J. For. 110(6):299–303
http://dx.doi.org/10.5849/jof.11-018
Copyright © 2012 Society of American Foresters

wildlife management

Evaluating the Efficacy of Protected Habitat Areas for the California Spotted Owl Using Long-Term Monitoring Data

William J. Berigan, R.J. Gutiérrez, and Douglas J. Tempel

The USDA Forest Service has adopted a management strategy for the California spotted owl (*Strix occidentalis occidentalis*) in the Sierra Nevada that relies on protecting habitat (Protected Activity Centers [PAC]) around suspected owl territory centers. We discuss the history of the PAC concept and evaluate its efficacy by comparing owl core areas of use, derived from usage distributions based on long-term location data of territorial owls, with their associated PACs. The average size of core areas used by spotted owls (334.7 ac; SE = 40.2; $N = 29$; 95% usage distribution for roost and nest locations) was similar to the average PAC size (287.5 ac; SE = 4.3; $N = 29$; $t = 1.16$; $P < 0.25$; 28 df). The 50 and 90% usage distributions for owl use area were smaller than their corresponding PACs ($t = 38.88$, $P < 0.0001$, and 28 df; $t = 2.31$, $P < 0.03$, and 28 df, respectively). The spatial overlap between owl core areas of use and PACs was also high. The average proportions of each core area that coincided with a PAC area was 0.84, 0.70, and 0.61 for the 50, 90, and 95% usage distributions, respectively. Moreover, there were more owl locations found inside ($\bar{x} = 36.0$; range, 8–76; SE = 2.96) than outside ($\bar{x} = 6.9$; range, 0–26; SE = 1.03) of PACs ($t = 9.289$; $P < 0.0001$; 68 df). We concluded that PACs, even though derived through an ad hoc but reasoned method, appear to be a key element for conservation of California spotted owls because owls have used these areas over long periods of time (up to 24 years). We also suggest that location data collected during long-term monitoring programs may be useful for identifying core areas for habitat protection not only for spotted owls but also for other species.

Keywords: California spotted owl, core area estimation, long-term monitoring data, Protected Activity Center, *Strix occidentalis occidentalis*, Sierra Nevada

The spotted owl (*Strix occidentalis*) has been a focal management species in the western United States because of its association with mature and old-growth forests (Gutiérrez et al. 1995). Two subspecies (northern spotted owl [*S. o. caurina*] and Mexican spotted owl [*S. o. lucida*]) have been listed as threatened under the US Endangered Species Act, whereas the third subspecies (California spotted owl [*S. o. occidentalis*]) was denied listing (US Department of Interior 2006). The US Fish and Wildlife Service strongly considered the "inadequacy of existing regulatory mechanisms" when making its listing decisions for both the northern and the Mexican spotted owls (US Department of Interior 1990, 1993), whereas management strategies for the California spotted owl were deemed adequate (US Department of Interior 2006).

The USDA Forest Service's management strategy before the listing of the northern spotted owl in 1990 consisted of a network of conservation reserves (i.e., protecting habitat surrounding one to three owl pairs separated by 6–12 mi throughout the landscape). Because the US Fish and Wildlife Service found this approach lacking as a conservation strategy for the northern spotted owl, the Forest Service and state agencies

Received February 28, 2011; accepted April 17, 2012; published online May 31, 2012.

Affiliations: *William J. Berigan (wberigan@wisc.edu) was research fellow, Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, 1980 Folwell Avenue, St. Paul, MN 55108; current address, Department of Forest and Wildlife Ecology, University of Wisconsin - Madison, 226 Russell Laboratories, 1630 Linden Drive, Madison, WI 53706. R.J. Gutiérrez (gutie012@umn.edu) is professor and Gordon Gullion Endowed Chair in Forest Wildlife Research, and Douglas J. Tempel (temp0059@umn.edu) is research fellow, Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, 1980 Folwell Avenue, St. Paul, MN 55108.*

