Chapter 4.3—Post-Wildfire Management

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Summary

Wildfires, especially large, severe, and unmanageable events, exert major influences on socioecological systems, not only through risks to life and property, but also losses of important values associated with mature forest stands. These events prompt decisions about post-wildfire management interventions, including short-term emergency responses, salvage logging, and other actions to influence long-term ecological trajectories, including tree planting and treatment of fuels and shrubs. The cost-effectiveness of such interventions has been increasingly scrutinized, and scientists have noted the potential for unintended or undesirable ecological effects of postfire treatments. Research has highlighted the importance of targeting postfire treatments to specific contexts where benefits are expected to exceed the costs of interventions. Implementation of these approaches would tend to result in patchy treatments within high-severity burns that vary with landscape attributes and presence of important values.

Salvage of fire-killed trees is one of the most influential and contentious tools applied to postfire landscapes. One possible ecological benefit of salvage is to reduce uncharacteristically high levels of fuel accumulations that have resulted from combinations of past fire suppression, past timber harvest, and severe wildfire. Other benefits may result from accelerating long-term establishment of mature forests that provide timber and habitat for various wildlife species of concern. The most immediate benefit of postfire salvage is the sale of fire-killed timber, which often pays for rehabilitation and provides returns to local economies. The reduction of the hazard of falling trees is another socioeconomic benefit important to recreational users and others working in the forest, potentially including tree planters

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and firefighters. Local support for salvage operations can be quite high, although that support appears to depend on beliefs or assurances that salvage operations do not cause ecological harm.

Further research is needed to understand effects of wildfires, and high-severity patches in particular, over long periods (and after multiple fires), including effects on fire behavior, ecological trajectories, wildlife species associated with postfire conditions and old forests, streams, watersheds, economic values, and social well-being. Extensive reburns, such as the Chips Fire of 2012, may present valuable opportunities to better understand long-term changes in ecological conditions and how to promote socioecological resilience through interventions before and after reburn events. Because wildfires are expected to be a major influence on the forests of the synthesis area in coming decades, enhanced understanding of their effects, particularly of large high-severity patches, is an important research gap discussed throughout this chapter.

Introduction

Wildfires trigger management decisions about postfire interventions to mitigate potentially undesirable outcomes. Because uncharacteristically large patches of high-severity wildfire are expected to occur in the synthesis area in coming decades, these postfire decisions may have significant implications for the resilience of socioecological systems. Postfire situations entail several types of responses, including a short-term response through the Burned Area Emergency Response (BAER) program to protect life, property, water quality, and ecosystems; potential salvage logging of burned trees; and longer term restoration efforts. A range of options and approaches, many of which are outlined below, are available to address these issues. The Forest Service in California has recently developed a postfire restoration strategy template to help guide national forests in planning for restoration and long-term management of burned landscapes.

Complex tradeoffs between economic values, ecological values, and risks across short and long time scales render post-wildfire management a particularly challenging issue, and the limited frequency of these events makes it important to monitor and evaluate outcomes to promote social learning.

The intent of this chapter is to inform strategic planning to prepare responses for inevitable future wildfires. Application of a long-term, landscape-scale, and integrated socioecological approach, as highlighted throughout the synthesis, is especially important in postfire contexts. A number of recent scientific publications point to postfire tree mortality and erosion as important mechanisms for rejuvenating habitats and promoting resilience to changing climates that could be undermined by postfire interventions (Dellasala et al. 2004, Dunham et al. 2003). Swanson et al. (2010) noted that the period of early succession after wildfire (fig. 1) or other stand-replacing disturbances is important for promoting high productivity of understory herbs and shrubs, large nutrient fluxes, and highly complex food webs

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Figure 1—Stand-replacing burn patches, such as this one on the Piute Fire of 2008, lead to discussions about postfire management strategies based upon a range of ecological and social considerations.

and forest structure. Thinking about wildfire events proactively and reviewing them after they happen provide important feedbacks to adapt larger strategies designed to promote resilience of socioecological systems (see chapter 1.2, "Integrative Approaches: Promoting Socioecological Resilience," as well as McCool et al. [2007]). This perspective highlights the need to accurately predict when postfire trajectories are likely to result in significant losses of values and whether the full socioecological costs and benefits of interventions justify the investment. Complex tradeoffs between economic values, ecological values, and risks across short and long time scales render post-wildfire management a particularly challenging issue, and the limited frequency of these events makes it important to monitor and evaluate outcomes to promote social learning.

Short-Term Management Actions and Recommendations

In the 1970s, federal agencies adopted BAER programs as a coordinated approach to address short-term threats to life, property, and natural and cultural resources. Teams with members representing multiple resource concerns and disciplines collaborate to inventory damage, assess future impacts, identify values at risk from potential flood events and accelerated erosion, and recommend cost-effective mitigation treatments (Robichaud et al. 2000, Wohlgemuth et al. 2009). These responses are commonly limited to the first 3 years after a fire, which accords with the period during which flood and erosion risks may be particularly elevated (Berg and Azuma 2010). However, Robichaud et al. (2010) note that risks may extend for several more years, especially in semiarid regions. Short-term postfire response varies depending on the values at risk, fire severity, topography, and other context-specific factors. A tool has been developed to evaluate cost effectiveness of short-term treatments based upon protection of values at risk, including both monetary and nonmonetary values (Calkin et al. 2007).

Short-term postfire concerns often focus on flooding, erosion, and sedimentation, which are interconnected in complex ways, because water and sediment can be routed and stored in different places at different times. Effects of wildfire on soils and water are discussed in chapters 5.1, "Soils," and 6.1, "Watershed and Stream Ecosystems," and they have been the focus of recent science syntheses (Elliot et al. 2010, Neary et al. 2005). Postfire flooding is a function of excess overland flow from hillslopes, although conditions of downstream channel networks can exacerbate flood hazards through potential failures of debris jams, culverts, and dams. Based upon a study in the Sagehen watershed that found a short-term reduction in woody debris following fire, Berg et al. (2002) recommended surveying the extent and length of woody debris relative to channel bankfull widths when evaluating the risk of postfire debris jams.

