. Radio-telemetry monitoring of owls is also difficult with limited road access, as is the case with at least one watershed in the adaptive management study. This decreases the reliability of gathering sufficient data. Finally, whereas we believe the reduction of transmitter size and improvement in harness design has greatly reduced the potential negative effects of transmitters on owls, chronic effects of SPLATS on owls may be confounded by possible adverse effects of transmitters on owls. Therefore, we propose to band owls and examine the long-term (chronic) effects of SPLATS on owls using banding, subsequent recapture (resighting of color bands) of individual birds, and determination of annual reproductive output. Our experience on the Eldorado study suggests that banding has no short-term or long-term negative effect on owls and is a reliable way to estimate the key parameters of interest: reproduction, survival, and occupancy of territories.

Methods:

We do not know how many owls are present on the two treatment or control watersheds. However, given the size of these potential watersheds, we suspect that no more than 4 pairs/watershed will be present. Therefore, we propose to intensively survey each watershed for owls, and then capture and band all owls within each watershed. In addition, we will survey adjacent areas to locate and monitor any birds whose home ranges could conceivably overlap the selected watersheds. Regardless, the number of birds available for study should be relatively small.

Because at least one of the watersheds appears to have limited road access, many of the surveys will have to be conducted by cross-country night surveys, which will require a great deal more survey time/unit area than would ordinarily be required in a spotted owl survey. However, it is imperative that the surveys be sufficiently intensive to locate all owls in each watershed. Prior work on spotted owls has demonstrated that all territorial owls on a study area can be detected given adequate survey effort (Franklin et al. 2004, Anthony et al. 2006). The specific techniques for finding, capturing, banding, and monitoring owls are well documented in the literature and will not be discussed here.

The specific analyses of the mark-recapture data in this proposed study will enable us to examine chronic effects of SPLATS, given the potential for small sample sizes. We propose to estimate reproductive, survival, and occupancy rates of owls using Jolly-Seber demographic parameters under a Bayesian statistical framework. These parameters or vital rates are well documented to be estimable for spotted owls using mark-recapture approaches (Franklin et al. 2004, Seamans et al. In Press, Anthony et. al. 2006). Recent analyses of spotted owl vital rates have relied on estimating these parameters under a model-selection framework based on Akaike's Information Criterion (AIC) values. Because sample sizes are likely to be small in this study, we will encounter convergence problems when calculating AIC values. We propose to instead use a Bayesian framework, involving the calculation of Bayesian Information Criterion (BIC) values. Since BIC values can be estimated using Monte Carlo simulations, we can estimate demographic parameters despite the expected small sample sizes. We will then compare the estimated demographic parameters (survival, reproductive output, occupancy) among the three watersheds using either a model-selection or Bayesian framework. Sex of the bird will be included as a covariate in this final analysis. Thus, we have a reference group that is experiencing the ongoing management regime in the central Sierra Nevada (i.e., the Eldorado Study Area), two treatment areas receiving a SPLAT prescription, and a control area receiving no treatments. We believe this approach provides the alternative for examining the potential chronic effects of SPLATS on spotted owls. One note for completeness is that the analysis of survival may be problematic because of problems with detectability. That is if owls leave the watershed (e.g., adult dispersal), remains alive, and remains undetected that survival rates will be biased. We know from other analyses that the size of a study area has to be much larger than the proposed watersheds if one wants to avoid bias in survival estimates due to undetected emigration. Thus, we believe that estimation of occupancy may be the best source of information on examining the long-term effects of SPLATS on spotted owls (Seamans 2005).

In terms of the demographic parameters, we know that reproduction is highly variable and likely dependent on weather (Seamans 2005). Survival is a better direct measure of SPLAT effects than reproduction because it is less strongly influenced by weather and more strongly influenced by habitat quality in the Sierra Nevada (Seamans 2005). Occupancy may be the best measure of measuring SPLAT effects because we can estimate owl occupancy more reliably than survival in this study, given the expected small sample size and duration of the study.

We will also test the predictions of models relating occupancy to habitat quality within owl territories (e.g., canopy cover and size class of dominant trees). Seamans (in preparation) has modeled the effects of habitat reduction in owl territories considered to contain good habitat versus those considered to contain poor habitat. Habitat quality was based on occupancy rates of owls on the Eldorado Study Area. The preliminary results suggest a greater relative impact of habitat reduction to owls located on better territories. Although one might expect that owls on better territories could better cope with habitat loss, the simulations suggest the existence of a threshold level of high-quality habitat, below which occupancy rates decrease greatly. Estimation of occupancy rates can occur with two years of data versus three needed for survival analysis. Examining occupancy also has the advantage of the analysis being conditional only on a bird having occupied a site in one year. It may be possible to use the disturbance regime of the SPLATS to predict occupancy rates of the owls with different habitat composition within their nearest neighbor distance.

Literature Cited

Anthony, R.G., E.D. Forsman, A.B. Franklin, D.R. Anderson, K.P. Burnham, G.C. White, C.J. Schwarz, J. Nichols, J.E. Hines, G.S. Olson, S.H. Ackers, S. Andrews, B.L. Biswell, P.C. Carlson, L.V. Diller, K.M. Dugger, K.E. Fehring, T.L. Fleming, R.P. Gerhardt, S.A. Gremel, R.J. Gutiérrez, P.J. Happe, D.R. Herter, J.M. Higley, R.B. Horn, L.L. Irwin, P.J. Loschl, J.A. Reid, and S.G. Sovern. Status and trends in demography of Northern Spotted Owls, 1985-2003. Wildlife Monographs 163.

Franklin, A. B., R. J. Gutiérrez, J. D. Nichols, M. E. Seamans, G. C. White, G. S. Zimmerman, J. E. Hines, T. E. Munton, W. S. LaHaye, J. A. Blakesley, G. N. Steger, B. R. Noon, D. W. H. Shaw, J. J. Keane, T. R. McDonald, and S. Britting. 2004. Population dynamics of California spotted owls: a meta-analysis. Ornithological Monographs 54.

Seamans, M. E. 2005. Temporal and Spatial Variability in California Spotted Owl Demographic Rates as Related to Weather, Habitat, and Habitat Modification. Doctoral Dissertation, University of Minnesota, St. Paul, MN.

Seamans, M. E., and R. J. Gutiérrez. In Press. Sources of variability in spotted owl population growth rate: testing predictions using long-term mark-recapture data. Oecologia

Time Schedule

2007 1 April – 30 August. Survey, trapping, and banding of owls. Complete at least 3 surveys of entire study area.
1 September – 30 March. Enter data, evaluate survey and banding success, make recommendations for future of study given results, and complete annual report. Engage in public outreach as required by Adaptive Management Team.

2008 1 April – 30 August. Survey, trapping and banding of new owls, and resighting of color bands of owls captured in 2007. Complete at least 3 surveys of entire study area.
1 September – 30 March. Enter data, evaluate survey and banding success, make recommendations for future of study given results, and complete annual report. Engage in public outreach as required by Adaptive Management Team.

2009 1 April – 30 August. Survey, trapping and banding of new owls, and resighting of color bands of owls captured in previous years. Complete at least 3 surveys of entire study area.
1 September – 30 March. Enter data, evaluate survey and banding success, make recommendations for future of study given results, and complete annual report. Engage in public outreach as required by Adaptive Management Team.

2010 1 April – 30 August. Survey, trapping and banding of new owls, and resighting of color bands of owls captured in previous years. Complete at least 3 surveys of entire study area.
1 September – 30 March. Enter data, evaluate survey and banding success, make recommendations for future of study given results, and complete annual report. Engage in public outreach as required by Adaptive Management Team.

2011 1 April – 30 August. Survey, trapping and banding of new owls, and resighting of color bands of owls captured in previous years. Complete at least 3 surveys of entire study area.
1 September – 30 March. Enter data, evaluate survey and banding success, make recommendations for future of study given results, and complete final report. Engage in public outreach as required by Adaptive Management Team.

Appendix I: SNAMP Publications

Appendix I lists publications associated with the Sierra Nevada Adaptive Management Project as of August 2015. Additional publications will likely be forthcoming. All these publications used data generated by SNAMP and/or were funded at least in part under the SNAMP budget. SNAMP was funded by USDA Forest Service Region 5, USDA Forest Service Pacific Southwest Research Station, US Fish and Wildlife Service, California Department of Water Resources, California Department of Fish and Game, California Department of Forestry and Fire Protection, and the Sierra Nevada Conservancy.

Peer-reviewed journal articles

SNAMP PUB #1: Collins, B.M., S.L. Stephens, J.J. Moghaddas, and J. Battles. 2010. Challenges and approaches in planning fuel treatments across fire-excluded forested landscapes. Journal of Forestry 108(1): 24-31.

SNAMP PUB #2: Collins, B.M., S.L. Stephens, G.B. Roller, and J.J. Battles. 2011. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. Forest Science 57(2): 77-88.

SNAMP PUB #3: Phillips, C.E., D.J. Tempel, and R.J. Gutiérrez. 2010. Do California spotted owls select nest trees close to forest edges? Journal of Raptor Research 44(4): 311–314.

SNAMP PUB #4: Guo, Q., W. Li, H. Yu, and O. Alvarez. 2010. Effects of topographic variability and lidar sampling density on several DEM interpolation methods. Photogrammetric Engineering & Remote Sensing 76(6): 701–712.

SNAMP PUB #5: García-Feced, C., D.J. Tempel, and M. Kelly. 2011. LiDAR as a tool to characterize wildlife habitat: California spotted owl nesting habitat as an example. Journal of Forestry 108(8): 436-443.

SNAMP PUB #6: Li, W., Q. Guo, M.K. Jakubowski, and M. Kelly. 2012. A new method for segmenting individual trees from the lidar point cloud. Photogrammetric Engineering & Remote Sensing 78(1): 75-84.

SNAMP PUB #7: Blanchard, S.D., M.K. Jakubowski, and M. Kelly. 2011. Object-based image analysis of downed logs in disturbed forested landscapes using Lidar. Remote Sensing 3: 2420-2439.

SNAMP PUB #8: Popescu, V.D., P. de Valpine, D. Tempel, and M.Z. Peery. 2012. Estimating population impacts via dynamic occupancy analysis of Before–After Control–Impact studies. Ecological Applications 22(4): 1389–1404.

SNAMP PUB #9: Berigan, W.J., R.J. Gutiérrez, and D.J. Tempel. 2012. Evaluating the efficacy of protected habitat areas for the California spotted owl using long-term monitoring data. Journal of Forestry 110(6): 299–303.

SNAMP PUB #10: Keller, S.M. M. Gabriel, K.A. Terio, E.J. Dubovi, E. VanWormer, R. Sweitzer, R. Barret, C. Thompson, K. Purcell, and L. Munson. 2012. Canine distemper in an isolated population of fishers (*Martes pennanti*) from California. Journal of Wildlife Diseases 48(4): 1035–1041.

SNAMP PUB #11: Sulak, A. and L. Huntsinger. 2012. Perceptions of forest health among stakeholders in an adaptive management project in the Sierra Nevada of California. Journal of Forestry 110(6): 312–317.

SNAMP PUB #12: Kelly, M., S. Ferranto, S. Lei, K. Ueda, and L. Huntsinger. 2012. Expanding the table: The web as a tool for participatory adaptive management in California forests. Journal of Environmental Management 109: 1-11.

SNAMP PUB #13: Jakubowski, M.K., Q. Guo, B. Collins, S. Stephens, and M. Kelly. 2013. Predicting surface fuel models and fuel metrics using lidar and CIR imagery in a dense, mountainous forest. Photogrammetric Engineering & Remote Sensing 79(1): 37–49.

SNAMP PUB #14: Zhao, F., Q. Guo, and M. Kelly. 2012. Allometric equation choice impacts lidar-based forest biomass estimates: A case study from the Sierra National Forest, CA. Agricultural and Forest Meteorology 165: 64– 72.

SNAMP PUB #15: Kocher, S., A. Lombardo, and R.A. Sweitzer. 2013. Using social media to involve the public in wildlife research – the SNAMP fisher sock collection drive. Journal of Extension 51(1): Article 1IAW3.

SNAMP PUB #16: Zhao, F., R.A. Sweitzer, Q. Guo, and M. Kelly. 2012. Characterizing habitats associated with fisher den structures in southern Sierra Nevada forests using discrete return lidar. Forest Ecology and Management 280: 112–119.

SNAMP PUB #17: Gabriel, M.W., L.W. Woods, R. Poppenga, R.A. Sweitzer, C. Thompson, S.M. Matthews, J.M. Higley, S.M. Keller, K. Purcell, R.H. Barrett, G.M. Wengert, B.N. Sacks, and D.L. Clifford. 2012. Anticoagulant rodenticides on our public and community lands: Spatial distribution of exposure and poisoning of a rare forest carnivore. PLoS ONE 7(7): e40163.

SNAMP PUB #18: Jakubowski, M.K., Q. Guo, and M. Kelly. 2013. Tradeoffs between lidar pulse density and forest measurement accuracy. Remote Sensing of Environment 130: 245–253.

SNAMP PUB #20: Eitzel, M., J. Battles, R. York, J. Knape, and P. de Valpine. 2013. Estimating tree growth from complex forest monitoring data. Ecological Applications 23(6): 1288–1296.

SNAMP PUB #21: Tempel, D.J. and R.J. Gutiérrez. 2013. Relation between occupancy and abundance for a territorial species, the California spotted owl. Conservation Biology 27(5): 1087–1095.

SNAMP PUB #22: Matthews, S.M., J.M. Higley, J.T. Finn, K.M. Rennie, C.M. Thompson, K.L. Purcell, R.A. Sweitzer, S.L. Haire, P.R. Sievert, and T.K. Fuller. 2013. An evaluation of a weaning index for wild fishers (*Pekania* [*Martes*] *pennanti*) in California. Journal of Mammalogy 94(5): 1161–1168.

SNAMP PUB #23: Thompson, C., R. Sweitzer, M. Gabriel, K. Purcell, R. Barrett, and R. Poppenga. 2014. Impacts of rodenticide and insecticide toxicants from marijuana cultivation sites on fisher survival rates in the Sierra National Forest, California. Conservation Letters 7(2): 91–102.

SNAMP PUB #24: Jakubowski, M.K., W. Li, Q. Guo, and M. Kelly. 2013. Delineating individual trees from lidar data: A comparison of vector- and raster-based segmentation approaches. Remote Sensing 5: 4163-4186.

SNAMP PUB #25: Popescu, V.D., P. de Valpine, and R.A. Sweitzer. 2014. Testing the consistency of wildlife data types before combining them: the case of camera traps and telemetry. Ecology and Evolution 4(7): 933-943.

SNAMP PUB #26: Tempel, D.J., R.J. Gutiérrez, S.A. Whitmore, M.J. Reetz, R.E. Stoelting, W.J. Berigan, M.E. Seamans, and M.Z. Peery. 2014. Effects of forest management on California spotted owls: implications for reducing wildfire risk in fire-prone forests. Ecological Applications 24(8): 2089-2106.

SNAMP PUB #27: Wengert, G.M., M.W. Gabriel, S.M. Matthews, J.M. Higley, R.A. Sweitzer, C.M. Thompson, K.L. Purcell, R.H. Barrett, L.W. Woods, R.E. Green, S.M. Keller, P.M. Gaffney, M. Jones, and B.N. Sacks. 2014. Using DNA to describe and quantify interspecific killing of fishers in California. Journal of Wildlife Management 78(4): 603–611.

SNAMP PUB #28: Martin, S.E., M.H. Conklin, and R.C. Bales. 2014. Seasonal accumulation and depletion of local sediment stores of four headwater catchments. Water 6: 2144-2163.

SNAMP PUB #29: Tao, S., Q. Guo, L. Li, B. Xue, M. Kelly, W. Li, G. Xu, and Y. Su. 2014. Airborne lidar-derived volume metrics for aboveground biomass estimation: A comparative assessment for conifer stands. Agricultural and Forest Meteorology 198-199: 24-32.

SNAMP PUB #30: Tempel, D.J., M.Z. Peery, and R.J. Gutiérrez. 2014. Using integrated population models to improve conservation monitoring: California spotted owls as a case study. Ecological Modelling 289: 86–95.

SNAMP PUB #31: Peery, M.Z. and R.J. Gutiérrez. 2013. Life-history tradeoffs in spotted owls (*Strix occidentalis*): Implications for assessment of territory quality. The Auk 130(1): 132-140.

SNAMP PUB #32: Sulak, A., L. Huntsinger, and S.D. Kocher. 2015. UC plays a crucial facilitating role in the Sierra Nevada Adaptive Management Project. California Agriculture 69(1): 43-49.

SNAMP PUB #33: Sweitzer, R.A., V.D. Popescu, R.H. Barrett, K.L. Purcell, and C.M. Thompson. In Press. Population size, density, and demography of fishers (*Pekania pennanti*) in the Sierra National Forest, California. Journal of Mammalogy.

SNAMP PUB #34: Collins, B.M., A.J. Das, J.J. Battles, D.L. Fry, K.D. Krasnow, and S.L. Stephens. 2014. Beyond reducing fire hazard: fuel treatment impacts on overstory tree survival. Ecological Applications 24(8): 1879–1886.

SNAMP PUB #35: Stoelting, R.E., R.J. Gutiérrez, W.L. Kendall, and M.Z. Peery. 2015. Life history trade-offs and reproductive cycles in spotted owls. The Auk 132(1): 46-64.

SNAMP PUB #36: Lei, S. and M. Kelly. 2015. Evaluating collaborative adaptive management in Sierra Nevada forests by exploring public meeting dialogues using self-organizing maps. Society & Natural Resources 28(8): 873–890.

SNAMP PUB #37: Li, L., Q. Guo, S. Tao, M. Kelly, and G. Xu. 2015. Lidar with multi-temporal MODIS provide a means to upscale predictions of forest biomass. ISPRS Journal of Photogrammetry and Remote Sensing 102: 198-208.

SNAMP PUB #38: Lei, S., A. Iles, and M. Kelly. 2015. Characterizing the networks of digital information that support collaborative adaptive forest management in Sierra Nevada forests. Environmental Management 56: 94-109.

SNAMP PUB #39: Tempel, D.J., R.J. Gutiérrez, J.J. Battles, D.L. Fry, Y. Su, Q. Guo, M.J. Reetz, S.A. Whitmore, G.M. Jones, B.M. Collins, S.L. Stephens, M. Kelly, W.J. Berigan, and M.Z. Peery. In Press. Evaluating short- and long-term impacts of fuels treatments and simulated wildfire on an old-forest species. Ecosphere.

Book chapters

SNAMP PUB #19: Thompson, C.M., R.A. Green, J. Sauder, K.L. Purcell, R.A. Sweitzer, and J.M. Arnemo. 2012. The use of radiotelemetry in research on *Martes* species: Techniques and technologies. Pages 284-319 in Aubry, K.B., W.J. Zielinski, M.G. Raphael, G. Proulx, and S.W. Buskirk, editors, Biology and conservation of martens, sables, and fishers: A new synthesis. Ithaca, NY: Cornell University Press.

Doctoral dissertations

Rodrigues, K.A. 2008. Evaluating a Collaborative Adaptive Management model through the lens of participatory democracy. PhD Dissertation, University of California, Berkeley.

Jakubowski, M.K. 2012. Using airborne LiDAR in wildfire ecology of the California Sierra-Nevada forests. PhD Dissertation, University of California, Berkeley.

Krasnow, K.P. 2012. Managing novel forest ecosystems: Understanding the past and present to build a resilient future. PhD Dissertation, University of California, Berkeley.

Li, W. 2013. Geographic Modeling with One-Class Data. PhD Dissertation, University of California, Merced.

Lei, S. 2014. Mapping webs of information, conversation, and social connections: Evaluating the mechanics of Collaborative Adaptive Management in the Sierra Nevada forests. PhD Dissertation, University of California, Berkeley.

Tempel, D.J. 2014. California spotted owl population dynamics in the central Sierra Nevada: An assessment using multiple types of data. PhD Dissertation, University of Minnesota.

Alvarez, O. 2015. Understanding climate change and the impact on biodiversity. PhD Dissertation, University of California, Merced.

Martin, S. – in preparation.

Saksa, P. – in preparation.

Su, Y. – in preparation.

Masters theses

Flanagan, J.P. 2015. Efficient open source lidar for desktop users. MS Thesis, University of California, Merced.

Reports

Gutiérrez, R.J. et al. 2008. Acute effects of canopy reduction on California spotted owls: Challenges for adaptive management. Final Report Revision: Contract #53-91S8-5-ECO54.

Conklin, M., R. Bales, R. Ray, S. Martin, P. Saksa, and P. Womble. 2012. Sierra Nevada Adaptive Management Project Water Team Field Activities, Methods, and Results. California Department of Water Resources Task Order #UC 10-6.

University of California Cooperative Extension. 2014. Facilitation Skills for a Collaborative Adaptive Management Process: A workbook to train natural resource managers and stakeholders in facilitation of collaborative projects.

Conklin, M., R. Bales, P. Saksa, S. Martin, R. Ray, B. Tobin, and P. Womble. 2015. Sierra Nevada Adaptive Management Project Water-Team Update. Data report addendum to California Department of Water Resources.

Non-peer reviewed articles

Ingram, K. 2010. Reducing wildland fire impacts: Research to learn what treatment strategies work best. Forestland Steward, Spring 2010: 6-7.

Battles, J.J. 2012. Fuel Treatments Can Address Wildfire Severity. California forests 16(1): 14-15.

Appendix J: SNAMP final report peer reviews, public and MOU Partner comments, and UC Science Team responses to peer reviews and comments

Note: this appendix is in draft form, awaiting the final version of the Water Team chapter and associated reviews and response. Page numbers will be added to document and the TOC once the Appendix is in final form.

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Introduction

The UC Science Team submitted the draft SNAMP final report for review in spring-summer 2015. The individual team chapters (Appendices A-F) underwent peer review as described below, and the entire report was provided to the public and the MOU Partners to review. In accordance with the UC Science Team's commitment to transparency, all peer reviews, public and MOU Partner comments, and UC Science Team responses are included in this Appendix.

Peer review process

Each team's draft individual team chapter was reviewed by 2 reviewers, 1 academic reviewer and 1 reviewer from a government agency. Peer reviewers were not affiliated with the University of California or with Forest Service Region 5 or Forest Service PSW to avoid potential conflicts of interest. Chapters 1-6 were not peer reviewed.

To ensure the integrity of the peer review process, neither the UC Science Team nor the MOU Partners were involved in the process. The Office of the Associate Vice President of the University of California's Division of Agriculture and Natural Resources agreed to conduct the peer review process on behalf of SNAMP. Peer reviewers were provided with a brief overview of SNAMP (see **Sierra Nevada Adaptive Management Project summary for peer reviewers** below) and were notified that their anonymous reviews would be made public as part of SNAMP's transparent participation process.

Each team wrote a response letter describing whether and how they revised their individual team chapter in response to the peer reviews. The peer reviews and the team responses are provided in this Appendix.

Public and MOU Partner comment process

The draft chapters of the SNAMP final report were posted on the SNAMP website as they came available. The Participation Team sent out an email announcement to all the SNAMP participants on the SNAMP email list when a new chapter was posted on the website. In addition, the MOU Partners received a direct email notifying them when a chapter was ready for review.

The Participation Team provided a website at which comments about any component of the SNAMP final report could be submitted by anyone so inclined. Comments could be submitted anonymously or with name and affiliation included. The UC Science Team's goal was to allow at least one month for public and MOU Partners review. In one instance, we were unable to meet this goal. For the draft versions of chapters 3 and 4 that were revised to include contributions from the Water Team, we asked for comments within a week so that we could adhere to our timeline; we subsequently extended the comment period for the entire report by an additional week.

All comments received by the deadline were passed on to the appropriate team for consideration. Teams revised their chapters in some instances based on comments received, and they addressed public and MOU Partners comments in their team response letter. Comments and response letters are provided in this Appendix.

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Sierra Nevada Adaptive Management Project summary for peer reviewers

The Sierra Nevada Adaptive Management Project (SNAMP) is a joint forest management assessment by the University of California (UC), state and federal agencies, and the public. SNAMP came into being in response to uncertainty over forest fuels management in the Sierra Nevada and the controversy resulting from the United States Forest Service's 2004 Record of Decision that established the current legal boundaries for management prescriptions in the Sierra Nevada national forests. SNAMP was created to assess the efficacy of forest fuels management on fire behavior and the impacts of that management on three natural resources, forest ecosystem health, wildlife, and water, while incorporating participation by all interested stakeholders, including the public.

The 2004 Record of Decision amended the 2001 Sierra Nevada Forest Plan Amendment. This decision led to significant controversies, including direct conflict between the State of California Resources Agency, the Department of the Interior's Fish and Wildlife Service, and the U. S. Forest Service. To reduce interagency conflict, the California Resources Agency, the Fish and Wildlife Service, the Forest Service, and the Pacific Southwest Research Station signed a Memorandum of Understanding (MOU) in 2005. Stipulated in the MOU was a request for the assistance of the University of California to convene a "neutral, third party" of experts.

Consequently, the agencies and the UC formed the Sierra Nevada Adaptive Management Project to learn how to apply adaptive management as required in the 2004 Record of Decision, with an emphasis on engaging the public in a meaningful way. A key SNAMP objective was to evaluate the impact of Strategically Placed Landscape Treatments (SPLATs), a forest fuel treatment, across four response variables:

- fire and forest ecosystem health,

- wildlife, focusing on the Pacific Fisher (*Pekania pennanti*) and the California Spotted Owl (*Strix occidentalis occidentalis*),
- water quality and quantity, and
- public participation.

Each response variable had an associated science team, and the response variable teams were supported by a spatial analysis team. As a whole, the university researchers were called the "UC Science Team".

Given the challenge of replicating landscape-scale research projects across the expansive mixed conifer forests of the Sierra Nevada, SNAMP took a case-study approach. The feasible alternative was to pick sites that would represent the primary biogeographic gradient – latitude – by selecting one northern and one southern Sierra site. SNAMP considered sites that were broadly representative of northern and southern Sierra Nevada mixed conifer forest; sites that were outliers in any major characteristic were rejected. In 2007, the two SNAMP study sites were selected:

1) the northern site, called the Last Chance Project, was in the American River Ranger District of the Tahoe National Forest. The expanded California spotted owl study area included portions of the Eldorado National Forest. The northern site contained Sierra Nevada mixed conifer forest with considerable numbers of residual old growth trees.

2) the southern site, called the Sugar Pine Project, was in the Bass Lake Ranger District of the Sierra National Forest. The forest was mixed conifer. The southern site provided habitat for the Pacific Fisher, and, as with the spotted owl team study area, the fisher study site encompassed more than just the Sugar Pine Project area.

The fireshed, approximately 4,000 ha, was chosen as the most appropriate spatial scale for reporting SNAMP results and making management recommendations. Each study site comprised a pair of firesheds, one in which a SPLAT treatment was implemented by the Forest Service, the other serving as an untreated control. The spatial scale at which the various response variables were evaluated varied: water on the catchment scale (approximately 100 ha), fire and forest ecosystem health on the fireshed scale, wildlife on larger scales appropriate to the two species under study, and public participation on multiple scales. Once assessments were complete, findings were scaled up or down to the fireshed scale. The integrated SNAMP analyses also employed a uniform time scale: immediate effects (0-5 years post-SPLAT treatment) and long-term effects (up to 30 years post-implementation, the estimated lifespan of a SPLAT treatment). Impacts were assessed both directly with 7 years of field data and with modelling, especially for longer term effects.

The UC Science Team began pre-treatment data collection at both sites in summer 2007. Pre-treatment data collection continued for more years than had been initially anticipated because there were delays in SPLAT implementation at both sites. The bulk of SPLAT implementation at both sites took place in 2011 and 2012; the Forest Service was solely responsible for designing and implementing the SPLATs. Following SPLAT implementation, the UC Science Team collected 1-2 years' worth of post-treatment data in 2012 and 2013.

The original SNAMP workplan envisioned a rigorous Before-After Control-Impact (BACI) study design for the evaluated resources. However, significant delays in implementing SPLATs truncated the "After" measurement period. Since an extension of the original study timeline was not financially feasible, the UC Science Team was not always able to use the planned BACI design and instead developed other study designs, including the use of datasets from related studies, to address the project's primary question of SPLAT impacts on resources. In addition to addressing the primary question, the UC Science Team developed multiple new methods and analytic techniques as well as new insights into the ecology and management of these forest ecosystems.

The primary research goals for each team were as follows:

California Spotted Owl

The primary tasks of the Owl Team were to: 1) assess the impacts of forest management and vegetation change on owl demography over the past 20 years on the Eldorado demography study area, and 2) project the effects of wildfire on the quantity and quality of owl habitat in the Last Chance study area over the next 30 years, with and without SPLATs.

Fire and Forest Ecosystem Health

Understanding SPLAT impact on fire behavior was the primary analytical product. The team also developed the necessary modeling tools to predict longer-term changes in forest composition and structure as well as fire behavior.

Pacific Fisher

Similar to the goals of the Owl Team, the primary tasks of the Fisher Team were to: 1) assess the impacts of forest management and vegetation change on fisher demography and behavior based on multiple datasets, and 2) project the effects of wildfire on the quantity and quality of fisher habitat in the study area over the next 30 years, with and without SPLATs.

Public Participation

The overarching goals were to create a model public participation process that agencies can emulate and to foster an engaged, knowledgeable group of stakeholders to work constructively with the management agency (i.e., the Forest Service). The assessment goal of the Public Participation Team was to estimate how much the various participants learned from each other, from science, and from SNAMP outreach efforts. Further, this team attempted to discover if that learning changed relationships among the involved parties and if constructive channels of communication were built and used.

Spatial

A primary goal was to develop algorithms to extract tree attributes such as height, dbh, height to live crown, location of individual trees, volume, and leaf area index, using lidar data, including metrics from the point cloud and from individual trees. These lidar-derived forest products and maps were used by the Fire and Forest Ecosystem Health, Water, Wildlife, and Public Participation teams. The Spatial Team also produced the pre- and post-treatment vegetation maps that formed the basis for the SNAMP integrated product.

Water

Primary goals were to measure and model the hydrology of paired headwater catchments and streams in the firesheds, to scale this modeling to the fireshed, and to predict and assess impacts of SPLATs on water-cycle attributes over a range of inter-annual climate conditions and across the broader forest landscape.

Additional notes to peer-reviewers

The office of the associate vice-president of the UC Agriculture and Natural Resources Division will conduct the peer-review. As part of the UC Science Team's commitment to transparency in our SNAMP research, we release peer reviews of workplans and reports to the public. Please be aware that we plan on posting the peer reviews of the final report on the SNAMP website. The peer reviews will be redacted to maintain anonymity.

The UC Science Team sincerely thanks you for reviewing our research.

REVIEWER # 1

SNAMP – CALIFORNIA SPOTTED OWL

Retrospective Analysis

The data available for the retrospective analysis is very good. However, the analysis seems very cursory given the importance of the question. Following are some questions and comments concerning how the analysis was conducted.

"We found some evidence that high-severity fire was correlated with a reduced likelihood of territory colonization, but the standard error was unestimable for the parameter coefficient, suggesting that we lacked a sufficient sample size of burned territories to draw definitive conclusions." This sounds like the authors had a model that was over-parameterized. The beta parameters should be estimable.

Site occupancy – how were sites determined? Only territories that were occupied initially are used? What about territories that were unknown until some point during the study? It seems that estimates of psi have to be biased high, because you start with all territories initially occupied. As a result, extinction is biased high, and colonization biased low. "We estimated a single center for each owl territory as the geometric mean of the most informative owl location(s) from each year that the territory was occupied. We used a nest location if one was located that year, but if we did not find a nest, we used the mean location of all roost trees located that year." What did you do if a territory was not occupied?

Page 11. "We conducted the modeling in 3 steps to reduce the number of candidate models and thus reduce the likelihood of finding spurious relationships (Table 2). In the first step, we evaluated covariates that represented the amount of potential owl nesting and roosting habitat within territories. In the second step, we used the covariates from the top-ranked model from the first step and included additional covariates for potential owl foraging habitat, amount of private land, and the spatial distribution of forest cover types. In the third step, we used the covariates from the top-ranked model in the second step and included additional covariates that represented different types of forest disturbance. By using this hierarchical approach, we were able to control for existing habitat conditions within each territory when assessing the impacts of forest disturbance. For steps 1 and 2 of our modeling, we used the entire 20-year data set. For step 3, we used the covariates from the most parsimonious models from step 2, but then used reduced data sets for the three temporal scales because we lacked timber harvest data for years prior to 1993. None of the covariates that we used were highly correlated with each other ($r > 0.60$)." AICc handles highly correlated covariates, because if you put 2 covariates with 0.99 correlation in a model, the models with each of these covariates separately will both rank higher than the 2-variable model. Further, the AICc score of the single-variable models will be nearly identical. Thus, it is not necessary to toss correlated covariates.

AIC, not AICc? Sample sizes are decent, but not so large as to assume that AICc is equivalent to AICc. Did you actually use AIC when you should have been using AICc?

No time models for apparent survival or p? How much time variation existed after time-varying covariates were used? Proportion of time variation explained by time-varying covariates? GOF generated using a fully time-specific model, so readers need to know how this full model relates to the covariate models. Both the null and global models AICc values are needed to evaluate the covariate models.

Age in apparent survival – 2 age classes?

I realize that *p* in the occupancy models is visit-specific, whereas *p* for the CJS models is year-specific. Yet, it appears considerably more analysis was done on *p* for the occupancy models, including more covariates than for the CJS models.

Sensitivity analyses were based on a uniform distribution of covariates. What about individual differences in covariate values, and more importantly, time variation in these covariates? Also, if there is a covariance between the covariates, then simulating them independently will bias the sensitivity analysis. Bootstrapping from the actual values might be a better approach.

"If we set the habitat covariates equal to their mean value for all territories, apparent survival was estimated to be 0.73, 0.66, 0.63, and 0.56 for adult males, adult females, subadult males, and subadult females, respectively." These estimates of apparent survival seem really low. Is this because the habitat variables are so skewed that the mean is not very representative? Would the median of the habitat variables provide a more typical estimate of survival?

Table 3 really needs the base model for each of the steps so that the reader can see how much improvement was made during the step. Further, the reader needs to know the value of the deviance of each model, and the saturated model's deviance, so that the proportion of the deviance explained by the individual covariates can be assessed through ANODEV. Just presenting the covariate models leaves the reader wondering whether any were better than the dot model.

No mention of goodness-of-fit is made. Was there any attempt to evaluate over-dispersion of the data?

Prospective Analysis

This analysis is pretty much out of my area of expertise. The approach seems reasonable, but I don't know how experts on these topics might take different approaches.

May 19, 2015

Review of "Sierra Nevada Adaptive Management Plan (SNAMP) - Spatial Team Final Report", dated March 15, 2015. Authors: M. Kelley and Q. Guo.

General Comments:
The objective of the Sierra Nevada Adaptive Management Project was to quantitatively assess the effects of forest fuels management practices in the Sierra Nevada Mountains on four scientific areas of inquiry: 1. fire and forest ecosystem health, 2. wildlife, specifically the California spotted owl and the Pacific fisher, 3. water quality and quantity, and 4. public participation. Four science teams were established to investigate each of these four topics. A fifth team, the Spatial Team was responsible for providing each of the science teams with digital remote sensing and mapping data, including airborne laser ranging data, digital vegetation maps, field ground-reference data, and a variety of measures and estimates derived from these airborne laser system (ALS) and optical system observations.

This reviewer's area of expertise is airborne and space laser remote sensing of forest resources, and this review specifically looks at the approaches taken by the Spatial Team to derive products useful to the 4 Science Teams. This review tries to address the following questions.
1. Did the Spatial Team provide the best available ALS products to the Science Teams?
It is important to note that this reviewer views SNAMP as an "operational" project rather than a research project. The USFS and California state agencies will, based on SNAMP findings, implement specific forest fuels management plans in the Sierra Nevadas. As such, this reviewer approaches the report assuming that the primary responsibility of the Spatial Team is to supply proven ALS measurements and estimates to the Science Teams. It is *not* the responsibility of the Spatial Team to develop and validate new, experimental, innovative techniques or measures. Did the Spatial Team provide ALS products that have been well documented in the scientific literature?

In short, the answer is yes. ALS systems measure topography (elevation, slope, aspect) and a wide variety of vegetation canopy heights and densities directly, i.e., no models need to be developed to calculate these height and density numbers once a ground surface is defined. These include many, though not all, of the height, percentile, and pulse density metrics listed in Table 1, page 16 and 17. From these measurements, a second suite of useful estimates can be derived, e.g., Lorey's height, tree volume, tree biomass, canopy base height, canopy volume.
2. The Spatial Team developed their multi-temporal ALS measures and estimates using a multi-stop ALS system. They write repeatedly in their final report that a small-footprint waveform system might have provided better results. Such waveform systems are now commercially available (e.g., www.riegl.com), but I am not convinced that the extra data load and post-processing requirements provide a significant advantage except in situations where users want to summarize vertical vegetation profiles on relatively small raster cell sizes, e.g., smaller than a 5m x 5m cell. Admittedly, my previous statement is arguable, however Skowronski et al. (2011, *Remote Sensing of Environment* 115: 703-

714) have reported some success estimating canopy bulk density and canopy fuel weight with an ALS multistop system. I suggest that the authors not characterize a small-footprint waveform system as a possible solution to multistop limitations until direct comparisons can be made. The authors may be correct, but unless you can cite a refereed study where waveform outperforms multistop as regards prediction of, for instance, forest fuels variables, e.g., canopy base height, canopy bulk density, you should not make the claim.

3. Could SNAMP have been managed better so that Spatial Team products better addressed the concerns of the four Science Teams?

3.1. Yes. The USFS should have implemented their forest fuels treatments on schedule so that the original BACI approach could have been implemented. As written, the seven year SNAMP was designed (1) to study empirically (via field sampling and remote observations) post-treatment effects over a 0-5 year time period and (2) to model post-treatment effects out to 30 years. The UC field teams started pre-treatment data collection in 2007. The fuels treatments were not done until 2011 and 2012. Only 1-2 years of post-treatment fieldwork was done The fact that the fuel treatments were delayed for 3-4 years certainly significantly impacted the 5 year empirical study and most likely impacted the long-term models. This comment is not meant to reflect badly on the Spatial Team since they most likely had little control over treatment implementation, but it does reflect poorly on overall project management.

3.2. The multitemporal ALS flights should have been timed to be seasonally coincident to improve comparability. To manage costs and logistics, SNAMP wisely took a case study approach, selecting two study areas, one in the north (Last Chance), and one south (Sugar Pine). The Last Chance ALS data collects were done in September 2008 - pre-treatment, and November 2012 and August 2013 (post-treatment). The Sugar Pine collects were done September 2007 (pre-treatment) and November 2012 (post-treatment). Both north and south sites are most likely predominantly coniferous, but if there are significant hardwood components on each area, then leaf-on / leaf-off differences pre- and post- fuels treatment will be convolved, adding noise to any comparisons made and uncertainty to any of the conclusions reached. Project managers should have insisted that multitemporal ALS data collects be done in the same month years apart, preferably leaf-on, preferably mid-summer.

4. Although the Spatial team provide rasterized products to the Science Teams at requested cell sizes, I was surprised to see that you base these raster products on individual tree delineation and measurement. I wonder why you made this choice as opposed to using an area-based approach used by Næsset and many others. The individual tree delineation numbers that I see in the literature vary from about 60 - 80%, meaning that individual trees are properly located and identified for measurement only 60-80% of the time. Understory trees and trees in closed canopy situations are typically undercounted. Somewhere in your report I would suggest that you add a paragraph that explains what you gained by delineating individual trees in the ALS data. I do not say that what you did is wrong, but your individual tree approach brought along with it a host of problems that included individual tree omission and commission errors, increased sensitivity to relatively small GPS misregistration errors in the field and in the lidar data, a more complicated field protocol that included logging locations of all individual stems

and crowns. What did you gain, and in hindsight, would you do it the same way again or make some changes such as considering an area-based approach with a minimum cell size? In your defense, I understand that at least two of your Science Teams - Wildlife and the fire fuels treatment team - would be interested in changes as regards specific individual trees, and that consideration may have drove your decision to identify and measure individual canopies.

5. Is the report clearly written? Can changes be made which might improve Spatial Team Final Report readability?

In general the report is clearly written, however the specific suggestions below should improve readability. By way of generalities, the authors should clearly draw a distinction between measured variables and estimated variables since the latter incorporate model error. Too often, the variables are muddled together in tables and text. For instance, you measure maximum height or average canopy height or various height or density deciles (or quintiles or quartiles) on a given cell by accumulating first-return and secondary-return laser ranging information as needed. You'd estimate that cell's biomass or canopy bulk density or Lorey's Height by developing an equation that relates field estimates of biomass or canopy bulk density or basal-area-weighted tree height to some subset of ALS measurements listed in the previous sentence.

Finally, define acronyms when first used. This report may be read by folks (like me) not familiar with SNAMP.

Specific Comments:

1. Should the title of this report be "Sierra Nevada Adaptive Management Project (SNAMP) - Spatial Team Final Report" (instead of Plan)?
2. pg 5. Define AGB. I realize that AGB = aboveground biomass, but is it total aboveground dry biomass, green biomass, stem only, all aboveground components including leaves/needles? Does tree volume equal stem volume to a certain top limit, or are you actually talking about the volume of space defined by the outer periphery of the tree crown?
3. pg 5. Use of Lidar for biomass estimation: You write the following:
"… the availability of, and uncertainly in, equations used to estimate tree volume allometric equations influences the accuracy with which Lidar data can predict biomass volume." Two things: First, the majority of the uncertainty associated with biomass estimation using lidar data has to do with the fact that, with ALS data, we don't know the diameter of the tree. With ALS, we estimate biomass (or stem volume, for that matter) based on height and canopy density. The primary driver in ground-based allometry is diameter, not height. The choice of allometric equation certainly makes a difference, but our inability to measure or infer dbh drives the uncertainty in ALS estimates of biomass. Second, what is biomass volume? Do you mean biomass density, i.e., biomass weight per unit area, e.g., 250 t/ha? Or biomass weight within a certain crown volume? I've worked in this field for 30+ years and have never heard the term biomass volume. Define.
4. pg 6, 2. Wildlife: I suggest that you qualify your first Wildlife bullet. Two points. First, ALS data can only be used to map potential habitat, not actual habitat. We can't measure critters, we can only identify/map areas that might make a particular critter happy if it should choose to show up in a given area. Second, we can only map potential

habitat if we can define a particular set of habitat characteristics that can be measured or estimated by the ALS, e.g., particular height, density, overstory/understory, biomass criteria.

5. pg 6, 4. Forest Management: Actually, standard lidar products do currently meet the requirements of at least some forest managers, just not, in general, public sector foresters here in the US. This might change soon if USFS managers adopt laser-assisted ground inventory procedures to inventory undersampled areas in Alaska. Scandinavian companies routinely map/inventory forests with ALS, producing stand-level volume maps for sale to private landholders, and their public sectors are actively transferring that technical know-how to selected countries in Africa, SE Asia, and South America under the auspices of U.N. REDD+ and carbon programs. Your point is correct as far as CONUS goes; just be aware that some European countries are way ahead of us when it comes to operationally using ALS data in conjunction with ancillary (e.g., optical) data.

6. pg 9, 2nd to final paragraph: As previously discussed, I'm not sure that I agree with your statement that a waveform lidar can provide a better description of forest structure. And as noted above, small-footprint waveform lidars are available and it's my understanding that some lidars can be set up as either multistop or waveform, depending on the needs of the mission. In other words, the same laser system can serve as a waveform lidar on one mission and a multistop on the next (they cannot sequentially toggle between these two modes from one pulse to the next).

7. pg 10, bottom: You write that there are no standard ALS metrics that capture forest structure. That's not really true; you list many of the "standard" variables in Table 1, specifically the height deciles and density deciles. Most of the remaining height and density variables listed in Table 1 are typically very highly correlated with these height and density deciles.

8. pg 11, 4th paragraph: Waveform lidar systems are typically sampled at 1 ns, a sampling interval that corresponds to a vertical distance of 15 cm - true. What is not true is the suggestion that this distance depends on maintaining a typical flying height. It has nothing to do with flying height and everything to do with the speed of light, ~30 cm/ns, regardless of the altitude of the aircraft.

9. pg 12, 2nd paragraph: I think that you meant to say that your Optech GEMINI collected up to 4 discrete returns per pulse. Sometimes you'd receive only a first return, sometimes 2 or 3 returns, and, I suspect only rarely, 4 returns per pulse. Perhaps you could provide a percentage breakdown of 1-, 2-, 3-, and 4-return pulses, though do this only if that information is readily available. Also report the maximum scan angle considered in your analyses, e.g., ±7.5°, ±15°.

10. pg 12: In Section 2.2, report the nominal XYZ accuracy of a given Optech pulse. Also report in 2.3.1 the XYZ accuracy of a given GPS reading.

11. Considering all error sources, can you provide an estimate of location error, ground versus ALS near the bottom of page 12?

12. pg 17, Table 1: Suggest that you identify Lorey's height as a modeled variable with a superscript, e.g., *.

13. pg 20, 5th line from bottom: change depended to dependent,
4th line from bottom: change expansive to expensive.

14. Section 4, general comment: You discuss the accuracy of many products in this section and report accuracy in Table 2. In order to assess accuracy, you need some sort of ground reference measure, i.e., a validated product that you trust more than the comparable ALS product being evaluated. In Section 4.3, you compare ground-based tree counts to ALS-derived tree counts. This is good, though I believe that you should report the range of percentage of trees under- or over-counted on each plot so that the reader gets a better feel for site variability; a scatterplot would be more informative. In Section 4.1, you conclude that the accuracy of DTM and DSM products increase with sampling density. This makes intuitive sense, but how do you know this? Did you compare the ALS DTM products to field-measured ground elevations? Did you compare, on a per-tree basis, DSM measures derived from various pulse density products to tree height measurements + ground GPS elevations? My point here is that, in each section and in Table 2, tell the reader what "truth" is and what lidar metrics specifically are compared to that ground reference information. When I look at Table 2, I see many R^2 values, but that's not really a measure of accuracy; it's a measure of percentage of variability explained by a linear model. On a per-tree basis, you can compare field-measured maximum height to the lidar maximum height for the same tree. But tell me how you're going to measure mean tree height in the field. Where is the mean height of a tree when you are on the ground looking through an angle-finder? You can't measure mean tree height in the field, though you certainly can with a laser which takes multiple height measurements on a single tree. So you move to a regression approach as you indicate in Table 2, but what are you regressing? Scatterplots would help greatly here for those comparisons denoted by "Indirect: from regression". An explicit identification of the ground reference data set would be most helpful for those ALS metrics directly compared to a reference data set. And the reader should not be forced to go to the NCALM report or references 4, 6, 24, 13, or some unnamed report yet to be submitted to find out how you assessed accuracy, or your surrogate for accuracy.

This table is the backbone or the skeleton of your report. Spend some time and column inches on it so that the reader knows explicitly what comparisons were made. It's very important that the reader knows, for instance, that some very critical measures of forest fuels cannot be reliably characterized using ALS measures.

Many of your comments made in Sections 5 and 6 have already been addressed above. As noted previously, I disagree with your statement that standard lidar products do not operationally meet the requirements of forest managers. They can, and in the future, they will. The only items currently stopping their use in the US is cost, need, and the technological intransigence of state and federal forest managers. Airborne lidars can not only tell you where the wood is and approximately how much is there, but for no additional cost will report topographic challenges of interest to forest engineers. Perhaps in 10 years, public sector forest managers will realize this and begin to come up to technical levels attained by Norwegian foresters 10 years ago.

Review of SNAMP Public Participation Team Final Report

Thank you for the opportunity to review the Sierra Nevada Adaptive Management Project (SNAMP) Public Participation Team Final Report. From the "Sierra Nevada Adaptive Management Project summary for peer reviewers," it is my understanding that the primary goal of the public participation team was to develop a model public participation process to engage stakeholders in the Forest Service planning process. The related assessment goals are to determine: (1) how much participants "learned from each other, from science, and from SNAMP outreach efforts;" (2) whether "learning changed relationships among the involved parties, and (3) if constructive channels of communication were built and used."

The Public Participation Team's final report provides a detailed overview of the SNAMP outreach efforts and the Participation Team's assessment of stakeholder learning and relationships. Summarizing the efforts of a ten year project is commendable. My comments and recommendations for the report follow.

1. First, the report addresses each of the three assessment goals noted above, as well as the five goals outlined in the report's introduction – transparency, inclusiveness, learning, relationship building, and effectiveness. The executive summary addresses the first two goals noted in the peer review summary but does not clearly address if "constructive channels of communication were built and used. It also does not clearly address the last goal identified in the report - "effectiveness." It would be helpful to add a sentence or two describing how these goals were met in the executive summary.

2. In my first read-through of the report I found it difficult to follow how it was organized. The first part of the executive summary provides a brief overview of the goals and the findings of the participation team. I recommend clarifying the statement of purpose for SNAMP and the Public Participation Team in the first paragraph of the executive summary. After an initial overview of the purpose and goals, provide a brief summary of the accomplishments and evaluation. I suggest devoting just one paragraph describing how the report is organized, similar to (or copying) what is written in the introduction on page 12, rather than having it

interspersed over several pages. Much of the information on pages 3 to 6 could be incorporated into the introduction or deleted.

3. The introduction does a nice job of providing a brief history of the project while also identifying the goals and activities of the Public Participation Team. You might consider identifying or listing the six other teams involved in the SNAMP to provide context for people who only read this section of the report.

4. For Section II, as a literature review and background, there should be a substantial increase in the use of citations throughout the section; some paragraphs have only one citation yet refer to many conclusions. It is important to also include page numbers for direct quotes in your citations. Also consider creating adding a sub-heading on page 20 before the second paragraph beginning with, "Concerns of the California Resource Agency…" because these paragraphs introduce the specific context for the SNAMP case. Another option would be to re-organize so the background on decision-making processes and constraints to co-management are at the beginning of this section, with no references to SNAMP. This would be followed with a subsection discussing SNAMP and how it provides a new approach within the previous context.

5. Also in Section II, I like the use of Figure F-3 to identify different management approaches over time. It appears the second model in Figure F-3 is not summarized explicitly in the text and this would be helpful for readers to understand how the shift in decision-making was affected by NEPA, litigation, FACA, and other factors mentioned, as well as the challenges which led to the development of the third model.

6. I found Sections III provides a good summary to the public participation process used by SNAMP. I am curious about the annual meeting evaluations reported on page 33 – is what you report the average across all fourteen annual meeting evaluations? It would be helpful to know if there was any significant change in responses over time for the annual meetings, as well as for the integration meetings (page 35), field trips (page 37), and management workshops (page 39). The format used to report the evaluations differs across these meeting types and it would be helpful to report using the same format as was used for the annual

meeting (i.e. include the number of evaluations completed and the rating scale). Also report evaluations of the special projects or mention if there were no evaluations for these projects.

7. In Section III you provide a detailed summary for the in-person meetings but not the distance outreach. It would be helpful to know how the distance learning affected transparency, information exchange, and relationship-building, as was written for the in-person outreach.

8. Section IV does a very nice job of outlining the development of the SNAMP collaboration workbook and workshops. I am curious if there were any significant differences (using a paired samples t-test) in the pre- and post-workshop surveys? It would be helpful to identify significant differences in Table F-5, as well as in the text.

9. Section V summarizes the assessment of the process very thoroughly. My primary concerns relate to the methods and reporting of the email surveys.
   First, does the population of email contacts maintained by Extension adequately represent all stakeholders? It is noted that the email contacts "represent the community of interest in Sierran forest management that wanted to maintain email contact," but do the respondents represent the full population of stakeholders? It would be good to know if a non-response bias check indicated whether those who did not respond differed from those who had responded.
   Second, it would be helpful to state why Chi-square statistics were used to compare results from 2010 and 2014, rather than a paired-sample t-test. The independent samples t-test, or paired samples t-test where applicable, provides a better assessment of differences or similarities across the two years of surveys.
   Third, for the interview and email demographics you provide the range for ages and income levels; it would be helpful to have the averages/means for these demographics. Also consider using the same format for the interview and email demographic descriptions so that it is easier for the reader to compare across populations.
   Fourth, rather than mentioning the *p*-value throughout your results and discussion you can state in the methods section that a significance value of *p*.05 was used.

10. Section VI provides a nice in-depth overview of learning that occurred with the concept of forest health. One suggestion to improve the readability of this section is to combine the description of the four themes with the description of their evolution over time rather than having the description of the theme as a separate sub-section from the evolution. If you prefer keeping these descriptions separate it would be helpful to have them in the same order for both sub-sections.

11. Section VII summarizes the achievements and challenges of the project. It identifies how participant learning occurred and how participants believed the process had reduced conflict, indicating constructive channels of communication were developed. One suggestion for this section is to provide more detail at the end of the first paragraph on the percentage of respondents who felt "part of the project" and who valued the learning opportunities, etc. Otherwise this section provides a nice summary and Section VIII provides a good compilation of the lessons learned from throughout the report.

12. Lastly, there were several formatting and grammatical issues throughout the report.
    - Many of the tables were split across pages making them difficult to read (e.g. Table F-3). I suggest moving tables so they fit on one page; if too large for one page continue the heading across pages and try not to split text that is in one cell). Some tables were also split from their headings which also creates confusion for the reader (e.g. Table F-1).
    - Indented sub-headings should be formatted (i.e. italicized or underlined) so they stand out from the text more distinctly.
    - Many of the legends used for figures are difficult to read when printed in black and white (e.g. Figure F-17). I recommend switching the legend from vertical layering to horizontal layering (e.g. Figure F-26) so the legend matches the layout in the figure. Or change the color scheme so it is identifiable in black and white.
    - Also, check that all abbreviations are defined at first mention in the chapter or appendix and used consistently throughout the report.
    - Check the wording and the order of the headings and sub-headings are consistent across different areas of the report. For example, the heading – "SNAMP distance outreach summary" (page 60) differs from the format for the in-person outreach on page 41.

- There are several grammatical instances where punctuation is outside quotations rather than inside, e.g. text”. instead of text.” Search and replace can quickly fix this.

Thank you for the opportunity to review your report and learn more about the SNAMP project!

Thank you for the opportunity to review the SNAMP Fisher project report. I found this report to be very well written and it contained a remarkable abundance of valuable new information on the biology and ecology of fishers. In concluding my review of the document, I will provide my overarching comments in this letter and I have attached my marginal editorial comments in the attached pdf of the report. Thank you again for the opportunity to review this report.

Major Comments

As mentioned above, this report and the associated publications will provided valuable new additions to the fisher literature and will certainly provide needed information for fisher conservation in California and elsewhere.

The findings in the report demonstrated that the research was effective at addressing the first two objectives of the research project. Meeting the third objective of the project was apparently complicated by the delayed or incomplete implementation of SPLATs in portions of the study area. The complications of SPLAT implementation apparently made it difficult to conduct the before and after comparisons that were originally envisioned for the research project. I had expected to see specific demographic and land use measures for fishers before and after SPLAT implementation, but those data were not presented. I am hopeful that further research will allow for those comparisons to be made. I think they could be important for fisher conservation in California.

While the details of before and after response data were not available, this research project did use a number of useful measures to assess population responses across a large portion of the fisher's range in the southern Sierra Nevada. Further these measures will be useful for assessing fisher occupancy and population performance in other areas of the fisher's west coast range.

Other Comments

I think it will be important to make sure you keep the reader aware of any differences that might exist between annual survival rates, mean annual survival rates, and 2-year survival rates (survival over a 2-year period). I was not sure if a 2-year survival rate meant an average of 2 annual survival rates or if it meant the product of 2 annual survival rates or something else.

I was surprised to see how large the home range sizes were for the fishers in your study area. Not having the home range sizes for other CA fisher populations committed to memory, I wondered if they were comparable to those in your study area or if they were considerably smaller. I ask because I wondered if there was some ecological phenomenon that exists at the northern extent of the SSN fisher population (your study area) that results in fishers using larger home ranges at this margin of their range. Generally larger home ranges imply lower habitat quality for the species in question.

I also wanted to mention several wording change suggestions that I think would help with clarifying the message to the reader:

- You use the term grid to describe what other researchers refer to as grid cells. I am used to the term grid cells and would recommend using that term and referring to the collection of grid cells as the grid.
- You interchangeably use Camera Years and Camera Survey Years to define the timing of camera survey efforts. I think Camera Survey Years is the best term to use.
- You interchangeably use the words gender and sex. I have recently been warned off using the term gender (a behavior role) because it differs from sex (anatomy) and it is most commonly used when describing humans.
- Also, I noticed that the spacing between sentences was inconsistent

Lastly, I made a number of smaller comments in the text and in the tables and figures that could be hard to see, so I wanted to make you aware of those so they weren't overlooked.

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SIERRA NEVADA ADAPTIVE MANAGEMENT PLAN (SNAMP)

Appendix D: Fisher Team Final Report

3 May 2015

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i. Executive Summary

Illustration 1: Image of an adult female fisher on a den tree in spring 2009.

Fishers (*Pekania pennanti*) are a medium-sized mammalian carnivore with a pre-European distribution encompassing the boreal forest zone of Canada, the Great Lakes region and northeastern United States, a relatively limited portion of the Rocky Mountains in the United States, and mountainous areas of Washington, Oregon, and California, USA (Powell 1993). Ecologically, fishers are a mature or old forest-obligate species (Zielinski et al. 2005), and in central to eastern Canada and the northeastern United States their numbers were reduced historically by the combination of intensive trapping and loss of forest habitats (Powell and Zielinski 1994). The species is uncommon to rare in the western United States, and is a candidate for listing under the US Endangered Species Act. The California Department of Fish and Wildlife (CDFW) is reviewing the status of fishers in the state, with recommendations concerning listing to the Commission expected in 2014. In advance of listing decisions, conservation planning has been underway since 2013 to develop an approach to maintaining viable populations of fishers in both northwestern California and in the southern Sierra Nevada. Information from the SNAMP Fisher Project (published manuscripts, submitted manuscripts, and unpublished data) described herein has been included in a Southern Sierra Nevada Fisher Conservation Assessment developed by the Conservation Biology Institute, with input from a team of 13 fisher researchers and scientists.

The SNAMP Fisher Project was initiated by the UC Berkeley Fisher Science Team in Fall 2007 in association with multiple other SNAMP research programs designed to provide an independent evaluation of how vegetation management, prescribed by the 2004 Sierra Nevada Forest Plan Amendment, affects fire risk, wildlife, forest health and water. Fuel reduction management includes a mix of activities including mechanical mastication of shrubs and small trees, hand thinning/precommercial thinning, commercial thinning, and controlled burning.

Illustration 2: Fuel reduction management treatments observed in the SNAMP Fisher Study area; *mastication/mowing, control burning, commercial thinning*

The range and number of fishers in the Sierra Nevada declined by over 50% after the early 1900s (Spencer et al. 2014). A major goal of the SNAMP Fisher Project was to determine whether or not current rates of survival and reproduction will allow fishers to persist in the Sierra Nevada in the context of active forest management to reduce fuels and the risk of catastrophic wildfire. Toward this end, in October 2007 the SNAMP Fisher Team initiated fieldwork by placement of survey cameras (camera traps; O'Connel et al. 2011) in the focal study area referred to as the four "Key Watersheds" (Nelder Creek, Sugar Pine, White Chief, Rainier Creek) where the Before-After-Control-Impact (BACI) design for the larger SNAMP research would be centered. Based on information provided by the Bass Lake Ranger District of the Sierra National Forest, three different fuel reduction projects were planned during the course of the study: Sugar Pine (main focus of SNAMP), Cedar Valley (started in fall/winter 2007-08), and Fish Camp (started in 2010-11). Our approach for assessing how fishers would respond to Strategically Placed Landscape Area Treatments (SPLATs) was designed to be multifaceted including (1) life history responses to fuels reduction (changes in survival, reproduction/fecundity, lifespan), (2) changes in local scale habitat use within individual home ranges, and (3) shifts or changes in habitat use at the home range scale of animal resource use/resource selection. The research required capturing, radiocollaring, and monitoring multiple individual fishers, which were monitored using high intensity aerial radiotelemetry to identify deaths and quickly recover carcasses for necropsy, and repeated camera surveys within and around the Key Watersheds. Specific objectives included:

1. *Determination of all key demographic parameters including age- and sex-specific survival, reproductive rates, and fecundity, and metrics on dispersal and movements*
2. *Identify population limiting factors based on cause-specific mortality due to*

predation, disease, and human-linked factors such as roadkill on local highways

3. *Evaluate the effects of SPLATS on occupancy, survival, and fecundity*

The SNAMP Fisher Project study area is at the northern edge of the southern distribution of fishers in California, encompassing the area bounded by the Merced River in the north and the San Joaquin River in the south. Administratively, the study area was within the Bass Lake Ranger District in the Sierra National Forest, but early in the study a radio-collared fisher dispersed north into Yosemite National Park, which effectively expanded the research to encompass the southern area of Yosemite National Park. The overall study area encompassed approximately 1300 km^2 of a topographically complex landscape with elevations ranging from 758 m to 2652 m. The smaller focal study area (Key Watersheds) was located in the approximate center of the study area, and the Key Watersheds entirely encompassed the firesheds designated for the SNAMP BACI research design.

A range of standard methods were used in the study to live-trap, radiocollar and monitor survival status of individual fishers. Monitoring was accomplished almost entirely by fixed-wing aerial radiotelemetry, supported by an "in house" aviation program developed specifically for SNAMP Fisher and administered by the USDA Forest Service. Ground-based radiotelemetry was used to monitor female fishers during denning seasons, and to recover carcasses of deceased fishers. Camera traps were systematically placed in the Key Watersheds and elsewhere in the study near the center points of 1-km^2 grids. Camera traps in the Key Watersheds were surveyed for fisher activity in each year of the study, whereas those placed elsewhere were not (some of the "external Key Watershed" grids were surveyed in multiple years when other forest management projects had occurred). Three "Management Indicators" were developed and assessed annually to provide stakeholders and managers with information on the status of the fisher population in the study area. The indicators were designed to link to local, home range, and landscape scale responses by fishers to forest management activities occurring in the Bass Lake Ranger District. We also developed five different focused research efforts related to fisher ecology considered relevant for fisher management and conservation. These "Focused Research Topics" related to the use of camera traps for identifying gender of fishers, evaluating fisher activity patterns, and evaluating the distribution of several forest carnivores in relation to roads or other species. One of the focused research topics addressed roadkill mortalities of fishers on a major highway (Highway 41) that bisected the study area.

Surveys with camera traps were completed in 905 unique 1-km^2 grids throughout the overall study area, including 56 grids within the southern region of Yosemite National Park from a companion study funded by the California Department of Fish and Wildlife. Fishers were detected in 448 of the unique grids surveyed, which helped to identify that fishers in this part of the southern Sierra Nevada were most common between 4500 and 6500 feet elevation (1372 and 1981 m elevation). Occupancy estimates for multi-year surveyed grids corrected for imperfect detection < 1.0 ranged from 0.62 to 0.80. Detection rates for fishers at camera trap stations were much higher in the fall, winter, and spring seasons compared to summer, likely due to availability of a more abundant and diverse prey base in summer compared to winter especially.

A total 110 individual fishers were captured and radiocollared Project from Dec 2007 to Dec 2013 (62 females, 48 males). Sixty-six (60%) of the 110 individual fishers radiocollared during the study were known to have died, including 32 females and 34 males. On average 10.5 radiocollared fishers died in each population year over the course of the study, and the most common cause of death was predation by felid carnivores (bobcats, *Lynx rufus*, and mountain lions, *Puma concolor*). Four deaths were caused by, or associated with, canine distemper virus in 2009 when a relatively small scale epizootic event occurred in the study area. Other disease deaths included Toxoplasmosis and septicemia. Septicemia-linked deaths were caused by injuries the animals suffered weeks or months before death that led to infection that sometimes contributed to starvation/emaciation. Two radiocollared fisher deaths were roadkills on Highway 41. Four others were directly linked to anticoagulant rodenticides being used in association with illegal marijuana grow sites in the Sierra National Forest, and a fifth mortality is suspected yet currently unconfirmed.

The SNAMP Fisher study generated information on all key vital rates needed to evaluate the population growth rate (λ) and for understanding whether the population has the potential to persist. We developed an age-structured matrix model to estimate a series of five deterministic population growth rates (λ) for the SNAMP Fisher study population using the observed, “empirical” data on denning rates and litter sizes (fecundity), and survival. Estimates of survival and fecundity were produced for five 2-year groups/pairs of years starting with population years 2008-09 and 2009-10 and ending with 2012-13 and 2013-14. The Leslie-matrix population model was used to integrate data on fisher survival for three age classes, and fecundity for four female age classes: juveniles and subadults (non-reproductive), and young and mature adults (reproductive). Estimates for λ for the SNAMP Fisher study area were below 1.0 in two 2-year groups (population decline), equal to 1.0 in one 2-year group (stable), and slightly positive in two 2-year groups (increasing population). Lambda across all years was 0.90, which was suggestive of general population decline, however, the annual and cumulative 95% confidence intervals all overlapped with 1.0.

Prior to the SNAMP Fisher study there was limited information on the distribution and abundance of fishers at the north margin of their extant southern range. Many years of survey-based research with cameras and track plates conducted by the US Forest Service Region 5 and the Pacific Southwest Research Station suggested that the population in the SNAMP Fisher study area was likely sparse (low density), and there had been no indication that "surplus animals" were dispersing northward into suitable, unoccupied habitat north of the Merced River in Yosemite Valley. We used resightings of individual radiocollared fishers in a Robust Design capture-mark-resight framework (CMR) to estimate the fisher population size and density in the overall SNAMP Fisher study area. The SNAMP Fisher study area corresponds to the "Fisher Habitat and Core Connectivity area 5" being used for conservation planning. Fisher population size ranged from 48.2 in 2010 to 61.8 in 2012, whereas mean population density ranged between 0.072 fishers/km^2 in 2010 and 0.093 fishers/km^2 in 2012. We considered data from other studies in California and elsewhere that used CMR methods similar to ours, and determined that the population density for fishers in the SNAMP study area was the lowest reported for the continental United States. Also, and in support of conservation planning, we used the mean density from the study to estimate that there were 93 fishers (range 80-107) in the Southern Sierra Nevada Habitat Core and Connectivity area 5.

Den cameras used in association with ground-based monitoring provided detailed information on the activities of 32 different individual adult female fishers during six spring denning seasons. Denning and reproduction in the SNAMP Fisher study area typically began in the last week of March, and adult female fishers ceased regular use of den trees in the first week of June. The earliest and latest known regular use of den trees was March 22, and June 20, respectively. Seventy-six (85%) breeding-age female fishers either exhibited denning behavior (n = 63) or were determined to have denned and weaned at least 1 kit. Among the 76 breeding-age females that initiated denning, 64 (84%) were identified as weaning kits. Overall, 72% of adult female fishers for which reproductive status was known produced at least 1 weaned kit. Eleven (17.5 %) of 63 cases of denning for females that were monitored during spring periods failed prior to kits being weaned. Eight den failures were due to death of the denning female; 7 denning females were killed by predators and 1 died after exposure to rodenticides. We were able to determine litter size for 48 of 59 denning females. A total of 73 kits were known produced, with an average litter size of 1.5. After accounting for known mortalities, we estimated that 64 of the 73 kits produced were weaned from den trees, whereas seven kits died or would have died had they not been rescued.

The availability of suitable den structures is a critical, and potentially limiting, feature of fisher habitat The mean number of den trees used per female per denning season was 2.4 (range 1 to 5). We identified 125 unique structures used as natal or maternal dens, including 54 black oak trees, 41 incense cedar trees, 19 white fir trees, 10 sugar pine or ponderosa pine trees, and one canyon oak (*Quercus chrysolepsis*). We discovered that repeat use of den trees was not uncommon. Sixteen individual den trees were used more than once; 15 trees were used in two years, and one tree was used in four different den seasons. In most cases of repeat den tree use the same individual reused one or several den trees between successive years, but in two cases a female used a den that had been used by a different female in a previous year. Fifty-six percent of the unique individual trees used for denning in the SNAMP area were live trees (*n* = 70), whereas 44% (*n* = 55) were snags. Black oak was the most common tree species used for denning (live or snag; 43%), but a high percent of incense cedar were also used for denning (33%). Among snags used as denning structures, black oak and incense cedar were both commonly used (18% each), whereas white fir and pines (sugar pine or ponderosa pine) were less common as snag-type den trees (4% each). Overall mean DBH of black oak denning structures was 74.4 cm, 115.6 cm for incense cedar, 108.3 cm for white fir, and 111.2 cm for the two large pine species (sugar pine and ponderosa pine; Table 18). Mean heights of live trees were taller for live trees compared to snags of the same species, reflecting that many of the snags used for denning were at advanced stages of decay. The majority of denning structures used in the SNAMP Fisher study area (83%) were in the elevation range 4500 feet (1371 m) to 6000 feet (1829 m), and denning structures were typically embedded in areas of high canopy cover (mean = 72%). Shrub cover and aspect near den trees was variable, and most den trees had multiple large down trees/logs nearby, whereas concealment cover to the base of den trees averaged more than 45%. Also, information on denning habitats near den trees from high resolution Lidar (Zhao et al. 2012) identified that fishers selected den sites with tall trees and steep slopes within a 10-m radius of the den tree, and denning areas were associated with high levels of forest structural complexity and clusters of multiple large trees within 30-50 m.

Dispersal behavior by fishers is of high management interest in California because the southern Sierra Nevada population does not appear to be expanding geographically despite changes in management promoting restoration of suitable fisher habitat. Also, dispersal movements by fishers are potentially inhibited by exposure to multiple restrictive habitat elements (burned forests) and landscape features (steep river canyons). The SNAMP Fisher Project used a combination of data on juvenile and adult home ranges, and maternity assignments based on microsatellite DNA analyses to assess natal dispersal by young fishers based on Euclidean distance between natal areas and subadult or adult home ranges. We also applied an "expert" cost surface to the landscape, and used Least Cost modeling approaches to predict more realistic dispersal paths/distances based on presence of restrictive habitat or landscape elements considered aversive to fisher movement and life history. The combination of field (juvenile home ranges) and genetic data (maternal assignments) allowed us to assess dispersal for 43 (74%) of 58 juvenile or young subadult fishers in the study population. The average Euclidean distance natal dispersal for female fishers was 5.8 km, compared to 9.8 km for male fishers. The longest Euclidean distance dispersal for a female fisher was 24.5 km, compared to 36.2 km for a male fisher. Although male fishers tended to disperse longer distances than females, the difference was not significant. One male fisher from the Kings River Fisher Project on the High Sierra District of the Sierra National Forest moved across the San Joaquin River canyon and immigrated into the SNAMP Fisher Study area. The Euclidean distance for this dispersal movement was over 36 km, but the more likely Least Cost dispersal path was predicted in the range of 67-69 km. In general, we found very limited evidence for male-biased natal dispersal according to any of the typical metrics reported in the literature for this life history phenomenon. Dispersal distances were not longer for males compared to females based on either Euclidean distances or more realistic Least Cost movement paths, and there was no difference in the proportion of each gender that dispersed, or that remained philopatric. Timing of dispersal was focused during mid-February into July when 80% of dispersal events were initiated and subsequently completed.

Management indicator 1 (occupancy/presence of fisher detections in 1-km^2 grids within the Key Watersheds), ranged from a low of 53% in 2012-13 to a high of 76% in 2011-12 (mean: 62 ± 9.2%). An index of fisher activity developed for Management Indicator 1 indicated that the estimated detection rate (detections/100 camera survey days) ranged from 10.5 in 2010-11 to 18.6 in 2012-13 (mean: 13.9 ± 2.9). Camera year 2012-13 was atypical in that many grids in the Key Watershed were surveyed during summer when detection rates are significantly lower compared to fall and winter, and it was therefore possible that the low detection rate for 2012-13 was related to timing of surveys.

Management Indicator 2 (number of resident subadult and adult fishers using the Key Watersheds) identified an overall average of 5.0 subadult or adult females and 2.0 subadult or adult males using the Key Watershed focal study area. For both sexes, the number of resident fishers using the focal study area ranged from 6.2 to 7.7, and the variation among years was minor.

Management Indicator 3 (adult female survival in the study population): For this report we expanded the original Management Indicator 3 to estimate survival for adult female fishers for a sequence of 2-year groups of demographic data and included results for juvenile and subadult females, and estimated population growth rates. Adult female survival ranged from a low of 0.69 in Year group 3 to a high of 0.86 in Year group 4. Relatively low levels of survival and reproduction suggested the population was in decline ($\lambda < 1.0$) between 2008 and 2010, stable between 2010 and 2012 ($\lambda \approx 1.0$), and increasing by 3-4%/year during 2012 to 2014 ($\lambda = 1.04$ and 1.03, respectively).

Occupancy modelling indicated that fishers reduced their use of forest patches exposed to higher levels of restorative fuel reduction; i.e. persistence of occupancy declined with additional acreage treated for fire resiliency. However neither restorative nor extractive (i.e. commercial thinning) fuel reduction was related to either initial probability of occupancy or local extinction. This pattern is likely due to interaction of several factors. First, the overall spatial scale of treatments, both restorative and extractive, is relatively small compared to a fisher's home range. Second, evidence indicates that fishers simply shift their space use patterns to avoid small treated areas. And third, evidence indicates that the reduction of surface and ladder fuels may change the small mammal community, therefore limiting fisher prey availability.

We found that SPLATs caused an immediate 6% reduction in potential fisher habitat. However they also moderated the impact of fire, resulting in greater available fisher habitat within 30 years. In the absence of simulated fire, the amount of habitat steadily increased over time due to forest succession, and was actually slightly greater on the treated landscape in year 30 than in year 0. The net benefits of SPLATs for the Pacific fisher will depend upon the true, but unknown, probability that high-severity fire effects will occur on a given portion of the landscape. However, future probabilities for specific fire behaviors (e.g., crown-fire initiation) are difficult to estimate, and it is therefore difficult to quantify trade-offs associated with SPLATs in absolute terms (Finney 2005). We further note that the SPLATs which were implemented at Sugar Pine appeared to have relatively modest impacts on forest structure and simulated fire behavior, and that it may be necessary to evaluate additional SPLATs of different intensities over a larger scale to fully assess the effects of SPLATs on fisher habitat.

Fishers have been the focus of systematic monitoring in the southern Sierra Nevada since the mid-1990s. Recent analyses of baited track plate detection histories from 2002 to 2009 found no evidence that the population trajectory for fishers in the area has been significantly positive or negative, based on constant and positive persistent values (Zielinski et al. 2013). In contrast, recent genetics research suggests that the fisher population in the SNAMP Fisher study area was produced by a significant post-1990s population expansion involving dispersal of animals from south of the Kings River (Fisher Core Habitat Area 4) (Tucker et al. 2014). However genetic data are not typically used to make inferences about population processes over extremely short periods in evolutionary time, and an expansion of such magnitude (approx. 30% range increase) would require a significantly positive population growth rate.

The combination of an overall negative population growth rate and the relatively small estimated number of fishers in Fisher Core Habitat area 5 (*n* = 93, range 80-107), warrants concern for the long term viability of the fishers in the region. Any small population will be at high risk to stochastic events such as disease and large perturbations to critical habitats (e.g. forest fires or drought; Noss et al. 2006), and genetic limitation resulting from genetic drift after founder events (Tucker et al. 2014) will hinder population recovery and expansion (Reed et al. 2003). Minimum viable population size has been under debate (Shoemaker et al. 2013, Reed and McCoy 2014), but at <500 individuals (Spencer et al. 2014), the current southern Sierra Nevada fisher population will likely require active management and conservation measures to maintain a positive growth rate across its entire range. The estimated population growth rate in the SNAMP Fisher study area reaffirms the vulnerability of the small, isolated population to external threats (Spencer et al. 2014), especially wildfires that are likely to increase in frequency and intensity with climate change. Moreover, the SNAMP Fisher study spanned a limited period of six years during which multiple novel threats to fisher survival within the study area were identified, and when three large wildfires significantly reduced availability of suitable habitat for fishers immediately to the south and north of the study site. We recommend continuous monitoring of the status of fisher populations in the southern Sierra Nevada region. Development of ways to mitigate for major threats to fisher survival and fisher habitats and population viability analyses are necessary for evaluating the long-term prospects for fishers in the southern Sierra Nevada. Data from the SNAMP Fisher study have provided important new insights on the status of a fisher population at the north margin of their current distribution in the southern Sierra Nevada Range, which will be useful towards developing a comprehensive conservation strategy for fishers in California.

LIST OF TABLES (shortened titles)

Table 1. Major recent and ongoing field studies focused on the distribution, population biology and habitat use/requirements for fisher populations in California.

Table 2. Details and characteristics of Southern Sierra Nevada Fisher Conservation Assessment area "Fisher Core Habitat areas."

Table 3. Description of different types of locations for fishers during the study period from December 2007 to December 2013. Data are for research in the Bass Lake District, Sierra National Forest, CA.

Table 4. Overview of potential negative effects of fuel reduction treatments and other forest management activities on the biology and natural history of fishers.

Table 5. Body measurements taken during fisher captures and from suitable camera images.

Table 6. Data on existing culverts that were identified and measured along Highway 41 in the Sierra National Forest, California.

Table 7. Radiocollared fishers with home ranges overlapping Highway 41 in the Sierra National Forest.

Table 8. Summary data on numbers of trap nights, new fishers captured, and recaptures for the SNAMP Fisher Project from December 2007 to December 2013.

Table 9. Number of radiocollared fishers being monitored for the SNAMP Fisher Project at the start and end of six different population years.

Table 10. Number of $1km^2$ grids surveyed with camera traps by camera survey year (Oct 15 to Oct 14).

Table 11. Summary data on the number of camera days for all camera traps used to survey for fishers (effort), and the number of fisher visits during each camera survey year (~Oct 15 to Oct 14).

Table 12. Fisher visits to survey cameras and camera effort by season from October 2007 to October 2013.

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Introduction

Fishers are a medium-sized mammal carnivore with a pre-European distribution encompassing the boreal forest zone of Canada, the Great Lakes region and northeastern United States, a relatively limited portion of the Rocky Mountains in the United States, and mountainous areas of Washington, Oregon, and California, USA (Powell 1993). Ecologically, fishers are a mature or old forest-obligate species (Zielinski et al. 2005), and in central to eastern Canada and the northeastern United States their numbers were reduced historically by the combination of intensive trapping and loss of forest habitats. Although fishers have recovered portions of their former range in this region aided by reintroductions and more sustainable levels of timber harvest (Lewis et al. 2012, Powell et al. 2003), they remain uncommon to rare in the western states and provinces of the USA and Canada (Lofroth et al. 2010).

The fisher of the US Pacific states, or the West Coast Population Segment, is a candidate for listing under the US Endangered Species Act and is the target of recovery and conservation efforts (Lewis et al. 2012). The US Fish and Wildlife Service (USFWS) is under court order to make a proposal to list (or not) the West Coast population by September 2014 and to make a final decision to list, if proposed, by September 2015 (Center for Biological Diversity 2013). The fisher is also a candidate for listing under the California Endangered Species Act pursuant to a 2012 court order that compelled the California Fish and Game Commission to set aside its 2010 finding that listing was not warranted (Center for Biological Diversity v. California Fish and Game Commission et al. 2012). The California Department of Fish and Wildlife (CDFW) is reviewing the status of fishers in the state pursuant to the court order, with recommendations concerning listing to the Commission expected in 2014 (Spencer et al. 2014).

In the west coast states of the USA fishers currently exist in three remnant populations in southern Oregon, northern California, and the southern Sierra Nevada, California (Zielinski et al. 2005). In California the fisher occupies less than half of its historical range as described by Grinnell in the early 1900s (Grinnell et al. 1937). The decline in range extent and abundance of fishers in California into 2 remnant populations geographically separated by around 400 km had been considered due to widespread timber harvest and fur trapping during the early to mid-1900s (Zielinski et al. 2005), but recent genetic research suggests that the northern California and southern Sierra Nevada populations may have been genetically isolated prior to European settlement (Tucker et al. 2012). Notwithstanding uncertainty regarding the timing or cause of the range retraction, there may be fewer than 500 total fishers in the southern Sierra Nevada population (Spencer et al. 2011), where the species currently occupies approximately 4,400 km^2 of mid-elevation, mixed-coniferous forest (Spencer et al.

2014). While fishers in the western US are considered at risk of extirpation from disease and other factors (Lofroth et al. 2010; Spencer et al. 2014), the recent reintroduction of fishers at one site in Washington state and another in northern California is promising for maintaining the species.

Fisher Range Size and Trends

Grinnell et al. (1937) described the original range of the fisher in California as including the entire western slope of the Sierra Nevada, the southern Cascades, Klamath Mountains, and northern Coast Range, a total area of ~100,000-110,000 km^2 (Spencer et al. 2014). Lofroth et al. (2010) estimated that the current range of the fisher in California represents <50 percent of the historical range, and fishers are currently absent from most of the northern and central Sierra Nevada, leaving a ~400-km gap separating the two populations in the state (Zielinski et al. 1995) (Fig. 1), one in the northern Coast Range and one in the southern Sierra Nevada (Spencer et al. 2014). Recent analysis suggests that these two population regions may have been genetically isolated prior to European

Figure 1. Current estimated distribution of fisher habitat in California, and location of major fisher field studies (Table 1 provides details on the field studies). Current distribution based on minimum convex polygon enclosing recent (>1970) fisher locality points from a comprehensive USFWS fisher locality database; map and methods used to produce the distribution boundaries are described in the Southern Sierra Nevada Fisher Conservation Assessment (Spencer et al. 2014). Question marks illustrate uncertainty on the degree to which eastern and northern portions of historical range were actually occupied.

Illustration 3: Camera trap image of a female fisher from SNAMP.

Map source: *Spencer et al. 2014*

settlement of California (Knaus et al. 2011, Tucker et al. 2012). Spencer and Zielinski (in review) used an updated fisher locality database to estimate their current geographic range in California at 55,000-60,000 km^2, with ~45,000-50,000 km^2 in northern California and 10,000-12,000 km^2 in the southern Sierra Nevada. Although the range areas estimated by Spencer and Zielinski (In review) included a mix of suitable and unsuitable habitats, the analysis suggested a 30-50 percent reduction compared to the historical range of the species. Caveats included that there is uncertainty about how wide "the gap" was historically, and how much of the mid elevation forest areas in the northern and central Sierra Nevada were actually occupied (Spencer et al. 2014).

Table 1. Major recent and ongoing field studies focused on the distribution, population biology and habitat use/requirements for fisher populations in California.