Acknowledgments: *The authors thank the many field technicians who helped conduct owl surveys during the study. Christine Moen and Mark Seamans acted as project leaders during this time. Carlos Ramirez was helpful in explaining the USDA Forest Service PAC delineation process, data, and shapefiles. Sheila Whitmore and Zach Peery provided technical and logistical help. The University of California's Blodgett Forest provided housing. Casey Phillips and Paul Kapfer read previous drafts of this article. This is publication 9 of the Sierra Nevada Adaptive Management Project (SNAMP). SNAMP is 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. The authors received additional long-term funding from Region 5 of the USDA Forest Service, the State of California Resources Agency, the California Fish, Game Department, and the Pacific Southwest Research Station to R.J. Gutiérrez.*

in California sponsored a technical assessment to evaluate the status of the California spotted owl and to make management recommendations (we hereafter refer to this status review as "CASPO;" Verner et al. 1992). The CASPO team proposed an interim conservation strategy for the California spotted owl. One element of this interim strategy was the protection of core habitat around each site occupied by California spotted owls (Verner et al. 1992). Verner et al. (1992) referred to these core habitat areas as Protected Activity Centers (PAC).

To determine the size and configuration of PACs, CASPO used the biological concept of core area of use (Verner et al. 1992). Core areas of use are those areas within an animal's home range that receive concentrated use and are often thought to encompass critical components within a species' home range such as nest sites, refugia, and foraging areas (Samuel et al. 1985, Swindle et al. 1999). Generally, core areas are identified using radiotelemetry (Bingham and Noon 1997, Millspaugh and Marzluff 2001), but the use of telemetry on rare or endangered species may confer some risk (Barron et al. 2010). Moreover, telemetry data for California spotted owls were limited at the time, so CASPO incorporated existing knowledge about owl locations, owl selection of nesting, and roosting habitat (i.e., forests having large trees and high canopy cover), and limited telemetry information on habitat use into a novel, but uncertain, approach to estimate a core area for protection. They first identified the forest stand that contained the nest or primary roost of each known owl territory in the Sierra Nevada. Then, they calculated the size of this stand plus all contiguous stands that were shown by analysis to be preferentially selected habitats (see Verner et al. 1992 for definitions of preferentially selected habitat types). On average, they estimated that these ad hoc "core areas" were approximately 290 ac, which they increased to 300 ac for purposes of defining a PAC. They then recommended to the Forest Service that it use vegetation maps to identify the best contiguous 300 ac for protection around all known owl nest or roost locations in the Sierra Nevada, California, to serve as PACs for territorial owls. No stand-altering activities, except light underburning, would be permitted within PACs. The PAC recommendation became part of an interim conservation strategy for the California spotted owl (Verner et al. 1992).

The Forest Service has continued using PACs to the present day, despite its original intent as an interim management strategy. The agency has delineated PACs around owl nest or roost sites (one PAC per owl territory) by using aerial photography to identify ≈300 ac of contiguous habitat for protection (USDA Forest Service 2004). The CASPO strategy, like all owl conservation strategies that protect specific areas, has been contentious because of the constraints it places on management flexibility (Collins et al. 2010). To our knowledge, no one has quantitatively evaluated whether PACs have been effective at protecting the core habitat areas that are actually used by owls.

In this article, we used long-term monitoring data to examine whether PACs delineated by the Forest Service in the early 1990s were effective at protecting the core habitat used by owls. We have been conducting surveys to locate spotted owls in the central Sierra Nevada since 1986 as part of a long-term population monitoring study (Seamans and Gutiérrez 2007, Blakesley et al. 2010). We estimated core areas of owl use by using nest and roost location data from 1986 to 2009, which we presumed to encompass critical core areas of owl habitat within an owl's territory. Our specific objectives were to assess whether (1) the size of owl core areas estimated using long-term monitoring data were similar in size to PACs established by managers and (2) whether these owl core areas overlapped spatially with PACs delineated using habitat maps.

Materials and Methods

Study Area

Our study area (133 mi^2) was located in the central Sierra Nevada near Georgetown, California (120.5° W, 39.0° N). The area was comprised of both public (62.5%) and private lands (37.5%). We systematically surveyed our entire contiguous area for spotted owls each year from 1986 to 2009 (Blakesley et al. 2010). Our study area was comprised primarily of conifer forest, but hardwood forest was also present. Dominant tree species included ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), and California black oak (*Quercus kelloggii*). Elevations ranged from 1,200 to 7,877 ft.