Recent reviews have examined techniques to mitigate erosion and other postfire damage and found that many once widely used treatments for hillslopes and channels have demonstrated inconsistent effectiveness (Robichaud et al. 2000, Wohlgemuth et al. 2009). These findings have supported a general trend toward non-intervention, except when targeting areas of particularly high vulnerability with carefully designed and implemented measures (Wohlgemuth et al. 2009). In some areas, hillslope erosion may be greatly exceeded by erosion from channels (Moody and Martin 2001). Few postfire in-channel treatments have been widely recommended because they are costly to engineer to inhibit failure. For example, strawbale check dams can rapidly fill, and there are many reports of widespread failure of such dams (fig. 2) within two years of installation; consequently, studies have recommended limiting such treatments to very small catchments (e.g., less than 1 ha) (Wohlgemuth et al. 2009). However, careful and intensive design, construction, and maintenance may allow check dams to be effective in larger watersheds (deWolfe et al. 2008).

Hillslope Erosion

Erosion on hillslopes through rainsplash, sheetwash, and rilling is often a focus for postfire treatment, as these are the most common and widespread causes of postfire erosion (Miller et al. 2011). In addition, rehabilitation strategies often target hillslopes based upon a general principle of treating the problems as close to the source as possible, and because hillslope treatments (see box 4.3-1) appear generally more successful than in-channel treatments. Research and monitoring have consistently found that ground cover is the most significant factor in reducing hillslope erosion (Robichaud et al. 2009). Predictive tools, including the Water Erosion Prediction

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Figure 2—Failure of check dams with straw bales and wattles following an extreme rain event.

Project (WEPP), are also designed to address hillslope rather than channel processes. These tools are designed to work on a local scale for prioritizing vulnerable areas for potential treatment (Miller et al. 2011).

Debris Flows

Debris flows are an important concern in BAER assessments because of the threat they can pose to life, property, and ecological values for a few years after wildfire. Additional discussion of debris flows is presented in chapter 6.1. Postfire erosion associated with debris flows can pose threats to downstream public water supplies (deWolfe et al. 2008, Goode et al. 2012). Although impacts to channels from severe wildfires can rejuvenate aquatic habitats, they can also kill aquatic life and result in extirpation of vulnerable aquatic species that are not able to recolonize the affected streams (Neville et al. 2012). If postfire landforms persist beyond the wildfire recurrence intervals, successive wildfires will have an important cumulative impact on watershed morphology (Moody and Martin 2001). Some researchers suggest a general lack of good options to prevent postfire debris flows (Goode et al. 2012).

Box 4.3-1

Treatments for Hillslope Erosion

- **Straw and other dry mulches**: Straw mulch is a highly effective means of providing groundcover on burned hillslopes to protect the topsoil against rainsplash, slowing surface flows, and helping control hydrophobic soil conditions (Bautista et al. 1996, Robichaud et al. 2000). Relatively less expensive than most other hillslope treatments, straw mulch has become one of the most widely employed postfire erosion control techniques (Robichaud et al. 2010). However, it may be problematic to apply in areas with windy conditions, and denser materials such as wood particles can be effective but more costly alternatives (Wohlgemuth et al. 2009). There are also concerns about the effects of different kinds of dry mulches (e.g., agricultural straw, rice straw, wood mulch) on introduction of invasive species such as cheatgrass and establishment of native herbaceous and woody species (Robichaud et al. 2010). One approach being explored is to chip and shred burned trees on site to generate native mulch materials (Robichaud et al. 2010).
- **Hydromulch**: Most hydromulch mixes consist of a bonded-fiber matrix combined with a non-water-soluble tackifier, which allows the aerially applied mulch to penetrate into and bond with the soil substrate. Hydromulch can be highly effective, but it is several times more expensive than straw mulch (Hubbert et al. 2012). Treatment effectiveness decreases after the first year as the product breaks down (Robichaud et al. 2010).
- **Contour-felled log erosion barriers (LEBs) and fiber rolls (straw wattles)**: Both logs and fiber rolls are used to improve infiltration, slow overland flow velocity by breaking up the slope length, and, to a lesser degree, capture and keep sediment on the slopes. Reviews show that effective use of these treatments requires a skilled workforce for proper placement; poor installation and foot traffic during installation can be a source of hillslope disturbance and rilling if water flows are concentrated (Robichaud et al. 2000). The fiber rolls may be easier to place and entail less ground disturbance than downing and placement of LEBs. Because both of these treatments are expensive and labor intensive, they are used primarily for protection of high-value areas (Robichaud et al. 2000). Both treatments lose effectiveness as the barriers fill with sediment, so they require maintenance. Use of LEBs in particular has decreased in recent years in favor of dry mulch treatments (Robichaud et al. 2010).

Box 4.3-1 (continued)

- **Seeding**: Grass seeding for postfire hillslope stabilization has decreased as a percentage of burned areas since the 1970s, likely owing to concerns about both cost effectiveness and ecological effects; however, more has been spent on reseeding as area burned and use of native species for seeding have increased (Peppin et al. 2011b). Because natural revegetation may be sufficient, erosive precipitation events may not occur, or erosive precipitation events may wash out the seeds, there may be a relatively narrow window of conditions where seeding would be successful in preventing erosion. However, within most of the synthesis area, that window may be wider than in regions where intense storms are more likely to happen after fires and before winter precipitation (Peppin et al. 2011a). However, where seeding is successful, it may reduce richness of native species, especially annual fire followers, and reduce establishment of woody plant seedlings (Beyers 2004, Peppin et al. 2011a, Stella et al. 2010). Use of mulch with seeding increases the establishment of seeded grasses, but generally the combination does not provide greater cover than mulch by itself (Robichaud et al. 2010). The effectiveness of seeding for reducing nonnative invasive plants after fire is mixed, as suppression of one species may entail replacement with one or more nonnative competitors (Peppin et al. 2011a). A particular concern of reseeding has been introduction of nonnative species or poorly adapted genotypes. The latter issue has been noted as requiring further research to determine the extent to which poorly adapted genotypes die off or reduce the fitness of native plants (Hufford and Mazer 2003).