Study name	Location	Period	Brief description of research focus
Sierra Nevada Adaptive Management Project (SNAMP Fisher)	Bass Lake Ranger District, Sierra National Forest	2007-2013	Comprehensive study; population biology, space use, responses to vegetation management
USFS PSW Kings River Fisher Project (KRFP)	High Sierra Ranger District, Sierra National Forest	2007-2018	Comprehensive study; population biology, space use, responses to vegetation management
USFS PSW Sugar Pine Fisher Project (SPFP)	Bass Lake Ranger District, Sierra National Forest	2014-2016	Continuation of the SNAMP fisher research effort to document post-treatment population status.
USFS PSW Fisher Regional Monitoring Program (Regional monitoring)	National Forests in the southern Sierra Nevada: Stanislaus, Sierra, Sequoia, Inyo	2002-present	Landscape-level occupancy monitoring
Southern Sierra Fisher and Marten Study (SSN fisher and Marten)	Tule River Ranger District, Sequoia National Forest, Tule River Indian Reservation	1994-1996	Comparative study; marten and fisher home range, habitats, diets, and interspecific competition
California Department of Fish and Wildlife Fisher Translocation (Stirling translocation)	Stirling Management Area of Sierra Pacific Industries, Butte, Tehama counties	2009-present	Monitoring of introduced fishers; population biology, habitat and space use
Hoopa Valley Fisher Study (Hoopa Study)	Hoopa Valley Indian Reservation, Humboldt County	2004-present	Comprehensive study; population biology, space use, responses to vegetation management

Population Size and Trends

The southern Sierra Nevada fisher population is small (≈500 total individuals and <300 adult fishers; Spencer et al. 2011), but appears to be stable over about the past decade (Zielinski et al. 2013). Following substantial population contractions in the past (Knaus et al., 2012), fishers in this part of California may have expanded in the late 20th century (Tucker et al. 2014). The overall distribution of fisher in the southern Sierra Nevada has been monitored by a mix of track plates and motion detecting cameras since the mid-1990s (Truex et al. 1998, Zielinski et at al. 2005, Jordan 2007). Zielinski et al. (2013) analyzed occupancy records from this effort for the period 2002 to 2012, when a systematic survey design was in place, and found no detectable change in occupancy for the entire area or for any of the three subareas examined (Zielinski et al. 2013). The Zielinski et al. (2013) analyses suggest that despite fishers being protected from fur harvest for over 60 years during a time when large scale clearing of forest habitat was diminished (Collins et al. 2010), this population isolate is not showing significant evidence of numeric or spatial recovery. However, genetic patterns and survey data suggest that the population north of the Kings River may have expanded during the 1990s, before the regional monitoring program was established (Tucker et al. 2014).

Insight from prior research in the High Sierra District, Sierra National Forest (KRFP study, ≈60 Km southeast of the Key Watersheds) suggests that fisher population densities range from 0.07 to 0.28 fishers/km^2 (Jordan et al. 2011, Thompson et al. 2012). Records from research in northern California (Hoopa Study) indicate the potential for fisher densities to change rapidly. In the Hoopa Valley area of Northern California, fisher densities were estimated at 0.52 fishers/km^2 in 1998, but fell to 0.14 fishers/km^2 in 2005 (Matthews et al. 2013). Due to the apparent variability in density estimates, developing precise density estimates for different subpopulations and in different habitat types is critical for effective management.

Management and Conservation Planning

Federal and state resource agencies are currently developing strategies to aid in the maintenance of viable populations of fishers in both northwestern California and in the southern Sierra Nevada. As part of a cooperative agreement between the Conservation Biology Institute and USDA Forest Service Region 5, and with input from a team of 13 fisher researchers and scientists, a conservation strategy for fishers in the southern Sierra Nevada has been developed. The “SSN Fisher Conservation Strategy” is based on the findings from a conservation assessment that was previously completed by the same team of scientists. The SSN Fisher Conservation Assessment (Spencer et al.

2014) included a review of all previous published and credibly collected unpublished data on fisher ecology in the southern Sierra Nevada Region. Information from the SNAMP Fisher Project (published manuscripts, submitted/draft manuscripts, and unpublished data) were included in the SSN Fisher Conservation Assessment. In the Conservation Assessment and in association with conservation planning, the SNAMP Fisher overall study area is essentially Fisher Habitat Core Area 5 (Fig. 2).

Insights from SNAMP Fisher appear simultaneously encouraging and discouraging for management and conservation of the species. Causes of mortality were more diverse than was previously known, including evidence for periodic outbreaks of disease, and significantly higher levels of predation than previously documented for any other intensively studied population in North America. Fishers are challenged by the need to cross busy roads passing through foraging and

Table 2. Details and characteristics of Southern Sierra Nevada Fisher Conservation Assessment area "Fisher Core Habitat areas."

Core, Status[a]	Total area (suitable habitat)[b]	Primary (secondary) jurisdiction
1. Occupied	430 km^2 (50.4%)	Sequoia NF
2. Occupied	936 km^2 (62.2%)	Sequoia NF
3. Occupied	985 km^2 (56.4%)	Sequoia NP (Sequoia NF)
4. Occupied	751 km^2 (55.1%)	Sierra NF
5. Occupied	1096 km^2 (57.4%)	Sierra NF (Yosemite NP)
6. and 7. No fishers	1678 km^2 (55.8%)	Yosemite NP (Stanislaus NF)

[a] Indicates whether known occupied by a breeding fisher population.
[b] Habitat suitability based on updated modeling for the Southern Sierra Nevada Fisher Conservation Assessment.

Table 2 and Figure 2 Adapted from Southern Sierra Nevada Fisher Conservation Assessment (Spencer et al. 2014)

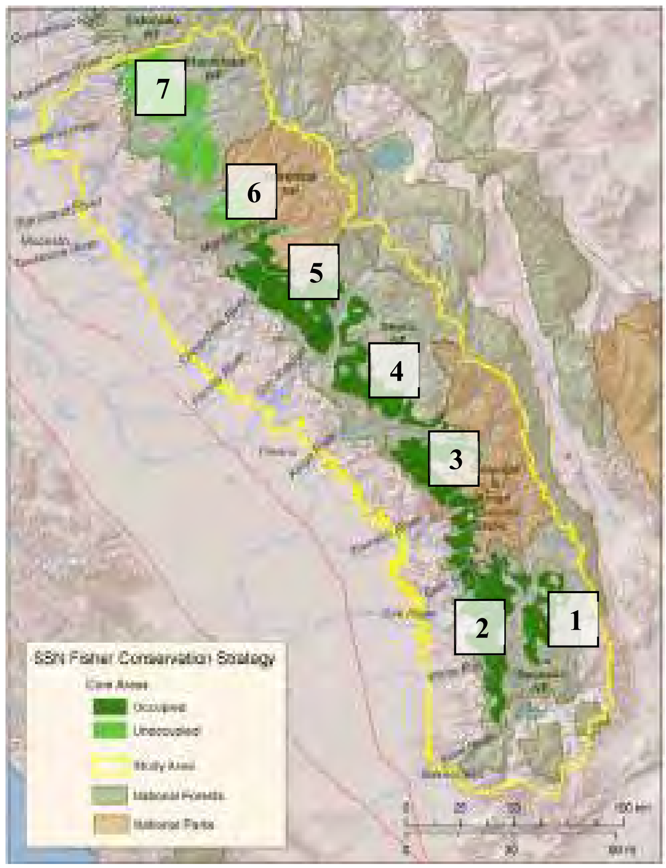


Figure 2. Distribution of occupied and unoccupied fisher habitat core areas in Southern Sierra Nevada Fisher Conservation Assessment area. Habitat cores were mapped as contiguous polygons having a predicted probability of fisher occupancy exceeding 0.41, and large enough to support ≥5 adult female fishers (see Spencer et al. 2014 for details).

denning habitats, they must avoid accidental entrapment in human structures, and coexist with illegal marijuana farmers spreading poisons on the landscape that kill or sicken them and their prey. Encouraging results include that, even with these challenges, fisher survival and demography at our southern Sierra Nevada study sites was comparable to other closely monitored populations in northern California and southern Oregon not considered at imminent risk of extirpation. Management should continue to maintain suitable denning, foraging, and resting habitats, as detailed in current planning documents (North et al. 2009). Moreover, the SNAMP Fisher study spanned a limited period of six years when multiple threats to fisher survival within Fisher Habitat Core Area 5 were identified, and when three large wildfires either significantly reduced availability of suitable habitat for fishers to the south and north of Core Area 5. We believe that continuous monitoring of the status of this population and mitigation of the major threats to persistence, along with population viability analyses, are necessary for evaluating the long-term viability of fishers in the southern Sierra Nevada.

Forest Management and Fisher Populations

Fishers were formerly widespread in mixed conifer forests across mountainous areas of northwestern California and in the Sierra Nevada of eastern California. Populations in the Sierra Nevada appear 30-50% reduced (Spencer et al. 2014) and it is possible that the isolated population of fishers in the southern Sierra Nevada will be impacted as the USDA Forest Service implements fuel reduction measures (Strategically Placed Land Allocation Treatments; SPLATS) to mitigate risk of catastrophic wildfire (Scheller et al. 2011). Fuel reduction treatments are becoming the dominant forest management activity in western forests in response to increases in the frequency of intense, stand-replacing forest fires over the past several decades (Mallek et al. 2013, Safford 2013). Advances in fire modeling have greatly improved managers' ability to plan and evaluate various landscape fuel treatment scenarios intended to reduce fire risks (Collins et al. 2010, Scheller et al. 2011). However, there remains a considerable gap between modeling landscape-scale fuel treatments and implementing them due to concern over the status of rare and uncommon species associated with multi-storied, late-seral stage forests, such as the fisher and spotted owl (*Strix occidentalis occidentalis*) (Naney et al. 2012, Truex and Zielinski 2013). Presence of fishers has strongly influenced managers' ability to delineate landscape-scale fuel treatments in this fire-prone region (Collins et al. 2010, Weir and Corbould 2010). The amended Sierra Nevada Forest Plan represents the most recent attempt to reconcile the need to reduce fuel loadings in Sierra Nevada mixed-conifer forests and retain characteristics of late-successional forests that are important for these species. The strategy involves a network of "Strategically Placed Area Fuel Treatments" (SPLATS) that allow up to a 60% reduction in basal area and a 30% reduction in canopy cover in habitats used by fishers and spotted owls. In the long-term, this strategy may increase availability of important habitats for both organisms by reducing wildfire-induced losses (Spencer et al. 2011), but treatments may impact habitat quality for fishers in the near-term (Thompson et al. 2011).

To provide a framework for balancing the habitat needs of fishers with fuel treatments intended to reduce fire risks, SNAMP initiated a coordinated effort to assess the effects of fuel treatments on many environmental features including the fisher, spotted owl, forest health, and water quality as quantity in the central Sierra Nevada. SNAMP began in 2007 and was designed to evaluate the effects and effectiveness of fuel treatments implemented according to the revised Sierra Framework (USFS 2004) under a design of stakeholder participation. SNAMP is a landscape-scale, ecosystem-level experiment in natural resource management and involves a Before-After-Control (BACI) design developed specifically to assess the impacts of SPLATs on the overall forest ecosystem (Popescu et al. 2012).

In September 2007 SNAMP Fisher was launched as 6-7 year study of fishers in the Bass Lake Ranger District, Sierra National Forest to determine population limiting factors, and to evaluate the effects of SPLATS on resource use, survival, and persistence of fishers in the southern Sierra Nevada. We used repeated surveys of small 1 km^2 blocks of forest habitat with automatic cameras, mark-recapture, and intensive monitoring of individual collared fisher for evaluating how SPLATS contribute to changes in habitat use, dispersal, survival, and reproduction by fisher.

Research Goals and Primary Objectives

1. Estimate population parameters including age and sex-specific survival, and fecundity
    a. What are the vital rates (reproduction, survival, population growth rates)?
    b. What is the population size and density in the study area?
    c. What are the patterns of dispersal movements?
2. Identify population limiting factors in the region encompassed by the study area
    a. What are the causes of mortality? Are predators, parasites or diseases important?
    b. What are the patterns of home range and habitat use?
3. Evaluate effects of SPLATS on occupancy, survival and fecundity
    a. Characterize resource use by fishers; do SPLATs influence habitat use
    b. What are the patterns of fisher occupancy in relation to forest management?
    c. Do patterns of fisher occupancy change before and after by SPLATS?

Project planning for the study was initiated in early 2007, and in September 2007 a research station near Bass Lake, California was established and staffed with a team of field biologists and research assistants. Field work was initiated in late October 2007. All permits were in place when we initiated live trapping on December 21, 2007 and captured the first two fishers on December 23, 2007. In late December 2007 we initiated the SNAMP Aviation program in cooperation with Forest Service Supervisory Pilot John Litton (R5 Regional Aviation Group, Lancaster, CA). One of the principle goals of the study was to maintain a minimum of 20 actively monitored fishers, a milestone that was achieved on July 23, 2008.

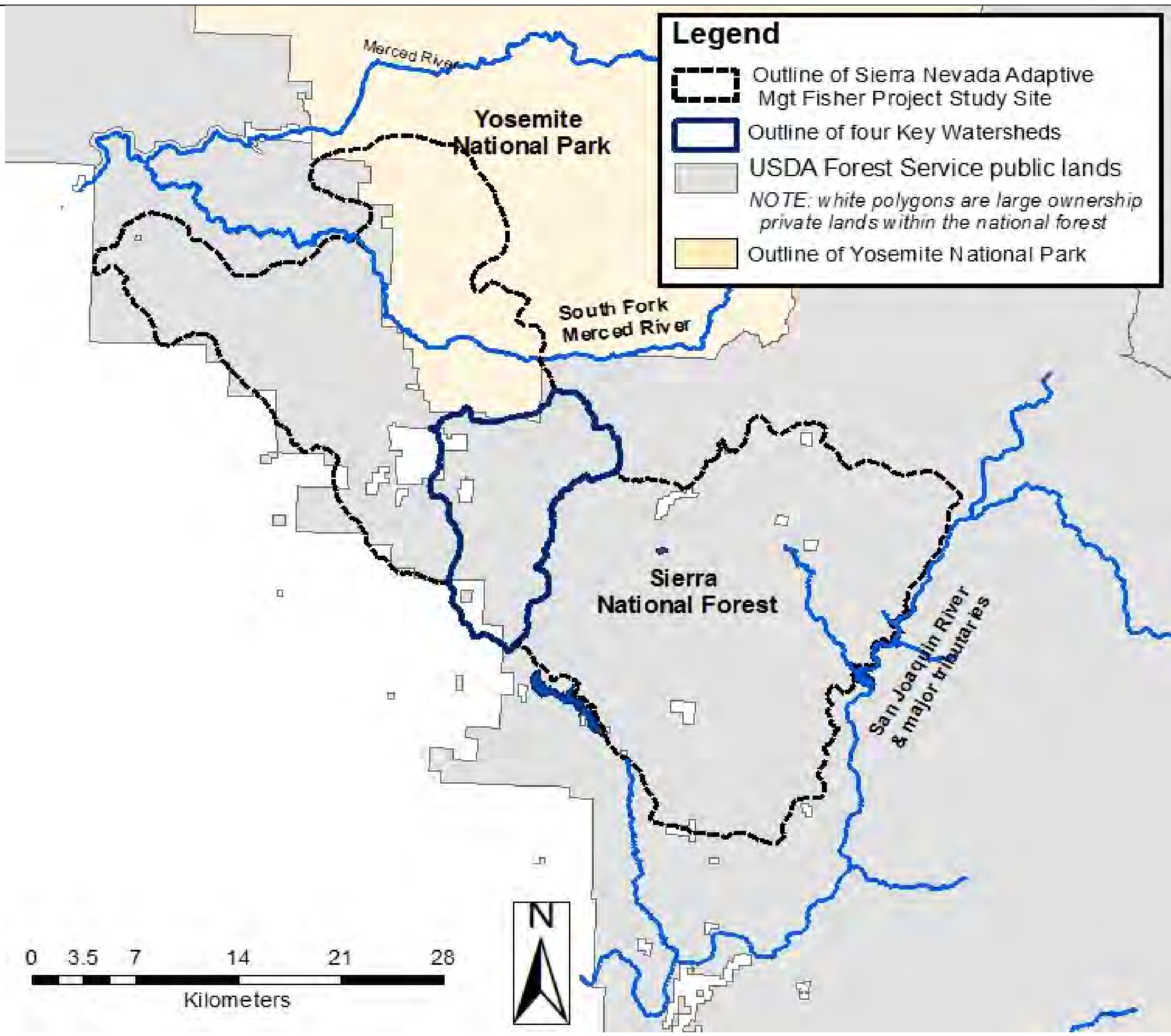


Figure 3. Overall Study Area of the SNAMP Fisher Project, including administrative boundaries, including the outer boundary of the "Key Watersheds" focal study area in the approximate center of the map region.

Site Description and Study Area

The SNAMP Fisher Project study area is at the northern end of the southern Sierra Nevada fisher population in California, encompassing the area bounded by the Merced River in the north and the San Joaquin River in the south (Fig. 3). Administratively, the focal study area for the research is the Bass Lake Ranger District in the Sierra National Forest, but early in the study a radio-collared fisher dispersed north into Yosemite National Park, which effectively expanded the research to encompass a part of Yosemite National Park (Fig. 3). Permission was granted by Yosemite National Park to monitor SNAMP radio-collared fishers for survival by fixed-wing aircraft overflights, but the research agreement did not extend to any significant ground-based activities by project staff.

The overall study area was the non-wilderness region of the Bass Lake Ranger District in the Sierra National Forest, near Oakhurst, California, and covered approximately 1300 km^2. This area encompasses a mix of public and private land and is topographically complex with elevations ranging from 758 m to 2652 m. Field work was carried out between 1,000 m and 2,400 m in elevation, corresponding to fisher occurrence in the region. Primary tree species in approximate order of abundance for conifers and then hardwoods in the overall study area are incense cedar (*Calocedrus decurrens*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), California black oak (*Quercus kelloggii*), canyon live oak (*Quercus* chrysolepis), mountain dogwood (*Cornus nuttallii*), and white alder (*Alnus rhombifolia*). Common shrubs and tree-like shrubs include whiteleaf manzanita (*Arctostaphylos viscida*), greenleaf manzanita (*Arctostaphylos patula*), mountain misery (*Chamaebatia foliolosa*), bush chinquapin (*Chrysolepis sempervirens*), mountain whitethorn (*Ceanothus cordulatus)*, and snowberry (*Symphoricarpos mollis*).

Key Watersheds

We already noted that the distribution and overall abundance of fishers in the Sierra Nevada, California declined by 30-50% in association with fur trapping, and timber harvest that removed large expanses of mature and old growth forest habitats in the early to mid-1900s. One of our overarching organizing hypotheses was that fuel reduction management (SPLATS; commercial thinning, understory brush and small tree removal by hand thinning and machine mastication) might exacerbate this contraction by preventing maturation of second-growth forests in the southern Sierra Nevada to where they are less capable of supporting a long term viable fisher population. Therefore within the overall study area, we initiated more intensive monitoring within the Southern SNAMP study area:

four “Key Watersheds” that encompassed three Forest Service projects expected to occur in the study period near the communities of Fish Camp (Fish Camp Project), Sugar Pine (Sugar Pine Project), and Cedar Valley (Cedar Valley Project). The four Key Watersheds are the Sugar Pine, Nelder Creek, Rainier Creek and White Chief Branch watersheds (Fig. 4). A 1 x 1 km grid (1-km^2) was overlaid for the Key Watersheds, and used to organize the sampling effort; National Forest land within each 1 km^2 cell were surveyed annually for fisher occupancy by automatic camera traps (O’Connell et al. 2011). Elevation within the Key Watersheds increases from 900-1100 m in the south/southwest to >2200 m

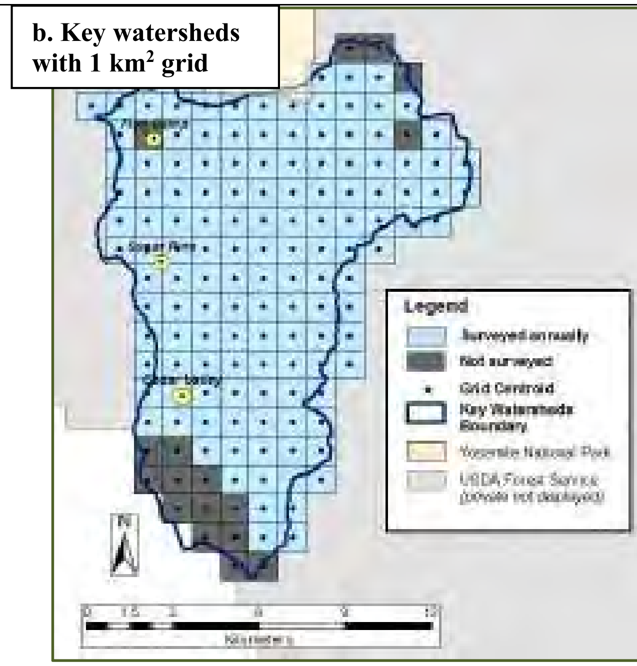
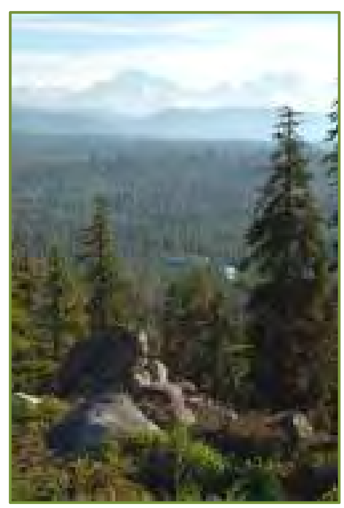


Illustration 4 (bottom right): Photograph of study area from Chiquito Ridge looking east

Figure 4. (a) Map views of Key Watersheds focal study area, including the SPLAT polygons originally produced for the Sugar Pine, Cedar Valley, and Fish Camp forest management projects. (b) Key Watersheds overlain with 1km^2 grid used to organize research effort for camera trap surveys. Yellow circles indicate the three communities located within the watersheds. NOTE: camera traps were placed at or very near the grid center points as plotted.



in the northeast portion of the study area. This elevation gradient corresponds with a mix of hardwoods(California bay, *Umbellularia californica,* Canyon live oak, black oak, and several conifer species at lower elevations (ponderosa pine, incense cedar; California Wildlife Habitat Relationship system MHW, PPN, and MHC habitat types), a mix of multiple conifers(Jeffrey pine, *P. jeffreyi,* white fir, incense cedar), and hardwoods (black oak, white alder, *Alnus* (ponderosa *rhombifolia*, mountain dogwood, *Cornus nuttallii*) between 1300 m and 1850 m (CWHR Habitat types SMC, MHC, PPN), and grading into red fir (*Abies magnifica*) and lodgepole pine (*P. contorta*) (CWHR Type RFR) above 1900 m. Giant sequoia (*Sequoiadendron giganteum*) are present, but primarily restricted to the Nelder Grove Historic Area within the Nelder Creek watershed. Permanent streams in the Key Watersheds are important for fishers and other wildlife and include Big Creek and Rainier Creek in the Rainier Creek watershed, Lewis Creek in the Sugar Pine watershed, and California Creek and Nelder Creek in the Nelder Creek watershed.

Methods

Vital Rates and Basic Population Parameters

Introduction and Background

Information on population size and demographic parameters is fundamental for managing wildlife populations, especially when declines in abundance or range size have occurred and the species is the focus of conservation management. The fisher is one such species, and it is at the center of intense conservation efforts as a candidate for listing under the USA Federal, Oregon, and California endangered species acts (USFWS 2004).

The southern Sierra Nevada fisher population is small (<500 individuals), appears to be stable over about the last 15 years (Zielinski et al. 2013a), but may have expanded from an even smaller population during the late 20th century (Tucker et al. 2014). Spencer et al. (2011) used a spatially explicit population model to estimate the potential fisher carrying capacity south of the Merced River and concluded there are probably <300 adult fishers. Fisher density estimates from the Sierra National Forest based on mark-recapture camera station data (Jordan 2007) or scat-detector dog data (Thompson et al. 2012), suggest that the total population (including adults, subadults, and some juveniles) could number up to ~450 total fishers in overall southern Sierra Nevada region of California.

The ecology and habitat use of fishers in the southern Sierra Nevada has been the focus of research since the mid-1990s (Jordan 2007, Mazzoni 2002, Truex et al. 1998). Insight from prior research in this region suggests population densities may vary from 0.07 to 0.28 fishers/km^2 (Jordan et al. 2011, Thompson et al. 2012). Information on current density is needed for other areas of the southern Sierra Nevada as well, because as the area of suitable habitat available to fishers in the southern Sierra Nevada is refined by improved modeling (Spencer et al. 2014), density values can be used to develop more accurate estimates of fisher abundance for conservation planning. Although regional occupancy trends (Zielinski et al. 2013*a*) suggest that the southern Sierra Nevada fisher population is relatively stable, records from elsewhere indicate fisher densities can change rapidly. On the Hoopa Fisher Project study area in northern California, density was estimated at 0.52 fishers/km^2 in 1998, but fell to 0.14 fishers/km^2 in 2005 (Higley et al. 2013).

Resource agencies are currently developing strategies to aid in maintaining viable populations of fishers in the southern Sierra Nevada. Data from SNAMP Fisher have aided this process by providing current data on population size and demographic parameters for the species in an area at the northern margin of their current range in the southern Sierra Nevada. Using data on detections of fishers from camera surveys and live trapping to estimate population size and density and estimates of reproductive rates and fecundity from close monitoring of denning behavior, we integrated data on survival and demographic rates into a matrix model to estimate the population growth rate.

Field Methods

Live Trapping.--Although noninvasive methods can be used to generate important data on wildlife populations (Long 2008), estimating vital rates (survival, reproduction, dispersal) almost always requires trapping to radiocollar and then closely monitor the study animal. We followed standard live-trapping procedures previously developed for fishers in California (Jordan 2007, Matthews et al. 2013*a*), with only a few minor changes. Individual fishers were live-captured in steel mesh traps (Tomahawk Live Trap Company, Tomahawk, WI) modified to include a plywood cubby box to provide the animals with a secure refuge where they were less likely to injure themselves (Wilbert 1992). Trapping to mark animals with radiocollars was focused during the fall and winter seasons between December 2007 and March 2012. Also, with the exception of the first year of the study when we needed to capture fishers to initiate the study, we did not trap during the spring denning period (late March to mid-June) to minimize disturbance to reproduction. Live traps were baited with venison, and checked daily by late morning. Captured animals were restrained in a handling cone, and sedated using a mixture of Ketamine hydrochloride and Diazepam (1 mg Diazepam/200 mg Ketamine) injected intramuscularly. Sedated fishers were weighed, classified by age and gender based on examination of teeth and genitalia, and measured for standard morphological features. Small samples of ear tissue were collected for microsatellite DNA analysis using a sterile dermal biopsy punch. Several strands of hair were removed from the nape and rump region, also for DNA analysis. Hair samples were stored in a dry paper envelope, whereas tissue samples were stored in 95% ethanol until analysis at the USDA Forest Service Wildlife Genetics Lab (Rocky Mountain Research Station, Missoula MT). Teats on females were measured for base diameter and height using digital calipers (± 1mm), and those data were used to identify females that weaned at least 1 kit when they had not been monitored during the denning period (Matthews et al. 2013*b*). Each animal was permanently identified by subcutaneous insertion of passive integrated transponder (PIT) tags (Biomark, Boise, ID), and fitted with a radio collar (Holohil Systems Model MI-2M, Ontario, Canada) modified by attaching small bands (0.5-1.0 cm) of infrared reflective tape (3M® Scotchlite™) along the lengths of the antennas. Custom breakaway devices were inserted into radiocollars fitted to juvenile fishers to reduce the risk of injury or strangulation between recaptures (Thompson et al. 2012). Bands of infrared reflective tape and breakaways were modifications not used in previous studies. After handling, we returned animals to the cubby box and released them at the point of capture after recovery from anesthesia. Capture and handling procedures followed American Society of Mammalogist guidelines (Sikes and Gannon 2011), and were approved by the Institutional Animal Care and Use Committee of the University of California, Berkeley (protocol R139).

Live-trapping is labor intensive, and the effort was designed to gain advantage from detections of non-collared fishers at camera traps. Live traps were most frequently placed in the same area of camera trap stations after cameras had been removed (to prevent interference with camera surveys). Data from camera detections were used to design linear traplines of 5-10 traps bracketing positive detection stations. Distance of separation between traps was typically ≥500 m, and traplines were usually successful at capturing targeted animals within five nights of trapping. Live-trap success was further enhanced in later years of the study by placing traps in locations where fishers had been captured in the past. Trap success was also enhanced by cleaning and sanitizing traps after captures. In winter, snow falling from tree branches can ice up the treadle mechanism inside live traps. We used lightweight, rectangular canvas tarps (1.12 width, 1.36 length) to protect the inside of the live traps from falling snow, and debris used to camouflage the traps. Traplines were generally removed the day after targeted fishers were captured, and always after 10 nights of trapping when no fishers were captured.

Illustration 5: Camouflaged live trap near the base of a white fir tree, and a radiocollared fisher being released after processing

Aerial Telemetry and Radiotelemetry Monitoring.--Tracking radiocollared animals from an aircraft is an alternative to locating them from the ground by homing or triangulation (Thompson et al. 2012). Researchers have been using fixed-wing aircraft to locate wildlife since the early 1970s (Mech 1974). The unique ability of observers in aircraft to rapidly search and locate radiocollared animals over large and inaccessible areas while allowing for nearly line of sight reception between transmitter and receiver makes aerial radio telemetry an attractive research technique in general (Gilmer et al. 1981), and specifically for studying fishers, which often occur in remote mountainous areas where access can be difficult (Weir and Corbould 2008). Partly for these reasons, we used fixed-wing airplanes to monitor and relocate radiocollared fishers for the entirety of the SNAMP Fisher Project. Beginning in December 2007, we worked with USDA Forest Service Supervisory Pilot John Litton to develop an aviation program in support of SNAMP Fisher, which was fully established in August 2008 when a full time pilot was hired and the first of two dedicated aircraft were based at the Mariposa-Yosemite Airport in Mariposa, CA.

The two USDA Forest Service-owned aircraft acquired for supporting the project were a Cessna (Cessna Aircraft Co., Wichita, KS) and a Piper PA-18 Super cub (Piper Aircraft Inc., Vero Beach FL). Two aircraft were considered necessary to maintain continuous monitoring of radiocollared fishers when routine maintenance or engine repair was necessary (John Litton, personal communication).

Illustration 6. Forest Service-owned Piper Supercub (left) and Cessna 185 (right) on the tarmac at the Mariposa Airport, California.

The optimal search procedure used when locating animals from light aircraft varies depending on the number of animals tracked, and the antenna configuration supported and approved for the airplane being used (Gilmer et al. 1981). Additional details are provided elsewhere (Thompson et al. 2012), but we used two, 2-element H antennas (Telonics Inc., Mesa, AZ) mounted in a sideways configuration on each wing strut, and a single 3-element Yagi antenna (Advanced Telemetry Systems, Isanti, MN) mounted forward-facing on the right wing strut. This antenna configuration was effective in allowing the pilot and biologist to search for radiocollared fishers using the Yagi antenna (detection range 5-20 km), and then switching to the H-antennas to localize to a relatively precise location above the animal using a circling technique (Seddon and Maloney 2004).

Fixed-wing flights (aerial telemetry missions) to locate radiocollared fishers in the study area were scheduled in advance for 4-6 missions/week, depending on weather conditions considered safe for departure and return to the Mariposa-Yosemite Airport. Flights typically occurred in the morning hours, and lasted 2-3 hours. Afternoon telemetry flights were relatively infrequent, and the large majority of aerial radiotelemetry locations were acquired in the AM period of the day. As part of each aerial-telemetry mission, we systematically searched for all active radiocollars deployed on fishers in the study area. Biologists in the airplane recorded (1) active/inactive status for each fisher, (2) time of location, (3) an estimated UTM location for each fisher (typically logged into a handheld GPS unit; Garmin 60 CSx, Olathe, KS), (4) a qualitative ranking for each location (poor, fair, good, excellent), and (5) a record of any radiocollared fishers that were not located. Additional descriptive details were often recorded related to the nature of weather conditions influencing the aircraft at the time of the location (turbulence, "bumpy", clouds occluding visibility to the ground, etc.), or if the animal had moved an unusual distance or to an atypical area. At the end of each aerial telemetry mission, the

Illustration 7: Forest Service Cessna 185 airplane, and antenna configuration on the right side wing strut.

biologists summarized details on departure and return times and weather and flight conditions during the flight.

Aerial radiotelemetry can be efficient for locating animals that range over large areas in difficult terrain (Gilmer et al. 1981), but the accuracy, or precision of aerial telemetry locations is generally less than for ground-based radiotelemetry (e.g. triangulation; Koen 2005, Gantz et al. 2006). Location error from fixed-wing airplanes varies with flight speed, elevation above ground level, pilot and biologist experience, and signal reflection in rugged topography (Thompson et al. 2012). We assessed error for aerial radiotelemetry locations on the SNAMP Fisher project by calculating the Euclidean distance between GPS locations logged by biologists in the airplane and positions of test collars placed at known locations on the ground. Test collar locations were generally radiocollars that were placed in locations unknown to the biologist in the airplane; biologists were required to regularly estimate positions for test collars during aerial telemetry missions. Other aerial radiotelemetry locations used to quantify accuracy included dropped radiocollars, carcass locations, fishers in live traps, and female fishers in a cavity in a den tree whose locations were also unknown to the biologist in the airplane.

Fisher Reproduction

Background.--Den sites, where female fishers bear and raise their kits, are probably the most limiting habitat element for fisher populations in California. Females typically use more than one den during the denning season (late March to mid-June). Natal dens are where adult female fishers give birth and initially care for young, and they may then move kits to one or more maternal dens from early April to June until they are weaned (Powell et al. 2003, Matthews et al. 2013*a*). Reproductive dens, both natal and maternal, are nearly always cavities in large trees, live or dead, and are found in forest stands with dense canopy cover and complex multi-layered structure (Zhao et al. 2012). Suitable denning sites are likely a subset of suitable resting sites because the requirements are more stringent: (1) den cavities must be large enough to shelter both mother and kits for weeks rather than days; (2) the female needs to provision her young while they are restricted to the den, so dens must be located close to high-value foraging areas; and (3) denning begins in late March-early April, when temperature are colder and slope position may be more critical in assisting with kit thermoregulation.

Identifying den trees and evidence of reproduction.—Female fishers exhibiting behavior consistent with denning were identified during late March-mid April and then monitored. Denning behavior was characterized by an abrupt change from a pattern of successive aerial radiotelemetry locations being dispersed within a female's home range, to a pattern where locations were spatially clustered (3-5 locations within 500 m over a 7-day period; Zhao et al. 2012). When clustering of locations occurred, a biologist navigated to the area with a handheld Global Positioning System device to investigate. Standard ground-based radiotelemetry techniques with a handheld receiver (model R1000; Communication Specialists, Inc. Orange, California) and an H-type antenna were then used to home towards telemetry signals of radiocollared females. Once a collared female was isolated in an area, the biologist circled the fisher until the individual tree or snag was identified (Matthews et al. 2013*a*). When female fishers were localized to a possible den structure, 2-4 automatic "den cameras" that had been cleaned and de-scented were attached to nearby trees and focused on the bole of the den structure (scent and bait lures were not applied around den trees to avoid attracting other predators). We returned to these structures the day after initial placement of den cameras, and then every 3-5 days to confirm use for denning based on regular occupancy and images indicating up and down movements on the tree or snag. Trees and snags used ≥3 times in succession and with camera-based evidence of up-down movements were considered denning structures (Zhao et al. 2012). We defined "denning opportunities" as the total number of individual, breeding-age female fishers (≥24 months) either directly monitored in mid-March to June (Matthews et al. 2013*a*), or measured for teat size during July to January to assess weaning status (Matthews et al. 2013*b*). We considered kits weaned when denning behavior continued until 31 May or later (Matthews et al. 2013*a*), unless the female was known to have died before June 30.

Activities of known-denning female fishers were chronicled for the duration of each denning season by continuous monitoring with cameras and ground checks of den trees. Female fishers typically transfer kits from natal den trees in which they were born to 1-6 other maternal dens during April to June (Matthews et al. 2013*a*). Each time we had evidence that a denning fisher moved kits to a new maternal den (images of females transporting kits away from den trees, cessation of occupancy over multiple checks), we searched for the female using ground telemetry and repositioned cameras around the next den structure (Zhao et al. 2012). Den cameras were removed in mid-June when females ceased localizing to den structures.

Information on litter size was determined from images from den cameras, or, less frequently, by climbing den trees and using a video camera (Peep-A-Roo Video Probe System, Sandpiper Technologies, Manteca, CA) to count kits inside den cavities (Matthews et al. 2013*a*). We minimized disturbance to denning females by (1) restricting visits to den structures to service cameras to once every 3-5 days, (2) using deployments of multiple den cameras for obtaining the majority of kit counts, and (3) by not approaching den trees for climbing until ground-based telemetry indicated the female was well away from the den structure (Zhao et al. 2012).

Illustration 8: Female fisher F46 moving a 1-month old fisher kit from her natal den tree.

Maximum reproductive rate was estimated as the sum of the number of adult-age female fishers in the population that localized to den trees during the den season plus the number of adult females with enlarged teats that were not monitored but captured and measured before January, divided by the number of adult-age female fishers in the population during mid-March to late January. Weaning rate was estimated as the number of adult-age females known to have survived and localized to den trees through May plus those with enlarged teats that were captured after the den season, divided by the number of adult-age female fishers in the population during mid-March to late January. We note that measurements of teat size were shown to correctly identify over 90% of current year reproducing females that weaned at least 1 kit, and all but 3 adult females for which teat measurements were used to determine reproductive status were part of the Matthews et al. (2013*b*) dataset. Annual estimates of fecundity were calculated as the total number of weaned kits/number of females with known kit counts.

Illustration 9: Female fisher ascending a den tree. Note that the image from one camera also shows two other cameras positioned on adjacent trees that were monitoring the same den tree.

Habitat Characteristics within Fisher Denning Areas.--Denning structures are considered a limiting habitat element for fishers in California and elsewhere (Weir et al. 2012), but site characteristics immediately surrounding the denning structures are also important (Zhao et al. 2012). Current forest vegetation management to reduce hazardous fuel levels, improve the vigor of selected trees (pines and oaks), increase spatial heterogeneity, and provide forest products for society may impinge on denning habitats in a variety of ways (Naney et al. 2012, Powell and Zielinski 1994,). These management actions can negatively affect fisher habitat (Weir and Corbould 2008), at least in the short term (Thompson et al. 2011), while others may have little impact on fisher habitat suitability (Spencer et al. 2014). Without detailed "local scale" information on habitat characteristics directly associated with fisher denning structures, it will not be possible to adequately manage Sierra Nevada forests in ways that will maintain viable fisher populations.

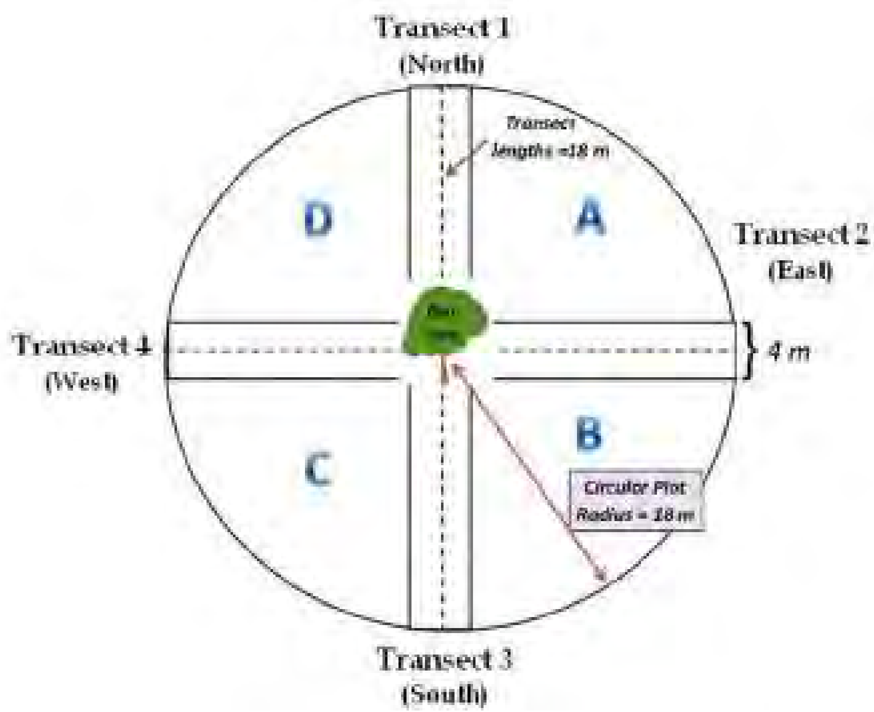


Figure 5. Diagram illustrating the layout of 18m radius circular plots and associated measurement transects for fisher denning structures for the SNAMP Fisher Project in the Bass Lake District, Sierra National Forest. See Appendix X for additional details.

Habitat characteristics for denning structures.—We developed a protocol for determining the combination of biotic and abiotic characteristics female fishers are likely selecting/using for denning habitats. The protocol was designed to collect similar types of data as those being recorded by the Forest Health Team on the Core Plots in the Sugar Pine area, while also capturing the same types of data being recorded by the USDA Forest Service PSW Kings River Fisher Project at den trees used by fishers in the High Sierra District, Sierra National Forest. Full details on how different habitat data were assessed are provided as an Appendix. Briefly, we used an 18m radius circular plot centered on the denning structure (Fig. 5) to organize collection of data on (1) canopy cover, (2) litter, duff, and coarse woody debris (associated abundance of fuels), (3) cover and height of herbaceous plants and understory woody shrubs (concealment cover), (4) slope and aspect, and (5) size, number, and height of trees and snags (3 size classes, 4 crown classes). Data on habitat characteristics for den trees were typically collected during late spring or summer, and always when the den trees were no longer in use for denning.

Fisher Survival

Background.--Understanding survival and the details of cause-specific mortality is fundamental for insight into the population biology of any species, and crucial for understanding the limits to population growth and recovery for rare or endangered species of wildlife. Historical loss and fragmentation of important habitats, combined with overexploitation by hunting and trapping are the most common drivers of endangerment of wildlife (Lande 1993). Although changes in management may sometimes succeed in reversing problems associated with loss of critical habitats, emergence of new threats that impinge on survival or reproduction can counteract improvements that might otherwise reverse population declines. Emerging threats to survival and population persistence may be obvious such as exposure to novel pathogens and increased occurrence of road-kill deaths (Gaskill 2013, Litvaitis and Tash 2008), or less discernible and linked to changes in community structure or composition that produces an imbalance in predator-prey relations (Roemer et al. 2001).

Factors that contribute to limited growth and expansion of fisher populations in the southern Sierra Nevada are likely linked to a combination of resource and population phenomena. Fishers may be challenged by limited access to suitable resting and denning habitats (Purcell et al. 2009) or insufficient numbers of prey (Zielinski and Duncan 2004), whereas survival may be reduced by high rates of predation (Wengert 2013), wildlife-vehicle collisions (Chow 2009), and exposure to anticoagulant rodenticides (Gabriel et al. 2012a, Thompson et al. 2013). Although habitat requirements of fishers and their responses to forest management are increasingly well known (Aubry et al. 2013, Garner 2013, Zielinski et al. 2013), it has only recently been documented that high numbers of otherwise healthy fishers were succumbing to attacks by other forest carnivores (Wengert et al. 2014) and that illegal use of anticoagulant rodenticides and other toxicants associated with illegal marijuana grow sites on national forests and parks in the southern Sierra Nevada was contributing to both direct mortality and reduced survival of fishers in this region (Gabriel et al. 2012a, 2013, Thompson et al. 2013). Because of heightened concern over the stability of the small population of fishers in the southern Sierra Nevada, our primary objective was to evaluate factors contributing to variation in survival among fishers in the region. Young mammals (particularly males) often experience higher mortality early in life associated with dispersal and establishing independent home ranges (Chepko-Sade and Halpin 1987), and general naiveté with predators and other environmental risks (Farias et al. 2005, Murdoch et al. 2010). Fishers typically disperse before they reach maturity at ≈ 24 months (Arthur et al. 1993), when lower survival related to this life history event might be evident. Fishers may experience lower survival during fall and winter due to the combined effects of higher energetic costs associated with deep snow cover (Powell 1979) and prey limitation when several species of rodent prey (Zielinski and Duncan 2004) enter into torpor. Therefore, we hypothesized that (1) survival would be lower for juvenile and yearling fishers compared to adults, (2) males would experience lower survival than females related to higher rates of movement and potential longer dispersal distances, and (3) survival would be lower during fall and winter than in spring and summer.

Determination of survival rates.--We monitored the status (alive, dead, or missing) of radio-collared fishers from time of first capture until death, censorship (due to dropped or failed collars on animals that were not quickly recaptured), or the end of the study. Breakaway devices in the radio-collars occasionally resulted in premature detachment, requiring efforts to re-collar animals that were short-term missing (1-2 months). Because of the relatively common incidences when animals were missing for less than one month, we evaluated survival on monthly intervals rather than weekly or bi-weekly. Overall patterns of survival were determined using the Kaplan-Meier (KM) staggered entry method (Koen et al. 2007, Pollock et al. 1989, Price et al. 2010). KM models were used to produce estimates for annual survival and combined year survival (data pooled by month across all years) by population year. The population year was defined as April 1 to March 31 based on the timing of reproduction for female fishers in California with most offspring produced during March 21 to early April (Matthews et al. 2013*a*). Annual survival can be moderately to highly variable and may result in a negative population growth trajectory that may not be appropriate for a long-lived species with a generation time of two or more years. We therefore combined monthly data on survival status for individual fishers for five 2-year periods (population years 2 and 3, population years 3 and 4, population years 4 and 5, population years 5 and 6, and population years 6 and 7). Live-trapping to capture young-of-the year juveniles was focused during mid-October to February (a few juvenile fishers were occasionally captured before October or in early March). Kaplan-Meier models to estimate "annual" survival for juveniles were typically initiated in December, thereby producing survival estimates for juveniles for a 3-4 month period from December or January to March. When data for juveniles were pooled across population years, however, the dataset allowed for evaluating juvenile survival for the all years combined model for the 6 month period from October to March. Z-tests were used to compare estimates for combined year survival for all possible age and sex combinations. Significance levels (α) for multiple comparisons were adjusted for Type I error rates using the Bonferroni procedure (McCann et al. 2010).

Causes of Mortality

Background—Understanding the details of cause-specific mortality provides insight necessary to understand overall survival in relation to factors that are most likely to limit population growth and recovery for rare or endangered species of wildlife. Factors that contribute to limited growth and expansion of fisher populations in the southern Sierra Nevada, California are likely linked to a combination of resource and population-level phenomena. In addition to the challenges described previously, it has been hypothesized that the recent change to more open canopy forest conditions with an understory of small trees and more shrubs is contributing to higher rates of predation by bobcats (*Lynx rufous*) and coyotes (*Canis latrans*) (Wengert 2013). Although the habitat requirements for fishers are generally known (Lofroth et al. 2010), details of cause-specific mortality in the southern Sierra Nevada had not been rigorously evaluated until the SNAMP and KRFP studies were initiated in 2007.

Monitoring to detect mortality.-- All radio-collars fitted to fishers on the SNAMP study were equipped with mortality or activity sensors, allowing us to detect inactive signals and investigate fisher mortalities and recover carcasses soon after death in most cases. When a mortality signal was detected, immediate attempts were made to investigate the area of the signal to recover shed radiocollars or recover the carcass when an animal was confirmed dead. Carcasses were generally recovered within 24 hrs of death, aided by the near daily aerial radiotelemetry missions.

Radiocollared fishers have been monitored effectively and relocated by ground-based radiotelemetry as part of KRFP study centered approx. 60 km southeast of the SNAMP Fisher Study Area (Garner 2013). However, most prior studies have been unable to identify causes of death for many deceased study animals because carcasses were not retrieved within 12-48 hours after death (Truex et al. 1998, Aubry and Raley 2006, Jordan 2007). Decomposition begins immediately after death, which can prevent identification of underlying disease processes directly linked to death (Gabriel 2013, Keller et al. 2012). Because of this, our primary rationale for monitoring radiocollared fishers by fixed-wing aircraft up to 6 days/week was to recover carcasses of animals as soon after death as possible. The protocol that was in place from the start of the study until approx. June 2012 was for the biologist in the airplane to use the audio system in the airplane to (1) transmit the estimated location coordinates for any radiocollared fishers detected on inactive pulse to the research office, whereupon (2) a staff biologist in the vicinity would immediately investigate the location and recover the carcasses following an approved forensic protocol, (3) transport the carcass to the research office where they were placed in -20^{0} C freezer for storage until (4) a necropsy could be scheduled at the UC Davis School of Veterinary Medicine.

Once a radiocollar is activated and deployed, it will typically function (emit a radio signal) for 18-24 months until the battery is expended. In 2011 the SNAMP Fisher project began using radiocollars from Advanced Telemetry Systems (ATS), but discovered that many of the electronic “mortality switches” built into the ATS radiocollars became defective within 8-10 months of being deployed on study animals. Electronic mortality switches are designed to emit pulses at twice the normal pulse rate when the radiocollar has been stationary for at least 8 hours. When the mortality switches in the ATS brand radiocollars became defective they began to emit intermittent and then consistent false inactive signals. SNAMP Fisher was forced to modify the inactive signal protocol by first plotting locations determined for inactive signals in ArcGIS, whereupon a decision on whether to investigate the location was based on a judgment of the distance of separation between successive aerial radiotelemetry locations (investigation triggered when successive locations were <1000 m apart). The revised protocol was situation specific: the first time an ATS collar was detected emitting an inactive signal, efforts were made to investigate the location immediately. Subsequent inactive signals from that collar were examined carefully prior to on-the-ground investigation. This process may have delayed the recovery of a limited number of carcasses. Efforts were made to correct for the problem of false inactive signals by replacing defective collars with collars of a different manufacture as soon as possible.

When fisher carcasses were discovered we followed a standardized forensic protocol for collecting samples and documenting circumstances at mortality sites using photographs and diagrams of mortality sites (Wengert et al. 2013). When predation was suspected as the cause of death (e.g. obvious punctures, partial consumption), we recorded information on the characteristics of the predation event including patterns of consumption and evidence of caching or burying. Samples included swabs of visible bite wounds, clipped fur from near the bite wounds (clipped to avoid fisher DNA in root bulbs), swabs of the claws and teeth, and any non-fisher hairs left on or near the carcass (Wengert et al. 2013). Carcasses were double-bagged in plastic bags, labeled, and transported back to the field offices where they were frozen in a -20°C freezer until being shipped to University of California, Davis for necropsy.

Pathology.--We submitted all carcasses for necropsy and disease and DNA assessment to cooperating pathologists at the University of California Davis, Veterinary Medical Teaching Hospital, and California Animal Health and Food Safety Laboratory in Davis, CA. When possible, the team of pathologists determined cause of death for each fisher using all available information, including necropsy examination, disease and toxicological results, DNA forensics, evidence recovered or identified as important from the mortality site, and habitat characteristics around the carcass. During necropsy, liver samples were collected and subsequently tested for the presence of anticoagulant rodenticide residues using liquid chromatography-tandem mass spectrometry to screen for presence of anticoagulant rodenticides and high-performance liquid chromatography to quantify positive samples. When predation was determined to be the cause of death, all lesions attributed to predation were described in detail. To distinguish between ante and post-mortem wounds (i.e. between predation and scavenging), we noted whether the lesions had associated hemorrhage and edema,. In 14 cases, too few remains were present to identify hemorrhaging at wound sites, so only molecular analyses were conducted in these cases. Age-class at time of death was estimated as adult (≥24 months), subadult (12-23 months), and juvenile (<12 months) based either on tooth wear or cementum annuli counts.

Molecular Analyses-- Forensic samples were processed and analyzed for predator (either felid or canid) DNA according to the methods of Wengert et al. (2013). Because multiple polymerase chain reaction (PCR) products were occasionally obtained when the products were visualized on an agarose gel, we gel-excised the appropriately sized fragment (200–300bp for felids and 400 for canids) and extracted DNA using Qiagen Qiaquick Gel Extraction kit according to the manufacturer's instructions. The PCR products were sequenced, then aligned using RidomTraceEdit (Ridom GmbH, Würzberg, Germany). Sequences were cross-referenced on GenBank using Basic Local Alignment Search Tool (BLAST) to match them to the most closely aligned sequence to identify species of predator DNA.

Population Growth Rates

Background.—All wildlife will respond to changes in habitat, food availability, and recent weather conditions by fluctuations in animal numbers. Fishers are no exception to this general pattern (Jensen et al. 2012). As a rare species, however, variation in population size or abundance of fishers is of conservation concern for maintaining a minimum viable number of animals on the landscape (Spencer et al. 2011, Reed and McCoy 2014).

Information on the growth trajectory for fishers in the SNAMP Fisher study area is unknown, but there are several competing hypotheses regarding population status in the broader region encompassing the SNAMP Fisher study area. Research conducted between 2002 and 2012 suggested no evidence for population increase (Zielinski et al. 2013), which may indicate that despite protection from fur trapping and development of policies designed to better sustain sensitive birds and mammals (North et al. 2009), fishers in the southern Sierra Nevada may not be in numeric or spatial recovery. In agreement with the "no increase" hypothesis, a body of research suggests that fishers in the Sierra Nevada experienced a range retraction of 30-50% over the last 75-100 years (Zielinski et al. 2005, 2013, Spencer et al. 2014). An alternative hypothesis is that fishers were very uncommon in our study area prior to 1990, and the current population resulted from a northward expansion from south of the Kings River (Fisher Habitat Core Area 3; Fig. 2; Tucker et al. 2014), equivalent to an approx. 30% increase in distribution in the overall southern Sierra Nevada region based on analyses of fisher habitat by Spencer et al. (2014) (Fig. 2). This alternative view is based primarily on genetic evidence of population subdivision (Tucker et al. 2012, 2014), and potentially supported by increasing fisher detections from track plate and camera trap monitoring after the mid-1990s (Zielinski et al. 1995, 2005, 2013). Research on the ecology and habitat use of fishers in the southern Sierra Nevada has been the focus of research since the mid-1990s, and although much insight on fisher ecology has been gained with regards to home range size, population density, and habitat use for resting and other activities (Jordan et al. 2011, Thompson et al. 2012, Purcell et al. 2009), no prior study has reported on the growth rate of any fisher population in this area.

Population growth rates and Leslie-matrix modeling.— Intensive research as part of the SNAMP Fisher study has generated information on all key vital rates needed to evaluate the population growth rate (λ) in the area, critical for understanding whether the population has the potential to persist, or if it is in decline. We developed an age-structured matrix model to estimate a deterministic population growth rate (λ) for the SNAMP Fisher study population using observed data on denning, fecundity, and survival. We defined 2 "adult" age classes (24 months, ≥36 months) for developing and including estimates of fertility in the matrix model for the population. Fertilities (F_i) were calculated for adult-age female fishers as:

$$F_i = b(_i)Pi \qquad \text{Equation 1}$$

where fecundity, *b(i)*, was the mean number of female kits weaned per reproductive female (sex ratio at birth assumed = 0.5), and P_i was the age-specific survival rate (Gotelli 2001). Age-specific survival rates were estimated for radiocollared juvenile (6-11 months), subadult (12-23 months) and adult-age (≥24 months) female fishers in the study area using monthly encounter histories in Kaplan-Meier staggered entry model analyses (KM survival). Survival estimates were produced for combined data on numbers of radiocollared fishers in each age class during the six year study period (All-year), as well as for a series of five 2-year periods. Data on numbers of fishers in each age class for each pair of years were combined for KM survival estimates, starting with population years 2008-09 and 2009-10, and ending with population years 2012-13 and 2013-14.

Data from radiocollared animals from the study area indicated that female fishers commonly die by 6-8 years of age. We therefore included 8 age classes in our Leslie Matrix (**A**) formulation, where the numbers of fishers in each age class n_1 to n_8 at time $t+1$ = **A** X **n** vector at t_0 according to equation 2:

$$\begin{bmatrix} n1\,(t+1) \\ n2\,(t+1) \\ n3\,(t+1) \\ n4\,(t+1) \\ n5\,(t+1) \\ n6\,(t+1) \\ n7\,(t+1) \\ n8\,(t+1) \end{bmatrix} = \begin{bmatrix} F1 & F2 & F3 & F4 & F5 & F6 & F7 & F8 \\ P1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & P2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & P3 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & P4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & P5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & P6 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & P7 & 0 \end{bmatrix} X \begin{bmatrix} n1(t0) \\ n2(t0) \\ n3(t0) \\ n4(t0) \\ n5(t0) \\ n6(t0) \\ n7(t0) \\ n8(t0) \end{bmatrix} \quad \text{Equation 2}$$

Estimates for fertility were from data on weaning rates, fecundity, and survival for known-age juvenile (F_1; 1 month old), subadult (F_2; 12 months), young adult (F_3; 24 months), and adult fishers ($F_{4,5,6,7,8}$ ≥36 months).

Numbers of fishers in age classes n_2, n_3, and n_4 for the **n** vector at time t_0 were based on the number of radiocollared female fishers present at the start of population year 3 on April 1, 2009 (n_2 = 5, n_3= 6, n_4 = 5, n_5 = 5), whereas n_1 was the number of juvenile females in the radiocollared population on Dec 31, 2009 (4 animals). We multiplied the Leslie matrix by the new vector of abundances for N_{t+1} for 20 successive years, and summed the number of individuals in each age class each year to obtain a total N, and the population growth rate (λ) for year t+1 was calculated as N_{t+1}/N_t. After several years a stable age distribution was achieved and λ converged to a constant value, which was the estimate of λ for the set of demographic parameters evaluated. We calculated a lower and upper range for λ based on the 95% lower and 95% upper C.I.s for age-specific survival and age-specific fertility. Finally, due to uncertainty in estimates for several demographic parameters related to methodology [small body size prevents radiotelemetry-based monitoring of survival for juveniles until 6 months of age (Facka et al. 2013); teat measures used to identify weaning for a small subset of adult females were less than 100% accurate in assigning reproductive status (Matthews et al. 2013*a*)], We evaluated the sensitivity of the matrix model to 20% reductions in rates of survival and fertility for each age class. Fertility is linked to age-specific survival according to Equation 1, and changes to fertility associated with reductions in survival were carried into the model when evaluating sensitivities.

Population Size and Density

Background

Information on population size and demographic parameters are fundamental for managing wildlife populations, especially when declines in abundance or range size have occurred and the species is the focus of conservation management. As previously noted, the overall southern Sierra Nevada fisher population is small (<350 adult fishers; Spencer et al. 2014), but appears to be stable over about the past decade (Zielinski et al. 2013). Research focused on the ecology and habitat use of fishers in the southern Sierra Nevada has been ongoing since the mid-1990s (Jordan 2007, Mazzoni 2002, Truex et al. 1998), but primarily for the area encompassed by the Kings River Fisher Project in the High Sierra District, Sierra National Forest (Fisher Habitat Core area 4; Fig. 2). For that area, Jordan et al. (2011) used a capture-mark-resight/recapture design (CMR) to estimate a density of 0.063-0.109 fishers/km^2 in 2002-2004, whereas Thompson et al. (2012) used scat detector dogs and genetic detections in a spatially explicit CMR framework to estimate a fisher density of 0.065-0.28 fishers/km^2. Information on density is needed for other areas of the southern Sierra Nevada as well, because as the area of suitable habitat available to fishers in the southern Sierra Nevada is refined by improved modeling (Fig. 2; Spencer et al. 2014), density values can be used to develop more accurate estimates of fisher abundance for conservation planning. Information from the SNAMP Fisher study has aided the process by providing current data on population size and density for the Fisher Core Habitat area 5 (Table 2). Here, we estimated fisher population size and density in the middle four years of the study using mark-resight techniques (McClintock and White 2009) from camera trap surveys and live trapping.

General Methods for Camera Surveys and Camera Traps

Motion sensing camera traps (Silent Image Professional, Rapidfire PC85; RECONYX Inc., Holmen, WI) were systematically deployed near the center of 1–km^2 grids in the study area beginning at the start of each of five “fall-winter” camera survey years (October 15-October 14 the following year). Placement of camera traps within 1-km^2 grid cells was determined based on the presence of habitat elements important for fishers (e.g., presence of mature or large diameter trees, moderate to steep slopes, canopy cover ≥60%, proximity to permanent streams; Purcell et al. 2009, Zielinski et al. 2004). Cameras were focused on bait trees upon which we attached baits and applied scent lures as attractants. Baits were small pieces of venison (140-250 grams) in a dark colored sock (reduced consumption by insects), and 8-10 hard-shell pecans strung onto a wire (initial purpose was to index squirrel abundance, but were also consumed by fishers). Scent lures were Hawbaker's Fisher Scent Lure (Fort Loudon, PA) dabbed on the bait sock, Caven's "Gusto" scent lure (Minnesota Trapline Products, Pennock, MN) applied near the base of the bait trees and on several nearby trees, and ~4 grams of peanut butter smeared on the nut ring (Popescu et al. 2014). Camera survey stations were typically visited (checked) every 8-10 days over 32-40 days to refresh scent lures and bait, and to maintain camera units, but the protocol varied depending on whether the survey station was within the Key Watershed part of the study area, or outside that area. Survey cameras within the Key Watersheds were left in place a minimum of 32 days (four 8-10 day checks), whereas cameras outside this area were deployed for a minimum two 8-10 day checks but removed on check two or three if fishers had been detected. We removed survey cameras after four checks unless the unit had been disturbed (most frequently by black bears, *Ursus americanus*) to where the bait tree was out of view or if the unit had been inoperative due to expended batteries or malfunction for more than five days during a check period. In those cases the survey was extended by one or more 8-10 day periods to assure adequate survey effort (Slauson et al. 2009).

Camera surveys, live trapping, and radiocollar data.—Camera surveys were done during all months of each camera survey year, but the time frame of interest for this part of the study was October 15 to March 15, related to assumptions for mark-resight analyses of a closed population scenario. There are 145 1-km^2 grid cells within or overlapping the Key Watersheds boundary; 128 of them are at least 50% USDA Forest Service ownership, and were surveyed in all four survey years. A total 319 1-km^2 grid cells external to the Key Watersheds and within the study area boundary (Fig. 4) were surveyed in at least one fall-winter camera survey year, and 221 (69%) of those were surveyed in two or more years.

Full details on live-trapping to radiocollar and mark individual fishers was provided above. However, for the purposes of mark-resight analyses, data on captures and recaptures of known fishers were included in the mark-resight dataset. Also, fishers sometimes shed their radiocollars, or collars separated at the breakaways as designed. Dropped radiocollars were retrieved from the field, and the locations of shed radiocollars were included in the resight dataset.

Monitoring and home ranges.—Radio collared fishers were monitored for activity status and relocated 4-6 days/week throughout the year by fixed-wing airplane. Standard methods were used to obtain locations from the airplane as previously detailed, and mean error associated with aerial telemetry locations was estimated at 339 m.

Location records were used to develop home range models for individual fishers using the fixed kernel density method in Home Range Tools for ArcGIS 9.3 (Rodgers et al. 2007). Ninety-five percent fixed kernel home ranges were produced for individual animals for four fall-winter (October 15 to March 16) periods from 2008 to 2012 when ≥ 25 locations were available for an individual fisher. Home range area estimates from fixed kernel utilization distributions are sensitive to the choice of bandwidth as a smoothing parameter (Gitzen and Millspaugh 2003). We used the Ad Hoc method to identify the most appropriate reference bandwidth for smoothing fisher home ranges and minimizing formation of multiple polygons (Kie et al. 2010, Kie 2013).

Resighting and Mark-resight Analyses.—Radiocollared fishers detected by cameras were identified by the antennal pattern of bands of infrared reflective tape (Popescu et al. 2014). Detections of known fishers were counted once per camera station per calendar day. We were not able to unambiguously identify all radiocollared fishers detected at camera traps due to occasional loss of bands and breakage of antennas; these detections were scored as collared unknown. Non-collared animals were counted as unmarked seen.

We considered the population as approximating closure during Oct 15 to Mar 16 because (1) most mortalities in the study site occurred between mid-March and September, (2) natal dispersal by juvenile-age fishers in the population was focused during March to August, and (3) fisher reproduction in California begins the third week in March (Matthews et al. 2013*a*, this study). Data on individual fisher resightings at camera stations or live traps were scored based on presence within 1-km^2 grid cells. Individual animal detection histories were developed identifying whether fishers were available for resighting based on the presence of survey cameras or live traps within the boundaries of their 95% fixed kernel fall-winter home ranges. Data were also compiled on the numbers of survey cameras and live traps deployed, survey camera nights, and live trap nights for the fall-winter resight period.

Illustration 10. Example of infrared tape on collar antenna used to identify individual fishers for mark-resight analyses.

The resighting data were analyzed using robust design mark-resight, log-normal Poisson models (McClintock and White 2009). The mark-resight robust design is analogous to the mark-recapture robust design of Kendall et al. (1995) and Kendall et al. (1997), in that it allows for individual covariates in modeling resighting probabilities, and an open population between primary sampling occasions. Along with data on marked animals, mark-resight models incorporate sightings of unmarked animals, while the robust design allows for estimating abundance (*N*), apparent survival between primary intervals (ϕ), mean (α) and overall resighting probabilities (λ), random individual heterogeneity (σ^2), and transition probabilities between observable and unobservable states (γ'' and γ') (McClintock and White 2009). The parameter of interest, abundance (*N*), is a derived parameter, as Poisson log-normal models estimate the number of unmarked individuals in the population, *U* (McClintock and White 2009).

The Poisson log-normal mark-resight model takes the following form:

$$[\alpha(.)\ \sigma(.)\ U(.)\ \phi(.)\ \gamma''(.)\ \gamma'(.)]$$

in which ϕ and γ'' (and γ') were modeled using a *sin* link, while α, σ, and *U* were modeled using a *log* link.

The model assumptions are: (1) geographic closure, (2) population closure within primary intervals, (3) no loss of marks, (4) no error in identifying marked and unmarked animals, (5) equal resighting probability for both marked and unmarked individuals, and (6) sampling is with replacement within secondary periods (McClintock and White 2009). We used camera survey years as the primary sampling intervals and the number of resights and live trap recaptures for marked fishers within each primary occasion as the resighting histories (Appendix I). Along with capture histories, robust-design Poisson log-normal models require three other quantities: (1) marked superpopulation, the number of marked individuals known to be in the population during primary interval *j*, (2) number of times marked individuals were sighted, but individual marks could not be identified, and (3) total unmarked individual sightings during primary interval *j*.

Because camera and live trapping was unbalanced across the study region among years, we added a grouping variable for subregion, with three subregions defined by the spatial segregation of camera trap efforts (Fig. 6) Each fisher was assigned to a particular mark-resight subregion based on the position of its 60% fall-winter home range isopleth. In addition, we included *area* and *time* (primary sampling interval) covariates, *cams* (camera effort for each subregion during each primary sampling interval in hours), and *live* (number of days live trapping was conducted) to account for variation in resighting probabilities, individual covariates *weight* and *sex* to account for individual and gender-based resighting probabilities. In the model parameterization, state transition probabilities remained constant [$\gamma'(.)$ and $\gamma''(.)$], apparent survival was modeled as function of region [$\phi(area)$], and different combinations (additive and interactions) of the individual and time and region-based covariates were allowed.

We considered 19 candidate models and used AICc [Akaike Information Criterion adjusted for small sample size; (Burnham and Anderson 2002)] to rank models. We used model averaging for the top ranked models with a cumulative Akaike weight >0.95 to compute parameters and unconditional variances. The *Area* grouping parameter allowed for estimating population size and density for each subregion separately. We conducted analyses in program RMark v2.1.7 (Laake 2013) for R 3.0.2 (R_Core_Team 2013), which is an interface for program MARK (White and Burnham 1999). Lastly, the subregion and year-specific abundances were converted to densities by dividing population estimates by the area sampled by cameras and traps for each subregion and year. Areas sampled were estimated from subregion- and year-specific polygons created in ArcGIS 10.2 that encompassed the centroids of all 1-km^2 grid cells with a survey camera or a live trap with a fisher capture during October 15 to March 16. We then plotted the fall-winter home ranges with the sampling polygons, and, based on visual assessment of spatial intersection of the 95% home range isopleths, applied a 1300 m buffer for each polygon. The width of the buffer for the polygons was the radius of the mean 95% fixed kernel fall-

Figure 6. —Map illustrating the outlines of subregions used to organize camera trap and live trap data for mark-resight analyses. The study area is within the Bass Lake Ranger District, Sierra National Forest, California, but also included a relatively small portion Yosemite National Park.

winter home range for subadult and adult female fishers in the population (mean = 20.8 km^2 ± SE 0.89, *n* = 70; Jordan 2007), which encompassed most areas used by radiocollared fishers resident in each subregion and excluded areas below or above the typical elevation range of fisher camera detections in the study area.

Dispersal Movements

Background

By simply moving from one habitat patch to another, dispersal of individuals has consequences not only for fitness, but also for population dynamics, population genetics, and species distribution at the landscape scale (Chepko-Sade and Halpin 1987, Lambin 1994, Clobert et al. 2001). For these reasons, processes that foment dispersal behavior have been the focus of research interest in relation to inbreeding avoidance, intraspecific competition for mates and resources (Estes-Zumpf and Rachlow 2009, Wolff et al. 1988), and costs and benefits of dispersal, particularly in relation to gender (Pusey 1987).

Natal dispersal, permanent movement from the natal area to the location where individuals reproduce or would have reproduced depending on survival (Howard 1960), is the most common type of dispersal. Gender bias in which one sex, typically males, disperses more frequently or farther than the other, has been documented in many mammals (Greenwood 1980; Pusey 1987, Sweitzer and Berger 1998). Proximate mechanisms triggering natal dispersal and potentially influencing dispersal distance include population density (Gaines and McClenaghan 1980), habitat quality (Lidicker 1975), and body condition (Dufty and Belthoff 2001, Nunes and Holekamp 1996). Information on dispersal provides insights on how far, and over what sorts of terrain, individuals may move and therefore how populations may be demographically and genetically interconnected or isolated. Barriers or impediments to dispersal reduce gene flow and may prevent populations from colonizing or recolonizing suitable habitat areas.

Dispersal behavior by fishers is of high management interest in California where the species currently occupies less than half of its historical range as described in the early 1900s (Grinnell et al. 1937). In the southern Sierra Nevada conservation planning area, fishers occupy approx. 4,400 km^2 of mid-elevation, mixed-coniferous forest between the Merced River in Yosemite National Park in the north to the Greenhorn Mountains in the Sequoia National Forest in the south (Fig. 2, Table 2). The southern Sierra Nevada population does not appear to be expanding geographically (Zielinski et al. 2013), despite changes in management promoting redevelopment of suitable fisher habitat in the Sierra

Nevada (North et al. 2009). Dispersal movements by fishers are potentially inhibited by exposure to multiple restrictive habitat and landscape features (Spencer et al. 2014, Tucker 2013). Moreover, Matthews et al. (2013a) suggested that because of their relatively limited vagility, conservation-directed management to promote fisher recovery in formerly occupied portions of their range in California may require translocations, unless population growth rates significantly exceed 1.0.

We used information on juvenile home ranges, likely maternal home ranges (determined by genetic analyses), and adult home ranges to evaluate patterns in natal dispersal for fishers in the SNAMP Fisher study area. We hypothesized that (1) young male fishers would disperse at a higher rate than females, (2) dispersal distances for males would be longer than for females, and (3) long distance movements would be more frequent for males compared to females. Because of their large home ranges, dispersal movements by fishers may be mediated by restrictive landscape features (Carroway et al. 2011). Therefore, in addition to estimating Euclidean distance between juvenile or maternal home ranges and adult home ranges, we also used a least-cost corridor analyses with an expert opinion-based cost surface to estimate both short and longer distance movement paths associated with natal dispersal.

Assessing dispersal using home range models

Location records were used to develop home range models for individual fishers using the fixed-kernel density method in Home Range Tools for ArcGIS 9.3 (Rodgers et al. 2007; ESRI, Redlands, CA). We developed 95% fixed-kernel home range models for juvenile, subadult, and adult-age fishers when ≥ 25 locations were available for the pre-dispersal or post-dispersal period of interest. Approximate center positions (centroids) were estimated for each home range using the XTools extension in ArcGIS (Data East LLC, Novolsibirsk, Russia). Because both area estimates and shapes of fixed kernel home ranges are sensitive to the choice of bandwidth as a smoothing parameter (Gitzen and Millspaugh 2003), w used the Ad Hoc method to identify the most appropriate reference bandwidth for smoothing fisher home ranges and minimizing formation of multiple polygons (Kie 2013). Finally, in some cases radiocollars were shed by juveniles within a few weeks of initial capture, before ≥25 locations records had been acquired. In these cases we used centroids from 100% Minimum Convex Polygons for natal area centroids (Aubry and Raley 2006).

Dispersal distance by Euclidean geometry

Minimum distances moved between natal or maternal home ranges, and subadult or adult home ranges were estimated as the Euclidean distance between each pair of centroids. For juvenile fishers without maternity assignments, we used fall and winter location records to identify a centroid for natal areas, but excluded locations that were associated with initiation of dispersal. Fall and winter location records for juvenile fishers were visually screened in ArcGIS to identify calendar dates associated with initiation of the exploratory, or transitional period of the dispersal process (Vangen et al. 2001). Location datasets used to develop home ranges for juvenile fishers (natal area home ranges) were truncated by date to exclude transitional movements. Transitional movements were not apparent for all juvenile fishers, however, and in these cases we used the pool of location records from capture to approx. March 31 for the natal area home range.

Microsatellite genetic analyses for identifying maternity

We used microsatellite genotypes to assign maternity for juvenile and subadult fishers, which allowed for estimating natal dispersal from the centroids of denning season home ranges for their mothers. Whole genomic DNA was extracted from fisher tissues and hair using the QIAGEN Dneasy Tissue Kit (Qiagen, Valencia, CA, USA) according to manufacturer's instructions. We analyzed 111 samples at the following thirteen microsatellite loci: *Ma1*, *MP059*, *MP144*, *MP175*, *MP197*, *MP200*, *MP247*, *Ggu101*, *Ggu216*, *Lut604*, *Lut733*, *Mer022* and *Mvis002* (Davis and Strobeck 1998; Flemming et al. 1999, Dallas and Piertney 1998; Jordan et al. 2007). These loci were previously found to be variable in fishers in the Southern Sierra (Jordan et al. 2007; Tucker et al. 2014).

Maternity of kits was evaluated using two approaches; the first was by evaluating allele sharing. Fishers in the southern Sierra Nevada were previously known to be genetically limited (Wisely et al. 2004, Knaus et al. 2011), and prior to step 1 we used insight from field associations (capture positions, home range patterns, denning season data to identify small subsets of 3-6 adult females considered possible mothers for each juvenile/subadult. These subsets of possible mothers were further narrowed to a smaller “candidate set” by excluding those that did not share alleles with the juveniles. We applied the maximum likelihood approach in program CERVUS v3.03 (www.fieldgenetics.com) to evaluate the candidate set of females for maternity assignment. CERVUS is a Windows-based software package for inferring parentage in natural populations wherein laboratory typing error is considered along with data on population allelic frequencies, the number of candidate mothers, and the proportion of potential mothers sampled in Monte Carlo simulations, which produce confidence levels for the candidate set of putative parents (Slate et al. 2000). The confidence measure of CERVUS is based on delta, which is the difference between the likelihood ratio for the most likely candidate and the second most likely candidate (Marshall et al. 1998). We assigned maternal-offspring pairs based on likelihood ratio LOD scores (natural log of the likelihood ratio) using both strict (99%), and relaxed (95%) confidence. In the last step we considered the maternity assignments with field data to verify, or select the next most likely female from the LOD scores based on the known biological status of putative mothers (reproductive or non-reproductive, age as juvenile, subadult or adult in the season juveniles were born). In several cases, the overall analysis was unable to link juveniles to a known, radiocollared female in the population. Developers of CERVUS previously determined that the analytical procedure correctly assigned parentage for ~92% of known fathers in red deer (*Cervus elaphus*)(Slate et al. 2000). In our study we evaluated the performance of CERVUS to correctly identify mothers using five known mother-offspring pairs.

Dispersal distances for juvenile or subadult-age fishers with maternity assignments were estimated as the Euclidean distance between the centroid of the denning season home range of the mother, and the centroid for the subadult or adult home range where the juvenile settled. In some cases the mother had not been monitored during the denning season when a juvenile was produced. In these cases we used the centroid for the female's "annual" home range. Annual home ranges were calculated when we had at least 75 location records, with a minimum of five locations in at least three of the four seasons of the year. Seasons were spring (Mar 21 to Jun 20), summer (Jun 21 to Sep 20), fall (Sep 21 to Dec 20), and winter (Dec 21 to Mar 20).

Least-cost paths for natal dispersal

Dispersal is most often reported as the Euclidean, or straight-line distance between the natal area and the subadult or adult home range (Matthews et al. 2013). Fishers in the southern Sierra Nevada inhabit mountainous areas within a limited elevation range and with a mix of forested areas with mild topography, and ridges and deep river canyons with extreme topographic relief. In these types of landscape and habitat conditions opportunities for straight-line movement traversing multiple kilometers will be constrained.

Least-cost modeling is an approach for assessing potential animal routes across the landscape based on the assumed cost of movement between locations or termini (Beir et al. 2008). Least-cost models have previously been used to predict dispersal paths for mammals from empirical data (Driezen et al. 2007), and we took a similar approach in this study. Connectivity analysis was performed between centroids of natal and established juvenile home ranges for 24 female and 20 male fishers with Linkage Mapper (McRae and Kavanagh 2011). Linkage Mapper uses a resistance to movement (cost) surface layer to delineate least cost paths between focal point pairs. A cost surface layer was developed that assigned a resistance score (inverse permeability value) representing the cost to fishers of moving through each land cover type, including potential risk and averse responses to roads and steep topography in river canyons (Fig. 7).

Expert opinion resistance scores were modified from those developed previously for Sierra Nevada fisher least-cost corridor models (Spencer and Rustigian-Romsos 2012) by (1) simplifying the land cover divisions, (2) expanding the overall cost range, and (3) incorporating recent published and unpublished data on fisher ecology summarized in a conservation assessment developed for fishers in the southern Sierra Nevada by a group of 13 research scientists (Spencer et al. 2014). We used the Polynomial Approximation with Exponential Kernel (PAEK) algorithm in ArcMap 9.3.1 (ESRI 2009) to smooth the movement paths for purpose ~~of display~~. Length of least cost paths between juvenile or maternal home range centers and subadult or adult home range centers were calculated in ArcGIS 10.2. Basic metrics on least cost paths (means, range, standard error of the mean) were produced and summarized for comparison with mean dispersal distances from Euclidean geometry.

Analysis

Mean dispersal distances were compared between female and male fishers using two-sample *t*-tests. We also assessed potential gender differences in dispersal behavior using Pearson χ^2 or log-linear model analyses. We used dispersal distances to classify each fisher as being either philopatric (dispersal distance ≤ 5.4 km) or a disperser (dispersal distance > 5.4 km), where 5.4 km was the diameter of average 95% fixed kernel home range of adult females fishers in the study population (22.93 km^2, n = 56; Table 31). We also assessed the overall pattern in dispersal behavior by assessing the proportion of each gender that was very philopatric (dispersal distance <2.7 km; one-half the diameter of the mean 95% fixed-kernel home range for adult female fishers), short distance philopatric (2.7 km ≤ dispersal distance < 5.4 km), a mid-distance disperser (5.4 km ≤ dispersal distance < 10.8 km), or a long distance disperser (dispersal distance greater than 10.8 km; 2x the diameter of the average adult female home range).

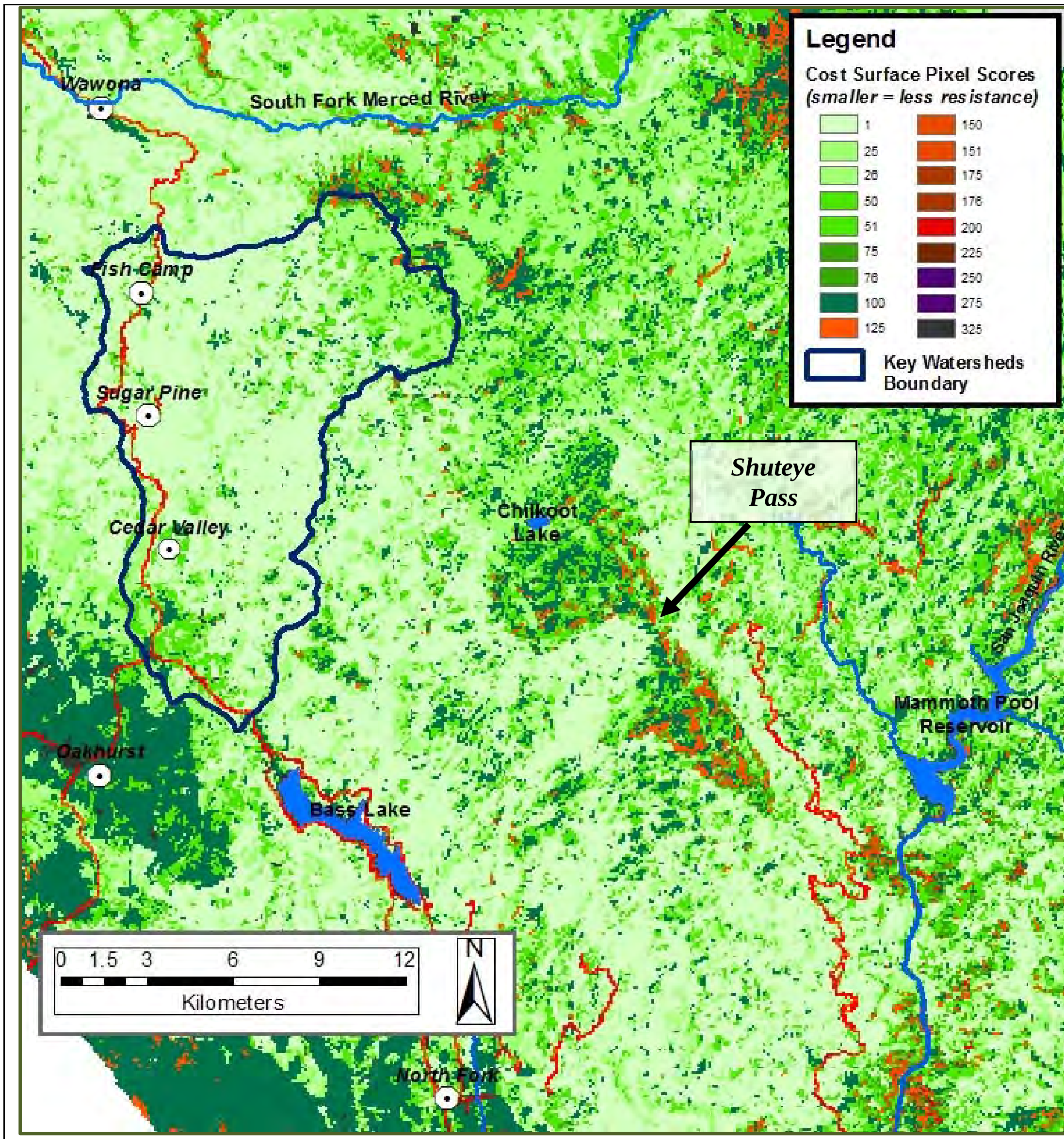


Figure 7. Illustration of the Expert opinion cost surface used to develop Least Cost movement path for dispersing fishers. The map encompasses the portion of the SNAMP Fisher Study Area including the Key Watersheds and the area to the southeast including Chilkoot Lake and Mammoth Pool Reservoir. NOTE: Chilkoot Lake is at the northwestern edge of the Chiquito Ridge, a high elevation region including Little Shuteye Peak, Shuteye Peak, and Shuteye Pass; notice the narrowness of restrictive habitat at the Shuteye Pass topographic feature.