Spotted Owl Surveys

We completely surveyed the entire study area using vocal lures from early April to late August each year regardless of habitat type or landownership (Forsman 1983). We conducted both nighttime and daytime surveys. We located owls at night primarily using permanent survey stations that we placed throughout the entire study area to obtain complete survey coverage of the area. At least two independent surveys were conducted at each calling station per year. If an owl was detected during a night survey, we followed up with daytime surveys to locate nest and roost sites, assess reproduction, and identify marked individuals. We typically surveyed each territory three or more times,

Management and Policy Implications

We recommend that PACs should remain an integral feature of owl management strategies in the Sierra Nevada because owls use these areas over long time periods. In addition, long-term monitoring of rare and endangered species is now routinely conducted within many conservation programs (Franklin et al. 2004, Thompson 2004, Anthony et al. 2006). Thus, long-term monitoring may present an opportunity to use location data gathered over many years to delineate core areas of use, and, hence, could be useful for defining key areas for protection or special management for the species being monitored. Once protected areas are delineated, long-term data can be used to adjust the boundaries of protected areas, and, indeed, this has been done for some PACs by Forest Service biologists. For example, the PAC boundaries were later adjusted at the five territories having the lowest proportion of owl locations inside the original PAC boundary (see Discussion section). That is, Forest Service biologists used our data to make an appropriate adaptive management response by reconfiguring the PAC. Hence, our analysis was a conservative estimate of overlap because our analysis was based on original PAC delineation, not current PAC delineation. Although it is likely that using long-term data to identify core areas of use will be most useful for long-lived species, such as spotted owls, we think it may also be useful for other species that have specialized habitat needs and that can be consistently detected when present within an area.

and our detection probabilities on individual surveys were ≈0.70 (Seamans and Gutiérrez 2007). Therefore, we likely detected most of the territorial owls on the study area each year.

Location Data

For our analysis we only used those locations where we visually detected owls during daylight or twilight hours because observations during these time periods indicated that an owl was using a site for roosting or nesting. In addition, California spotted owls are often not as responsive during daylight hours as are northern spotted owls (personal observation), so we frequently located owls shortly after sunset (i.e., civil twilight). Although owls located at twilight could have moved from their daytime location in response to our vocalizations, they were unlikely to be far from their daytime roosts (Gutiérrez et al. 1995). Visually detected owls often also exhibited territorial defense vocalizations during twilight hours thus providing behavioral evidence for territory residency. We excluded vocal detections of owls during daylight or twilight hours and all owl detections (visual or vocal) at night because of uncertainty about owl identity, the exact location of responding owls, and whether the location was near a roost or nest site.

From 1986 to 1995, we estimated locations to the nearest 109.4 yards (100 m) using compass, altimeter, and 1:24,000 topographic maps. From 1996–2001, we used the same process to estimate locations to the nearest 10.9 yd (10 meters). From 2002 to 2009, we estimated locations to the nearest 1.1 yd (1 m) using either a Garmin XL12 or 60CSx global positioning systems unit (Garmin International, Inc., Olathe, Kansas). We distinguished between twilight and nocturnal detections by using a sunrise/sunset and twilight time calculator (Edwards 2001, US Naval Observatory 2007).

Estimation of Core Area Size

We considered owl locations to be independent if they were spaced at least 7 days apart (Franklin et al. 1996). We used these independent locations to estimate core areas of use for roosting and nesting as one would use telemetry location data to estimate an individual animal's space use. Therefore, we used program Animal Space Use (Horne and Garton 2007) to compare fixed and adaptive kernel estimators based on our combined diurnal and twilight locations. We reiterate that we estimated core areas of use within territories (i.e., part of the actively defended portions of the home range; Burt 1943), which comprise only a portion of actual home ranges. Because kernel distributions can be greatly influenced by sample size (Seaman et al. 1999), we maximized our sample size by using all years of location data to estimate the kernel distribution. We used the likelihood cross-validation criterion to select the estimator that best fit the data for each owl territory (Horne and Garton 2006). We then used likelihood cross-validation as a smoothing parameter for kernel generation (Horne and Garton 2006). We estimated core areas using Home Range Tools Version 1.1 for ArcGIS 9.2 (Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada) (Rodgers et al. 2005) because of its ability to generate core areas as polygon shapefiles, which facilitated our comparison with PAC boundaries. This also minimized data processing time and potential data loss resulting from converting data formats. Location data for each territory were also rescaled within Home Range Tools before kernel generation as recommended by Worton (1989) and Rodgers et al. (2005). We estimated core areas for 50, 90, and 95% usage distributions.