However, one postfire study reports that a combination of well-designed, well-implemented, and well-maintained hillslope treatments (straw mulch, seeding, and LEBs) and channel treatments (check dams and debris racks) can reduce debris-flow volumes (deWolfe et al. 2008). Further research is needed to evaluate where and when such interventions are likely to be an efficient response. One possible aid in that effort is a debris flow volume prediction model based upon steep slopes, burn severity, and rainfall that has been developed and tested, although not for the synthesis area in particular (deWolfe et al. 2008, Gartner et al. 2008). Because climate change is expected to increase the incidence of severe wildfire, high-intensity storms, and rain-on-snow events, the threat of post-wildfire debris flows is expected to increase and become more widespread (Cannon and DeGraff 2009).

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Roads—

Because roads can concentrate runoff, obstruct streamflow, and alter other hydrologic processes, they are a focus of postfire treatments. In addition, research from western Oregon indicated that roads and debris flows can interact to facilitate spread of invasive plants (Watterson and Jones 2006), which is a particular concern after wildfires. A recent synthesis report (Foltz et al. 2008) provides information to guide decisions about postfire road rehabilitation based upon surveys of BAER specialists; it reported that treatments favored across all regions included upgrading road drainage features and culverts and increasing cleaning and armoring of ditches.

Identifying Erosion Hotspots Using Landscape Analysis Tools

Prioritizing areas for treatment can be guided by a range of factors, in particular soil attributes, such as postfire soil cover, burn severity, and soil type, in addition to expected precipitation, vegetation type, and resource values (Benavides-Solorio and Macdonald 2005). Analyses of topography provide additional information for prioritizing treatments following wildfires (Istanbulluoglu et al. 2002), especially because research has shown that convergent swales have greater potential for postfire erosion (Benavides-Solorio and Macdonald 2005). The spatial distribution of postfire effects can be mapped in relation to landscape features using remote sensing and geographic information system tools. Postfire monitoring of burned watersheds to evaluate erosion rates and consequences can enhance understanding of postfire erosional processes, help to develop and refine models (including WEPP) to inform and improve treatment strategies, and inform forest treatment planning by identifying areas that appear particularly vulnerable to postfire erosion. Tools to predict postfire debris flows in southern California and the Intermountain Region (Cannon and DeGraff 2009) could be tested and refined so that they could be used for BAER and longer term planning in the synthesis area. Detailed terrestrial and airborne LiDAR surveys offer tools for evaluating post-wildfire erosion (Bremer and Sass 2012, Buckman et al. 2009, Canfield et al. 2005, Perroy et al. 2010). These studies suggest that as airborne LiDAR sets become more widely available in the synthesis area, it will become more practical to identify erosion hotspots and debris flows and to quantify erosion and deposition in channels, although more detailed terrestrial LiDAR surveys may be required to evaluate finer hillslope processes. Low-cost techniques can be used to monitor postfire floods and debris flows in channels that do not already have stream gages (Kean et al. 2012). Evaluating risks at finer reach scales can help to evaluate the likelihood of extirpation of aquatic life within basins by relating the probability and location of expected debris flows to occupied habitats.

Research Needs

Robichaud et al. (2009) identified three research needs to support short-term rehabilitation, including predictive models of watershed processes, refinement of remote sensing tools, and development of mulches using local site materials. However, they also emphasized the importance of long-term monitoring to evaluate treatments.

Postfire Salvage Logging and Replanting

One of the more controversial activities in the postfire environment is salvage logging of fire-killed trees. Salvage logging is controversial because few short-term positive ecological effects and many potential negative effects have been associated with postfire logging (Peterson et al. 2009), while the potential economic returns from salvaging timber in a timely manner can be very large (Sessions et al. 2004). Several of the more common reasons given for doing this work are (1) utilizing the dead wood while it is still merchantable; (2) generating revenue for postfire rehabilitation activities, including site preparation and replanting of severely burned areas; (3) reducing the level of future fire hazard that may result as the dead wood accumulates on the ground as surface fuel; and (4) enhancing the ability of firefighters to safely control future fires (Peterson et al. 2009, Ritchie et al. 2013). Effects on greenhouse gas emissions are another consideration. Salvage removes carbon from the forest; however, much of the carbon in dead trees may be released to the atmosphere through decomposition. By converting those trees into forest products, there is potential to avoid greenhouse gas emissions (Powers et al. 2013). Finally, some scientists and others contend that, for both pragmatic and ecological reasons, salvage and replanting are needed to speed recovery of complex or mature forest conditions for future timber production or restoration of old forest habitat (especially large trees) for some wildlife species (Sessions et al. 2004). This argument has been countered by claims that salvage and replanting disrupts an important seral stage and recovery processes that favor other wildlife species (Hutto 2006). Although this debate points to a fundamental tradeoff between early seral habitat and late seral habitat, promoting heterogeneous conditions may allow both objectives to be realized. It is important to consider that only a portion of most large fires on public lands are typically proposed for salvage while other areas are left untreated, whereas on industrial timberlands, salvage and replanting would be expected to return lands to full timber production. Accordingly, another consideration may be the combined effect of actions on public and private lands where large fires have burned across ownerships.

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Reviews of Ecological Considerations

Knowledge of the ecological effects of postfire logging, most of which is short-term, has been summarized by McIver and Starr (2000), Lindenmayer et al. (2004), Lindenmayer and Noss (2006), Lindenmayer et al. (2008), and Peterson et al. (2009). These reviews note that general ecological concerns associated with salvage logging include impacts to soils; impacts to understory vegetation and recruitment; potential increases in surface fuel loads; reductions in key structural elements, such as snags and burned logs and their associated habitat values; and other influences on forest development. Reviews of the effects of salvage logging on aquatic systems reflect more general concerns about timber harvest (e.g., increased sedimentation and runoff from roads and logging disturbance, and loss of large trees and coarse woody debris inputs), although effects could be more significant because the timing of salvage logging imposes a stress following the disturbance of severe wildfire (Beschta et al. 2004, Karr et al. 2004, McCormick et al. 2010, Peterson et al. 2009).