Home Range Dynamics Methods

Background

Among terrestrial vertebrates, mammalian carnivores have the largest home ranges for their body size of any organism. The fisher, like other mammalian carnivores, occupies a relatively large amount of space for its body mass, with average annual home range areas of 38 km^2 for adult males and 15 km^2 for adult females across North America (Powell 1994). Studies of the two remnant populations in California have produced home range area estimates generally consistent with North American averages: 22 to 58 km^2 for adult males and 5 to 15 km^2 for adult females (Boroski et al. 2002, Zielinski et al. 2004). Zielinski et al. (2004) also reported intraspecific variation in home range size between adult females of the northern coastal and southern Sierra Nevada populations.

Intraspecific variation in home range size has been linked to ecological factors such as population density, prey availability, body mass, and latitude (Buskirk and McDonald 1989, Gompper and Gittleman 1991), and to methodological factors such as sampling interval and duration (Buskirk and McDonald 1989, Swihart and Slade 1985). Our review of the literature suggests that little attention has been paid to potential relationships between home range size and field techniques used to obtain animal locations. Further, the choice of an appropriate bandwidth, or smoothing parameter when creating utilization distributions is a critical step during kernel-based home range estimation in need of standardization (Kie et al. 2013).

We present and discuss home range dynamics for fisher in the Sierra National Forest, while also describing seasonal variation in home range movements for female and male fishers. We hypothesized that aerial telemetry would be more likely than ground telemetry to detect animals outside of their core use areas and during dispersal events and sallies, and would therefore produce larger home range estimates. Our primary objective was to compare our fisher home range sizes with those generated by other studies in the southern Sierra Nevada, where ecological factors would be held relatively constant. Additionally, we ~~wished to~~ characterize variation in space use between genders, among age classes, and across seasons for our study population.

Locations and analyses

Fisher locations from live-trap captures, dropped or shed radiocollars, carcasses, dens and rest trees, camera trap detections, a small number of GPS radiocollars (Telemetry Solutions, Livermore, CA) and position estimates from fixed-wing aerial radiotelemetry (Table 3) were used to delineate home ranges. Accuracy of locations obtained by homing to den tree or rest tree locations by ground telemetry, camera trap detections, capture positions, and carcass and dropped collar positions were generally ± 15 m from a handheld global positioning system device. We addressed and minimized autocorrelation by discarding locations in excess of two per animal per day, or less than 8 hours apart per individual. Location records were used to develop home range models for individual fishers using the fixed kernel density method in Home Range Tools for ArcGIS 9.3 (Rodgers et al. 2007). Ninety-five percent fixed kernel home ranges were produced for individual animals for four seasons, and for "annual" population years. Seasons were defined as follows: fall - September 21 to December 20; winter - December 21 to March 20; spring - March 21 to June 20; summer - June 21 to September 20.Season-specific home range models were produced when ≥25 locations were available for a fisher. Annual home range models were developed when we had location records in fall, winter, and least one other season, and sample size was ≥75 for all annual home range models. Kernels were smoothed using the minimum proportion of reference bandwidth that produced a contiguous home range polygon (Kie 2013). Areas (km^2) of home ranges were calculated during kernel processing. We tested for differences in home range areas between males and females, stratified by age and season, using two sample t-tests ($P<0.05$). Potential differences in home range size among seasons was assessed using repeated measures analysis of variance (ANOVA) ($P<0.05$).

Table 3. Types of locations determined for fishers during the study period from December 2007 to December 2013. Data are for research in the Bass Lake District, Sierra National Forest, CA.

Location type	No. of locations	UTM accuracy	Description of methods and details
Aerial telemetry[a]	31,367	± 339 m	Standard methods by fixed-wing airplane (Sweitzer 2013)
Camera trap detections	2,454	± 10 m	Position of camera trap; individuals fishers identified by infrared tape on radiocollar antennas (Popescu et al. 2014)
GPS radiocollar[b]	633	± 15 m	Used on limited number of animals (N = 8) in 2009 and 2010
Den or rest tree	526	± 10 m	Homing to trees by ground radiotelemetry during spring denning seasons; did not identify rest trees in other seasons
Live trap capture	277	± 10 m	Trap positions for known ID captures; most live-trapping was in October to March
Shed radiocollars, fisher carcass	97	± 10 m	Homing to inactive signals by ground radiotelemetry

[a] Accuracy determined as the mean Euclidean distance between aerial telemetry location and fixed position of test collars (n = 501) on the ground. Test locations also included locations to dropped radiocollars, carcass locations, and fishers in live traps (Technicians were "blind" to locations of test collars, or other test locations).
[b] Used for limited duration and primarily on male fishers (596 locations for 6 different males; 37 locations for 2 females). SNAMP Fisher ceased using GPS collars due to poor reliability and bias in fix rates; fix rates were high when GPS collars were left in open areas with mild topography, and low when GPS collars were placed at locations with dense overhead canopy and steep topography.

SNAMP Fisher Management Indicators

Background

In 2008 there was great interest in new information developing from SNAMP Fisher that might be important for management and management planning. We therefore developed three Indicators for fisher management that would provide insight on the status of the study population of fishers in the Bass Lake District, Sierra National Forest. These management indicators were chosen based on information that could be summarized annually, and that linked to the likely responses of fishers to management and potential habitat change at the local (sub home range scale), home range, and population level (larger landscape scale relevant to District-level forest management; Table 4).

Table 4. Overview of potential negative effects of fuel reduction treatments and other forest management activities on the biology and natural history of fishers, organized according to three scales in the SNAMP Fisher study area, Bass Lake District, Sierra National Forest.

Scale of effect, Description	*Likely response*	*Data requirements*	*Management Indicator*
LOCAL: SPLATS may cause habitat patches to become less suitable for current use; foraging, refuge/escape cover	Use of treated areas declines or ceases	Before/After and ongoing use of areas altered by management activities	Use of 1-km^2 grids within Key Watersheds (or in other areas), estimated annually using camera trap surveys
HOME RANGE: SPLATS may reduce availability of key resources such as den sites, rest sites, availability of prey	Individual fishers cease use of treated areas	Monitor individual fishers, acquire locations, develop home range models, track dispersal movements	Estimate of the number of individual fishers using the Key Watershed focal study area during population years
POPULATION/REGION: Multiple projects implemented every few years may degrade suitable habitat for fishers; population source areas become sink areas	Survival and reproduction decline; population size and density decline over time	Information on survival and reproduction of individual fishers in the overall study area (min 20 fishers monitored by radiotelemetry at all times)	Survival and reproduction of fishers in the overall study area. Estimate population growth rate, evaluate population viability in the Sierra National Forest

Management Indicator 1: Occupancy/Activity of fishers within Key Watersheds.

Beginning October 2007 we implemented regular camera trap surveys of all 1-km^2 grids that are partly or entirely encompassed by the boundary of the SNAMP Fisher Key Watersheds (Fig. 4). Several grids that were predominantly private lands (e.g., the Fish Camp area), or that were below the typical elevation range of fishers in the region (< 914 m) were not surveyed unless we had permission of access from the landowner. The annual resurvey of the Key Watersheds was a research priority in all years, and camera trap surveys were initiated at the start of each camera survey year (mid-October), continuing until most grids had been surveyed by late winter or early spring. High elevation areas (northeast portion of Key Watersheds) were generally surveyed first, due to more difficult access during mid and late winter. Deep snow conditions in most winters required use of snowmobiles or an all-terrain-vehicle modified with tracks to access high elevation grid centers. Results of the Key Watersheds camera surveys were summarized according to (1) fisher presence or absence, and (2) level of fisher activity based on the number of days fishers were detected in each grid.

Management Indicator 2: Number of resident female and male fishers using the Key Watersheds area.

Juvenile fishers exhibit exploratory movements, and sometimes dispersed away from their natal areas where we first captured and monitored them. Dispersal by juvenile fishers often extends into summer when they are 13-15 months old and considered subadults. We considered subadult fishers (12 to 23 months old) to be "settled" after natal dispersal in late August/September. Ninety-five percent fixed kernel home range models were developed from location records during September 1 to March 15 for all radiocollared fishers (Sept-March home range). Analyses were completed in ArcGIS 9.3.1 to estimate the proportion of each Sept-March home range for subadult and adult fishers that were included or "intersected" within the boundary of the Key Watersheds. Management Indicator 2 was calculated as the sum of the proportions of individual subadult and adult Sept-March home ranges within the Key Watersheds focal study area. Management Indicator 2 was calculated for female and male fishers for each of six September to March 15 periods beginning September 2008 and ending March 2013.

Management Indicator 3: Survival of adult-age female fishers in the SNAMP Fisher Study Area

Survival, and survival of adult females in particular, is an important demographic parameter necessary for understanding the population growth trajectory for most vertebrate wildlife species (Murdoch et al. 2010). All radiocollared fishers were monitored 4-6 days/week by fixed-wing aerial telemetry to assess live/dead status. Information on survival status for radiocollared fishers was organized by month of each population year (Apr 1 to March 31), and analyzed using the Kaplan-Meier (KM) staggered entry method (Koen et al. 2007, Pollock et al. 1989, Price et al. 2010). KM models were used to produce estimates of annual survival and combined year survival for the study population. Annual survival can be moderately to highly variable, thereby suggesting a negative population growth trajectory that may not be appropriate for a long-lived species with a generation time of two or more years. We therefore combined monthly data on survival status for individual fishers for five 2-year periods (population years 2 and 3, population years 3 and 4, population years 4 and 5, population years 5 and 6, population years 6 and 7) beginning April 2008 and ending March 2014. We further extended the inference for this management indicator by estimating survival for juvenile and subadult females, and by compiling data on weaning reproductive rates and weaning litter sizes from data collected on fisher reproduction during April 2008 to June 2013. These data were used to estimate fertility rates, which, along with data on juvenile, subadult, and adult female survival, were used to estimate deterministic population growth rates using a four age class Leslie Matrix population model.

Fisher response to fuel management

Occupancy modeling

For the purpose of occupancy surveys, we deployed cameras in the 128 1-km^2 grids that were ≥50% public lands and within the 4 focal watersheds. We also deployed cameras in areas with recent histories of extractive or restorative fuel reduction, between 2002 and October 2008, or because forest management projects were planned to occur in the areas before December 2011. Most of these grids were repeat surveyed in 7 different camera years, as part of our initial plan of using a BACI framework for the occupancy analyses (Popescu et al., 2012). However because we were not aware of all planned or prior Forest Projects within the study area when the project was initiated, some of the multi-season grids were added to the group that were repeat surveyed several years after the first camera year (2007-08).

The distribution of fishers in the southern Sierra Nevada, CA is constrained by elevation, and closely associated with mixed-conifer forest habitats with relatively large trees, and high canopy cover (Davis et al., 2007). We therefore developed local, patch-specific biophysical covariates for use in analytical models of occupancy. We calculated the mean elevation (*elev*) for each surveyed grid, which was always included in occupancy analyses with its quadratic term *(elev^2)*. These covariates were standardized. Habitat covariates included the proportion forest (i.e., total tree) and hardwood cover (*denMD*) based on land-cover data derived from satellite imagery (CWHR CalVeg; USDA Forest Service 2012). We did not include covariates representing average tree size and slope because of their colinearity with forest cover and elevation.

There were a diversity of forest management activities that occurred on the Sierra NF from 2002 (5 years before the start of our study) until the last camera survey year starting in October 2013 (period 2002 to 2013). Most of the management activities we used for covariates were developed from the USDA Forest Service FACTs database. FACTs (Forest Service Activity Tracking System; http://www.fs.usda.gov/main/r5/landmanagement/gis), is a tracking system including a geospatial database of forest management activities that occur on national forest service lands in California and elsewhere (FACTs User Guide 2013). Polygon layers included in the FACTS database are associated with attributes detailing management activity codes, and dates for when activities were initiated and completed. There are known uncertainties in FACTS with regard~~s~~ spatial precision, area of treatment polygons, and lack of details on whether a treatment activity was completed for an entire polygon (Garner~~,~~ 2013). We also know that some entries represent perimeters encompassing smaller subunits treated at the same time as well as some areas unaffected by the management activity (Zielinski et al., 2013). Nevertheless, FACTS data constitute the best available and consistent record of the annual management activities that occurred on national forest lands in our study area.

Two recent studies used FACTS information to assess how fishers respond to disturbances from Forest Projects elsewhere in the southern Sierra Nevada (Garner 2013; Zielinski et al., 2013). We considered FACTS activities that were previously used in those studies, but also reviewed full descriptions of each management activity included in the FACTs User Guide (2013) when identifying a subset of 24 that were considered as potentially influencing local scale habitat use by fishers related to how each altered forest habitat structure or if they represented significant ground-disturbing activities (Zielinski et al., 2013; FACTs User Guide 2013). For example, we included forms of harvest (e.g., code 4152 Group Selection Cut) and vegetation management (e.g., code 4220 Commercial Thinning, code 4580 Mastication/Mowing) that would ~~have direct effects on the basis of their disturbance and alteration of~~ forest structure (Zielinski et al., 2013). We excluded activities that did not meet this criterion, and several that rarely occurred, or that silviculturalist Dave Smith with the Sierra NF recommended against using (e.g., code 4290 Administrative Changes; code 4314 Pretreatment Exam for Reforestation; code 4530 Prune; code 4511 Tree Release and Weed; code 4552 Area Fertilizing; code 4980 Other Tree Improvement; code 4540 Control of Understory Vegetation).

There were 4 other activities or events that were not systematically tracked by the FACTS system; hazard tree removals (e.g. hazard tree logging), private timber harvests (THPs), and historical or recent wildfires. Hazard tree logging was the removal of medium and large trees (no DBH restriction) within 91 m of forest roads when they were considered likely to fall during storms, or if they were decadent or diseased (SNFP 2004). Information on hazard tree logging in the Bass Lake Ranger District was available for 2009, 2010, and 2011, and we were provided with GIS shapefiles identifying road segments along which hazard tree logging occurred. Private timber harvest occasionally occurred on large parcels of private land within or adjacent to the Sierra NF in Madera County and Mariposa County. Harvesting of timber on private lands in California requires preparation of Timber Harvest Plans (THPs) that are reviewed and approved by state agency Calfire, which was our source for geospatial data on private THP activities in Madera County and Mariposa County (ftp://ftp.fire.ca.gov/forest). Basic records on the estimated spatial extent of wildfires that occurred in the national forest portion of study area were maintained by the Sierra NF, and included polygon shapes and ignition dates of wildfires that occurred from 1911 to 2013. We also acquired geospatial data on natural ignition and management fires for Yosemite NP for 1930 to 2008, which was sufficient for our analyses because there were no camera surveys completed in southern Yosemite NP after May 2009. Attribute information included with the various geospatial data were used to assign activities and wildfires to individual camera survey years. For example, if a management activity was identified as completed before October 15, 2009, the disturbance was assigned to camera year 2008-09.

We used ArcGIS 10.2 (ESRI, Redlands, CA) to estimate the area of each 1-km^2 surveyed grid with hazard tree logging, private timber harvest, and wildfires, which were merged with the FACTs information for 2002 to 2013. After merging, we reviewed the entries, and removed polygons that were duplicated in several years (e.g. those with the same FACTS code with identical shapes and areas but with different years of completion). We also removed any duplicate wildfire records that were included in both the FACTs data and in the local Sierra NF wildfire database. We then used the detailed descriptions of each FACTs activity type to create 3 composite variables for use as covariates for occupancy analyses. Covariates for extractive fuel reduction (*log.5*) and restorative fuel reduction (*hazfuel.5*) included the cumulative areas of these activities in each grid in the 5 years immediately preceding each camera trap survey. For example, the *hazfuel.5* covariate for any grids that were surveyed in camera year 2012-13, was calculated as the sum of the areas (m^2) of all restorative fuel reduction activities that occurred in those grids during fiscal years 2007-08, 2008-09, 2009-10, 2010-11, and 2011-12, from which we calculated the proportion of the 1-km^2 grids disturbed by the treatment. Because of the coordinated series of extractive and restorative fuel treatments associated with SPLATs, multiple different treatments could be applied on the same forest stand within a 5 year period (Zielinski et al., 2013). It was therefore possible that the cumulative area of a grid that was treated during a 5-year period could exceed 1-km^2. In the few cases where this occurred (*hazfuels.5* only), the proportion of the grid treated was truncated at 1.0 (100%).

The third composite variable that was related to fisher presence in model analyses was for managed burning and wildfires within each 1-km^2 grid. When we reviewed the FACTS and Sierra NF and Yosemite NP databases, it was apparent that managed burning was uncommon in the study area during 2002 to 2013. Although managed burns were commonly planned in the Sierra NF portion of the study area as part of SPLAT-based fuel reduction, many managed burns were cancelled and not rescheduled because weather conditions were not suitable, or because burning was prohibited by the San Joaquin Valley Air District (D. Martin, personal communication). Also, a late summer managed burn in Yosemite NP in 2009 escaped containment and burned 7,425 ha (Big Meadow Fire), which discouraged other managed burns in the region for several years thereafter. We therefore combined information on managed burning and the longer time-series of wildfires in the study area into a single composite variable representing managed burn+wildfires within 50 years of a survey (*burn.1.50*).

We used multi-season occupancy models to evaluate the importance of forest management covariates to explain the persistence of fishers at occupied grids and colonization of unoccupied grids (Zielinski et al., 2013). We defined colonization (γ) as the probability that a grid unoccupied in year *t* would be occupied in year *t* +1, and modeled it as: $\text{logit}(\gamma) = \beta\gamma_0 + \beta_{\gamma 1}x_1 + \beta_{\gamma 2}x_2 + \ldots.$ We defined persistence as 1- extinction where extinction (ϕ) was the probability that a grid occupied in year *t* would be unoccupied in year *t* +1, and modeled it as: $\text{logit}(\phi) = \beta_{\phi 0} + \beta_{\phi 1}x_1 + \beta_{\phi 2}x_2 + \ldots.$ The multi-season models also included a component for occupancy in the initial year a site was surveyed: $\text{logit}(\psi_{\text{initial}}) = \beta_{\psi\text{initial}0} + \beta_{\psi\text{initial}1}x_1 + \beta_{\psi\text{initial}2}x_2 + \ldots.$

We created a detection history of whether a fisher was observed by a camera trap within each grid during each consecutive survey period after set-up or re-baiting for up to 5 8-10 day periods during a survey year. This was repeated for up to 6 consecutive years (e.g., 00101 00000 01110 00010 01101 00000) for every grid. If surveys did not occur during any of the 5 periods and 6 seasons at any of the grids these data were treated as missing data. Models were solved by maximum likelihood estimation (MLE) via R statistical software (Version 3.0.1, www.r-project.org) using the *unmarked* package and the *colext* function. (Fiske and Chandler 2011). We followed an information-theoretic approach for evaluating the relative importance of different candidate models, and for assessing the relative importance of individual covariates [sum of AIC weights (AIC_{wi}) for candidate models including each covariate; Burnham and Anderson 2002].

Covariates for potentially explaining detection probability included a categorical, first order Markov process reflecting whether a fisher was detected in the previous survey period in a season (*auto.y*; Hines et al., 2010; Slauson et al., 2012), the number of functional camera days in a survey period divided by 10 (*camdays*), *denMD*, and a categorical variable representing whether the survey was conducted in summer (*summer*) instead of in fall to spring.

Due to the smaller sample size of sites available for fitting multi-season models ($n = 361$), we only evaluated the role of forest management covariates (*log.5*, *hazfuels.5*, and *burn.1.50*) in explaining annual transitions in occupancy state (colonization and extinction). For the initial occupancy component of the multi-season models, we restricted potential explanatory covariates to *denMD* and $elev + elev^2$. For multi-model evaluations of multi-season models, we first fit models including all 8 combinations of the forest management covariates on the colonization component and an intercept-only extinction component. We considered any covariate with a relative importance value > 0.65 to be predictive and important for colonization. Next, we fit models including all 8 combinations of the forest management covariates on the extinction component multiplied by all combinations of colonization covariates identified as important. We deemed any covariate in the extinction models with a relative importance value > 0.65 as predictive for explaining local extinction. Finally, we computed model-averaged parameter estimates for the colonization and extinction covariates identified as important. Model averaging was based on only those models summing to the top 0.95 of model weights.

Integration

Development of vegetation map

We refer the reader to Appendix C for more complete details because we used the same mapping procedure at Sugar Pine as we did at Last Chance. In summary, we developed a pre-treatment vegetation map using a combination of LiDAR, high-resolution digital color-infrared (CIR) aerial imagery, and an intensive network of field plots. First, we used LiDAR and CIR data to create an initial polygon-based map where the polygons represented areas of homogeneous vegetation in terms of species, vertical structure, basal area, and canopy cover. We collected the LiDAR and CIR data before the SPLAT implementation, and we sampled vegetation at the field plots before and after treatment. We then used the field-plot data to impute detailed attributes (e.g., tree lists and fuels models) for each polygon. Thus, we derived two different maps (with and without treatment), which we used in fire and forest-growth modeling.

Modeling fire and forest dynamics

We again refer the reader to Appendix C for more complete details of the fire and forest-growth simulations because we followed the same general procedure at Sugar Pine as we did at Last Chance. We used FARSITE (Finney 1998) to simulate a likely wildfire scenario based on the weather conditions during the 2014 French Fire, which burned 13,837 ac (5,602 ha) 12.5 mi (20 km) southeast of the study area. We obtained weather information from the Batterson Remote Automatic Weather Station, limited to the active burning period of the French Fire (August-September 2014), which served as the basis of our fire modeling. Moisture content for live and dead woody fuels and live herbaceous fuels used in the model were equivalent to 97th percentile weather conditions. Our ignition location was established using fire-origin point data supplied by the Bass Lake Ranger District of the Sierra National Forest. Based on the mapped data, we identified an area with the highest ignition frequency, which was located on the west ridge of the Cedar Valley watershed (see Figure 1). The simulation duration was set to allow the fire perimeter to expand through the entire study area.

For all four scenarios (treated/fire, untreated/fire, treated/no fire, untreated/no fire), we then simulated 30 years of forest growth on the study area in 10-year time steps using the Forest Vegetation Simulator (FVS; Dixon 2002) with the Fire and Fuels Extension (FFE; Reinhardt and Crookston 2003). The simulations were performed using the integrated platform ArcFuels (Ager et al. 2006, Vaillant et al. 2011), which runs FVS-FFE to produce the forest structure inputs needed for FARSITE.

Assessing the effects of fire and SPLATs on fisher habitat

We identified canopy cover and large trees as the most important elements of forest structure for fisher habitat because fisher den and resting locations in the southern Sierra Nevada were associated with high canopy cover and large trees (Zielinski et al. 2004, Purcell et al. 2009, Thompson et al. 2011). We defined fisher habitat as forest stands where the canopy cover was ≥60% and the density of large trees (≥24 in [61.0 cm] dbh) was ≥15.4 trees/ac (38 trees/ha).

We defined the canopy cover threshold for fisher habitat as ≥60% because 95% fixed kernel home ranges for 16 adult female fishers in the Kings River Project area in the Sierra National Forest averaged 63% (Thompson et al. 2011). Furthermore, fisher resting habitat sites are characterized by high canopy cover that is typically >60% (Purcell et al. 2009, Thompson et al. 2011), and the California Wildlife Habitat Relationships database uses a 60% canopy cover threshold as one of the criteria in its definition of high-quality fisher reproductive habitat (California Department of Fish and Game 2008).

We defined a large tree as ≥24 in (61.0 cm) diameter at breast height (dbh) because resting trees at the lower end of the size distribution (i.e., mean minus the standard error) in two different studies were of a similar size (Zielinski et al. 2004, Purcell et al. 2009). Thus, any tree ≥24 in dbh was potentially suitable as a fisher resting site. Next, we determined the threshold density of large trees (i.e., 24 in dbh) by examining stand-level tree lists surrounding den locations of 28 female fishers in the Kings River study area from 2008-2013 (Rebecca Green, unpublished data). When there were multiple dens per female, we randomly chose a single den for that individual. Data for natal dens were used preferentially; natal dens were where the young were born. We used data at maternal den locations for 7 females for which natal den locations were not available; fisher young were moved to maternal dens when conditions were no longer suitable at the natal dens. We defined the threshold density for large trees as ≥15.4 trees/ac (38 trees/ha) because this was the median density of large trees surrounding the 28 den locations.

Results

Basic Fisher Population

A total of 110 individual fishers were captured in live traps as part of the SNAMP Fisher Project from Dec 2007 to Dec 2013 (62 females, 48 males). In the first 3.5 months of trapping in population year 1 we captured 3.6 noncollared ("new") fishers/100 trap nights, and 6.8 total fishers/100 traps nights. During population years 2008-09 to 2011-12 a mean of 0.94 previously unknown individual fishers were captured per 100 trap nights, and there ~~were~~ an average 2.43 total captures per 100 trap nights. Data on traps nights were not available for 2012-13 or for March to December 2013, when a total of 9 new fishers and 19 total captures occurred (Table 8).
No fishers died during capture and handling in the study. However, one adult female fisher captured in October 2009 did not fully recover. The female fisher was held in the trap cubby overnight for additional time to recover, but died the next morning while in transit to the Fresno Chaffee Zoo for treatment by a wildlife zoo veterinarian. A necropsy completed for the fisher identified her cause of

death as septicemia from a previously fractured jaw, which led to emaciation and starvation.

Table 8. Summary data on numbers of trap nights, new fishers captured, and recaptures for the SNAMP Fisher Project from December 2007 to December 2013. Population years start April 1 and end March 31

Population Year	Trap nights[a]	New individuals[b]	Recaptures	Total captures
2007-08	280	10	9	19
2008-09	2793	34	40	74
2009-10	2898	20	52	73
2010-11	2173	15	30	44
2011-12	1914	22	27	48
2012-13	*No data*[c]	8	11	19
2013[d]	*No data*	1	8	9

[a] Number of traps set for capture during an overnight period.
[b] Includes one orphan fisher kit captured in a live trap in 2010-11, and one orphan fisher kit captured in a live trap in 2011-12.
[c] PSW Forest Service trapping, no data on trap nights.
[d] Apr 1 to Dec 31; end of SNAMP Fisher.

An overarching goal of the study was to monitor a minimum of 20 radicollared fishers at all times, which was considered a requirement for producing reliable estimates of survival and reproduction for the population. The study achieved that milestone in mid July 2008, about six months after live trapping was initiated in late December 2007 (Fig. 10, Table 9). There were brief periods in several years when the radiocollared population declined below 20 individuals (Fig. 10). The annual oscillation in numbers of radiocollared fishers was related to the combination of dropped or shed radiocollars (breakaway units built into radiocollars parted as designed), and mortality which was focused during spring and summer in all years of the study. After the end of our annual pause in live trapping during the spring denning season, the number of radiocollared fishers gradually or rapidly increased when trapping resumed, and as young-of the-year juvenile fishers were recruiting into the study population in the fall and winter (Fig. 10). With the exception to the first and last year of the study, we were able to monitor survival for at least 40 different fishers in each population year. Notably, in 2011-12 we were monitoring more than 40 individual fishers for several successive months (Fig. 10, Table 9).

Table 9. Number of radiocollared fishers being monitored for the SNAMP Fisher Project at the start and end of six different population years.

Population Year	Start N	End N	Individual fishers N[a]
2007-08		7	11
2008-09	6	30	41
2009-10	30	32	51
2010-11	32	32	55
2011-12	32	44	59
2012-13	44	33	50
2013[b]	33	14	33

[a] Number of individual fishers radio-collared and monitored for ≥ 1 day

[b] Apr 1 to Dec 31; end of SNAMP Fisher

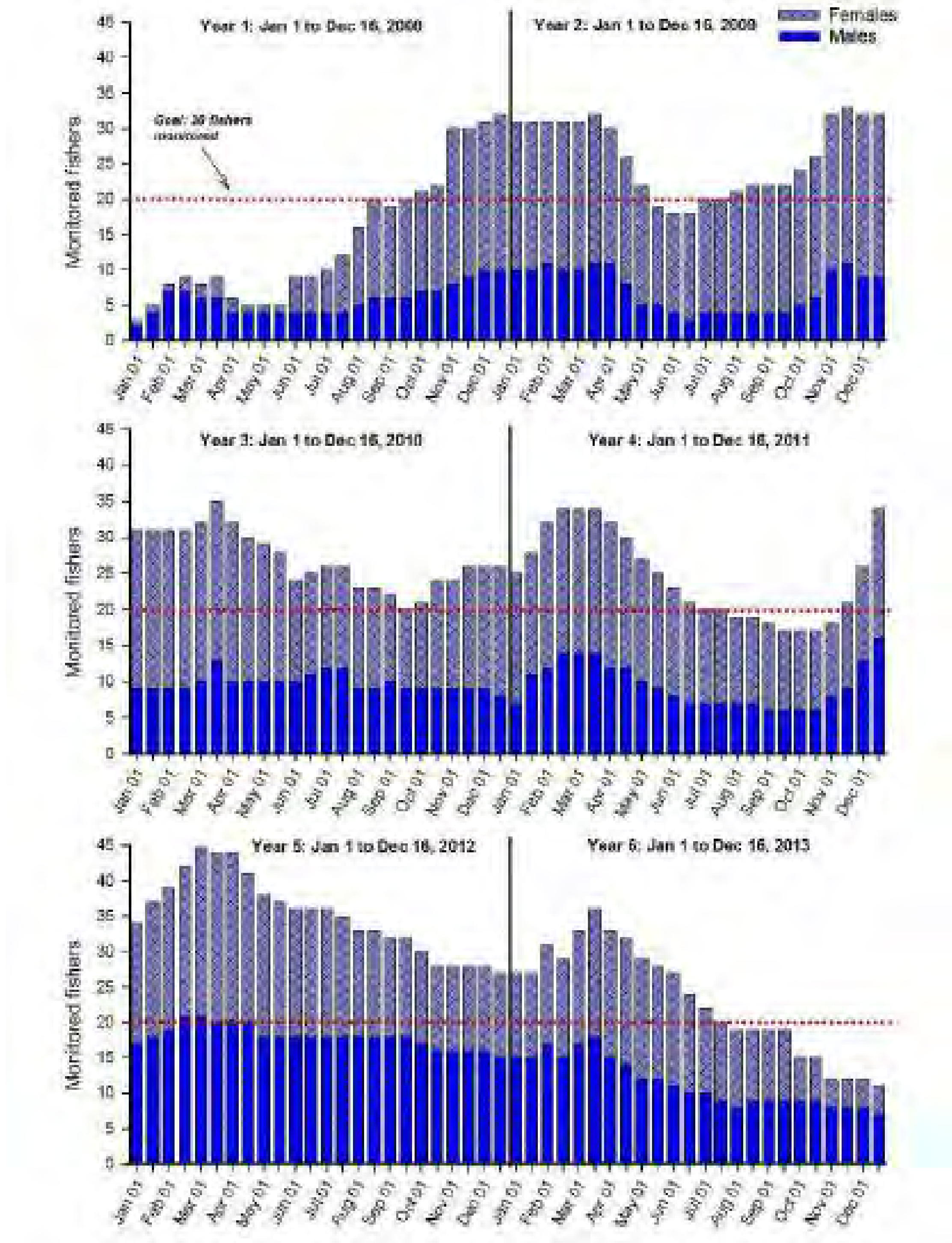


Figure 10. Number of radiocollared fishers that were monitored for survival and reproduction (females) during the period of SNAMP Fisher from December 2007 to December 2013.

Basic Camera Survey Results

Camera trap surveys were a major aspect of SNAMP Fisher in all years. In the overall period of the study we surveyed for fisher presence in 905 unique 1-km^2 grids. The distribution of camera surveys extended from Yosemite Valley in the north, to the slopes above the San Joaquin River canyon to the south and southeast (Fig. 11). Surveys occurred within Yosemite National Park in winter 2009 only, research that was part of a companion study organized by Reginald Barrett and funded by the California Department of Fish Wildlife. We also obtained data from camera trap surveys in 24 grids located north of the Merced River in Yosemite Valley (not displayed) that were completed by cooperating biologists from Yosemite National Park or the Central Sierra Nevada Environmental Research Center (CSERC). Fishers were not detected in any of the 24 grids, reinforcing that the Merced River is the northern edge of the range of fishers in the southern Sierra Nevada.

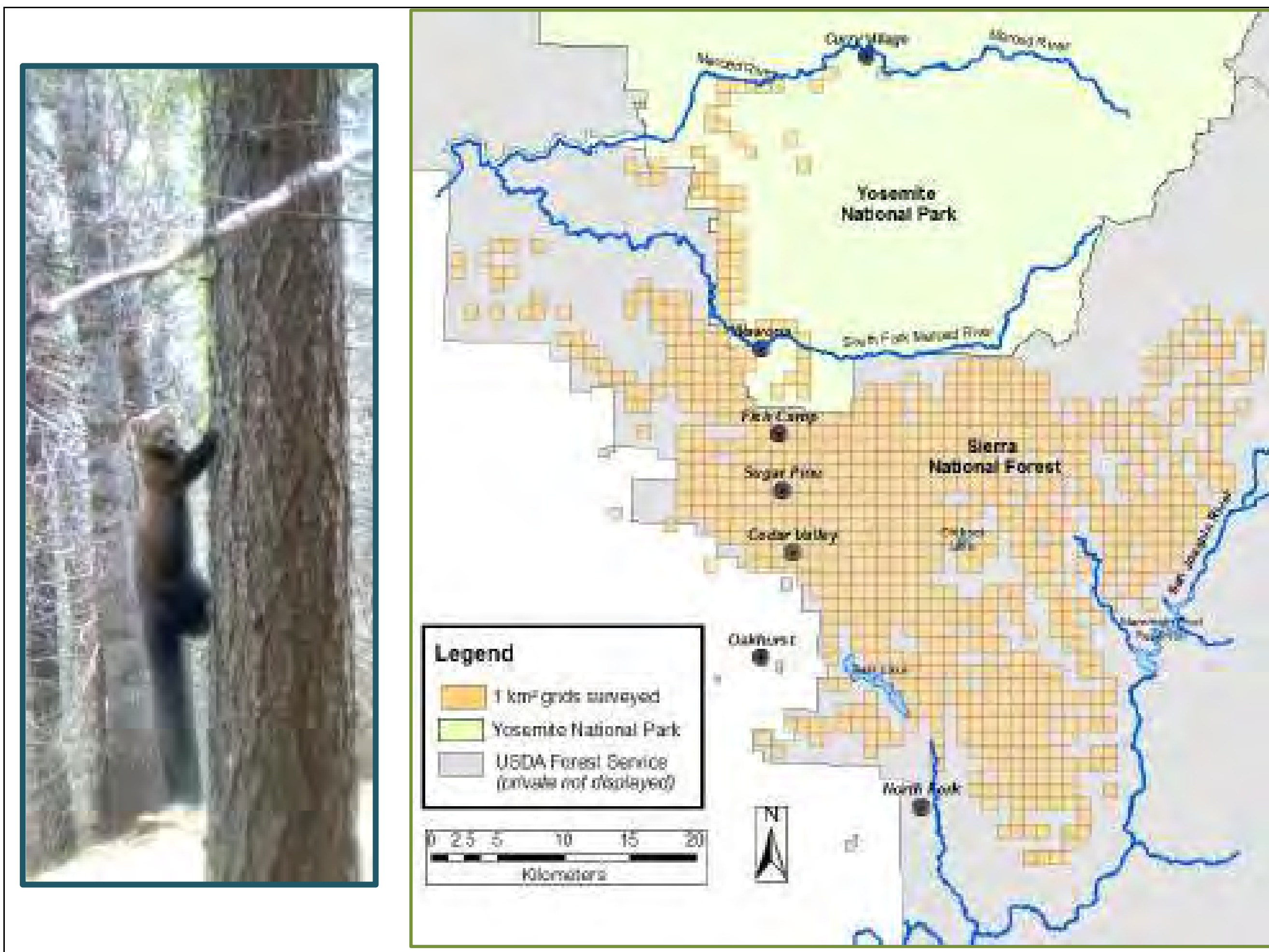


Figure 11. Distribution of camera trap surveys in the SNAMP Fisher study area from October 2007 to October 2013.

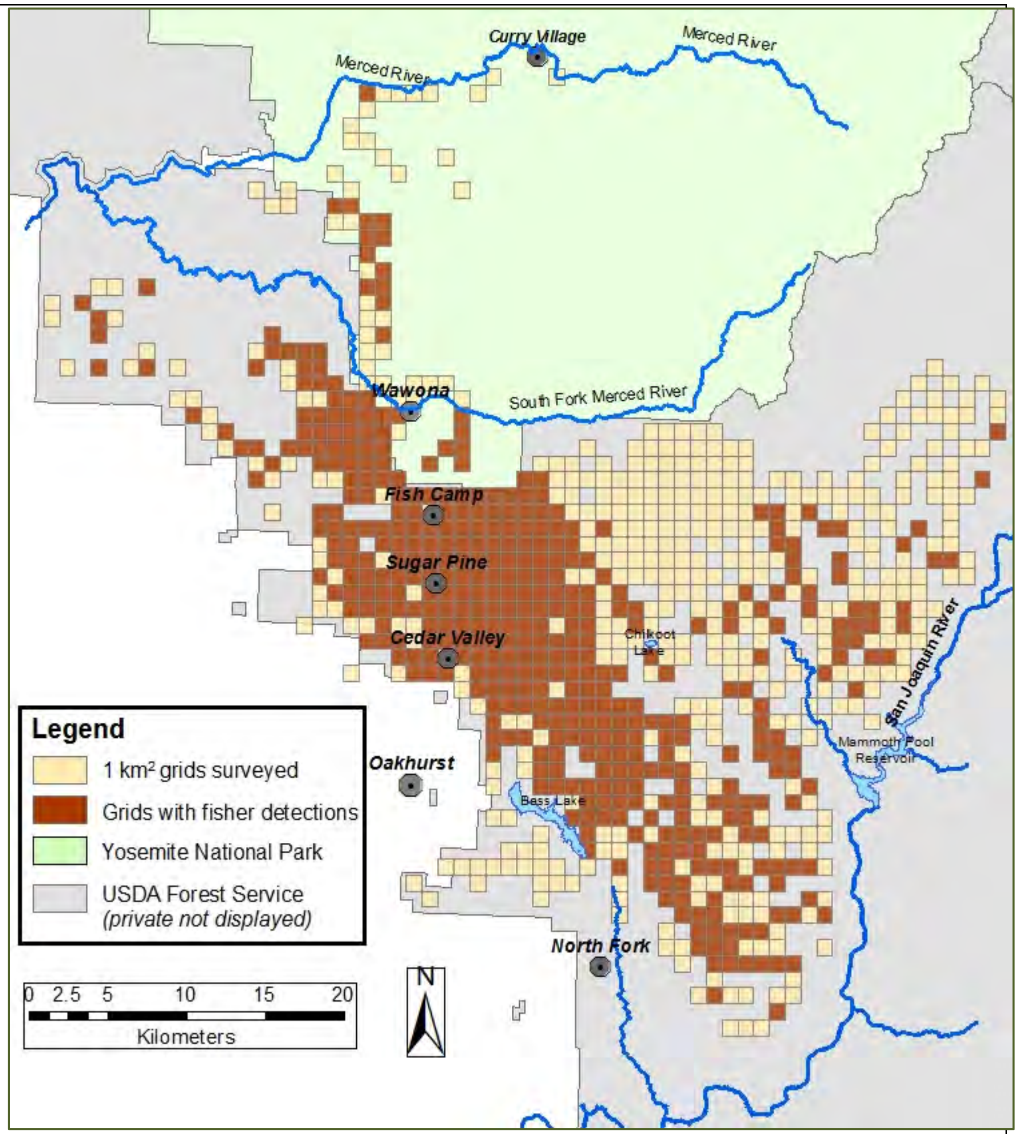


Figure 12. Distribution of fisher detections from camera trap surveys in the overall SNAMP Fisher study area in the period from October 2007 to October 2013.

Fisher activity was identified in 448 of the 905 unique grids surveyed (Fig. 12). We used information on the proportion of surveyed grids surveyed with fisher detections to estimate the elevation range for fishers in the overall study area (Fig. 13). Fishers were most common between 4500 and 6500 feet elevation (1372 and 1981 m elevation). Fisher detections were uncommon above 7500 feet (2286 m) elevation, but the pattern suggested fishers occasionally use private lands outside of the Sierra National Forest as low as 3000 feet (914 m) elevation (Fig. 13).

Camera trap effort was focused in the Key Watershed focal study area. The number of 1-km^2 grids surveyed ranged from 122 in 2007-08 and 133 in 2012-13 (Table 10). Across the larger overall SNAMP Fisher study area we surveyed 204 1-km^2 grids in 2012-13 and 409 grids in camera year

2010-11 (Table 10).

Naïve occupancy for all grids surveyed varied from ≈ 0.60 in 2008-09 to ≈ 0.40 in 2009-10 (Table 10). Occupancy for multi-year surveyed grids (corrected for probability of detection <1.0) oscillated from ≈ 0.80 in 2007-08 to 0.62 in 2009-10 and then increased back to ≈ 0.80 in 2011-12 (Fig. 14).

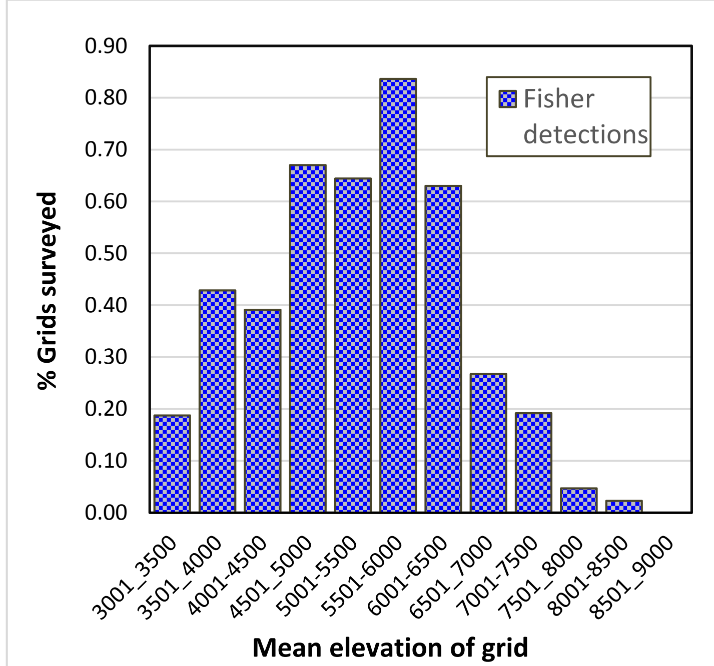


Figure 13. Elevation range of fishers in the SNAMP Fisher study area based on the proportion of grids surveyed with fisher detections in 500 foot (152 m) elevation bins.

In addition to basic naïve occupancy (presence/absence), we assessed fisher activity based on the number of occasions that fishers visited camera trap stations. Visit occasions were defined as distinct event periods when fishers activated the motion sensors with at least a 15 minute break between successive visits. Review of images suggested this was an appropriate period of time separating distinct visit periods. We scored a total 4727 fisher visits to camera trap stations during the study (range 583 to 951; Table 11). Fisher visits ranged from 11.6 (2010-11) to 20.4 (2012-13) per 100 trap nights (Table 11). However, and in accordance with our finding of lower probability of detection for fishers during summer season compared to fall and winter

Table 10. Number of 1km^2 grids surveyed with camera traps by camera survey year (Oct 15 to Oct 14).

	Key Watersheds			Outside Key Watersheds			Entire study area		
Camera Year	Grids	Fisher detected	Naïve occupancy	Grids	Fisher detected	Naïve occupancy	Grids	Fisher detected	Naïve occupancy
2007-08	122	71	0.582	98	41	0.418	220	112	0.509
2008-09	129	75	0.581	212	128	0.604	341	203	0.595
2009-10	127	75	0.591	275	100	0.364	402	175	0.435
2010-11	125	82	0.656	284	80	0.282	409	162	0.396
2011-12	128	98	0.766	226	104	0.460	354	202	0.571
2012-13	133	70	0.526	71	41	0.577	204	111	0.544

All years unique grids surveyed: $N = 905$

[a] Some grids were surveyed twice during a camera year; those grids were counted once for this summary.

seasons (Popescu et al. 2014), fisher visits/100 camera survey days was very low during summer (3.6) , and highest during winter (33.3; Table 12). Higher probability of detection during winter is due to presence of fewer species of squirrels and other prey during winter compared to in summer. For example, California ground squirrels (*Otospermophilus beecheyi*) and long-eared chipmunks (*Tamias quadrimaculatus*) enter into torpor (hibernation) during winter, and data on alligator lizards (*Elgaria multicarinata*) and other summer season prey are not available.

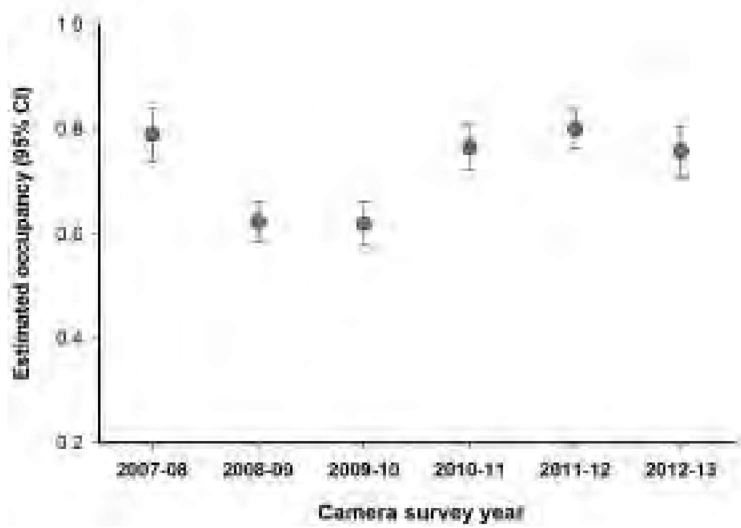


Figure 14. Estimated fisher occupancy (95% CI) for multi-year surveyed (n = 292) during six camera survey years for the SNAMP Fisher study. Occupancy is corrected for imperfect probability of detection.

Table 11. Summary data on the number of camera days for all camera traps used to survey for fishers (effort), and the number of fisher visits during each camera survey year (~Oct 15 to Oct 14).

Camera year	Camera days (all cameras)[a]	Camera days (Fisher grids)[b]	Fisher visits[c]	Visits per 100 camera days[c]
2007-08	7914	4328	583	13.5
2008-09	10605	5550	794	14.3
2009-10	14955	5990	951	15.9
2010-11	16457	5614	649	11.6
2011-12	14059	7149	949	13.3
2012-13	7584	3926	801	20.4

[a] Estimated days that camera traps were functioning and focused on the bait tree
[b] Functional camera days for grids with fisher detections
[c] Based on images sequences with fishers (fisher detections) that were separated by a minimum of 15 minutes.
[d] Fisher visits divided by functional camera days for grids with fisher detections x 100

Table 12. Fisher visit to survey cameras and camera effort by season from October 25, 2007 to October 15, 2013. Seasons were based on the solar cycle: Fall - Sep 21 to Dec 20; Winter - Dec 21 to Mar 20; Spring - Mar 21 to Jun 20; Summer - Jun 21 to Sep 20.

Season	Fisher visits	Estimated camera days	Camera days (925 to 2135 m elev)[a]	Visits per 100 camera days	Visits per 100 camera days (fisher elevation)
Fall	1103	19027	7010	5.8	15.7
Winter	2543	22113	7629	11.5	33.3
Spring	733	12069	5032	6.1	14.6
Summer	348	18365	9597	1.9	3.6

[a]Camera days within the typical elevation range for fishers in the SNAMP Study area [925 m (3000 ft) to 2135 m (7000 ft); see Fig. 9.

Illustration 17: Winter period and summer period fisher detections at camera trap survey stations

Fisher Denning and Reproduction

Denning period

Den cameras provided detailed information on the activities of 32 adult female fishers during six spring denning seasons. Based on information from the spatial clustering of aerial telemetry locations, ground-based telemetry, and den cameras, denning was initiated in the last week of March in most years (earliest date was March 22), and females typically ceased regular use of den trees in the first week of June (Table 13). The latest known regular use of a den tree was June 20 in spring 2012. It is likely that females continued to use trees as short term den/rest structures during summer when their dependent kits were trailing them, but we did not attempt to systematically identify those types of short duration use structures.

Table 13. Estimated dates for the initiation and end of denning by female fishers in the Sierra National Forest, California. Data are from March 2008 to June 2013.

	Mean start of denning[a]		Mean end of denning	
Season	N	Estimate	N	Estimate
2008	1	27-Mar-08	1	4-Jun-08
2009	12	27-Mar-09	9	6-Jun-09
2010	13	25-Mar-10	8	4-Jun-10
2011	8	1-Apr-11	5	5-Jun-11
2012	11	31-Mar-12	7	2-Jun-12
2013	12	27-Mar-13	7	1-Jun-13

[a]Estimated from spatial clustering of sequential aerial radiotelemetry locations (Zhao et al 2012).

Table 14. Summary data on denning activities by female fishers determined from monitoring den trees with remote cameras. Data are from the Sierra National Forest, California from April 2008 to June 2012.

						Daily rates	
Spring	Female fishers	Den trees monitored	Monitor days[a]	Avg monitor days/female	Total detections[b]	Detection rate[c]	Up/Down movements[d]
2008	1	3	37	37.0	30	0.568	1.1
2009	13	45	449	34.5	366	0.601	1.2
2010	14	47	479	34.2	353	0.568	1.1
2011	9	28	260	28.9	264	0.725	1.1
2012	11	37	406	36.9	439	0.733	1.3
2013	12	40					

[a] Excludes periods when females moved kits and the next maternal den tree had not yet been located.
[b] All detections identified as a departure or return to the den tree, as well as events when fishers were at the base of den trees but not identified as departing or returning.
[c] Proportion of days den trees were being monitored for which at least one detection was made by den cameras
[d] Mean number of return and departures movements for days when fishers were detected by cameras.

In the spring 2008 den season SNAMP Fisher monitored a single female fisher, but in all other years we monitored at least nine individual females (Table 14). The mean number of dens used per female per season was 2.4 (range 1 to 5), and the mean number of cameras used to monitor each den structure was 3.1. On average each denning female was monitored with den cameras 34.3 days/season (range 28.9 to 37; Table 14), excluding days or periods when successive use maternal den trees were yet to be identified. Fifteen female fishers were monitored with den cameras in one den season, 11 were monitored in two seasons, three were monitored in three seasons, two were monitored in four seasons, and one was monitored in five denning seasons

Denning activity, litter size and weaning rates

Denning status was determined for 89 of 93 total denning opportunities for breeding-age (≥24 months) females in 6 denning seasons from 2008 to 2013 (Table 15). We were unable to adequately monitor 4 breeding-age females for determining denning status when radiocollars were shed (n = 3) or ceased functioning (n = 1) within the first 31 days of a denning season. The average date that females initiated denning behavior was March 28 (range March 22 to April 9). The average date that females ceased localizing to den trees was June 9 (range May 30 to June 22).

Seventy-six (85%) breeding-age female fishers either exhibited denning behavior (n = 63) or were determined to have denned and weaned at least 1 kit based on size of teats (n = 13; Table 15). Among 76 breeding-age females that initiated denning, 64 (84%) were identified as weaning kits. Overall, 72% of 89 known status, adequately monitored denning opportunities for breeding-age females produced at least one weaned kit (Table 15).

Eleven (17.5 %) of 63 cases of denning for females that were monitored during spring periods failed prior to kits being weaned (Table 16). Three of the 11 denning failures were females that initiated denning but ceased localizing to natal den trees 17, 35, and 41 days later, potentially related to the death of kits. Eight den failures were due to death of the denning female; seven deaths were by attacks by predators, and one was the result of a denning female either dying of internal bleeding induced by exposure to rodenticides, or from the combination of trauma from being struck by a vehicle on a highway and internal bleeding related to exposure to rodenticides. One of the seven females that died from predator attack was infected with canine distemper virus, which may have contributed to her vulnerability (Keller et al. 2012).

Table 15.--Summary of female fisher (≥2 years old) denning and weaning rates by age class and year on the Bass Lake Ranger District in the Sierra National Forest, California, 2008-2013.

Pop Year	No. Adult Females[a]	Monitored mid-Mar to May 31[b]	Teats measured (Jul to Jan)[c]	Denning[d]	Proportion denned[e]	Unknown status[f]	Failed[g]	Died while denning	Weaned[h]	Proportion weaned[i]
Age class (Years)										
2	30	26	1	21	0.78	3	1	2	18	0.67
3-5	63	48	13	55	0.87		3	5	46	0.75
≥6	12	10	2	9	0.75			1	8	0.67
Year										
2008	11	2	9	9	0.82				9	0.82
2009	17	14	3	15	0.88		1	1	13	0.76
2010	17	15	1	14	0.88	1		3	11	0.69
2011	16	11	3	12	0.86	2	1	1	10	0.71
2012	17	17		14	0.82			3	11	0.65
2013	15	15		12	0.86	1	1		10	0.79

[a] All females ≥ 24 months of age that were known in the population during the year. Includes females that were captured after the end of the denning season in mid June.

[b] Number of females monitored by radio telemetry during all ~~of~~ part of the period before they died or had a dropped/failed collar after denning status had been determined.

[c] Number of females the were not monitoring during the denning period, but were captured during July to January when teat measurements were taken and used to determined weaning status as described by Matthews et al. (2013).

[d] Number of females that exhibited denning behavior, or that were determined to have weaned at least one kit based on teat measurements.

[e] Number of denning females divided by the number of adult females minus the number of females of unknown status.

[f] Number of females (≥ 2 years old) for which denning was unknown or suspected, but dropped or failed radiocollars prevented determination of denning status.

[g] Number of females (≥2 years old) that exhibited denning behavior and ceased denning behavior prior to weaning.

[h] Number of denning females that were known alive and exhibited denning behavior until after May 31.

[i] Number of females that denning to weaning divided by the number of adult females minus the number of females with unknown status.

Table 16.--Information on female fisher kit production for six spring denning seasons (March 21 to June 31) in the Sierra National Forest, California, October 2008 to June 2013.

Age class (Years)	Denning females[a]	Denning Females with kit counts[b]	Kits [c]	Litter size[d]	Denning female deaths[e]	Known kit deaths[f]	Denned to Weaning[g]	Kits weaned[h]	Kits weaned per litter (fecundity)
2	19	15	21	1.40	1		14	19	1.27
3-5	32	26	40	1.60	3	7	22	34	1.32
≥6	8	7	12	1.71			7	12	1.71
Year									
2008	2	1	1				1	1	
2009	12	9	15	1.5	1		10	15	1.5
2010	13	11	20	1.8	3	7	7	13	1.9
2011	8	7	11	1.6	1		7	11	1.6
2012	14	11	16	1.5	3	2	10	14	1.4
2013	10	8	10	1.3			8	10	1.3

[a] Number of females (≥2 years old) that exhibited denning behavior and were monitored by radiotelemetry, den cameras, or both. Excludes females whose reproductive status was not known and those that initiated denning behavior but ceased denning before May.

[b] Number of denning females for which kit counts were determined by images from den cameras, den cavity video camera, or both.

[c] Total number of kits counted.

[d] Number of denning females with kit counts divided by the number of kits counted.

[e] Number of denning females known to have died during the denning season while provisioning kits in den trees. Numbers of kits in litters were not known for all of the denning females that died.

[f] Kits that were known present in den trees when the mother died, or those that were found dead inside den cavities. This estimate assumes that 5 orphan kits that were removed from den cavities would have perished if they had not been rescued.

[h] Number of monitored denning female fishers exhibiting denning behavior that continued to weaning.

Six of eight deaths of denning females occurred when the locations of den trees were known and were being monitored. In one case den camera images included a bobcat with a dead kit in its mouth, and the partial carcass of the denning female was recovered nearby. In a second case the den structure was a large, unstable snag, and we did not attempt to climb the tree to determine litter size due to safety considerations. In each of the other four cases we climbed the den trees to assess litter size, and recover kits in accordance with California Department of Fish and Wildlife policy. A total five live kits were recovered from two of the den trees (litter size 2, 3), two deceased kits were found in a den cavity of the third tree, and we failed to find kits in the fourth tree. For this fourth tree, the lack of images of the female from den cameras suggested she had moved the litter to a different, unidentified den tree several days prior to her death.

The five orphan kits that were rescued were raised in captivity by a local wildlife rehabilitation organization licensed by the California Department of Fish and Wildlife, and under the care and supervision of a professional zoo veterinarian. One of the orphan kits died in captivity by urinary tract blockage attributed to a parasitic nematode, whereas the other 4 survived captive rearing. Two kits from one litter were released within their mother's home range, and the two kits from the second litter were released into an area with suitable fisher habitat abutting the south margin of the study site.

We used a combination of images from den cameras (*n* = 43) and den cavity investigations with a video camera (*n* = 4) to determine litter size for 48 of 59 denning females that were monitored (Table 16). A total 73 kits were known produced, and average litter size was 1.5 (Table 16). After accounting for known mortalities of denning females, we estimated that 64 of the 73 kits produced were weaned from den trees, whereas seven kits died or would have died had they not been rescued (Table 16).

Denning structures

We identified 125 unique structures used as natal or maternal dens, including 54 black oak, 41 incense cedar, 19 white fir, 10 sugar pine or ponderosa pine, and one canyon oak (*Quercus chrysolepsis*) (Table 17).

Repeat use of den trees was not uncommon. Sixteen individual den trees were used more than once; 15 trees were used in two years, and one tree was used in four different den seasons. In all but two cases of repeat den tree use the same individual reused one or several den trees between successive years. In two cases a female used a den that had been used by a different female in a previous year. Successive dens of females that used more than 1 den structure were located an average of 413 m apart (*n* = 52, range 75-1398), and the average total distance moved between successive dens was 693 m (*n* = 31, range 75-1687). Also, the distance between the natal den tree and the first maternal den tree averaged 419 m, whereas successive use maternal den trees were in closer proximity (mean=287 m, t_{69} =1.75, *P*=0.04), potentially because older kits are larger in size and mass and therefore more difficult for the female to carry.

Fifty-six percent of the unique individual trees used for denning in the SNAMP area were live trees (*n* = 70), whereas 44% (*n* = 55 were snags (Table 17). Black oak was the most common live tree used for denning, but a high percent ~~of incense cedar were also selected by female fishers~~ (Table 17). Among snags used as denning structures, black oak and incense cedar were both commonly used, whereas white fir and pines (sugar pine or ponderosa pine) were less common as snag-type den trees (Table 17). Overall, black oaks and incense cedar were the two most common tree species used for denning (Table 17).

Table 17. Information on the number of times (denning events) different species of trees were used for denning by female fishers in the SNAMP Fisher study. Includes counts for live trees, snags, and both types of denning structures.

Tree type, Species	Denning events[a]	Percent within group	Unique structures[b]	Repeat use structures[c]
Live trees				
Black oak	34	43	31	3
Incense cedar	25	32	19	4
White fir	14	18	14	
Sugar pine	3	4	3	
Ponderosa pine	2	3	2	
Canyon oak	1	1	1	
Snags				
Black oak	27	42	23	
Incense cedar	27	42	22	4
White fir	5	8	5	5
Pine species[d]	5	8	5	
Live tree or snag				
Black oak	61	43	54	3
Incense cedar	52	36	41	8
White fir	19	13	19	5
Pine species	10	7	10	
Canyon oak	1	1	1	
Total den structures	143		125	16

[a] Count of all known denning events for each species of tree.
[b] Count of individual trees; those used in multiple seasons counted once.
[c] Number of individual trees used ≥ two times for denning; one live cedar tree was used by the same female in four successive denning seasons, but all other repeat use trees were known used in two den seasons only.
[d] Pine snags could not always be identified as sugar pine or ponderosa

Habitat characteristics of den structures

Mean diameter at breast height (DBH) of black oak denning structures was smaller than that for other tree species used (Table 18). Mean heights of live trees were taller than snags of the same species (Fig. 15), reflecting that many of the snags used for denning were at advanced stages of decay.

Table 18. Basic information on the size (DBH) and height of trees (live or snag) used as denning structures by female fishers in the SNAMP Fisher study from March 2008 to June 2013.

	Live trees			Snags or dead trees		
Tree species	*n*	Mean DBH (cm)	Mean height (m)[a]	*n*	Mean DBH (cm)	Mean height (m)
Black oak	30	74.2	21.7	5	69.5	8.8
Incense cedar	18	127.2	32.5	22	105.1	16.4
White fir	14	110.8	33.9	22	103.7	27.4
Pines	5	112.8	37.4	5	109.6	27.6

[a]Data on mean tree height are for the subset of den trees for which detailed data on habitat measurements were completed (*n* = 84).

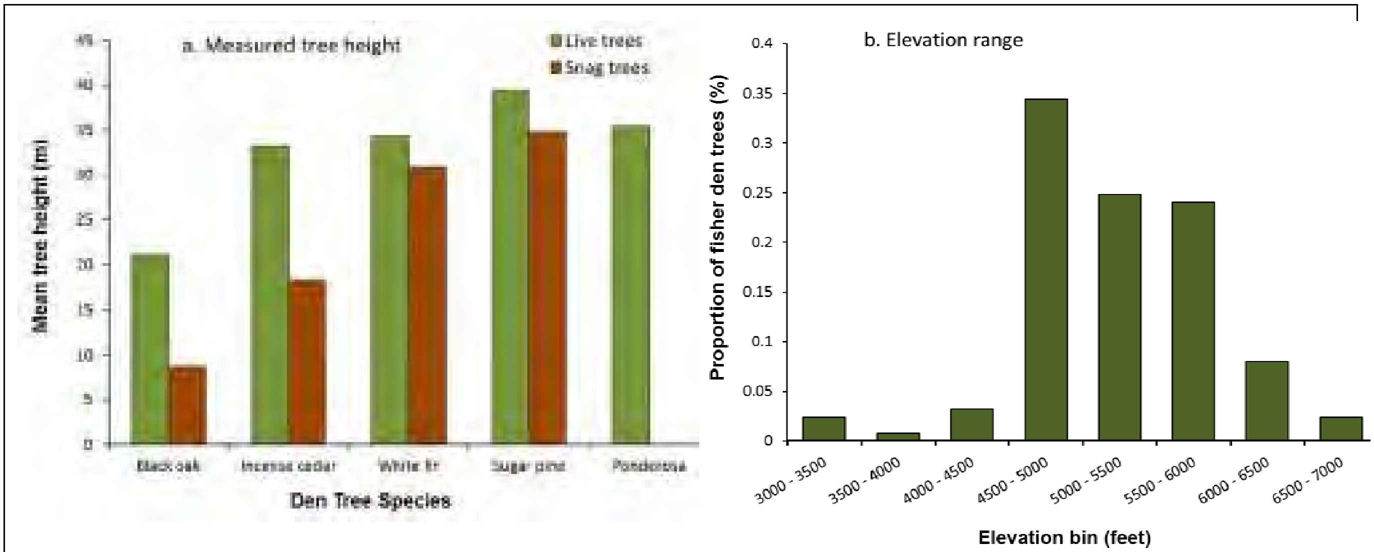


Figure 15. Summary information on the (a) mean height of denning structures (unique trees), and the (b) elevation range for fisher den trees for the SNAMP Fisher Study during 2008 to 2013 (6 denning seasons).

The majority of denning structures used by fishers in the SNAMP Fisher study area were in the elevation range from 4500 (1371 m) to 6000 feet (1829 m; 83%, *n* = 104; Fig. 15b). Additional information obtained from circular habitat plots assessments included indications of high canopy cover, limited herbaceous cover, and relatively low shrub cover near most den trees (Table 19).

Concealment cover was 64% low ground cover, 46% high ground cover, and 38% and 36% low shrub and high shrub cover, respectively. On average, belt transects within the circular habitat plots around den trees included an average of 6.5 down logs (coarse woody debris, CWD; logs/branches with a minimum large end diameter of 15 cm, ≥1 m total length). Many denning structures were on steep slopes (Table 19) but there was no obvious preference for aspect (Fig. 16).

Table 19. Basic habitat attributes around fisher den trees for the SNAMP Fisher Study area in spring 2008 to spring 2012.

Attribute[a]	Mean	Range
Canopy cover	72%	30-94%
Shrub cover	19%	0-82.5%
Herbaceous cover	6%	0-29%
Prevailing slope	37%	3-75%

[a] Habitat attributes are from circular plots (18 m radius) centered on fisher den trees (*n* = 82). Habitat data were not available for other confirmed den trees.

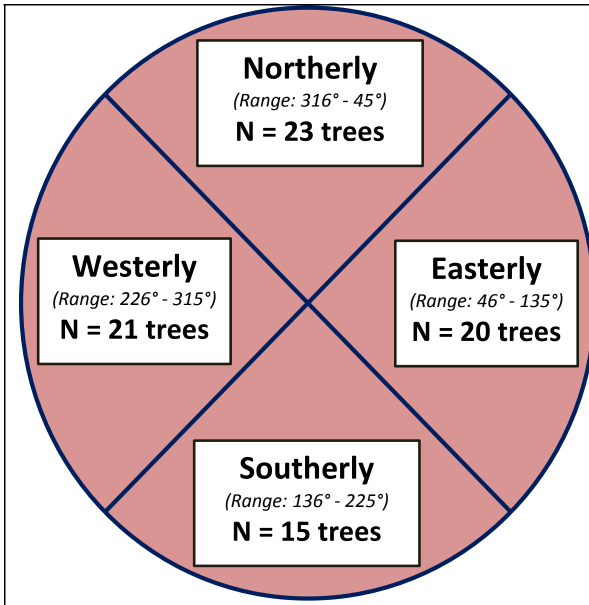


Figure 16. Aspect orientation of fisher den structures on the SNAMP Fisher Study. Data are for 79 den trees.

Illustration 10: Black oak used for denning in spring 2011. Image of tree from a distance (left), and view of the forked branching higher up the bole of the denning structure (right).

Activity patterns of denning females

Additional insight on denning activities by adult female fishers was provided by analyses of den camera images. Adult females were detected by den cameras at known active dens an average of 0.64 times/day (range 0.57 to 0.73) (Table 14) and the mean number of detections of up and down movements ranged from 1.1 to 1.3 per day (Table 14), indicating that fishers do not typically leave and return to den trees multiple times a day. In addition to information on male visits to den trees (we obtained image sequences of eight mating, or copulation events at the base of den trees), den cameras identified three occasions when a female fisher briefly returned to a den tree at least one day after she had already moved kits to another tree nearby (Table 20). On eight occasions den cameras detected other female fishers (non-collared or different collared fisher) at den trees of female fishers (Table 20).

Table 20. Summary data on denning activities by female fishers determined from monitoring den trees with remote cameras. Data are from the Sierra National Forest, California from April 2008 to June 2012.

Spring	Departing	Returning	Base tree[a]	Bringing food to tree[b]	Kit move	At tree after kits moved	Other female at tree
2008	15	9	6		1		
2009	118	198	35		12	1	
2010	133	163	37	1	20		2
2011	120	127	10		14	1	6
2012	178	234	11	8	25	1	
2013[c]					*min 11*		

[a] Detections at base of tree, or on the tree for which directionality or activity was uncertain
[b] Detections when the female was carrying objects as they returned and ascended the den tree
[c] General information only available for 2013.

Information from the 83 occasions when females were detected moving kits was used to estimate fecundity. A total of 1295 detections were identified as female fishers departing from, or returning to the den tree, whereas there were 99 detections of females at or near the base of den trees that could not be unequivocally classified except as active outside the den cavity (Table 20). We were able to identify 316 image sequences consistent with either continuous den attendance, or continuous time away from the den when denning females were likely foraging. Den attendance bouts were shortest late in the den season and longest in the middle of the den season (Table 21). Forage bouts away from den trees were shortest early in the den season and approximately similar in duration thereafter (Table 21).

Table 21. Information on den attendance and ~~away from den tree~~ foraging excursions, developed from analyses of data from cameras used to monitor fisher den trees during five denning seasons. Data are from the Sierra National Forest, California from April 2008 to June 2012.

Den attendance bouts (minutes)					Forage away bouts (minutes)			
Season[a]	Cases	Mean	Min[b]	Max[c]	Cases	Mean	Min	Max
Early	38	371.0	4.4	1072.5	64	235.1	34	746.1
Middle	43	535.6	2.3	996.2	53	431.8	29.3	811.4
Late	68	323.3	6.0	1049.4	50	405.5	22.8	807.8
Overall	149	396.7	2.3	1072.5	167	348.6	22.8	811.4

[a] Seasons were Early (March 26 to April 20), Middle (April 21 to May 15), and Late, (May 16 to June 11), identified by dividing the overall den season into three 25 day periods from late March to mid-June.
[b] shortest duration bout.
[c] longest duration bout.

Fisher Survival

Sixty-six (60%) of the 110 individual fishers radiocollared during the study were known to have died, including 32 females and 34 males (Table 22). Excluding population year 2007-08, an average of 10.5 radiocollared fishers perished each population year (Fig. 17). The mean number of deaths by gender for population year 2008-09 through population year 2013-14 was 5.3 for females and 5.2 for males.

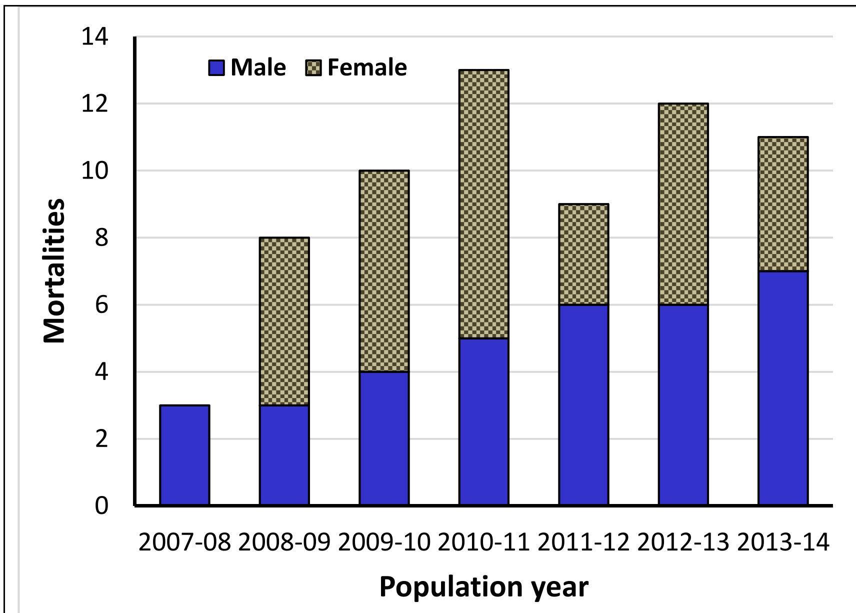


Figure 17. Number of radiocollared female and male fishers known to have died during the SNAMP Fisher Study.

Fisher survival with population data combined into 2-year periods was generally higher for adult and juvenile fishers than for subadults (Table 23). Ninety-five percent confidence intervals overlapped for females and males in all two-year period with the possible exception of subadults in year group 3. Two-year survival rates among females ranged from a low of 47% to a high of 89% for

Table 22. Review of all known deaths of radiocollared fishers in seven population years (Apr 1 to Mar 31), summarized by gender, and cause-specific mortality from necropsy examinations by pathologists at the UC Davis School of Veterinary Medicine (Davis, CA). Necropsy reports were not available for 16 fishers.

Year, Gender	Predation[a]	Disease[b]	Starvation-related injury, septicemia[c]	Road kill	Rodenticide toxicosis	Indeterminate, unknown[d]	Pending necropsy
2007-08							
Female							
Male	1	1		1			
2008-09							
Female	4		1				
Male	1	1		1			
2009-10							
Female	5		1				
Male		3			1		
2010-11							
Female	5		1		1	1	
Male	4					1	
2011-12							
Female	3						
Male	5		1				
2012-13							
Female	3						3
Male	1			1	1	1	2
2013[e]							
Female							4
Male							7
All years							
Female	20		3		1	1	7
Male	12	5	1	3	2	2	9

[a] One female death by predation in 2009-10 may have been related to the animal being weakened/sick from CDV when it encountered a coyote (*Canis latrans*); further discussed by Keller et al. (2012).
[b] Three disease deaths were associated with canine-distemper virus, one was considered by Toxoplasmosis, and one was due to pleruritus+pneumonia.
[c] Most deaths in this category were associated with prior injury that contributed to starvation and septicemia.
[d] Necropsies were completed, but cause of death could not be determined.
[e] Includes deaths of two male fishers that died January 1, 2014 and March 31, 2014. Although this was after the end of SNAMP Fisher, both of the animals were radiocollared as part of SNAMP.

Table 23. Estimates of survival (s(t)), for radiocollared fishers using population data combined for analysis into a series of five 2-year groups beginning in population year 2 (2008-09) and ending in population year 7 (2013-14), and for all years of data combined. Survival was assessed using Kaplan-Meier staggered entry analyses. Population years were from April 1 to March 31, and ages were defined as juvenile, ≤ 12 months, subadults, 12 to 23 months, and adults, ≥ 24 months.

	Juveniles		Subadults		Adults	
Year group, Gender	s(t)	95% CI	s(t)	95% CI	s(t)	95% CI
2008-09, 2009-10						
Female	0.80	0.58-1.02	0.47	0.28-0.66	0.81	0.66-0.96
Male	0.83	0.50-1.17	0.40	0.10-0.70	0.73	0.52-0.95
2009-10, 2010-11						
Female	0.80	0.59-1.01	0.67	0.42-0.92	0.70	0.54-0.86
Male	0.60	0.30-0.90	0.43	0.06-0.79	0.71	0.52-0.91
2010-11, 2011-12						
Female	0.74	0.54-0.94	0.89	0.71-1.07	0.69	0.53-0.86
Male	0.67	0.42-0.92	0.50	0.29-0.71	0.56	0.37-0.75
2011-12, 2012-13						
Female	0.80	0.55-1.05	0.73	0.52-0.94	0.86	0.71-1.00
Male	0.83	0.56-1.11	0.92	0.77-1.06	0.61	0.44-0.77
2012-13, 2013-14[a]						
Female			0.73	0.48-0.98	0.74	0.56-0.93
Male			0.75	0.33-1.17	0.66	0.49-0.83
All Years; Dec 07-Mar-14						
Female	0.75	0.60-0.89	0.71	0.57-0.84	0.74	0.64-0.83
Male	0.60	0.42-0.78	0.57	0.40-0.74	0.64	0.54-0.75

[a] Insufficient data for estimating survival for juveniles in this Year group.

subadult females (Table 23). Two year survival for juvenile females was always ≥ 74%, whereas among adult females it ranged from a low of 0.69% to a high of 0.86 (-Table 23). Fisher survival for all years combined was highest for juvenile females and lowest for subadult males (Table 23). Also, although not significantly different, survival was consistently higher for females compared to males (all age classes; Table 23). In general, survival among females is more important for understanding the status of this fisher population than male survival, particularly because there were a ~~good~~ number of males in the population in all years of the study (Fig. 10).

Causes of Mortality

Necropsy reports have been completed for 50 of the 66 radiocollared fishers that died during the SNAMP Fisher study. Assignment of cause-specific mortality was possible for 47 of the 50 animals with necropsy reports ~~(94%)~~. Three necropsies reports were indeterminate with regards cause of death for the fisher (Table 22). To date, a known cause of death has been determined for 71% of the 66 mortalities.

Among known-cause mortalities predation was the primary cause of death, accounting for 68% of 47 known-cause deaths (Fig. 18). Deaths by disease, injury-related starvation or septicemia, and human-linked factors combined to account for 32% of known-cause mortalities (Fig. 18).

Predation accounted for nearly twice as many known cause deaths for females (43%) than for males (26%), whereas all of the disease and roadkill deaths were males (Fig. 18). Serological testing of blood samples collected at captures revealed low levels of exposure to canine distemper virus in the study population (Gabriel 2013). However, in spring 2009 a relatively small scale epizootic of CDV occurred in the study population, which contributed to the deaths of four fishers; three by direct infection, and one that was killed by a coyote attack, but was likely in a weakened state due to presence of CDV infection (Table 22, Fig. 18; Keller et al. 2012).

In Spring 2009 the SNAMP Fisher research team recovered the first fisher known to have died by toxicosis after exposure to rodenticides. In total, three fishers were known to have died after exposure to rodenticides as of June 2014, including two males and one female. The discovery of death associated with rodenticides led to two peer-reviewed

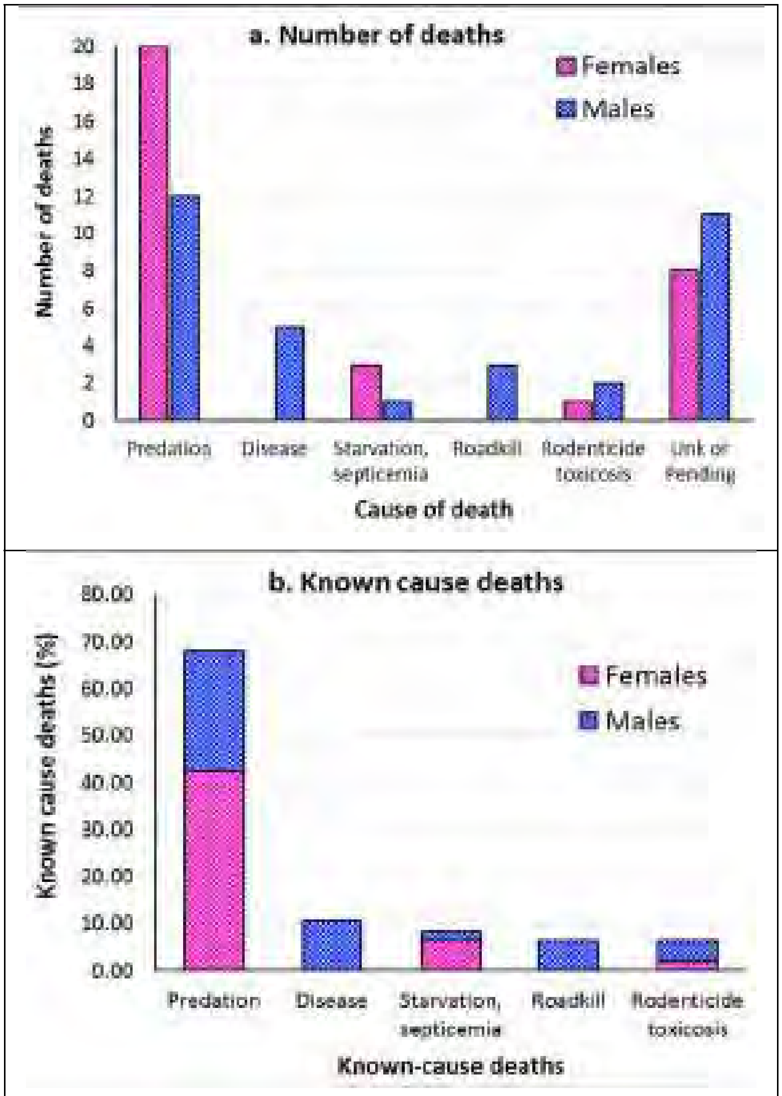


Figure 18. Summary of necropsy-determined causes of death for radiocollared female and male fishers (a), and percent of known-cause mortalities for female and male fishers on the SNAMP Fisher Project from Dec 2007 to Dec 2013.

papers. One detailed issues with anticoagulant rodenticides on public lands (Gabriel et al. 2012) and a second paper revealed that female fishers with larger numbers of marijuana grow sites within their home ranges experience reduced survival (Thompson et al. 2013).

Illustration 11: Remains of a female fisher killed by a predator (left), and a male fisher that was determined to have died by infectious disease (right).

Population Growth Rates

Empirically developed estimates of key demographic parameters needed to estimate a deterministic growth rate for the population (λ) were developed during the study (Tables 22, 23). Estimates for λ were below 1.0 (population decline) in two 2-year groups, equal to 1.0 in one 2-year group (stable), and slightly positive in two 2-year groups (increasing population) (Table 24). The All Years λ was 0.90, which was suggestive of population decline, however, the range for all results overlapped 1.0.

Table 24. Demographic parameters and deterministic population growth rates (range) for five two-year groups[a], and for population data for all years of the study combined (All years).

Parameter, Age class	Year group 1	Year group 2	Year group 3	Year group 4	Year group 5	All Years
Weaning reproduction						
Young adult	0.67	0.89	1.00	0.83	0.70	0.68
Adult	0.75	0.67	0.83	0.82	0.87	0.74
Weaning litter size						
Young adult	1.27	1.57	1.50	1.20	1.20	1.19
Adult	1.31	1.31	1.60	1.55	1.40	1.45
Weaning fecundity $(b_i)^b$						
Young adult	0.42	0.70	0.75	0.50	0.42	0.41
Adult	0.49	0.44	0.67	0.64	0.61	0.53
Survival (P_i)						
Juvenile	0.76	0.80	0.74	0.80	1.00	0.75
Subadult	0.47	0.67	0.89	0.73	0.73	0.71
Adult	0.81	0.70	0.69	0.86	0.74	0.73
Fertility $(b_i)P_i$						
Young adult	0.20	0.47	0.67	0.36	0.31	0.29
Adult	0.40	0.30	0.46	0.55	0.45	0.39
Leslie Matrix λ^c	0.87 *(0.65-1.08)*	0.88 *(0.63-1.12)*	1.00 *(0.77-1.22)*	1.04 *(0.81-1.26)*	1.03 *(0.77-1.22)*	0.90 *(0.71-1.12)*

[a] Two-year groups were 2008-09 and 2009-10 (1), 2009-10 and 2010-11 (2), 2010-11 and 2011-12 (3), 2011-12 and 2012-13 (4), and 2012-13 and 2013-14 (5).