Comparison between Core Areas and PACs

We obtained PAC boundary data from the Forest Service, Region 5, GIS Clearinghouse (USDA Forest Service 2010); we used the original delineation of PACs as our basis of comparison. By design, a PAC was supposed to be designated by the Forest Service for every territorial owl (or pair of owls) detected in the Sierra Nevada. Thus, there was one PAC for every owl territory we monitored during our study. We used a paired sample *t*-test (Zar 1996) to compare the size of owl core use areas with PACs. We excluded three owl territories where birds used more than one PAC because it was unclear which PAC should be used in the comparison. We compared the spatial overlap between owl core use areas and PACs by calculating the proportion of each core area that coincided with a PAC boundary and each PAC that coincided with a core area using the Feature Density extension in ArcView 3.2 (Environmental Systems, Research Institute, Redlands, CA) (Schaub 2004). Finally, we compared the number of locations inside and outside of PACs using a two-tailed paired *t*-test as a second measure of concordance with owl use of these areas.

Results

We monitored owl nest and roost locations from 1986 through 2009. Over our 24-year study, we located 43 owl territories on our study area that corresponded to PACs established for owl conservation, of which 38 yielded long-term data (see previous data). On average, these 38 territories were occupied for 15.3 (range, 7–24 years) years. We recorded an average of 43.1 (range, 14–78) daytime and twilight locations per territory. Although we were not estimating home ranges of owls and we used very long-term data, we only used territories of owls for which we had ≥30 locations to avoid bias from small sample sizes (Seaman et al. 1999). Therefore, we did not use six territories in our analysis because they did not meet this standard. In addition, owls at three territories used portions of two different PACs over time, although typically only one PAC was used during a single breeding season. Thus, we excluded these owl territories because movement between two PACs confounded comparisons. Therefore, we were able to compare the size of areas used by owls to PAC size at 29 sites and overlap between owl core areas and PACs at 38 sites.

The average size of the 38 core areas estimated from long-term owl location data was 347.2 ac (range, 87.8–1026.9 ac; SE = 38.5), 237.5 ac (range, 68.6–639.4 ac; SE = 24.4), and 50.7 ac (range, 12.7–169.6 ac; SE = 5.6) for the 95, 90, and 50% usage distributions, respectively. The average size of the 38 PACs that were designated to protect each of these owl sites was 282.3 ac (range, 128.5–310.3 ac; SE = 5.6), and PACs were comprised of an average of 1.6 patches of suitable habitat (range, 1–7). The average size of the 29 owl core areas we used for comparison of area size was 334.7 ac (range, 108.3–910.2 ac; SE = 40.2), 227.3 ac (range, 87.8–639.4 ac; SE = 25.6), and 48.4 ac (range, 12.7–128.1 ac; SE = 5.6) for the 95, 90, and 50% usage distributions. The average size for the 29 corresponding PACs was 287.5 ac (range, 199.7–310.3 ac; SE = 4.3). We found no difference in size between the 95% core areas of use and their associated PACs (paired-sample two-tailed *t*-test; $t = 1.16$, $P < 0.25$, and 28 df), but both the 50 and 90% core areas of use were smaller than PACs ($t = 38.88$, $P < 0.0001$, and 28 df, and $t = 2.31$, $P < 0.03$, and 28 df, respectively).