Currently, there is only one published experiment that was designed to study the effects of varying the intensity of postfire logging within the synthesis area (Ritchie et al. 2013). The initial publication from this study focused on snag longevity and buildup of surface fuels over the first eight years following the Cone Fire (2002). The study found that most ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) snags had fallen within 8 years of the fire (only 16 percent were partially intact in the 30 to 45 cm class, compared to 41 percent in the >45-cm class). White fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) snags were more durable (42 percent partially intact in the 30 to 45 cm class and 92 percent in the >45-cm class). Further, regardless of the intensity of postfire logging, approximately 80 percent of the biomass of retained snags was on the ground 8 years after the fire. Correspondingly, 8 years after the fire, surface fuels were greater where more snag basal area had been retained. Additional studies would be needed within the synthesis area to understand these processes to account for variation in snag and log decay and other ecological factors.

Generally, effects of postfire logging vary considerably by forest type, fire severity, and the timing and nature of the treatment (Peterson et al. 2009). Impacts on tree recruitment have been observed when logging has been delayed until after seedlings have become established (Donato et al. 2006, Newton et al. 2006, Roy 1956). Salvage logging by helicopter is likely to avoid more of the ground disturbance. However, the economic feasibility of salvage logging in general, and especially more costly methods such as helicopter logging, may depend on removing larger, more merchantable dead trees (Han 2004). Larger trees are likely to be disproportionately valuable for wildlife species that use postfire snags (Hutto 2006).

These relationships suggest a fundamental tradeoff, although identifying thresholds for snag size and patch size would likely require additional research.

Wildlife associated with high-severity wildfire—

Patches of high-severity fire create ecologically important habitat that support distinctive species assemblages for several years after fire (Hutto 2006, Saab et al. 2011). One species in particular, the black-backed woodpecker, is associated with patches of high-severity fire that have high densities of snags colonized by wood-boring beetles. Woodpeckers such as the black-backed woodpecker create cavities that are used by many other cavity-nesting birds and mammals, leading some scientists to consider them to be a useful indicator of ecological condition (Drever et al. 2008) and potentially a keystone species (Bednarz et al. 2004). The habitat requirements of wildlife species that are associated with snags created by fire may be quite different from reference snag densities and other habitat qualities from unburned forests (Hutto 2006). For example, a study of three fires on the western slope of the Sierra Nevada detected foraging by black-backed woodpeckers only in high-severity patches that were unlogged, with an average of 124 large (>50 cm diameter at breast height [DBH]) and 128 medium (>25 and <50 cm) snags per hectare, and none in high-severity patches that were logged and contained a residual average of 18 large and 170 medium snags per hectare, or in lower severity patches (Hanson and North 2006b). In addition, Seavy et al. (2012) reported a small study from two fires (Moonlight and Cub) in the northern Sierra Nevada and found that black-backed woodpecker nest in areas where snag densities exceed 200 snags/ha. These studies reinforce findings from the Pacific Northwest and the northern Rocky Mountains to suggest that the species may benefit from patches with very high snag densities, and that salvage in such patches may have negative effects on postfire biodiversity (Hutto 2006, Kotliar et al. 2002). However, a survey of black-backed woodpeckers in 72 wildfires across the synthesis area found a relatively weak relationship between occupancy and reduction in canopy cover (Saracco et al. 2011). The authors interpreted their results as indicating that the species uses a range of burn severities that provide a broad window of favorable habitat and may represent broader postfire habitat use than has been reported for other regions. Note that studies of salvage impacts on wildlife within the synthesis area have been observational rather than experimental, so it may not be appropriate to generalize the findings. However, such studies still provide insights into important dynamics for consideration. For example, a study from a jack pine forest in Michigan (Youngman and Gayk 2011), though based upon a very different ecosystem, indicated how populations of black-backed woodpeckers can reflect complex

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dynamics, including use of burned and unburned forest, competition with other woodpeckers, and potential for enhanced availability of beetles as food following early season fires. Studies of black-backed woodpeckers within unburned forests are pending in the synthesis area, and further research on this and other wildlife species of special concern (see chapter 1.5, “Research Gaps: Adaptive Management to Cross-Cutting Issues”) will be needed to understand effects of fires with different patch sizes, severities, and configurations and postfire logging on habitat suitability over time and space.

Despite these uncertainties regarding effects of postfire treatment on biodiversity, there are important data sources about postfire environments that have not entered into peer-reviewed literature but could still serve to inform management decisions. Thus, there may be sufficient information to develop a decision support tool to guide managers in the synthesis area regarding decisions about particular postfire landscapes. For example, a tool called the “Decayed Wood Advisor” (DecAID) was developed to manage for biodiversity in Washington and Oregon (Marcot et al. 2002, Mellen et al. 2002).

Predictions of postfire tree mortality—

Some of the controversy around postfire salvaging is related to the variable ability to accurately predict which trees are likely to die from fire damage (Hood et al. 2007b). Although areas burned by high-intensity fire typically result in high tree mortality, some trees that appear dead may survive (especially in young ponderosa pine trees) and others may take up to several years to die depending on the nature of fire damage and other postfire impacts, such as bark beetle attacks (Hanson and North 2006a, Hood et al. 2007a). Furthermore, prescribed fires often result in increased tree mortality when compared to similar unburned sites (Fettig and McKelvey 2010; Fettig et al. 2008, 2010a, 2010b). Improving the ability to accurately predict which trees are likely to live or die following fire has been the focus of several studies completed in the last decade. These studies developed a better understanding of the characteristics of fire injuries that are associated with subsequent tree mortality (Hood 2010). Hood et al. (2007b) cautioned that the Ryan and Amman mortality model (Ryan and Amman 1994), which is based on tree scorch and size, should be applied with caution in areas where the majority of trees are large (greater than 55 cm dbh). By improving identification of trees that are likely to die within a few years of a fire based on characteristics of fire effects, such information can help support postfire activities (Hood et al. 2007b, 2010).