[b] Fecundity is the number of female offspring produced, calculated as weaning reproduction*weaning litter size*0.5 (assumes equal sex ratio at birth)

[c] The range for λ was based on the 95% confidence intervals for the survival rates for the five two-year groups (Table 23). The range for λ for the All years data was based on the 95% CIs for the means for weaning reproductive rate and litter size, and for the 95% CIs for age-specific survival (Table 23).

Population Size and Density

Table 25.--Summary data on camera and live trap activities within 4 fall-winter camera survey years (October 16 to March 15) in the Bass Lake District, Sierra National Forest Study area, October 2008 to March 2012.

Subregion, Year	Camera surveys		Live traps		Estimated area surveyed (km^2)[a]
	Grids	Nights	Grids	Nights	
Subregion 1. Nelder Grove, Sugar Pine, Miami Mountain					
2008-09	147	4462	121	1027	223.2
2009-10	160	5817	161	875	307.2
2010-11	132	4995	72	411	214.3
2011-12	141	5245	147	1016	224.6
Subregion 2. Central Camp, Whisky, Grizzly, Jackass					
2008-09	48	1289	17	158	267.6
2009-10	12	349	56	272	248.0
2010-11	20	1048	47	237	244.2
2011-12	65	2522	80	316	305.5
Subregion 3. Chowchilla Mountain, Rush Creek, Sweetwater					
2008-09	16	400	25	144	128.8
2009-10	2	79	39	252	111.8
2010-11	1	33	22	124	136.2
2011-12	14	513	32	149	132.8

[a] Based on a 1300 m buffer applied to polygons encompassing grids surveyed by cameras and grids with live trap captures.

Population size was estimated for the middle four population years of the six year study. In population year 1 (2007-08) we had only a small number of fishers radiocollared during the last few months of that period (Tables 9, Fig. 10) and camera trap images for the entire population year 2012-2013 were not available due to the conclusion of SNAMP Fisher field work. During the central four year period we captured and radiocollared 101 individual fishers (57 females and 44 males) on 258 occasions during 9732 trap-nights between December 2007 and March 2012. Resighting efforts, both by camera and live traps, varied by subregion and, to a lesser extent, year (Table 25). Camera traps accounted for 86% of 1421 total radio-marked fisher detections, with live trap recaptures providing 201 sightings.

Mean overall abundance across all subregions ranged from 48.2 individuals in Year 2 to 61.8 individuals in Year 4. Variation was at least partly related to differences in area surveyed among years (Table 26). Estimates of areas sampled were generally consistent within subregions among years (Table 26). The increase in area surveyed in Subregion 1 in fall-winter 2009-10 was due to a program that extended camera surveys north into the Yosemite South region of Yosemite National Park (Fig. 3) in winter 2010. In fall-winter 2011-12 research effort was expanded in the Grizzly and Jackass subregion when non-collared fishers were detected in areas that had not been surveyed previously. Mean annual population density for the three subregions ranged from 0.072 to 0.097 fishers/km^2 (Fig. 19).

Table 26.--Mark-resight estimates of population size for three subregions in 4 Fall-Winter survey years (October 16 to March 15) in the Bass Lake District, Sierra National Forest, October 2008 to March 2012.

Subregion, Year	*n*	95% C.I.	Density[a]	Density range[b]
Subregion 1: Nelder Grove, Sugar Pine, Miami Mtn				
2008-09	27.9	23.6-32.2	0.125	0.106-0.144
2009-10	22.3	19.0-25.6	0.073	0.062-0.083
2010-11	19.1	16.3-22.0	0.089	0.076-0.103
2011-12	23.2	20.2-26.2	0.103	0.090-0.117
Subregion 2: Central Camp, Whisky Ridge, Grizzly, Jackass				
2008-09	18.8	10.5-21.2	0.070	0.044-0.097
2009-10	16.3	10.4-21.4	0.066	0.037-0.094
2010-11	22.5	15.4-24.5	0.092	0.066-0.118
2011-12	24.6	17.8-26.5	0.080	0.062-0.099
Subregion 3: Chowchilla Mtn, Rush Creek, Sweetwater				
2008-09	7.2	5.8-8.6	0.056	0.045-0.067
2009-10	9.7	8.7-10.6	0.086	0.078-0.095
2010-11	10.0	8.8-11.3	0.074	0.065-0.083
2011-12	14.0	12.8-15.3	0.106	0.096-0.115

[a] Population size (*n*) divided by the estimated sample area for the subregion in the Fall-Winter camera year, included in Table 1.
[b] Calculated based on the lower and upper values of the 95% C.I., divided by the estimate of the sampled area provided in Table 1.
[c] Sum of the year- and subregion-specific estimates of population size from the mark-resight analyses.

Subregion 1 had consistently high average densities (0.073-0.125 individuals/km^2), with an increasing trend across the last three years of the period (Table 26, Fig. 19). Subregion 3 had initial low density (0.056 ± 0.005 individuals/km^2), but gradually increased by the end of the period (0.106 ± 0.005 individuals/km^2). Subregion 2 showed no particular trend, and average densities varied across seasons between 0.066 (fall-winter 2009-10) and 0.092 individuals/km^2 (fall-winter 2010-11). Temporally, mean population density was lowest in fall-winter 2009-10 at 0.075 ± SE 0.006 individuals/km^2, and increased thereafter to a high of 0.097 ± SE 0.008 in fall-winter 2011-12 (Fig. 19). Mean

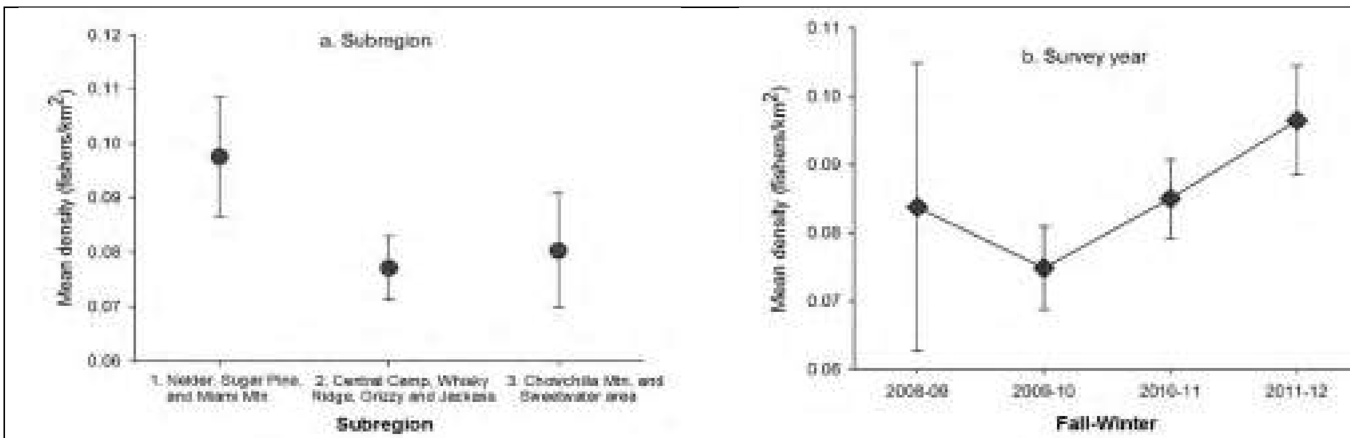


Figure 19. Mean density (± SE) of fishers in three subregions during 4 fall-winter camera survey years (a), and change in mean density (± SE) of fishers during 4 fall-winter camera survey years (b).

population density was consistently high in the last 2 years of the study across all subregions (0.089 – 0.106 individuals/km^2).

Dispersal Behavior and Movements

The combination of field data and genetic data allowed for the *possibility* of assessing dispersal for 33 female and 25 male fishers that were captured as juveniles (*n* = 53), or young subadults (*n* = 8; ≤18 months old) (-Table 27). Fifteen of those fishers (25.8%) either died, disappeared, or were caught too late in the year to define a juvenile home range (Table 27). Dispersal was assessed for 43 (74%) of the 58 animals, based on identification of likely natal areas from either field data or genetic-based maternity assignments (Table 27).

Considering data for dispersal using either field or genetic-based natal area determination and based on Euclidean distances, male fishers tended to disperse longer distances than females, but the difference was not significant (Table 28). The longest Euclidean distance dispersal for a female fisher was 24.53 km, compared to 36.17 km for a male fisher, however the large range of dispersal distances for both sexes precludes precise statistical comparison.

Euclidean dispersal movements often originated from within the Key Watershed focal study area, but other Subregions of the study area produced dispersing animals as well (Fig. 20). There was no clear patterning with regards directionality of dispersal, except perhaps the general northwest to southeasterly orientation associated with the Sierra Nevada range (Fig. 20).

One male fisher immigrated into the SNAMP Fisher Study area in the Bass Lake Ranger District from south of Shaver Lake within the High Sierra District. This fisher, KRFP ID M38 (SNAMP ID M47), was originally captured and marked with a PIT tag on the Kings River Fisher Project in December 2010. M38 was recaptured by the KRFP researchers in the KRFP study area in February 2012, when he was released without a radiocollar due to an abrasion from his original radiocollar. M38 was captured 13 months later in March 2013 within the SNAMP study area. Although his Euclidean distance-based dispersal track was estimated at ≈ 36 km, it is more likely that his dispersal track was more circuitous, and in the range of 67-69 km (Fig. 21).

Dispersal movements predicted by Least Cost Movement (LCP) analyses over landscape features considered restrictive to fishers produced longer mean dispersal distances than Euclidean paths (Table 29, Fig. 22). Nevertheless, and in accordance with data from Euclidean distances, there was no evidence for a significant gender-bias in LCP predicted dispersal tracks (Table 29).

Table 27. Review of information on juvenile or subadult fishers captured on the SNAMP Fisher study for which dispersal assessments were possible from field data, maternal assignments from genetic analyses, or from either source.

		Dispersal not assessed[a]			Dispersal assessed			
Maternal year, Gender	*n*	Died	Missing, disappear	Late capture	Field[b]	Genetics[c]	Both[d]	Total[e]
2007								
Female	3	1			2	2	2	2
Male	3	1			2	1	1	2
2008								
Female	8	2			4	5	3	6
Male	4			1	3	3	3	3
2009								
Female	7	1	1		5	3	3	5
Male	4	1			3	3	3	3
2010								
Female	6	1			5	4	4	5
Male	8	1			5	6	4	7
2011								
Female	7	1			4	6	4	6
Male	4			1	3	3	3	3
2012								
Female	2	1		1				
Male	2			1	1			1
All years								
Female	33	7	1	1	20	20	16	24
Male	25	3		3	17	16	14	19

[a] Dispersal was not assessed if the animals died before <18 months old, when they were missing and not recaptured, or if they were captured after mid-January (<10 months old).
[b] Animals for which home ranges allowed identification of likely natal areas (juvenile home ranges), as well as post dispersal home ranges as subadults or adults.
[c] Animals for which maternal assignments were made using DNA analyses; natal areas were based on maternal home ranges.
[d] Animals for which dispersal could be assessed using both field data (juvenile home ranges) and maternal assignments from genetic analyses.
[e] Number of juveniles/young subadults for which dispersal could be assessed using either field-based home range data, or genetic-based maternal assignments.

Table 28. Estimates of mean Euclidean distances moved by dispersing fishers ≤18 months old on the SNAMP Fisher study. Dispersal was estimated by (1) distance between centroids for juvenile home ranges and subadult or adult home ranges, (2) distance between centroids for maternal home ranges (based on genetic-based maternity assignments) and adult or last known home ranges, or (3) distance between either juvenile home range centroids (fishers without maternity assignments) or maternal home range centroids and adult or last known home ranges.

Dispersal, Gender	*n*	Mean distance (SE)	Range	*t*-test contrasts[a]
1. Juvenile to adult home range (field data)				
Female	20	4.89 (1.36)	0.24-22.26	t_{35}= 1.35, P = 0.19
Male	17	8.48 (2.39)	0.94-36.17	
2. Maternal to adult home range (genetics)				
Female	20	5.00 (1.21)	0.46-24.53	t_{34} = 1.32, P = 0.20
Male	16	7.44 (1.41)	1.82-21.20	
3. Juvenile or Maternal to adult home range (combined field and genetics)				
Female	24	5.76 (1.26)	0.52-24.53	t_{41} = 1.67, P = 0.10
Male	19	9.81 (2.22)	0.94-36.17	

[a] Unequal variance *t*-tests.

Table 29. Mean Least Cost Movement paths (LCP) developed to evaluate dispersal by fishers ≤ 18 months old in the SNAMP Fisher Study area. LCP tracks were estimated for (1) dispersal between centroids for juvenile home ranges and subadult or adult home ranges, (2) for dispersal between centroids for maternal home ranges (based on genetic-based maternity assignments) and adult or last known home ranges, and for (3) dispersal between either juvenile home range centroids (fishers without maternity assignments) or maternal home range centroids and adult or last known home ranges.

Dispersal, Gender	*N*	Mean Least Cost path	Range	*t*-test contrasts[a]
1. Juvenile to adult home range				
Female	20	7.53 (2.39)	0.47-44.09	t_{35}= 0.90, P = 0.38
Male	17	11.63 (4.11)	1.03-69.82	
2. Maternal to Adult home range				
Female	20	6.95 (1.62)	0.47-34.06	t_{34}= 1.07, P = 0.29
Male	16	9.52 (1.77)	1.85-26.15	
3. Juvenile or Maternal to Adult home range				
Female	24	8.76 (2.11)	0.47-44.09	t_{41}= 1.16, P = 0.25
Male	19	13.48 (3.71)	1.03-69.82	

[a] Unequal variance *t*-tests.

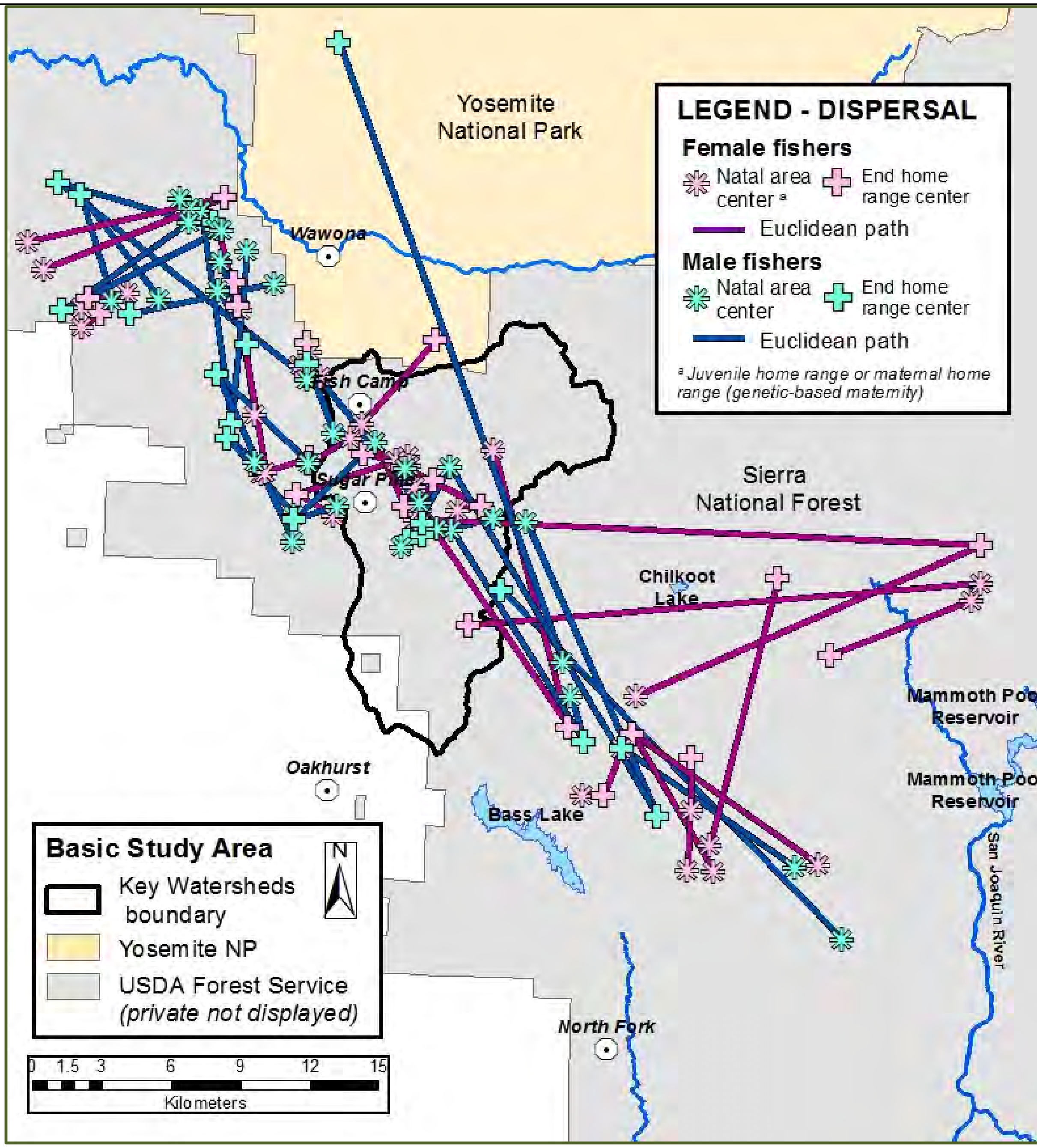


Figure 20. Plot of Euclidean distance dispersal movements for juvenile and young subadult female and males fishers within the SNAMP Fisher Project study area. NOTE: plot excludes the dispersal track for fisher M47 (KRFP fisher that dispersed north from south of Shaver Lake (High Sierra District) to near "Central Camp" in the Bass Lake District.

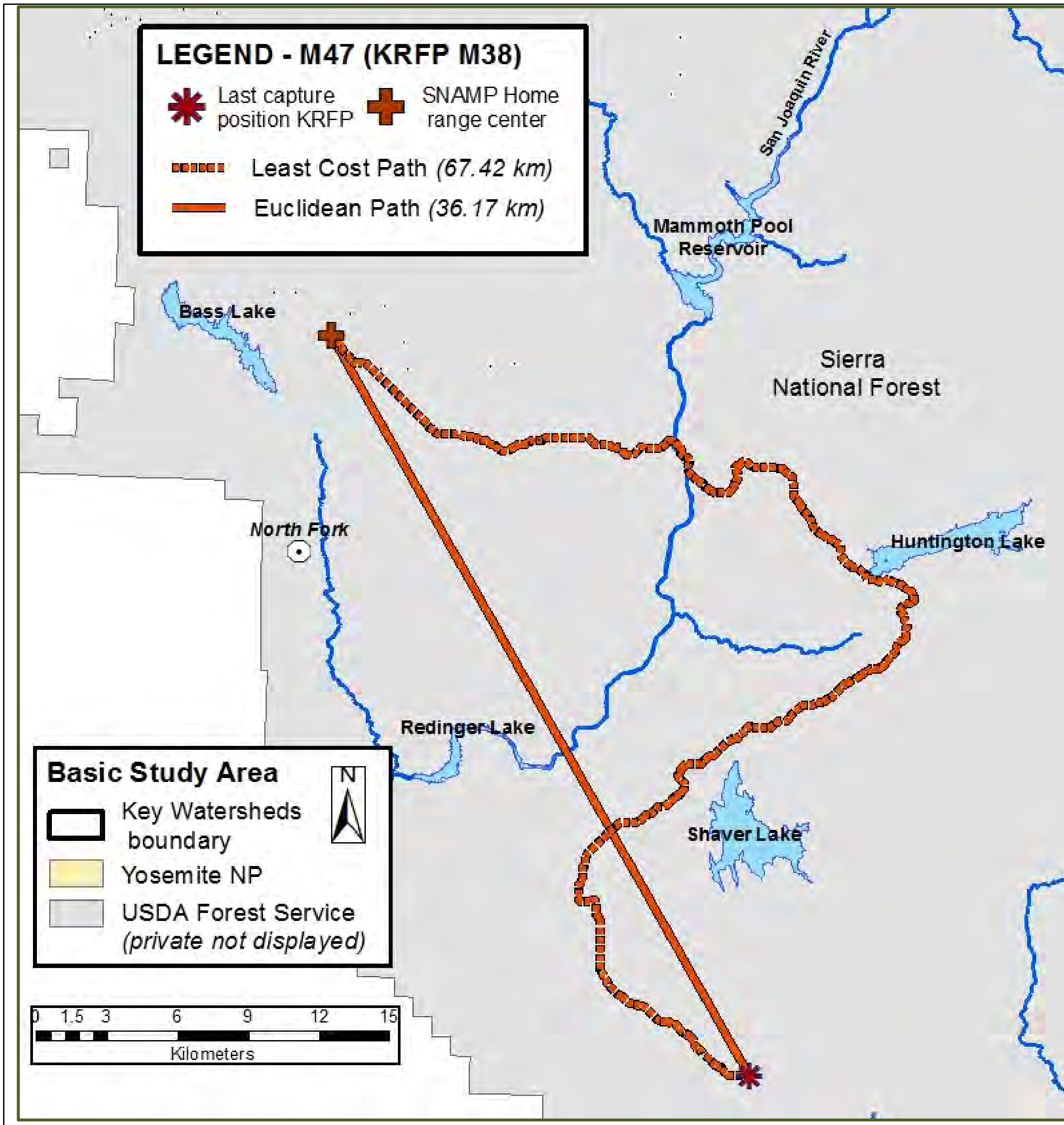


Figure 21. Plot of the Euclidean dispersal track for KRFP Fisher M38 from his last live-trap position in February 2013 to his postdispersal home range centroid near Central Camp within the SNAMP Fisher Study area. The plot also includes the estimated Least Cost Movement path for the M38 dispersal event, which we consider more realistic given the very steep, and vertical cliffs typical of the San Joaquin River canyon east of Redinger Lake.

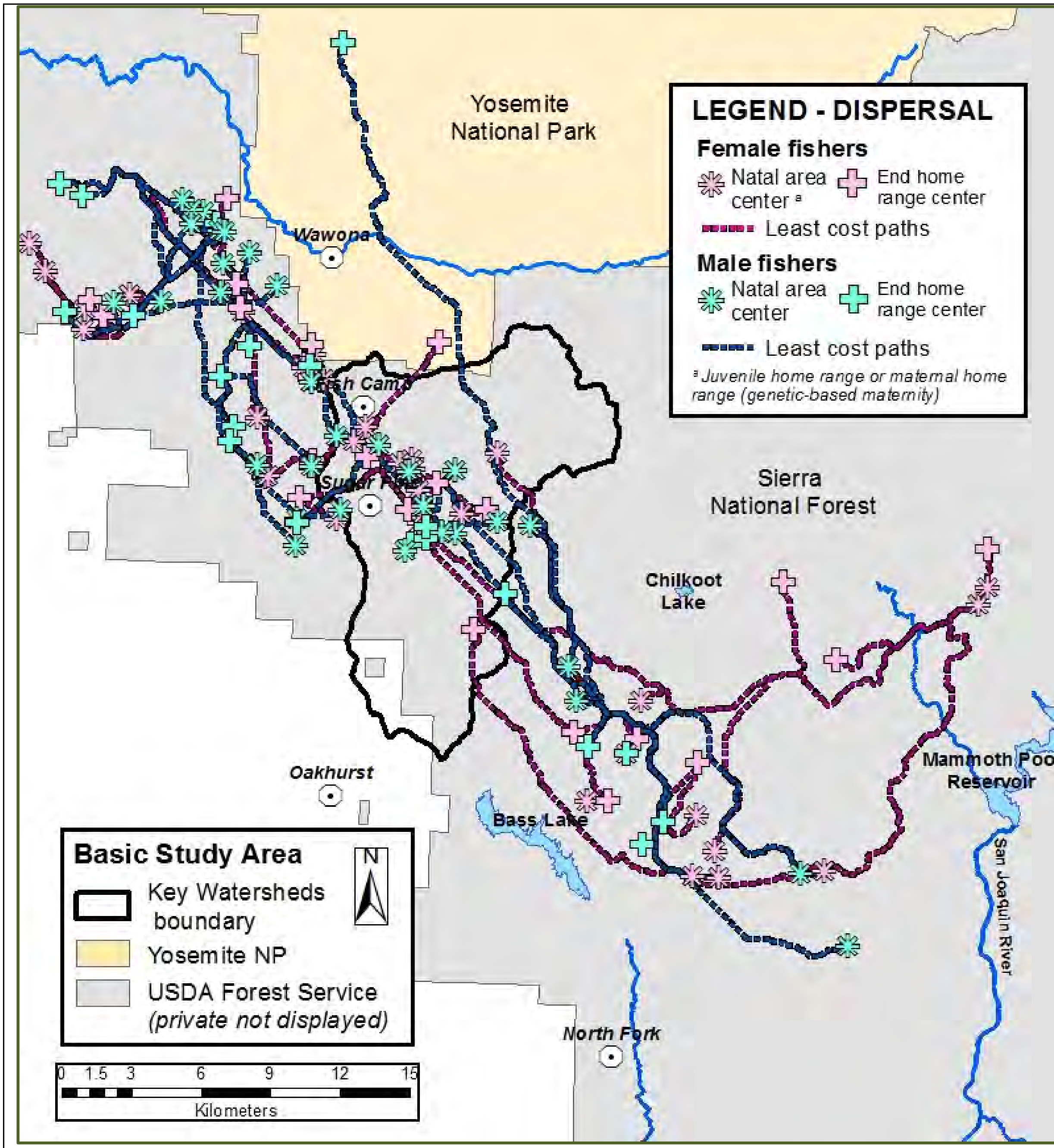


Figure 22. Estimated Least Cost Movement paths for young fishers (≤ 18 months) that were assessed for dispersal in the SNAMP Fisher study area from 2008 to 2013. Least cost movement path were developed as a more realistic way to assess fisher movements given that a number of landscape and habitat features are known avoided or restrictive to fishers as part of their overall natural history.

Young female fishers appeared somewhat more philopatric than male fishers, based on the proportion that moved less than the mean diameter of the annual home range for adult females in the study population) (Fig. 23). The pattern was not significantly different however (Pearson $\chi^2 = 1.12$, $P = 0.29$). Also, there was no statistical evidence that male fishers dispersed farther than female fishers when dispersal distances were scored based on two levels of philopatry and two levels of dispersal (Euclidean distance Likelihood ratio $\chi^2 = 3.89$, P = 0.27; Fig. 24). The same analysis using LCP distances visualized in Fig. 22 was also nonsignificant (LCP Likelihood ratio $\chi^2 = 1.87$, P = 0.60; Fig. 22). However, it was noteworthy from a genetic perspective that 67% of females were philopatric, compared to about 45% of young males (Fig. 24; Table 30).

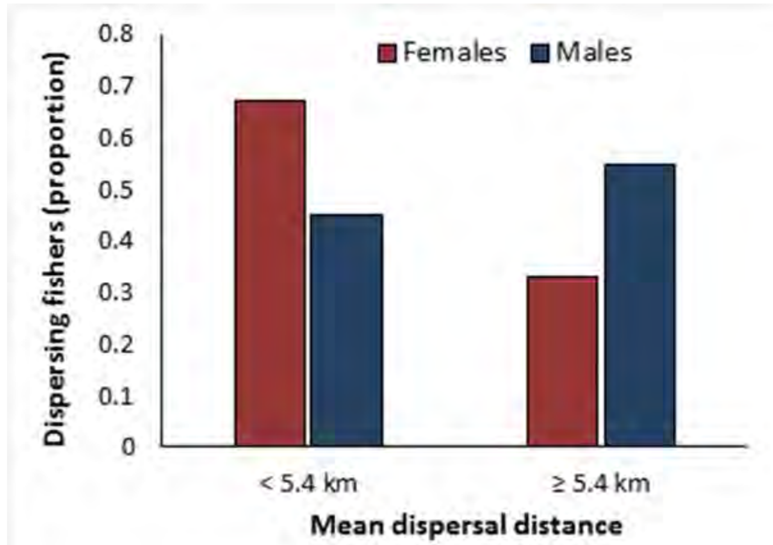


Figure 23. Proportion of female and male fishers that dispersed less than the diameter of the mean annual home range for adult female fishers (22.99 km; diameter = 5.401 km) in the SNAMP Fisher study area. Fishers that dispersed <5.4 km were considered as exhibiting philopatry, whereas those that moved >5.4 km were considered dispersers.

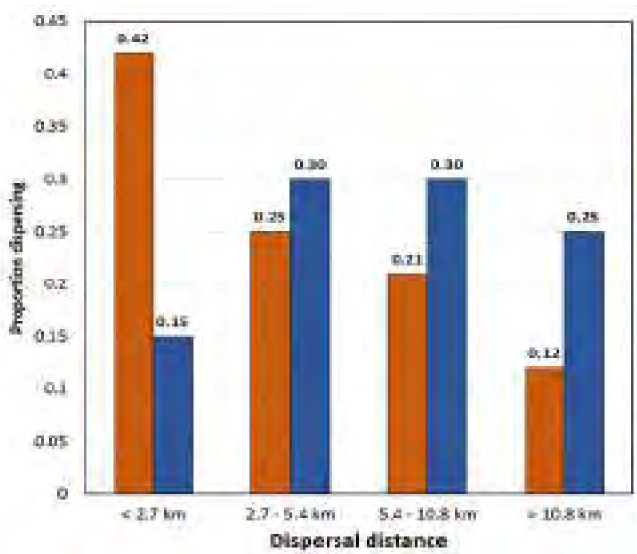


Figure 24. Plot of four different categories of dispersal distances for male and female fishers. Categories are based on dispersal distances of less than 0.5, 1.0, 1.5 and >2 times the mean diameter of the annual adult female home range in the study area. ***Illustration 12 (right):*** female fisher on the move.

Table 30. Information on periods of the year when juvenile fishers initiated transitional movements as part of natal dispersal[a], and numbers of young fishers (<18 months old) that were philopatric, or that dispersed more than 1 diameter of the mean adult female home range (22.99 km; diameter = 5.41).

Dispersal parameter	Female	Male	Total
Timing of dispersal initiation			
Fall to mid-winter (Oct 15 - Feb 4)	2	3	5
Late winter to mid-spring (Feb 5 - May 5)	7	7	14
Late spring or summer (May 6 - Sep 20)	2	3	5
Dispersal distance			
Short distance philopatric (< 2.7 km)[b]	10	3	13
Philopatric (2.7 km to 5.4 km)[c]	6	6	12
Medium distance dispersal (5.4-10.8 km)[d]	5	6	11
Long distance dispersal (>10.8 km)[e]	3	5	8

[a] Data on initiation of dispersal were for a smaller subset of juveniles (*n* = 22) that made transitional movement that were apparent based on aerial telemetry locations and home range models
[b] <0.5X diameter of mean adult female home range
[c] 0.5-1X diameter of mean adult female home range
[d] 1-2X diameter of mean adult female home range
[e] >2X diameter of mean adult female home range

Information on timing of dispersal is important for understanding whether juveniles captured in fall and winter were resident (born near the area of capture and initial locations), or if they originated elsewhere. Five dispersal events (20.8%) were initiated by juvenile fishers during fall to mid-winter (Table 30). Fourteen (58.3%) were initiated during the late winter to mid-spring time frame, and five started in late spring or summer (Table 30). Thus, nearly 80% of natal dispersal events occurred after February 5 when fishers were 11-13 months old.

Home Range Dynamics

We obtained and processed ≈ 35,365 location records from all sources (Table 3; Fig. 25) from October 2007 to December 2013. The location dataset was screened for errors and duplicates (same day, same animal, <8 hrs apart in time), after which approx. 32,370 of the locations were retained for detailed analyses of movements (home ranges) for 109 different fishers. Most of the location records were from aerial radiotelemetry (88%), which were less accurate than other types of locations in the database (Table 3).

Annual 95% fixed-kernel home range areas differed by gender for all age classes (Fig. 26), with mean values ranging from 20.98 km^2 for juvenile females to 86.18 km^2 for adult males (Table 31). Male fishers are larger in body mass and morphological size than females (Powell 1993), and size dimorphism was already evident between genders when juvenile fishers were captured and

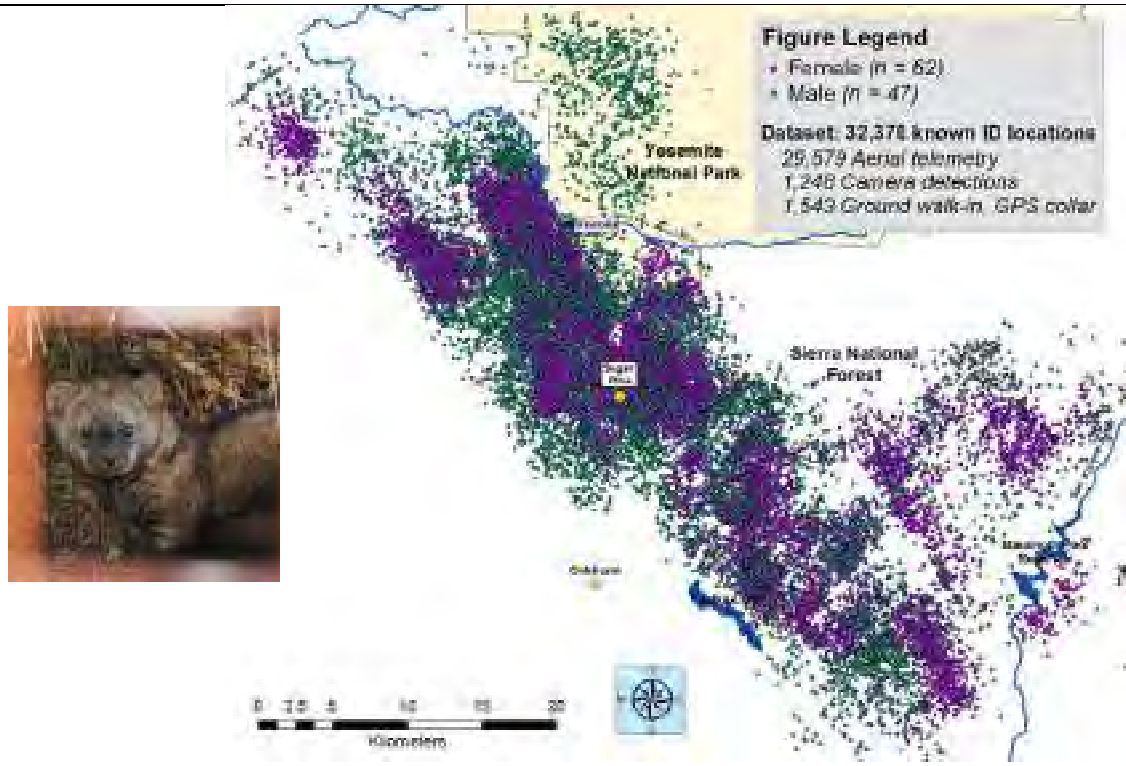


Figure 25. Distribution of location records used to evaluate movements and home range size for fishers that were radiocollared and monitored for survival from Dec 2007 to Dec 2013. ***Illustration 13:*** juvenile female fisher "bycatch" in a Bobcat Trap in 2011.

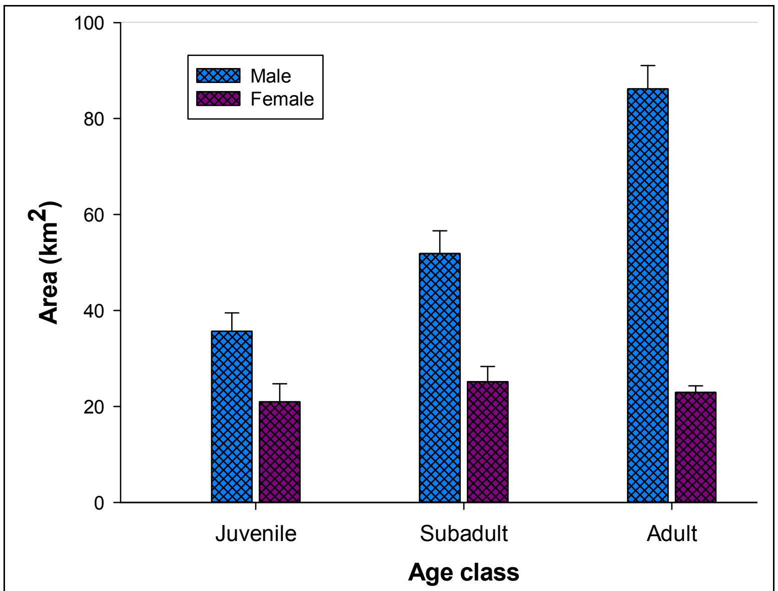


Figure 26. Mean annual home range size (SE bars) for male and female fishers from the SNAMP Fisher Project. More details, including size of core use areas are provided in Table 10.

measured in October and November (7-8 months old) (Focused Research Topic 1; Table 36). Body size is closely related to home range size in mammals (Swihart et al. 1988), which helps explain the larger size of annual home ranges for all age classes of male fishers in this study (Table 31, Figure 21).

Although fishers have previously been described as exhibiting intrasexual territoriality (Powell et al. 2003), we noted considerable overlap between the annual home ranges of adults of the same sex (Fig. 27). Annual home ranges

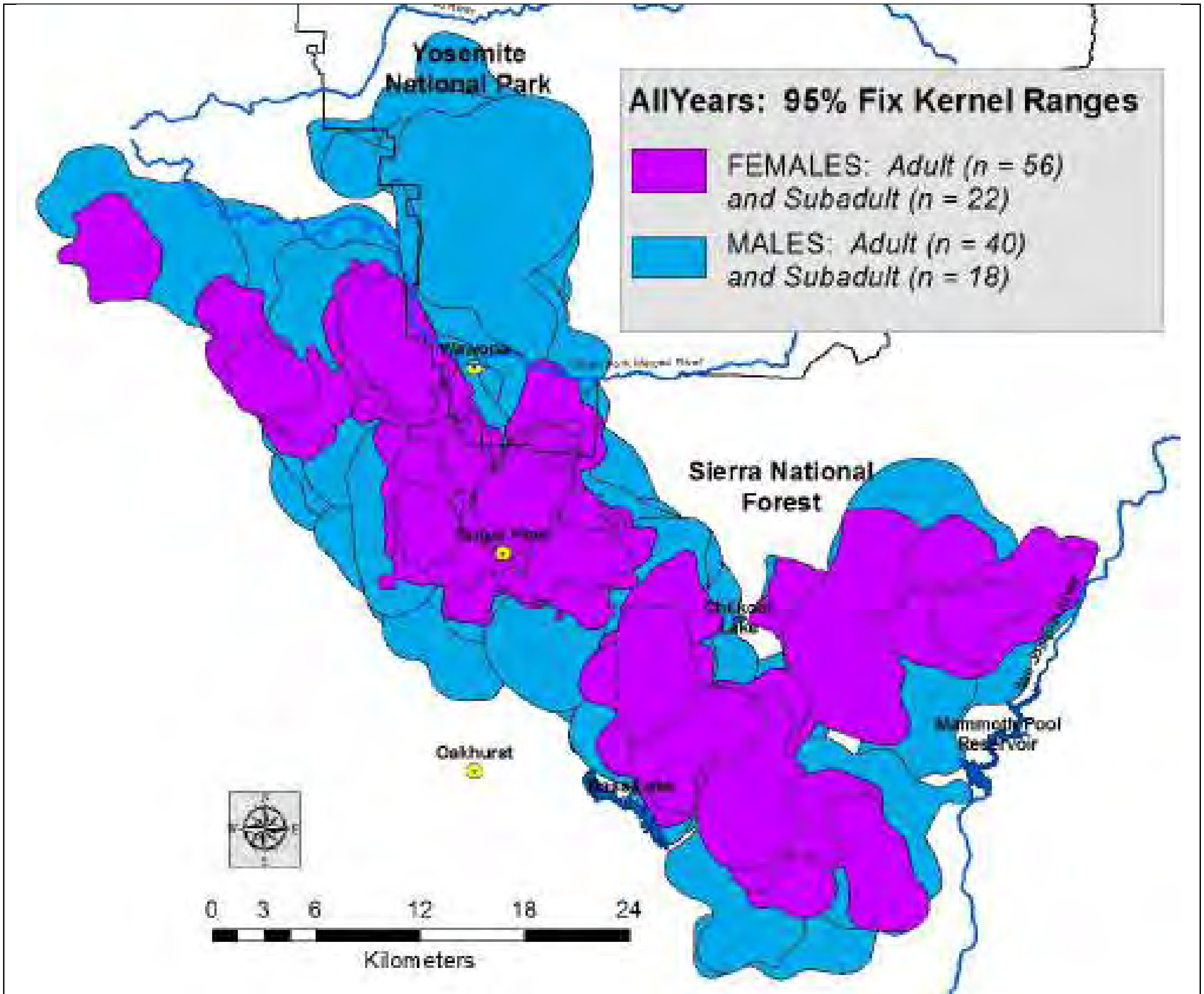


Figure 27. Annual home ranges for female and male fishers. The plot illustrates space use behavior where (1) the larger home ranges of males (Fig. 12) overlap home ranges of all females in the population, and (2) high overlap in space use among resident females at the 95% home range isopleth.

overlapped extensively among neighboring females, but overlap declined at the 70 or 60 percent fixed-kernel isopleths. These results suggest that female fishers maintain exclusive intra-sexual territories in their core use areas. Adult males move widely during the breeding season, resulting in widely overlapping use areas during spring (Popescu et al. 2014).

Home range sizes for fishers varied seasonally (Table 32; Fig. 28). Adult female home ranges were smallest during the spring, and reproducing females have smaller home ranges than non-reproducing females during this time when mothers are constrained to the den area and provisioning kits at den structures. Home ranges of denning females were smaller than non-reproductive female home ranges through the summer, before offspring become independent. Size of seasonal home ranges ~~among~~ adult male fishers was smallest during the summer and largest during the spring, reflecting ~~wide~~ movement associated with mating during March and April (Table 32). In contrast, seasonal home ranges of subadult males (likely non-reproductive) were largest during winter and relatively stable during spring, summer, and fall (Table 32).

Excluding the spring season home range for adult males, home range size was largest for all age and sex classes of fishers during winter, likely due to scarcity of prey

.

Table 31. Mean annual and core use home range sizes ($km^2 \pm$ SE) for radio-tracked fishers at the SNAMP site, December 2007 to March 2013

Age/Sex	N	Annual[a]	Core use[b]
Juvenile (<12 months)[c]			
Female	10	20.98 ± 3.76	6.59 ± 1.18
Male	4	35.68 ± 3.83	11.86 ± 1.02
Subadult (12 to 23 months)			
Female	22	25.15 ± 3.20	8.59 ± 1.09
Male	18	51.85 ± 4.76	18.15 ± 1.66
Adult (≥24 months)			
Female	56	22.93 ± 1.36	7.78 ± 0.59
Male	40	86.18 ± 4.87	30.23 ± 1.78

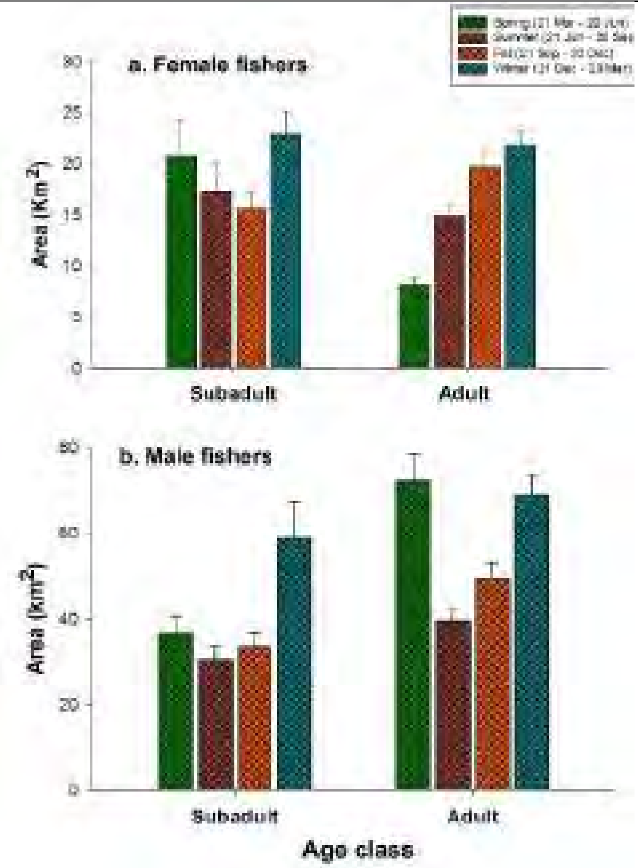
[a]Annual home ranges were estimated for fishers for which locations were available for ≥6 months between Apr 1 and Mar 31; number of location records used for annual home models ranged from 77 to 326.
[b] Core use home range estimated using methods described in Seaman and Powell (1990) and Bingham and Noon (1997); ~2/3 of the core use areas were the 60% isopleth, the remainder were the 70% isopleth.
[c] Home ranges for juvenile fishers monitored ≥5 months in Oct to Mar period; excludes fishers that exhibited dispersal movement behavior.

Table 32. Mean home range sizes (95% ~~Fix Kernel~~; $km^2 \pm$ SE) for fishers during four seasons[a] of the year. Data for animals radio-collared on the Sierra National Forest, CA from December 2007 to March 2013.

Age	*n*	Spring	*n*	Summer	*n*	Fall	*n*	Winter
Juvenile[b]								
Female					11	16.24 ± 2.52	17	18.72 ± 2.46
Male					4	20.10 ± 3.51	9	48.92 ± 12.73
Subadult[b]								
Female	17	20.78 ± 3.59	21	17.19 ± 2.73	21	15.61 ± 1.41	22	22.87 ± 2.28
Male	12	36.48 ± 4.26	13	30.49 ± 3.31	14	33.51 ± 3.15	19	58.90 ± 8.61
Adult								
Female[c]	59	8.18 ± 0.64	43	14.92 ± 1.02	50	19.70 ± 1.37	50	21.77 ± 1.28
Male	35	72.07 ± 6.39	34	39.49 ± 2.75	32	49.25 ± 4.04	37	68.91 ± 4.73

[a]*Seasons were Spring: 21 Mar to 20 Jun; Summer: 21 Jun to 20 Sep; Fall 21: 21 Sep to 20 Dec; Winter: 21 Dec to 20 Mar.*
[b] *Excludes home ranges for fishers that exhibited movements associated with dispersal*
[c] *Includes home ranges for adult females that denned during the spring period of each year and excludes nondenning adults.*

Figure 28. Plot illustrating size of the mean seasonal home range size (SE bars) for female (a) and male (b) fishers from the SNAMP Fisher Project. NOTE: the scale is different for the two plots, which helps to illustrate similarities in habitat use patterns for the different age and sex groups. More details are provided in Table 32. (***Illustration 14***: adult female fisher departing a black oak den tree in spring 2011)



SNAMP Fisher Management Indicators

Management indicator 1 (occupancy/presence of fisher detections in 1-km^2 grids within the Key Watersheds) ranged from a low of 53% in 2012-13 to a high of 76% in 2011-12 (Table 33). The index of fisher activity developed for Management Indicator 1 indicated that the estimated detection rate (detections/100 camera survey days) was highest in 2012-13 and lowest in 2010-11. It was unusual that the detection rate was highest in the same year that naïve occupancy was lowest (Table 33). Camera year 2012-13 was atypical in that many grids in the Key Watershed were surveyed during summer when detection rates are significantly lower (Popescu et al. 2014). It was therefore possible that the low occupancy for 2012-13 compared to most other years was related to timing of surveys.

Spatially, the distribution of ~~fisher~~ active grids changed among years (Fig. 29). Visually, there was the appearance that fisher detections were somewhat reduced in the Cedar Valley Project region of the Key Watersheds (center-south; Figs. 4, 29) immediately after project implementation. There were also changes in fisher detections in the northeast region of the Key Watersheds, which may have been associated with mastication and other activities associated with the Fish Camp Project (Figs. 4, 29).

Visual comparisons of presence/absence are not appropriate for detecting patterns or trend in occupancy (persistence, extinction, recolonization) related to forest management projects, however. Detailed, multi-year occupancy modeling analyses are underway, which include the proportion of each grid treated in each of six years by different forest management activities. Models also include other covariates potentially important for understanding detection histories and habitat use (e.g., season, elevation).

Table 33. Management indicator for fisher activity in the Key Watershed focal study area, based on the number of 1 km^2 grids in which fishers were detected during annual surveys with camera traps.[a] Camera trap surveys were completed in each of six "camera years" (≈ Oct 15 to Oct 14) using our standard protocol.

Camera year	Grids surveyed	Grids with fisher detections	Naïve occupancy	Fisher detections per 100 survey days[c]
2007-08	122	71	0.582	11.4
2008-09	129	75	0.581	13.2
2009-10	127	75	0.591	15.2
2010-11	125	82	0.656	10.5
2011-12	128	98	0.766	14.2
2012-13	133	70	0.526	18.6

[a] Camera trap surveys were completed in each of six "camera years" (≈ Oct 15 to Oct 14) using a standard protocol (see report)

[b] Number grids with fisher detections divided by the total number of grids surveyed; occupancy rate is not corrected for a survey-specific probability of detection < 1.0.

[c] Estimated as the number of functional camera survey days with fisher detections, but excluded camera days for grids with no fisher detections.

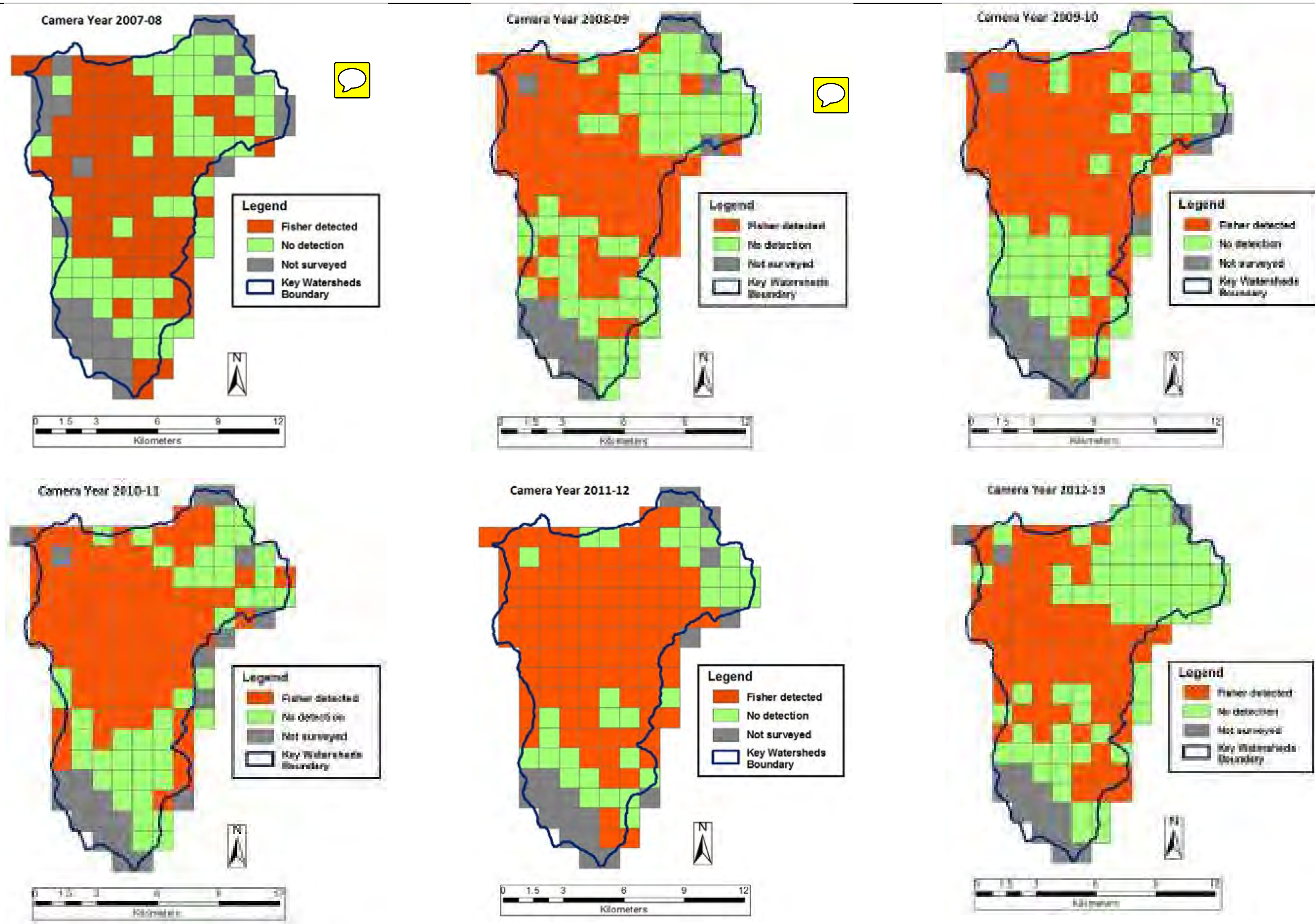


Figure 29. GIS plots illustrating change in patterns of occupancy for Management Indicator 1 for six camera years (Table **33** for details).

As an extension to Management Indicator 1, We we also created an overall index of fisher activity for each grid based on mean number days in each camera survey year with fisher detections and the proportion of survey years with fisher detections (Fig. 30). The index illustrates that fisher activity was consistently high in the center and northwest region of the Key Watersheds, and lowest from Cedar Valley southward (Fig. 30).

Management Indicator 2 identified an average of 5.0 subadult or adult females and 2.0 subadult or adult males using the Key Watershed focal study area across all years (Table 34). For both sexes combined, the number of resident fishers using the focal study area ranged from 6.2 to 7.7, and the variation among years was small (Table 34, Fig. 31).

Table 34. Management indicator for the number of resident subadult and adult fishers using the Key Watershed focal study area for their various home range activities during Sep 1 to Mar 15 of each year.

Year	Females[a]	Males	Both genders
2007-08[b]			
2008-09	5.6	2.1	7.7
2009-10	6.1	1.4	7.5
2010-11	4.1	2.1	6.2
2011-12	4.0	2.9	6.9
2012-13	5.0	1.7	6.7

[a] Numbers are based on the sum of the proportion of each individual fishers' 95% fixed kernel home range included within the Key Watershed region.

[b] Because of the limited number of fishers radiocollared during the first project year (n = 7, before March 31, 2008) it was not informative to calculate this Management Indicator in that year.

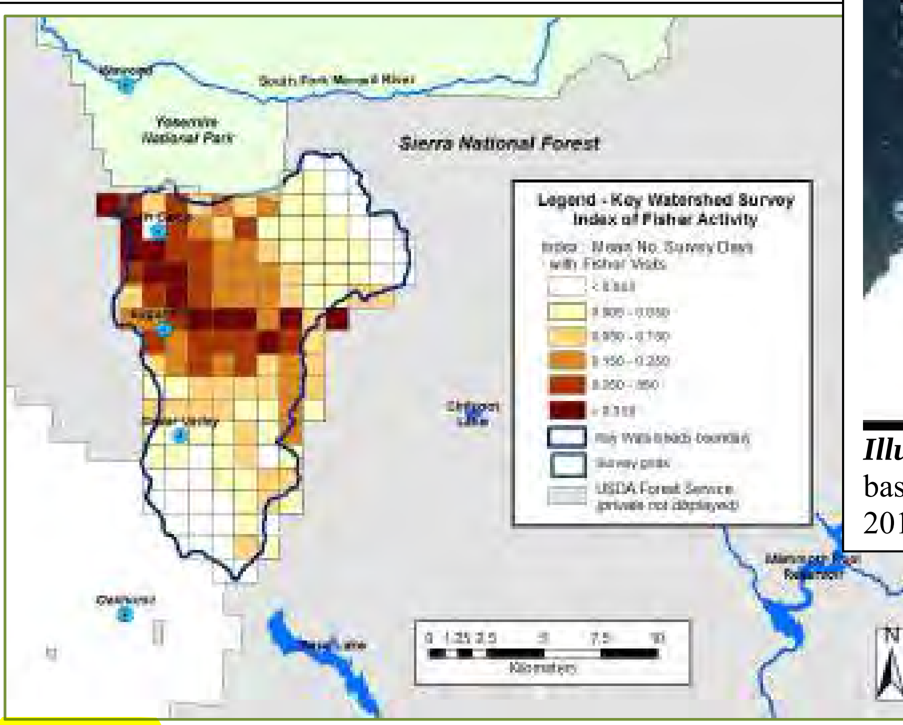


Figure 30. Index of fisher activity from repeat camera surveys completed in the Key Watersheds focal study area. The Index was calculated as the mean no. of days with fisher activity for years that the grid was surveyed/1 + proportion of surveyed years with fishers detections in the grid.

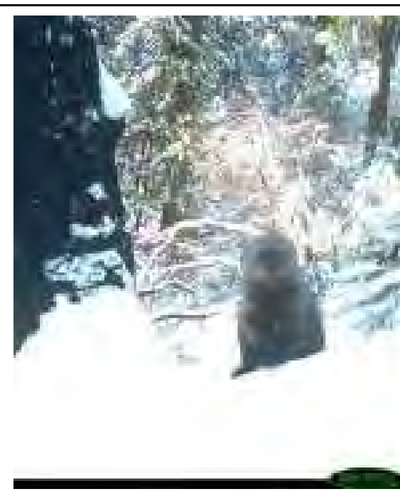
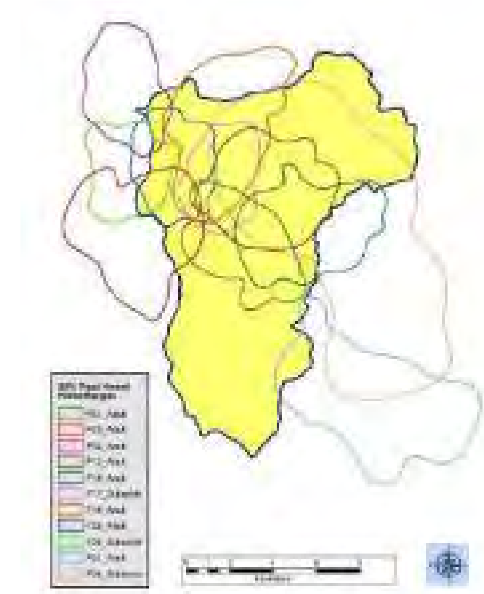


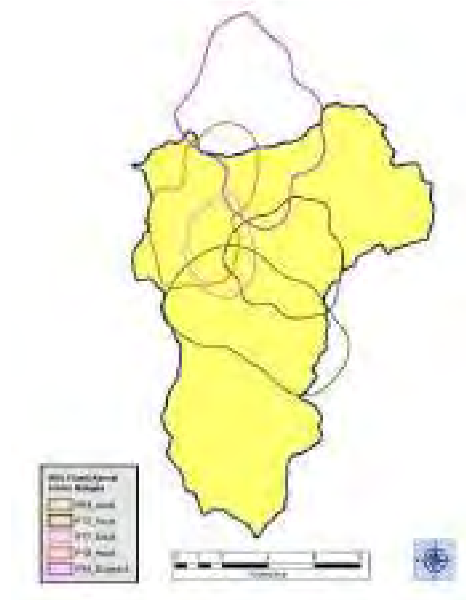
Illustration 15: Male fisher at base of a den tree in spring 2010.

Population Year 2: *5.6 resident females*

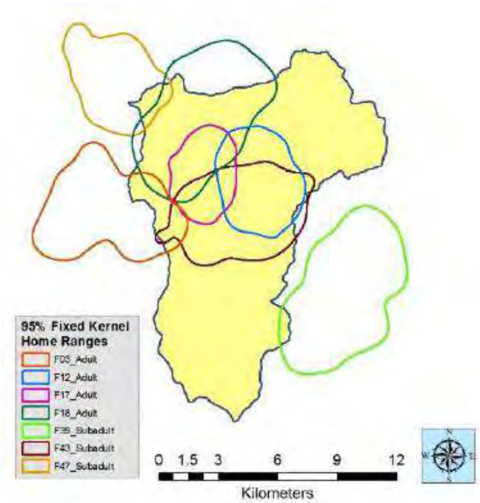
Population Year 3: *6.1 resident females*



Population Year 4: 4.*1 resident females*



Population Year 5: *4.0 resident females*



Population Year 6: *5.0 resident females*

Figure 31. Estimated number of subadult and adult female fishers (resident females) with home ranges including portions of the Key Watersheds focal study area. Polylines are individual 95% fixed kernel home ranges based on location records during the Sep 1 to Mar 15 period during each population year (Apr 1 to Mar 31).

The original Management Indicator 3 was recast to estimate survival for adult female fishers for a sequence of 2-year groups of demographic data (data combined for Kaplan-Meier models of survival). For the first 2-year group, we included data for the small number of fishers (*n*=7) that were captured and radiocollared from mid December 2007 to March 31, 2008. We further summarized data on Juvenile and subadult female survival, and calculated point estimates of weaning reproduction and weaning litter size for each of the five 2-year groups (Table 24). Expanded Management Indicator 3 identified that adult female survival ranged from a low of 0.69 in Year group 3 to a high of 0.86 in Year group 4 (Table 35). Corresponding data on survival for juvenile and subadult females and data on reproduction identified that relatively low levels of survival and reproduction suggested the population was in decline ($\lambda < 1.0$) ~~population~~ between 2008 and 2010, stable between 2010 and 2012, and increasing by 3-4%/year during 2012 to 2014 (Table 35). However the fact that 95% CI for λ overlapped 1.0 in all years indicates that these values should be interpreted carefully.

Table 35. Expanded Management Indicator 3 for adult female survival, including Leslie Matrix population growth rates for two year running average starting in 2008 and ending in spring 2014. Population years start April 1 and end March 31. Numbers in parentheses for survival are the 95% CIs based on Kaplan-Meier staggered entry survival analyses for the group of years identified.

Year group, Demographic rate	Juvenile	Subadult	Adult	λ[a]
1. 2007-08, 2008-09, 2009-10 [b]				
Survival, s(*t*)	0.76 (0.53-0.99)	0.47 (0.28-0.67)	0.81 (0.66-0.96)	0.87 (0.65-1.08)
2. 2009-10, 2010-11				
Survival, s(*t*)	0.8 (0.59-1.01)	0.67 (0.42-0.92)	0.70 (0.54-0.86)	0.88 (0.63-1.12)
3. 2010-11, 2011-12				
Survival, s(*t*)	0.74 (0.54-0.94)	0.89 (0.71-1.07)	0.69 (0.53-0.86)	1.00 (0.77-1.22)
4. 2011-12, 2012-13				
Survival, s(*t*)	0.80 (0.55-1.05)	0.73 (0.52-0.94)	0.86 (0.71-1.00)	1.04 (0.81-1.26)
5. 2012-13, 2013-14				
Survival, s(*t*)	1.0	0.73 (0.48-0.98)	0.74 (0.56-0.93)	1.03 (0.77-1.22)

[a] Population growth rate was estimated using the demographic parameters developed for each Year group in a Leslie-Matrix model formulation described previously. The range in values for λ was based on the 95% CIs for survival for each age class when producing fertility (F_i) rates using the equation $F_i = b_i P_i$, where $b(i)$ was fecundity, and P_i was the age-specific survival rate (see Table 23).
[b] Year group 1 includes information for a small number fishers monitored for survival from late December to March 2008. All other year groups include two population years of data.

Fisher response to fuel management

Management disturbances and wildfire

Our analyses of FACTS and other extractive and restorative management activities revealed that the estimated area of forest disturbing activities that occurred in the study area was highest for restorative fuel reduction, moderate for logging, and lowest for managed burning and natural or human caused wildfires (Table 36). We estimated that there was an annual average 1.9% (SD 0.70) of the study area treated for restorative fuel reduction each year from 2002-03 to 2012-13, and 20.6% of the study area was disturbed by these activities in all 11 years. We estimated that there was an annual average of 1.1% (SD 0.70) of the study area with extractive fuel reduction each year from 2002-03 to 2012-13, and an estimated 12.1% of the study area was disturbed by logging in all 11 years. We estimated that there was an annual average of 0.25% (SD 0.28) of the study area with managed burning each year from 2002-03 to 2012-13, and an estimated 2.8% of the study area was disturbed by managed burns in all 11 years. Also, the combined area disturbed by all 3 management activities averaged 36.3 km^2 /year from 2002-03 to 2012-13, which represented an annual disturbance of 3.2%/year from SPLATS in the overall study area. Our fire variables included managed burns+forest fires, and we estimated that the annual average portion of the study area with managed burns+wildfires was 0.56%/year (SD, 0.83) from 2002-03 to 2012-13, and 6.2% of the overall study area was exposed to those disturbances in the 11 years. Also, in the 44 years from 1957 to 2001, we estimated that 130.2 km^2 (11.6%) of the overall study area was burned by wildfires.

Multi-season occupancy

The mean detection probability for fishers per 8-10 day survey period in the 361 multi-season survey grids was 0.31 (95% CI: 0.28, 0.37). Naïve inital occupancy among the multi-season grids was 0.66, whereas our modeled estimate for intial occupancy averaged across survey sites was 0.75 (95% CI: 0.59, 0.87). Mean annual persistence (1-extinction) was 0.87 (95% CI: 0.82, 0.91), whereas the annual colonization rate was 0.34 (95% CI 0.28, 0.42).

Our multi-season occupancy modeling identified a single best model for local colonization that included the intercept only (Table 37). Covariates *hazfuels.5*, *log.5*, and *burn.1.50* were included in 3 lower ranking colonization models with support, but the relative importance for each individual variable was≤ 0.35. We therefore fit an intercept-only colonization component in our subsequent evaluation of extinction covariates.

Table 36. Estimates of the areas (km^2)[a] disturbed by logging activities, fuel reduction treatments, and managed burns in the Bass Lake District, Sierra National Forest, and southwestern Yosemite National Park in 11 camera survey years (Oct 15 to Oct 14) from 2002 to 2013 as well as wildfire activity in 5-year periods from 1957 through 2001.

5 yr period or survey year	Restorative fuel reduction		Extractive fuel reduction		Managed burns + forest fire	
	Area	Study area (%)	Area	Study area (%)	Area	Study area (%)
1957 to 1961					36.40	7.28
1962 to 1966					5.30	1.06
1967 to 1971					6.05	1.21
1972 to 1976					3.43	0.69
1977 to 1981					4.65	0.93
1982 to 1986					11.46	2.29
1987 to 1991					41.91	8.38
1992 to 1996					0.99	0.20
1997 to 2001					20.05	4.01
2002-03	23.7	2.10	11.6	1.03	3.5	0.31
2003-04	13.7	1.21	2.9	0.26	3.7	0.33
2004-05	13	1.15	7	0.62	4.3	0.38
2005-06	26	2.31	6.8	0.60	2.4	0.21
2006-07	34.5	3.06	13.1	1.16	5.3	0.47
2007-08	15.8	1.40	2.1	0.19	34.0	3.02
2008-09	29.1	2.58	11.4	1.01	3.8	0.34
2009-10	27.4	2.43	27	2.39	1.0	0.09
2010-11	12.4	1.10	13.8	1.22	6.1	0.54
2011-12	12.6	1.12	24.3	2.16	0.1	0.01
2012-13	23.9	2.12	16.1	1.43	5.7	0.50
Total area	*232.1*		*136.1*		*69.87*	

[a] Areas of disturbance were derived from FACTs data, private timber harvest data, and Sierra National Forest and Yosemite National Park databases (Table 1). The overall study area was 1125.6 km^2 (Fig. 1), which was used to estimate percent disturbance of each type within the study area.
[b] Totals for 1957 to 2001, and 2002-03 to 2012-13, respectively.
[c] Means for 1957 to 2001 (44 years), and 2002-03 to 2012-13 (11 years), respectively.

Our multi-season models evaluating local extinction identified a single top model including covariate *hazfuels.5* only (*hazfuel.5* relative importance = 0.98) (Table 37). There were 2 models with support that included the covariates *log.5* and *burn.1.50,* but the individual relative importance metrics for both were low. We found that fisher persistence (1 - extinction) was negatively associated with *hazfuels.5;* probability of persistence decreased by 27% as the proportion of the grid treated for cumulative restorative fuel reduction increased from 0 (occupancy = 0.89, 95%CI 0.85, 0.92) to 1.0 (occupancy = 0.65, 95%CI 0.46, 0.81).

Table 37. Candidate models for multi-season occupancy evaluations of local patch extinction and colonization for camera trap surveys for fishers in the Bass Lake District, and southwestern Yosemite National Park, California from Oct 2007 to Oct 2014.

Model, covariate	AIC	ΔAIC	AIC_{wt}	Cumulative AIC_{wt}	Covariate importance
Colonization					
intercept only	4211.96	0.00	0.34	0.34	
hazfuels.5	4213.15	1.19	0.19	0.53	0.35
log.5	4213.87	1.91	0.13	0.66	0.27
burn.1.50	4213.95	2.00	0.13	0.79	0.27
hazfuels.5 + log.5	4215.14	3.19	0.07	0.86	
hazfuels.5 + burn.1.50	4215.15	3.19	0.07	0.93	
burn.1.50 + log.5	4215.87	3.91	0.05	0.97	
hazfuels.5 + burn.1.50 + log.5	4217.14	5.19	0.03	1.00	
Extinction					
hazfuels.5	4205.26	0.00	0.50	0.50	0.98
hazfuels.5 + log5	4207.08	1.82	0.20	0.70	
hazfuels.5 + burn.1.50	4207.11	1.85	0.20	0.90	
hazfuels.5 + burn.1.50 + log.5	4208.96	3.70	0.08	0.98	
intercept only	4212.67	7.42	0.01	0.99	
log.5	4214.16	8.90	0.01	0.99	0.29
burn.1.50	4214.61	9.36	0.00	1.00	0.28
burn.1.50 + log.5	4216.05	10.80	0.00	1.00	

Integration

Fire modeling

Fuels treatments reduced the intensity of the simulated fire, as evidenced by the predicted flame lengths (Figure 1). On the untreated landscape, 68.6%, 18.4%, 11.2%, and 1.8% of the study area experienced flame lengths of <2, 2-4, 4-8, and >8 m, respectively. In contrast, on the treated landscape, 75.1%, 16.4%, 7.5%, and 1.0% of the study area burned at these flame lengths. Collins et al. (2011) noted that flame lengths >2 m often corresponded to areas with crown fire initiation (i.e., torching). Thus, a greater proportion of the untreated landscape was exposed to potential crown fire (31.4%) than for the untreated landscape (24.9%).

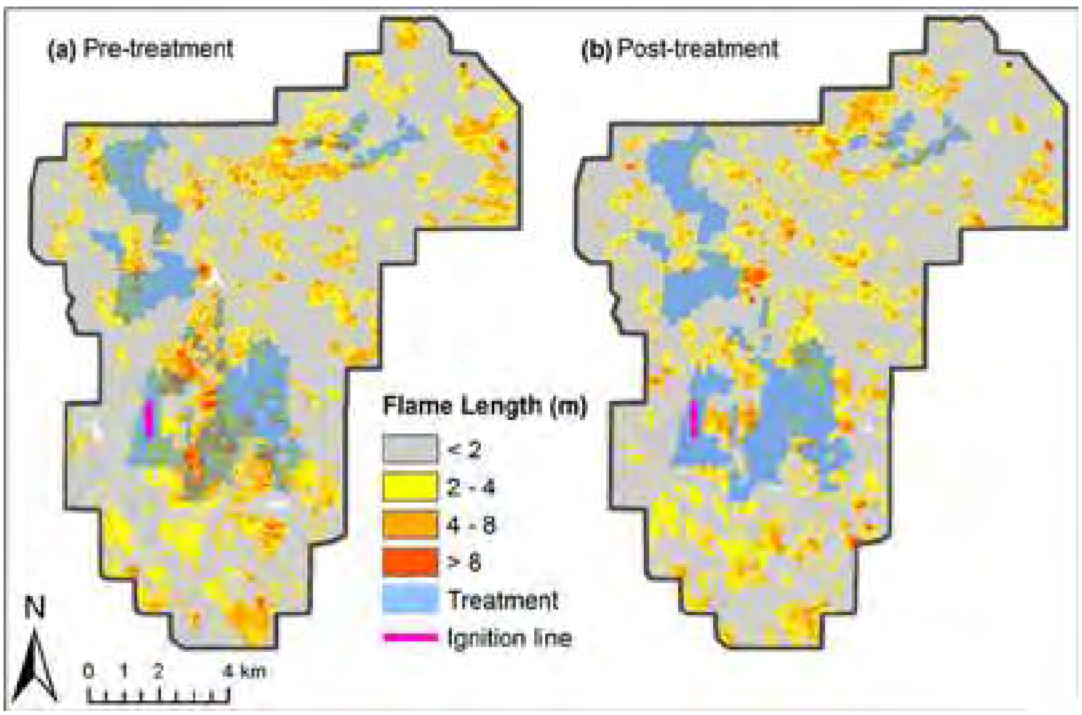
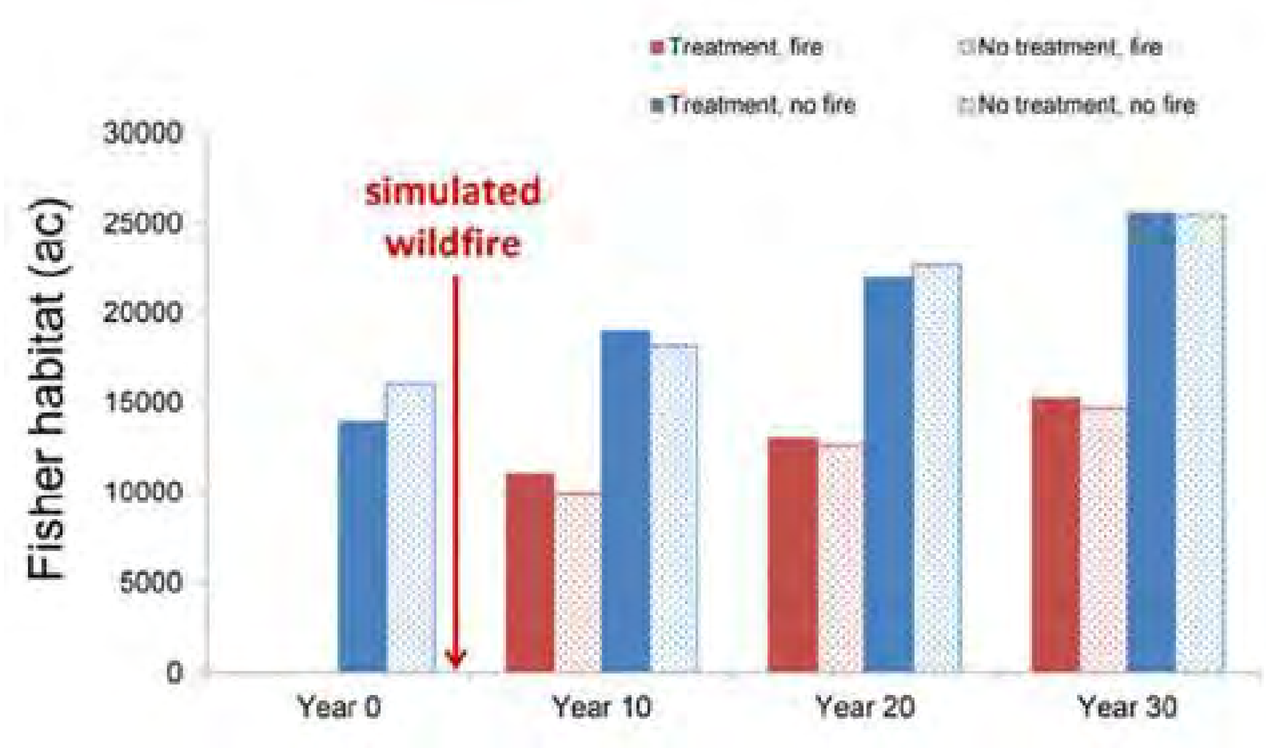


Figure 32. Flame lengths (m) of simulated fires at Sugar Pine on (a) untreated and (b) treated landscapes. We show the location of treatment polygons in (a) for ease of comparison, but treatments were not implemented in (a).

Assessing the effects of fire and SPLATs on fisher habitat

We found that SPLATs caused an immediate, slight reduction in potential fisher habitat. The entire area of the four watersheds was 35,103 ac (14,206 ha), and in year 0, there were 16,013 ac (6,480 ha) of potential fisher habitat on the untreated landscape compared to 13,938 ac (5,641 ha) on the treated landscape (Figure 2). In the absence of simulated fire, the amount of habitat steadily increased over time and was actually slightly greater on the treated landscape in years 10 and 30 (Figure 2). When fire was simulated, SPLATs had a slight, positive effect on the amount of potential fisher habitat up to 30 years later. In year 30, there were 14,653 ac (5,930 ha) of potential fisher habitat on the untreated landscape compared to 15,254 ac (6,173 ha) on the treated landscape (Figure

2).



~~igure~~ **33.** ~~:~~ The amount of potential fisher habitat on the 35,103-ac Sugar Pine study area under four scenarios: 1) no SPLATs and no wildfire; 2) SPLATs and no wildfire; 3) no SPLATs and wildfire; and 4) SPLATs and wildfire. Year 0 for the "no treatment" scenarios was 2008, and year 0 for the "treatment" scenarios was 2013 (i.e., after SPLATs were implemented). Simulated fires occurred in year 0 for both the "no treatment" and "treatment" scenarios, and post-fire effects were first assessed in year 10.

Discussion

Reproduction and Basic Demography

Empirical data on reproductive rates and litter sizes are important for understanding the ability of a population to withstand challenges to survival, and to produce realistic estimates of population size in landscape level population models being developed for conservation planning (Lofroth et al. 2010, Spencer et al. 2011). The basic life history of fishers with regards reproduction is generally well known. Fishers have a long gestation period due to the reproductive strategy of delayed implantation

(Powell 1993). Once the blastocyst implants in the uterine wall 10-11 months after fertilization of the egg, embryonic development resumes and ≈ 36 days later 1-4 kits are typically born.

Parturition for fishers in northern California typically occurs in mid to late March (Matthews et al. 2013a), and female fishers in the SNAMP Fisher population were no exception based on initiation of denning around March 22-31 (Table 13). Also, duration of denning for fishers in our study (≈ 70-75 days; Table 13), and cessation of localization to den trees in early to mid-June was typical of elsewhere in the western United States (Matthews et al 2013*a*, Aubry and Raley 2006). The mean denning rate for female fishers in the SNAMP Fisher study was 0.85 (Table 15), which was slightly lower than for fishers in the Hoopa Fisher Study in northern California (0.88; Matthews et al. 2013a), similar to in the Kings River Fisher Project area (0.86; R. Green, unpublished), and higher than in southern Oregon (0.59; Aubry and Raley 2006). The average weaning rate from SNAMP females in our study area (0.74; Table 15) was higher compared to the Hoopa Fisher Study (0.65; Matthews et al. 2013a), and in southern Oregon (0.44; Aubry and Raley 2006). However, as Matthews et al. (2013*a*) noted, reports of low weaning rates from some studies may be due to issues with age assignment. On our study we closely tracked most animals in the population from when they were juveniles until death, and ages for nine female fishers that were captured early in the study were determined by cementum annuli (Mattson's Laboratory, Milltown, MT; Poole et al. 1994).

Average litter sizes are larger for female fishers in eastern North America (2-4 kits/litter; Paragi et al. 1994, York 1996) compared to in the western United States where litter sizes are most commonly 1 or 2 kits (Lofroth et al. 2010, Aubry and Raley 2006, Matthews et al. 2013). The mean litter size from SNAMP Fisher (1.5 kits/litter, Table 16) was similar to reports from the Kings River Fisher Project (1.6; R. Green, unpublished), but lower than 1.8 kits/litter reported for the Sequoia National Forest, California (Truex et al 1988), 1.9 kits/litter from the Hoopa Fisher Study in northern California (Matthews et al. 2013a), or 1.8 kits/litter in southern Oregon (Aubry and Raley 2006).

Close monitoring of denning behavior by several current studies including SNAMP Fisher is providing insight on difficulties female fishers encounter while attempting to reproduce. In the course of five denning seasons, we documented eight cases when females died or were killed with dependent kits in den cavities (Tables 15, 16). Death of denning female fishers appears fairly common, based on reports from the Hoopa Fisher Study (*n* = 5; Matthews et al. 2013a), the USFS Kings River Study (*n* = 3; C. Thompson, unpublished data), the ongoing California Department of Fish and Wildlife, U.S. Fish and Wildlife, and Sierra Pacific Industries "Stirling Fisher Reintroduction Project" (*n* = 5; Powell et al. 2013), and the Olympic Fisher Reintroduction Project (*n* = 2; Lewis et al. 2012). Evidence that a significant number of females exhibiting denning behavior may die before weaning is important because weaning rates may be biased high unless estimates are based on complete monitoring through the duration of the denning period (Facka et al. 2013).

Denning Structures and Denning Habitats

Across their range in North America female fishers give birth to kits in cavities in live trees or snags (Paragi et al. 1996, York 1996, Weir et al. 2012, Zhao et al. 2012, Matthews et al. 2013a). Den cavities and habitats in the immediate vicinity of denning structures provide protection from predators and inclement weather during the early spring to late spring when females are rearing their young (Weir et al. 2012). Most female fishers use more than one denning structure during a den season (range 1-6; Matthews et al. 2013a), and female fishers on the SNAMP Fisher study used an average of 2.4 different denning structures per den season (range 1-5), compared to 3.4 on the Kings River Fisher Study (R. Green, unpublished data), and 3.1 in northwestern California (Matthews et al. 2013). Female fishers may use more than one denning structure in a season for several reasons: to accommodate kit growth by moving to larger cavities, to reduce predation risk, as bobcats and mountain lions may discover a den location due to odors from the accumulation of urine and feces, to move closer to unexploited foraging areas, and to avoid exposure to feces and parasites that may accumulate in den cavities.

The lower mean number of den trees used by female fishers on the SNAMP Fisher study area compared to on the KRFP or the Hoopa Fisher Study may be related to disturbance by researchers. Biologists on both the KRFP and Hoopa Fisher studies climb den structures of most known denning female fishers to obtain kit counts, and they also attempt to extract kits from den cavities to measure body size, collect tissue samples, and to insert PIT tags for later identification (Thompson et al. 2011, Matthews et al. 2013*a*,*b*). This process requires presence of multiple biologists at the den tree for periods of 60 to 180 minutes. Although we occasionally ascended den trees in the SNAMP study area to obtain kit counts (n = 9 total den tree climbs during six denning seasons), most kit counts (≈ 90%) were obtained using images from 2-4 motion-sensing cameras placed around denning structures to monitor and chronicle denning activities remotely. Moreover, we noticed that some individual female fishers were sensitive to presence of technicians setting up den cameras (the process requires 30 to 60 min), based on short duration use of their denning structures after the first visit. Our den camera protocol was adjusted to minimize time needed to setup and service den cameras by quickly switching out memory cards and reviewing images away from the denning structure. Also, whenever possible, we did not approach den trees to service cameras when radiotelemetry identified presence of the denning female.