The average proportion of PACs that

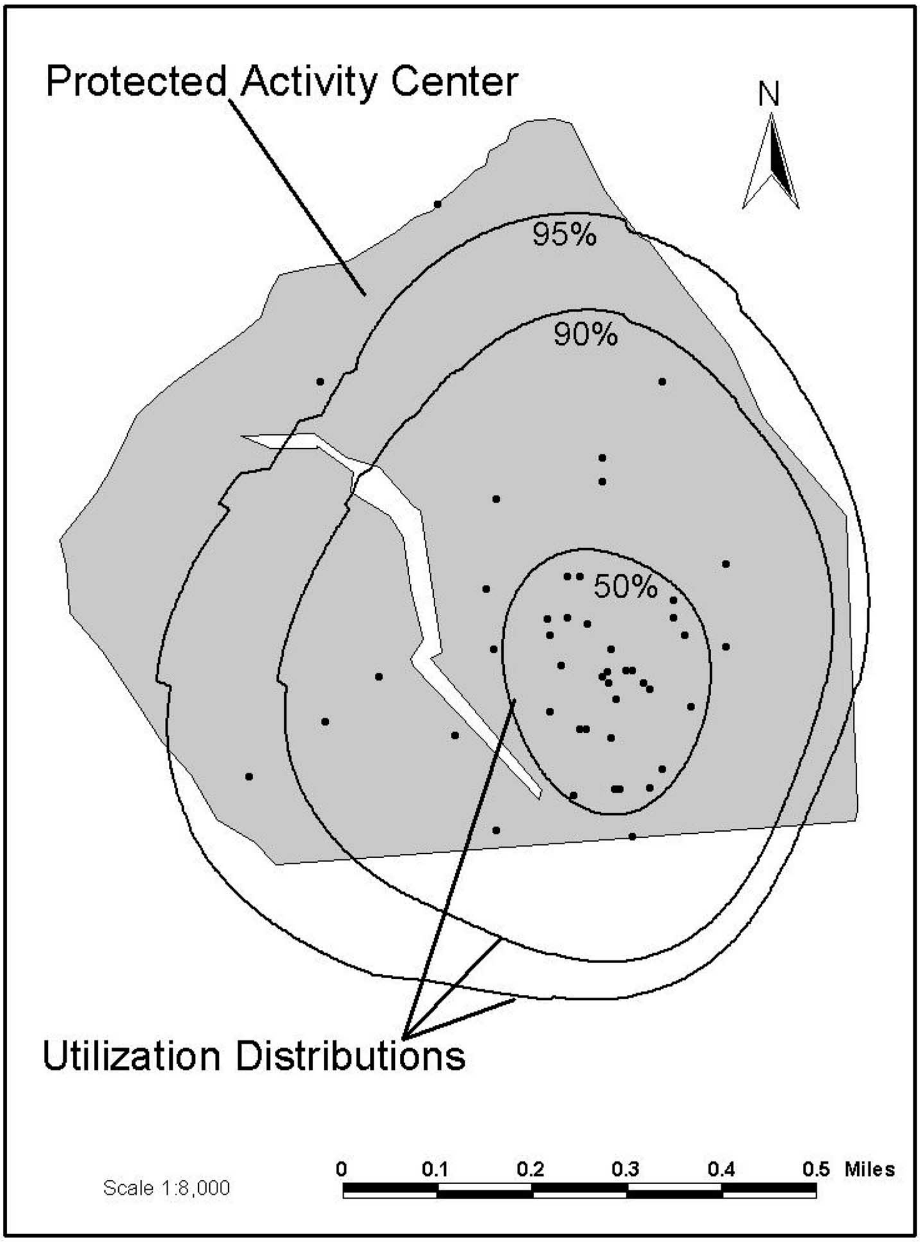

Figure 1. An example of the overlap between a spotted owl core area of use (50, 90, and 95% usage distributions estimated from long-term monitoring data) and its corresponding PAC in the central Sierra Nevada, California. The solid dots are owl nest or roost locations detected over time (in this case from 1986 to 2009). The nonshaded area in the PAC is an area of unsuitable habitat.

overlapped with owl core areas of use ($N = 29$) was 0.13 (SE = 0.02), 0.49 (SE = 0.04), and 0.60 (SE = 0.04) for the 50, 90, and 95% usage distributions, respectively. The overlap was highest with the 95% usage distributions because they represented the largest and most dispersed area of owl use. The average proportion of owl core areas of use that overlapped with PACs ($N = 38$) was 0.84 (SE = 0.04), 0.70 (SE = 0.04), and 0.61 (SE = 0.04) for the 50, 90, and 95% usage distributions, respectively. The PAC overlap was highest for the 50% usage distributions because they represented the smallest (i.e., more concentrated) areas of use and were most likely to be found within the boundaries of a PAC (Figure 1). The average number of owl locations was greater inside ($\bar{x} = 36.0$; range, 8–76; SE = 2.96; $N = 34$) than outside ($\bar{x} = 6.9$; range, 0–26; SE = 1.03) of PACs ($t = 9.289$, $P < 0.0001$, and 68 df). On average, 83% (range, 30–100%) of owl roost and nest locations were found inside the boundaries of established PACs. In only one case did the number of locations outside of a PAC exceed the number of locations inside the PAC (see the following Discussion and Management Implications sections).