Reburns—

The long-term ecological effects of reburns, including potential ecological benefits of postfire salvage of dead trees, are an important gap in our knowledge of postfire management in the synthesis area. There are many conflicting accounts of fire behavior during reburns in areas that had previously experienced different levels of fire severity and postfire logging, but to date, no systematic studies have been done in forests similar to those in the synthesis area (Peterson et al. 2009). Studies in Oregon (Thompson and Spies 2010; Thompson et al. 2007, 2011) looked at reburn severity in southwestern Oregon within the area that burned in the Silver Fire (1987) and burned again in the Biscuit Fire (2002). They found that high-severity burns from the Silver Fire led to a condition dominated by shrubs and regenerating trees that burned again at high severity during the Biscuit Fire. They also found that the postfire treatments had promoted relatively dense and homogeneous fuelbeds that were vulnerable to reburn, and that the vulnerability of the planted stands was likely to persist for 25 years (Thompson et al. 2011). They found higher proportions of crown damage in stands that had been salvage logged and replanted after the Silver Fire than in the areas that had been left unmanaged. However, as with many retrospective studies of salvage, they did not have details about the planting treatment and extent of pretreatment differences between the treated and untreated areas. There were likely initial differences between the treated and untreated areas that led to the decision to treat some and not the others; Thompson et al. (2011) noted that most of the unmanaged stands were >50 years old and therefore less vulnerable. Note also that the area in that study was a relatively productive environment in which fuels could accumulate rapidly. Most of the synthesis area is very different in vegetation and climate, so more long-term, site-specific research would help improve understanding of postfire recovery. Ongoing studies of the Storrie Fire (2000) may provide an opportunity for this type of research, given that a large portion of that area was reburned in the Chips Fire of 2012. Remeasurement of existing plots in the Storrie Fire area would yield more detailed data than were available to Thompson and Spies (2010). Reburns can provide valuable opportunities to learn about long-term dynamics in ways that may better evaluate resilience. For example, studying the area burned by the Storrie and Chips fires could help to understand reburns in areas where dead wood was removed or left after the Storrie Fire and may have affected fire-severity patterns, coarse woody debris and snags, and regrowth of conifers, hardwood trees, understory shrubs, and chaparral stands.

Reforestation—

One of the key questions is how long it will take for severely burned forests to grow, and what the composition of those forests will be, with and without intervention, including salvage, replanting, and reduction of shrubs, especially given the likelihood of reburn. The combination of fire exclusion and high-severity fire has potential to shift forest systems toward shrubs or shade-tolerant conifers that can grow through hardwood and shrub cover (Crotteau et al. 2013). This question begs a larger discussion about desired conditions for different ecological areas, which is the focus of the final section in this chapter. This particular issue demonstrates the complexity of managing systems that are affected by multiple stressors (see chapter 1.2), because choices involve tradeoffs among different risks across long time periods.

Tree planting may be conducted independently of salvage, but the treatments are often planned as a combined treatment. Although regeneration can be extensive following severe burns, it is often highly variable (Crotteau et al. 2013, Shatford et al. 2007). Regeneration of pine species in particular may be compromised in large high-severity fires patches, both now and as the climate changes (Crotteau et al. 2013, Feddema et al. 2013). Perry et al. (2011) noted that the more time it takes for conifers to grow large enough to survive reburns, the less chance they have of becoming dominant over shrubs and being able to survive the next fire. Replanting trees can accelerate conifer establishment and, when combined with vegetation management, reduce the time to regenerate forest conditions (Zhang et al. 2008). In addition, Sessions et al. (2004) argued that tree planting may be important when confronting diseases such as white-pine blister rust, which affects trees such as sugar pine and western white pine in the synthesis area. Populations of those species in the synthesis area generally exhibit some resistance to the disease; there are trees that are fully resistant (because they have a single major resistance gene) and others that are susceptible to infection but can tolerate it (partially resistant or “slow-rusting” trees). Accordingly, tree planting may include a mixture of both types of stock to reduce the likelihood of widespread tree losses and the risk of the disease overcoming the simple form of resistance (Maloney et al. 2012).

Another component of postfire treatment can include the use of herbicides to reduce shrubs and favor conifer survival and growth (McDonald and Fiddler 2010, Zhang et al. 2008). A study comparing active postfire management to passive management on private forest lands that burned in the large Fountain Fire (1992) in the synthesis area concluded that active postfire reforestation treatments were more effective at quickly restoring forest cover than passive management (Zhang et al.

2008). In another retrospective study of several large severe wildfires in the synthesis area, (McGinnis et al. 2010) examined complex interactions among logging, tree planting, herbicides to reduce shrubs, and alien species, especially cheatgrass (*Bromus tectorum*). This study found that salvage logging increased dead fuel loads in the short term but only in the largest size class (1,000-hour fuels) and that modeled fire hazards did not change over the long term. The salvage and replanting treatment did not affect shrub cover, grass and forb cover, alien species cover or alien species richness, but the combination of salvage, planting, and herbicides reduced shrub cover in favor of forbs and grasses, including several invasive species. The fire modeling in that study indicated that reburns could threaten the planted conifers for two decades, and the authors expressed concern that frequent reburns in herbicide-treated areas might cause type conversion into alien-dominated grass areas. This study provides another illustration of the complex interactions that arise when considering postfire interventions, especially in systems that have been invaded.

Social Considerations

Despite concerns over the ecological effects of salvage logging, several studies have found a high level of public support for salvage logging in communities that have experienced a nearby wildfire, or are located in an area where the risk of wildfire is high. For instance, McCaffrey (2008) found that 75 percent of sampled homeowners in Incline Village at Lake Tahoe believed salvage logging was an acceptable practice. The study also found that respondents who had direct experience with wildfire were 15 percent more likely to find salvage logging acceptable than respondents who lacked experience with wildfire. Older residents were more likely to approve of salvage logging, with approval at 93 percent among the 65-and-older group in this study. Respondents in the study who found salvage practices unacceptable cited general distrust of logging and a specific concern that mature trees that did not pose a fire risk would be removed. However, the study noted that environmental concerns by most residents in that community might have been alleviated by the fact that logging practices in the basin are highly regulated. The study also reported that half of the respondents considered use of herbicides to be unacceptable.