On the nearby Kings River Fisher Project where habitats are similar to the SNAMP Fisher study area, denning structures used by female fishers were most commonly black oaks (54%: 50% live, 4% snags). Overall, 91% of denning structures used on the Kings River Fisher Project were live trees. When repeat use den trees were counted just once, 43% of the unique denning structures used in the SNAMP Fisher study area were black oak trees (Table 17; 25% live, 18% snags), and the remaining unique den trees were primarily incense cedar (33%) or white fir (15%). Only 56% of the denning structures used by female fishers in the SNAMP study area were live trees.

Weir et al. (2012) noted that trees need to have two very specific features for female fishers to use them for denning; some form of physical damage to the tree bole to provide access for decay organisms, and the damage must be of particular dimensions to ~~provide predator-secure access for the female~~ to the interior of the tree via frost cracks, fire-scars, large anchored branches pulling out from the tree bole, or woodpecker holes (Lofroth et al. 2010). McDonald (1990) noted that live black oaks are susceptible to internal decay and probably last longer on the landscape than conifer snags. However, 26% of 125 unique den structures used by fishers on the SNAMP study site were in conifer snags (Table 17), suggesting they are not especially uncommon on the landscape in our area. Also, our observations of incense cedars and white fir suggested these two tree types were susceptible to the types of damage identified by Weir et al. (2012), particularly with regard to fire scars for cedar trees. Many of the cedar trees selected for use as den trees had basal fire scars, and the actual den cavities in both cedar trees and white fir were commonly associated with large branch break points.

Habitat and site characteristics immediately surrounding the denning structures are likely important for appropriate thermal conditions, availability of prey, and avoidance of predators (escape cover and concealment cover). Denning structures used in the SNAMP Fisher study area were generally larger than available trees and snags; mean DBH was relatively large (larger for conifers than the hardwoods) and mean tree heights were taller for live conifers compared to conifer snags or oaks in general (Table 18, Fig. 15). Canopy cover was greater than 80% in the vicinity of many den trees (Table 19). Shrub cover near den trees was variable, as was aspect (Table 19, Fig. 16). Most den trees had multiple large down trees/logs nearby, and concealment cover to the base of den trees averaged more than 45%. Although detailed analyses of data from fixed radius habitat plots have not been completed, habitat characteristics were developed from high resolution Lidar data for many den trees within the Key Watersheds. As part of collaborative work with the Spatial Team, Zhao et al. (2012)

identified that fishers selected den sites with tall trees and steep slopes within a 10-m radius of the den tree, high forest structural complexity within 20 m, large tree clusters within 30 m, and high canopy cover and larger mature trees within 50 m. Finally, at the larger landscape scale, the mean elevation for denning structures used in the SNAMP Fisher study was 1,591 m (Fig. 15).

Fisher Survival and Cause-specific Mortality

The SNAMP Fisher study uncovered a wider diversity of causes of mortality for fishers in the region than anticipated (Table 22). In the first five years of the study many newly deceased fishers were recovered before the pilot and biologist in the airplane landed back at the Mariposa Airport, and almost always within six hours of the first indication that an animal's radiocollar was pulsing inactive. Although the fixed-wing aerial telemetry effort was expensive, the ~~research~~ identified the first known death for the species caused by active infection with Canine Distemper Virus (CDV). We also recovered the fresh carcass of a fisher in spring 2009 that was subsequently determined to have died from exposure to anticoagulant rodenticides. This discovery prompted testing of archived tissue samples of dead fishers throughout California and in the western United States, leading to two peer-reviewed papers focused on the problem of rodenticides and other poisons used at clandestine marijuana grow sites on California public lands (Gabriel et al. 2012, Thompson et al. 2013). Moreover, an important and very real benefit from the investment in an aviation program in support of SNAMP Fisher has been the discovery that survival and reproduction of fishers in the Sierra National Forest is challenged by multiple factors external to, and not directly linked to current forest management activities.

Well over half of the individual fishers captured and radiocollared during the study had perished as of April 2014. Known sources of ~~cause-specific~~ mortality in the SNAMP Fisher study population include high numbers of attacks by predators (interspecific killing; Wengert et al. 2014), roadkill deaths on Highway 41, infection by canine distemper virus (CDV; Keller et al. 2012) and *Toxoplasma gondii*, injury-induced starvation or septicemia, entrapment in a water tank, and acute toxicosis and hemorraghing caused by exposure to rodenticides (Gabriel et al. 2013, Thompson et al. 2013). ~~Most deaths~~ from infectious disease, roadkill, and rodenticide exposure ~~were males~~. On other hand, proportion~~ally more~~ females than males were killed by predators (Fig. 11), and research with collaborators from UC Davis indicated that males ~~are~~ less susceptible to ~~death by bobcat attack~~ than females (Wengert et al. 2014).

The diverse threats to survival that ~~impinge on~~ population growth in our study population ~~are~~ not unique to the southern Sierra Nevada region. Fishers in the Hoopa Valley in northern California area also died as a result of predation (Wengert et al. 2014), disease (Gabriel 2013), and rodenticides and other toxicants (Gabriel et al. 2013). Also, fishers that were reintroduced in northern California as part of the Stirling Fisher Reintroduction Project site have succumbed to predation, disease, and trauma from collisions with vehicles (Powell et al. 2013).

Survival estimators generally assume that live-trapping and radiocollars do not influence survival of study animals. Based on necropsies and extensive pathological tests completed on carcass remains of 47 dead fishers, no mortalities on the SNAMP Fisher study site were *directly* attributable to capture-related injury or radiocollars (e.g., strangulation or infection from chafing on the neck). However, one adult female fisher failed to survive the capture process to recovery and release. We acknowledge that the stress of capture and anesthesia contributed to the death of this female, even though detailed pathological examination revealed that she was extremely emaciated and suffering from systemic infection from serious injury (laceration to the rostrum, fractured mandible, partially disarticulated lower jaw) prior to capture (Gabriel 2013).

Analyses of live/dead status of individual fishers from SNAMP Fisher indicated that survival rates for adult females were within the range observed for other areas in the western United States. Overall survival for adult female fishers was 0.74, compared to 0.77 at the KRFP site (Sweitzer et al., In revision), which was higher than the 0.61 rate reported for a smaller sample of radio-collared female fishers on the Sequoia National Forest south of our study region (Truex et al. 1998). Aubry and Raley (2006) reported an adult female survival rate of 0.78 from a study in southwestern Oregon, whereas Higley et al. (2012) estimated adult female survival at 0.77 to 0.79 in northwestern California based on two different analytical methods (Known-fate models and Capture-Mark-Recapture, respectively). Jordan et al. (2011) reported a combined male-female adult survival rate of 0.94 for research completed in the KRFP study area in 2002-2004, however, their survival estimate was based on camera detections rather than radio-collared individuals, and the values reported were considered to have low precision related to tag loss and other factors.

In general, survival of male fishers on the SNAMP Fisher study area was consistently lower among all age ~~and sex~~ classes compared to females (Table 22). All year survival for SNAMP Fisher males ranged from 0.57 to 0.64, which was lower than adult male survival for fishers in southwest Oregon (0.85; Aubry and Raley 2006), in the Sequoia National Forest, California (0.73; Truex et al. 1996) and in northwest California (0.75 to 0.72; J. M. Higley unpublished report).

At the outset of the study we anticipated that survival would be lower for juvenile and subadult fishers compared to adults, as is typical for several species of mesocarnivores (Farias et al. 2005, Murdoch et al. 2010). Although survival among subadults trended lower than for adults, juvenile survival by both male and female fishers was often very similar or trended higher than adult survival (Table 22). We believe this is unlikely and an artifact of our inability to monitor juvenile survival during their first six months of life. Juvenile fishers are small in size and body mass during summer, and in our study and for most prior studies attempting to ascertain survival, juveniles were not fitted with radiocollars until fall or winter when many individuals within the cohort may have already perished (Facka et al. 2013). Even less is known about survival of kits when they are being provisioned inside den cavities (Lofroth et al. 2010). This is important because modeling efforts using empirically derived demographic parameters identify that population size and likelihood of persistence are relatively insensitive to juvenile survival (Buskirk et al. 2012, Spencer et al. 2011), potentially because juvenile survival is biased high.

The all year estimate of female survival on the SNAMP Fisher site was higher for juveniles, similar for subadults, and lower for adults compared to parameter values used by Spencer et al. (2011) to simulate fisher population dynamics under different management scenarios for the southern Sierra Nevada region. Our combined year estimates of survival for juvenile females was 0.75 (value used by Spencer et al. = 0.50), 0.71 for subadult females (value used by Spencer et al. = 0.70), and 0.74 for adult females (value used by Spencer et al. = 0.90). Spencer et al. (2011) reported their model was relatively insensitive to juvenile and subadult survival (and other demographic parameters), but highly sensitive to adult female survival. Our empirically derived estimate for adult female survival (Table 23) was 15% lower than 0.90, which is important because Spencer et al. (2011) noted that a 5% decrease in female survival produced an approximate 18% reduction in the ending population size 40 years after model initiation. Similarly, 10% and 25% reductions in female survival resulted in 37% to 72% reductions in the ending population size. The significantly higher survival rate we estimated for juvenile females might ameliorate the reduced end year population size associated with 15% lower adult female survival. A new modeling effort is underway that will integrate new information on demographic rates from the SNAMP and KRFP study sites (Spencer et al. 2014).

Wildlife populations are exposed to a variety of mortality factors, which vary in importance ~~towards limiting or impinging on~~ population growth. Predation was clearly identified as the most important source of mortality on the SNAMP Fisher ~~research site~~ (Table 21, Fig. 11). Data on percent deviation in survival described by Sweitzer et al. (In revision) indicated that predation was more important than disease processes and human-linked factors for limiting fisher survival at the site.

Disease in the form of canine distemper, toxoplasmosis, or pleururitus+pneumonia caused death for five radiocollared fishers during the SNAMP Fisher study, and an additional four fishers died of septicemia or starvation due to puncture wounds or other injury (Table 22; Gabriel 2013). The death of four fishers on our study by infection or starvation after suffering wounds or debilitating injury was not unusual or surprising for an animal as active as the fisher. Other long-term studies of radio-collared fishers have reported similar circumstances (Aubry and Raley 2006, Weir and Corbould 2008).

Infectious disease has been a conservation concern for the two isolated populations of fishers in California since exposure to CDV and other pathogens was first documented in northern California in the early 2000s based on serological testing (Brown et al. 2008). Canine distemper is of special concern because widespread, near catastrophic population-wide mortality among multiple species of endangered and uncommon carnivores has been reported (Timm et al. 2009, Williams et al. 1998, Woodroffe 1999). An outbreak, or localized epizootic of CDV that likely originated on the SNAMP site in spring 2009, and then spread south into KRFP during summer 2009 resulted in death of four fishers (Keller et al. 2012, Table 2). This disease-related mortality event confirmed that exposure by fishers to CDV and other agents of disease is of conservation concern for fishers in the western United States in general (Gabriel et al. 2012*b*), but particularly for the small, isolated population of fishers in the southern Sierra Nevada (Gabriel 2013). One fisher on the SNAMP study site was also confirmed to have died by complications after parasitic infection by *Toxoplasma gondii* (Gabriel 2013). Although exposure of fishers to *Toxoplasma gondii* was previously documented for fishers in North America (Larkin et al. 2011), this was the first case where complications from toxoplasmosis resulted in death (Gabriel 2013).

Wildlife-vehicle collisions may be a locally-critical mortality factor. Highway 41 is a very busy road locally referred to as the Wawona Road once it enters Yosemite National Park near the small community of Fish Camp. During the study period six non-collared fishers were also known to have been killed by vehicle strikes on Highway 41. Nine fishers were known to have been killed by vehicles along a 42 km stretch of Highway 41 during January 2008 to March 2013 in Yosemite National Park. Chow (2009) previously reported 4 fisher roadkill deaths between 1992 and 2004 along the same section of Highway 41, identifying this roadway as problematic for fisher survival in the region. Roadkill deaths of fishers have been reported in northern California as well, including two near Trinity Lake, (in either Shasta County or Trinity County – not specified; Truex et al. 1998), eight along paved highways in Humboldt and Siskiyou County (Gabriel 2013), and one in Butte County (Powell et al. 2012). In total, we are aware of 34 documented cases of fisher mortality by vehicle-strikes in California from 1992 to 2013 (Table 21). Moreover, seven fisher deaths were reported in western Washington state in association with the Olympic Fisher Reintroduction Project (Lewis ~~et al. 2012 unpublished report~~), ~~and fishers regularly die on highways in British Columbia (R. D. Weir, personal communication), and the northeastern United States (Douglas and Strickland 1987, York 1996)~~.

Our original prediction was that survival would be lowest during winter ~~compared to in spring or summer~~. Sweitzer et al (In revision) found that this prediction was not supported by the data, and that a disproportionate number of fisher deaths occurred during spring and summer. Increased mortality of fishers in this period is potentially related to exposure to second generation anticoagulant rodenticides, which ~~is~~ typically applied most heavily in the spring growing season. Expanded testing for anticoagulant rodenticides in archived tissues for fishers that died on our study before 2009, and for fishers that died ~~on~~ the Hoopa fisher study in northern California revealed that the majority of the animals had been exposed to anticoagulant rodenticides (>80%) and other toxicants being ~~broadcast dispersed~~ around illegal marijuana grow sites on California public and tribal lands (Gabriel et al. 2012*a*). Ongoing investigations focused ~~on this issue~~ indicate that use of anticoagulant rodenticides at illegal grow sites is focused during spring and early summer when the marijuana plants are small and vulnerable to herbivory by rodents and insects (Gabriel et al. 2012*a*, 2013, Thompson et al. 2013). A total of eight fishers (three from SNAMP Fisher, five from the Hoopa fisher study in northern California) have now been documented as dying from exposure to rodenticides or other toxicants associated with marijuana grow sites ~~died during April to June~~ (Gabriel 2013).

Another human-linked source of death for fishers in our study was entrapment or drowning in water tank. At the SNAMP site in spring 2008 we recovered the carcass of a non-collared fisher on the ground next to an open water tank (the cover had been ajar) where maintenance crews servicing the tank deposited the animal. Truex et al. (1998) and Powell et al. (2012) both reported deaths of single radio-collared fishers in abandoned water tanks at research sites in north central California, whereas Folliard (1997) recovered skeletal remains of eight fishers from an abandoned water tank on private timberlands in northwestern California. Finally, L. Davis (personal communication, Sept 7, 2013) reported the death of a radio-collared fisher that ~~maneuvered into~~ a relatively short section of an upright culvert during a study of fishers in the Cariboo-Chilcotin region of British Columbia, Canada (Davis 2008). It appears that death of fishers by entrapment in water tanks and other human structures may not be uncommon. Folliard's (1997) 15-year-old recommendation that abandoned water tanks on private and public forests in California be covered, or modified by inserting branches or poles so that fishers and other wildlife can self-rescue should be applied whenever possible.

Population Size and Density

Prior to this study, there was limited information on the distribution and abundance of fishers at the north margin of their ~~extant~~ range in the southern Sierra Nevada. Despite many years of surveys with cameras and track plates, the lack of evidence of fishers north of Yosemite Valley suggested that the population in the SNAMP Fisher study area was likely sparse (low density). Also, there had been no indication that surplus animals were dispersing northward into suitable, but unoccupied habitat north of the Merced River (Spencer et al. 2011, Spencer et al. 2014). Moreover, reports of multiple roadkill fishers along Highway 41/Wawona Road between the south boundary of the park and the tunnel just north of Yosemite Valley suggested that dispersal and the overall population was being limited by deaths on that highway (Chow 2009).

Federal and state agencies are currently developing strategies to manage for long term viable populations of fishers in the southern Sierra Nevada, and six years of intensive research as part of the SNAMP Fisher study has recently produced the first estimates of abundance for ~~the region~~. We estimated the size of the fisher population in the overall SNAMP study population at 48 to 62 individuals (Table 4). Narrow confidence intervals for the population estimates were ~~likely due~~ to the combination of a relatively high probability of detection (0.4 to 0.75) for our camera protocol when cameras were within the home ranges of radiocollared fishers (Popescu et al. 2014) (Table 4).

Mean annual population density for the three Subregions of the overall study area ranged from 0.072 to 0.097 fishers fishers/km^2 (Fig. 2), which was consistent with data from two previous studies of fishers in the High Sierra District of the Sierra National Forest, located 50 km south of our study site. Jordan et al. (2011) used a similar CMR design to estimate a density of 0.063-0.109 fishers/km^2 for the Kings River study area in 2002-2004. Thompson et al. (2013) used scat detector dogs and genetic detections in a spatially explicit CMR framework modified for variable search intensity to estimate a fisher density of 0.065-0.28 fishers/km^2 for the Kings River Fisher Project area in fall 2007. Thompson et al. (2013) emphasized that a modal density of 0.104 fishers/km^2 was the most appropriate point estimate developed from their research. At a research site on the Hoopa Valley Indian Reservation (Hoopa Fisher Study) in northern California, Higley et al. (2013) used CMR methods to determine that density of fishers was stable and increasing at 0.12-0.29 fishers/km^2 over a 9-year period from 2005-2013. In central Massachusetts, USA, Fuller et al. (2001) applied CMR models to camera sightings and determined fisher densities of 0.19-0.25 fishers/km^2. Considering the subset of studies that used CMR methods, the densities we estimated for the SNAMP Fisher study area are the lowest reported (Table 4).

As previously detailed, conservation planning is underway for fishers in the southern Sierra Nevada, including new modeling to estimate areas of suitable habitat for fishers in occupied "core" regions within the southern Sierra Nevada (Spencer et al. 2014). Our study area is within Habitat Core and Connectivity Area 5, for which the area of suitable habitat was estimated as 1,096 km^2 (Table 2, Spencer et al. 2014). We calculated the mean density and 95% C.I. for 12 area- and year-specific densities developed by our CMR modeling (Table 4; 0.085 fishers/km^2, 95% C.I. 0.073-0.097), and estimated that there were 93 (range 80-107) fishers in the Southern Sierra Nevada Habitat Core and Connectivity area 5.

In the context of similar data from other studies, the population of fishers in the Bass Lake Ranger District extending into southern Yosemite National Park is small, genetically limited (Tucker et al. 2014), and exists at a density that is lower than has been reported for any part of California or North America with the exception of boreal forest regions of northern British Columbia, Canada (Weir and Corbould 2006). Moreover, there are important challenges to the long term viability of fishers in the southern Sierra Nevada region as a whole, including periodic epizootics of canine distemper (Keller et al. 2012), exposure to poisons and other toxicants that directly and indirectly reduce survival (Thompson et al. 2013), and large, catastrophic wildfires capable of eliminating thousands of hectares of foraging and denning habitat in short periods of time (days or weeks; Final Update on 2013 Rim Fire: http://inciweb.nwcg.gov/incident/article/3660/21586/).

Dispersal and Home Range Movements

Information on dispersal provides important insight on how far individuals of a species may move on their own, which is valuable for understanding the potential that unoccupied but otherwise suitable habitat will be colonized or recolonized by the species without management intervention. For their body size, fishers appear to be relatively poor dispersers and large scale genetic substructure analysis supports this observation (Kyle et al. 2001). Fisher movement ecology varies by age, sex, season, and habitat characteristics. Juvenile dispersal may vary widely, depending on habitat availability and landscape permeability.

Intensive monitoring of individual fishers by fixed-wing aircraft, in combination with an expansive trapping effort across the entire SNAMP Fisher study area provided insight on dispersal that would have been difficult to acquire otherwise. Microsatellite DNA analyses to identify maternity for many juveniles and some subadults further extended our inference to larger numbers of ~~females (*n* = 24) and males (*n* = 19)~~.

We found limited evidence that natal dispersal was male-biased according to any of the typical metrics reported in the literature for this life history phenomenon. Dispersal distances were not longer for males (mean = 8.46 km) compared to females (4.89 km) based on either Euclidean distances or for more realistic Least Cost movement paths (Table 29, Figs. 17). There was no difference in the proportion of each gender that dispersed, or that remained philopatric (Fig. 17, Table 29), and, similar numbers of males (*n* = 5) and females (*n* = 3) undertook long distance dispersal movements from their likely natal areas (Fig. 18). Timing of dispersal in the SNAMP Fisher study population was focused during mid-February to July, and the longest distance dispersal event a female fisher in the population undertook was 22.3 km (44.1 by the Least Cost Path), compared to 36.2 km for a male (69.8 by the Least Cost Path)(Tables 28, 29). We did document dispersal by several fishers across landscape features previously identified as restrictive based on population genetics (Tucker et al. 2012, Wisely et al. 2004). Four fishers regularly moved across the Chiquito Ridge (via Shuteye Pass), and two male fishers transitioned across the San Joaquin River canyon.

Our data on dispersal differed from reports from southern Oregon and northwestern California. Aubry and Raley (2006) reported that mean juvenile male dispersal distance was 29 km, while the mean dispersal for females was 6 km. Dispersal distance in the Hoopa area of Northern California averaged 4.0 km (range = 0.8-18.0 km) for 7 females, and was 1.3 km for one male (Matthews et al. 2013a), however the authors noted that their focus on capturing adult females limited their ability to estimate male dispersal.

The maximum known dispersal distance for fishers from the literature was 100 km (York 1996), while the maximum observed movement of a translocated individual in unoccupied habitat was 163 km ~~(Lewis et al. 2012).~~ The relatively limited number of long distance dispersal events noted during the six year SNAMP Fisher study suggests that long distance movements are uncommon and that the effective dispersal distance may be less than maximum dispersal capacity (Tucker et al. 2013).

Population Growth and Threats to Population Persistence

Estimates of λ for fishers derived from empirical data specific to the area of inference are rare for California, and absent for the southern Sierra Nevada. The All Year survival and empirically derived demographic rates produced a λ of 0.90 (range 0.77-1.22). While this point estimate suggests a negative growth rate, it was encouraging that the range for the all year population growth rate extended above 1.0 (Table 34). Elsewhere in California, Higley et al. (2013) integrated data on apparent survival from CMR models and data on reproduction in a series of random effects models to evaluate λ for fishers in the Hoopa Fisher Study. Two models produced λ estimates close to or greater than 1 (Both sexes, Females only; see Higley et al. 2013). Swiers (2013) used Robust Design models, software program POPAN, and Pradel models to develop information on demographic rates, population size~~, and population growth rates~~ for assessing whether removal of adult fishers from a population in northern California/southern Oregon for translocation elsewhere negatively affected population growth. Swiers' (2013) top-ranked Pradel model produced a population growth rate of 1.06 (95% CI = 0.97-1.15), suggesting a stable or slightly increasing population after nine 'prime breeding adult' fishers had been live-trapped and removed from the population for translocation.

We identified several sources of mortality in the study population, and indication of a possible overall negative growth rate for the population was in accordance with the fact that 60% of the 110 fishers that were radiocollared died (Table 22). The matrix model we developed was realistic and based on current knowledge of fisher life histories in California, but some demographic parameters were less well known than others. Survival of juvenile fishers during the three month period from mid-June to October is poorly known for our study and for all other detailed studies of fishers in California (Facka et al. 2013). The estimate for juvenile female survival used in the matrix model was based on the 6-7 month period from October to March, which likely overestimated the number of juveniles recruited into the population. However, a basic sensitivity analysis indicated that the population growth rate was insensitive to variation in fertility for all age classes, and least sensitive to juvenile survival compared to subadult and adult survival.

SNAMP Fisher Management Indicators

Three management indicators we developed in 2008-09 as a mechanism for interim reporting on the status of fishers in the study area appeared useful when considered in relation to data on population growth rates and population density. Naïve occupancy in the Key Watershed was lowest in Camera years 2007-08, 2008-09, and 2009-10 when population growth rates were negative, but then increased in the later years when the growth rate was stable or positive (Tables 33, 35). The number of resident female fishers using the Key Watersheds did not track changes in population growth rates as closely, but the proportion was lowest in Population years 4 and 5 when the growth rate was negative or at approximate stasis. Adult female survival tracked change in population growth rate closely, declining from 2-year group 1 to 3, and then increasing afterwards (Table 34). Also, population density was in decline from 2007 to 2009, but then increased during Camera years 3 (2010-11) and 4 (2011-12) (Fig. 13), coincident with improved survival among juvenile and adult female survival (Table 34). We recommend that future long-term studies consider developing similar metrics as a monitoring tool, and for interim reporting to interested stakeholders.

Fisher response to fuel management

Concerns that initiation of focused management to reduce fuel levels in Sierra Nevada mixed-conifer forests to correct for 90 to 100 years of fire suppression might have negative effects on habitat use by fishers were only partly supported by results from our study. Fisher occupancy was not negatively associated with either extractive or restorative fuel reduction, though disturbances from restorative fuel reduction had a negative effect on local scale persistence. We believe that the lack of a relationship between extractive fuel reduction and occupancy by fishers was most likely due to the combination of related factors. First, the overall extent of logging in our study in the 11 years from 2002 to 2013 was likely much lower than historically, and was likely further diminished by poor market conditions for wood products when a severe recession began in 2008. Second, estimates of annual disturbance from extractive fuel reduction among occupancy survey grids was equivalent to levels known "tolerated" by fishers elsewhere in the Sierra NF (Zielinski et al. 2013). Among the 361 multi-season survey grids, 172 of them encompassed 51.9 km^2 of disturbance from extractive fuel reduction, representing disturbances of 2.7%/year to grids with disturbance, and 1.3%/year among all grids. Zielinski et al. (2013) investigated tolerance of fishers to forest management in the High Sierra District, Sierra NF, and reported that 14 km^2 patches of forest habitat with high use by fishers typically had 2.6% of the areas disturbed by forest management annually, whereas 14 km^2 patches of forest with low use by fishers averaged 3.5% disturbance/year. Thus, the areas of extractive fuel reduction in our study were comparable to the 2.6% disturbance in fisher ~~high~~ use forest patches in the High Sierra District, Sierra NF, and below some threshold of ≥ 3.5% management disturbance/year that would likely cause fishers to ~~forage elsewhere~~ (Zielinski et al., 2013).

Our occupancy modeling supported the hypothesis that fishers would reduce their use of local patches of forest exposed to proportionally higher levels of cumulative restorative fuel reduction. Nevertheless, an important prediction from our multi-season model was that small patches of forest with 100% cumulative 5-year disturbance from mechanical mastication and reduction of understory trees and surface fuels would maintain an occupancy of 0.65. Thus, even at what would be considered a very high level of disturbance, fishers were not predicted to completely cease using those areas. For context, an occupancy rate of 0.65 for fishers elsewhere in the southern Sierra Nevada would be considered high, and a positive observation with regards long term continuation of occupancy (Zielinski et al., 2013).

Ladder fuels, surface fuels, and thick layers of duff targeted under SPLAT-based management provide important habitat for squirrels and rodents preyed on by fishers, owls, and other forest carnivores (Kelt et al., 2013). Therefore, if forest patches that were extensively treated for restorative fuel reduction harbored less abundant prey, fishers may have shifted to nearby less disturbed forest patches to forage. The possibility that thinning of trees and shrubs, and reduction in understory surface fuels (coarse woody debris) has a negative effect on rodent populations has been considered by several recent studies. Meyer et al. (2007) reported reduced captures of northern flying squirrels in forest stands that were thinned and underburned in the High Sierra District, Sierra NF. Treated stands had reduced canopy cover and relatively shallow litter depth, and Meyer et al. (2007) considered that reduced abundance of flying squirrels may have been due to reduced abundance of truffles (fruiting bodies of hypogeous fungi) when duff was removed or reduced in depth after fuel reduction. Amacher et al. (2008) reported a negative effect of fuel reduction treatments (without follow-on burning) on abundance of deer mice, a positive effect of managed burning for deer mice, but no detectable effects of thinning or burning treatments on long-eared chipmunks, California ground squirrel, or brush mouse (*Peromyscus boylei*) at a research site in the north-central Sierra Nevada. Amacher et al. (2008) suggested that scattered debris and wood shards from rotary mastication was associated with the negative treatment effect for deer mice, whereas follow-on burning removed residual woody debris and thinned the understory, thereby improving conditions for deer mice. Converse et al. (2006) reported lower density or a trend for lower density for gray-collared chipmunks (*Neotamias canipes*) and Mexican woodrats (*Neotoma mexicana*) in thinned+burned forest stands in Arizona, which was linked to reduced coarse woody debris and reduced density of shrubs. In that same study abundance of deer mice increased after thinning+burning, and there was no treatment-linked change in abundance for golden-mantled ground squirrel (*Spermophilus lateralis*) (Converse et al., 2006). In restoration-treated ponderosa pine forests in Arizona, Lobeerger et al. (2011) found that winter season home ranges of tassel-eared squirrels (*Sciurus aberti*) disproportionately encompassed areas that had not been treated, whereas in other seasons their home ranges included a subset of the treated stands that retained relatively high canopy cover. Bull and Blumton (1999) indexed presence of small mammals from track surveys in lodgepole pine (*Pinus contorta*) and mixed-conifer forest stands treated for fuel reduction in northeastern Oregon. We were unable to identify studies that reported responses of Douglas squirrels or dusky footed woodrats (*Neotoma fuscipes*) to fuel reduction treatments, but, based on habitat associations for *Neotoma* (Innes et al., 2007; Kelt et al., 2013), understory thinning and removal of surface fuels and coarse woody debris may be problematic for woodrats (Lehmkuhl et al., 2006), whereas Douglas squirrels are a habitat generalist and less likely to be negatively impacted by fuel reduction (Coppeto et al., 2006, Herbers and Klenner, 2007; Kelt et al., 2013). Kelt et al. (2013) suggested that small mammal assemblages in the Sierra Nevada showed relatively limited responses to canopy thinning under current forest management. Abundance of small mammals in the Sierra Nevada has been linked to variation in production of cones or hard mast by pines and oaks (Coppeto et al., 2006; Wilson et al., 2008), which is important because a general pattern in many studies we reviewed was that interannual variation in abundance of small mammals was evident, and either masked or was much more important than the smaller effects introduced by fuel reduction-induced change to habitats (Converse et al., 2006; Coppeto et al., 2006; Amacher et al., 2008, Wilson et al., 2008; Kelt et al., 2013). We therefore conclude that reduced persistence of local scale habitat use by fishers in grids with larger areas treated for restorative fuel reduction was not likely to have been caused by changes in abundance of rodent prey from the associated disturbance to their habitats.

We consider it likely that the predicted 27% decline in persistence of local scale habitat use when cumulative restorative fuel reduction in a 1-km^2 grid approached 1.0 (100%) was associated with fishers shifting to forage in adjacent areas with less disturbance. A 27% decline in persistence of occupancy coupled with an annual colonization rate of 34%, suggests that fishers are flexible with regards local scale habitat use, and they might resume use of treated areas after several years of ecological recovery. Modeling analyses by Thompson et al. (2011) applied to a fisher occupied area of the High Sierra District, Sierra NF (Bear Fen) suggested that tree thinning (≤ 89 cm DHB) in mixed-conifer forest did not significantly reduce habitat suitability or "displace" habitat components from reference conditions in home ranges of resident female fishers. Based on these results from a nearby area in the Sierra NF, we believe it likely that fishers in our study area are likely to resume using forest patches treated for restorative fuel reduction within a few years of extensive disturbance. Also, fishers are known to adjust space use to avoid disturbed areas within their home ranges. Garner (2013) reported that resident fishers included areas treated for extractive+restorative fuel reduction in their overall and core home ranges in proportion to availability on the overall landscape. At the finer scale of individual locations, Garner (2013) found that those same resident fishers avoided using areas within ≈ 200 m of fuel treatments. We interpret this result as consistent with ours; fishers were predicted to continue using 1-km^2 patches of forest with more extensive cumulative disturbance by fuel treatments, but at a reduced level compared to areas with less disturbance. Finally, our assessment of how fishers responded to forest management was at the scale of 1-km^2 patches of forest, which was small in relation to resident adult female (≈ 23 km^2) and resident adult male home ranges in our study area (86 km^2; Sweitzer, In review – SNAMP Report). If a 1-km^2 patch of habitat within the home range of a resident female fisher was 100% treated for fuel reduction of any type, 95.7% of that animal's home range could remain available for normal levels of foraging, contingent on SPLATs being dispersed on the landscape and not locally concentrated as appears typical (Modhaddas et al., 2010).

Integration

We found that the SPLATs at Sugar Pine slightly reduced simulated fire behavior and resulted in greater amounts of projected fisher habitat up to 30 years after the fire. In the absence of simulated fire, we found that the SPLATs had an immediate, negative effect on the amount of fisher habitat, but SPLATs did not generally have a negative effect on fisher habitat when we modeled future forest growth for 30 years. In all scenarios, the differences between the treated and untreated landscapes were small.

Our results were in general agreement with prior findings. Thompson et al. (2011) performed an analogous study to ours, in which they modeled fire and forest growth under treatment and no treatment scenarios and assessed fisher habitat suitability in the southern Sierra Nevada. They projected that fuels treatments had slight negative effects on fisher habitat in the absence of fire, but provided significant positive benefits up to 37 years after simulated fire. Truex et al. (2013) suggested that less fisher resting habitat was present immediately after mechanical fuels treatments were implemented in the Sierra Nevada. However, fishers consistently used areas in the southern Sierra Nevada where some timber harvest had occurred, so it may be possible to implement fuels-reduction treatments at an extent and rate that achieves fire-hazard-reduction goals (Zielinski et al., 2013).

As we noted in Appendix C for the California spotted owl, the net benefits of SPLATs for the Pacific fisher will depend upon the true, but unknown, probability that high-severity fire effects will occur on a given portion of the landscape. However, future probabilities for specific fire behaviors (e.g., crown-fire initiation) are difficult to estimate, and it is therefore difficult to quantify trade-offs associated with SPLATs in absolute terms (Finney 2005). We further note that the SPLATs which were implemented at Sugar Pine appeared to have relatively modest impacts on forest structure and simulated fire behavior, and that it may be necessary to evaluate additional SPLATs of different intensities over a larger scale to fully assess the effects of SPLATs on fisher habitat. Nonetheless, we have no reason to believe that Forest Service managers should alter their current policy of avoiding the placement of SPLATs near known fisher denning sites (U.S. Forest Service 2004) because these sites have significant biological importance for this species.

Management Implications of Findings from SNAMP Fisher

Fishers have been the focus of systematic monitoring in the southern Sierra Nevada by track plates, hair snares, and camera traps since the mid-1990s (Truex et al. 1998, Zielinski et at al. 2005, Jordan 2007). Analyses of baited track plate detection histories from 2002 to 2009 for the entire southern Sierra Nevada fisher population found no evidence that the population trajectory for fishers in the area has been significantly positive or negative, based on constant and positive persistent values (Zielinski et al. 2013). In contrast, Tucker et al. (2014) suggested that the fisher population in the SNAMP Fisher study area was produced by a significant post-1900s northward population expansion involving dispersal of animals from south of the Kings River (Fisher Core Habitat Area 4; Fig. 2). Tucker et al. (2014) reported evidence of 'strong genetic clustering' to the north of Little Shuteye Peak (part of a high elevation ridge that forms the east boundary of Subregion 2 in our study area; Fig. 6), which, along with evidence for other small genetic clusters, was suggestive of multiple founder events associated with contemporary population expansion. Data from track-plate surveys in the Sierra National Forest in the early 1990s rarely detected fishers (Zielinski et al. 1995, 2005), which suggested a very sparse population in the SNAMP Fisher study area (Fisher Core Habitat area 5; Table 2, Fig. 2), compared to the more recent surveys in 2002-2009 (Tucker et al. 2014). Tucker et al (2014) postulated that very few fishers were present in the SNAMP Fisher study area prior to the 1990s, and that an expansion that occurred only during the last 20-25 years produced the population in this region.

Genetic data are not typically used to make inferences about population processes operating over extremely short periods in evolutionary time. The genetic analyses of Tucker et al. (2014), and the large increase in fisher detections in the region encompassing our entire study area between the early 1990s and 2002-2009 (Zielinski et al. 2013), suggest that a significantly positive population growth rate would be a requirement for understanding the current distribution and abundance of fishers in the SNAMP Fisher study area. During the period from 2007 to 2014, our results suggest that the fisher population in this region has not been experiencing consistently positive or significant population growth (Table 24).

The suggestion of an overall negative population growth rate, the low density, and the relatively small estimated number of fishers in Fisher Core Habitat area 5 (n = 93, range 80-107), warrants concern for the long term viability of fishers in the region. Any small population will be at high risk to stochastic events such as disease and large perturbations to critical habitats (e.g. forest fires or drought; Noss et al. 2006), and genetic limitation resulting from genetic drift after founder events (Tucker et al. 2014) will hinder population recovery and expansion (Reed et al. 2003). Minimum viable population size has been under debate (Shoemaker et al. 2013, Reed and McCoy 2014), but at <500 total individuals (Spencer et al. 2004), the current southern Sierra Nevada fisher population will likely require active management and conservation measures to maintain a positive growth rate across its entire range. The observed variation in fisher abundance and rates of population growth in the SNAMP Fisher study area (Table 4) reaffirms the vulnerability of the small, isolated population to external threats (Spencer et al. 2014), especially wildfires that are likely to increase in frequency and intensity with climate change (Bonan 2008, Safford et al. 2012). Moreover, our study spanned a limited period of six years when multiple threats to fisher survival within the study area were identified and during which three large wildfires further isolated the population by significantly reducing the availability of suitable habitat immediately to the south and north of the study site. We recommend continuous monitoring of the status of fisher populations in the southern Sierra Nevada region. It will be necessary to mitigate for major threats to fisher survival while maintaining contiguous expanses of suitable fisher habitats, and detailed analyses using realistic and empirically developed data on population parameters are necessary for evaluating the long-term viability of fishers in the southern Sierra Nevada. Data developed from the SNAMP Fisher study have provided important new insights on the status of a fisher population at the northern margin of their current distribution in the southern Sierra Nevada Range, which will be useful towards developing a comprehensive conservation strategy for fishers in California.

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Literature Cited

Ager, A. A., B. Bahro, and K. Barber. 2006. Automating the fireshed assessment process with ArcGIS. Pages 163–168 *in* P. L. Andrews and B. W. Butler, editors. Fuels management– how to measure success: conference proceedings, March 28-30, 2006, Portland, Oregon. Proceedings RMRS-P-41. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA.

Amacher, A. J., Barrett, R. H., Moghaddas, J. J., Stephens, S. L., 2008. Preliminary effects of fire and mechanical fuel treatments on the abundance of small mammals in the mixed-conifer forest of the Sierra Nevada. Forest Ecology and Management, 255, 3193-3202.

Arthur, S. M., T. F. Paragi, and W. B. Krohn. 1993. Dispersal of juvenile fishers in Maine. The Journal of Wildlife Management 57:868-874.

Arthur, S. M., and W. B. Krohn. 1991. Activity patterns, movements, and reproductive ecology of fishers in southcentral Maine. Journal of Mammalogy 72(2):379-385.

Arthur, S. M. and T. E. Paragi. 1993. Dispersal of juvenile fishers in Maine. Journal of Wildlife Management 57: 868-874.

Aubry, K. B., and C. M. Raley. 2006. Ecological characteristics of fishers (*Martes pennanti*) in the southern Oregon Cascade Range. USDA Forest Service, Pacific Northwest Research Station, Olympia, Washington, USA.

Aubry, K. B., C. M. Raley, S. W. Buskirk, W. J. Zielinski, M. K. Schwartz, R. T. Golightly, K. L. Purcell, R. D. Weir, and J. S. Yaeger. 2013. Meta-analysis of habitat selection by fishers at resting sites in the Pacific coastal region. Journal of Wildlife Management 77:965-974.

Bonan, G. B. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science 320: 1444-1449.

Bowman, J., Donovan, D., Rosatte, R.C., 2006. Numerical response of fishers to synchronous prey dynamics. Journal of Mammalogy, 87, 480-484.

Boroski, B.B., R.T. Golightly, A.K. Mazzoni, and K.A. Sager. 2002. Fisher research and the Kings River sustainable forest ecosystems project: current results and future efforts. Pp. 143-154 *In* USDA Forest Service, Pacific Southwest Research Station, Albany, CA. General Technical Report PSW-GTR-183.

Brown, R. N., M. W. Gabriel, G. M. Wengert, S. Matthews, J. M. Higley, and J. E. Foley. 2008. Pathogens associated with fishers. Pages 2-48 *in* Pathogens associated with fishers (*Martes pennanti*) and sympatric mesocarnivores in California. Final Report submitted to the USDI Fish and Wildlife Service, Yreka, California, USA.

Bull, E. L., Blumton, A. K., 1999. Effect of fuels reduction on American martens and their prey. USDA Forest Service Pacific Northwest Research Station, PNW-RN-539, Portland, OR, USA.

Burnham, K. P, and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, NY.

Buskirk, S. W., L. L. McDonald. 1989. Analysis of variability in home-range size of the American marten. Journal of Wildlife Management 53: 997-1004.

Buskirk, S. W., J. Bowman, and J. H. Gilbert. 2012. Population biology and matrix demographic modeling of American Martens and Fishers. Pages 138-135 *in* K. B. Aubry, W. J. Zielinski, M. G. Raphael, G. Proulx, and S. W. Buskirk, editors. Biology and Conservation of Martens, Sables, and Fishers: A New Synthesis. Cornell University Press, Ithaca, New York, USA.

California Department of Fish and Game. 2008. California Interagency Wildlife Task Group. CWHR version 8.2 personal computer program. Sacramento, CA. <http://www.dfg.ca.gov/biogeodata/cwhr/>.

Center for Biological Diversity (CBD) website. 2013. http://www.biologicaldiversity.org/programs/biodiversity/species_agreement/#timeline.

Chepko-Sade, D. B., and Z. T. Halpin. 1987. Mammalian dispersal patterns: the effects of social structure on population genetics. University of Chicago Press, Illinois.

Chow, L. 2009. A survey for fisher in Yosemite National Park 1992-1994. Transactions of the Western Section of the Wildlife Society 45:27-44.

Clobert, J., E. Danchin, A. A. Dhont, and J. Nichols. 2001. Dispersal—causes, consequences and mechanisms of dispersal at the individual, population and community level. In: Danchin, E, A. A. Etienne, A. A. Dhondt, and J. D. Nichols, editors. Dispersal. Oxford University Press, Oxford.

Collins, B. M., S. L. Stephens, G. B. Roller, and J. J. Battles. 2011. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. Forest Science 57:77–88.

Collins, B. M., S. L. Stephens, J. J. Moghaddas, and J. Battles. 2010. Challenges and approaches in planning fuel treatments across fire-excluded forested landscapes. Journal of Forestry 108:24-31.

Collins, B. M., H. A. Kramer, K. Menning, C. Dillingham, D. Saah, P. A. Stine, and S. L. Stephens. 2013. Modeling hazardous fire potential within a completed fuel treatment network in the northern Sierra Nevada. Forest Ecology and Management 310: 156-166.

Converse, S. J., Block, W. M., White, G. C., 2006. Small mammal population and habitat responses to forest thinning and prescribed fire. Forest Ecology and Management, 228, 263-273.

Coppeto, S. A., Kelt, D. A., Van Vuren, D. J., Wilson, J. A., Bigelow, S., 2006. Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada. Journal of Mammalogy, 87, 402-413.

Corlatti, L., K. Hacklander, and F. Frey-Roos. 2008. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. Conservation Biology 23: 548-556.

Coulter, M. W. 1966. Ecology and management of fishers in Maine. Dissertation, Syracuse University, Syracuse, New York, USA.

Dallas, J. F., and S. B. Piertney. 1998. Microsatellite primers for the Eurasian otter. Molecular Ecology 7: 1248.

Davis, L. 2008. Management for fisher (*Martes pennanti*) reproductive denning habitat in the Cariboo-Chilcotin. Unpublished report. Davis Environmental Ltd., Williams Lake, British Columbia, Canada. report,t Folliard, L. 1994. Discovery of an accidental trap for Pacific fishers. The Marten 2:7.

Davis, C. S., and C. Strobeck. 1998. Isolation, variability, and cross-species amplification of polymorphic microsatellite loci in the family Mustelidae. Molecular Ecology 7: 1776-1778.

Dixon, G. E. 2002. Essential FVS: a user's guide to the Forest Vegetation Simulator. USDA Forest Service Internal Report, Fort Collins, CO, USA (revised on 19 November 2013).

Douglas C.W., and M. A. Stickland. 1987. Fisher. Pages 511-529 *in* M. Novak, J. A. Baker, M. E. Obbard, and B. Malloch, editors. Wild furbearer management and conservation in North America.

Ontario Ministry of Natural Resources and the Ontario Trappers Association, Toronto, Ontario, Canada.

Driezen, K., F. Adriaensen, C. Rondinini, C. P. Doncaster, and E Matthysen. 2007. Evaluating least-cost model predictions with empirical dispersal data: A case-study using radiotracking data of hedgehogs (*Erinaceus europaeus*). Ecological Modelling 209: 314-322.

Facka, A. N., R. A. Sweitzer, S. Matthews, and R. A. Powell. 2013. A note on standardization of reproductive and survival rates for populations of *Martes*. Newsletter of The Martes Working Group 20: 10-14.

Farias V., T. K. Fuller, R. K. Wayne, and R. M. Sauvajot. 2005. Survival and cause-specific mortality of gray foxes (*Urocyon cinereoargenteus*) in southern California. Journal of Zoology (London) 266:249-254.

Finney, M. A. 1998. FARSITE: Fire area simulator-model development and evaluation. Research Paper RMRS-RP-4. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT, USA.

Folliard, L. 1997. Discovery of an accidental trap for Pacific fishers. The Marten 2:7.

Fuller, T. K., E. C. York, S. M. Powell, T. A. Decker, and R. M. DeGraaf. 2001. An evaluation of territory mapping to estimate fisher density. Canadian Journal of Zoology 79:1691-1696.

Gabriel, M.W. 2013. Population health of California fishers. Dissertation, University of California Davis. Davis, CA, USA.

Gabriel, M. W., L. W. Woods, R. Poppenga, R. A. Sweitzer, C.M. Thompson, S. M. Matthews, J. M. Higley, S.M. Keller, K. L. Purcell, R. H. Barrett, G. M. Wengert, B. N. Sacks, and D. L. Clifford. 2012*a*. Anticoagulant rodenticides on our public and community lands: spatial distribution of exposure and poisoning of a rare forest carnivore. *PLoS ONE* 7: e40163. doi:10.1371/journal.pone.0040163.

Gabriel, M. W., G. M. Wengert, R. N. Brown. 2012*b*. Pathogens and parasites of Martes species: Management and Conservation Implications. Pages 138-135 *in* K. B. Aubry, W. J. Zielinski, M. G. Raphael, G. Proulx, and S. W. Buskirk, editors. Biology and Conservation of Martens, Sables, and Fishers: A New Synthesis. Cornell University Press, Ithaca, New York, USA.

Gabriel, M. W., G. M. Wengert, J. M. Higley, S. Krogen, W. Sargent, and D. L. Clifford. 2013. Silent Forests? Rodenticides on illegal marijuana crops harm wildlife. Wildlife Professional 7: 46-50.

Gantz, G. F., L. C . Stoddart, F. F. Knowlton. 2006. Accuracy of Aerial Telemetry locations in mountainous terrain. Journal of Wildlife Management 70: 1809-1812.

Garner, J.D. 2013. Selection of disturbed habitat by fishers (*Martes pennanti*) in the Sierra National Forest. MS thesis, Humboldt State University, Arcata, CA. http://hdl.handle.net/2148/1483

Gaskill, M. 2013. Rise in roadkill requires new solutions. Scientific American, May 16, 2013.

Gitzen, R. A, and J. J. Millspaugh. 2003. Comparison of least-squares cross-validation bandwidth options for kernel home-range estimation. Wildlife Society Bulletin 31: 823-831.

Gompper, M. E., and J. L. Gittleman. 1991. Home range scaling: intraspecific and comparative trends. Oecologia 87: 343-348.

Gotelli, N. 2001. A Primer of Ecology, Third Edition. Sinauer Associates, Sunderland, MA.

Grinnell, J., J. S. Dixon, and J. M. Linsdale. 1937. Fur-bearing mammals of California: their natural history, systematic status, and relations to man. University of California Press, Berkeley, California, USA.

Harihar, A., M. Ghosh, M. Fernandes, B. Pandav, and S. Goyal. 2010. Use of photographic capture-recapture sampling to estimate density of striped hyena (Hyaena hyaena): implications for conservation. Mammalia 74: 83-87.

Herbers, J., Klenner, W., 2007. Effects of logging on squirrel demography. Journal of Wildlife Management, 71, 2655-2663.

Hines, J.E. (2006). PRESENCE2- Software to estimate patch occupancy and related parameters. USGS-PWRC. http://www.mbr-pwrc.usgs.gov/software/presence.html.

Higley, J. M., G. M. Wengert, S. M. Matthews, and K. M. Rennie. 2013. Bobcat ecology and relationship with and influence on fisher survival on the Hoopa Valley Indian Reservation, California. Final Report. U.S. Fish and Wildlife Service Tribal Wildlife Gran CA U-29-NA-1. Hoopa Valley Tribe, Hoopa, California, USA.

Innes, R.J., Van Vuren, D.H., Kelt, D.A., Johnson, M.L. Wilson, J.A., Stine, P.A., 2007. Habitat associations of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forest of the northern Sierra Nevada. Journal of Mammalogy, 88, 1523-1531.

Janecka, J. E., B. Munkhtsog, R. M. Jackson, G. Naranbaatar, D. P. Mallon, and W. J. Murphy. 2011. Comparison of noninvasive genetic and camera-trapping techniques for surveying snow leopards. Journal of Mammalogy: 92(4):771-783.

Jensen, P. G., C. L. Demers, S. A. McNulty, W. J. Jakubas, M. M. Humpries. 2012. Marten and fisher responses to fluctuations in prey populations and mast crops in the northern hardwood forest. Journal of Wildlife Management 76: 489-502.

Jordan, M.J. 2007. Fisher ecology in the Sierra National Forest, California. Dissertation, University of California, Berkeley, USA.

Jordan, M. J., J. Higley, S. M. Matthews, O. E. Rhodes, M. K. Schwartz, R. H. Barrett, and P. J. Palsbøll. 2007. Development of 22 new microsatellite loci for fishers (*Martes pennanti*) with variability results from across their range. Molecular Ecology Notes 7: 797-801.

Jordan, M. J., R. H. Barrett, and K. L. Purcell. 2011. Camera trapping estimates of survival of fishers Martes Pennanti. Wildlife Biology 17:266-276.

Keller, S. F., M. Gabriel, K. A. Terio, E. J. Dubovi, E. Van Wormer, R. A. Sweitzer, R. H. Barret, C. M. Thompson, K. L. Purcell, and L. Munson. 2012. Canine Distemper in an isolated population of fishers (*Martes pennanti*) from California. Journal of Wildlife Diseases 48:1035-1041.

Kelt, D. A., Van Vuren, D. H., Johnson, M.L., Wilson, J.A., Innes, R. J., Jesmer, B.R., Ingram, K.P., Smith, J. R., Bigelow, S. W., Burnett, R. D., Stine P. A., 2013. Small mammals exhibit limited spatiotemporal structure in Sierra Nevada forests. Journal of Mammalogy, 94, 1197-1213.

Kendall, W. L., K. H. Pollock, and C. Brownie. 1995. A likelihood-based approach to capture-recapture estimation of demographic parameters under robust design. Biometrics 51:293-308.

Kendall, W. L., J. D. Nichols, and J. E. Hines. 1997. Estimating temporary emigration using capture-recapture data with Pollock's robust design. Ecology 78:563-578.

Kie, J. G. 2013. A rule-based ad hoc method for selecting a bandwidth in kernel home-range analyses. Animal Biotelemetry 1-13.

Kie, J. G., J. Matthiopoulos, J. Fieberg, R. A. Powell, F.Cagnacci, M. S. Mitchell, J. M. Gaillard, and P. R. Moorcroft. 2010. The home-range concept: are traditional estimators still relevant with modern telemetry technology? Philosophical Transactions of the Royal Society B: Biological Sciences 365: 2221-2231.

Koen, E. 2005. Home range, population density, habitat preference, and survival of fishers *(Martes pennanti)* in eastern Ontario. Thesis. Ottawa – Carleton Institute of Biology. Ottawa, Ontario, Canada.

Koen, E. L., J. Bowman, C. S. Findlay. 2007. Fisher survival in eastern Ontario. Journal of Wildlife Management 71:1214-1219.

Knaus, B., R. Cronn, A. Liston, K. Pilgrim, and M. Schwartz. 2011. Mitochondrial genome sequences illuminate maternal lineages of conservation concern in a rare carnivore. BMC Ecology 11:14pp

Krohn, W. B., S. M. Arthur, and T. F. Paragi. 1994. Mortality and vulnerability of a heavily trapped fisher population. Pages 137-146 *in* S. W. Buskirk, A. S. Harestad, M. G. Raphael and R. A. Powell, editors. Martens, sables, and fishers: biology and conservation. Cornell University Press, Ithaca, New York, USA.

Krohn, W.B., K.D. Elowe, and R.B. Boone. 1995. Relations among fishers, snow, and martens: Development and evaluation of two hypotheses. The Forestry Chronicle 71(1):97-105.

Laake, J. 2013. R Code for MARK Analysis. http://www.phidot.org/software/mark/rmark/.

Lambin, X. 1994. Sex ratio variation in relation to female philopatry in Townsend's voles. Journal of Animal Ecology 63: 945-953.

Lande, R. 1993. Risks of population extinction from demographic and environmental stochasticity and random catastrophes. American Naturalist 142, 911-927

Larkin, J. L., M. Gabriel, R. W. Gerhold, M. J. Yabsley, J. C. Wester, J. G. Humphreys, R. Beckstead, and J. P. Dubey. 2011. Prevalence to *Toxoplasma gondii* and *Sarcocystis* spp. in a reintroduced fisher (*Martes pennanti*) population in Pennsylvania. Journal of Parasitology 97:425–429.

Lehmkuhl, J.F., Kistler, K. D., Begley, J.S., 2006. Bushy-tailed woodrat abundance in dry forests of eastern Washington. Journal of Mammalogy, 87, 371-379.

Lewis, J. C., R. A. Powell, and W. J. Zielinski. 2012. Carnivore translocations and conservation: insights from population models and field data for fishers (*Martes pennanti*). PLoS ONE 7:e32726.

Lewis, J. C., P. J. Happe, K. J. Jenkins, and D. J. Manson. 2012. Olympic fisher reintroduction project: progress report 2008-2011. Washington Department of Fish and Wildlife and Olympic National Park. (http://wdfw.wa.gov/wlm/diversty/soc/fisher/; accessed Aug 30, 2013).

Litvaitis, J. A., and J. P. Tash. 2008. A approach toward understanding wildlife-vehicle collisions. Environmental Management 42:688-697.

Loberger,C. D., Theimer,T.C., Rosenstock, S.S., Wightman, C.S., 2011. Use of restoration-treated ponderosa pine forest by tassel-eared squirrels. Journal of Mammalogy, 92, 2011, 1021-1027.

Long, R. A. 2008. Noninvasive survey methods for carnivores. Island Press, 2008.

Lofroth, E. C., C. M. Raley, J. M. Higley, R. L. Truex, J. S. Yaeger, J. C. Lewis, and P. J. Happe. 2010. Conservation of fishers (Martes pennanti) in South-Central British Columbia, Western Washington, Western Oregon, and California–Volume I: Conservation Assessment. USDI Bureau of Land Management, Denver, Colorado, USA.

Magle, S. B., B. T. McClintock, D. W. Tripp, G. C. White, M. F. Antolin, and K. R. Crooks. 2007. Mark-resight methodology for estimating population densities for prairie dogs. Journal of Wildlife Management 71:2067-2073.

Mallek, C.R., H.D. Safford, J.H. Viers, and J.D. Miller. 2013. Modern departures in fire severity and area vary by forest type, Sierra Nevada and southern Cascades, California, USA. Ecosphere 4:1-28.

Manning, T., Hagar, J.C., McComb, B.C., 2012. Thinning of young Douglas-fir forests decreases density of northern flying squirrels in the Oregon Cascades. Forest Ecology and Management, 264, 115-124.

Marshall, T. C., J. B. K. E Slate, L. E. B Kruuk, and J. M. Pemberton. 1998. Statistical confidence for likelihood-based paternity inference in natural populations. Molecular Ecology 7: 639-655.

Matthews, S. M., J. M. Higley, K. M. Rennie, R. E. Green, C. A. Goddard, G. M. Wengert, M. W. Gabriel, and T. K. Fuller. 2013a. Reproduction, recruitment, and dispersal of fishers (*Martes pennanti*) in a managed Douglas-fir forest in California. Journal of Mammalogy 94:100-108.

Matthews, S. M., J. M. Higley, J. T. Finn, K. M. Rennie, C. M. Thompson, K. L. Purcell, R. A. Sweitzer, S. L. Haire, P. R. Sievert, and T. K. Fuller. 2013b. An evaluation of a weaning index for wild fishers (Pekania [Martes] pennanti) in California. Journal of Mammalogy 94: 1161-1168.

Mazzoni, A.K. 2002. Habitat use by fishers (*Martes pennanti*) in the southern Sierra Nevada, California. MS thesis, California State University, Fresno, CA.

McCann, N. P., P. A. Zollner, and J. H. Gilbert. 2010. Survival of adult marten in northern Wisconsin. Journal of Wildlife Management 74:1502-1507.

McRae, B.H. and D.M. Kavanagh. 2011. Linkage Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle WA. Available at: http://www.circuitscape.org/linkagemapper.

McClintock, B. T. and G. C. White. 2009. A less field-intensive robust design for estimating demographic parameters with mark-resight data. Ecology 90:313-320.

McDonald, P.M. 1990. *Quercus kelloggii* Newb. California black oak. Silvics of North America 2:661-671.

McKelvey, K. S., and M. K Schwartz. 2005. Dropout: a program to identify problem loci and samples for noninvasive genetic samples in a capture-mark-recapture framework. Molecular Ecology Notes 5: 716-718.

Mech, L.D. 1974. Current techniques in the study of elusive wilderness carnivores. Pp 315-322 *in* XI International Congress of Game Biologists, National Swedish Environmental Protection Board.

Meyer, M. D., Kelt, D. A., North, M. P. 2007. Microhabitat associations of northern flying squirrels in burned and thinned forest stands of the Sierra Nevada. The American Midland Naturalist, 157, 202-211.

Moghaddas, J. J., Collins, B. M., Menning, K., Modhaddas, E. E. Y., Stephens, S. L., 2010. Fuel treatment effects on modeled landscape-level fire behavior in the northern Sierra Nevada. Canadian Journal of Forest Research, 40,1751-1765.

Murdoch, J. D., T. Munkhzul, S. Buyandelger, and C. Sillero-Zubiri. 2010. Survival and cause-specific mortality of corsac and red foxes in Mongolia. Journal of Wildlife Management 74:59-64.

Naney, R.H., L.L Finley, E.C. Lofroth, P.J. Happe, A.L. Krause, C.M. Raley, R.L. Truex, L.J. Hale, J.M. Higley, A.D. Kosic, J.C. Lewis, S.A. Livingston, D.C. Macfarlane, A.M. Myers, and J.S. Yaeger. 2012. Conservation of fishers (Martes pennanti) in south-central British Columbia, western Washington, western Oregon, and California. Volume III: threat assessment. USDOI Bureau of Land Management, Denver, CO.

North, M., P. Stine, P. O'Hara, W. J. Zielinski, and S. Stephens. 2009. An ecosystem management strategy for Sierran mixed-conifer forests. General Technical Report 220. Albany, CA: USDA Forest Service, Pacific Southwest Research Station. 49 p.

Noss, R. F., J. F, Franklin, W. L. Baker, T. Schoennagel, and P. B. Moyle. 2006. Managing fire-prone forests in the western United States. Frontiers in Ecology and the Environment 4: 481-487.

O'Connell, A. F., J. D. Nichols, and K. U. Karanth. 2011. Camera traps in animal ecology. Tokyo: Springer, 2011.

Paragi, T. F., S. M. Arthur, and W. B. Krohn. 1994. Seasonal and circadian activity patterns of female fishers, Martes pennanti, with kits. The Canadian Field Naturalist 108:52-57.

Pollock, K. H., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

Poole, K. G., G. M. Matson, S. A. Strickland, A. J. Magoun, R. P. Graf, and L. M. Dix. 1994. Age and sex determination for American martens and fishers. Pp. 204–223 in Martens, sables, and fishers: biology and conservation (S. W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, eds.). Comstock Publishing Associates, Cornell University Press, Ithaca, New York.

Popescu, V. D., P. deValpine, D. Tempel, and M. Z. Peery. 2012. Estimating population impacts via dynamic occupancy analysis of Before-After Control-Impact studies. Ecological Applications 22:1389-1404.

Popescu, V.D., P. deValpine, and R. A. Sweitzer. 2014. Testing the consistency of wildlife data types before combining them: the case of camera traps and telemetry. Ecology and Evolution 4: 933-943.

Powell, R. A. 1979. Ecological energetics and foraging strategies of the fisher (*Martes pennanti*). Journal of Animal Ecology 48:195-212.

Powell, R. A. 1993. The fisher: life history, ecology, and behavior, 2nd ed. University of Minnesota Press, Minneapolis, Minnesota, USA.

Powell, R. A., and W. J. Zielinski. 1994. Fisher. In L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, andW. J. Zielinski, editors. The scientific basis for conserving forest carnivores: American marten, fisher, lynx, and wolverine. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, USA.

Powell R, S. Buskirk and W. Zielinski. 2003. Fisher and marten. *In* G. Feldhamer, B. Thompson, and J. Chapman, editors. Wild mammals of North American, Second edition. Johns Hopkins University Press, Baltimore, Maryland, USA.

Powell, R. A., A. N. Facka, D. Clifford, C. Beach, and K. Smith. 2013. Reintroduction of fishers into the northern Sierra Nevada of California: annual report for 2012. Annual report to US Fish and Wildlife Service, Yreka, CA, California Department of Fisher and Game, Redding, CA, and Sierra Pacific Industries, Anderson, CA. May 31, 2013. (https://r1.dfg.ca.gov/Portal/LinkClick.aspx?fileticket=DpX4VZ4WJUk%3d&tabid=832; accessed Apr 24, 2014).

Price, A. J., W. Estes-Zumpf, and J. Rachlow. 2010. Survival of juvenile pygmy rabbits. Journal of Wildlife Management 74:43-47.

Purcell, K. L., A. K. Mazzoni, S.R. Mori, and B.B. Boroski. 2009. Resting structure and resting habitat of fishers in the southern Sierra Nevada, California. Forest Ecology and Management 258 (12): 2696-2706.

Pusey, A. E. 1987. Sex-biased dispersal and inbreeding avoidance in birds and mammals. Trends in Ecology & Evolution 2: 295-299.

Raine, R. M. 1983. Winter habitat use and responses to snow cover of fisher (Martes pennanti) and marten (Martes americana) in southeastern Manitoba. Canadian Journal of Zoology 61:25-34.

Reed, D. H., J. J. O'Grady, B. W. Brook, J. D. Ballou, and R. Frankham. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. Biological Conservation 113:23–34.

Reed, J. M. and E. D. McCoy. 2014. Relation of Minimum Viable Population Size to Biology, Time Frame, and Objective. Conservation Biology, 28: 867–870.

Reinhardt, E., and N. L. Crookston. 2003. The Fire and Fuels Extension to the Forest Vegetation Simulator. General Technical Report RMRS-GTR-116. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA.

Rodgers, A. R., A. P. Carr, H. L. Beyer, L. Smith, and J. G. Kie. 2007. HRT: Home Range Tools for ArcGIS. Version 1.1. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada. Available at http://flash.lakeheadu.ca/~arodgers/hre/

Roemer, G. W., T. J. Coonan, D. K. Garcelon, J. Bascompte, and L. Laughrin. 2001. Feral pigs facilitate hyperpredation by golden eagles and indirectly cause the decline of the island fox. Animal Conservation 4:307–318.

R_Core_Team. 2013. R: A language and environment for statistical computing. Vienna, Austria. ISBN 3-900051-07-0. http://www.R-project.org/.

Safford, H.D., M.P. North, and M.D. Meyer. 2012. Climate change and the relevance of historical forest conditions. Pp. 23-46 In Managing Sierra Nevada forests (M.P. North, editor). USDA Forest Service, Pacific Southwest Research Station, Albany, CA. General Technical Report GTR-PSW-237.

Safford, H.D. 2013. Natural range of variation (NRV) for yellow pine and mixed conifer forests in the bioregional assessment area, including the Sierra Nevada, southern Cascades, and Modoc and Inyo national forests. USDA Forest Service, Pacific Southwest Region, Vallejo, CA. Internal report.

Scheller, R. M., W. D. Spencer, H. Rustigian-Romsos, A. D. Syphard, B. C. Ward., and J. R. Strittholt. 2011. Using stochastic simulation to evaluate competing risks of wildfires and fuels management on an isolated forest carnivore. Landscape Ecology 26:1491-1504.

Seddon P.J., and R.F. Maloney. 2004. Tracking wildlife radio-tag signals by light fixed-wing aircraft. Department of Conservation Technical Series, Department of Conservation, Wellington, vol 30, pp 1–23

Sikes, R. S., and W. L. Gannon and the Animal Care and Use Committee of the American Society of Mammalogists. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. Journal of Mammalogy 92:235-253.

Shoemaker, K. T., A. R. Breisch, J. W. Jaycox, and J. P. Gibbs. 2013. Reexamining the minimum viable population concept for long-lived species. Conservation Biology 27:443–452.

Slauson, K.M., J.A. Baldwin, W.J. Zielinski, T.A. Kirk. 2009. Status and Estimated Size of the Only Remnant Population of the Humboldt Subspecies of the American marten (*Martes americana humboldtensis*) in Northwestern California, final report. Unpublished report dated November 25, 2009. USDA FS, PSW, Redwood Sciences Laboratory, Arcata, California.

Slauson, K.M., J. Baldwin, W. J. Zielinski, and M. Schwartz, M. 2009. Estimating detection probabilities for fishers using non-invasive methods, and implications for survey protocols. pp. 68. Final Report. U.S. Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, CA.

Spencer, W. and H. Rustigian-Romsos. 2012. Fisher denning habitat distribution on and near Sierra National Forest, California. Unpublished report prepared for Sierra National Forest. July.

Spencer, W. D., H. Rustigian-Romsos, J. Strittholt, R. Scheller, W. Zielinski, and R. Truex. 2011. Using occupancy and population models to assess habitat conservation opportunities for an isolated carnivore population. Biological Conservation 144:788–803.

Spencer W., S. Sawyer, W. J. Zielinski, R. Sweitzer, C. Thompson, K. Purcell, D. Clifford, L. Cline, H. Safford, S. Britting, R. Powell, J. Sherlock, and J. Tucker. 2014. Draft Southern Sierra Nevada Fisher Conservation Assessment. Conservation Biology Institute, San Diego, CA.

Svagelj, W. S. and F. Quintana. 2007. Sexual size dimorphism and sex determination by morphometric measurements in breeding imperial shags (Phalacrocorax atriceps). Waterbirds 30(1): 97-102.

Swiers, R. C. 2012. Non-invasive genetic sampling and mark-recapture analysis of a fisher (Martes pennanti) population in northern California used as a reintroduction source. 2013. Thesis, North Carolina State University, Raleigh, NC.

Swihart, R. K., N. A. Slade. 1985. Influence of sampling interval on estimates of home-range size. The Journal of Wildlife Management 49: 1019-1025.

Swihart, R. K., N. A. Slade, and B. J. Bergstrom. 1988. Relating body size to the rate of home range use in mammals. Ecology 69: 393-399.

Thompson, C. M., W. J. Zielinski, and K. L. Purcell. 2011. Evaluating management risks using landscape trajectory analysis: a case study of California fisher. Journal of Wildlife Management 75:1164–1176.

Thompson, C.M., K. Purcell, J. Garner, and R. Green. 2011. Kings River Fisher Project Progress Report 2007-2010. USDA Forest Service Pacific Southwest Research Station Sierra Nevada Research Center. Unpublished report.

Thompson, C.M., J.A, Royle, and J.D. Garner. 2012. A framework for inference about carnivore density from unstructured spatial sampling of scat using detector dogs. The Journal of Wildlife Management 76(4): 863-871.

Thompson, C.M., R.A. Green, J. Sauder, K.L. Purcell, R. A. Sweitzer, and J. Armeno. 2012. The use of radiotelemetry in research on Martes species, techniques and technologies. Pages 284-319 in K. B. Aubry, W. J. Zielinski, M. G. Raphael, G. Proulx, and S. W. Buskirk, editors. Biology and Conservation of Martens, Sables, and Fishers: A New Synthesis. Cornell University Press, Ithaca, New York, USA.

Thompson, C., R. Sweitzer, M. Gabriel, K. Purcell, R. Barrett, and R. Poppenga. 2013. Impacts of rodenticide and insecticide toxicants from marijuana cultivation sites of fisher survival rates in the Sierra National Forest, California. Conservation Letters 6:1-12.

Timm, S. F., L. Munson, B. A. Summers, K. A. Terio, E. J. Dubovi, C. E. Ruprecht, S. Kapil, and D. K. Garcelon. 2009. A suspected canine distemper epidemic as the cause of a catastrophic decline in Santa Catalina Island foxes (*Urocyon littoralis catalinae*). Journal of Wildlife Diseases 45: 333–343.

Truex, R. L., W. J. Zielinski, R. T. Golightly, R. H. Barrett, and S. M. Wisely. 1998. A meta-analysis of regional variation in fisher morphology, demography, and habitat ecology in California. Draft report submitted to California Department of Fish and Game, Wildlife Management Division, Nongame Bird and Mammal Section, Sacramento, California, USA.

Truex, R.L., and W.J. Zielinski. 2013. Short term effects of fuel treatments on fisher habitat in the Sierra Nevada, California. Forest Ecology and Management 293:85-91.

Tucker, J.M., M.K. Schwartz, K.L. Pilgrim, and F.W. Allendorf. 2012. Historical and contemporary DNA indicate fisher decline and isolation occurred prior to the European settlement of California. PLoS ONE 7(12): e52803. doi: 10.1371/journal.pone.0052803.

Tucker, J.M., Schwartz, M.K., Truex, R.L., Wisely, S.M., and F.W. Allendorf. 2014. Sampling affects the detection of genetic subdivision and conservation implications for fisher in the Sierra Nevada. Conservation Genetics. 15: 123-136. doi: 10/1007/s10592-013-0525-4.

United States Fish and Wildlife Service. 2004. 50 CFR part 17 Endangered and threatened wildlife and plants; 12 month finding for a petition to list the west coast distinct population segment of the fisher (*Martes pennanti*); proposed rule Federal Register.

United States Fish and Wildlife Service. 2004. 50 CFR part 17 Endangered and threatened wildlife and Gilmer, D. S., L. M. Cowardin, R. L. Duval, L. M. Mechlin, and C. W. Shaiffer. 1981. Procedures for the use of aircraft in wildlife biotelemetry studies. U.S. Fish and Wildlife Resource Publication 140.

U.S. Forest Service. 2004. Sierra Nevada forest plan amendment: final supplemental environmental impact statement. U.S. Forest Service, Pacific Southwest Region, Vallejo, California.

Vaillant, N. M., A. A. Ager, J. Anderson, and L. Miller. 2011. ArcFuels 10 system overview. General Technical Report PNW-GTR-875. USDA Forest Service, Pacific Northwest Research Station, Portland, OR, USA.

Vangen, K. M., J. Persson, A. Landa, R. Andersen, and P. Segerström. 2001. Characteristics of dispersal in wolverines. Canadian Journal of Zoology 79: 1641-1649.

Verner, J., and A.S. Boss. 1980. California wildlife and their habitats: western Sierra Nevada. USDA Forest Service General Technical Report PSW-37.

Weir, R., F. Corbould, and A. Harestad. 2004. Chapter 9 – effect of ambient temperature on the selection of rest structures by fishers. Pages 187-197 in D. J. Harrison, A. K. Fuller, and G. Proulx, edtors. Martens and fishers (Martes) in human-altered environments: an international perspective Springer Science + Business Media, New York, USA.

Weir, R. D., and F. B. Corbould. 2006. Density of fishers in the sub-boreal spruce biogeoclimatic zone of British Columbia. Northwestern Naturalist 87:118-127.

Weir, R. F., and F. B. Corbould. 2007. Factors affecting diurnal activity of fishers in north-central British Columbia. Journal of Mammalogy 88(6): 1508-1514.

Weir, R., and F. Corbould. 2008. Ecology of fishers in the sub-boreal forests of north-central British Columbia: Final Report. Peace/Williston Fish and Wildlife Compensation Program Report No. 315.

Weir, R.D., and F.B. Corbould. 2010. Factors affecting landscape occupancy by fishers in north-central British Columbia. Journal of Wildlife Management 74(3):405-410. Wengert, G. M. 2013. Ecology of Intraguild Predation on Fishers (*Martes pennanti*) in California. Dissertation, University of California Davis. Davis, CA, USA.

Weir, R. D., M. Phinney, and E. C. Lofroth. 2012. Big, sick, and rotting: why tree size, damage, and decay are important to fisher reproductive habitat. Forest Ecology and Management, 265: 230-240.

Wengert, G. M., M. W. Gabriel, J. E. Foley, T. Kun, B. N. Sacks. 2013. Field and molecular techniques for identifying intraguild predators of fishers and other North American small carnivores. Wildlife Society Bulletin 37:659-663.

Wengert, G., M. Gabriel, S. Matthews, J. M. Higley, R. Sweitzer, C. Thompson, K. Purcell, R. Barrett, L. Woods, R. Green, S. Keller, P. Gaffney, M. Jones, and B. Sacks. 2014. Using DNA to describe and quantify interspecific killing of fishers in California. Journal of Wildlife Management 78: 603-611.

White, G. C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement, 120-138.

Wilbert, J. C. 1992. Spatial scale and seasonality of habitat selection by martens in southeastern Wyoming. Thesis, University of Wyoming, Laramie,Wyoming.

Williams, E., E. Thorne, M. Appel, and D. Belitsky. 1988. Canine distemper in black-footed ferrets (*Mustela nigripes*) from Wyoming. Journal of Wildlife Diseases 24: 385-398.

Wilson, J. A., Kelt, D.A., VanVuren, D.H., Johnson, M.L., 2008. Population dynamics of small mammals in relation to production of cones in 4 types of forests in the northern Sierra Nevada, California. The Southwestern Naturalist, 53, 346-356.

Wisely, S. M., S.W Buskirk, G. A Russell, K. B Aubry, and W. J. Zielinski. 2004. Genetic diversity and structure of the fisher (*Martes pennanti*) in a peninsular and peripheral metapopulation. Journal of Mammalogy 85: 640-648.

Wolff, J. O., K. I. Lundy, and R. Baccus. 1988. Dispersal, inbreeding avoidance and reproductive success in white-footed mice. Animal Behaviour 36: 456-465.

Woodroffe, R. 1999. Managing disease threats to wild mammals. Animal Conservation 2: 185–193.

York, E. 1996. Fisher population dynamics in north-central Massachusetts. Thesis, University of Massachusetts, Amherst, USA.

Zhao, F., R. A. Sweitzer, Q. Guo, and M. Kelly. 2012. Characterizing habitats associated with fisher den structures in the Southern Sierra Nevada, California using discrete return lidar. Forest Ecology and Management 280:112-119.

Zielinski, W.J., N.P. Duncan, E.C. Farmer, R.L. Truex, A.P. Clevenger, and R.H. Barrett. 1999. Diet of fishers (*Martes pennanti*) at the southernmost extent of their range. Journal of Mammalogy 80:961-971.

Zielinski, W.J., T. E. Kucera, and R.H. Barrett. 1995. Current Distribution of fishers (Martes pennanti) in California. California Fish and Game 81:104–112.

Zielinski, W. J., and N. P. Duncan. 2004. Diets of sympatric populations of American martens (*Martes Americana*) and fishers (*Martes pennanti*) in California. Journal of Mammalogy 85:470-477.

Zielinski, W. J., R. L. Truex, G. A. Schmidt, F. V. Schlexer, K. N. Schmidt, R. H. Barrett. 2004. Resting habitat selection by fishers in California. Journal of Wildlife Management 68: 475-492.

Zielinski, W. J., R. L. Truex, F. V. Schlexer, L.A. Campbell, and C. Carroll. 2005. Historic and contemporary distributions of carnivores in forests of the Sierra Nevada, California, USA. Journal of Biogeography 32:1385-1407.

Zielinski, W. J., J. A. Baldwin, R. L. Truex, J. M. Tucker, and P. A. Flebbe. 2013. Estimating trend in occupancy for Southern Sierra Fisher Martes pennanti population. 2013. Journal of Fish and Wildlife Management 4:3-19.

Zielinski, W.J., C.M. Thompson, K.L. Purcell, and J.D. Garner. 2013. An assessment of fisher (*Pekania pennanti*) tolerance to forest management intensity on the landscape. Forest Ecology and Management 310: 821–826.

Peer Review
Introduction

The reviewed report describes a study of the public participation process in a joint forest management project involving a federal agency, the public, and an academic monitoring/science participant engaged in natural resource collaborative adaptive management. The goals of the public participation component of the project were to design a three party model public participation process to be used as a model for designing similar processes; as well as to foster an engaged, knowledgeable group of stakeholders to work constructively with the management agency (the Forest Service). The public participation process was designed based on five core elements: inclusivity, transparency, learning, relationship building, and effectiveness. The authors describe the in-person and virtual public engagement conducted throughout the project. To evaluate the success of the process design in accomplishing the core elements, the authors gathered statistics and profiles of participants at each in-person participation event. They also used affiliation social network mapping and self-organizing maps (SOM) to examine relationships between participants and events. In addition, the authors used a combination of surveys following in-person participation events and qualitative interviews and quantitative email surveys of participants early and late in the project. The goal of the assessment was to estimate how much the various participants learned from each other, from science, and from SNAMP outreach efforts. The authors determined that SNAMP science and outreach were effective at fostering learning and building relationships. They concluded the public participation process was successful overall, particularly in that the third party monitoring/science participant was perceived as independent, unbiased, and responsive to public input. They propose this process serve as a model of other collaborative adaptive management projects.

Merits

This study of collaborative adaptive management represents an important area of research in collaboration in natural resource management. The three party model, in particular, represents a potentially valuable contribution in monitoring for federal agencies. The scope and magnitude of the seven-year public participation process provides valuable information for evaluating the effectiveness of this approach. The review of the public participation process and the assessment results from in-person and virtual participation events generally supported the discussion of the success of these events in achieving the five core elements. The qualitative interviews and quantitative email surveys early and late in the project were well documented and provided good evidence to support the authors’ claims relative to the five core elements.

Critique

This report has general problems with framing and organization and clarity that make it difficult to evaluate how the theory links to the design and data and to evaluate how well the data supports the authors' claims about the overall success of this public participation process. In addition, while the study is data rich, the findings are not sufficiently analyzed. As a result, the study raises some critical questions that are not addressed.

Framing: One problem with the framing for this study was that there was not a clear link between the theoretical foundation for the study and the design and results of the study. The theory overviewed the historical evolution toward collaboration in natural resource management and addressed the limitations on the degree to which federal agency decision processes could be collaborative. The authors argued the third party model in monitoring allowed stakeholders to have an influence on management decisions that was within the legal constraints of the agency. They also contended that this third party model provided a system of "check and balances" on the science and agency decision-making. Further, they noted the prevailing belief that actively engaging people from multiple backgrounds led to increased support for decisions and better decisions overall. However, these claims were not supported by the study. The authors acknowledged that participants could not track how the science and public input was being used, so there was no way to validate how science or public input influenced agency decisions. Instead, the participants had to trust in the good will of the scientists and the agency to use the information. Many participants at the end of the project still had a "wait and see" attitude toward success.

In addition, key concepts such as adaptive management, collaboration, and public participation were not defined as they were being used in this study. Thus, phrases such as "the left hand side of the adaptive management circle" and "close the loop" were not clear to the reader. Further, it was less clear how the authors were making connections between improving public participation with the goal of fostering an engaged, knowledgeable group of stakeholders and increasing public influence on agency decisions or improving adaptive management.

Organization and Clarity: The general design, execution, and analysis of data in this study were difficult to track. As noted above, the line of argument was not always clear. Further, study results and lessons learned were repeated in multiple sections, and even contradicted at times. For example, discussion of survey results and interviews were intermixed and confusing, with references such as first round and second round that did not easily cross-reference to the chart and graph figures.

Analysis of Findings: The study is reported factually, with insufficient analysis of the findings. For one, some data from the study was presented to support general claims that were disputed by discussions in later sections. For example, the claim that collaboration focused on shared learning helps foster new and improved relationships was brought into question in the discussion of MOU partners and the funding issues. SNAMP MOU partners expressed frustration over frequent turnover among representatives and lack of commitment, and conflicts over funding created tensions and undermined relationships within the three party model. The authors even cite research that indicates experience in collaboration is not correlated with building trust, but instead is negatively associated with trust.

In addition, the groupings of participants from the surveys and interviews did not support the stated goals of building and assessing the learning between and among the scientists, the agency, and the public in the three party model. At times, there were noticeable differences in learning or changes in opinions among the three parties or even between different public groups, such as the forest products group, that were suggestive, but not addressed in any depth.

Because the analysis was not sufficiently robust, the lessons learned failed to capitalize on key learnings that would be of value in developing a model public participation process. For example, given the inevitable concern with shrinking budgets and limited capacity and resources, the analysis and lessons learned could better indicate which in-person or virtual forums are most critical for accomplishing the process goals and what design factors contributed to the success of these forums. The Management Workshops appear to be the only forum where scientists were able to learn from managers about key management questions and the context for management, which enabled the scientists to better understand how their research could help address these management questions. Given the importance of relevant science to inform decisions in adaptive management, I would expect the lessons learned to remark on the Management Workshops as a critical part of this three party model.

Discussion

The study on which this manuscript is based has great value to the field. Once the general problems are addressed, the findings will be more clear and compelling and useful for achieving the purpose of providing others with a public participation model.

Framing: Clearly define terms in the introduction to the study and clarify assumed relationship between improved public participation and improved decision-making. Qualify claims about the three party model. State these as assumptions or desired outcomes or provide research or information to support those claims.

Organization and Clarity: Improve organization and clarity by organizing the study into goals, design, implementation, findings, and lessons learned, with headings and subheadings for navigation and reference. It would also be useful to summarize the finding for each goal for easy reference.

Analysis of findings: Analyze the data more closely to address inconsistencies. This can be done by addressing the nuanced differences in the responses among the MOU partners, frequent participants, and those who just maintained a familiarity with the process. Also use groupings that better illustrate the relationship between and among the three parties in this model: the scientists, the agency, and the public.