Discussion

We found very strong congruence between the size of California spotted owl core areas estimated using long-term monitoring data and PACs delineated by the Forest Service using forest cover maps and criteria established by CASPO (Verner et al. 1992). We also found that in most cases (38 of 43 situations), owls detected in a location usually represented an owl territory that persisted for several to many years, which supported the PAC strategy as a mechanism to conserve nesting and roosting habitat of territorial owls (Verner et al. 1992). In one situation less than 50% of the owl locations were inside the original PAC boundary, and in four other cases between 53 and 65% of owl locations were inside the original PAC boundaries. In all remaining cases, at least 69% of owl locations were inside the original PAC boundaries. Although our owl monitoring project was designed for other purposes (i.e., primarily to estimate trends of population vital rates; Franklin et al. 2004, Blakesley et al. 2010), our long-term data for owl locations had the potential to delineate core areas for protection of this species' nesting and roosting habitat.

We found no significant size differences between PACs and the 95% usage distributions of core areas; however, we observed some discrepancies in spatial overlap between the two for several reasons. First, adaptive kernel estimators infer the use of areas adjacent to the actual locations (see Figure 1), which may include areas of nonuse in some cases. For example, adjacent area may contain private land or other cover types not used by nesting owls (Gutiérrez 1994). Second, PACs were designed to preserve the best available habitat where the owls were originally detected and were then managed largely as static entities by the Forest Service. Although spotted owls exhibit a high degree of nest site fidelity, they will occasionally relocate territory centers in response to mate replacement, nesting failure, nest trees that fall, habitat changes, and inter- and intraspecific competition. Third, habitat types may be misidentified using aerial photography during the PAC designation process. Habitats that appear to be high quality in a photo may not be for secondary reasons (e.g., south-facing aspect, presence of predators), and aerial photography often reveals little about the structural complexity of lower canopy layers, which is an important component of spotted owl roosting habitat (Gutiérrez et al. 1995).

PACs for the California spotted owl are designed to protect areas used by owls for nesting and roosting. We know from a wide variety of spotted owl studies that owl home ranges are much larger than PAC areas (Gutiérrez et al. 1995, Bingham and Noon 1997, Williams et al. 2011), so we do not infer that PACs serve all conservation functions for spotted owls. Because we intentionally eliminated the use of nighttime locations in our kernel estimates, our core areas do not include foraging locations in areas more distant from nests and roosts. An alternative method to derive more comprehensive protection for core areas of use would be that of Bingham and Noon (1997). They derived much larger core areas of use from radiotelemetry data that included both foraging and roosting habitat. However, owls use a greater variety of habitats and forest conditions for foraging than for roosting and nesting, so reserving much larger areas for protection would be more difficult to justify based on habitat selection patterns (Williams et al. 2011). Importantly, the most concentrated areas of core use (i.e., the 50% usage distributions) on our study area had a high degree of spatial overlap with designated PACs. Thus, we believe that PACs serve a critical function for conserving key habitats used by owls for nesting and roosting.

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. 2006. Status and trends in demography of northern spotted owls, 1985–2003. *Wildl. Monogr.* 163:1–163.

Barron, D.G., J.D. Brawn, and P.J. Weatherhead. 2010. Meta-analysis of transmitter effects on avian behaviour and ecology. *Methods Ecol. Evol.* 1:180–187.

Bingham, B.B., and B.R. Noon. 1997. Mitigation of habitat "take": Application to habitat conservation planning. *Conserv. Biol.* 11:127–139.

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. *Wildl. Monogr.* 174:1–36.

Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. *J. Mammal.* 24:346–352.

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. *J. For.* 108: 24–31.

Edwards, S. 2001. *Custom sunrise/sunset, moonrise/moonset, and twilight time calendar calculator.* Available online at www.sunrisesunset.com/custom_srss_calendar.asp; last accessed Jan. 15, 2009.

Forsman, E.D. 1983. *Methods and materials for locating and studying spotted owls.* US For. Serv. Gen. Tech. Rep. PNW-GTR-162, Portland, OR. 8 p.

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. *Stud. Avian Biol.* 17:12–20.

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. *Ornithol. Monogr.* 54:1–54.

Gutiérrez, R.J. 1994. Changes in the distribution and abundance of spotted owls during the past century. *Stud. Avian Biol.* 15:293–300.

Gutiérrez, R.J., A.B. Franklin, and W.S. LaHaye. 1995. Spotted owl (*Strix occidentalis*). P. 1–28 in *The birds of North America*, No. 179, Poole A., and F. Gill (eds.). The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, DC.