Salvage logging was also viewed favorably by the majority of respondents in three communities in California, Colorado, and New Mexico who recently had suffered extensive wildfires (Ryan and Hamin 2009). One of the three communities was the town of Arnold, within the synthesis area. Respondents cited concerns over aesthetics (especially seeing large numbers of dead trees), and the potential for economic benefit, as reasons for their support. The study found that recreational users cited the safety hazard posed by dead or dying trees as a primary reason to support salvage. Public support appeared to depend on salvage logging being undertaken in a manner that was ecologically appropriate, with particular concerns for keeping a large number of snags for wildlife, limiting road building or removing roads after logging, and removing post-logging slash. Another study by Ryan and Hamin (2006) found that residents in Los Alamos, New Mexico, supported salvage logging after the Cerro Grande Fire of 2000, but preferred not to have any new logging roads built. Their support was based on a perceived "wastefulness" of leaving burned trees standing. In this study, participants found salvage logging preferable to the logging of unburned forests. A qualitative study in Washington state (Mendez et al. 2003) reported general attitudes consistent with the themes in these other studies, but gave more weight to environmental concerns in a community that had experienced recent growth.

Salvage logging can generate several economic benefits if done in a timely manner. It provides an option to recover economic value from dead and damaged timber and helps prepare the burned site for new investments (Prestemon and Holmes 2004). It can provide economic benefit to affected local timber industries and owners of damaged timber, enabling them to recover value from an otherwise economically catastrophic event (Prestemon et al. 2006). However, large salvage timber sales associated with major disturbances such as wildland fire or hurricanes have the potential to lower prices in the short term by flooding the market with a large quantity of logs. Although this can benefit consumers by bringing down prices, it can hurt the owners of undamaged forests. Over the longer term, this initial decrease in prices may be followed by higher-than-average prices, reflecting the reduction in standing timber volume (supply) caused by the disturbance event. The tables then turn, benefitting owners of undamaged timber but hurting consumers (Prestemon et al. 2006).

Prestemon and Holmes (2004) stress the importance of focusing timber salvage operations on burned stands that contain higher value materials in order to optimize economic benefits. Dead and damaged timber decays and loses value by the day; delays in the salvage process can result in major economic losses unless timber salvage recovery plans are carried out as designed (Prestemon et al. 2006). There are two common reasons for harvesting delays in salvage situations: administrative delays, and appeals and litigation, the latter often resulting from environmental concerns (Prestemon et al. 2006).

Management Guidance and Research Gaps

The issue of salvage logging may well be regarded as fundamentally a tradeoff between ecological and socioeconomic values, although there are some contexts in which salvage may have ecological benefits. As with other issues considered in the synthesis, these contexts include ecosystems that have been extensively modified by past land use practices or introductions of nonnative species. Franklin and Agee (2003) suggested that salvage may be ecologically appropriate in dry forests that have uncharacteristically high amounts of standing dead and down trees, likely owing to fire suppression and other legacy effects of past management. As a general strategic approach, reviews have suggested retaining untreated patches and limiting the removal of biological legacies, especially larger structures (Lindenmayer et al. 2008). Public attitudes appear to rest heavily upon the perceived ecological impacts of the practice (McCool et al. 2006, Prestemon et al. 2006, Ryan and Hamin 2009). As a result, a concerted research effort would be needed to resolve the many questions that remain concerning the short- and long-term effects of postfire salvage logging, not only from a purely scientific perspective, but also to reconcile public concerns. Scientific reviews emphasize the lack of experimental research on postfire logging, particularly regarding long-term effects, that would provide a basis for more specific management guidelines. Understanding of fire behavior in reburns with and without salvage is an important research gap, and would aid understanding of both long-term ecological impacts and short-term fire conditions, including safety hazards faced by firefighters. The consequences of salvage logging following wildfire on carbon and nitrogen cycling and storage are another area of uncertainty (Bradford et al. 2012, Powers et al. 2013).

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Managing Long-Term Post-Wildfire Outcomes

Proactively considering the likelihood of large wildfires and how to respond to them is an important component to promoting ecosystem resilience to future stressors. Although postfire rehabilitation is a rapid process that focuses on short-term flooding and erosion risks, planning based upon long-term objectives and consideration of future climate can help evaluate the goals and rate of progress for achieving desired ecological composition, structure, and function (Littell et al. 2012). Taking a broader perspective on long-term resilience can promote consideration of the circumstances under which interventions are most appropriate. Public support for management actions may be strongly tied to the ecological context of the wildfire as well as to its social impacts, especially in terms of impacts to homes, viewsheds, public safety, and local economies. Although expectations for interventions are likely to be higher in communities that are more immediately connected to the burned areas, an important finding is that success may depend heavily on communication regarding not only the initial treatments but also longer term recovery.

Many parts of the landscape, such as steep terrain and roadless or wilderness areas, may be largely untreatable because of access limitations and other related restrictions. In addition, attempting to reestablish prefire forest communities may be problematic given expectations for a warmer climate with more fire and less snow in much of the synthesis area. Because fire and climate are likely to be conjoined drivers of ecological change, developing more detailed climate and fire scenarios should help to assess system vulnerability in a spatially explicit manner (Nydick and Sydoriak 2011). Historical studies can not only provide valuable insights into past dynamics, but also identify areas that may be more sensitive to the combined influence of wildfire and changing climate, which, based on work in the Klamath Mountains, might include areas with more productive soils (Briles et al. 2011).