Use the lessons learned to synthesize information and clarify which parts of the process are most critical and for whom for accomplishing collaborative adaptive management. For example, the field trips and management workshops were most highly rated (pg. 48) and were cited as excellent venues for mutual learning.

Also address the concerns voiced with funding, scalability, staff turnover, lack of commitment, and unclear decision-making in the lessons learned. It is important information for anyone considering using this model.

References

Anonymous authors (2015) Appendix F: Public Participation Team Final Report (unpublished manuscript) – University of California.

Additional Comments for Authors

There is a typo on page 15 in the sentence beginning with "The legacy of this policy has was a problem…"

The word "in" is repeated in the last sentence on page 57.

There is a typo on page 100 in the sentence beginning with "Learning also played an important role…"

The word "in" is missing from the sentence beginning with "The UC Science Team email survey respondents agreed with the Forest Service…"

There are extra words in the last sentence on page 155 which begins with "Use webinars can be used to transfer information…"

Figure F-5 on page 42 is confusing and doesn't illustrate information well. The numbers are small and there are too many lines and colors.

I thought the use of the self-organizing maps was very interesting, since it illustrated that public discussion stayed focused on content information, but contentious and critical issues (presumably topics such as funding and roles and responsibilities) continued to dominate discussions. I would assume this meant that the more general public discussions remained focused on content, but the meetings among partners who were most involved in the project were dominated by administrative and organizational issues. This data would be interesting to examine more closely.

I am not as clear on how the affiliation network analysis contributed to the study. The lessons learned was that it was a valuable tool to characterize social dynamics, since it illustrated a strong clustering around the northern and southern meeting locations. However, it did not seem to contribute any more information than what was presented in Figure F-8 on the attendance at SNAMP event. Further, I was not clear on the value of characterizing social dynamics to this adaptive management process.

I also do not see the value in the story about people mailing in sox for the fisher project. I understand that it was meant to illustrate the value of the web presence, but I do not think the level of detail provided, including pictures and graphed locations, was warranted or added much value to a generally scholarly report.

I see great value in having this report condensed into key findings and recommendations that could be used as a reference for those designing similar processes. It is too long and inaccessible in its current form to serve the purpose of providing a model for others to use.

REVIEWER # 6

SNAMP – CALIFORNIA SPOTTED OWL

June 12, 2015

TO: Bill Frost, Associate Vice President, University of California Division of Agriculture and Natural Resources, University of California-Davis
CC: Joan Taylor Warren
RE: Review comments on the California Spotted Owl Team Report

The California Spotted Owl Team Report is a component of the Sierra Nevada Adaptive Management Project (SNAMP) which addresses uncertainty over forest fuels management in the Sierra Nevada and potential adverse effects of the population dynamics of the California Spotted Owl (CSO). A key SNAMP objective was to evaluate the impact of Strategically Placed Landscape Treatments (SPLATs), a forest fuel treatment, across a number of response variables including CSO demography. The primary tasks of the Owl Team were to: 1) assess the impacts of forest management and vegetation change on owl demography over the past 20 years on the Eldorado demography study area, and 2) project the effects of wildfire on the quantity and quality of owl habitat in the Last Chance study area over the next 30 years, with and without SPLATs.

The California Spotted Owl Team Report is divided into two sections. The first section is based on a recent publication by D.J. Tempel and others published in Ecological Applications (Tempel et al., 2014). This publication, based on data collected from a long-term demographic study of CSOs populations on the Eldorado National Forest, evaluates the effects of forest management practices on CSO populations. I have thoroughly reviewed this publication and found the paper to provide information highly relevant to the possible consequences of forest fuels management on California Spotted Owl (CSO) population dynamics.

I concur with the major conclusions drawn in Tempel et al. (2014) regarding the potential effects of medium-intensity harvest practices on CSO demography. Specifically, these authors focus on possible adverse effects of forest management on both CSO reproduction and survival rates. I believe the data they collected, and the analyses they conducted, to explore the relationship between covariation in habitat and vital rates are compelling. Their finding of a strong association between demographic performance and the key habitat attributes of canopy closure (> 70%) and the density of large trees (>~60 cm dbh) is well-supported by their data and consistent with the majority of published studies on spotted owl habitat ecology (both Northern and California Spotted Owls).

A key concern pointed out by Tempel et al. (2014) is the possible trade-off between fuels management to reduce fire risk and the short-term demographic consequences of these management practices. Given that CSO populations in most areas of the Sierra Nevada are in decline (Blakesley et al. 2010, Conner et al. 2013, Tempel and Gutierrez 2013), whether it is prudent to introduce an additional source of demographic cost to the CSO is debatable. The life history structure of Spotted Owls (delayed age at first reproduction and limited reproductive potential) constrains them from rapid population growth should their populations become both small and geographically distinct (Noon and Biles 1990).

The key unknown in the proposed management practices to reduce fuel loads is the likelihood of future loss of habitat due to an increased fire frequency or severity. Given the impossibility of knowing the future until it arrives, the proposal by Tempel et al. (2014) to focus fuel treatments in dense stands and to emphasize thinning from below to maintain high levels of canopy cover and vertical stand structure seems a very logical recommendation. Climate change projections for much of the Sierra Nevada region suggest an increase in fire frequency and intensity (Geos Institute 2013). These projections suggest that silvicultural practices to reduce fire risk are justified.

In the second section of the California Spotted Owl Team Report, the results of a prospective analysis of the possible effects of fuels treatments on CSO habitat suitability are modeled. The Team simulated forest growth 30 years into the future under four combinations of modeled wildfire and treatment: treated with fire, untreated with fire, treated without fire, and untreated without fire. Effects of treatment scenarios were evaluated with a habitat suitability index model using canopy cover and large-tree measurements as predictor variables. Estimates of population growth rate and equilibrium occupancy were made for four spotted owl territories within the study area for each scenario using the statistical relationships between forest structure and CSO population parameters reported in Tempel et al. (2014).

The 30-year simulations demonstrated that the effects of fuels treatments are contingent on the probability of fire occurrence. Treatments had a positive effect on owl nesting habitat and demographic rates up to 30 years after simulated fire, but a negative effect in the absence of fire. Simulations results showed fuels treatments to reduce territory fitness and occupancy in the short-term, but with the potential to promote higher CSO fitness and occupancy after 30 years in the event of high-severity fire. The report concluded that fuels treatments may provide long-term benefits to spotted owls if fire occurs under extreme weather conditions, but can have long-term negative effects on owls if fire does not occur. Similar to the conclusions of Tempel et al. (2014), the net benefits of fuels treatments on CSO habitat and demography will depend on the future probability of significant fire events.

In general, I found the modeling approach, types of models used (e.g., FARSITE and Forest Vegetation Simulator), data-based model inputs, and inference to be defensible. Actual on-the-ground field measurements, both before and after treatment, are a real strength of this study.

Simulations and model projections are inherently less certain than retrospective analyses based on “hard” data. Despite these limitations, the modeling and analyses reported in this section of the Report are quite useful and robust. The data input to the models was based on extensive field survey data collected both before and after fuels treatments. In addition, field measurements were augmented with remotely sensed data (e.g., LIDAR imagery) to detect post-treatment changes in forest structure.

The conclusions drawn in section two of the Report are consistent with those in section one. Specifically, the net effect of fuels treatments on CSOs depends upon the unknown probability that high-severity fire effects will adversely affect CSO habitat. However, estimating the likelihood of severe fires at the spatial scale of individual CSO territories is almost impossible given the complexity of fire events and our current understanding of fire dynamics in topographically diverse landscapes. I agree with conclusions drawn in this section of the Report that fuels-reduction treatments will likely have short-term demographic consequences to CSOs but the potential to provide long-term (30-year) benefits the event of severe and extensive fires.

I have a few minor suggestions/caveats on section two of the Report:

- Inference is limited because empirical analyses were available for only four CSO territories. Given this small sample, and inferences to population-level responses need to made carefully.
- The logisitic model used to estimate the suitability of nesting habitat is based on just two predictors—canopy cover and large tree density (equation 4 in the report). These are logical predictors to include in the model but it is unclear how well the model fit the data. I suggest an ad-hoc measure of model adequacy using some sort of pseudo-R2 metric. For example, the following metric could be used: $R^2 = 1 - \ln(L_m)/\ln(L_0)$, where L_m is the likelihood of the fitted model, and L_0 is the likelihood of the intercept-only model.
- A similar comment to the above is relevant to equation 5 as well.
- In equation 6, how was female age assigned to future projections?

Striking the appropriate balancing between full CSO habitat protection versus some level of active fuels treatment within CSO habitat should be done gradually and accompanied by ongoing demographic monitoring of both CSO and CSO prey species (specifically, flying squirrels). Thus, a continuation of the ongoing CSO demographic studies with a specific focus on the effects of fuels treatments on CSO reproduction and survival should be part of an overall adaptive management program. Importantly, the adaptive management program should have specific decision points, expressed in terms of target CSO demographic thresholds, to constrain levels of fuels treatments if they result in unacceptable risks to CSO viability (Noon 2003, Nichols et al. 2012).

References:

Blakesley, J.A., et al. 2010. Population dynamics of spotted owls in the Sierra Nevada, California. Wildlife Monographs 174.

Conner, M.M., J.J. Keane, C.V. Gallagher, G. Jehle, T.E. Munton, P.A. Shaklee, and R.A. Gerrard. 2013. Realized population change for long-term monitoring: California spotted owl case study. Journal of Wildlife Management 77: 1449–1458.

Geos Institute. 2013. Future climate, wildlife, hydrology, and vegetation projections for the Sierra Nevada, California: A climate change synthesis in support of the vulnerability assessment/adaptation strategy process.

Nichols, J. D., M. J. Eaton, and J. Martin. 2012. Thresholds for conservation and management: structured decision making as a conceptual framework. In *Application of threshold concepts in natural resource decision making,* ed. G. Guntenspergen.. NewYork: Springer.

Noon, B. R. 2003. Conceptual issues in monitoring ecological resources. In *Monitoring ecosystems:Interdisciplinary approaches for evaluating ecoregional initiatives,* ed. D. E. Busch, and J. E. Trexler, 27–72.Washington, D.C.: Island Press.

Noon, B.R., and C.M. Biles. 1990. Mathematical demography of spotted owls in the Pacific Northwest. Journal of Wildlife Management 54:18-27.

Tempel, D.J., and R.J. Gutierrez. 2013 Relation between occupancy and abundance for a territorial species, the California spotted owl. Conservation Biology 27:1087-1095.

Tempel, D. J., R. J. Gutiérrez, S. A. Whitmore, M. J. Reetz, R. E. Stoelting, W. J. Berigan, M. E. Seamans, and M. Z. Peery. 2014. Effects of forest management on California spotted owls: implications for reducing wildfire risk in fire-prone forests. Ecological Applications 24:2089–2106.

Peer Review 7: Reviewer #7 Spatial
REVIEWER #7
SNAMP- Spatial Team Final Report

June 2015

Review:

Overall, the spatial team has done a lot of work and definitely have fulfilled the the goal of the SNAMP project. The number of peer-reviewed papers (11 published) speaks by itself. However, I wouldn't claim the work as technical breakthroughs. To promote the wide adoptation of lidar for forest management, two goals have to be achieved: the high accuracy of the derived veg products compared to the ones from conventional methods, and the capability of applying the lidar-based methods to larger area. Unfortunately, the two goals are rarely met at the same time in most of the current methods. Most methods can get good accuracy at local scale with lidar, but they often require a lot of inputs from the user and fine tuning. When the methods are applied over larger scales, they could break down simply because of the computation demand and the intensive inputs from the users to achieve reasonable accuracy (e.g., how long does it take to apply the point cloud-based method to map trees for the whole study area instead of just those in the field plots? how accurate is it to apply the OBIA method to detect down logs over other areas?). I have no intent to play down the works the spatial team has done, but simply mention a direction in which remote sensing scientists all need to make big breakthroughs.

REVIEWER #8
SNAMP – PACIFIC FISHER TEAM REPORT

Peer Review

Title: Sierra Nevada Adaptive Management Project (SNAMP), Appendix D: Fisher Team Final Report

Authors: Rick Sweitzer, Craig Thompson, Kathryn Purcell and Reginald Barrett

COMMENTS FOR ADMINISTRATORS AND EDITORS

This is a good overview of the results of the research done by the Fisher Team related to general life history of fishers and related to responses of fishers to fire management actions. I have no major concerns related to the research methods or the results. I have some comments that I think should help clarify results in some places and that will make reading this Report easier.

GENERAL COMMENTS FOR THE AUTHORS

I do not know whether this Report will ever stand alone. If so, it needs a succinct introduction to the Sierra Nevada Adaptive Management Project as a whole. As is, the fisher project lacks context at the start and gains context only piecemeal as land management actions are introduced.

In your list of objectives, both in the Executive Summary and in the body of your Report, you emphasize mortality as the population limiting factor. I know that you know that reproduction can limit populations just as well as mortality but you do not mention in your objectives that your population could be limited by reproduction. Given the probable small litter sizes of the fishers in your population, reproduction could very well be a limiting factor, maybe THE crucial limiting factor. You need to mention reproduction in your objectives.

For your Leslie matrix, you used single values for adult reproduction and adult survival. Thus, F4 = F5 = F6 = F7 = F8 and P4 = P5 = P6 = P7. You should use just F4 and P4 in your matrix on page 33. In building your matrix, you have assumed that no fishers live beyond page 8, which is not true. If you replace the 0 in the bottom right corner of the matrix with P4, your matrix will allow survival beyond age 8. Given that you use constant adult reproduction and survival, you can actually collapse the matrix to a 5x5 matrix, assuming you are willing to let model fishers live beyond age 8.

Given that F1 = 0, why not simply put 0 in the matrix? As far as I can tell, F2 = 0, too, for your matrix. Although you state that the matrix was built to estimate the population at 1 month following birth (approximately 1 May), your estimates of litter size appear more accurate for later ages, probably 2-3 months old. And your estimates of kit survival starts at age 6 months. In the end, I am confused as to whether your matrix estimates population size just before or just after reproduction. Do your fishers die and then reproduce or do they reproduce and then die? Leslie matrices can work either way.

You should state that your estimates of litter size are biased low because cameras do not always show all kits in a litter. Opposing that bias, your estimates of kit survival are biased high, because you have few data on survival of kits to weaning and no data on survival of kits from weaning until trapping in October.

Also related to the biased estimates of reproduction and kit survival, the elasticity analyses that I did for the population model used by Lewis et al. (2012, PloS One) and Powell et al. (2012, Martes 2009 book), showed that the model was most sensitive (via elasticity calculations) to estimates of litter size and kit survival. I do not know why you found your model not to be most sensitive to those variables, contrasting with our results. Sensitivity analyses sometimes yield results that contrast with elasticity analyses (a substantial literature on the differences exists, dated to 10-15 years ago). I encourage you to do an elasticity analysis if you did not.

Writing about the biases for litter size and kit survival reminds me that your estimates of dispersal distance are biased low. This point is worth making clear right from the start. Your bias is undoubtedly smaller than that for research not so flight-based. When trapping fishers for reintroduction in the northern Sierras, we trapped a male 50 km from where he had been marked as a kit on the Hoopa Reservation.

Page 89 – Home range overlap. You must do your analyses using raster values for the entire utilization distributions and not for ranges of contours. Using the contours is a modest improvement over using everything with the 95% contours. Nonetheless, to gain truly good understanding of overlap, you have to use the entireties of the utilization distributions. Really, no study of home ranges can be done well using vector analyses. You need to use raster GIS.

Page 90, Figure 31 and elsewhere – You must justify defining a core as the 60% contour. Why 60% and not 55, or 42, or 73.1415927? Really? Using 60% is arbitrary and not based on the behavior of the fishers, as far as I can tell. If you zeroed in on 60% after doing some undescribed analyses of your fishers' utilization distributions, then that could be OK but you need to explain the analyses.

Page 114 – Your result that occupancy was not negatively associated with fuel reduction could have been caused by lack of power in your analyses. You should report power so that readers (and you) understand the strength of your result.

I recommend that you be careful about occupancy vs abundance or density. Populations can change in abundance without changing occupancy. You report estimates both. You should recheck how you address occupancy and abundance to make certain that you do not slip back and forth without realizing it, thereby misunderstanding population change or stasis.

REVIEWER #8
SNAMP – PACIFIC FISHER TEAM REPORT

SPECIFIC COMMENTS

I have some specific suggestions for wording saved on a Word file with TrackChanges. Let me know if you want them. If you do a lot of revising, my suggestions might end up being irrelevant.

Does SNAMP stand for Sierra Nevada Adaptive Management Project or for Sierra Nevada Adaptive Management Plan? Which is it? You are not consistent and must be.

I suggest using the word "sex" throughout and deleting all references to "gender". "Gender" has become a politically correct word to use but it does not have a serious place in biology. Gender refers to social roles that only humans play. In fact, "gender" originally referred to linguistic categories of nouns in many languages. In German the linguistic genders are referred to as "male", "female" and "neuter" (a girl is neuter). In Danish the linguistic genders are "common" and "neuter". Thus, gender is languages is tremendously inconsistent with respect to sex. Justice Bader-Ginsburg began the move to use "gender" to mean "sex" for humans because she noted that the word "sex" conjures up ideas in men's minds that muddled the legal questions that judges and lawyers must handle. I assure you that fishers do not get distracted by the use of "sex" in the ways that human men do and fishers do not have trouble with social roles or trouble with how to refer to gay, lesbian and trans-gender fishers. You do a little switching back and forth, which implies that you use "sex" and "gender" to have different meanings. They do have different meanings but I do not really think that you have used them to mean different things.

Use "sex" for all non-human animals.

Cameras are not traps, they are cameras. They do not capture animals or photographs, they take photographs or, better yet, cameras photograph animals. I recommend removing all references to cameras as traps. In many places you do refer to cameras simply as cameras, den cameras for example. Your survey cameras were cameras also and not traps. Just use the simple language you would use when describing a person using a camera to photograph something. I know that "trap" and "capture" are jargon often used today. Avoid them (don't fall into their trap). Your readers will thank you.

I strongly urge you not to use acronyms. You are simply stuck with some acronyms, like SNAMP, which is horrid. Had I been in charge, I would have avoided that tongue twister like the plague. You should minimize the acronyms and use only those that are absolutely necessary.

Asking readers to remember acronyms is not a big request, I know, but readers who have just read another paper that required them to remember abbreviations for other things, perhaps some with the same acronyms or abbreviations, can easily forget yours. Recently I reviewed a manuscript that asked readers to remember abbreviations for 3 types of forest, one of which was mixed deciduous forest, abbreviated as MDF. Before reading that manuscript, however, I had been reading a woodworking magazine and all I could think when I read "MDF" was "medium-density fiberboard". You do not want readers to be confused like that. Spelling out whole names is worth the space used to be clear. If you can think of ways to shorten long names, that is good. For example, "mixed forest" worked for "mixed deciduous forest". Remember, use abbreviations and acronyms only when they serve to improve your ability to communicate with your readers. Do not use abbreviations and acronyms to save space, to save you from having to write out long names many times, or to make you think that your manuscript is important because it has a bunch of capital letters strewn through it. Do not use acronyms and abbreviations simply out of habit when they are not needed. By and large, acronyms are a sign of authors who have not been thinking. Given that your goal should be to help your readers understand your research, avoiding acronyms is your best approach.

Define all your acronyms the first time you use them, both in the Executive Summary and in the body of your manuscript. You did not define SPLAT (another horrid acronym) when first used. Either that or I simply had difficulty finding a definition when I needed it.

You must include a table of acronyms. I did not have time to read your entire manuscript in one shot. When I picked up the manuscript to re-start reading after a break, I could not remember all the acronyms and had trouble finding their definitions.

All the passive verbs got b-o-r-i-n-g: "was" this and "were" that. Please revise to use active verbs. I know that unimaginative writing with active verbs can come be boring as well, with "We did this" and "We did that." Even that unimaginative writing is less boring than passive verbs, and I know that you can write imaginatively to make reading more fun.

In your Executive Summary, I am not always certain whether you are writing about individual fishers or fisher years (1 fisher yielding data for 2 years is 2 fisher years). When you had data for individual fishers for >1 year, did you test for independence, did you average data for individuals over years, or did you do something else? For my own data over the past decades, I have seldom found that using animal years showed an animal effect. Any effects of individual animals appear overwhelmed by other sources of variation.

The term "subadult" is possibly the most ill-used term in wildlife biology. What exactly is a "subadult"? Is a "subadult" not an adult? If so, then use "juvenile". If a "subadult" is an adult, then use simply "adult". If a "subadult" is an adult that has special characteristics, such as not being an effective breeder, then another term, such as "non-breeding adult", would be more clear. Reading your manuscript, I had trouble remembering whether a "subadult" was 1-2 years old or 2-3. I recommend not using the term "subadult" but using ages.

The term "subadult" can be particularly confusing for males, since males just turning 2 are probably not effective breeders, while females are effective breeders at that age. Thus, females can be considered adults at age 1 because they breed, yet they do not produce their first offspring till they are age 2. Males are one year behind (maybe 2?).

If you insist on using "subadult", define it clearly in both your Executive Summary and in the body of your Report. You should define it in your table of acronyms and abbreviations, too.

You used 2-year periods to estimate vital rates and you used 2-year groupings of camera data. You appear to be good about stating which 2-year groupings are the topic of discussion but I could not remember how they differed. I suggest you help readers somehow keep these groupings straight.

Page 7, bottom paragraph – You imply that the genetic data contradicts the 400 km break having been caused by logging and trapping (and perhaps change of climate at the end of the Little Ice Age). Given the number of canyons that break the Sierras from the Feather R down to the Merced R, given that fishers do not cross the Merced enough now to colonize the north side, and given the genetic subdivisions caused by canyons in the present fisher population in the Southern Sierras, the fisher population in 1800, 1850 or 1900 could well have been continuous from Yosemite to Mt Shasta and still not have had genetic exchange between the 2 extremes for >1000 years. You should acknowledge this very real possibility.

Page 14, just above fisher – This sentence is wrong. The goal was to MAINTAIN $\geq$20 fishers on the air. The number 20 was reached in July 2008 but not the goal of maintaining that number. As written, "milestone" refers to the goal, not to the number of fishers on the air. This sentence needs revising. You have a similar sentence elsewhere in the Report somewhere.

A grid is a set of (usually) perpendicular, intersecting lines. A common grid that we (both you and me) use in our research is the UTM grid. Each square outlined by grid lines is a cell within the grid. Throughout your Report you use the term "grid" to mean "cell". What you did was lay out a grid of lines that intersected to make 1x1 km cells. Usually your misuse of "grid" is just irritating but sometimes it can be misleading and lead to misunderstanding. Use the Search & Destroy capability of Word to find every use of "grid" and make certain you do not mean"cell". I bet that you will have to change 99% of them. An easier way to make the change would probably be to change every "grid" to "cell" and then check for the minuscule number of changes that should not have been made.

You have some ambiguous citations needing and "a" or "b". One page 31, bottom paragraph, to which publication by Zielinski et al. (2013) do you refer? Check your citations.

Page 22, Background paragraph – Avoid opinion. I have seen no data and analyses that show that den sites limit any fisher population. I have read assumptions to that effect but not data and analyses. If you know of data and analyses that support the first sentence in this paragraph, then cite them. Otherwise, consider den shortage to be an hypothesis that needs to be tested but is not KNOWN to be a major problem.

Page 27, paragraph 2 – Zielinski & Duncan (2004) did not report any data on prey numbers and, therefore, your reference to "insufficient numbers of prey" is an (albeit minor) unethical citing of a reference to provide false support a statement. Check all of your citations to be certain that the references actually support the statements you make.

Page 31, bottom paragraph – Remember that occupancy and abundance are not the same thing. Zielinski et al. presented data on occupancy, not abundance. You do not know from their research whether abundance changed or not.

Page 36, top – To be able to compare home ranges among fishers using a kernel estimator, all utilization distributions developed for all fishers should have the same "h". To be able to compare utilization distributions across studies, both "h" and the kernel used must be known. For example, the bivariate normal kernel emphasizes peripheries more than does Silverman's k2 because a bivariate normal distribution has infinite tails. You must state what "h" and what kernel you used.

Page 42, 2nd paragraph – What do you mean by "centroid"? Do you mean the geographic mean of all locations, the point with the highest probability of use, or something else? Be clear.

Page 45, 2nd paragraph – Choosing the kernel is also critical and is critically important for being able to make comparisons across studies. Studies that use different kernels can not be compared quantitatively.

Page 45, bottom – Discarding data in a no-no. This is a point that Ken Pollock makes strongly and regularly. Discarding data also makes no sense, really. You worked hard to collect those data, so why throw some away? You will have better results if you weight locations by the times between them and use all locations (locations farther apart in time than autocorrelation time get full weight). On the flip side, all locations of a given animal are always biologically correlated, otherwise the animal would not have a home range. Animals choose where to go and how fast and when because of background information they have. From this point of view, statistical autocorrelation makes no biological sense and should be ignored.

Page 74 – The reference to Figure 10 is an error. Figure 10 shows that number of males wearing collars and not the number of males in the population.

Page 75, Figure 18 and elsewhere – Numbering the y-axis with numbers to 2 decimal places is false precision.

Page 100, line 2, "By contrast" – Not much of a contrast here.

Page 101, paragraph 2, line 3 – I know of no data that demonstrate that the habitats around dens protect fishers from predators or weather. Den holes can protect fisher kits from predators too large to fit into the holes and deep holes can protect kits from predators that might reach into the holes. Den holes do keep some weather out but how much depends on how deep the hole is and how wide the entrance is. Does anyone know why martens do not raid fisher dens and eat young?

Page 106, paragraph 2 – I think it worth mentioning that the single female that did not recover from handling would have died anyway, had you not trapped her.

Page 115, paragraph 2 – Complex structure on the forest floor probably helps fishers catch prey, as it does for martens. So, fuel reduction might affect prey populations, might affect fishers' hunting abilities, or both.

REVIEWER #9
SNAMP – FIRE AND FOREST ECOSYSTEM HEALTH REPORT

July 30, 2015

I have reviewed the "Fire and Forest Ecosystem Health Report" component of the *Sierra Nevada Adaptive Management Project* per the request. Based on my 20 years of experience with fuel management and fire behavior, and my working knowledge of the literature on these topics, I find this report extremely well assembled. The team has an impressive track record in this area of study, made thorough use of the literature (and beyond their own work), employed solid methodologies for this analysis, presented a wide range results, and drew solid conclusions from those results. Beyond this, they give fair treatment to potential weaknesses in the design and in various modeling approaches. Overall, as a reviewer, I found that refreshing.

The report concludes, and I concur, that there are reasonable improvements to fire behavior/effects following the treatments, and that those improvements are limited by the intensity and extent of those treatments – only a relative small percentage of the two areas was treated, and a very small percentage treated with prescribed fire; the Sugar Pine unit had no prescribed burning. Given the importance of prescribed fire in fuel treatments and the effect of residual slash on surface fuels following mechanical treatments, it is no surprise that the improvements to fire risk were modest.

The larger advantage of the treatments as implemented was apparently associated with tree and stand vigor and growth efficiency. This could be of great importance given climate change. Increased vigor will aid in the growth of larger trees, there resistance to disturbance agents (including fire), and the resilience of ecosystems as larger percentages of trees and basal area survive into the future beyond one of more future wildland fire events.

In summary, this synthesis is sound despite being a case study on only two sites, that treatments were delayed (limiting the ability to measure post-treatment responses), and that some plots required relocation. The authors adequately handled these design limits, the need to span scales among the different analyses, and the need to model fuel succession and fire behavior. I found their report solid, well presented, and well defended.

Thank you for the opportunity to review it. I hope my comments will be helpful.

REVIEWER #10
SNAMP – FIRE AND FOREST ECOSYSTEM HEALTH REPORT

July 31, 2015

Review comments

Sierra Nevada Adaptive Management Project / Fire and Forest Ecosystem Health Report

Overall comments:

The body of the report presents a thorough professional analysis of fire and forest health in the SNAMP. The concepts guiding the analysis were based on an informed assessment of the scientific literature, although the definition of "forest health" was limited and overlooked a potentially useful approach, ecological restoration. The authors applied appropriate methods of sampling and modeling. The experimental design was well-conceived but factors beyond the control of the authors prevented its full implementation. In any event, the field sampling was quite intensive. As with any modeling exercise, there are a number of uncertainties associated with the predictions. The authors did a good job of describing potential sources of error. The authors may not have been tasked with addressing how the treatment effects may be altered as climate changes, but any modern assessment of multidecadal treatment effects should have such an assessment, in my opinion. Detailed comments (below) may be useful to consider but are not essential.

The Appendix to the report, titled "Appendix A.1, Spatial and temporal components of historical fire regimes in a mixed conifer forests [sic], California", describes a fire history reconstruction study done in a portion of the SNAMP landscape. The study in the Appendix appears to have been carried out competently in terms of sampling and some of the analysis. However, there are additional analyses that would have been important to include. In addition, the text suffers from some unsupported statements, some exaggeration, and a remarkable number of spelling and grammatical errors. In its current form, the Appendix is not suitable as a professional report.

Detailed comments on the body of the report:

1. General comment on units: in part of the text, both English & metric units are used, in one part metric only (e.g., L. 429), and in the Tables English only. Please be consistent.
2. Abstract p. i: should read "in order to quantify…", not "quantity"
3. L. 16: of the three references here, only one is relevant to the species in the present study and mentioned on L. 12-13. The Brown and Naficy papers are on ponderosa pine forests in South Dakota and Montana, respectively.
4. L. 25: would be helpful to give a quantitative range of reduced fire risks associated with treating 30% of the area, rather than just saying fire risk "can be decreased". Presumably fire risk would be "decreased" due to treating 1% of the landscape, or 99%. The point Finney was arguing is that "strategically" located treatments would give a disproportionate benefit in term of reducing the likelihood of severe fire.
5. L. 38-40: awkwardly worded sentence starting "This concern…"
6. L. 45: besides adding sediment (due to soil disturbance associated with treatment?), in what other way would the treatment "lower water quality"?
7. L. 57: should read "forests OF the Sierra Nevada…"
8. L. 61: Westerling's study was over a much larger area, the western US.

9. L. 64: the "fire deficit" described by Marlon et al. appears to be mainly the result of fire suppression, as the authors stated, but it reflects a deficit of surface fires, the theme of the present study, as well as severe fires, which in the context of this study are to be avoided. The Marlon reference blurs the distinction between surface vs. severe fire regimes & therefore is not helpful in the present context (in my opinion).
10. L. 93: would be useful to give a quantitative figure, rather than "noticeable reductions".
11. L. 106-110: great point about buying time. Note the reference to "restoration activities", see comments below.
12. L. 115-158: the authors give a reasonable presentation of the literature on "forest health", a concept with strengths and weaknesses. They make a logical case for the selection of tree mortality and tree growth as useful indicators of tree health and, roughly, "forest health" in this study. However, the review is brief and limited. A surprising omission, in the light of the Forest Service´s emphasis on ecological restoration and the references to restoration in the text itself, is the literature on ecological restoration. A basic element of restoration is the reference condition, which includes as much information as possible about ecosystems prior to recent human-caused degradation: plants, animals, forest structure, ecological processes, influences of non-industrial human societies, etc. See for example the Primer by the Society for Ecological Restoration. Many of these elements are mentioned in the text here and in the Discussion, but not in an integrated manner.
13. L. 122: "trees and trees alone" sounds a bit colloquial.
14. L. 183: not clear whether the figure of 1182 mm refers to total precipitation (water equivalent) or to snow depth?
15. L. 208-218: it´s not clear what is the relationship between the cited studies (e.g., Scholl and Taylor 2010) and the fire history study in Appendix A1. Would be helpful to clarify the distance to the previously studied sites, the species, etc. As written, since the cited studies are used to describe the pre-Euro-American fire regime, it is not clear to the reader why new fire history data were collected. (Incidentally, given the long history of Spanish colonization, what do the authors consider to the date of "Euro-American settlement"?).
16. L. 220, Methods section: field sampling was logically designed and a substantial amount of data was collected.
17. L. 239: "were navigated to using…" is awkward.
18. L. 240: should read "Garmin".
19. L. 264: please give more detail about prescriptions: was there a target forest structure? Residual basal area?
20. L. 282-292: the authors did a good job of assembling the treatment boundary data but this section highlights the ridiculous situation of the lack of detailed spatial information about treatments in the National Forests. The Forest Service doubtless retains all receipts for repair of its vehicles or purchase of a desk, but is incapable of adequately describing the contracts for management treatments on FS lands!
21. L. 299: the Lidar data should be explained to the reader. The report references an Appendix B which was not included for this review.
22. L. 323: why were numbers of seedlings randomly generated? A citation is given but the logic should be explained and justified.
23. L. 326-331: please clarify the role of FVS & FFE. Were any fires simulated in FVS-FFE? Or were these models used solely to grow trees & track fuels, in the absence of fire, with all fire behavior simulations occurring in Farsite or FlamMap?
24. L. 342: describe the use of Lidar to describe topography. My (limited) understanding of Lidar was that different measurement approaches would be appropriate for measuring vegetation vs. measuring the surface underneath the vegetation.
25. L. 344: the use of a "problem" fire is traditional & reasonable, but the reader would expect a discussion of the limitations of the concept.
26. L. 355: was spotting enabled in the Farsite simulation? See later comment about windspeed. In a real fire, higher windspeeds and spotting would be a critical combination.
27. L. 359: should read "used A command-line…"

28. L. 415: true that the design “accounts for” changes, but the BACI design is limited, with no or limited replication.
29. L. 430: is the term “conditional burn probabilities” a standard term? It sounds confusingly similar to the concept of “conditional crown fire” suggested by J. Scott. Please clarify and please also explain how the authors dealt with the situation called “conditional crown fire”, when the canopy bulk density is sufficient to carry crown fire horizontally but the canopy base height is too tall for simulated vertical propagation of the fire.
30. L. 434: where does the 2-m flame length threshold come from?
31. L. 446: it seems quite illogical to calculate the trees that were intentionally cut as “mortality”. Why was this done?
32. L. 495: delete the word “on”.
33. L. 512: LAI appears here as a critical variable, yet it was not measured in the Methods. Where did the LAI values come from? How reliable are LAI estimates?
34. L. 644-647: complicated way to say that trees from dense stands have a large growth response when released by thinning…
35. L. 693: appropriate discussion of the weaknesses of the fire behavior model. See also comment on windspeed below.
36. L. 709: reasonable discussion of CBH modifications.
37. L. 720: good discussion of fuel model issues.
38. L. 738: Lidar needs more explanation.
39. L. 762-764: authors say there is no explanation beyond self-thinning, but what about drought effects during these years?
40. L. 798 & 806: here, very late and only mentioned in passing, are key issues of ecological restoration and global change. These themes merit more discussion in the context of the treatments.
41. Table 2: these windspeeds are extraordinarily low, averaging 6-10 mph. Are these mid-flame or 20-ft windspeeds? Are the problem fires in the Sierra Nevada really associated with such low windspeeds? Please clarify, justify, or change if appropriate.
42. Table 4: the Last Chance site seems quite open at the beginning, BA 133 and TPA 252. Is this really a fuel problem?
43. Table 4: what is Lorey height & why was it used? Please also present actual height values.
44. Table 6 & 7: why such a big difference in mastication effects on fuels, with a doubling at LC but little effect at SP?
45. Table 7: column headers out of line.
46. Table 8 & 9: shouldn´t the treatment impact be “delta mu” rather than “mu”?
47. Figure 7: repeats data given in Table.
48. Figure 9: illustrates the minimal (negligible?) impact of these treatments.

Comment 13: Anonymous comments on SNAMP report [Survey Response 819751]

Comments on SNAMP Whole Document

I have participated in SNAMP in the following ways *(choose all that apply)* *

Attended SNAMP meetings, Just the last meeting

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**: Agree
- **This document summarizes research findings well.** Agree
- **The research findings described in this document are understandable.** Agree
- **The research findings described in this document can be applied to Sierra Nevada forest management.** Agree

The most interesting research findings in this document are: I'm completed biased and drawn to the fisher work.

The most important findings from this document to apply to Sierra Nevada public forest management are: The ways to incorporate the habitat needs of multiple (at least the fisher and SPOW) species in an uncertain environment.

The research findings that I found least applicable to Sierra public forest management are: The quotes of the four people interviewed in the study units. It wasn't clear how the four were selected, and it seemed more like gossip than generalizations from a random sample. For example, a long-timer saying 'city people are unfriendly' could easily be paired with a newcomer stating that "long-timers are unwelcoming." I would prefer there was a clearer study design, or just put these anecdotal comments in an appendix.

The biggest questions I have after reading this document are: How will this research be integrated with other research and how will the management implications be distributed?

The biggest concerns I have after reading this document are: 1. The graphics (particularly in the integration section) were chosen to simplify the results, which is a good idea. However, it doesn't have the intended result because in this study, the changes in forest structures were not consistent by treatment. As a result, the simplification may lead a manager to make a decision opposite of what was intended. Instead of using the four treatment types, I suggest grouping results by the changes in forest structure that came about as a result of the treatments. 2. The spatial scale of the treatments was limiting in making conclusions. The document states this several times, but it is critical to note that this was one of several studies that can inform management. 3. For managers, the Integrated Management Recommendations will be the most useful section - I made my comments on this section at the last public meeting. 4. It isn't clear how research results from other owl studies were integrated with results from this owl study to form the management recommendations. Several studies aren't cited. It was much clearer to see the integration with the fisher work.

Additional comments for the authors: This looks like an enormous amount of work. Congratulations on finishing!

Commentor: Please keep my name and affiliation confidential in any summary of these comments.

Comment 14: Dave Martin, retired District Ranger, Bass Lake Ranger District, comments on SNAMP report

I did not do as thorough a review of the various SNAMP documents as I (perhaps) should have. However, the more I reviewed the various documents, the more satisfied I was with the depth of science, the thoroughness of the evaluation methods and the conclusions reached. That being said, I have a couple of general comments, generated from my 10,000 foot overview. I hope this is helpful.

In the FFEH Draft Report (page ii), the conclusions about the 4% reduction in fire behavior with and without SPLATS being characterized as "modest", is not necessarily how I would characterize such a small reduction. Indeed, there is other science demonstrating greater basal area reductions resulting in greater effects to fire behavior, notwithstanding the issue of studying SPLATS. A more thorough acknowledgement/discussion regarding the nature of the limitations placed on management of SPLATS (in SP) and whether or not it would result in a higher % reduction would, at least point out a limitation of the study. From a fuel hazard reduction/prevention of catastrophic fire management perspective, 4% is unacceptable. I know that was not SNAMP's charge to make such judgments but clearly articulating the limitations may give greater perspective to the results.

Another area where additional science assists land managers in making management decision and something that, perhaps SNAMP could not really measure (and/or draw conclusions upon) is the idea of sustainability of the stand structure in the key Fisher denning and foraging habitat stands, which by design and management restrictions were effectively off limits from any substantive vegetation treatments. Most of these stands are overstocked from a tree-health perspective. Catching overstocked stands "in the act" of losing vigor and increasing mortality in a 7 year period, even with 4 below-average rain years is difficult, if not impossible but is something that I also feel could have been highlighted as a limitation/ caveat in the conclusions not only in the FFEH but also the Wildlife sections. Many of the stands presented to SNAMP, although looking like mixed conifer, were in fact pine stands. Railroad logging and fire suppression changed that so a different profile was presented. It is one of higher stand densities (typical of MC) and larger trees (owing to the timing of RR logging and the removal of the dominant, more representative pine). This structure lends itself to much larger trees, higher Basal Areas and conditions much more favorable to quality fisher habitat. Much of the reason white fir was not reduced as much, as would be preferred, is the fact that in all areas, especially key fisher areas, many that those trees are too big to be able to manage in lower, more ecologically sustainable number and sizes (for a pine stand). They were either > 30" DBH or they were the primary component of the dominant/codominant canopy structure needed for retention. Both of these restrictions are part of the management box we had to play in. The control area (Nelder) is GROSSLY overstocked and we feel may put the giant sequoias in jeopardy not only from fire but also competition-induced tree mortality. Literature review over the past many years (and decades) does not support the long-term sustainability of such "artificial" stands, especially in view of the reality of climate change. At least putting greater emphasis on a potential management challenge of sustaining what is likely "artificial" fisher habitat would help elevate the true nature of tradeoffs in managing for such habitat and the potential effect of FFEH.

Again, the vast store of knowledge and the enormous benefits to be gained and the real questions that still need to be answered (good science always brings up the harder questions!) are a real triumph of the SNAMP study. I am so lucky to have been part of it and my hat is off to the UC Study Team! SUPER JOB!

Comment 15: Forest Service Region 5 comments on SNAMP report

Chapter 1

Good job of setting up the background and describing the design for non-scientists.

p. 2 (2005) Should be "Forest Service Pacific Southwest Region" -- as well as "Forest Service Pacific Southwest Research Station". Or, "Forest Service, Pacific Southwest Region and Pacific Southwest Research Station". Both are separate entities of the FS. Similar corrections at the top of p. 3. Other than references related to MOU signatories, you can probably just say "Forest Service" to mean region and station collectively. Also in other chapters.
p. 5 last para – have not yet defined "Participation Team" and its relation to UCST.
p. 6 last para -- Just FYI… We usually just refer to the SNFPA without reference to the Record of Decision. In fact, fireshed is not mentioned in the 2004 ROD and receive only casual reference (not as a "spatial unit of management") in the FSEIS, so this statement is incorrect. Similar corrections needed in Chapter 2,….
p. 7 para 2 – you might also mention that the fisher BACI assessment will be completed at a later date in collaboration with the PSW station.
Figure 1-1. UC did not actually sign the MOU. Figure caption should define all the acronyms (e.g., MOUP has not been mentioned in the chapter). Adaptive management adjustments..: adjustments are not to policy (as stated) but to management. Suggest delete "to policy". Also, I think that parties other than USFS will do this – for example stakeholders, USFWS are already doing this.

Thanks for providing Box 1.

Chapter 2

p. 11 – Why does the LC site have two pairs of firesheds and SP only one pair? See figures and tables.
This is a really good description of the sites, especially the explanations for the expanded areas for owl and fisher studies. The appendixes for owl and fisher may not be entirely consistent with this description.
Figure 2-9 – Please include the dates (i.e., 2007-2013?) that encompass the treatments displayed in the figure caption.
I also like the descriptions of the communities and socioeconomic information associated with each site. The stories (anecdotes) about perceptions of interviewees are also interesting.

Chapter 3

These extended abstracts are a good idea, and they are mostly well-done.
p.4 Results para 1 – You should explain the positive and negative percent values – are they increases or decreases?
p. 26 – Explanation that "revised approach" was due to delays in implementing treatments contradicts with Chapter 2 and the fact that this change occurred around 2008-2009, well before the delays were known. The number of owls in the Last Chance site was just too small to follow the original plan.

p. 28 – "…amount of edge… higher demographic rates" – Does this mean that all demographic rates increase (i.e., survival, reproduction, colonization, extinction,…)? Could use an explanation.
p. 28 Discussion – Medium intensity harvests include more intense treatments than SPLATs. How many SPLATs resulted in decrease to <70% CC? You should be able to give us that information even though you had to use medium intensity in the demographic model.
p. 30 -- I think it would be a good idea to explain why the objectives for fisher are so different from the other modules. You could reference the original work plan that did not refer to the treatment x fire design of SNAMP.
This fisher extended abstract is MUCH better than the executive summary in the appendix. You might consider modifying the former to use for the latter.

Chapter 4

Running out of time here… My overall impression is this is a good summary of the integration process and results. It was good to discuss, however briefly, the limitations of the approach you took and your results.
p. 23 – You recommend a larger spatial scale for wildlife and mention the greater costs for such studies and more cost-effective approaches. You might also discuss the greater cost for these two at-risk species (one proposed for listing) of imposing potentially detrimental treatments on a larger number of individuals.

Chapter 5

I appreciate the conditional recommendation approach ("If your goal is…") you took. Science is only part of the decision space that managers use, and this approach helps us with that message. Also, being clear about what comes from the study and what is expert opinion is helpful, although I suspect some of the recommendations in the second part are going to be problematic. Some of these recommendations should be quite useful.
#2. Integrate what across firesheds? Can you suggest what we give up without optical or ground data?
#5 If SPLATs are placed as suggested, do we know that fire will behave as predicted to protect owls? I suspect not.
#22 I'm pretty sure this was not the first SPLAT treatment network implemented.
#24 Stand thermal conditions?
#29 I think I disagree with this one – or maybe don't fully understand it. The definition of AM may differ for different uses. Can we be adaptive in all aspects of the AM cycle? See papers by Lindenmeyer & Likens on adaptive monitoring.

Appendix A – FFEH

Nothing from me… Good job.

Appendix B – Spatial

Linking Lidar data to CWHR classes may not be the best strategy – CWHR is used because it's all we have. Can Lidar give us a better way to describe wildlife habitat? Also, I do not see where you actually accomplished the link to CWHR classes.

Please make figure 4 bigger so we can see details.
Figures 6 & 7– need a scale for colors.

3.7 & 4.7 – How do results of investigating point density to predict forest metrics at the plot scale translate to stand or landscape scale metrics?

5.1 – Are tools used (Matlab, etc.) available for other users? What is "multi-path effect"? Combination of "high resolution multi-spectral … imagery" with what?

5.2 – Are there results to support this paragraph? Seems results are not here -- may be more appropriate for wildlife appendices.

5.3 – I'm not sure that managers would need this level of detail about fuel treatments to justify the cost.

5.4 & 5.5 – Link to results is weak. Will adequacy of use for fire behavior models be discussed in the integration report?

Appendix C – Owl

There is no need to invoke the delay in implementation of treatments to explain your change in approach. The change was made before the delay and short post-treatment time was known. The real reason for the change is that there were too few owls to do the original design, and additional years of post-treatment data would not improve the situation. See Chapter 2 (p. 26).

In the executive summary, please explain the apparent paradox that SPLATs may provide long-term benefit if fire occurs and long-term negative effects if fire does not occur. Better yet, instead of saying that there were long-term negative effects if fire does not occur, say that the negative effects of SPLATs decline over time and persist for at least 30 years – as your figures 11 & 12 show. The effects of SPLATs and fire on owls are similar to those for fisher and the language used to describe those effects should also be similar.

I did not review the previously published paper that is reproduced here.

Methods. How much of this is in other chapters? Could you reference them for details?
p. 51 – "Our pre-treatment … after the Peavine…" -- I think you mean post-treatment rather than post-fire.
p. 52 – Why the 2001 Star fire?
p. 54 – Why include CC in the model despite being ns in the model? Is CC ns perhaps because LT is significant and there is considerable collinearity between CC and LT? In effect, this model conflicts with the demographic model.

p. 55 – Results are based on only 4 territories – discuss later? Discrepancy between 30.5 cm dbh in owl habitat and the 71.3 cm dbh in the model (p. 54)? Maybe this is why the models conflict?

Discussion (pp 59 ffl) – The discussion is written as for a scientific paper. That is fine for the appendix if a more general discussion occurs in the report chapters. If not, you need to add here.
p. 61 – You should make clear that the Roberts et al (2011) paper was mostly low to moderate severity. The next sentence about your modeled declines being overestimated doesn't clearly follow.
p. 61 – Please know that "species of conservation concern" has specific meaning for the Forest Service, and the species you mention are not SCCs for us. Another term would be helpful.
p. 62 – I don't I agree that your results have "broader applicability" to other species – those species use large trees and canopy cover differently.

Figures 11 & 12 – please show standard errors on fig 11 and indicate significant differences on both.

Appendix D – Fisher

p. iii – What about the effects of fire objective? Was it really necessary to expand the study area into YNP just because an animal dispersed there? Tell us what the "management indicators" and "focused science efforts (or topics") are – better yet, leave that out. Are there 4 or 5 of the latter (I count 4)? These details are just confusing in an executive summary. The executive summary is much too long, with too much detail on some things like methods and little overall focus. The executive summary should give us the take-home messages.
p. iv – The fifth mortality is only "suspected" – don't you know that it died? What do you mean by "five deterministic population growth rates"? I count somewhere between 3 and 6. Again, too much detail about methods and results.
p. v – You need citations for statements in the first paragraph, except that you should not review the literature in an executive summary. Most of this paragraph does not belong here at all and is out of order – it should come before discussion on p. iv.
p. v – vii – This is better, but still too detailed.
p. vii – starting with "Management indicator 1…" This just does not make sense. How are these management indicators? None of this belongs here.
p. viii – starting with "Occupancy modelling…" is better again.

At this point, I am ending my review of the executive summary, which should be re-written. The other team reports provide examples of good summaries. An executive summary should be just that – a high-level summary <u>of the study</u> that requires limited technical knowledge of the science. It should also not require the reader to have studied the entire report in detail. It should not be a literature review. There is so much rich, new information in the report that is not mentioned in this executive summary or is lost in all the extraneous material. Please give us the major findings and take-home messages.

Starting on p. 7:

General Comments: The authors should be aware that it is now 2015 and references to things that are "expected", etc. in 2014 or earlier must be updated. Also, update references. There were changes to Spencer et al. (2014) between draft and final (Spencer et al. 2015) that should be updated here.

Need to distinguish the two Zielinski et al (2013) papers.

Why such a long introduction? We do not need another version of the DRAFT Fisher Conservation Assessment (Spencer et al. 2014) because it distracts from this report and perpetuates some errors in the draft that have been corrected in the final (the final version was published in January 2015 and is readily accessible). Focus on the introduction needed for this report. You also have results, discussion, and conclusions of the SNAMP project in the introduction – save them for later. Or maybe replace the executive summary.

In general, references to Spencer et al (2014 or 2015) should be kept to the minimum needed to provide context for this work, so that readers are clear about the work that was conducted for SNAMP.

p. 10 – "fishers in this part of California may have expanded in the late 20th century (Tucker et al. 2014)" and "expanded during the 1990s" are misrepresentations of the research – I believe the genetic study identified that it was some time during the 20th century (about 100 years). This error must be corrected multiple times in the appendix.
p. 10 – "The Zielinski et al. (2013) analyses suggest…" The paper did not suggest what follows. You suggest these things based on an extrapolation of the analyses. In fact, the time scale of the monitoring is much shorter than 60 years and the suggestion is inappropriate.
p. 12 – It's Sierra Nevada Forest Plan Amendment (SNFPA), not "amended Sierra Nevada Forest Plan" – there is no Sierra Nevada Forest Plan.
p. 13 – The reductions (% BA and CC) for treatments (SPLATs) are not allowed in many habitats used by fishers and spotted owls in the SNFPA.
p. 13 – Please explain why your objectives are more broad and general than the adaptive management objective of SNAMP: effects of fuel treatments and fire. Why don't you have the long-term fire objective that the other teams have?
p. 15 -- Was it really necessary to expand the study area into YNP just because an animal dispersed there? Sounds like you didn't really extend the study area, just the area for aerial tracking.
p. 17-18 –This material is really more appropriate to the paper introduction section than much of what you have there now. Also discussion material here. The METHODS section should be renamed to reflect the actual content.
p. 26 – Reference to an Appendix that is not included. "Appendices" are in the TOC, but not in the document. We can't understand this sampling scheme without the appendix. There are other references to Appendices that are not in the document.
p. 31 – "fishers … may not be in numeric or spatial recovery" – recovery from what? In this paragraph, you should take another look at Spencer et al (2015) to see how what you extracted from the 2014 draft may have changed.
p. 43 – Where is table 31? Should be nearby.
p. 52 – At some point, you should explain that the spacing of grid points is smaller than a fisher home range and how your models and inferences may be affected by a single animal showing up

on several grid cells – or how you dealt with that. Your colonization and extinction estimates are not really what we expect them to be.
Fig 10 – Legend should note that each bar represents a 2-week period. Also, bars should be grouped by population years in Table 9 to be consistent and less confusing to readers. Might also be good to mention why the # of fishers monitoring in Nov & Dec 2013 did not rebound as in previous years.
Table 13 – What is N?
Figure 16 is difficult to understand. How does a den structure have an "aspect orientation"?
Table 24 – the label for Leslie Matrix λ should be up two lines – to align with the estimates (0.87, 0.88, …0.90) instead of the range. And some spacing between Fertility and λ.
p. 97ffl – Where are *hazfuels.5*, *log.5*, etc. defined?

By the way, the last sections are mostly quite good.

Appendix F – Public Participation

Good job on the executive summary of this very long report.
Parts of this Appendix are inconsistent with Chapter 1 of the report.
p. 8 – It isn't necessary to distinguish between the SNFPA and the ROD. We generally just refer to the SNFPA. I'm pretty sure that there was not a legal battle between the FWS and FS – that would be one federal agency suing another. The last three sentences of this paragraph make no sense to me and are at odds with the collaborative nature of SNAMP. What is a non-negotiable boundary (or boundaries in general)? Hardly autocratic. Limitations on democratic forms of participation?
p. 9 – Paragraph starting "Clear communication…" is also hard to understand. It seems to be a mish-mash of jargon and opinion with little explanation of the statements. It is also out of place with the rest of the section.
p. 11 – It's a bit of a stretch to say that "the Sierra urbanizes". It's still mostly locked up in federal land ownership. I think most local residents would not say they are "far removed from … forest management".
Section II. – This section generally needs more citations to support the statements made and opinions expressed. I'm going to share some of my opinions. I'm really not sure why all this detail is necessary to this report.
p. 15 – I think it's inaccurate to claim that the early FS policy of frequently moving Rangers "was a problem for SNAMP". That was a historic policy. The FS personnel changes observed with SNAMP were either promotions to higher levels of responsibility and pay or retirements. Similar changes occurred with other agencies and even some stakeholder groups. Outside academia these changes are common in all organizations.
Figure F-3 – This figure requires much more explanation to be able to understand it. Where does it come from?
p. 17 – "By the end of the decade…" – which decade? I wouldn't put much emphasis on "outdoor recreation" being listed first in the MUSY act – it's an alphabetical list. It's also important to know that professionals in the FS were also driving (and continue to drive) the shifts to multiple use of the forests. Some employees were quite pleased with the legislated changes.
p. 18 – "by the late 1960s" there was actually a national enthusiasm for "technology and science" driven largely by the successes of the space program (and not just sending men to the moon). What was happening, with respect to the FS, was a distaste for industrial forestry and its visual

and environmental consequences – and a general distrust of the federal government because of Vietnam and other policies.

p. 20 – “Concerns of …” – again, USFWS was not part of “pending litigation”. The Forest Service is a federal agency. The FS and other agencies didn’t “support the SNAMP effort in 2005” – they worked with UC to develop an “adaptive management and monitoring process” between 2005 and 2007 (via the MOU). The proposal for SNAMP came later, in 2007, as a result of that collaboration.

p. 21 – The Forest Service is not a “representative of Congress”; it is an agency of the USDA and part of the executive branch. Still, the FS can’t delegate decisions to others. Here and elsewhere, terms like collaboration and consultation are used without definition, which would help us understand your points and decide if we agree. Collaboration isn’t in figure F-4. I am rather confused about this paragraph. It starts by saying that the FS is constrained from co-management and ends with a discussion of the Science Team. I think you are also saying that the Science Team is also constrained to consultation (or gather input and decide) in F-4, though not because of legal doctrine (as stated in the next paragraph). That could be said better. At the end of the page, past tense is used in references to management recommendations – wrong tense because we are just now seeing the recommendations. Where results were available, they have (past tense) been used as listed on the next page.

p. 22 – What is FLPMA? This sentence is out of date; the 2012 rule for NFMA now requires much more public participation (see 36CFR219.4).

p. 23 – Congress hardly has “supreme authority”. See recent Supreme Court decisions.

p. 27 – Another term in widespread use is multi-party monitoring. Citizen science (p. 28) is another thing altogether.

Figure F-9 c) -- What does the year represent? The last time discussed? Most frequent? I don’t understand c) at all. Odd that you highlight funding, process, and MOUP in b) – fire & water are what stand out for me. Nor do I understand the second lessons learned about the figure.

p. 115-116 – General comment, not specific to this page: At this point, I am struck by how much of the discussion is based on anecdotal evidence, like the example here of a single (or very few) respondent. I’m not very confident that this evidence is the basis for any sort of valid conclusion.

Comment 16: Chad Hanson, John Muir Project and Justin Augustine, Center for Biological Diversity comments on Appendix D-Pacific Fisher

CENTER *for* BIOLOGICAL DIVERSITY

THE JOHN MUIR PROJECT *of* EARTH ISLAND INSTITUTE

July 24, 2015

Dear SNAMP:

Thank you for the opportunity to provide feedback on the SNAMP Project Report. Below are comments regarding the fisher (Appendix D).

The SNAMP (2015) fisher appendix, on pages 51, 58-62, and 97-99, describes camera-survey results for fishers, concluding that mechanical thinning to reduce "hazardous fuels" has a negative effect on fisher occupancy, and suggesting some impact of wildland fires on fisher occupancy as well. The report (pages 114-117, and 119) then minimizes adverse effects of mechanical thinning and instead suggests that wildland fire is a substantially greater "threat" or "risk" to fishers than thinning, such that landscape-level thinning, and even potential expansion of thinning, might be justified from a net benefits/risks standpoint. However, there are four significant problems with this conclusion.

First, the results described on pages 98-99 do not support such a conclusion. Those results state that the single top model regarding local extinction identified "only" thinning ("*hazfuels.5*"), and that fisher persistence decreased with increasing thinning. The results (pages 98-99) indicate some effect of fire but state that the "relative importance" of this variable was "low". Therefore, there is not a sound basis for the conclusion that thinning is justified to mitigate fire effects; in fact, the results contradict this conclusion.

Second, we followed the methods described in the SNAMP fisher appendix with regard to fires in the camera-survey study area, and digitized the grids shown in Figure 12 of the SNAMP report. We used GIS to overlay fires on the camera-survey grids, and used Google Earth satellite imagery to evaluate whether post-fire logging had occurred in any of the fires. We found that post-fire logging—often extensive—had been conducted in numerous camera-survey grids within fire areas, e.g., in portions of the 2001 North Fork fire and in the 2004 Nehouse fire (see figures below). Therefore, there is a significant methodological issue in the study, in that it states it is only testing the effects of fire on fisher occupancy, but is actually instead testing effects of post-fire logging in numerous grids. This is important, given that all but one of the grids that are approximately 50-100% within fire perimeters, and that we identified as having been post-fire logged, had no documented fisher occupancy, according to Figure 12 of the SNAMP (2015) fisher appendix.

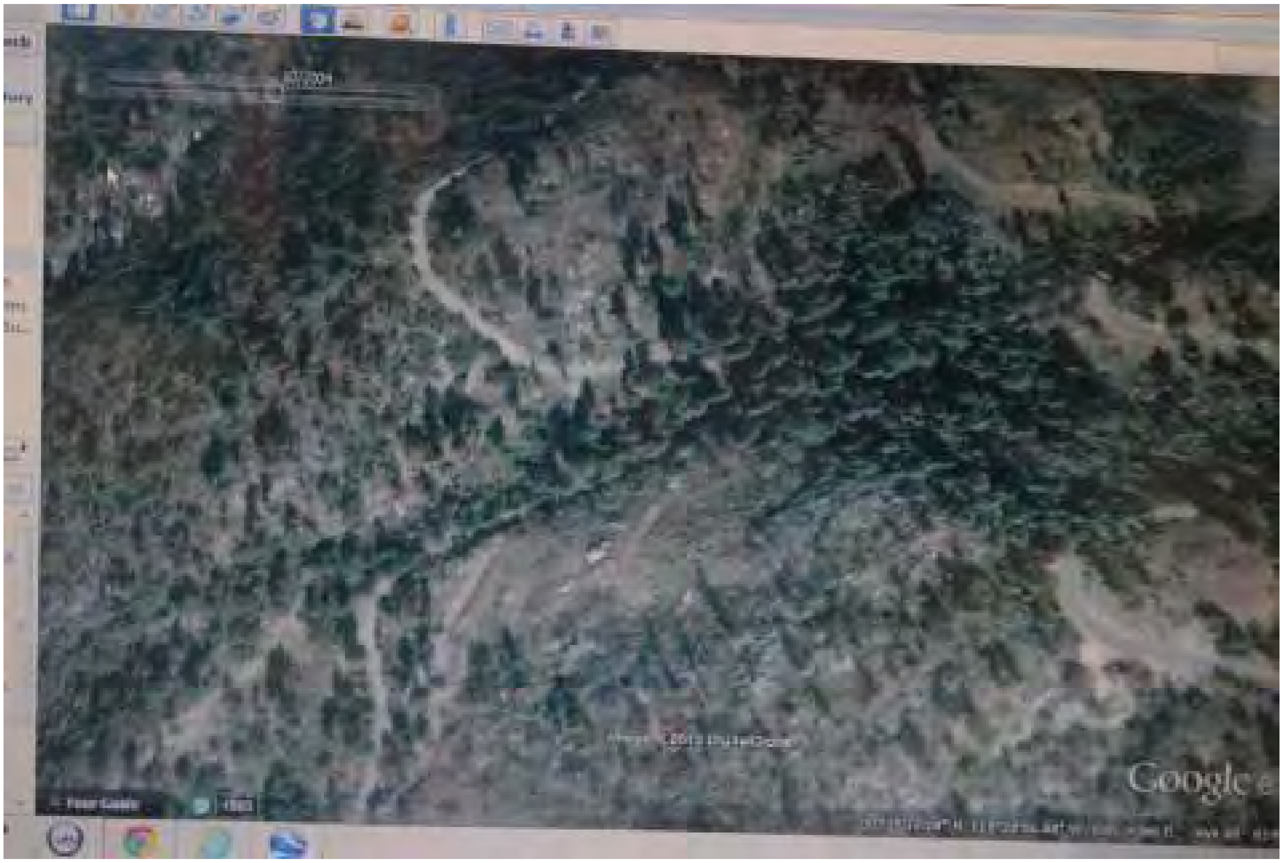

Figure 1. Post-fire logging (above and below the center of image) in the North Fork fire of 2001. The center of the grid, where the fisher survey camera was located, is the post-fire clearcut just south of the center of the image. There were no fisher detections in this grid.

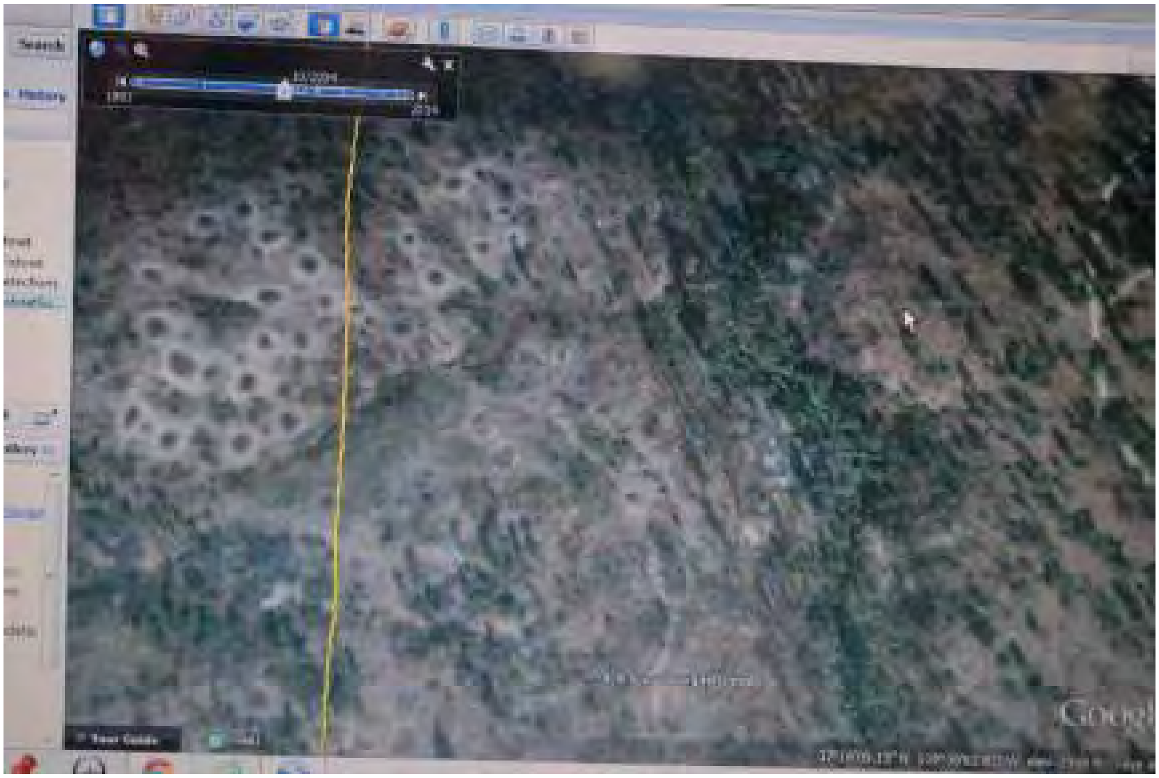

Figure 2. Post-fire logging in another grid within the North Fork fire of 2001 (post-fire clearcutting, and burning of logging slash piles, can be seen in the center and left of center portion of the image). There were no fisher detections in this grid.

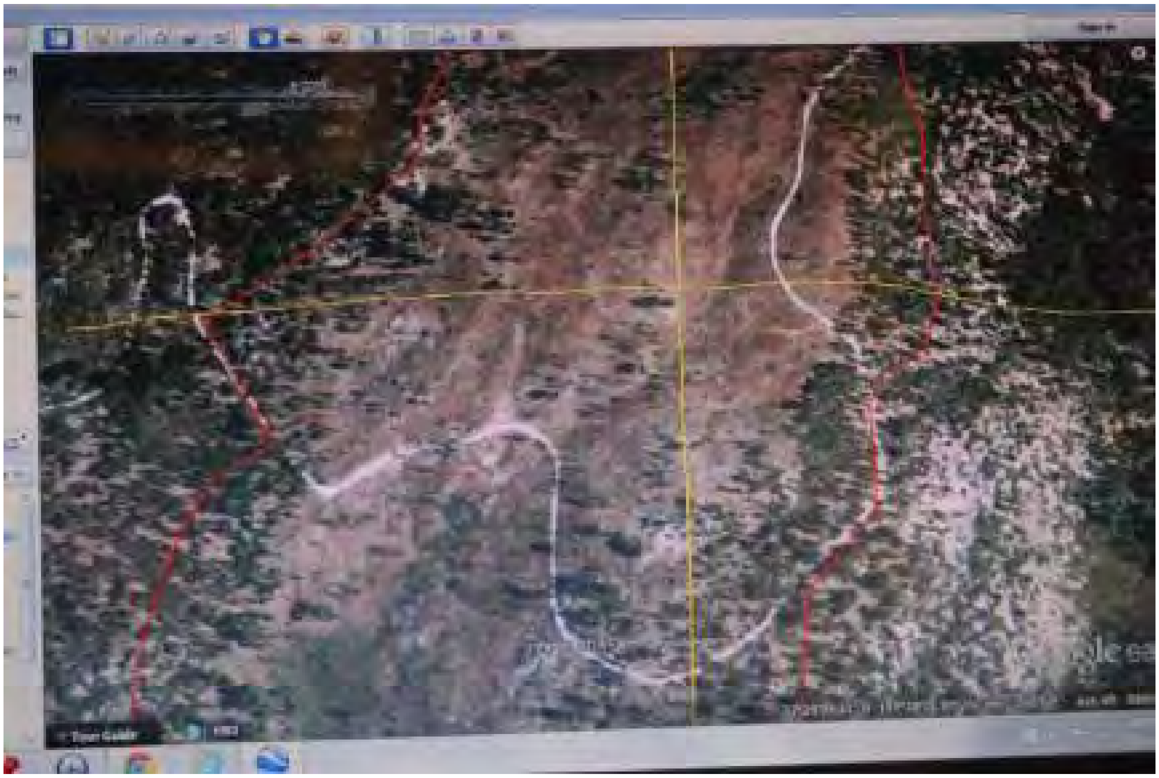

Figure 3. Post-fire clear-cutting in the Nehouse fire of 2004 (post-fire logging skid trails are shown to the northeast and southwest of the center of the image). There were no fisher detections in this grid.

Third, among camera-survey grids mostly/wholly within fire perimeters, a disproportionately large cluster are in a fire (the 1990 Steamboat fire in Yosemite National Park) at the northern extreme of the fisher's range in the southern Sierra Nevada (generally, north of 37 degrees and 39 minutes latitude). Figure 12 of the SNAMP fisher appendix shows that fishers are almost completely absent in this area, and only one camera-survey grid had a fisher detection—and it is partially in the fire area. None of the unburned grids in this northernmost portion of the study area had any detections. The effect of this was to create a bias in the results toward reporting lower fisher use of fire areas.

Fourth, the SNAMP fisher appendix does not incorporate Hanson (2013) or Hanson (2015), which are peer-reviewed studies (see references below) conducted on fishers and fire based upon field data (as opposed to modeling assumptions). These two research studies regarding fishers and burned forests have found that post-fire landscapes, when left unlogged, can provide important, critical habitat to fishers.

In Hanson (2013), using specially trained scat-detecting dogs to assess the frequency of Pacific fisher scat detections/km of survey transect in different habitat types, I analyzed Pacific fisher habitat selection in post-fire habitat and adjacent unburned forest on Sequoia National Forest. Specifically, I analyzed fisher habitat selection by fire severity and pre-fire structure/composition – both dominant size class and canopy cover – and forest type (see Abstract, and Results at p. 26, of Hanson 2013). In my Methods (see p. 25 of Hanson 2013), I described the fire severity categories analyzed, and the level and range of tree basal area mortality associated with each, where higher-severity was defined as 50-100% basal area mortality. I found that, in unburned forest, fishers selected areas of dense, mature/old conifer forest significantly more than open or young forests (Hanson 2013, Table 2b). I also found that, within fire areas (not subjected to post-fire logging), fishers similarly selected areas where the pre-fire condition was dense, mature/old conifer forest, as opposed to areas where the pre-fire forest was open or young (Hanson 2013, Table 2a). This relationship was not statistically significant at the 0.05 significance level, but was significant at the 0.10 significance level (Hanson 2013, Table 2a), which is often used in studies pertaining to wildlife habitat selection. This indicates that fishers are selecting dense, mature/old conifer forest in its unburned, and burned, states. Further, I found that the proportion of higher-severity fire was significantly higher within 0.5 kilometers of fisher detection locations than at random locations, indicating that fishers are selecting areas with relatively higher levels of higher-intensity fire for foraging (Hanson 2013, Figure 2). When fishers are near fire perimeters, they strongly select the burned side of the fire edge (Hanson 2013, Table 3). Both males and female fishers are using large mixed-intensity fire areas, such as the McNally fire, including areas >10 kilometers into the fire area.

Moreover, I gathered additional data in the 61,000-hectare McNally fire of 2002, using the same methods described in Hanson (2013), but focused mainly in large higher-severity fire patches, and found very strong use of large, intense fire patches in dense, mature/old conifer forest, especially by female fishers. My findings are in-press in a new study, Hanson (2015). In Hanson (2015), the current hypothesis among land managers that fishers will avoid higher-severity fire areas was rejected, and fishers used unlogged higher-severity fire areas at levels comparable to use of adjacent unburned dense, mature/old forest. Female fishers demonstrated a significant selection in favor of the large, intense McNally fire over adjacent unburned mature/old forest, and the highest frequency of female fisher scat detection was over 250 meters into the interior of the largest higher-intensity fire patch (over 5,000 hectares).

For the above reasons, the SNAMP fisher appendix conclusions regarding fishers, fire, and logging (mechanical thinning) should be changed.

Please let us know if you have any questions about the information we have provided. Thank you.

Sincerely,

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References

Hanson, C.T. 2013. Pacific fisher habitat use of a heterogeneous post-fire and unburned landscape in the southern Sierra Nevada, California, USA. The Open Forest Science Journal 6: 24-30.

Hanson, C.T. 2015. Use of higher-severity fire areas by female Pacific fishers on the Kern Plateau, Sierra Nevada, California, USA. The Wildlife Society Bulletin (in press).

Comment 17: Chad Hanson, John Muir Project and Justin Augustine, Center for Biological Diversity comments on Appendix C-California Spotted Owl

CENTER *for* BIOLOGICAL DIVERSITY

THE JOHN MUIR PROJECT *of* EARTH ISLAND INSTITUTE

July 24, 2015

Dear SNAMP:

Thank you for the opportunity to provide feedback on the SNAMP Final Report. Below are comments regarding the California spotted owl (Appendix C).

1. "We conclude that SPLATs may provide long-term benefits to spotted owls if fire occurs under extreme weather conditions, but can have long-term negative effects on owls if fire does not occur."

   The above statement should reflect that mechanical treatments can be ineffective in extreme weather, and therefore the perceived benefit may not even be realized. For example, Lydersen et al. 2014 states: "Our results suggest that wildfire burning under extreme weather conditions, as is often the case with fires that escape initial attack, can produce large areas of high-severity fire even in fuels-reduced forests with restored fire regimes."

   Explain also that even if fire does occur, there may be no long term benefits from mechanical treatments. Instead, fire (including mixed-severity fire with a high-severity component) can occur in ways that provide benefits to owls (e.g. foraging habitat), and therefore, in addition to causing harm to unburned owl habitat, mechanical treatments could also cause harm in terms of how they impact the post-fire condition.

2. "Therefore, we recommend adopting a landscape approach that restricts timber harvest within territory core areas of use (~125 ha in size) that contain critical owl nesting and roosting habitat (Berigan et al. 2012) and locates fuels treatments in the surrounding areas to reduce the potential for hazardous fire to spread into PACs."

   Discuss that mechanical treatments outside the 125 ha acre could have significant negative impacts to owls as well, while mixed-severity fire (in the absence of mechanical treatments) could have benefits to owls. The following bullet points, for example, discuss mechanical thinning in relation to spotted owls:

   - California spotted owl populations are declining (e.g., Conner et al. 2013), and the only area not experiencing declines is Sequoia Kings-Canyon National Park, which has an active mixed-severity fire regime and no mechanical thinning fuels treatment or post-fire logging programs.

- Gallagher (2010) examined foraging-site selection of 10 radio-marked California spotted owls in the Meadow Valley Project area on the Plumas National Forest. The project was governed by the Herger-Feinstein Quincy Library Group Forest Recovery Act of 1998. Treatments included 1) DFPZs, landscape-scale forest thins designed to function as fire breaks by a reduction in canopy cover, tree density, and ladder fuels; 2) understory thin, prescribed as removal of shrubs and trees < 10 inches diameter; 3) understory thin followed by underburn; and 4) group selection, a removal of all trees < 30 inches diameter in < 0.8-ha patches. Gallagher (2010) found that across all birds and both study years, only 8 percent of owl foraging locations were located within fuels treatments, and nearly half of those locations were accounted for by a single owl. Owl foraging sites were primarily located in mixed-conifer forest dominated by trees 12–24 inches diameter with an additional large proportion of trees > 30 inches diameter and with a multi-layered understory with numerous small trees. The mean proportion of owl locations in DFPZs was lower than expected by chance, thus the owls avoided foraging in this treatment type.

  Gallagher (2010) found that home-range size of California spotted owls in the Meadow Valley Project area of the Plumas National Forest increased as the total area of fuels treatments within the home range increased, particularly of DFPZ (mechanical thinning) and group selection treatments under the 2004 Sierra Nevada Forest Plan Amendment, indicating lower territory fitness in such areas.

- Keane et al. (2012) reported that the Meadow Valley fuels treatment project on the Plumas National Forest, under the 2004 Sierra Nevada Forest Plan Amendment, began in 2006 (Keane et al. 2012, Fig. 10) and was completed in 2007–2008 (Keane et al. 2012, p. 88). After the logging, from 2007 to 2011, the total number of territorial sites of California spotted owls in the Meadow Valley project area declined from 9 to only 4—in just four years (Keane et al. 2012, Table 7).

- Tempel et al. (2014) found that mechanical thinning is significantly harming California spotted owls. The authors noted also that the adverse effects of mechanical thinning on California spotted owls is likely even larger than their results indicated: "Understory removal is generally an important component of fuel-reduction strategies, but we caution that medium-intensity harvesting with understory treatments occurred on only 5.2% of the total area within owl territories, which could have limited our power to detect effects . . . " In other words, the adverse effects of mechanical thinning were apparent even with a relatively small portion of the study area affected by such logging. The authors further noted the following: "In addition, only 42.8% of medium-intensity harvests occurred in high-canopy forests; thus, over half of these harvests occurred in habitats that might be less important to spotted owls (Fig. 5c). When medium-intensity harvests were implemented within high-canopy forests, they reduced the canopy sufficiently for mapped polygons to be reclassified into a lower-canopy vegetation class in 90.1% of these treated areas (Fig. 5d). As described above, such changes were associated with reductions in survival and territory colonization rates, as well as increases in territory extinction rates. As a result, we believe the most appropriate inference about the influence of medium-intensity harvesting practices is that they appear to reduce reproductive potential, and when implemented in high-canopy forests, likely reduce survival and territory occupancy as well." The results of Tempel et al. (2014) indicated that some high-intensity logging on a very small percentage of the landscape, where dense brush had been allowed to grow after logging (possibly facilitating habitat growth for some small mammal species), was associated with lower levels of territory extinction, but the authors cautioned about such logging. Owl survival was positively associated with the juxtaposition of mature forest and brushy shrub/sapling habitat areas (not necessarily associated with past logging). Finally, Tempel et al. (2014) found no effect of wildland fire on spotted owl reproduction, survival, occupancy, or territory extinction. They did report an adverse effect of fire on territory colonization, but the fire covariate was "unestimable" due to very small sample size, meaning that the model could not be fitted and therefore the beta estimate for fire was not valid. The authors noted that territory colonization was low in fire-affected areas for two reasons: (1) in the largest fire that accounted for most of the fire-affected territories, 5 of the 9 territories remained occupied in every single year after the fire, thus "colonization could not occur by definition"; and (2) the authors noted that the main reason that the "effect of wildfire on territory colonization was strongly negative" was "due to a high-severity fire that occurred on our study area in 2001 and completely burned two territories, which were subsequently never colonized by owls", and two other territories had very low post-fire occupancy and colonization. The modeling result of the study, however, did not account for the fact that the loss of occupancy (and no colonization) in the two "completely burned" territories, and the two other territories with very low post-fire occupancy/colonization, was associated with intensive logging after the fire (see, e.g., *Sierra Club v. Eubanks*, 335 F.Supp.2d 1070, 1075 (E.D. Cal. 2004) [noting that all of the heavily burned forest in the Star fire of 2001 had been subjected to post-fire logging on public and private lands outside of the Duncan Canyon Inventoried Roadless Area, which is the portion of the Star fire that is outside of the Tempel et al. 2014b study area]). Google Earth imagery also shows heavy post-fire logging within 1.5 kilometers (and much closer) of the two territories that completely lost occupancy (PLA055 and PLA075) and the two with near-complete loss of occupancy and colonization post-fire (PLA016 and PLA099) (see Appendix A attached at end of these comments). Moreover, the study does not address other research—Lee et al. (2012)—which found that mixed-severity fire (dominated by moderate- and high-severity fire effects) did not reduce California spotted owl occupancy in the Sierra Nevada, while observational data suggested that post-fire logging did reduce occupancy. Unlike in Tempel et al. (2014), the fire covariate in Lee et al. (2012) was estimable because the sample size was much larger.

- A recent analysis by Stephens et al. (2014) found a 43 percent loss of California spotted owl occupancy within a few years following mechanical thinning and group selection logging in a study area in the northern Sierra Nevada. Specifically, the authors found the following: "In the Meadow Valley study area, the number of territorial owl sites declined after treatment. Prior to and throughout the implementation of the treatment, the number of owl sites ranged from seven to nine. Between the final year of the DFPZ and group-selection installations (2008) and two years after treatment (2009–2010), the number of owl sites declined by one (six territorial sites), and by 3–4 years after treatment (2011–2012), the number of sites had declined to four—a decline of 43% from the pretreatment numbers". The authors noted that, while spotted owl populations have been declining in the northern Sierra Nevada as a whole, the steep rate of decline in this fuels treatment study area were of "a greater magnitude" than elsewhere on the landscape.

3. "For millennia, low- to moderate-severity wildfires occurred at frequent (often less than 20-year) intervals in many western forests, naturally removed fuels such as woody debris, shrubs, and small trees, and shaped the ecology of these forests (Agee 1993, Noss et al. 2006). However, decades of wildfire suppression have disrupted historic fire regimes, increased the amount of surface and ladder fuels, and have led to more frequent high-severity wildfires that now threaten ecological and human communities (Westerling et al. 2006)."

   The above statement gives the impression that modern fires are not ecologically valuable. That implied message does not reflect a) recent research (e.g., Odion et al. 2014; Baker 2014) that finds that high-severity fire (including large patches of high-severity fire hundreds or thousands of acres in size), as a component of mixed–severity fire, is important to ecological communities in the Sierras, or b) extensive research finding that severely burned post-fire areas (including large patches of it) are critical for species such as black-backed woodpeckers (Siegel et al 2011, 2012, 2013, 2014, 2015; Tingley et al.

2014), numerous avian species (Hanson 2014; Burnett et al. 2010, 2011, 2012; Roberts et al. 2015; Siegel et al. 2011), bats (Buchalski et al. 2013), as well as owls (Bond et al. 2009) and fishers (Hanson 2015). Moreover, recent fires that are often referred to by the Forest Service as harmful – the McNally, the Moonlight, the Rim, and the King – all contain wildlife habitat created by high-severity fire that has been found to be inhabited by many species, including very rare species (see wildlife articles referenced above which occurred in part in the McNally and Moonlight fire areas; see also recent woodpecker data from the Rim and King fires). It is important therefore to reflect in this Appendix that high-severity fire is not categorically harmful to ecological communities and instead to explain the importance of high-severity fire to the ecological integrity of the Sierras; otherwise, it will continued to be perceived as a complete loss when in fact high-severity fire is essential and important.

4. "there is an urgent need to understand the effects of fuel-reduction treatments on old-forest-associated species so that fire risk can be managed"

   The urgent need exists because the Forest Service seeks to expand the use of mechanical treatments, and wants to do so far away from human communities. But it is important to differentiate fire impacts to humans from fire impacts to the forest. The former does require serious mechanical treatments very close to structures to protect those structures, while the latter does not require mechanical treatments and instead requires efforts that ensure that low, moderate and high-severity fire will be a substantial component of management in order to ensure ecological integrity of the forest. Outside of human communities, fire risk is not the issue; rather, in the backcountry, lack of fire (due to fire suppression) is the issue. Therefore, it should be explained that fire (of all severities) is needed on the landscape outside of human communities.

5. "While fuels management may provide long-term benefits to such species by reducing future habitat loss from high-severity fires"

   Reemphasize here, as is done elsewhere in this Appendix, that fuels management (in the form of mechanical treatments) may not provide any long-term benefit at all, and instead might only provide short and long term harm due to impacts to habitat. Moreover, it is worth explaining to readers that different management techniques will have different impacts—prescribed fire and managed wildfire, for example, will have much different outcomes and impacts than will mechanical treatments, and readers should be educated on the differences. Furthermore, not only are mechanical treatments harmful to owls, it may also be harmful, not beneficial, to reduce high-severity fire in light of the findings in the literature regarding owls and high-severity fire (e.g., Lee and Bond 2015, Lee et al. 2012, Bond et al. 2009, 2013).