Horne, J.S., and E.O. Garton. 2006. Selecting the best home range model: An information-theoretic approach. *Ecology* 87:1146–1152.

Horne, J.S., and E.O. Garton. 2007. *Animal space use*, Ver. 1.2. Available online at www.cnr.uidaho.edu/population_ecology/animal_space_use.htm; last accessed Oct. 23, 2008.

Millspaugh, J.J., and J.M. Marzluff. 2001. *Radio tracking and animal populations.* Academic Press, San Diego, CA. 474 p.

Rodgers, A.R., A.P. Carr, L. Smith, and J.G. Kie. 2005. HRT: *Home range tools for ArcGIS.* Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada. Available online at www.blueskytelemetry.com/downloads.asp; last accessed Nov. 13, 2009.

Samuel, M.D., D.J. Pierce, and E.O. Garton. 1985. Identifying areas of concentrated use within the home range. *J. Anim. Ecol.* 54:711–719.

Schaub, T. 2004. *Feature density for ArcView 3.x (FeatureDensity.avx).* Available online at www.arcscripts.esri.com/details.asp?dbid=12441; last accessed Jan. 26, 2009.

Seaman, D.E., J.J. Millspaugh, J.J. Kernohan, G.C. Brundige, K.J. Raedeke, and R.J. Gitzen. 1999. Effects of sample size on kernel home range estimates. *J. Wildl. Manag.* 63: 739–747.

Seamans, M.E., and R.J. Gutiérrez. 2007. Habitat selection in a changing environment: The relationship between habitat alteration and spotted owl territory occupancy and breeding dispersal. *Condor*. 109:566–576.

Swindle, K.A., W.J. Ripple, C.E. Meslow, and D. Schafer. 1999. Old-forest distribution around spotted owl nests in the central Cascade Mountains, Oregon. *J. Wildl. Manag.* 63: 1212–1221.

Thompson, W.L. (ed.). 2004. *Sampling rare or elusive species.* Island Press, Covelo, CA. 429 p.

US Department of Interior. 1990. Endangered and threatened wildlife and plants: Determination of threatened status for the northern spotted owl. *Fed. Regist.*55:26114–26194.

US Department of Interior. 1993. Endangered and threatened wildlife and plants: Final rule to list the Mexican spotted owl as a threatened species. *Fed. Regist.* 58:14248–14271.

US Department of Interior. 2006. Endangered and threatened wildlife and plants 12–month finding for a petition to list the California spotted owl (*Strix occidentalis occidentalis*) as threatened or endangered. *Fed. Regist.* 71: 29886–29908.

USDA Forest Service. 2004. *Sierra Nevada forest plan amendment: Final environmental impact statement.* Record of Decision. US For. Serv. Region 5, Vallejo, CA. 72 p.

USDA Forest Service. 2010. *California spotted owl Protected Activity Centers (ESRI Personal Geodatabase)*. Pac. Southw. Region, Remote Sensing Lab, McClellan, CA. Available online at www.fs.fed.us/r5/rsl/clearinghouse/gis-download.shtml; last accessed Nov. 20, 2009.

US Naval Observatory. 2007. *Table of sunrise/sunset, moonrise/moonset, or twilight times for an entire year*. Available online at www.aa.usno.navy.mil/data/docs/RS_OneYear.php; last accessed Jan. 15, 2009.

Verner, J., K.S. McKelvey, B.R. Noon, R.J. Gutiérrez, G.I. Gould, and T.W. Beck. 1992. Assessment of the current status of the California spotted owl, with recommendations for management. P. 3–26 in *The California spotted owl: A technical assessment of its current status*, Verner, J., K.S. McKelvey, B.R. Noon, R.J. Gutiérrez, G.I. Gould, and T.W. Beck (eds.). US For. Serv. Gen. Tech. Rep. PSW-GTR-133, Pac. Southw. Research Stn., Albany, CA.

Williams, P.J., R.J. Gutiérrez, and S.A. Whitmore. 2011. Home range and habitat selection of spotted owls in the central Sierra Nevada. *J. Wildl. Manag.* 75:333–343.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* 70:164–168.

Zar, J.H. 1996. *Biostatistical analysis,* 3rd ed. Prentice Hall, Upper Saddle River, NJ. 662 p.