Determining which kinds of changes are adaptive and which ones are undesirable will likely remain a central challenge in postfire management planning. Refraining from interventions may be appropriate in areas where the ecological trajectory of a postfire landscape seems to align with desired conditions, which may include regeneration of hardwoods, chaparral, or other nonconiferous vegetation (Taylor 2004). Severely burned patches may enhance diversity within the landscape by restoring ecological communities that were displaced by conifer expansion under altered fire regimes. For example, in the mixed-conifer forests of the Lake Tahoe Basin, Nagel and Taylor (2005) estimated that fire suppression has reduced the average size of montane chaparral stands by more than 60 percent. Recovery of shrubfields may be an important dynamic on upper and south-facing slopes in particular (Beaty and Taylor 2008, Crotteau et al. 2013, Nagel and Taylor 2005). Swanson et al. (2010) noted that the early successional conditions following stand-replacing wildfire increase availability of sunlight and nutrients that can support both terrestrial and aquatic biodiversity. Canopy gaps created by severe burns might also facilitate long-term rejuvenation of California black oak (*Quercus kelloggii* Newb.) by reducing competition from encroaching conifers (Cocking et al. 2012). However, loss of large, mature oaks may reduce acorn production, which is important to many wildlife species and to Native Americans (see chapter 4.2, “Fire and Tribal Cultural Resources”).

High-severity fire may also induce “type conversions” or “transformations.” These outcomes may be more likely in areas where fuels have accumulated owing to management actions over the last century and then burned with high severity (Skinner and Taylor 2006). The size of high-severity patches may be a particularly important indicator of whether changes constitute a major shift, especially because natural recovery processes such as natural reseeding of conifers may be limited by the distance to live trees (Crotteau et al. 2013). Recent patterns of increased stand-replacing fires in coniferous forests of the synthesis area point to the importance of tracking high-severity patch size, postfire forest regeneration, availability of old-forest habitat, and related landscape attributes that may veer beyond the historical range of variation (Miller et al. 2009).

The spread of invasive species may increase the potential for transformations. For example, increased fire frequencies, such as those found in some shrub communities in southern California, coupled with nonnative plant invasions, may facilitate conversions of woody communities to grasslands dominated by nonnative annuals (Keeley and Brennan 2012, Keeley et al. 2011). Although this kind of transformation has not appeared to be a widespread problem in the synthesis area, it could be a growing concern in the future, particularly in lower elevation and drier areas (Sherrill and Romme 2012).

Landscape Approach and Multiscale Heterogeneity

Evaluation of the landscape context of high-severity patches in relation to unburned and low- to moderate-severity burned areas (fig. 3) will be important for setting priorities and designing management strategies to promote landscape resilience. For example, patchy configurations of unburned and lower burn severity areas within or adjacent to large, severely burned areas may provide a seed source for natural tree regeneration and reduce the need for artificial planting. It may be important to promote connectivity of remaining habitat patches within the burn perimeter to areas outside of the burn, as well as to design strategies to conserve such patches (see chapter 7.1, “The Forest Carnivores: Marten and Fisher,” for more specific discussions of connectivity for wildlife). In addition, evaluating effects across private and public lands will be an important part of the post-management decisionmaking process.

Postfire management might also consider stand-scale heterogeneity in vegetation structure. For example, where tree planting is deemed appropriate, those treatments can be designed to promote finer scale heterogeneity and ecological resilience. Specific tactics may include planting fire-resistant tree species, planting trees at variable densities in groups or as single stems with openings (Larson and Churchill 2012), and managing plantations with the intention of introducing fire as a management tool, which might include wider spacing (Kobziar et al. 2009). Such tactics may be important in helping to avoid an ecological trap of early successional, even-aged stand structures that are vulnerable to repeated fires.

Another strategy that might be considered would be to select tree stock that is diverse and adapted to local conditions given expectations for possible climate