6. "As with other western forests, the area burned by high-severity fires in the Sierra Nevada has increased over the past several decades (Miller et al. 2009)."

   First, recent research contradicts Miller et al. 2009—e.g., Hanson and Odion 2014; Hanson and Odion 2015. Moreover, even if high-severity fire were increasing, that is not necessarily a problem given the deficit of high-severity fire in the Sierras (e.g., Odion et al. 2014) and the importance of high-severity fire to biota. It is therefore important to reflect in this Appendix that an increase is likely a positive for Sierra ecosystems and is not at all categorically a negative.

7. "Long-term benefits will depend on both the risk that fire poses to spotted owls and the extent to which fuel treatments reduce high-severity fires."

   Again, this reflects an assumption that high-severity fire will occur in ways that solely are harmful when that is not accurate—high-severity, when it occurs, can occur in ways that are beneficial to owls.

8. Appendix C describes a prospective modeling effort regarding spotted owls. The report claims that thinning might have a net positive effect on owl occupancy if and where fire occurs. However, the model is based upon assumptions that are not consistent with current science. For example, on page 2, the Appendix states that the model was based only on spotted owl nesting habitat, not on the combination of nesting/roosting and foraging habitat -- fire can provide foraging habitat (Bond et al. 2009) and demographic benefits to owl territories. By basing the model only on nesting habitat, and excluding foraging habitat, the model necessarily treated any moderate/high-intensity fire as a negative/adverse effect that removes habitat and reduces occupancy. However, we also know from a large dataset of owls in territories in fire areas of the Sierras, in the absence of post-fire logging, mixed-severity fire does not reduce spotted owl occupancy--in fact, occupancy in mixed-severity fire areas was numerically higher than in unburned mature forest, but the difference was not statistically significant (Lee et al. 2012). For these reasons, the model does not represent the current state of scientific knowledge, and thus the statements/conclusions from it – that high-severity fire adversely affects owl occupancy, and that thinning benefits spotted owl occupancy – should be changed.

Please let us know if you have any questions about the information we have provided. Thank you.

Sincerely,

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References

Baker, W.L. 2014. Historical forest structure and fire in Sierran mixed-conifer forests reconstructed from General Land Office survey data. Ecosphere 5: Article 79

Bond, ML, DE Lee, RB Siegel, and MW Tingley. 2013. Diet and home-range size of California spotted owls in a burned forest. Western Birds 44:114-126.

Bond, M. L., D. E. Lee, R. B. Siegel, & J. P. Ward, Jr. 2009. Habitat use and selection by California Spotted Owls in a postfire landscape. Journal of Wildlife Management 73: 1116-1124

Buchalski, M.R., J.B. Fontaine, P.A. Heady III, J.P. Hayes, and W.F. Frick. 2013. Bat response to differing fire severity in mixed-conifer forest, California, USA. PLOS ONE 8: e57884.

Burnett, R.D., P. Taillie, and N. Seavy. 2010. Plumas Lassen Study 2009 Annual Report. U.S. Forest Service, Pacific Southwest Region, Vallejo, CA.

Burnett, R.D., P. Taillie, and N. Seavy. 2011. Plumas Lassen Study 2010 Annual Report. U.S. Forest Service, Pacific Southwest Region, Vallejo, CA.

Burnett, R.D., M. Preston, and N. Seavy. 2012. Plumas Lassen Study 2011 Annual Report. U.S. Forest Service, Pacific Southwest Region, Vallejo, CA.

Conner MM, JJ Keane, CV Gallagher, G Jehle, TE Munton, PA Shaklee, RA Gerrard. 2013. Realized population change for long-term monitoring: California spotted owls case study. Journal of Wildlife Management.

Hanson, C.T. 2014. Conservation concerns for Sierra Nevada birds associated with high-severity fire. Western Birds 45:204–212.

Hanson, C.T., and D.C. Odion. 2014. Is fire severity increasing in the Sierra Nevada, California, USA? International Journal of Wildland Fire 23: 1–8

Hanson, C.T., and D.C. Odion. Sierra Nevada fire severity conclusions are robust to further analysis: a reply to Safford et al. International Journal of Wildland Fire 24: 294-295

Lee, D.E., M.L. Bond, and R.B. Siegel. 2012. Dynamics of breeding-season site occupancy of the California spotted owl in burned forests. The Condor 114: 792-802.

Malison, R.L., and C.V. Baxter. 2010. The fire pulse: wildfire stimulates flux of aquatic prey to terrestrial habitats driving increases in riparian consumers. Canadian Journal of Fisheries and Aquatic Sciences 67: 570-579.

Odion DC, Hanson CT, Arsenault A, Baker WL, DellaSala DA, et al. 2014. Examining Historical and Current Mixed-Severity Fire Regimes in Ponderosa Pine and Mixed-Conifer Forests of Western North America. PLoS ONE 9(2): e87852.

Roberts, L.J., A.M. Fogg, and R.D. Burnett. 2015. Sierra Nevada National Forests Avian Management Indicator Species Project: 2014 Annual Report. Point Blue Conservation Science, Petaluma, CA.

Siegel, R.B., M.W. Tingley, and R.L. Wilkerson. 2011. Black-backed Woodpecker MIS surveys on Sierra Nevada national forests: 2010 Annual Report. A report in fulfillment of U.S. Forest Service Agreement No. 08-CS-11052005-201, Modification #2; U.S. Forest Service Pacific Southwest Region, Vallejo, CA.

Siegel, R.B., M.W. Tingley, R.L. Wilkerson, M.L. Bond, and C.A. Howell. 2013. Assessing home range size and habitat needs of Black-backed Woodpeckers in California: Report for the 2011 and 2012 field seasons. Institute for Bird Populations.

Siegel, R. B., M. W. Tingley, and R. L. Wilkerson. 2014a (July). Black-backed Woodpecker MIS Surveys on Sierra Nevada National Forests: 2013 Annual Report. Report to USFS Pacific Southwest Region. The Institute for Bird Populations, Point Reyes Station, CA.

Siegel, R. B., M. W. Tingley, and R. L. Wilkerson. 2014b (July). Assessing home-range size and habitat needs of Black-backed Woodpeckers in California: Report for the 2013 field season. Report to USFS Pacific Southwest Region. The Institute for Bird Populations, Point Reyes Station, CA.

Stephens, S.L., S.W. Bigelow, R.D. Burnett, B.M. Collins, C.V. Gallagher, J. Keane, D.A. Kelt, M.P. North, L.J. Roberts, P.A. Stine, and D.H. Van Vuren. 2014. California Spotted Owl, songbird, and small mammal responses to landscape fuel treatments. BioScience (in press)

Tempel, D.J., R.J. Guiterrez, S. Whitmore, M. Reetz, R. Stoelting, W. Berigan, M.E. Seamans, and M.Z. Peery. 2014. Effects of fire management on California spotted owls: implications for reducing wildfire risk in fire-prone forests. Ecological Applications http://dx.doi.org/10.1890/13-2192.1

Tingley, M. W., R. L. Wilkerson, M. L. Bond, C. A. Howell, and R. B. Siegel. 2014. Variation in home range size of Black-backed Woodpeckers (*Picoides arcticus*). *The Condor: Ornithological Applications*. 116:325–340. DOI: 10.1650/CONDOR-13-140.1

Appendix A

PLA055

PLA075

PLA016

PLA099

Comments on SNAMP Appendix D Fisher – User **827632**

I have participated in SNAMP in the following ways *(choose all that apply)* *

Heard a presentation about SNAMP at another meetings, Read SNAMP science articles or briefs, Read SNAMP newsletters, Read SNAMP emails, Other - Sequoia Forest Keepers was instructed by the lead fisher researcher on the protocol, so our summer intern teams could document Pacific fisher presence in Sequoia National Forest by the same protocol being used by SNAMP.

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**: Neutral
- **This document summarizes research findings well.** Strongly Disagree
- **The research findings described in this document are understandable.** Disagree
- **The research findings described in this document can be applied to Sierra Nevada forest management.** Strongly Disagree

The most interesting research findings in this document are:

The most important findings from this document to apply to Sierra Nevada public forest management are:

The research findings that I found least applicable to Sierra public forest management are: Appendix D: Fisher Team Final Report on page viii, asserts that further logging treatments of different intensities may need to be studied.

The biggest questions I have after reading this document are:

The biggest concerns I have after reading this document are: The SIERRA NEVADA ADAPTIVE MANAGEMENT PROJECT (SNAMP) Appendix D: Fisher Team Final Report on page viii, asserts that further logging treatments of different intensities may need to be studied.

“We found that SPLATs caused an immediate 6% reduction in potential fisher habitat. However they also moderated the impact of fire, resulting in greater available fisher habitat within 30 years. In the absence of simulated fire, the amount of habitat steadily increased over time due to forest succession, and was actually slightly greater on the treated landscape in year 30 than in year 0. The net benefits of SPLATs for the Pacific fisher will depend upon the true, but unknown, probability that high-severity fire effects will occur on a given portion of the landscape. However, future probabilities for specific fire behaviors (e.g., crown-fire initiation) are difficult to estimate, and it is therefore difficult to quantify trade-offs associated with SPLATs in absolute terms (Finney 2005). We further note that the SPLATs which were implemented at Sugar Pine appeared to have relatively modest impacts on forest structure and simulated fire behavior, and that it may be necessary to evaluate additional SPLATs of different intensities over a larger scale to fully assess the effects of SPLATs on fisher habitat.”

The SNAMP fisher report does not consider the analysis provided by the 2008 study Fire Probability, Fuel Treatment Effectiveness and Ecological Tradeoffs in Western U.S. Public Forests by Jonathan J. Rhodes and William L. Baker, which indicates that few treatment areas ever encounter fire (2.0% to 7.9%) during their assumed 20 year period of reduced fuels.

Similar to the statement questioned above, the SNAMP fisher report on, pages 117 and 118, contains a section titled “Integration” that is based on models that do not factor in the low chance of probability that the treatment area will experience fire.

“Integration We found that the SPLATs at Sugar Pine slightly reduced simulated fire behavior and resulted in greater amounts of projected fisher habitat up to 30 years after the fire. In the absence of simulated fire, we found that the SPLATs had an immediate, negative effect on the amount of fisher habitat, but SPLATs did not generally have a negative effect on fisher habitat when we modeled future forest growth for 30 years. In all scenarios, the differences between the treated and untreated landscapes were small. Our results were in general agreement with prior findings. Thompson et al. (2011) performed an analogous study to ours, in which they modeled fire and forest growth under treatment and no treatment scenarios and assessed fisher habitat suitability in the southern Sierra Nevada. They projected that fuels treatments had slight negative effects on fisher habitat in the absence of fire, but provided significant positive benefits up to 37 years after simulated fire. Truex et al. (2013) suggested that less fisher resting habitat was present immediately after mechanical fuels treatments were implemented in the Sierra Nevada. However, fishers consistently used areas in the southern Sierra Nevada where some timber harvest had occurred, so it may be possible to implement fuels-reduction treatments at an extent and rate that achieves fire-hazard-reduction goals (Zielinski et al., 2013).

As we noted in Appendix C for the California spotted owl, the net benefits of SPLATs for the Pacific fisher will depend upon the true, but unknown, probability that high-severity fire effects will occur on a given portion of the landscape. However, future probabilities for specific fire behaviors (e.g., crown-fire initiation) are difficult to estimate, and it is therefore difficult to quantify trade-offs associated with SPLATs in absolute terms (Finney 2005). We further note that the SPLATs which were implemented at Sugar Pine appeared to have relatively modest impacts on forest structure and simulated fire behavior, and that it may be necessary to evaluate additional SPLATs of different intensities over a larger scale to fully assess the effects of SPLATs on fisher habitat. Nonetheless, we have no reason to believe that Forest Service managers should alter their current policy of avoiding the placement of SPLATs near known fisher denning sites (U.S. Forest Service 2004) because these sites have significant biological importance for this species.

It will be necessary to mitigate for major threats to fisher survival while maintaining contiguous expanses of suitable fisher habitats, and detailed analyses using realistic and empirically developed data on population parameters are necessary for evaluating the long-term viability of fishers in the southern Sierra Nevada.”

The SNAMP fisher report fails to acknowledge the existence of Rhodes and Baker, 2008 as well as the other studies of fuel treatment impacts (Law and Harmon, 2011; Campbell et al., 2011; Price et al., 2012; Price, 2012; Restaino and Peterson, 2013) that have also shown: a) that analysis of the probability of fire affecting treated areas, such as that of Rhodes and Baker (2008),is essential to assessing the potential effectiveness of such treatments, and b) that the probability of fire affecting treated areas while fuels are reduced is relatively low. Yet the SNAMP fisher report continues to promote treatments in the hope that the treated areas will experience fire, so the models can hopefully work. The SNAMP fisher report projects fire in treatment areas even though the likelihood is low and the impact to the fisher habitat from treatment would be immediate and negative and it would take 37 years for the habitat to recover from the treatment and show positive benefits.

It would not be difficult to estimate the probability of fire affecting treatments; Rhodes and Baker, 2008 laid out how do it. Done properly, it will show a very low probability of fire affecting treated areas.

The conclusions of Rhodes and Baker, 2008 should be considered for inclusion in the SNAMP fisher report. If your team were to consider Rhodes and Baker (2008), the presumption in your final report that SPLATS of different intensities may need to be evaluated should be revised.

In addition, the SNAMP fisher report clearly indicates on page 32, that, “Data from radiocollared animals from the study area indicated that female fishers commonly die by 6-8 years of age.” Contrary to what the report implies, this means that more than four generations of Pacific fisher will not be able to use the treatment areas. While treating the forest may result in “relatively modest impacts on forest structure,” the impact of treatments on Pacific fisher would be extremely significant!

Additional comments for the authors: Sequoia ForestKeeper’s summer intern team has continued to follow your protocol and has again photo-documented fisher in Sequoia National Forest where the agency continues to propose logging projects. Thank you for all of your help guiding us with our project to document fisher presence.

Commentor: Mr. Ara Marderosian, Sequoia ForestKeeper® P.O. Box 2134 Kernville, CA 93238-2134

Rhodes and Baker (2008) statistically analyzed GIS data for more than 40,000 fires occurring over about 20 years in ponderosa pine forests on western USFS lands to quantitatively assess the regional probability of fire affecting treated areas during the window when fuels have been reduced in these forests, which provides an upper bound on potential fuel treatment effectiveness. Since publication, this paper has been repeatedly cited in peer-reviewed studies of: 1) fire frequency in forests (e.g., Williams and Baker, 2012), 2) the potential efficacy of fuel treatments (e.g., Price et al., 2012; Price, 2012), and 3) the impacts of wildfire and forest fuel treatments on forest carbon budgets (e.g., Law and Harmon, 2011; Campbell et al., 2011; Restaino and Peterson, 2013).

Several other studies of fuel treatment impacts (Law and Harmon, 2011; Campbell et al., 2011; Price et al., 2012; Price, 2012; Restaino and Peterson, 2013) have also shown: a) that analysis of the probability of fire affecting treated areas, such as that of Rhodes and Baker (2008),is essential to assessing the potential effectiveness of such treatments, and b) that the probability of fire affecting treated areas while fuels are reduced is relatively low.

Restaino, J. C., & Peterson, D. L. (2013). Wildfire and fuel treatment effects on forest carbon dynamics in the western United States. *Forest Ecology and Management*, *303*, 46-60.

Abstract

Sequestration of carbon (C) in forests has the potential to mitigate the effects of climate change by offsetting future emissions of greenhouse gases. However, in dry temperate forests, wildfire is a natural disturbance agent with the potential to release large fluxes of C into the atmosphere. Climate-driven increases in wildfire extent and severity are expected to increase the risks of reversal to C stores and affect the potential of dry forests to sequester C. In the western United States, fuel treatments that successfully reduce surface fuels in dry forests can mitigate the spread and severity of wildfire, while reducing both tree mortality and emissions from wildfire. However, heterogeneous burn environments, site-specific variability in post-fire ecosystem response, and uncertainty in future fire frequency and extent complicate assessments of long-term (decades to centuries) C dynamics across large landscapes. Results of studies on the effects of fuel treatments and wildfires on long-term C retention across large landscapes are limited and equivocal. Stand-scale studies, empirical and modeled, describe a wide range of total treatment costs (12–116 Mg C ha^{-1}) and reductions in wildfire emissions between treated and untreated stands (1–40 Mg C ha^{-1}). Conclusions suggest the direction (source, sink) and magnitude of net C effects from fuel treatments are similarly variable (−33 Mg C ha^{-1} to +3 Mg C ha^{-1}). ***Studies at large spatial and temporal scales suggest that there is a low likelihood of high-severity wildfire events interacting with treated forests, negating any expected C benefit from fuels reduction.*** The frequency, extent, and severity of wildfire are expected to increase as a result of changing climate, and additional information on C response to management and disturbance scenarios is needed improve the accuracy and usefulness of assessments of fuel treatment and wildfire effects on C dynamics.

See also (easy to find pdfs for them on google scholar):

Law, B. E., & Harmon, M. E. (2011). Forest sector carbon management, measurement and verification, and discussion of policy related to climate change. *Carbon Management*, *2*(1), 73-84.

Campbell, J. L., Harmon, M. E., & Mitchell, S. R. (2011). Can fuel-reduction treatments really increase forest carbon storage in the western US by reducing future fire emissions?. *Frontiers in Ecology and the Environment*, *10*(2), 83-90.

Price, O. F., Pausas, J. G., Govender, N., Flannigan, M., Fernandes, P. M., Brooks, M. L., & Bird, R. B. (2015). Global patterns in fire leverage: the response of annual area burnt to previous fire. *Int J Wildland Fire.[Internet]*.
-
"**In conclusion, we found that leverage [prob. that fire affects areas with reduced fuels] is positively related to the mean annual area burnt and cases where leverage occurs that is sufficient to effectively reduce area burnt by unplanned fire are rare.** Generally leverage occurs and is stronger where annual burnt area is high and also if fuel recovery periods are long.
[NOTE: Price et al., specifically found low probability of fire affecting fuel treatments in Sequoia]

All indicate that the probability of fire affecting areas with fuel reductions is small.

See also:

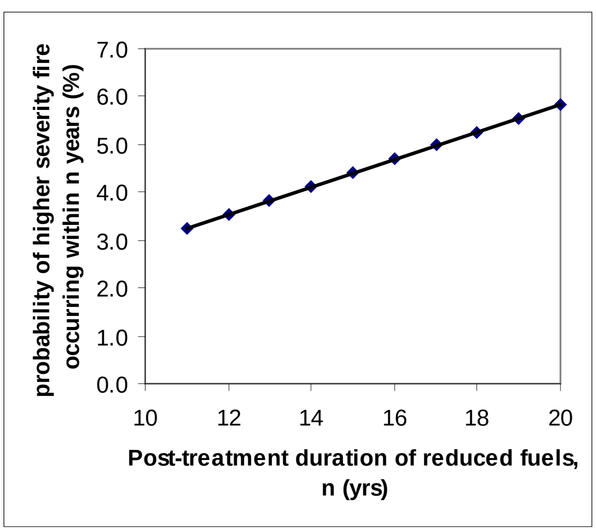
Garrett W. Meigs, John L. Campbell, Harold S. J. Zald, John D. Bailey, David C. Shaw, and Robert E. Kennedy 2015. Does wildfire likelihood increase following insect outbreaks in conifer forests? Ecosphere 6:art118. http://dx.doi.org/10.1890/ES15-00037.1

It demonstrates that fire affects less than 2% of forests in an ecoregion, making it highly unlikely that fire affects beetle-affected forests. (But it is the same for any type of forest)

Note that Rhodes and Baker (2008) paper assumed a 20 yr window of fuel treatment effectiveness, which we noted was the likely upper limit of duration effectiveness. It's much more likely that fuels are only actually reduced for about 10-12 yrs. The shorter the duration of fuel reduction, the lower the probability of fire affecting these areas while fuels are reduced, given a constant probability of fire.

(You can use the equation in Rhodes and Baker (2008) to calculate this effect)

For instance, with the annual probability of higher severity fire at 0.3%:



The SIERRA NEVADA ADAPTIVE MANAGEMENT PROJECT (SNAMP) *Appendix D: Fisher Team Final Report* on page viii, asserts that further logging treatments of different intensities may need to be studied.

> "We found that SPLATs caused an immediate 6% reduction in potential fisher habitat. However they also moderated the impact of fire, resulting in greater available fisher habitat within 30 years. In the absence of simulated fire, the amount of habitat steadily increased over time due to forest succession, and was actually slightly greater on the treated landscape in year 30 than in year 0. The net benefits of SPLATs for the Pacific fisher will depend upon the true, but unknown, probability that high-severity fire effects will occur on a given portion of the landscape. However, future probabilities for specific fire behaviors (e.g., crown-fire initiation) are difficult to estimate, and it is therefore difficult to quantify trade-offs associated with SPLATs in absolute terms (Finney 2005). We further note that the SPLATs which were implemented at Sugar Pine appeared to have relatively modest impacts on forest structure and simulated fire behavior, and that it may be necessary to evaluate additional SPLATs of different intensities over a larger scale to fully assess the effects of SPLATs on fisher habitat."

The SNAMP fisher report does not consider the analysis provided by the 2008 study *Fire Probability, Fuel Treatment Effectiveness and Ecological Tradeoffs in Western U.S. Public Forests* by Jonathan J. Rhodes and William L. Baker, which indicates that few treatment areas ever encounter fire (2.0% to 7.9%) during their assumed 20 year period of reduced fuels.

Similar to the statement questioned above, the SNAMP fisher report on, pages 117 and 118, contains a section titled "**Integration"** that is based on models that do not factor in the low chance of probability that the treatment area will experience fire.

> "**Integration**
> We found that the SPLATs at Sugar Pine slightly reduced **simulated** fire behavior and resulted in greater amounts of projected fisher habitat up to 30 years after the fire. In the absence of **simulated** fire, we found that **the SPLATs had an immediate, negative effect on the amount of fisher habitat**, but SPLATs did not generally have a negative effect on fisher habitat **when we modeled future forest growth for 30 years.** In all scenarios, the differences between the treated and untreated landscapes were small.
> Our results were in general agreement with prior findings. Thompson et al. (2011) performed an analogous study to ours, in which they modeled fire and forest growth under treatment and no treatment scenarios and assessed fisher habitat suitability in the southern Sierra Nevada. They projected that **fuels treatments had slight negative effects on fisher habitat in the absence of fire**, **but provided significant positive benefits up to 37 years after simulated fire**. Truex et al. (2013) suggested that less fisher resting habitat was present immediately after mechanical fuels treatments were implemented in the Sierra Nevada. However, fishers consistently used areas in the southern Sierra Nevada where some timber harvest had occurred, so it may be possible to implement fuels-reduction treatments at an extent and rate that achieves fire-hazard-reduction goals (Zielinski et al., 2013).
>
> As we noted in Appendix C for the California spotted owl, **the net benefits of SPLATs for the Pacific fisher will depend upon the true, but unknown, probability that high-severity fire effects will occur on a given portion of the landscape**. **However, future probabilities for specific fire behaviors (e.g., crown-fire initiation) are difficult to estimate, and it is therefore difficult to quantify trade-offs associated with SPLATs in absolute terms (Finney 2005). We further note that the SPLATs**

which were implemented at Sugar Pine appeared to have relatively modest impacts on forest structure and simulated fire behavior, and that it may be necessary to evaluate additional SPLATs of different intensities over a larger scale to fully assess the effects of SPLATs on fisher habitat. Nonetheless, we have no reason to believe that Forest Service managers should alter their current policy of avoiding the placement of SPLATs near known fisher denning sites (U.S. Forest Service 2004) because these sites have significant biological importance for this species.

It will be necessary to mitigate for major threats to fisher survival while maintaining contiguous expanses of suitable fisher habitats, and detailed analyses using realistic and empirically developed data on population parameters are necessary for evaluating the long-term viability of fishers in the southern Sierra Nevada."

The SNAMP fisher report fails to acknowledge the existence of Rhodes and Baker, 2008 as well as the other studies of fuel treatment impacts (Law and Harmon, 2011; Campbell et al., 2011; Price et al., 2012; Price, 2012; Restaino and Peterson, 2013) that have also shown: a) that analysis of the probability of fire affecting treated areas, such as that of Rhodes and Baker (2008),is essential to assessing the potential effectiveness of such treatments, and b) that the probability of fire affecting treated areas while fuels are reduced is relatively low. Yet the SNAMP fisher report continues to promote treatments in the hope that the treated areas will experience fire, so the models can hopefully work. The SNAMP fisher report projects fire in treatment areas even though the likelihood is low and the impact to the fisher habitat from treatment would be immediate and negative and it would take 37 years for the habitat to recover from the treatment and show positive benefits.

It would not be difficult to estimate the probability of fire affecting treatments; Rhodes and Baker, 2008 laid out how do it. Done properly, it will show a very low probability of fire affecting treated areas.

The conclusions of Rhodes and Baker, 2008 should be considered for inclusion in the SNAMP fisher report. If your team were to consider Rhodes and Baker (2008), the presumption in your final report that SPLATS of different intensities may need to be evaluated should be revised.

In addition, the SNAMP fisher report clearly indicates on page 32, that, "Data from radiocollared animals from the study area indicated that female fishers commonly die by 6-8 years of age." Contrary to what the report implies, this means that more than four generations of Pacific fisher will not be able to use the treatment areas. While treating the forest may result in "**relatively modest impacts on forest structure," the impact of treatments on Pacific fisher would be extremely significant**!

Ara

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(760) 376-4434
ara@sequoiaforestkeeper.org

Comments on SNAMP Appendix C-California Spotted Owl

I have participated in SNAMP in the following ways *(choose all that apply)* *

Attended SNAMP meetings, Attended SNAMP fieldtrips, Read SNAMP science articles or briefs, Read SNAMP newsletters, Visited the SNAMP website

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**: Agree
- **This document summarizes research findings well.** Agree
- **The research findings described in this document are understandable.** Agree
- **The research findings described in this document can be applied to Sierra Nevada forest management.** Neutral

The most interesting research findings in this document are:

One of the four territories in the prospective analysis, and the only territory within the treatment network, had more high severity fire with treatment than without.

The most important findings from this document to apply to Sierra Nevada public forest management are:

Moderate intensity timber harvests, consistent with fuels treatments, are correlated with CSO declines.

The research findings that I found least applicable to Sierra public forest management are:

The prospective analysis is mired by too many caveats and assumptions to be applicable anywhere.

The biggest concerns I have after reading this document are:

The only management recommendation from the prospective analysis is to simply avoid the PAC, a strategy that has led to a 50% decline on the ELD study area and there is no evidence a threshold has been reached. In addition, such a recommendation ignores the use of prescribed fire as an alternative to mechanical treatments to reduce fuels, despite the ever-growing body of literature that suggests low and moderate fire severity fire, with some high severity fire patches, do not affect occupancy.
The authors mistakenly assume there would be a long-term fuels treatment benefit of 30 years for spotted owls, but Collins et al. (2011), a study on the effectiveness of the fuels treatments in the LCSA, found that fuels treatments were only effective for about 20 years, at which time re-treatment would be necessary; meaning, between years 20 and 30 post-treatment the treatments effects to spotted owls are entirely negative.

Commentor: Please keep comments confidential in any public summary.

Comments on SNAMP Appendix A-Fire and Forest Health

I have participated in SNAMP in the following ways *(choose all that apply)* *

Heard a presentation about SNAMP at another meetings, Read SNAMP newsletters, Read SNAMP emails

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**: Agree
- **This document summarizes research findings well.** Agree
- **The research findings described in this document are understandable.** Agree
- **The research findings described in this document can be applied to Sierra Nevada forest management.** Agree

The most interesting research findings in this document are:

Left blank

The most important findings from this document to apply to Sierra Nevada public forest management are:

Left blank

The research findings that I found least applicable to Sierra public forest management are:

Left blank

The biggest concerns I have after reading this document are:

Given the increasingly broad impact of climate change, tree die off and catastrophic wild fire on the environment, are there new opportunities for SNAMP to have an even greater impact on the Sierra Nevada?

Commentor:

Comments on SNAMP Chapter 5 – User 809683

I have participated in SNAMP in the following ways *(choose all that apply)* *

Attended SNAMP meetings, Attended SNAMP fieldtrips, Attended a SNAMP workshop, Heard a presentation about SNAMP at another meetings, Read SNAMP science articles or briefs, Read SNAMP newsletters, Read SNAMP emails, Visited the SNAMP website

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**: Agree
- **This document summarizes research findings well.** Agree
- **The research findings described in this document are understandable.** Agree
- **The research findings described in this document can be applied to Sierra Nevada forest management.** Agree

The most interesting research findings in this document are:

The most important findings from this document to apply to Sierra Nevada public forest management are:

The research findings that I found least applicable to Sierra public forest management are:

The biggest questions I have after reading this document are: Chp. 5 – Integrated Mgt RecommendationsFindings on p. 2 regarding benefits of SPLATs in reducing high severity wildfire is inconsistent with the Findings on p.4 where it states that vegetation reduction was small and regrowth in the first decade was more than the fuel reduction treatment. “SPLAT networks will reduce the risk of uncharacteristically severe fire.” (p. 2) Vegetation density from the implementation of SPLATs – “The small reductions in vegetation from treatments were temporary, with regrowth exceeding the original pre-treatment vegetation density in the first decade.” (p. 4)

The biggest concerns I have after reading this document are:

Additional comments for the authors: In monitoring R5 forest health and fuels reduction accomplishments, I find that R5 is removing less than 10% of annual growth so the forests continue to get denser and denser and denser, which is leading to the megafires that are being experienced. With an average of 266 trees/ acre (FIA) across all R5 forests in productive forest lands, SPLATS are too little, too late. We need to take over 1/2 the vegetation off the landscape in a manner that leaves a heterogeneous pattern.

Commentor: Steve Brink, California Forestry Association

Comment 22: Steve Brink, California Forestry Association comments on Appendix A-FFEH [Survey Response 812964]

Comments on SNAMP Appendix A Fire and Forest Health – User 812964

I have participated in SNAMP in the following ways *(choose all that apply)**

Attended SNAMP meetings, Attended SNAMP fieldtrips, Attended a SNAMP workshop, Heard a presentation about SNAMP at another meetings, Read SNAMP science articles or briefs, Read SNAMP newsletters

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**: Agree
- **This document summarizes research findings well.** Agree
- **The research findings described in this document are understandable.** Agree
- **The research findings described in this document can be applied to Sierra Nevada forest management.** Agree

The most interesting research findings in this document are: There was not enough treatments to statistically indicate anything.

The most important findings from this document to apply to Sierra Nevada public forest management are:

The research findings that I found least applicable to Sierra public forest management are:

The biggest questions I have after reading this document are:

The biggest concerns I have after reading this document are:

Additional comments for the authors:

P. 16, line 352 - I believe the French Fire vegetation burn severity information is available from the Forest.

Commentor: Steve Brink, California Forestry Association.

Comment 23: Anonymous comments on Appendix B-Spatial [Survey Response 823867]

Comments on SNAMP Appendix B Spatial – User 823867

I have participated in SNAMP in the following ways *(choose all that apply)* *

Attended SNAMP meetings, Attended SNAMP fieldtrips, Heard a presentation about SNAMP at another meetings ,Read SNAMP science articles or briefs, Read SNAMP newsletters, Read SNAMP emails, Visited the SNAMP website, Other

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**: Strongly Disagree
- **This document summarizes research findings well.** Agree
- **The research findings described in this document are understandable.** Neutral
- **The research findings described in this document can be applied to Sierra Nevada forest management.** Agree

The most interesting research findings in this document are:

The most important findings from this document to apply to Sierra Nevada public forest management are:

The research findings that I found least applicable to Sierra public forest management are:

The biggest questions I have after reading this document are:

The biggest concerns I have after reading this document are:

Additional comments for the authors:

- Linking Lidar data to CWHR classes may not be the best strategy – CWHR is used because it's all we have. Can Lidar give us a better way to describe wildlife habitat? Also, I do not see where you actually accomplished the link to CWHR classes.
- Please make figure 4 bigger so we can see details. Figures 6 & 7– need a scale for colors.
- 3.7 & 4.7 – How do results of investigating point density to predict forest metrics at the plot scale translate to stand or landscape scale metrics?
- 5.1 – Are tools used (Matlab, etc.) available for other users? What is "multi-path effect"? Combination of "high resolution multi-spectral … imagery" with what?
- 5.2 – Are there results to support this paragraph? Seems results are not here -- may be more appropriate for wildlife appendices.
- 5.3 – I'm not sure that managers would need this level of detail about fuel treatments to justify the cost.
- 5.4 & 5.5 – Link to results is weak. Will adequacy of use for fire behavior models be discussed in the integration report?

Commentor: Please keep my name and affiliation confidential in any summary of these comments.

Comments on SNAMP Appendix D – Pacific Fisher

I have participated in SNAMP in the following ways *(choose all that apply)**

Attended SNAMP meetings, Attended SNAMP fieldtrips, Attended a SNAMP workshop, Heard a presentation about SNAMP at another meetings, Read SNAMP science articles or briefs, Read SNAMP newsletters, Read SNAMP emails, Visited the SNAMP website

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**: Disagree
- **This document summarizes research findings well.** Disagree
- **The research findings described in this document are understandable.** Disagree
- **The research findings described in this document can be applied to Sierra Nevada forest management.** Disagree

The most interesting research findings in this document are:

The most important findings from this document to apply to Sierra Nevada public forest management are:

The research findings that I found least applicable to Sierra public forest management are:

The biggest concerns I have after reading this document are:

Commentor:

Comments on SNAMP Chapter 5 User 836008

I have participated in SNAMP in the following ways *(choose all that apply)* *

Heard a presentation about SNAMP at another meetings,Read SNAMP science articles or briefs

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**:
- **This document summarizes research findings well.**
- **The research findings described in this document are understandable.**
- **The research findings described in this document can be applied to Sierra Nevada forest management.**

The most interesting research findings in this document are:

The most important findings from this document to apply to Sierra Nevada public forest management are:

The research findings that I found least applicable to Sierra public forest management are:

The biggest concerns I have after reading this document are:

I am uncertain how the integrated recommendation of limiting mastication is justified. The appendix on fisher states that occupancy following mastication was relatively high (0.65). Further, others have found that masticated material decomposes at relatively fast rates (depending on site productivity, cover, etc.). The management implication does not seem to consider that masticated material decomposes within the timeframe of expected fuel treatment longevity. Other work has demonstrated mastication to be effective at reducing fire severity, especially following the period of decomposition. The suggestion to limit its use does not seem warranted.

Additional comment:

Commentor:

Comment 26: Michael Anderson, California Department of Water Resources comments on SNAMP Appendix E-Water [Survey Response 836287]

Comments on SNAMP Appendix E- Water Quality and Quantity 836287

I have participated in SNAMP in the following ways *(choose all that apply)* *

Attended SNAMP meetings, Other - Provided funding for water team and some of the spatial LIDAR acquisition

Next, please tell us how much you agree or disagree with the following statements. *(Strongly agree, Agree, Neutral, Disagree, Strongly Disagree).*

- **This document is well written**: Disagree
- **This document summarizes research findings well.** Disagree
- **The research findings described in this document are understandable.** Disagree
- **The research findings described in this document can be applied to Sierra Nevada forest management.** Neutral

The most interesting research findings in this document are:

I think there is some good information buried in the document, but it is written more as a thesis than as a report to an agency. From what I understand, it would appear that forest treatments by themselves alter runoff production in the watershed to a small degree but mitigate runoff changes resulting from a fire.

The most important findings from this document to apply to Sierra Nevada public forest management are:

Forest treatments would seem to offer a way to improve the resilience of the watershed to fire and mitigate the negative runoff outcomes associated with fire events. However, I am not sure if this was the finding of the water team given the report I read.

The research findings that I found least applicable to Sierra public forest management are:

Left blank

The biggest concerns I have after reading this document are:

Additional comment:

I would have liked to see the management application section expanded beyond the single paragraph offered up. A distillation of the modeling results into the possible scenarios of no treatment, treatment, no treatment with fire and treatment with fire would have been really helpful.

Commentor: Michael Anderson, California Department of Water Resources

Comment 27: Leslie Reid, Forest Service Pacific Southwest Research Station comments on SNAMP Appendix E-Water

A few comments after a quick read-through of the Water Quantity section of Appendix E

1. Even if the study is outlined outside of the appendix, it would be useful to provide a brief outline here of the overall strategy for the water-quantity study so the reader starts off oriented with respect to how the pieces described in the appendix fit together.
2. It would be quite useful to provide a clear description of what parameters needed to be estimated or defined by calibration, the values used, and the uncertainty associated with each. This might be most easily presented by an expanded version of Table 12.
3. I'm confused by what weather conditions were actually modeled over the 30-yr period—were these the "average" condition? If so, is that meaningful, given the variation in responses over the 4 measurement years? Is the response to "average" conditions equivalent to the average of responses to the distribution of weather conditions likely?
4. It seems odd that all relations in Fig. 17 (or Fig. 16) would be turn out to be significantly different at the 0.05 level; this should be checked. In particular, relations for 2012 and 2013 in Fig. 17 appear to be nearly colinear while showing significant variance about each. In addition, the units need to be identified.
5. The calibrated discharge predictions in Fig. 18 do not look particularly close to the measured discharges. What is the percentage error for calculated annual water yields for the individual years used in calibration? The depiction of standard error bands for SWE and soil storage provide a very useful depiction of the uncertainties in those values—could something similar be done for discharge?
6. Given that there are so many parameters that had to be established by calibration or other means, it would be extremely useful—in fact, possibly critical—to carry out a sensitivity analysis to identify the level of uncertainty associated with the reported results.
7. Calculated discharges appear to be much less accurate for the validation period at KREW than for the calibration period, suggesting that the model may be significantly overfitted. A statistical analysis (maybe cross validation—check with a statistician on this) should be carried to determine whether this is indeed the case; this would also provide information useful for evaluating the uncertainty associated with reported results.
8. The pattern of variance in Fig. 5 suggests that a linear fit is inappropriate.
9. What is meant by treatment and control in Figs. 16 & 17? Wasn't treatment carried out after the major runoff period in 2012? It would be useful to distinguish data from before and after treatment.
10. It is not clear whether the 2013 (post-treatment?) data were used in calibration.
11. If the point of the correlations between headwater discharges and main-stem discharges was to establish a basis for estimating the downstream change associated with a change in runoff in the headwater drainages (and this is not clear in the text), then there needs to be very careful consideration of the difference between association and causation. The severity of my sunburn on a given day may be closely correlated with how much sunscreen you apply that day, but if you forget to put on sunscreen one day, that won't affect my sunburn. This may indeed be the most effective means available for scaling up results, but the potential pitfalls (and associated uncertainties) at least need to be discussed.

12. Figure 15 is difficult to follow because solid shapes are used rather than lines. At the point that the upper margin of shapes cross, the graph becomes uninterpretable.
13. The units need to be identified in Figure 7.
14. There appear to be some critical typos in Table 11.
15. Why does Sugar Pine control ET decrease in the with increasing LAI, while Last Chance control ET does the opposite (p.42)?
16. It would be very useful to provide some discussion of the groundwater loss component. What is it? How is it estimated? What are the implications of the calculated changes?

STATE OF CALIFORNIA—NATURAL RESOURCES AGENCY Edmund G. Brown Jr., Governor

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August 28, 2015

Ms. Susie Kocher
Central Sierra Cooperative Extension
1061 3rd Street
South Lake Tahoe, California 96150

Dear Susie:

Thank you for the opportunity to comment on the Sierra Nevada Adaptive Management Project (SNAMP) Water Team final report. The Water Team did a very good job compiling their extensive data set and modeling work in a readable document. The field results are consistent with the literature and they advance our knowledge about the impacts of low intensity forestry operations on water yield and water quality in the Sierra Nevada. I offer the following specific comments on the document based on my knowledge of the literature and field experience in the Sierra Nevada.

- The entire document should be reviewed by a technical editor to correct grammatical problems (e.g., capitalization).
- The entire document should have consistent use of units. Metric units should be provided first, with English units in parentheses if desired.
- Pg 6: MacDonald (1987) is incorrectly cited in the document and the reference in the literature cited section is also incorrect.
- Pg 7, literature review. I suggest citing and discussing Heard's (2005) study documenting that water yield changes associated with a prescribed burn covering 60% of a 250 ac basin were not detected in the Sierra Nevada, and including Burgy and Papazafiriou's (1970) study, that found that chemically treating and burning a small (210 ac) watershed at Hopland Field Station had an average 50% increase in water yield (converting chaparral to grass).
- Pg 8, top of page. I suggest citing Ziemer 1987, providing a realistic expectation regarding water yield increases at larger scales in the Sierra Nevada.
- Pg 9, study sites. More detailed precipitation data for the study sites would be beneficial to the reader. An estimate of annual precipitation can be obtained from the OSU PRISM site: http://www.prism.oregonstate.edu/explorer/. This site appears to provide an estimate of approximately 64 inches per year for Last Chance; how was the 78.3 inch estimate derived?
- Pg 22, model simulations: The modeled water yield increase following a wildfire without SPLATs at the Last Chance site that reduces vegetative cover by

approximately 50% is significant at roughly 67% (35.9 area-inches vs. 21.7 area-inches). The fireshed scale at Last Chance is approximately 10,000 acres. It would be beneficial for the reader to see what water yield changes in instrumented watersheds have been for basins either burned or converted to grass—with different drainage areas—to put this estimated percent increase in water yield in perspective. For example:

  - Anderson et al. (1976) and Beschta (1990) reported only a 9% (8 acre-inches) increase for the intensely burned Tillamook Fire in northwestern Oregon for the first 16 years following the burn. These increases were for the large Trask and Wilson River watersheds (91,520 acres and 101,760 acres, respectively).
  - Helvey (1974, 1980) reported that during the first post fire year total water yield from the intensely burned Entiat Experimental Forest in Washington was 50% greater than predicted. During water years 1972–1977, measured runoff predictions by 4.2 to 18.6 area-inches. Drainage basin size was approximately 1,200 acres (500 ha).
  - Lewis (1968) reported that a 99% vegetation removal in an oak grass woodland in the central Sierra Nevada foothills increased annual water yield 4.5 area-inches. Basin size was only 12 acres.

- The text should include verbiage stating that the large estimated increase in post wildfire water yield at the fireshed scale at Last Chance (approximately 67%), while possible at this scale, will not translate to much larger basins (that are not totally burned), where significant water storage occurs in the Sierra Nevada.
- Pg 43, first paragraph: I suggest referencing Minear and Kondolf (2009) regarding California reservoir sedimentation rates.
- Pg 43, second paragraph: Reference should be Dunne and Leopold 1978.
- Pg 44, first paragraph: Include Reid and Dunne 1996 as a reference indicating that in-channel erosion is an important sediment source in the Sierra Nevada. They completed a sediment budget for the Kings River Experimental Watershed's Teakettle Creek.
- Pg 44, second paragraph: Cite MacDonald et al. 2004 as a Sierra Nevada study that examined sediment transport at the small hillslope plot scale.
- Pg 45, first full paragraph: Several other Sierra Nevada citations should be considered for inclusion here, including Hunsaker and Neary 2012, Reid and Dunne 1996, Euphrat 1992, and Nolan and Hill 1991.
- Pg 46, top of page: Oliver et al. 2011 should be included as a Sierra Nevada example of wildfire (2007 Angora Fire) where sediment, turbidity, and nutrient level changes were documented.
- Pg 46, first full paragraph: Lewis et al. 2001 should be included here as an example of California clearcut logging impacts on sediment yields.
- Pg 63, channel bed movement: No suspended sediment concentrations are reported in the document, and it is not stated what percent of the total sediment yield is composed of suspended sediment. Other work in the Sierra Nevada at the Kings River Experimental Watershed should allow some conclusions to be made regarding this topic.

- Pg 63, management implications: No information is provided in the chapter regarding the locations of forest roads in the studied basins, the number and location of road-stream crossings, the surfacing of the forest roads, road density, etc., and the reasons why sediment input from forest roads was very low for this study. Forest roads and particularly road-stream crossings are known to be significant sediment source areas in Sierran watersheds. For example, Korte and MacDonald (2007) reported that for one KREW sub-watershed, roads were estimated to contribute 25-50 percent of the total sediment yield, and nearly all of the road-related sediment came from a single mixed surface road that crossed the stream a short distance above the weir pond. Detailed information on the forest roads in both the Sugar Pine and Last Chance sites would be beneficial to the reader.
- Added discussion in the Management Implications section on what changes could occur to water quality parameters with severe wildfire should be included (including discussion on key factors affecting erosion and sedimentation, such as vegetative cover, precipitation intensity and storm numbers the first two years after the fire, soil texture, slope, etc.).

Please do not hesitate to contact me if you have any questions regarding these comments.

Sincerely,

Peter H. Cafferata
Watershed Protection Program Manager

References

Anderson, H.W., M.O. Hoover, K.G. Reinhart. 1976. Forests and water: effects of forest management on floods, sedimentation, and water supply. USDA Forest Service GTR PSW-18. 115 p.

Beschta, R. L. 1990., Effects of fire on water quantity and quality, in Natural and Prescribed Fire in Pacific Northwest Forests, edited by J. D. Walsad et al., pp. 219–231, Oreg. State Univ. Press, Corvallis.

Burgy, R.H. and Z.G. Papazafiriou. 1970. Hydrologic studies and watershed management on brushlands. Progress Report No. 9, Department of Water Science and Engineering, University of California, Davis. 31 p.

Euphrat, F.D. 1992. Cumulative impact assessment and mitigation for the Middle Fork of the Mokelumne River, Calaveras County, California. Ph.D. dissertation, University of California, Berkeley, CA. 107 p.

Heard, A.M. 2005. Effects of landscape scale prescribed fire on hydrology and stream chemistry. Master of Science Thesis. Colorado State University, Fort Collins, CO. 119 p.

Helvey, J.D. 1974. Watershed behavior after forest fire in Washington, paper presented at Irrigation and Drainage Division Specialty Conference, pp. 403–422, Am. Soc. of Civ. Eng., Fort Collins, Colo.

Helvey, J.D. 1980. Effects of a north central Washington wildfire on runoff and sediment production. Water Resources Bulletin 16(4): 627-634.

Hunsaker, C.T. and D.G. Neary. 2012. Sediment loads and erosion in forest headwater streams of the Sierra Nevada, California. Revisiting Experimental Catchment Studies in Forest Hydrology (Proceedings of a Workshop held during the XXV IUGG General Assembly in Melbourne, June–July 2011. IAHS Publ. 353: 195-203.

Korte, A. and L.H. MacDonald. 2007. Preliminary summary: sediment production and delivery in the southern Sierra Nevada. Unpubl. Paper dated 1 March, 2007. Watershed Science Program, Colorado State University, Fort Collins, CO. 5 p. plus figures.

Lewis, D.C. 1968. Annual hydrologic response to watershed conversion from oak woodland to annual grassland. Water Resources Res. 4: 59-72.

Lewis, J., S.R. Mori, E.T. Keppeler, and R.R. Ziemer. 2001. Impacts of logging on storm peak flows, flow volumes and suspended sediment loads in Caspar Creek, California. Pp. 85-125 in: Wigmosta, M.S.; and S.J. Burges (Eds.) Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas. Water Science and Application, Volume 2. American Geophysical Union, Washington, D.C. 228 p.

MacDonald, L.H., 1987. Forest harvest, snowmelt and streamflow in the Central Sierra Nevada. In R.H. Swanson et al. (eds.), Forest Hydrology and Watershed Management, International Association of Hydrologic Sciences Publication no. 167, p. 273-284.

MacDonald, L. H., D.B. Coe, and S.E. Litschert, 2004. Assessing cumulative watershed effects in the Central Sierra Nevada: hillslope measurements and catchment-scale modeling, pp 149-157. IN Murphy, D. D. and P. A. Stine Editors. 2004. Proceedings of the Sierra Nevada Science Symposium; 2002 October 7-10; Kings Beach, CA; Gen. Tech. Rep. PSW_GTR-193. Albany, CA. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 287 p.

Minear, T. and G.M. Kondolf. 2009. Estimating reservoir sedimentation rates at large spatial- and temporal-scales: a case study of California. Water Resources Research 45, W12502, doi:10.1029/2007WR006703.
Noland, K.M. and B.R. Hill. 1991. Suspended-sediment budgets for four drainage basins tributary to Lake Tahoe, California and Nevada, 1984-87. U.S. Geological Survey. Water-Resources Investigations Report 91-4054. 40 p.

Oliver, A.A., J.E. Reuter, A.C. Heyvaert and R.A. Dahlgren. 2011. Water quality response to the Angora fire, Lake Tahoe, CA. Biogeochemistry: DOI 10.1007/s10533-011-9657-0.

Reid, L.M. and T. Dunne. 1996. Rapid evaluation of sediment budgets. Reiskirchen: Germany, Catena Verlag (GeoEcology paperback). 164 p.

Ziemer, R.R. 1987. Water yields from forests: an agnostic view. In: R. Z. Callaham and J. J. DeVries (Tech. Coord.), Proceedings of the California Watershed Management Conference, 18-20 November 1986, West Sacramento, California. Wildland Resources Center, University of California., Berkeley, California. Report No. 11. Feb. 1987. p. 74-78.

SNAMP Fire and Forest Ecosystem Health Team
RESPONSE TO COMMENTS/REVIEWS

Danny L. Fry
John J. Battles
Brandon M. Collins
Scott L. Stephens

August 31, 2015

A. Response to comments regarding Owl Chapter from Center for Biological Diversity and John Muir Project

Point 1 in Comments

SNAMP REPORT: *"We conclude that SPLATs may provide long-term benefits to spotted owls if fire occurs under escaped wildfire conditions, but can have long-term negative effects on owls if fire does not occur."*

COMMENT: The above statement should reflect that mechanical treatments can be ineffective in extreme weather, and therefore the perceived benefit may not even be realized. For example, Lydersen et al. 2014 states: "Our results suggest that wildfire burning under extreme weather conditions, as is often the case with fires that escape initial attack, can produce large areas of high-severity fire even in fuels-reduced forests with restored fire regimes."

COMMENT: Explain also that even if fire does occur, there may be no long term benefits from mechanical treatments. Instead, fire (including mixed-severity fire with a high-severity component) can occur in ways that provide benefits to owls (e.g. foraging habitat), and therefore, in addition to causing harm to unburned owl habitat, mechanical treatments could also cause harm in terms of how they impact the post-fire condition.

RESPONSE: We changed the statement to clarify that the potential benefits will be if fire occurs under "escaped wildfire conditions." Lydersen et al. (2014) is one study that only looked at the effects of prescribed burning on severity patterns in a large wildfire. There are numerous studies that demonstrate effectiveness of fuel treatments under high to extreme fire weather conditions, or more generally "escaped wildfire conditions" (e.g., Ritchie et al. 2007, Safford et al. 2009, Safford et al. 2012, Martinson and Omi 2013). Regarding the second-half of the comment, the survival of large overstory trees following wildfire and the potential for treatments to reduce large, homogenous patches of stand-replacing fire are the long-term benefits we are referring to.

Lydersen, J.M., M.P. North, and B.M. Collins. 2014. Severity of an uncharacteristically large wildfire, the Rim Fire, in forests with relatively restored drequent fire regimes. Forest Ecology and Management 328: 326-334.
Martinson, E.J., Omi, P.N., 2013. Fuel Treatments and Fire Severity: A Meta-analysis. USDA For. Serv. Res. Pap., RMRS-RP-103WWW, Fort Collins, CO, 35p.

Ritchie, M.W., Skinner, C.N., Hamilton, T.A., 2007. Probability of tree survival after wildfire in an interior pine forest of northern California: effects of thinning and prescribed fire. Forest Ecology and Management 247, 200–208.

Safford, H. D., Schmidt, D.A., Carlson, C.H. 2009. Effects of fuel treatments on fire severity in an area of wildland–urban interface, Angora Fire, Lake Tahoe Basin, California. Forest Ecology and Management 258:773-787.

Safford, H. D., J. T. Stevens, K. Merriam, M. D. Meyer, and A. M. Latimer. 2012. Fuel treatment effectiveness in California yellow pine and mixed conifer forests. Forest Ecology and Management 274:17-28.

Point 3 in Comments

SNAMP REPORT: *"For millennia, low- to moderate-severity wildfires occurred at frequent (often less than 0-year) intervals in many western forests, naturally removed fuels such as woody debris, shrubs, and small trees, and shaped the ecology of these forests (Agee 1993, Noss et al. 2006). However, decades of wildfire suppression have disrupted historic fire regimes, increased the amount of surface and ladder fuels, and have led to uncharacteristic proportions and patch sizes of stand-replacing fire wildfires that now threaten ecological and human communities (Mallek et al. 2013, Stephens et al. 2013, Stephens et al. 2014, Stephens et al. 2015)."*

COMMENT: The above statement gives the impression that modern fires are not ecologically valuable. That implied message does not reflect a) recent research (e.g., Odion et al. 2014; Baker 2014) that finds that high-severity fire (including large patches of high-severity fire hundreds or thousands of acres in size), as a component of mixed–severity fire, is important to ecological communities in the Sierras, or b) extensive research finding that severely burned post-fire areas (including large patches of it) are critical for species such as black-backed woodpeckers (Siegel et al 2011, 2012, 2013, 2014, 2015; Tingley et al. 2014), 2014), numerous avian species (Hanson 2014; Burnett et al. 2010, 2011, 2012; Roberts et al. 2015; Siegel et al. 2011), bats (Buchalski et al. 2013), as well as owls (Bond et al. 2009) and fishers (Hanson 2015). Moreover, recent fires that are often referred to by the Forest Service as harmful – the McNally, the Moonlight, the Rim, and the King – all contain wildlife habitat created by high-severity fire that has been found to be inhabited by many species, including very rare species (see wildlife articles referenced above which occurred in part in the McNally and Moonlight fire areas; see also recent woodpecker data from the Rim and King fires). It is important therefore to reflect in this Appendix that high-severity fire is not categorically harmful to ecological communities and instead to explain the importance of high-severity fire to the ecological integrity of the Sierras; otherwise, it will continued to be perceived as a complete loss when in fact high-severity fire is essential and important.

RESPONSE: We revised the text in the report to be more clear with our language and added several references to support the revised text. Each of the fires referenced in this comment demonstrates our point regarding uncharacteristic proportions and patch sizes of stand-replacing fire (see references cited in revised text).

Point 6 in Comments

SNAMP REPORT: *"As with other western forests, the area burned by high-severity fires in the Sierra Nevada has increased over the past several decades (Miller et al. 2009)."*

COMMENT: First, recent research contradicts Miller et al. 2009—e.g., Hanson and Odion 2014; Hanson and Odion 2015. Moreover, even if high-severity fire were increasing, that is not necessarily a problem given the deficit of high-severity fire in the Sierras (e.g., Odion et al. 2014) and the importance of high-severity fire to biota. It is therefore important to reflect in this Appendix that an increase is likely a positive for Sierra ecosystems and is not at all categorically a negative.

RESPONSE: We believe that the weight of evidence supports our assertion that area burned by high-severity (stand-replacing) fire is increasing in the mixed conifer region of the Sierra Nevada (see Miller et al. 2009, Miller and Safford 2012). The Hanson and Odion (2014) study that purportedly contradicts Miller et al. (2009) has been comprehensively rebutted by Safford et al. (2015) and rendered unsound scientifically. Beyond the issue of increasing stand-replacing fire effects in contemporary forests, the proportions of stand-replacing fire are well outside of the historical range of variability for Sierra Nevada pine-mixed-conifer forests (Mallek et al. 2013). The notion of a current deficit of stand-replacing fire is unclear, but what is ubiquitously agreed upon is the deficit of low-moderate severity fire (see Mallek et al. 2013).

Hanson, C.T. and D.C. Odion. 2014. Sierra Nevada fire severity conclusions are robust to further analysis: a reply to Safford et al. International Journal of Wildland Fire 24: 294-295.

Mallek, C., Safford, H.D., Viers, J., and Miller, J. 2013. Modern departures in fire severity and area vary by forest type, Sierra Nevada and Southern Cascades, USA. Ecosphere 4: Article 153.

Miller, J.D., H.D. Safford, M. A. Crimmins, and A. E. Thode. 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. Ecosystems 12:16–32.

Miller, J.D. and H.D. Safford. 2012. Trends in wildfire severity: 1984 to 2010 in the Sierra Nevada, Modoc Plateau, and southern Cascades, California, USA. Fire Ecology 8:41-57.

Safford H.D., Miller J.D., and Collins, B.M. 2015. Differences in land ownership, fire management objectives and source data matter: a reply to Hanson and Odion (2014). International Journal of Wildland Fire 24: 286-293.

B. Response to comment from Sequoia Forestkeeper regarding fire ignition probability

SNAMP REPORT (bold from Comments): *As we noted in Appendix C for the California spotted owl,* ***the net benefits of SPLATs for the Pacific fisher will depend upon the true, but unknown, probability that high-severity fire effects will occur on a given portion of the landscape****.* ***However, future probabilities for specific fire behaviors (e.g., crown-fire initiation) are difficult to estimate, and it is therefore difficult to quantify trade-offs associated with SPLATs in absolute terms (Finney 2005). We further note that the SPLATs which were implemented at Sugar Pine appeared to have relatively modest impacts on forest structure and simulated fire***

behavior, and that it may be necessary to evaluate additional SPLATs of different intensities over a larger scale to fully assess the effects of SPLATs on fisher habitat. *Nonetheless, we have no reason to believe that Forest Service managers should alter their current policy of avoiding the placement of SPLATs near known fisher denning sites (U.S. Forest Service 2004) because these sites have significant biological importance for this species.*

COMMENT: The SNAMP fisher report fails to acknowledge the existence of Rhodes and Baker, 2008 as well as the other studies of fuel treatment impacts (Law and Harmon, 2011; Campbell et al., 2011; Price et al., 2012; Price, 2012; Restaino and Peterson, 2013) that have also shown: a) that analysis of the probability of fire affecting treated areas, such as that of Rhodes and Baker (2008),is essential to assessing the potential effectiveness of such treatments, and b) that the probability of fire affecting treated areas while fuels are reduced is relatively low. Yet the SNAMP fisher report continues to promote treatments in the hope that the treated areas will experience fire, so the models can hopefully work. The SNAMP fisher report projects fire in treatment areas even though the likelihood is low and the impact to the fisher habitat from treatment would be immediate and negative and it would take 37 years for the habitat to recover from the treatment and show positive benefits.

RESPONSE: The Rhodes and Baker (2008) study is more limited than described above. 1) It assumes that the fire probability observed in the recent past is a reasonable predictor of future fire probability. This is not the case for most of the future fire-climate predictions. Furthermore, for the Sierra Nevada, the fire perimeter data maintained by CaFire show a 4-fold increase in fire probability over the last 10-15 years (D. Sapsis, unpublished data). 2) It ignores the fact that initial treatments, particularly those that focus on ladder fuel removal, allow for easier and cheaper follow-up or maintenance treatments, namely prescribed burning. 3) There is an implied assumption that if left untreated fire risk, which includes both hazard (potential loss of key ecosystem components) and probability of occurrence, is static. This is also not the case. We know that hazard continues to increase (see Stephens et al. 2012), and there is reason to believe that probability may also increase due to increased potential spread rates and greater difficulty for fire control (primarily line construction). For these reasons, we consider the Rhodes and Baker (2008) estimate of fire ignition probability not reliable enough to base management decisions. We agree that obtaining a better estimate is a priority and note this point in the SNAMP report. In regard to the probability of fire entering a treated area with reduced fuel loads, we explicitly quantify the longevity of the fuel treatments and illustrate how their effectiveness in modifying fire behavior declines with time (Fig. A20, Appendix A).

Rhodes, J.J. and W.L. Baker. 2008. Fire probability, fuel treatment effectiveness and ecological tradeoffs in western U.S. public forests. The Open Forest Science Journal 1: 1-7.
Stephens, S. L., B. M. Collins, and G. B. Roller. 2012. Fuel treatment longevity in a Sierra Nevada mixed conifer forest. Forest Ecology and Management 285:204-212.

C. Response to comments from Dave Martin.

COMMENT 1: In the FFEH Draft Report (page ii), the conclusions about the 4% reduction in fire behavior with and without SPLATS being characterized as “modest”, is not necessarily how

I would characterize such a small reduction. Indeed, there is other science demonstrating greater basal area reductions resulting in greater effects to fire behavior, notwithstanding the issue of studying SPLATS. A more thorough acknowledgement/discussion regarding the nature of the limitations placed on management of SPLATS (in SP) and whether or not it would result in a higher % reduction would, at least point out a limitation of the study. From a fuel hazard reduction/prevention of catastrophic fire management perspective, 4% is unacceptable. I know that was not SNAMP's charge to make such judgments but clearly articulating the limitations may give greater perspective to the results.

RESPONSE: The overall 4% reduction in potential fire behavior after SPLAT treatments were installed at the Sugar Pine site is small and does not reduce the potential for high severity fire as much as intended by the project. Since this southern Sierra Nevada site is within the Pacific Fisher's range the intensity of fuels treatments were limited. Almost no change in the forest canopy was detected and surface fuels were still moderate after treatment because the anticipated prescribed fires were not applied because of air quality constraints. Ladder fuels were the main component removed at this site which can lower the probability of passive crown fire (Agee and Skinner 2005, Stephens et al. 2009) but can still leave the overall landscape at relatively high risk to severe fire.

The overall goal of protecting the Pacific Fisher is logical but leaving large forested landscapes that are the core of its habitat with high fire hazards is likely to fail in the long-term, especially with warming climates. A recent paper that analyzed 1911 landscape-scale (> 25,000 acres) forest structure from mixed conifer and ponderosa pine forests in the southern Sierra Nevada found high heterogeneity in structure before the impacts of harvesting or fire suppression (Stephens et al. 2015). In 1911, total tree basal area ranged from 4 – 261 ft^2 acre^{-1} (1 to 60 m^2 ha^1) and tree density from 1 – 67 trees acre^{-1} (2 - 170 ha^1)(based on trees > 12 inches dbh). Comparing forest inventory data from 1911 to the present indicates that current forests have changed drastically, particularly in tree density, canopy cover, the density of large trees, dominance of white fir in mixed conifer forests, and the similarity of tree basal area in contemporary ponderosa pine and mixed conifer forests. Average forest canopy cover increased from 25–49% in mixed conifer forests, and from 12–49% in ponderosa pine forests from 1911 to the present. Current forest restoration goals in the southern Sierra Nevada are often skewed toward the higher range of these historical values, which will limit the effectiveness of these treatments if the objective is to produce resilient forest ecosystems into the future, as was found in the Sugar Pine site. Allowing more of the mixed conifer forests in the Sugar Pine area to received treatments that produced forest structures similar to those found in 1911 would have reduced potential fire behavior more than the 4% observed in this study.

Agee, J. K., and C. N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management 211:83–96.

Stephens, S. L., et al. 2009. Fire treatment effects on vegetation structure, fuels, and potential fire severity in western U.S. forests. Ecological Applications 19:305–320.

Stephens, S.L., Lydersen, J.M., Collins, B.M., Fry, D.L., Meyer, M.D., 2015. Historical and current landscape-scale ponderosa pine and mixed-conifer forest structure in the Southern Sierra Nevada. Ecosphere 304:492–504.

COMMENT 2: Another area where additional science assists land managers in making management decision and something that, perhaps SNAMP could not really measure (and/or draw conclusions upon) is the idea of sustainability of the stand structure in the key Fisher denning and foraging habitat stands, which by design and management restrictions were effectively off limits from any substantive vegetation treatments. Most of these stands are overstocked from a tree-health perspective. Catching overstocked stands "in the act" of losing vigor and increasing mortality in a 7 year period, even with 4 below-average rain years is difficult, if not impossible but is something that I also feel could have been highlighted as a limitation/ caveat in the conclusions not only in the FFEH but also the Wildlife sections. Many of the stands presented to SNAMP, although looking like mixed conifer, were in fact pine stands. Railroad logging and fire suppression changed that so a different profile was presented. It is one of higher stand densities (typical of MC) and larger trees (owing to the timing of RR logging and the removal of the dominant, more representative pine). This structure lends itself to much larger trees, higher Basal Areas and conditions much more favorable to quality fisher habitat. Much of the reason white fir was not reduced as much, as would be preferred, is the fact that in all areas, especially key fisher areas, many that those trees are too big to be able to manage in lower, more ecologically sustainable number and sizes (for a pine stand). They were either > 30" DBH or they were the primary component of the dominant/codominant canopy structure needed for retention. Both of these restrictions are part of the management box we had to play in. The control area (Nelder) is GROSSLY overstocked and we feel may put the giant sequoias in jeopardy not only from fire but also competition-induced tree mortality. Literature review over the past many years (and decades) does not support the long-term sustainability of such "artificial" stands, especially in view of the reality of climate change. At least putting greater emphasis on a potential management challenge of sustaining what is likely "artificial" fisher habitat would help elevate the true nature of tradeoffs in managing for such habitat and the potential effect of FFEH.

RESPONSE: The dramatic increase in growth efficiency observed at Sugar Pine in response to modest-to-minor reductions (Fig. A21B) in stand density supports the contention that trees in the Sugar Pine forest are under severe competitive stress. We also agree that the Nelder Grove (control area) is even more crowded than Sugar Pine (15% higher basal area than the reference, Table A9). But these differences in competitive stress have not yet manifested themselves in increased tree mortality (Fig. A8). Projections from the growth models for Sugar Pine lend further support to the argument that the forest is crowded. Under the "no treatment, no fire" scenario, there is no projected future increase in basal area (Fig. 3-4, Chapter 3). In short the forest is not growing due to competitive constraints. We emphasize the value of SPLATs to improving forest health in Chapter 5 (12th management recommendation). The question of the sustainability of the forest structure at Sugar Pine is crucial, but our empirically informed modeling results suggest stasis at Sugar Pine not decline (Fig. A21B). Also the long-term data from old-growth mixed conifer forests in nearby Yosemite and Sequoia-Kings Canyon National Parks suggest that these highly stocked stands have persisted for the last three decades (Fig. S2, van Mantgem and

Stephenson 2007). Of course van Mantgem and Stephenson (2007) also point out the recent increases in tree mortality driven apparently by a warming climate. Thus, while there is some support for the notion of an at-risk, “artificial" stand structure at Sugar Pine, our results are not definitive. While we intentionally frame management recommendations in terms of a specific goal, the trade-offs between managing for fisher habitat and tree growth efficiency are made implicitly. This approach follows the framework developed collectively among the SNAMP stakeholders.

van Mantgem, P.J., Stephenson, N.L., 2007. Apparent climatically-induced increase of tree mortality rates in a temperate forest. Ecology Letters 10: 909-916.

D. Response to comments from Peer Reviewer #9.

Thank you for the positive review.

E. Response to comments from Peer Reviewer #10

GENERAL COMMENT 1: The authors may not have been tasked with addressing how the treatment effects may be altered as climate changes, but any modern assessment of multi-decadal treatment effects should have such an assessment, in my opinion.

RESPONSE: We agree with Reviewer #10 about the impact of climate change, especially for results from models that project effects of SPLATs and fire thirty years forward. Climate is a pervasive driver of forest and fire dynamics. However our charge, as broad as it was in the Memorandum of Understanding among the agencies, did not include nor fund analyses that included climate change. In our summary statement (pages A61-62), we did acknowledge the importance of global environmental change to both the ecology and management of the Sierran forests.

GENERAL COMMENT 2: The Appendix to the report, titled “Appendix A.1, Spatial and temporal components of historical fire regimes in a mixed conifer forests [sic], California”, describes a fire history reconstruction study done in a portion of the SNAMP landscape. The study in the Appendix appears to have been carried out competently in terms of sampling and some of the analysis. However, there are additional analyses that would have been important to include. In addition, the text suffers from some unsupported statements, some exaggeration, and a remarkable number of spelling and grammatical errors. In its current form, the Appendix is not suitable as a professional report.

RESPONSE: These comments are general and do not offer any specifics for improving the report. The reviewer did generously offer to provide detailed suggestions later, but we did not receive them in time to respond here. We believe that the disconnect is due, at least in part, to expectations of the reviewer. Instead of doing a traditional analysis that would be similar to nearby published fire history studies, we produced spatially explicit fire return interval maps for both sites. This method provides additional information on how fire historically varied across the landscape. Nonetheless, we removed Appendix A.1 to revise more thoroughly and will submit separately as a peer-reviewed publication.

ITEMIZED RESPONSES TO DETAILED COMMENTS
(note that line numbers refer to the draft version of Appendix A).

1. General comment on units: in part of the text, both English & metric units are used, in one part metric only (e.g., L. 429), and in the Tables English only. Please be consistent.

RESPONSE: Good point. Given our goal of informing management, we have used English units for the measurements and provided metric conversions in the text. However in the tables and figures, the goal of a clean, uncluttered design prevents the inclusion of metric conversions. Thus we have revised all our tables and figures with English units as the primary measure.

2. Abstract p. i: should read "in order to quantify…", not "quantity"

RESPONSE: Fixed typo.

3. L. 16: of the three references here, only one is relevant to the species in the present study and mentioned on L. 12-13. The Brown and Naficy papers are on ponderosa pine forests in South Dakota and Montana, respectively.

RESPONSE: Ponderosa pine is a major component of forests in the SNAMP study but the reviewer is correct in noting the differences between the forest communities. We have deleted the Brown and Naficy references and added the Knapp et al. (2013) reference, a study conducted in the Sierra Nevada.

Knapp, E. E., C. N. Skinner, M. P. North, and B. L. Estes. 2013. Long-term overstory and understory change following logging and fire exclusion in a Sierra Nevada mixed-conifer forest. Forest Ecology and Management 310:903-914.

4. L. 25: would be helpful to give a quantitative range of reduced fire risks associated with treating 30% of the area, rather than just saying fire risk "can be decreased". Presumably fire risk would be "decreased" due to treating 1% of the landscape, or 99%. The point Finney was arguing is that "strategically" located treatments would give a disproportionate benefit in term of reducing the likelihood of severe fire.

RESPONSE: Good point. We have revised the sentence and added a specific example to illustrate the "disproportionate benefit."

5. L. 38-40: awkwardly worded sentence starting "This concern…"

RESPONSE: Sentence revised.

6. L. 45: besides adding sediment (due to soil disturbance associated with treatment?), in what other way would the treatment "lower water quality"?

RESPONSE: Sentence revised.

7. L. 57: should read “forests OF the Sierra Nevada…”

RESPONSE: Fixed.

8. L. 61: Westerling’s study was over a much larger area, the western US.

RESPONSE: True but the conclusions regarding earlier spring snowmelt and increases in large fire frequency specifically pertain to the Sierra Nevada. Indeed some of the largest effects seen are in the Sierra Nevada (Westerling et al. 2006) based on the maps depicted in Fig 4 (forest vulnerability to changes in spring timing) and Fig S2 (fire reporting by location). Thus we have retained the reference.

Westerling, A. L., H.G. Hidalgo, D.R. Cayan , and T.W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. Science 313: 940-943.

9. L. 64: the “fire deficit” described by Marlon et al. appears to be mainly the result of fire suppression, as the authors stated, but it reflects a deficit of surface fires, the theme of the present study, as well as severe fires, which in the context of this study are to be avoided. The Marlon reference blurs the distinction between surface vs. severe fire regimes & therefore is not helpful in the present context (in my opinion).

RESPONSE: The point we were making with this reference, which includes the following sentences in the paragraph, is that there is currently less fire on the landscape than would be expected given the current climate. This, combined with other evidence about departed fire patterns in these forests relative to historical conditions, suggest that there is real potential for future fires to not only continue current trends, but perhaps worsen. We added a sentence to clarify this point at the end of the paragraph.

10. L. 93: would be useful to give a quantitative figure, rather than “noticeable reductions”.

RESPONSE: We disagree on the need for more a more quantitative description. The inconsistencies in metrics used in each of the studies (i.e., fire size, conditional flame lengths, conditional burn probabilities, etc.) limit the comparisons to qualitative descriptions.

11. L. 106-110: great point about buying time. Note the reference to “restoration activities”, see comments below.

RESPONSE: See response below.

12. L. 115-158: the authors give a reasonable presentation of the literature on “forest health”, a concept with strengths and weaknesses. They make a logical case for the selection of tree mortality and tree growth as useful indicators of tree health and, roughly, “forest health” in this study. However, the review is brief and limited. A surprising omission, in the light of the

Forest Service´s emphasis on ecological restoration and the references to restoration in the text itself, is the literature on ecological restoration. A basic element of restoration is the reference condition, which includes as much information as possible about ecosystems prior to recent human-caused degradation: plants, animals, forest structure, ecological processes, influences of non-industrial human societies, etc. See for example the Primer by the Society for Ecological Restoration. Many of these elements are mentioned in the text here and in the Discussion, but not in an integrated manner.

RESPONSE: Forest health is an over-arching theme of SNAMP addressed from multiple perspectives by the various research teams. Clearly the status of sensitive wildlife species is relevant to forest health as is the quality and quantity of the water. Given that the term is meant to help convey a synoptic sense of forest condition to stakeholders, there is also an element of public perception to the concept of health. Even the Spatial Team with their deconstruction via remote sensing of spatial heterogeneity contribute to the evaluation of health. We acknowledge that our efforts to quantify forest health take a tree-centric approach. This approach is grounded on the premise that healthy trees are a necessary but not sufficient quality of a healthy forest. Thus, we focus on the vegetation response in this report. As part of the SNAMP integration process (Chapter 4), we bring together these elements in a consistent framework, one that more closely matches the reviewer's understanding of the term.

Regarding the link between forest health and ecological restoration, we agree that the status of North American ecosystems before colonization by Europeans is often considered an example of a healthy ecosystem. We also agree the ecological restoration is a priority for the US Forest Service. However, we disagree that the goal of SPLATs as envisioned in the 2004 Amendment to the Sierra Nevada Forest Plan is to restore the forest to a desired future condition defined by pre-European conditions. Instead, SPLATs are more a step in the right direction toward modifying an altered fire regime and improving tree survival and growth by reducing tree density and surface fuel loads. SPLATs is a form of triage designed to stabilize worrisome trends in fire hazard and tree morbidity until a more lasting solution can be found (see pages A1ff). Thus SPLATs are a step in the right restoration direction but they are not designed to return the landscape to a desired future condition. Thus detailed descriptions of potential target forest composition and structure are not relevant here.

13. L. 122: “trees and trees alone” sounds a bit colloquial.

RESPONSE: Revised.

14. L. 183: not clear whether the figure of 1182 mm refers to total precipitation (water equivalent) or to snow depth?

RESPONSE: Revised to make clear that 1,118 mm is the mean annual precipitation.

15. L. 208-218: it´s not clear what is the relationship between the cited studies (e.g., Scholl and Taylor 2010) and the fire history study in Appendix A1. Would be helpful to clarify the distance to the previously studied sites, the species, etc. As written, since the cited studies are

used to describe the pre-Euro-American fire regime, it is not clear to the reader why new fire history data were collected. (Incidentally, given the long history of Spanish colonization, what do the authors consider to the date of "Euro-American settlement"?).

RESPONSE: We revised the sentence to make it clear that we referring more generally to similar forest within the Sierra Nevada. The revised sentence now reads: "Fire history, inferred from fire scars recorded in tree rings, suggests the fire regime prior to systematic fire suppression and widespread timber harvesting in Sierra Nevada west-side pine-mixed conifer forests was dominated by frequent, low-severity fires occurring at regular intervals (Stephens and Collins 2004, Scholl and Taylor 2010)."

16. L. 220, Methods section: field sampling was logically designed and a substantial amount of data was collected.

RESPONSE: No response needed.

17. L. 239: "were navigated to using…" is awkward.

RESPONSE: Revised.

18. L. 240: should read "Garmin".

RESPONSE: Corrected.

19. L. 264: please give more detail about prescriptions: was there a target forest structure? Residual basal area?

RESPONSE: Targets for residual basal area and canopy cover retention added. Note that these are descriptions of the planned treatments. The actual treatments applied are quantified in great detail later (Tables A5-9, Fig. A7).

20. L. 282-292: the authors did a good job of assembling the treatment boundary data but this section highlights the ridiculous situation of the lack of detailed spatial information about treatments in the National Forests. The Forest Service doubtless retains all receipts for repair of its vehicles or purchase of a desk, but is incapable of adequately describing the contracts for management treatments on FS lands!

RESPONSE: We agree. It would be helpful if there were a more streamlined way to track treatments on public lands.

21. L. 299: the Lidar data should be explained to the reader. The report references an Appendix B which was not included for this review.

RESPONSE: We appreciate this criticism. We do not provide much explanation of the lidar data and how it is used our section. However, in the complete report on the SNAMP project, the acquisition of remote sensing products and spatial analysis are described in detail. This chapter immediately follows ours. Thus, we refrain from repeating information here.

22. L. 323: why were numbers of seedlings randomly generated? A citation is given but the logic should be explained and justified.

RESPONSE: The numbers of seedlings were randomly generated within bounds that varied by species. This was to done to attempt to represent the variable regeneration conditions observed across the studied landscapes. We added a sentence to explain this reasoning.

23. L. 326-331: please clarify the role of FVS & FFE. Were any fires simulated in FVS-FFE? Or were these models used solely to grow trees & track fuels, in the absence of fire, with all fire behavior simulations occurring in FARSITE or FlamMap?

RESPONSE: We have revised the methods describing our fire modeling (pages A18ff). First we explain the use of FVS to generate landscape forest structure maps for fire behavior modeling, for each of the treatment scenarios. Next, we explain our dual approach to fire behavior modeling with FARSITE and FlamMap. FVS was used to simulate fire effects (i.e., changes to forest structure) using the fire behavior outputs from FARSITE. We acknowledge that this is not clear in the text so we added several sentences to describe this step.

24. L. 342: describe the use of Lidar to describe topography. My (limited) understanding of Lidar was that different measurement approaches would be appropriate for measuring vegetation vs. measuring the surface underneath the vegetation.

RESPONSE: The reviewer is correct. Lidar alone was used to predict topography. The vegetation map used a combination of remote sensing products (lidar, NAIP imagery) and field plots. To avoid redundancy, we reference Appendix B of this report for the details of the lidar applications.

25. L. 344: the use of a "problem" fire is traditional & reasonable, but the reader would expect a discussion of the limitations of the concept.

RESPONSE: This is a good point. We added the following text at the end of this paragraph in the start of the next one: "This approach of using a single simulated fire for each treatment scenario (with and without treatment) limits inference that can be drawn from these results due to potentially different fire spread and behavior associated with different ignition locations. We used a single fire in order to obtain specific predictions on how fire would impact forest structure via tree mortality, as opposed to probabilistic predictions on fire occurrence at a specific location (e.g., Ager et al. 2007). By having spatially explicit predictions of fire effects on forest structure, we were able to track the impacts of fire on owl habitat and make more direct assessments of owl demography over time.

26. L. 355: was spotting enabled in the FARSITE simulation? See later comment about windspeed. In a real fire, higher windspeeds and spotting would be a critical combination.

RESPONSE: Yes, spotting was enabled with a 2% ignition frequency and a 2 min. delay. This is already in the text.

27. L. 359: should read “used A command-line…”

RESPONSE: Fixed.

28. L. 415: true that the design “accounts for” changes, but the BACI design is limited, with no or limited replication.

RESPONSE: Agreed but for ecosystem-scale research, true replication is hugely expensive. The BACI design used here (the paired firesheds) is a well-established alternative to replication that does provide some measure of reference to statistical evaluate the impact of treatments. However, there are limitations. Work by Murtaugh (2000, 2002) suggests that BACI designs tend to overestimate significant impacts (although see Stewart-Oaten 2003). Most of our statistical tests of treatment impact were not significant. Thus our conclusion of limited treatment impact on forest-wide composition and structure are conservative with respect to the statistical bias of BACI analyses.

Murtaugh, P. A. (2000). Paired intervention analysis in ecology. Journal of Agricultural, Biological, and Environmental Statistics, 280-292.
Murtaugh, P. A. (2002). On rejection rates of paired intervention analysis. Ecology, 83(6), 1752-1761.
Stewart-Oaten, A. (2003). On rejection rates of paired intervention analysis: Comment. Ecology, 84 (10), 2795-2799.

29. L. 430: is the term “conditional burn probabilities” a standard term? It sounds confusingly similar to the concept of “conditional crown fire” suggested by J. Scott. Please clarify and please also explain how the authors dealt with the situation called “conditional crown fire”, when the canopy bulk density is sufficient to carry crown fire horizontally but the canopy base height is too tall for simulated vertical propagation of the fire.

RESPONSE: Burn probability is a standard term (see FlamMap supporting documents) and is computed by dividing the total number of times a pixel is burned by the total number of simulated fires. The probabilities are “conditional” on the occurrence of an ignition within the larger buffered study area, under the modeled moisture and wind conditions. Issues with accurately estimating canopy base height are known, as well as the limitations in fire behavior models. The canopy base heights used in the model are from out plot data. The most common approaches to deal with the underestimation are to increase fuel models, fuel moisture, or weather conditions. We chose to adjust our fuel model assignments similar to the methods described in Collins et al. (2011, 2013), where assignments are skewed towards a more active fuel model (e.g., TL9 in place of TU2).

Collins, B.M., Stephens, S.L., Roller, G.B., Battles, J.J., 2011. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. For. Sci. 57, 77–88.

Collins, B.M., H.A. Kramer, K. Menning, C. Dillingham, D. Saah, P.A. Stine, and S.L. Stephens. 2013. Modeling hazardous fire potential within a completed fuel treatment network in the northern Sierra Nevada. Forest Ecology and Management 310:156–166.

30. L. 434: where does the 2-m flame length threshold come from?

RESPONSE: As mentioned in the text, we used methods described in Collins et al. (2011, 2013). A 2m cutoff allows us to separate out more problematic simulated fire occurrence, both from a fire effects and a fire suppression standpoint. Flame lengths >2 m typically correspond with crown fire initiation and present substantial challenges for suppression efforts (NWCG 2004). Further, using a fixed cutoff based on individual stand conditions (e.g., Ager et al., 2007, 2010) such as canopy base height places too much weight on a single, influential variable that can often be problematic to measure and may exhibit unrealistic ranges in calculated values given small changes in stand conditions (Rebain 2010).

Ager, A.A., Finney, M.A., Kerns, B.K., Maffei, H., 2007. Modeling wildfire risk to northern spotted owl (Strix occidentalis caurina) habitat in Central Oregon, USA. For. Ecol. Manage. 246: 45–56.

Ager, A.A., Vaillant, N.M., Finney, M.A., 2010. A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure. For. Ecol. Manage. 259: 1556–1570.