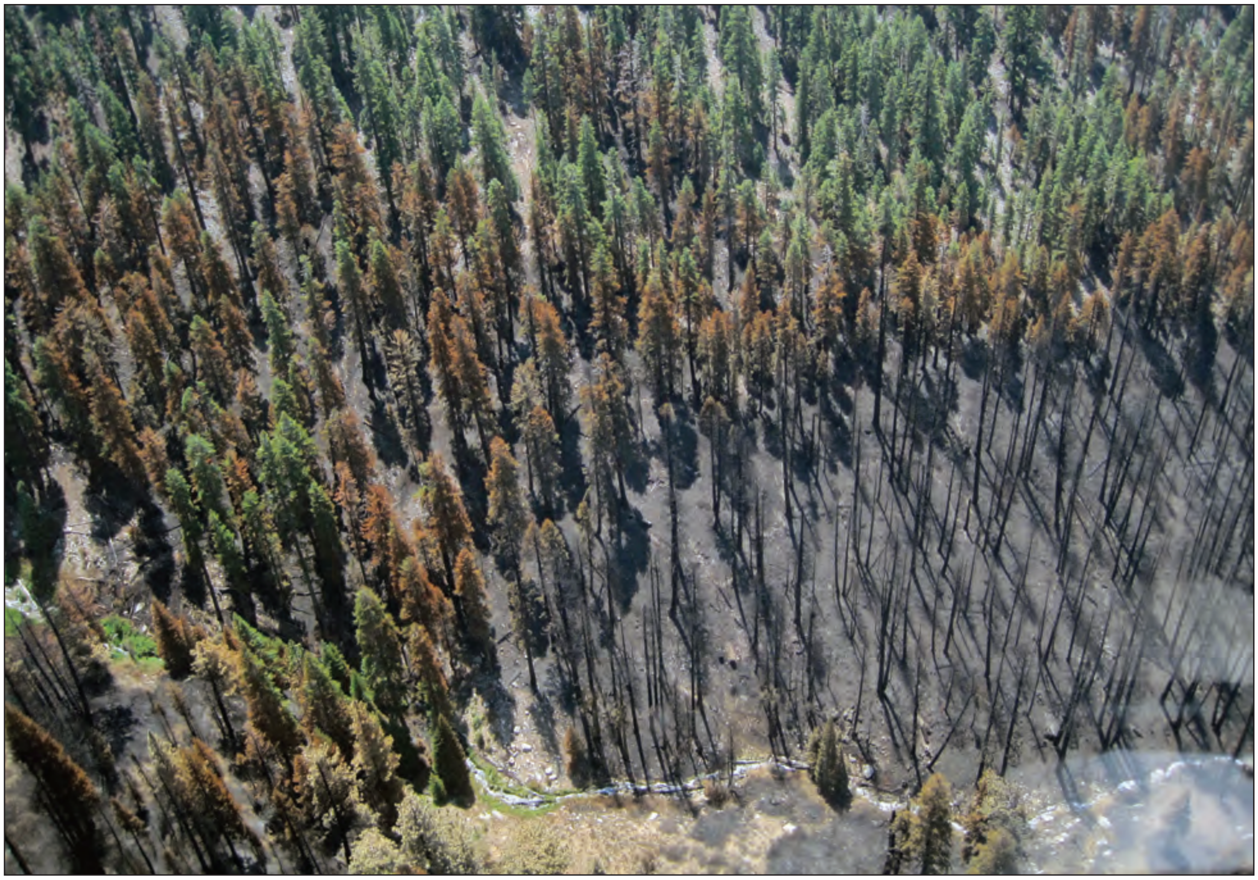
Brent Skaggs

Figure 3—An overhead view of part of the Lion Fire of 2011, which was managed to promote resource benefits, reveals heterogeneous burn conditions across both uplands and riparian areas in the Golden Trout Wilderness.

change; additional research will help to determine which traits might be most important for promoting forest resilience (see chapter 3.1, “Genetics of Forest Trees”). The expectation that tree planting will be conducted following wildfires could reinforce efforts to gather and store sufficient seed materials in advance of such events.

Advance Planning and Collaboration

Increased collaboration and integration of postfire considerations into management plans in anticipation of potential fires may facilitate implementation of postfire restoration. Timely implementation may be critical to avoid passing various thresholds of soil erosion, vegetation development, and suitability of harvestable materials. Incorporating postfire strategies into advance planning may help build capacity for timely implementation (Littell et al. 2012). For example, where salvage is identified to be a desirable component of postfire treatment, there could be substantial economic benefits from advance planning by reducing the potential for delayed harvest (Prestemon et al. 2006). Encouraging community participation in postfire rehabilitation efforts may be an important opportunity to mobilize volunteer labor and benefit community members (McCool et al. 2007), and participation may also be valuable in planning restoration (see chapters 9.1 and 9.6 on the benefits of community participation in restoration activities).

Monitoring and Research

Monitoring, modeling, and research of postfire landscapes can help determine the likely trajectory of ecosystem recovery in the postfire environment, prioritize areas for treatment, and evaluate when important thresholds might be crossed. Monitoring data would help calibrate models to estimate the likely direction of postfire vegetation succession under changing climate conditions. Researchers have used the LANDIS model to evaluate the time it takes for different tree species to reoccupy severely burned areas with and without planting (Wang et al. 2007). An important opportunity for monitoring-based research is to better understand successional pathways for forest types after fires of differing severity as the climate changes, especially if large areas of forests do not regenerate. These large-scale monitoring and research efforts underscore the increasing value of new remote-sensing techniques coupled with ground-based data in tracking these changes (Schimel et al. 2013). Chapter 1.5, “Research Gaps: Adaptive Management to Cross-Cutting Issues,” discusses the need for collaborative efforts to refine monitoring and research questions, because science-management partnerships can be an effective way to prioritize and design adaptation strategies (Littell et al. 2012). Given the importance of understanding social and ecological dimensions of systems, research and monitoring plans should also consider socioeconomic factors, including effects on water supplies, recreation, the forest products industry, human health, and other indicators of community well-being.

One of the most important parts of developing a long-term resilience strategy is to help better understand the implications of fire severity patterns, especially large high-severity burned areas, on the spatial and temporal distribution of various resources and social values. This approach will require integrated studies that consider the effects of multiple fires and reburns across large landscapes (in terms of fragmentation of habitat and changes in landscape fire behavior). Well-designed, long-term monitoring and research is essential to understanding postfire impacts to priority terrestrial and aquatic wildlife species. The effect of fire severity (including the size and spatial arrangement of different fire severity classes) on wildlife species will be an important subject of research within the synthesis area. Another important research gap is the effect of severe wildfires on species associated with old-forest habitats, such as California spotted owl and

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forest carnivores. By continuing to monitor within burned areas, existing fisher population monitoring in the Pacific Southwest Region could help to elucidate the influence of wildfire on fisher occupancy. This information would be valuable for testing occupancy models and designing landscape strategies to conserve values at risk over long periods. It is important to recognize that most mixed-conifer forests in the synthesis area are significantly departed from their historical fire regimes (see chapter 4.1, "Fire and Fuels"), and that wildlife living in such forests may respond very differently in landscapes with active fire regimes (see chapter 7.1). Differences in fire regimes and management history may be important factors in explaining why Roberts et al. (2011) found that spotted owls in Yosemite National Park, which are used to relatively frequent fire regimes, were less associated with large trees than was reported in an earlier study by Blakesley et al. (2005) from northeastern California. Because of these complex interactions, it remains important to test hypotheses about how sensitive wildlife species will respond to treatments and to wildfires (see chapter 7.2, "California Spotted Owl: Scientific Considerations for Forest Planning"). These issues underscore the themes considered in chapters 1.2, "Integrative Approaches: Promoting Socioecological Resilience," and 1.3, "Synopsis of Emerging Approaches."

Management Implications

- Proactively planning responses to future wildfires can help promote resilience by identifying critical values that may require postfire intervention and by facilitating implementation of time-sensitive postfire treatments.
- High-severity patches and resulting fuel loads that are larger than the range of expected variation may be a focus for interventions.
- Many questions remain concerning the long-term effects of multiple severe wildfires and postfire treatments such as salvage logging, not only from a purely scientific perspective, but also to reconcile public concerns.
- Promoting greater interaction between management and research, including using monitoring in a robust adaptive management framework, could help to answer key questions, such as under what conditions interventions such as postfire logging might yield benefits in terms of reducing undesirable impacts from reburns in heavy fuels.

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