Collins, B.M., Stephens, S.L., Roller, G.B., Battles, J.J., 2011. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. For. Sci. 57: 77–88.

Collins, B.M., H.A. Kramer, K. Menning, C. Dillingham, D. Saah, P.A. Stine, and S.L. Stephens. 2013. Modeling hazardous fire potential within a completed fuel treatment network in the northern Sierra Nevada. Forest Ecology and Management 310: 156–166.

NWCG, 2004. Fireline Handbook – Appendix B, Fire Behavior. National Wild-fire Coordinating Group, Incident Operations Standards Working Team PMS 410-1, 124p.

Rebain, S.A., 2010. The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated Model Documentation. USDA For. Serv. Internal Rep., Fort Collins, USA, 395p.

31. L. 446: it seems quite illogical to calculate the trees that were intentionally cut as “mortality”. Why was this done?

RESPONSE: We included the harvested trees in our estimate of mortality as another means to quantify the impact of the treatments on the entire fireshed. Thus, in Fig. A8 we are able to show that annual mortality (harvest trees NOT included) between the control and treated firesheds did not significantly differ over time. When we include harvest mortality, we do get significant differences between treatment and control. We realize that harvested trees are not typically considered as mortality, but we need a consistent metric. We use one term and provide a clear description of how it was calculated.

32. L. 495: delete the word “on”.

RESPONSE: Fixed.

33. L. 512: LAI appears here as a critical variable, yet it was not measured in the Methods. Where did the LAI values come from? How reliable are LAI estimates?

RESPONSE: We added details on the calculation of the LAI values in the text. The data came from a recently published study (Jones et al. 2015) that destructively sampled trees from across the Sierra Nevada. The LAI estimates are very reliable with generalized $R^2 \geq 0.87$.

Jones, D., K.O. O'Hara, J.J. Battles, and R. Gersonde. 2015. Alternative procedures for leaf area estimation in Sierra Nevada conifer trees. Forests 6: 6, 2631-2654.

34. L. 644-647: complicated way to say that trees from dense stands have a large growth response when released by thinning…

35. L. 693: appropriate discussion of the weaknesses of the fire behavior model. See also comment on windspeed below.

RESPONSE: No response needed.

36. L. 709: reasonable discussion of CBH modifications.

RESPONSE: No response needed.

37. L. 720: good discussion of fuel model issues.

RESPONSE: No response needed.

38. L. 738: Lidar needs more explanation.

RESPONSE: We have revised and expanded the explanation of the problem of abrupt transitions between stands. These transitions are introduced by the necessity of converting a finely resolved pixel-based vegetation map to the more coarse-scale stands needed for fire modeling. The breaks across stands are artefacts of the scaling but they can contribute to unpredictable fire behavior.

39. L. 762-764: authors say there is no explanation beyond self-thinning, but what about drought effects during these years?

RESPONSE: The interval between pre and post-treatment measurements included no more than the first two years of the current drought (remeasurements were conducted during the 2013 growing season). Thus, drought may play a role but the decrease in understory density was observed only at one site (LC). If it were drought, we would expect a more regional consistent response.

40. L. 798 & 806: here, very late and only mentioned in passing, are key issues of ecological restoration and global change. These themes merit more discussion in the context of the treatments.

RESPONSE: See previous responses regarding 1) the role of SPLATs in ecological restoration and 2) the charge to the science team in relation to climate change.

41. Table 2: these windspeeds are extraordinarily low, averaging 6-10 mph. Are these mid-flame or 20-ft windspeeds? Are the problem fires in the Sierra Nevada really associated with such low windspeeds? Please clarify, justify, or change if appropriate.

RESPONSE: Wind data used in the fire modeling were from nearby RAWS, which are considered to be 20-ft windspeeds. In both models, we used either actual wind data (FARSITE) or 95th percentile weather conditions (FlamMap) and these are the methods typical used. There are several limitations of wind measurements and use in the fire modeling programs, including averaging measurements over time which underrepresents wind gusts, wildfire induced winds are not considered, and a poor understanding of wildfire-winds interactions, and wind patterns over complex terrain.

42. Table 4: the Last Chance site seems quite open at the beginning, BA 133 and TPA 252. Is this really a fuel problem?

RESPONSE: At the landscape scale, the LC forest definitely has a more open structure with smaller canopy trees than SP. Certainly, part of the difference is due land-use history with a greater emphasis on timber cutting at LC. However, in absolute terms, the contemporary forest is more closed than pre-fire suppression forests (Collins et al. 2011). Also this fireshed average includes the shrubland and woodland patched in the landscape. There are extensive tracts of dense mixed conifer forests -- 59% of the area has canopy cover >60%. These dense stands do present a fuel problem.

Collins, B. M., Everett, R. G., & Stephens, S. L. 2011. Impacts of fire exclusion and recent managed fire on forest structure in old growth Sierra Nevada mixed-conifer forests. Ecosphere, 2(4), art51.

43. Table 4: what is Lorey height & why was it used? Please also present actual height values.

RESPONSE: Lorey height is the mean tree height weighted by the tree's basal area. Thus, Lorey height is calculated by multiplying the tree height by its basal area and then dividing the sum of this calculation by the total stand basal area. It is a more stable measure of stand height since the removal of small trees has only a minor influence on the mean. We report it because the Spatial Team found Lorey height (as estimated via lidar) to be one of the three primary determinants of vegetation type. However, we agree with the reviewer that mean tree height would be a better descriptor of the stand. We have revised Table A4 as suggested.

44. Table 6 & 7: why such a big difference in mastication effects on fuels, with a doubling at LC but little effect at SP?

RESPONSE: Fuels were measured using line transects before and after treatments. There were 5 masticated plots at LC and 10 at SP, and we relied on treatment polygons from the FS and field observations from our field crew to identify treatment type. It's unclear why there are such large differences in the temporal changes between sites. Two possibilities include the chance that the few masticated plots at LC were located in a productive area of the forest with high shrub cover, and undocumented pile burning may have occurred at SP that removed activity fuels from those plots.

45. Table 7: column headers out of line.

RESPONSE: Corrected.

46. Table 8 & 9: shouldn´t the treatment impact be "delta mu" rather than "mu"?

RESPONSE: Corrected.

47. Figure 7: repeats data given in Table.

RESPONSE: Figure A7 shows plot data averages for pre- and post-treatment conditions, by treatment type. Data illustrated in the tables are summarized by site and fireshed.

48. Figure 9: illustrates the minimal (negligible?) impact of these treatments.

RESPONSE: Yes we agree that there were no changes in tree-size distribution due to the SPLATs. As we state on page A36: *"There were no changes in tree size distribution in pre-to-post treatment greater than 10% in any of the firesheds."*

F. Response to comments from Steve Brink, California Forestry Association.

COMMENT: The most interesting research findings in this document are: There was not enough treatments to statistically indicate anything.

RESPONSE: We presume this comment refers to the lack of statistically significant treatment effects on forest structure (e.g., canopy cover, basal area) reported in Tables A8 and A9 in the report. The comment is not entirely accurate. There was a significant reduction in understory tree density at Last Chance (Table A8) as well as significant increases in overstory tree mortality at both sites due to the treatments (Figure A8). However, the general sense of the comment is valid – the impacts of the treatments on forest composition and structure were modest. As we explain in the report (page A13), treatment area was limited to only a fraction of the landscape. So the majority of the treated fireshed (> 70%) is identical to the control fireshed in that it was not treated. Thus, detecting significant change is a very high bar. Also, it is important to note that the most relevant impact of SPLATs is not changes in composition and structure but on wildfire behavior. This response is measured in our fire simulations and reported in Table A10. Given that the results are from models, statistical tests of the treatment impact are inappropriate. We extend the immediate pre-post effects reported in Table A10 with the results from our simulation scenarios over 30 years (Figure A20). In aggregate, these analyses are consistent; they demonstrate modifications to fire behavior due to SPLATs.

COMMENT: P. 16, line 352 - I believe the French Fire vegetation burn severity information is available from the Forest.

RESPONSE: As with all of our fire severity images we download the data from Monitoring Trends in Burn Severity (http://www.mtbs.gov/). At the time of this report the French Fire image was not available from the website.

SNAMP Spatial Team
Chapter Revision Document

Maggi Kelly and Qinghua Guo, Co-PIs of the Spatial Team of SNAMP

August 19, 2015

We received two peer reviews for our *Spatial Team Final Report* (Reviewer #2 and Reviewer #7), and several comments via the online survey tool. We address these comments in this document, and have revised the chapter.

Reviewer #2
General Comments:

1. *Did the Spatial Team provide the best available ALS products to the Science Teams?*
    a. In short, the answer is yes. ALS systems measure topography (elevation, slope, aspect) and a wide variety of vegetation canopy heights and densities directly, i.e., no models need to be developed to calculate these height and density numbers once a ground surface is defined. These include many, though not all, of the height, percentile, and pulse density metrics listed in Table 1, page 16 and 17. From these measurements, a second suite of useful estimates can be derived, e.g., Lorey's height, tree volume, tree biomass, canopy base height, canopy volume.
        Response: These are good suggestions.
    b. The Spatial Team developed their multi-temporal ALS measures and estimates using a multi-stop ALS system. They write repeatedly in their final report that a small-footprint waveform system might have provided better results. Such waveform systems are now commercially available (e.g., www.riegl.com), but I am not convinced that the extra data load and post-processing requirements provide a significant advantage except in situations where users want to summarize vertical vegetation profiles on relatively small raster cell sizes, e.g., smaller than a 5m x 5m cell. Admittedly, my previous statement is arguable, however Skowronski et al. (2011, Remote Sensing of Environment 115: 703-714) have reported some success estimating canopy bulk density and canopy fuel weight with an ALS multistop system. I suggest that the authors not characterize a small-footprint waveform system as a possible solution to multistop limitations until direct comparisons can be made. The authors may be correct, but unless you can cite a refereed study where waveform outperforms multistop as regards prediction of, for instance, forest fuels variables, e.g., canopy base height, canopy bulk density, you should not make the claim.
        Response: Good point. We have revised the text.
        Here are some references we have that showing waveform outperformed the discrete lidar in estimating forest parameters, such as biomass, detecting individual trees, etc.

        We agree that a discrete lidar system can produce accurate enough forest parameter estimations in most cases. However, there are studies that show that small footprint full-waveform lidar system outperformed the discrete *airborne lidar system in mapping forest aboveground biomass, delineating individual trees, etc. (Cao et al. 2014; Reitberger et al. 2009).*

References
Cao, L., Coops, N. C., Hermosilla, T., Innes, J., Dai, J., & She, G. (2014). Using small-footprint discrete and full-waveform airborne LiDAR metrics to estimate total biomass and biomass components in subtropical forests. Remote Sensing, 6(8), 7110-7135.
Reitberger, J., Schnörr, C., Krzystek, P., & Stilla, U. (2009). 3D segmentation of single trees exploiting full waveform LIDAR data. ISPRS Journal of Photogrammetry and Remote Sensing, 64(6), 561-574.

2. *Could SNAMP have been managed better so that Spatial Team products better addressed the concerns of the four Science Teams?*
   a. Yes. The USFS should have implemented their forest fuels treatments on schedule so that the original BACI approach could have been implemented. As written, the seven year SNAMP was designed (1) to study empirically (via field sampling and remote observations) post-treatment effects over a 0-5 year time period and (2) to model post-treatment effects out to 30 years. The UC field teams started pre-treatment data collection in 2007. The fuels treatments were not done until 2011 and 2012. Only 1-2 years of post-treatment fieldwork was done The fact that the fuel treatments were delayed for 3-4 years certainly significantly impacted the 5 year empirical study and most likely impacted the long-term models. This comment is not meant to reflect badly on the Spatial Team since they most likely had little control over treatment implementation, but it does reflect poorly on overall project management.

      Response: Thanks for the comment.

   b. The multitemporal ALS flights should have been timed to be seasonally coincident to improve comparability. To manage costs and logistics, SNAMP wisely took a case study approach, selecting two study areas, one in the north (Last Chance), and one south (Sugar Pine). The Last Chance ALS data collects were done in September 2008 - pre-treatment, and November 2012 and August 2013 (post-treatment). The Sugar Pine collects were done September 2007 (pre-treatment) and November 2012 (post-treatment). Both north and south sites are most likely predominantly coniferous, but if there are significant hardwood components on each area, then leaf-on / leaf-off differences pre- and post- fuels treatment will be convolved, adding noise to any comparisons made and uncertainty to any of the conclusions reached. Project managers should have insisted that multitemporal ALS data collects be done in the same month years apart, preferably leaf-on, preferably mid-summer.

      Response: We agree.

   c. Although the Spatial team provide rasterized products to the Science Teams at requested cell sizes, I was surprised to see that you base these raster products on individual tree delineation and measurement. I wonder why you made this choice as opposed to using an area-based approach used by Næsset and many others. The individual tree delineation numbers that I see in the literature vary from about 60 - 80%, meaning that individual trees are properly located and identified for measurement only 60-80% of the time. Understory trees and trees in closed canopy situations are typically undercounted. Somewhere in your report I would suggest that you add a paragraph that explains what you gained by delineating individual trees in the ALS data. I do not say that what you did is wrong, but your individual tree approach brought along with it a host of problems that included individual tree omission and commission errors, increased sensitivity to relatively small GPS misregistration errors in the field and in the lidar data, a more complicated field protocol that included logging locations of all individual stems and crowns. What did you gain, and in hindsight, would you do it the same way again or make some changes such as considering an area-based approach with a minimum cell size? In your defense, I understand that at least two of your Science Teams - Wildlife and the fire fuels treatment team - would be interested in changes as regards specific individual trees, and that consideration may have drove your decision to identify and measure individual canopies.

Response: We agree that area-based individual tree segmentation method is a more commonly used method. These area-based methods relied on the fine-resolution rasterized products (i.e., canopy height model, CHM) to identify the crown location of each individual tree. However, as mentioned by the reviewer, the problem of significantly underestimating the understory trees has been reported by many studies (Vauhkonen et al. 2011). Furthermore, the CHM-based method uses lidar data that only describe the outer surface of tree crowns, and thus the advantages of lidar data are not fully exploited. In SNAMP, we developed a new method to delineate individual trees directly from the raw lidar point cloud. These kind of vector methods have been reported to improve individual tree segmentation accuracy (Jakubowski et al. 2013), and have been used in other studies more and more widely (Vega et al. 2014; Lu et al, 2014)

References

Jakubowski, M. K., Li, W., Guo, Q., & Kelly, M. (2013). Delineating individual trees from Lidar data: A comparison of vector-and raster-based segmentation approaches. Remote Sensing, 5(9), 4163-4186

Lu, X., Guo, Q., Li, W., & Flanagan, J. (2014). A bottom-up approach to segment individual deciduous trees using leaf-off lidar point cloud data. ISPRS Journal of Photogrammetry and Remote Sensing, 94, 1-12.

Vauhkonen, J., Ene, L., Gupta, S., Heinzel, J., Holmgren, J., Pitkänen, J., ... & Maltamo, M. (2011). Comparative testing of single-tree detection algorithms under different types of forest. Forestry, cpr051

Vega, C., Hamrouni, A., El Mokhtari, S., Morel, J., Bock, J., Renaud, J. P., ... & Durrieu, S. (2014). PTrees: A point-based approach to forest tree extraction from lidar data. International Journal of Applied Earth Observation and Geoinformation, 33, 98-108.

3. *Is the report clearly written? Can changes be made which might improve Spatial Team Final Report readability?*

a. In general the report is clearly written, however the specific suggestions below should improve readability. By way of generalities, the authors should clearly draw a distinction between measured variables and estimated variables since the latter incorporate model error. Too often, the variables are muddled together in tables and text. For instance, you measure maximum height or average canopy height or various height or density deciles (or quintiles or quartiles) on a given cell by accumulating first-return and secondary-return laser ranging information as needed. You'd estimate that cell's biomass or canopy bulk density or Lorey's Height by developing an equation that relates field estimates of biomass or canopy bulk density or basal-area-weighted tree height to some subset of ALS measurements listed in the previous sentence.

Response: We agree. The lidar-derived topographic and forest parameters can be generally categorized into two groups, directly computed from lidar range measurements (e.g., digital elevation model, digital surface model, canopy height model, and canopy quantile matrices) and indirectly computed from regression method between the directly obtained lidar products and field measurements. We have clarified the method used to calculate each product in the corresponding text and Table 2.

b. Finally, define acronyms when first used. This report may be read by folks (like me) not familiar with SNAMP.

Response: We have endeavored to do this throughout.

Specific Comments:

1. Should the title of this report be "Sierra Nevada Adaptive Management Project (SNAMP) - Spatial Team Final Report" (instead of Plan)?

   Response: Done.

2. pg 5. Define AGB. I realize that AGB = aboveground biomass, but is it total aboveground dry biomass, green biomass, stem only, all aboveground components including leaves/needles? Does tree volume equal stem volume to a certain top limit, or are you actually talking about the volume of space defined by the outer periphery of the tree crown?

   Response: Defined AGB. Tree volume refers to the volume of space defined by the outer periphery of the tree crown.

3. pg 5. Use of Lidar for biomass estimation: You write the following: "… the availability of, and uncertainly in, equations used to estimate tree volume allometric equations influences the accuracy with which Lidar data can predict biomass volume." Two things: First, the majority of the uncertainty associated with biomass estimation using lidar data has to do with the fact that, with ALS data, we don't know the diameter of the tree. With ALS, we estimate biomass (or stem volume, for that matter) based on height and canopy density. The primary driver in ground-based allometry is diameter, not height. The choice of allometric equation certainly makes a difference, but our inability to measure or infer dbh drives the uncertainty in ALS estimates of biomass. Second, what is biomass volume? Do you mean biomass density, i.e., biomass weight per unit area, e.g., 250 t/ha? Or biomass weight within a certain crown volume? I've worked in this field for 30+ years and have never heard the term biomass volume. Define.

a. *Response: We agree that the ALS cannot obtain the tree diameter at breast height (DBH), which means that the DBH-based allometric equations cannot be used directly to estimate aboveground biomass (AGB). The regression methods based on field allometric-based AGB measurements and ALS-derived tree volume and height matrices are usually used to generate AGB from ALS data instead of DBH. Therefore, the aboveground biomass estimations from ALS data are highly reliant on the field-measured AGB. However, by comparing AGB estimates with Jenkins allometric equations, we found that the commonly used regional (FIA) allometric equations might favor species with more published allometric equations, and consequently influence the ALS-based AGB estimation (Zhao et al. 2012). This is the reason we conclude that the selection of allometric equations can influence the capacity of lidar data to estimate biomass significantly, and a careful selection of the equations is necessary.*
b. *Response: We agree that there is no such term as biomass volume. We have revised the text.*

References

Zhao, F., Guo, Q., & Kelly, M. (2012). Allometric equation choice impacts lidar-based forest biomass estimates: A case study from the Sierra National Forest, CA. Agricultural and forest meteorology, 165, 64-72.

4. pg 6, 2. Wildlife: I suggest that you qualify your first Wildlife bullet. Two points. First, ALS data can only be used to map potential habitat, not actual habitat. We can't measure critters, we can only identify/map areas that might make a particular critter happy if it should choose to show up in a given area. Second, we can only map potential habitat if we can define a particular set of habitat characteristics that can be measured or estimated by the ALS, e.g., particular height, density, overstory/understory, biomass criteria.
   Response: We have revised that paragraph as suggested.
5. pg 6, 4. Forest Management: Actually, standard lidar products do currently meet the requirements of at least some forest managers, just not, in general, public sector foresters here in the US. This might change soon if USFS managers adopt laser-assisted ground inventory procedures to inventory undersampled areas in Alaska. Scandinavian companies routinely map/inventory forests with ALS, producing stand-level volume maps for sale to private landholders, and their public sectors are actively transferring that technical know-how to selected countries in Africa, SE Asia, and South America under the auspices of U.N. REDD+ and carbon programs. Your point is correct as far as CONUS goes; just be aware that some European countries are way ahead of us when it comes to operationally using ALS data in conjunction with ancillary (e.g., optical) data.
   Response: Agreed. This is an important point. We have revised the text to say this.
6. pg 9, 2nd to final paragraph: As previously discussed, I'm not sure that I agree with your statement that a waveform lidar can provide a better description of forest structure. And as noted above, small-footprint waveform lidars are available and it's my understanding that some lidars can be set up as either multistop or waveform, depending on the needs of the mission. In other words, the same laser system can serve as a waveform lidar on one mission and a multistop on the next (they cannot sequentially toggle between these two modes from one pulse to the next).

Response: As we responded in previous comment, we agree that a discrete lidar system can produce accurate enough forest parameter estimations in most cases. However, there are studies showing that small footprint full-waveform lidar system outperformed the discrete airborne lidar system in mapping forest aboveground biomass, delineating individual trees, etc. (Cao et al. 2014; Reitberger et al. 2009). Moreover, you are correct that discrete lidar and waveform lidar data can be collected through the same lidar sensors. However, this is true of certain full-waveform lidar sensors. Discrete lidar sensors can only record certain amount of return signals, and cannot digitize the full returned lidar waveform.

References
Cao, L., Coops, N. C., Hermosilla, T., Innes, J., Dai, J., & She, G. (2014). Using small-footprint discrete and full-waveform airborne LiDAR metrics to estimate total biomass and biomass components in subtropical forests. Remote Sensing, 6(8), 7110-7135.
Reitberger, J., Schnörr, C., Krzystek, P., & Stilla, U. (2009). 3D segmentation of single trees exploiting full waveform LIDAR data. ISPRS Journal of Photogrammetry and Remote Sensing, 64(6), 561-574.

7. pg 10, bottom: You write that there are no standard ALS metrics that capture forest structure. That's not really true; you list many of the "standard" variables in Table 1, specifically the height deciles and density deciles. Most of the remaining height and density variables listed in Table 1 are typically very highly correlated with these height and density deciles.
   Response: We agree. The "standard" metrics here do not include the lidar derived metrics (e.g., canopy quantile metrics). Instead, our list includes standard forest structure parameter metrics. We have revised the text to clarify this.
8. pg 11, 4th paragraph: Waveform lidar systems are typically sampled at 1 ns, a sampling interval that corresponds to a vertical distance of 15 cm - true. What is not true is the suggestion that this distance depends on maintaining a typical flying height. It has nothing to do with flying height and everything to do with the speed of light, ~30 cm/ns, regardless of the altitude of the aircraft.
   Response: Agreed. We have revised the text.
9. pg 12, 2nd paragraph: I think that you meant to say that your Optech GEMINI collected up to 4 discrete returns per pulse. Sometimes you'd receive only a first return, sometimes 2 or 3 returns, and, I suspect only rarely, 4 returns per pulse. Perhaps you could provide a percentage breakdown of 1-, 2-, 3-, and 4-return pulses, though do this only if that information is readily available. Also report the maximum scan angle considered in your analyses, e.g., ±7.5°, ±15°
   Response: We agree, and have revised the text.
10. pg 12: In Section 2.2, report the nominal XYZ accuracy of a given Optech pulse. Also report in 2.3.1 the XYZ accuracy of a given GPS reading.
    Response: We agree. We have added this information in the section.
11. Considering all error sources, can you provide an estimate of location error, ground versus ALS near the bottom of page 12?
    Response: Done.

12. pg 17, Table 1: Suggest that you identify Lorey's height as a modeled variable with a superscript, e.g., *.

    Response: Done.

13. pg 20, 5th line from bottom: change depended to dependent, 4th line from bottom: change expansive to expensive.

    Response: Done.

14. Section 4, general comment: You discuss the accuracy of many products in this section and report accuracy in Table 2. In order to assess accuracy, you need some sort of ground reference measure, i.e., a validated product that you trust more than the comparable ALS product being evaluated. In Section 4.3, you compare ground-based tree counts to ALS-derived tree counts. This is good, though I believe that you should report the range of percentage of trees under- or over-counted on each plot so that the reader gets a better feel for site variability; a scatterplot would be more informative. In Section 4.1, you conclude that the accuracy of DTM and DSM products increase with sampling density. This makes intuitive sense, but how do you know this? Did you compare the ALS DTM products to field-measured ground elevations? Did you compare, on a per-tree basis, DSM measures derived from various pulse density products to tree height measurements + ground GPS elevations? My point here is that, in each section and in Table 2, tell the reader what "truth" is and what lidar metrics specifically are compared to that ground reference information. When I look at Table 2, I see many R^2 values, but that's not really a measure of accuracy; it's a measure of percentage of variability explained by a linear model. On a per-tree basis, you can compare field-measured maximum height to the lidar maximum height for the same tree. But tell me how you're going to measure mean tree height in the field. Where is the mean height of a tree when you are on the ground looking through an angle-finder? You can't measure mean tree height in the field, though you certainly can with a laser which takes multiple height measurements on a single tree. So you move to a regression approach as you indicate in Table 2, but what are you regressing? Scatterplots would help greatly here for those comparisons denoted by "Indirect: from regression". An explicit identification of the ground reference data set would be most helpful for those ALS metrics directly compared to a reference data set. And the reader should not be forced to go to the NCALM report or references 4, 6, 24, 13, or some unnamed report yet to be submitted to find out how you assessed accuracy, or your surrogate for accuracy.

    Response: The accuracy of the DTM, DSM and DEM are provided by the National Center for Airborne Laser Mapping. They were evaluated by hundreds of ground measured GPS transects. All the vegetation related products (including the forest parameters and vegetation maps) were evaluated by the field plot measurements. We have revised the text and tables in the report to clarify this.

15. This table is the backbone or the skeleton of your report. Spend some time and column inches on it so that the reader knows explicitly what comparisons were made. It's very important that the reader knows, for instance, that some very critical measures of forest fuels cannot be reliably characterized using ALS measures.

    Response: As mentioned in our previous comment, we have revised the text and tables in the report to clarify this.

16. Many of your comments made in Sections 5 and 6 have already been addressed above. As noted previously, I disagree with your statement that standard lidar products do not

operationally meet the requirements of forest managers. They can, and in the future, they will. The only items currently stopping their use in the US is cost, need, and the technological intransigence of state and federal forest managers. Airborne lidars can not only tell you where the wood is and approximately how much is there, but for no additional cost will report topographic challenges of interest to forest engineers. Perhaps in 10 years, public sector forest managers will realize this and begin to come up to technical levels attained by Norwegian foresters 10 years ago.

Response: This is a great point and we agree.

Reviewer #7

- Overall, the spatial team has done a lot of work and definitely have fulfilled the goal of the SNAMP project. The number of peer-reviewed papers (11 published) speaks by itself. However, I wouldn't claim the work as technical breakthroughs. To promote the wide adoptation of lidar for forest management, two goals have to be achieved: the high accuracy of the derived veg products compared to the ones from conventional methods, and the capability of applying the lidar-based methods to larger area. Unfortunately, the two goals are rarely met at the same time in most of the current methods. Most methods can get good accuracy at local scale with lidar, but they often require a lot of inputs from the user and fine tuning. When the methods are applied over larger scales, they could break down simply because of the computation demand and the intensive inputs from the users to achieve reasonable accuracy (e.g., how long does it take to apply the point cloud-based method to map trees for the whole study area instead of just those in the field plots? how accurate is it to apply the OBIA method to detect down logs over other areas?). I have no intent to play down the works the spatial team has done, but simply mention a direction in which remote sensing scientists all need to make big breakthroughs.
- *Responses:*
  1. *We have changed the wording “technical breakthroughs” to “technical advances”. We meant by the wording to distinguish between those advances that are ecological, and those that are technical.*
  2. *Scale issue. We do agree that with the increase in area, the computational burden to map the vegetation unit, detect forest treatment extents, and estimate forest parameters will increase significantly. We have used parallel processing and other computer techniques to increase the computational efficiency. Moreover, we have developed our own software which can process large amounts of lidar data. In addition, the vegetation mapping procedure developed in the SNAMP can be used to update and map vegetation units in large areas quickly. We have tested this method in an area over 5 000 km^2 in the Plumas and Lassen National Forests of the Sierra Nevada. The results show that the algorithm can produce reliable and consistent vegetation maps efficiently.*
  3. *Specific questions:*
     a. *How long does it take to apply the point cloud-based method to map trees for the whole study area instead of just those in the field plots?*
        i. *We have made the individual tree product for the SNAMP study areas. We have developed efficient software that can process a large amount of lidar data simultaneously. For the SNAMP two*

study sites, it only took around one hour to process the lidar data and obtain the individual tree information.

b. *how accurate is it to apply the OBIA method to detect down logs over other areas?*
    i. *Unfortunately, we do not have multi-temporal lidar data to do the test for other areas. However, we believe that it can be used to detect the forest treatment extent in other areas as well considering its insensitivity to any specific parameters.*

On-line Comments

Please make figure 4 bigger so we can see details.

- *Response: We have modified the figure in the report.*

Figures 6 & 7– need a scale for colors.

- *Response: We have added the color scale in the figure.*

3.7 & 4.7 – How do results of investigating point density to predict forest metrics at the plot scale translate to stand or landscape scale metrics?

- *Response: The methods to reduce the lidar point density and generate the vegetation products are based on the landscape-scale airborne lidar data. The influence of lidar point densities on the accuracy of various calculated vegetation parameters was evaluated by comparing with plot measurements in Jakubowski et al. 2013. We didn't explicitly evaluate the impact of point density on stand scale or landscape scale metrics, but this is a good idea. We believe that the results obtained should be also applicable to landscape scale.*

Jakubowski, M., Q. Guo, and M. Kelly. 2013. Tradeoffs between lidar pulse density and forest measurement accuracy. Remote Sensing of Environment. 130: 245–253.

5.1 – Are tools used (Matlab, etc.) available for other users? What is "multi-path effect"? Combination of "high resolution multi-spectral … imagery" with what?

- *Response(s): Yes, the Matlab code for the developed individual tree segmentation algorithm is free to other users.*
- *The multi-path effect of lidar data is that the emitted laser pulse can be reflected and scattered by multiple objects before being received by the lidar sensor. This effect can significantly reduce the received intensity of the signal, meaning that it does not reflect the real reflectance characteristics of the object.*
- *The text should read "the combination of high resolution multi-spectral aerial/satellite imagery and lidar data". We have revised the text.*

5.2 – Are there results to support this paragraph? Seems results are not here -- may be more appropriate for wildlife appendices.

- *Response: We agree. We have added the related references from the SNAMP project to support this.*

5.3 – I'm not sure that managers would need this level of detail about fuel treatments to justify the cost.

- *Response: The fine resolution forest structure estimations from lidar can help forest managers to understand the forest heterogeneity and forest change, and may be not necessary for the forest managers to justify the cost. To help the forest managers to justify the cost of lidar data acquisition based on the mission objective and coverage, we* *conducted a study on how different lidar pulse densities influence the accuracy of the obtained vegetation parameters (Jakubowski et al. 2013).*

Jakubowski, M., Q. Guo, and M. Kelly. 2013. Tradeoffs between lidar pulse density and forest measurement accuracy. Remote Sensing of Environment. 130: 245–253.

5.4 & 5.5 – Link to results is weak. Will adequacy of use for fire behavior models be discussed in the integration report?

- *Response: The pre-treatment vegetation maps and forest fuel treatment extents developed by the spatial team were used in the fire behavior modeling. We investigated the use of lidar in fire behavior modeling in Jakubowski et al. 2013.*

Jakubowski, M. K., Q. Guo, B. Collins, S. Stephens, and M. Kelly. 2013. Predicting surface fuel models and fuel metrics using lidar and CIR imagery in a dense, mountainous forest. Photogrammetric Engineering and Remote Sensing 79(1):37-49.

Chapter 5, Recommendation #2. Integrate what across firesheds? Can you suggest what we give up without optical or ground data?

- *Response: The vegetation maps and detected forest fuel treatment extents were used across the firesheds by all Science Teams. The vegetation maps were produced through the combination of lidar data and aerial imagery, and vegetation type data derived from field data; the forest fuel treatment extents were directly detected from the lidar data and further validated from the treatment areas from Forest Service data. Some specific lidar products were used by specific teams. For example, the LAI product was used by the water team; the individual tree information was used by the owl and fisher team, etc. The ground data provided the ground truth measurements for vegetation species and structure parameters. Although airborne lidar can be used to generate accurate forest height-related (e.g., tree height and canopy quantile metrics) and gap-related measurements (canopy cover and LAI), the individual tree species and certain vegetation parameters, e.g., DBH, height to live crown base, and aboveground biomass, cannot be directly obtained from lidar data. Classification/regression methods based ground measurements and lidar-derived height measurements are the commonly used method to generate these vegetation products. Moreover, the optical imagery can provide canopy surface reflectance measurements, which cannot be obtained from lidar data directly. This information can help to different tree species in the vegetation mapping process.*

SNAMP Owl Science Team
Response to peer-reviewed, public, and agency comments

Dr. M. Zach Peery
Dr. R. J. Gutiérrez
Dr. Douglas J. Tempel

August 27, 2015

We appreciate the excellent comments provided by two anonymous peer reviewers, a non-profit organization, and the U.S. Forest Service pertaining to the California spotted owl component of the Sierra Nevada Adaptive Management Project (SNAMP). We address in this cover letter what we believe to be the most important comments.

Reviewer #1 ("Peer Review 1") made a number of comments related to the statistical analyses that we conducted as part of our retrospective analysis, which we address sequentially as follows:

1) Reviewer #1 noted that the standard error for the beta parameter coefficient for the effect of fire on territory colonization was unestimable. While this does make it difficult to draw definitive conclusions regarding the effect of fire on territory colonization, we observed that the two territories where >90% of the territory burned at high severity during the 2001 Star Fire have never been recolonized, which suggests a threshold of high-severity fire within a territory that can make the territory unsuitable for spotted owls. This view is reinforced by our survey results from the 2015 field season at territories affected by the 2014 King Fire. We found owls in 2015 at only one of the nine territories occupied by owls in 2014 but burned at >50% high severity by the King Fire.
2) Reviewer #1 noted that if all of our territories were initially occupied, then our estimates of occupancy would be biased high at the beginning of our study period and could affect the extinction and colonization rates in the early years of our study. As we noted in the Owl Team Appendix, we identified owl territories as sites where reproduction occurred at least once during our study period (1993-2012). The majority of owl territories in our analysis (40 of 74) were located on our Eldorado Density Study Area (EDSA), and all of these territories within the EDSA had been occupied at least once by 1997. We surveyed

the EDSA from 1986-1992 but did not achieve sufficient sampling effort across the entire study area until 1993 (see Tempel and Gutiérrez 2013). Therefore, we only used data from 1993 onwards for our analysis to avoid the problem of biased estimates of occupancy, extinction, and colonization due to inadequate survey effort in the early years of our study. We further note that two of the EDSA territories were not occupied in 1993.

Tempel, D.J., and R.J. Gutiérrez. 2013. Relation between occupancy and abundance for a territorial species, the California spotted owl. Conservation Biology 27: 1087–1095.

3) We did not include highly correlated ($r > 0.60$) habitat covariates in our analysis, but reviewer #1 suggested that we could have included highly correlated habitat covariates. While this may be technically true, we do not believe it is a sound analytical practice to include highly correlated covariates in the same model because this can result in spurious effect sizes for the beta parameter coefficients. When two covariates were highly correlated, we opted to include the covariate that we believed to be most biologically relevant. For example, the amount of shrub/sapling vegetation was highly correlated ($r = 0.86$) with the amount of edge between shrub/sapling vegetation and forest dominated by trees ≥ 30.5 cm (12 in) dbh. We opted to only include the amount of edge in our analysis because previous research suggested that owls may forage along such edges.

4) We used AIC, rather than AIC_c, to rank our competing models because there is no agreement on how to calculate “effective sample size” in occupancy models, and in fact, “effective sample size” may vary for different model parameters (e.g., occupancy and detection probabilities; Dr. James Nichols, personal communication).

5) Reviewer #1 suggested that we run survival models where survival was constant or varied annually. As noted in the Methods section of the retrospective analysis in Appendix C of the SNAMP final report (owl chapter), we included a null constant model in stage 1 for all of our demographic rates, but we failed to include the constant model in our model list (Table 2). We corrected this omission. We did not include the constant model in our final list of top-ranked models (Table 3) because it was not the top-ranked model in stage 1 of our survival analysis. In fact, it was 7.16 AIC units behind the top-

ranked model in stage 1, and we now note this in the Results section. For annual survival, we compared the models [φ(age+sex), p(age+sex+year)] and [φ(age+sex+year), p(age+sex+year)] in Program MARK, and found that the model containing a year covariate for survival was 5.34 AIC units behind the model without a year covariate. This reviewer also suggested that we include the results from each modeling stage in Table 3 for each demographic parameter, so the reader can see how much improvement was made during each step. We omitted these results from the SNAMP report to conserve space, but we refer the reader to the appendices of the published version of the retrospective analysis (Tempel et al. 2014), which does contain the results from each modeling stage.

Tempel, D.J., R. J. Gutiérrez, S.A. Whitmore, M.J. Reetz, R.E. Stoelting, W.J. Berigan, M.E. Seamans, and M.Z. Peery. 2014. Effects of forest management on California spotted owls: implications for reducing wildfire risk in fire-prone forests. Ecological Applications 24: 2089–2106.

6) Reviewer #1 commented that our reported survival estimates (0.73, 0.66, 0.63, and 0.56 for adult males, adult females, subadult males, and subadult females, respectively) seemed low. The reviewer is correct, and we have added the following sentence to the Results section (survival): “These values were lower than previous estimates of annual survival (cf. Tempel and Gutiérrez 2013) because we removed portions of the capture history for 14 individuals that switched territories during our study but did not reappear on the new territory until a number of years had elapsed (see Methods—*Statistical modeling*), and thus we lost information on their survival during the intervening period.”
7) We assessed the goodness-of-fit for the survival, reproduction, and occupancy analyses in ways suitable to each analytical method. For the survival analysis, no methods exist for estimating overdispersion ($\hat{c}$) in Cormack-Jolly-Seber models containing individual covariates (Dr. Jeff Laake, personal communication), but we estimated overdispersion in Program MARK using a fully time-dependent global model and found no evidence for overdispersion ($\hat{c} = 0.998$). For the reproductive analysis, we used methods identical to those of Blakesley et al. (2010), who noted that McDonald and White (2010) reported

that analysis of variance (ANOVA) procedures based on a normal distribution performed well for small count data. We further note that our use of different variance-covariance structures in the ANOVA allowed us to account for heterogeneity and serial correlation in the model residuals. For the occupancy modeling, we assessed two critical model assumptions: 1) occupancy status at each territory did not change during the survey season (i.e., closure); and 2) detections at each territory were independent (MacKenzie et al. 2006). Because nearly all of the owls on our study area were marked, we could determine when individuals moved among territories during the survey season. Such movements only occurred 10 times in 20 years, and we only considered one of the territories to be occupied in these situations (i.e., where the individual was most frequently detected). In addition, we excluded nocturnal detections > 400 m from a territorial core area (see Methods—*Spotted owl surveys*) to help ensure independence of detections at territories. We discuss all of these points in the Methods section of the owl appendix (retrospective analysis).

Blakesley, J.A., M.E. Seamans, M.M. Conner, A.B. Franklin, G.C. White, R.J. Gutiérrez, J.E. Hines, J.D. Nichols, T.E. Munton, D.W.H. Shaw, J.J. Keane, G.N. Steger, and T.L. McDonald. 2010. Population dynamics of spotted owls in the Sierra Nevada, California. Wildlife Monographs 174: 1–36.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2006. Occupancy estimation and modeling. Boston, MA: Elsevier/Academic Press.

McDonald, T.L., and G.C. White. 2010. A comparison of regression models for small counts. Journal of Wildlife Management 74: 514–521.

Reviewer #6 ("Peer Review 6") made no critical comments on our retrospective analysis and agreed with our major conclusions. This reviewer also agreed with our major conclusions for the prospective analysis, but did have some minor suggestions. We followed this reviewer's suggestion to estimate an *ad hoc* R^2 for the logistic regression of owl nesting habitat (equation 4). Using the R^2 formula suggested by the reviewer, we found that our regression based on canopy cover and large tree density had an estimated $R^2 = 0.32$. The logistic equation for survival (equation 5) was based on the mark-recapture modeling that we conducted for the retrospective analysis, where we found no evidence for overdispersion in the data (see above). Finally, we note that we did not need to 'assign' a female age for the stage-based, matrix model; the value of lambda was simply calculated as the dominant eigenvalue of the matrix.

The most substantive and lengthy public comments were submitted as a 12-page document by the John Muir Project and the Center for Biological Diversity ("Comment 17"). We respond to their major comments as follows:

1) They request that we add language stating that even if fire does occur, there may be no long-term benefits from mechanical treatments. We believe that we have stated this in the Discussion section of the prospective analysis in Appendix C of the SNAMP final report (owl chapter), where we presented a lengthy paragraph on several caveats pertaining to our research. In this paragraph, we stated that two fires which burned on our study area (2001 Star Fire, 2014 King Fire) burned much differently than our simulated fire, in that large, contiguous areas burned at high severity in the actual fires. We conclude that: "Indeed, our past experience suggests that existing fire models are generally incapable of replicating the burn patterns seen in the most extreme real fires. Thus, improved fire models are needed to more reliably assess how fuels treatments modify fire behavior and effects on forest structure especially under extreme conditions." We also refer the reader to the responses to comments provided by the FFEH Team, where they address the potential benefits of fuel-reduction treatments under "escaped wildfire conditions."
2) They request that we explain that mechanical treatments could have significant negative impacts to owls, while mixed-severity fire could benefit owls. We state several times in our report that fuel treatments can have long-term negative effects on owls if fire does not occur (e.g., Executive Summary at beginning of Appendix C, final paragraph of Discussion for prospective analysis). Furthermore, we included a lengthy paragraph in the Discussion section (prospective analysis) on the potential benefits of fire, which included the following: "However, the effects of wildfire on spotted owls are undoubtedly complex and owls may benefit from the presence of a mosaic of habitat

types promoted by mixed-severity fire, and particularly from shrub patches and early-seral forests that harbor diverse prey assemblages (Roberts et al., 2015). For example, Bond et al. (2009) found that spotted owls in the southern Sierra Nevada selectively foraged in burned areas, even those that burned at high severity. We further note that not all previous studies of spotted owls have found reduced occupancy rates in burned areas relative to unburned areas (Roberts et al., 2011; Lee et al., 2012). Therefore, to the extent that low- or moderate-severity fire may benefit owls, the modeled declines in territory fitness and occupancy in our fire scenarios might be overestimated, and by extension the long-term (30-year) benefits of fuels reduction treatments overly optimistic."

3) They commented that our Introduction for the retrospective analysis suggested that modern fires are not ecologically valuable. We concur that modern fires may indeed be beneficial, but our statement concerned fires that burn large areas at high severity. We have modified the sentences in question to read: "For millennia, low- to moderate-severity wildfires occurred at frequent (often less than 20-year) intervals in many western forests, naturally removed fuels such as woody debris, shrubs, and small trees, and shaped the ecology of these forests (Agee 1993, Noss et al. 2006). However, decades of wildfire suppression have disrupted historic fire regimes, increased the amount of surface and ladder fuels, and have led to uncharacteristic proportions and patch sizes of stand-replacing fire that now threaten ecological and human communities (Mallek et al. 2013; Stephens et al. 2013, Stephens et al. 2014; Stephens et al. 2015)." We further acknowledge that large areas of high-severity fire may indeed benefit species such as the black-backed woodpecker, but we believe that a reasonable ecological basis exists for inferring that simplification or elimination of large areas of high-canopy-cover forest by high-severity fire could adversely affect spotted owl populations.

4) Many of their statements share the common theme that fire, including high-severity fire, is beneficial to spotted owls. As we noted above, we believe that fire can indeed benefit (or at least have a neutral effect) on spotted owls, including fires that have high-severity effects interspersed throughout the burned area. However, our concern is that fires that burn large, contiguous areas at high severity (such as the Star Fire and King Fire) can negatively affect spotted owls. As we noted in our response to Reviewer #1, the two territories where >90% of the territory burned at high severity during the 2001 Star Fire

have never been recolonized, and we found owls in 2015 at only one of the nine territories occupied by owls in 2014 but burned at >50% high severity by the King Fire.

5) We acknowledge that the effects of the Star Fire on territory colonization in our retrospective analysis were confounded with post-fire salvage logging. However, we maintain that the negative effect on colonization was primarily due to the habitat loss that occurred as a result of the fire itself. Thus, we added the following sentence to the Discussion section of the retrospective analysis (seventh paragraph): "Post-fire salvage logging occurred within two years of the Star Fire, and its effects on territory colonization were confounded with the effects of the fire itself. However, we believe that the negative effect of the fire on colonization was primarily due to habitat loss that resulted directly from the fire."
6) They commented that in our prospective analysis we modeled the effects of simulated fire on spotted owl nesting habitat, not the combination of nesting and foraging habitat. This is a good point, but we note that changes in owl habitat under the four scenarios were very similar to changes in territory fitness and occupancy (Figures 11 and 12 in Appendix C), and that high-canopy-cover (≥70%) forest was by far the best correlate of territory fitness and occupancy in our retrospective analysis.
7) We refer the reader to the responses to comments provided by the FFEH Team, where they address the contention that high-severity (i.e., stand-replacing) fire has not increased in the Sierra Nevada over the past several decades.

Finally, an anonymous public reviewer ("Comment 19") noted that avoiding management activities in PACs has not prevented a 50% decline on the Eldorado Study Area. We did not intend, however, that our recommendation for the continued use of PACs be construed as the only possible management strategy to conserve spotted owls in the Sierra Nevada. We view the use of PACs to be a necessary component of owl management, but not a sufficient component in and of itself. This reviewer also noted: "The authors mistakenly assume there would be a long-term fuels treatment benefit of 30 years for spotted owls, but Collins et al. (2011), a study on the effectiveness of the fuels treatments in the LCSA, found that fuels treatments were only effective for about 20 years…" We did not mistakenly assume a fuels-treatment benefit for spotted owls after 30 years; we inferred it from the results of our prospective analysis which clearly show slightly higher rates of territory fitness and occupancy on the treated landscape 30 years after a simulated fire (see Figure 12 in Appendix C). The reviewer is correct in pointing out that these results differ somewhat from Collins et al. (2011), but our prospective analysis was based on actual, post-treatment vegetation conditions. Because the analyses and simulations in Collins et al. (2011) occurred before the treatments were actually implemented at Last Chance, they necessarily simulated the effects of the treatments on vegetation before conducting their fire and forest-growth simulations.

Collins, B., S. Stephens, G. Roller, and J. Battles. 2011. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. Forest Science 57(2): 77-88.

We appreciate the time and effort expended by all of the individuals who submitted comments on the owl section of the final SNAMP report, and we believe that our responses and revisions have addressed these comments.

Sincerely,

Dr. M. Zach Peery
Dr. R. J. Gutiérrez
Dr. Douglas J. Tempel

SNAMP Fisher Team

Response to peer-review, public, and agency comments

Dr. Craig Thompson
Dr. Rick Sweitzer
Dr. Kathryn Purcell
Dr. Reginald Barrett

13 August, 2105

We appreciate the comments provided by two anonymous peer reviewers, several non-profit organizations, and the USDA Forest Service. Several comments were ubiquitous among multiple respondents. In particular, these focused on reducing the length and detail of the executive summary and introduction, and being consistent with terminology both within the Appendix and between the Appendix and other chapters. We attempted to address these concerns but will not discuss them at length here. Below, we provide detailed responses to what we considered the most substantive comments. In cases where we disagreed with the suggestions given, we attempted to clearly state our reasons.

Peer Review #4:

Reviewer #4 provided extensive comments and suggestions on language clarification, explanation of methods, and terminology, for which we are grateful. Additional comments included:

Comment 1: "I had expected to see specific demographic and land use measures for fishers before and after SPLAT implementation, but those data were not presented. I am hopeful that further research will allow for those comparisons to be made. I think they could be important for fisher conservation in California."

Response to comment 1: Given the delays in treatment that occurred and the protracted timeline over which it is necessary to evaluate management impacts on a species such as fisher, insufficient post-treatment data were available to support the original BACI design. However post-treatment monitoring is ongoing, extended through 2016, in hopes of supporting these analyses.

Comment 2: "I was surprised to see how large the home range sizes were for the fishers in your study area. Not having the home range sizes for other CA fisher populations committed to memory, I wondered if they were comparable to those in your study area or if they were considerably smaller. I ask because I wondered if there was some ecological phenomenon that exists at the northern extent of the SSN fisher population (your study area) that results in fishers using larger home ranges at this margin of their range. Generally larger home ranges imply lower habitat quality for the species in question,"

Response to comment 2: The home ranges reported here are significantly larger than those reported elsewhere in California. The most likely cause is the extensive use of aerial telemetry. Aerial telemetry generates a significantly larger sample size than ground telemetry, the method on which most prior home range estimates in California have been based. While ground-based telemetry can provide precise locations, animals are often lost for extended periods of time and topography can make it difficult to obtain locations in specific parts of the study area. Aerial telemetry does not suffer these handicaps, animals are relocated reliably and the increased ranges reported here most likely reflect a greater degree of monitoring "excursions", when animals break their typical movement pattern and explore less frequently used areas. It is debatable whether these excursions represent part of a home range, or whether they represent the 5% of locations that is traditionally excluded in home range analyses as outliers. Regardless of this, a collective analysis between SNAMP and KRFP data is ongoing to develop a "correction factor" for regional conservation planning.

Peer Review #8:

Reviewer #8 provided extensive comments on clarity of terminology and interpretations. He also provided a detailed review of the use of location data and the application to dispersal and home range analyses which helped improve the presentation greatly. Many of the suggested changes have been made in the text. Below we present what we felt were the most substantive, generalized comments and our response.

Comment 1: "For your Leslie matrix, you used single values for adult reproduction and adult survival. Thus, F4 = F5 = F6 = F7 = F8 and P4 = P5 = P6 = P7. You should use just F4 and P4 in your matrix on page 33. In building your matrix, you have assumed that no fishers live beyond page 8, which is not true. If you replace the 0 in the bottom right corner of the matrix with P4, your matrix will allow survival beyond age 8. Given that you use constant adult reproduction and survival, you can actually collapse the matrix to a 5x5 matrix, assuming you are willing to let model fishers live beyond age 8.

Given that F1 = 0, why not simply put 0 in the matrix? As far as I can tell, F2 = 0, too, for your matrix. Although you state that the matrix was built to estimate the population at 1 month following birth (approximately 1 May), your estimates of litter size appear more accurate for later ages, probably 2-3 months old. And your estimates of kit survival starts at age 6 months. In the end, I am confused as to whether your matrix estimates population size just before or just after reproduction. Do your fishers die and then reproduce or do they reproduce and then die? Leslie matrices can work either way.

You should state that your estimates of litter size are biased low because cameras do not always show all kits in a litter. Opposing that bias, your estimates of kit survival are biased high, because you have few data on survival of kits to weaning and no data on survival of kits from weaning until trapping in October.

Also related to the biased estimates of reproduction and kit survival, the elasticity analyses that I did for the population model used by Lewis et al. (2012, PloS One) and Powell et al. (2012, Martes 2009 book), showed that the model was most sensitive (via elasticity calculations) to estimates of litter size and kit survival. I do not know why you found your model not to be most sensitive to those variables, contrasting with our results. Sensitivity analyses sometimes yield results that contrast with elasticity analyses (a substantial literature on the differences exists, dated to 10-15 years ago). I encourage you to do an elasticity analysis if you did not."

Response to comment 1: We appreciate the suggestions on how to simplify the presentation of the Leslie matrix analysis. We limited the survival of females in the matrix to 8 years old because that was the upper limit of commonly observed lifespan. While it is possible that individuals may live beyond that, in fact we did observe several females living beyond 10 years of age, it was uncommon and those individuals generally showed signs of deterioration such as severely worn or missing teeth and emaciation. We chose to limit the matrix in this manner to better reflect the observed patterns of reproduction and senescence. Finally, a more detailed analysis of demographic parameters, including sensitivity and elasticity analyses, is in progress but is beyond the scope of this report.

We also attempted to more clearly describe potential biases in the first year survival and litter size estimates in the text.

Comment 2: "Writing about the biases for litter size and kit survival reminds me that your estimates of dispersal distance are biased low. This point is worth making clear right from the start. Your bias is undoubtedly smaller than that for research not so flight-based. When trapping fishers for reintroduction in the northern Sierras, we trapped a male 50 km from where he had been marked as a kit on the Hoopa Reservation."

Response to comment 2: We believe that the data we collected on dispersal distances for fishers are among the most accurate yet recorded, due to the daily aerial telemetry flights and our ability to follow dispersing animals easily. Longer dispersal events undoubtedly occur, but our data suggest they are infrequent at least in this region. There are also likely shorter dispersal events than what we observed. We present the mean and range for two different methods of evaluation. If there is a bias in the data, it likely reflects the fact that we presume to know the path taken. That bias is clearly presented in the text.

Comment 3: Page 90, Figure 31 and elsewhere **–** You must justify defining a core as the 60% contour. Why 60% and not 55, or 42, or 73.1415927? Really? Using 60% is arbitrary and not based on the behavior of the fishers, as far as I can tell. If you zeroed in on 60% after doing some undescribed analyses of your fishers' utilization distributions, then that could be OK but you need to explain the analyses.

Response to comment 3: In the footnote for Table 31, we refer the reader to two references regarding our approach to evaluating core use areas. We followed the approach described by Bingham and Noon (1991), which identifies the kernel estimate, for each individual animal, at which locations go from being under-dispersed to over-dispersed. Essentially this is the point at which area of the home range exceeds the expected level of use assuming a uniform distribution of locations. The closest 10% kernel estimate was then selected as the appropriate boundary to define a core use area. In all cases, this was either the 60% or 70% isopleth as noted in Table 31.

Agency Comment #15:

Comments from the USFS Region 5 focused on shortening the introductory and summary sections, updating references, and being consistent with terminology. One additional comment deserves mention here.

Comment 1: p. 10 **–** "fishers in this part of California may have expanded in the late 20th century (Tucker et al. 2014)" and "expanded during the 1990s" are misrepresentations of the research **–** I believe the genetic study identified that it was some time during the 20th century (about 100 years). This error must be corrected multiple times in the appendix.

"The Zielinski et al. (2013) analyses suggest…" The paper did not suggest what follows. You suggest these things based on an extrapolation of the analyses. In fact, the time scale of the monitoring is much shorter than 60 years and the suggestion is inappropriate.

Response to comment 1: This hypothesis, presented by Tucker et al. (2014) in their discussion, was an effort to reconcile genetic data with survey results for the region. It centers on the fact that genetic subdivision in the fisher population between Yosemite and the North Kings River could reflect recent founder events; i.e. fishers moving northward over Shuteye Peak post-1990. It is one of several competing hypotheses regarding the current state of the southern Sierra Nevada fisher population. Throughout the chapter, we attempted to revise the language regarding this hypothesis to better capture the current state of knowledge. We have also attempted to clarify which statements summarize published work and which reflect our own interpretation.

Public Comment #16

Comments from the Center for Biological Diversity and the John Muir Project fell into two categories, interpretation of the impacts of thinning on fisher habitat and our failure to account for the Hanson 2013 and Hanson 2015 publications regarding fisher use of post fire landscapes on the Kern Plateau.

Comment 1: "First, the results described on pages 98-99 do not support such a conclusion. Those results state that the single top model regarding local extinction identified "only" thinning ("*hazfuels.5*"), and that fisher persistence decreased with increasing thinning. The results (pages

98-99) indicate some effect of fire but state that the “relative importance” of this variable was “low”. Therefore, there is not a sound basis for the conclusion that thinning is justified to mitigate fire effects; in fact, the results contradict this conclusion.”

Response to comment 1: It is accurate to say that our analysis indicated that hazardous fuel reduction increased the likelihood of an occupied grid cell becoming unoccupied at some point in a 5-year window. It is also accurate to say that fisher persistence was negatively associated with hazardous fuel reduction activity. However it should be pointed out that the probability of persistence dropped from 0.89 to 0.65 as a grid cell went from 0% to 100% treated. Persistence or occupancy rates of 0.65 are considered a positive indication of population stability in other regions (Zielinski et al 2013). As described in the discussion, these results suggest that fishers are locally flexible, abandoning certain parts of their home range when unsuitable, then returning to use these areas after several years of recovery. Given the potential for limited thinning activities to reduce or mitigate fire effects, as well as further the goal of ultimately reestablishing a mixed-severity fire regime, and the limited negative impacts to fishers, we stand by the conclusions as presented.

Comment 2: “Second, we followed the methods described in the SNAMP fisher appendix with regard to fires in the camera-survey study area, and digitized the grids shown in Figure 12 of the SNAMP report. We used GIS to overlay fires on the camera-survey grids, and used Google Earth satellite imagery to evaluate whether post-fire logging had occurred in any of the fires. We found that post-fire logging—often extensive—had been conducted in numerous camera-survey grids within fire areas, e.g., in portions of the 2001 North Fork fire and in the 2004 Nehouse fire (see figures below). Therefore, there is a significant methodological issue in the study, in that it states it is only testing the effects of fire on fisher occupancy, but is actually instead testing effects of post-fire logging in numerous grids. This is important, given that all but one of the grids that are approximately 50-100% within fire perimeters, and that we identified as having been post-fire logged, had no documented fisher occupancy, according to Figure 12 of the SNAMP (2015) fisher appendix.”

Response to comment 2: We do not believe that anywhere in the Fisher Appendix does it state that we are “only testing the effects of fire on fisher occupancy”. In fact numerous grids were exposed to various combinations of hazardous fuel reduction, extractive thinning, and fire. Furthermore, we are unclear how post-fire salvage logging could be accurately determined from Google Earth. Instead, we calculated areas on which post-fire salvage logging occurred using the FACTS database, and included that in the “Extractive thinning” composite variable (*log.5*).

Comment 3: “Third, among camera-survey grids mostly/wholly within fire perimeters, a disproportionately large cluster are in a fire (the 1990 Steamboat fire in Yosemite National Park) at the northern extreme of the fisher’s range in the southern Sierra Nevada (generally, north of 37 degrees and 39 minutes latitude). Figure 12 of the SNAMP fisher appendix shows that fishers are almost completely absent in this area, and only one camera-survey grid had a fisher detection—and it is partially in the fire area. None of the unburned grids in this northernmost portion of the study area had any detections. The effect of this was to create a bias in the results toward reporting lower fisher use of fire areas."

Response to comment 3: If we understand the comment correctly, the concern stems from the belief that results from a cluster of 17 grid cells at the northernmost boundary of the study area will unduly bias the result against fisher use of burned areas. A subset of these cells, approximately 8, fall within the boundary of the 1990 Steamboat Fire, and in only one of those cells was a fisher detected. The concern is that fishers are "almost completely absent" from that area for reasons unrelated to the Steamboat fire, and therefore fishers were not detected in 7 of 8 grid cells.

As stated in the Methods: Fisher response to fuel management: Occupancy modelling section, occupancy models were developed using only data from grid cells that were surveyed for multiple seasons. And as stated in the Results: Basic Camera Survey Results section, surveys within Yosemite National Park were only conducted in winter 2009 under supplemental funding from the California Department of Fish and Wildlife. The Yosemite data were not included in the occupancy analysis and therefore could not have biased the results. We appreciate this confusion being pointed out, and have attempted to clarify the language.

Comment 4: "Fourth, the SNAMP fisher appendix does not incorporate Hanson (2013) or Hanson (2015), which are peer-reviewed studies (see references below) conducted on fishers and fire based upon field data (as opposed to modeling assumptions). These two research studies regarding fishers and burned forests have found that post-fire landscapes, when left unlogged, can provide important, critical habitat to fishers."

Response to comment 4: The authors are familiar with the Hanson 2013 and Hanson 2015 publications, and chose not to reference them or utilize the information for several reasons.

Methodologically, both analyses are seriously flawed. The author used scat dogs to locate fisher scats in burned and unburned areas. Dogs are an extremely effective tool for this, however scat locations are spatially autocorrelated and the associated clustering leads to pseudoreplication. This problem is particularly acute with small sample sizes and with species such as fishers that use latrines and mark territorial boundaries with scat. Instead, when evaluating scat data without genetic information to identify individuals, it is necessary to identify some independent spatial sampling unit appropriate for the species (e.g. a transect, grid cell, etc.) and then to examine occupancy or abundance within that unit (Thompson et al. 2011, Long et al. 2007, Smith et al. 2005) . The author's choice of a one-tailed chi-square analysis to assess habitat selection further inflates this problem, and the author fails to account for the fact that multiple statistical tests were conducted by reducing the significance level accordingly. Essentially this means that in Hanson (2013), the author's conclusions are based on nonsignificant statistical results; all p-values in the manuscript should be multiplied by 2 and then compared to a p-critical of 0.0125. Furthermore, Hanson (2015) relies heavily on the absence of statistical significance to claim that fishers select burned and unburned habitat equally. Given the small sample sizes and inappropriate analytical techniques applied, non-significant results were a forgone conclusion.

The conclusions in Hanson 2013 are further confused by the fact that the author altered the traditional definitions of fire severity classes. Hanson defines low-severity fire as areas with less than 15% basal area mortality (<316 RdNBR), moderate-severity fire as areas with 15% to 50% basal area mortality (316 – 477 RdNBR), and higher-severity fire as areas with greater than 50% basal area mortality (> 477 RdNBR). Management agencies, on the other hand, generally define low severity fire as less than 25% basal area mortality, moderate as 25% to 75% basal area mortality, and high as greater than 75% mortality. While there is no precise agreed upon threshold of high severity fire, Safford et al. (2008) recommended a 75% basal area mortality threshold, given that the most commonly used thresholds in the literature range from 70% to 80%. Hanson cites Miller et al. 2009 as justification for his fire severity definitions, despite the fact that his chosen values do not match the reference, particularly with respect to the threshold between moderate and high severity. After applying these novel definitions, Hanson further confounds his conclusions by combining the 'moderate' and 'higher' severity fire categories into a single broad category. By combining these two categories, the study then only differentiates between areas with less than 15% basal area mortality (arguably 'very' low severity) and areas with greater than 15% basal area mortality (which combines areas of low (<25% BA mortality), moderate (25-75%), and high (>75% BA mortality) severity fire). Hanson does not indicate relative representation of these three classes in the 'moderate/higher' severity category, thereby preventing any possible conclusions from being drawn about fisher use of any given fire-severity class. As a result of these changes, subsequent interpretation is biased toward higher severity fire (Fule et al. 2014). This pattern of altered and combined fire severity classes was continued in Hanson (2015), making those results equally difficult to interpret.

Hanson (2015) continues the same approach of creating false dichotomies and misrepresenting references. He cites a USFS document stating the agency's intention to 'implement commercial logging at an "unprecedented scale" to advance the goal of saving species such as the Pacific fisher from the effects of higher severity fire', despite the fact that what the document actually says is that increases in the number of human-caused fires is threatening fire-adapted chaparral with replacement by non-native grasslands, and "Only an environmental restoration program of unprecedented scale can alter the direction of current trends" (http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5351674.pdf). He incorrectly cites Truex and Zielinski (2013) as stating that fishers avoid mechanically treated areas, when what the authors actually wrote was "predicted resting habitat suitability was significantly lower for mechanical plus fire treatments, but the control *did not differ* from the fire only or the mechanical only treatment" (emphasis added) and that "fisher foraging habitat … was unaffected by treatments at either site." Hanson goes on to state that "forest management of fisher habitat, at present, is predicated on the belief that mechanical thinning, though not ideal for Pacific fishers, is better than allowing mixed-severity wildland fire", ignoring the evolution of management thought over the past 20 years and the reality that current management is based on the goal of combining mechanical thinning with managed wildfire and prescribed burning to restore a mixed-severity fire regime (North et al. 2009).

We do acknowledge one important result from the Hanson 2013 and 2015 efforts; the author located female fisher scats within the boundary of a high severity fire, 10+ years post-fire. This result warrants further investigation to determine if such female fishers are transient or resident, whether they successfully reproduce, or whether they simply venture into historic burns in search of prey. We don't necessarily doubt that a well-designed study of the use of burned and unburned areas by fishers, with adequate design and sample size, could arrive at the same or similar conclusions. However without such a robust foundation, we are forced to conclude that the interpretations presented in these papers are suspect and should not be used to guide management actions.

<u>Public Comment #18:</u>

Comments from the Sequoia Forest Keepers centered on the idea that the probability of any particular area experiencing wildfire is relatively low and therefore treating areas in the "hope that the treated area will experience fire, so that the models can hopefully work" are not justified. They stated "The SNAMP fisher report does not consider the analysis provided by the 2008 study *Fire Probability, Fuel Treatment Effectiveness and Ecological Tradeoffs in Western U.S. Public Forests* by Jonathan J. Rhodes and William L. Baker, which indicates that few treatment areas ever encounter fire (2.0% to 7.9%) during their assumed 20 year period of reduced fuels."

"The SNAMP fisher report projects fire in treatment areas even though the likelihood is low and the impact to the fisher habitat from treatment would be immediate and negative and it would take 37 years for the habitat to recover from the treatment and show positive benefits."

"In addition, the SNAMP fisher report clearly indicates on page 32, that, "Data from radiocollared animals from the study area indicated that female fishers commonly die by 6-8 years of age." Contrary to what the report implies, this means that more than four generations of Pacific fisher will not be able to use the treatment areas. While treating the forest may result in "relatively modest impacts on forest structure," the impact of treatments on Pacific fisher would be extremely significant!"

Response to Public Comment #18

A detailed response to the criticism is outlined in the FFEH: Response to Comments letter regarding shortcomings of the Rhodes and Baker (2008) analysis with respect to management decisions. In response to the statements regarding fisher habitat recovery, we believe the respondents misunderstood the data and conclusions drawn. The SNAMP Integration modeling showed that in the absence of fire, treatments reduced fisher habitat immediately (year 0) by 13%. However in the continued absence of fire, by year 10, there was 5% more fisher habitat available on treated landscapes than on untreated landscapes. And in the presence of fire at year 10, there was 10% more habitat available on the treated landscape than the untreated. Beyond year 10, regardless of the presence of fire, differences in the availability of fisher habitat between the treated and untreated landscapes were negligible (1-4%).

The statement that it would take 37 years for the habitat to recover is incorrect. That number stems from a separate analysis (Thompson et al. 2011), and reflected the conclusion that under the scenarios modelled in that analysis, fuel reduction efforts “provided significant positive benefits [to fisher habitat availability] up to 37 years after simulated fire”. ‘No treatment’ is a management choice that results in the homogenization of a forest landscape, over time, into a dense, closed canopy forest. Disturbances, whether natural or anthropogenic, serve to disrupt this homogenization and maintain a patchwork of seral classes. Fishers require a variety of habitat and seral types to meet their life history requisites, and the Thompson et al. (2011) analysis indicated that in the absence of fire, landscapes could quickly (10-25 years) become more homogenous than that what fishers were observed using. Fuel treatment not only provided significant benefits in the event of fire, they also slowed the forest homogenization and resulted in an additional 30-40 years of functional fisher habitat in the absence of fire.

We would add that in the past 18 months three significant fires have impacted fisher habitat within the SNAMP Fisher study area. The French (2014), Sky (2015), and Willow (2015) fires all consumed fisher denning habitat. Furthermore the Aspen/French fire complex (2013/2014) burned over 30,000 acres of habitat including a critical linkage zone spanning the San Joaquin River. The Sky Fire, threatening the Nelder Grove area (a significant source population for fishers in the region) was partly stopped by fuel treatments recently completed in the Cedar Valley area.

Public Comment #25

“I am uncertain how the integrated recommendation of limiting mastication is justified. The appendix on fisher states that occupancy following mastication was relatively high (0.65). Further, others have found that masticated material decomposes at relatively fast rates (depending on site productivity, cover, etc.). The management implication does not seem to consider that masticated material decomposes within the timeframe of expected fuel treatment longevity. Other work has demonstrated mastication to be effective at reducing fire severity, especially following the period of decomposition. The suggestion to limit its use does not seem warranted."

Response to Public Comment #25.

The recommendation to limit mastication is closely associated with the stated goal of increasing fisher foraging activity. The negative relationship between fisher persistence (continued use of an area) and hazardous fuel reduction was clear in our multi-season occupancy analysis. There was also evidence that this was a short-term impact; the integration analysis indicated that at larger temporal scales the effect of fuel treatment on fisher habitat availability was negligible. We recognize that mastication is an effective tool for reducing fire severity, however there is no natural analog to this activity; a masticated landscape is in an unnatural condition for some period of time determined by site productivity, local decomposition rates, weather, etc. The data we collected showed that fisher use of an area declined following mastication. It also showed that they did not abandon these areas entirely. We assume they simply moved around the masticated area until the forest floor recovered to a more natural state. Therefore limiting mastication if possible, dispersing masticated areas, and promoting forest floor recovery are reasonable recommendations if a manager's objective is to increase fisher activity in an area.

We appreciate the comments provided and the efforts of the commenters to help improve the Fisher Appendix. In particular, the two anonymous reviewers provided excellent feedback, and their help is greatly appreciated.

Dr. Craig Thompson
Dr. Rick Sweitzer
Dr. Kathryn Purcell
Dr. Reginald Barrett

Bingham, B. B. and B. R. Noon. 1997. Mitigation of habitat "take": Application to habitat conservation planning. Conservation Biology 11: 127-139.

Fulé, P. Z., T.W. Swetnam, P.M. Brown, D.A. Falk, D.L. Peterson, C.D. Allen, G.H. Aplet, M.A. Battaglia, D. Binkley, C. Farris, R.E. Keane, E.Q. Margolis, H. Grissino-Mayer, C. Miller, C.H. Sieg, C. Skinner, S.L. Stephens, and A. Taylor. 2014. Unsupported inferences of high-severity fire in historical dry forests of the western United States: response to Williams and Baker. Global Ecology and Biogeography 23: 825–830.

Hanson, C.T. 2013. Habitat use of Pacific fishers in a heterogeneous post-fire and unburned forest landscape on the Kern Plateau, Sierra Nevada, California. The Open Forest Science Journal 6: 24-30

Hanson, C.T. 2105. Use of higher severity fire areas by female Pacific fishers on the Kern Plateau, Sierra Nevada, California, USA. Wildlife Society Bulletin online release. DOI: 10.1002/wsb.560.

Long, R.A., T.M. Donavan, P. Mackay, W.J. Zielinski, and J.S. Buzas. 2007. Effectiveness of scat detection dogs for detecting forest carnivores. Journal of Wildlife Mgt 71: 2007-2017.

Miller, J.D., E.E. Knapp, C.H. Key, C.N. Skinner, C.J. Isbell, R.M. Creasy, and J.W. Sherlock. 2009. Calibration and validation of the relative differenced Normalized Burn Ratio (RdNBR) to three measures of fire severity in the Sierra Nevada and Klamath Mountains, California, USA. Remote Sensing of Environment 113: 645-656.

North, M., P. Stine, P. O'Hara, W. J. Zielinski, and S. Stephens. 2009. An ecosystem management strategy for Sierran mixed-conifer forests. General Technical Report 220. Albany, CA: USDA Forest Service, Pacific Southwest Research Station. 49 p.

Smith, D.A., K. Ralls, B.L. Cypher, and J.E. Maldonado. 2005. Assessment of scat-detection dog surveys to determine kit fox distribution. Wildlife Society Bulletin 33: 897-905.

Safford, H.D., J. Miller, D. Schmidt, B. Roath, and A. Parsons. 2008. BAER soil burn severity maps do not measure fire effects to vegetation: a comment on Odion and Hanson (2006). Ecosystems 11: 1-11.

Thompson, C.M., J.A. Royle, and J.D. Garner. 2011. A framework for inference about carnivore density from unstructured spatial sampling of scat using detector dogs. Journal of Wildlife Management 76: 863-871.

Truex, R.L., and W.J. Zielinski. 2013. Short term effects of fuel treatments on fisher habitat in the Sierra Nevada, California. Forest Ecology and Management 293:85-91.

Tucker, J.M., M.K. Schwartz, R.L. Truex, S.M. Wisely, and F.W. Allendorf. 2014. Sampling affects the detection of genetic subdivision and conservation implications for fisher in the Sierra Nevada. Conservation Genetics 15: 123-136.

Zielinski, W. J., J. A. Baldwin, R. L. Truex, J. M. Tucker, and P. A. Flebbe. 2013a. Estimating trend in occupancy for Southern Sierra Fisher Martes pennanti population. 2013. Journal of Fish and Wildlife Management 4:3-19.

SNAMP Participation Team

Response to reviews and comments

Authors: Adriana Sulak, Susie Kocher, Lynn Huntsinger, Kim Ingram, Anne Lombardo, Maggi Kelly, and Shufei Lei

August 2015

The comments we received, from the Forest Service (Comment 15), anonymous peer reviews (Peer Reviews 3 and 5), and others (Comment 13), have been constructive and very helpful in improving and revising our report. Most of them we were able to address, some we were unable to address due to the timeframe and scope of the report, and a few we disagreed with. Some improvements and changes will be most appropriate in the context of developing publications. The following are explanations of how we addressed some of the comments.

General comments:

--Qualitative vs. quantitative data (anecdotalness). This topic was the subject of our presentation at the final meeting. Both types of data are limited in what they convey. Quantitative data provide estimates of the proportion of a particular group that responds a certain way. Qualitative data provide more depth and nuance, and in our case, were specifically used to capture variation in opinion. (It is, in fact, a questionable assumption that the opinion of a majority is the most important opinion.) Both kinds of data in this project were collected and presented according to the standards in the field; we have published results from each independently. Both do require, as does all science, confidence in the integrity of the analyst. We believe the two kinds of data complement each other and enrich each other, providing for a robust analysis and well-rounded insight into the participant experience in SNAMP.

--Citations and citations to pages: we added some, but in general, believe we have enough for this report. We will be able to focus more on citations for future publications, depending on journal specifications.

Peer Review 3:

The executive summary was extensively revised in response to comments. Explanations of the purpose of each section of the report were added throughout the document. A table of contents, making it clear that the appendix is not a monograph, has been provided. Parts II and III have been revised to address comments that are within the scope of the report. Standardized data are presented in Table F-2. Clarification that the distance outreach data also applied to core elements was provided. An overview of the strengths and weaknesses of different outreach methods is in Tables F-3 and F-4. The point about the need for more development of the discussion of the second model is well taken and will be developed in future publication. Forest Service reviewers (Comment 15) commented that there was already "too much detail" in the appendix. Some modifications were made. The three party model remains a developing hypothesis, one developed as a result of SNAMP.

For the email survey, a non-response check was conducted using wave analysis. The close fit of the results of the two surveys and the meeting evaluations adds to our confidence in the consistency of the results. Reviewers and journals differ on where and how they want p-values presented. We chose to use the more complete information here. We clarified that the email survey does not represent the "full population of stakeholders." There is no such list.

As to the possible use of the t-test: The quantitative data collected were mostly ordinal and categorical, and do not meet the assumptions for t-test analysis. Chi-square is a simple and straightforward test that requires few assumptions about the data. More sophisticated analysis is possible with logistic techniques and demographic data but is not essential to this report. Likewise, the full capacity of NVivo-based qualitative analysis has also not as yet been fully exploited, but is not needed for reporting purposes. More demographic information about interviewees was added. Sections VI and VII were revised to address the comments.

With the remaining time, we had to prioritize other changes over changing all the figures to make them clear in black and white. We believe the report will be primarily used online. Similarly, we cannot change figure layering. We have addressed all further comments with modifications in the text and thank the reviewer for the suggestions.

Final formatting was not done by the authors. We did make the changes that were within our purview.

Peer Review 5:

We hope that the efforts we have made to improve organization and clarity will address many of this reviewer's very thorough comments. We substantially revised Part II to address comments. We added a figure to clarify what is meant by some of the language unique to SNAMP and tried to minimize our use of it. "Management workshops" were retitled to be "subject matter workshops" and were not limited to SNAMP but were on topics related to SNAMP.

As to a suggested guide, Section VIII on lessons learned at the end is the closest the authors are able to get to a short guide for others carrying out a CAM process within the limited time and funding for this report. We also point to the CAM curriculum and workbook as an excellent source of information on how to implement CAM (please see Appendix F-6: SNAMP Collaborative Adaptive Management Curriculum or http://snamp.cnr.berkeley.edu/documents/574/). However, any process developed to carry out CAM projects in other contexts would necessarily be constrained by different institutional, timeframe, and budget factors and require additional thought and guidelines. We added some additional lessons learned to address this reviewer's comments.

As the appendix is a compendium rather than a monograph (though this was not clearly stated in the original version—we hope we have improved that), the comments about theory and development will be applied to future publications derived from the various somewhat independent studies described in the appendix. Some clarity in main points should be achieved through the other SNAMP final report chapters and our revised executive summary. We have also striven to remove hyperbole from the document. We have addressed the remaining comments, with the caveat that some of the thoughts and ideas for further analysis will be used in future work—for those thoughts and ideas we are very grateful.

Forest Service (Comment 15) and Public (Comment 13):

For our Appendix F, we have substantially revised the text in part II as described above also based on comments received from the Forest Service. Most comments from the Forest Service not mentioned above were also addressed.

Suggestions regarding the interview data used in Chapter 2 and management recommendations in Chapter 5 were also addressed and those sections updated.

Please also see the qualitative vs quantitative data explanation above that responds to both the comment for Chapter 2 and the Forest Service comment about social science research methods.

We greatly appreciate the time and effort it took to review the Participation Team appendix drafts and thank our reviewers for sharing their insights with us.

SNAMP Project Integration and Management Team

Responses to peer-review, public, and agency comments

John Battles

Peter Hopkinson

August 31, 2105

In this response letter, we respond to comments relating to Chapters 1 through 5 of the SNAMP final report that were not addressed in the other team response letters. We appreciate the comments provided by an anonymous public commentator (Comment 13), Forest Service staff (Comment 15), and the California Forestry Association (Comment 21).

Comment 13, Anonymous comments [Survey Response 819751]:

Comment 1. The graphics (particularly in the integration section) were chosen to simplify the results, which is a good idea. However, it doesn't have the intended result because in this study, the changes in forest structures were not consistent by treatment. As a result, the simplification may lead a manager to make a decision opposite of what was intended. Instead of using the four treatment types, I suggest grouping results by the changes in forest structure that came about as a result of the treatments.

RESPONSE: We agree that the integration graph does not capture the differences in treatment intensity between the two sites. Our extended abstract (Chapter 3) does include these differences with additional graphs documenting treatment impacts on basal area and leaf area index. Also details of treatments and their impacts are included in the final report on fire and forest health (Appendix A).

Comment 2. The spatial scale of the treatments was limiting in making conclusions. The document states this several times, but it is critical to note that this was one of several studies that can inform management.

RESPONSE: The spatial scale was determined by management priorities, namely to modify fire behavior. Thus, the fireshed was the common scale used to report integrated results. For the empirical aspects of the water response to treatments, the small watershed was more appropriate. Scaling-up to the fireshed is common exercise in hydrology. The area where the extent of the fireshed was limiting was in regard to the spotted owl and the fisher. Both of these animals have such large home ranges that the firesheds encompass only a handful of individuals. The two studies did sample at a larger spatial scale and then used the results to develop indices that predict population responses to habitat changes caused by treatments and simulated wildfire. Given the diversity of scales, we are careful to note the potential limitations. At the same time, we made a dedicated and robust effort to report our findings at the scale most useful for management. Thus we agree with the comment that despite the limitations, our results do inform management.

Comment 15, Forest Service Region 5 staff comments:

Chapter 1

p. 2 (2005) Should be "Forest Service Pacific Southwest Region" -- as well as "Forest Service Pacific Southwest Research Station". Or, "Forest Service, Pacific Southwest Region and Pacific Southwest Research Station". Both are separate entities of the FS. Similar corrections at the top of p. 3. Other than references related to MOU signatories, you can probably just say "Forest Service" to mean region and station collectively. Also in other chapters.

p. 5 last para – have not yet defined "Participation Team" and its relation to UCST.

p. 6 last para -- Just FYI… We usually just refer to the SNFPA without reference to the Record of Decision. In fact, fireshed is not mentioned in the 2004 ROD and receive only casual reference (not as a "spatial unit of management") in the FSEIS, so this statement is incorrect. Similar corrections needed in Chapter 2,….

p. 7 para 2 – you might also mention that the fisher BACI assessment will be completed at a later date in collaboration with the PSW station.

Figure 1-1. UC did not actually sign the MOU. Figure caption should define all the acronyms (e.g., MOUP has not been mentioned in the chapter). Adaptive management adjustments..: adjustments are not to policy (as stated) but to management. Suggest delete "to policy". Also, I think that parties other than USFS will do this – for example stakeholders, USFWS are already doing this.

RESPONSE: All suggestions have been accepted and the text and figure amended.

Chapter 2

p. 11 – Why does the LC site have two pairs of firesheds and SP only one pair? See figures and tables.

RESPONSE: We have added the following text to Chapter 2 to clarify this issue:

> Sugar Pine had a classic paired-fireshed approach: one fireshed was treated and the immediately adjacent fireshed served as a control. At Last Chance, the topography limited the availability of a classic control. The best control in terms of matching vegetation, soils, terrain, area, and management history was to use the two adjacent watersheds (one north and one south of the treatment fireshed) to represent the "control" fireshed. The two watersheds were not spatially connected, but they did meet the criterion for fireshed designation in that we expected similar wildfire behavior in the two watersheds.

Comment 21, Steve Brink, California Forestry Association:

Chp. 5 – Integrated Mgt Recommendations Findings on p. 2 regarding benefits of SPLATs in reducing high severity wildfire is inconsistent with the Findings on p.4 where it states that vegetation reduction was small and regrowth in the first decade was more than the fuel reduction treatment. “SPLAT networks will reduce the risk of uncharacteristically severe fire.” (p. 2) Vegetation density from the implementation of SPLATs – “The small reductions in vegetation from treatments were temporary, with regrowth exceeding the original pre-treatment vegetation density in the first decade.” (p. 4).

In monitoring R5 forest health and fuels reduction accomplishments, I find that R5 is removing less than 10% of annual growth so the forests continue to get denser and denser and denser, which is leading to the megafires that are being experienced. With an average of 266 trees/ acre (FIA) across all R5 forests in productive forest lands, SPLATS are too little, too late. We need to take over 1/2 the vegetation off the landscape in a manner that leaves a heterogeneous pattern.

RESPONSE: It is important to note that the most relevant impact of SPLATs is not changes in forest composition and structure but in wildfire behavior. We document both an immediate change in wildfire behavior post-treatment and our models suggest that the effect is sustained to some extent for two to three decades. We do note the limited impact in regard to forest structure. We also discuss the link between the nature of the treatments (e.g., Recommendations #20 and #21 in Chapter 5) and the extent of the treatments in terms of their effectiveness in modifying fire behavior (Table 8, Table 9, Figure 20 in Appendix A). As for the comment about accomplishments of the US Forest Service in the Pacific Southwest (R5), it is unrelated to the SNAMP report and thus not within the purview of the UC Science Team to respond.