

Chapter 7.2—California Spotted Owl: Scientific Considerations for Forest Planning

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Summary

California spotted owls (*Strix occidentalis occidentalis*) are top trophic-level avian predators associated with mature forests characterized by dense canopies and large trees, snags, and logs in the Sierra Nevada. Owls show the strongest associations with mature forest conditions for nesting and roosting and will forage in a broader range of vegetation types. California spotted owls use habitat at multiple scales ranging from (1) patches and stands used for nesting and foraging, (2) home ranges that support a territorial pair of owls, and (3) landscapes necessary to support viable populations. Multiscalar management is needed to address the habitat requirements of California spotted owls. Recent research reinforces the importance of mature forest to spotted owl occupancy, survival, and habitat quality. These studies have also demonstrated that some level of heterogeneity is also associated with high-quality habitat for spotted owls. California spotted owls seem to be able to persist in landscapes that experience low- to moderate-severity fire, as well as some level of mixed-severity wildfire. Little information is available to evaluate how California spotted owls and their habitats are affected by mechanical treatments. New forest management concepts, based on recent research, have proposed focusing efforts on restoration of vegetation conditions at patch, stand, and landscape scales that would be more similar to the heterogeneous conditions that would occur under a wildfire-dominated natural disturbance regime. Although some degree of uncertainty exists, management approaches that seek to restore ecological resilience and the role of wildfire as the primary natural disturbance agent may produce landscapes capable of supporting viable populations of spotted owls, provided that mature forest conditions characterized by dense canopies and important large conifer and oak trees can be maintained. Current knowledge is incomplete regarding the conditions necessary to maintain high-quality owl territories and viable populations under these new forest management concepts. Future forest management efforts will require carefully constructed monitoring and adaptive management components to reduce uncertainty and advance current knowledge about owl territory needs and population viability. In addition to habitat concerns, California spotted owls face a significant emerging threat owing to the recent range expansion of barred owls into the Sierra Nevada. Barred owls appear to be competitively dominant over spotted

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owls and have the capacity to displace or replace spotted owls at sites where they co-occur. Future planning efforts may need to consider the potentially confounding effect of barred owls on California spotted owl habitat requirements, should barred owls continue to increase their distribution and abundance in the Sierra Nevada. This synthesis reviews the current knowledge and threats to California spotted owls in the Sierra Nevada reported since publication of the Sierra Nevada Forest Planning Amendment in 2001.

Introduction

California spotted owls (*Strix occidentalis occidentalis*) (fig. 1) have been at the forefront of Sierra Nevada management and conservation debates for 25 years because of their strong habitat associations with commercially valuable large trees, snags, and late-successional forests. Initial concerns focused on the effects of timber harvest on large trees and late-successional habitat and potential risks to California spotted owl population viability. In recent years, the debate over Sierra Nevada forest management and California spotted owls has broadened with growing recognition that past management practices, specifically timber harvest and fire suppression, have fundamentally changed forest structure, composition, and function over the last 100 years (North et al. 2009). Removal of fire as a primary natural disturbance process, coupled with reductions in large trees and late-successional forests through timber harvest, has resulted in contemporary Sierra Nevada forests that are generally more homogenous at multiple spatial scales, have higher densities of shade-tolerant tree species and reduced numbers of large trees, and are at greater risk of high-severity wildfire compared to their historical counterparts. Additionally, the extent and severity of wildfire has increased in the Sierra Nevada and across the Western United States as a result of climate change (Miller et al. 2009, Westerling et al. 2006). Eighty-five percent of known California spotted owl sites occur in moderate- or high-risk fire areas in the Sierra Nevada (USDA FS 2001), and though management and restoration of large trees and late-successional forest remains a primary objective of spotted owl management, there is uncertainty about the relative tradeoffs of actively managing forests to reduce wildfire risk and no-management approaches that leave habitat intact but do not address wildfire concerns. This issue is embedded within broader discussions about the most effective strategies for addressing long-term resilience and restoration of Sierra Nevada forests (North et al. 2009). Finally, range expansion of the barred owl (*Strix varia*) in the Sierra Nevada poses an increasing risk factor to California spotted owls.

Extensive scientific literature reviews on California spotted owls have been conducted as part of the California Spotted Owl Technical Review (CASPO)

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(Verner et al. 1992) and during development of the Sierra Nevada Forest Plan Amendment (SNFPA) (USDA FS 2001). The goal of this chapter is to synthesize scientific information on the California spotted owl that has been reported since the SNFPA. Although this section is focused on California spotted owl, relevant papers from the northern spotted owl (*S.o. caurina*) and Mexican spotted owl (*S.o. lucida*) subspecies are also included.

Ecological Context

As top-trophic level avian predators in Sierra Nevada forests, California spotted owls have several characteristics that are broadly associated with increased species vulnerability: they have large individual spatial requirements and low population densities, and they are habitat specialists. Spotted owls have high adult survival rates and low reproductive rates—life history characteristics associated with species that are long lived with sporadic reproduction in response to variable environmental conditions. Although they are adaptations to variable environments, these life history characteristics also render spotted owl populations slow to recover from population declines. Spotted owl populations are regulated by territorial behavior in which owl pairs defend non-overlapping territories that include nesting and foraging habitat. They exhibit this behavior in response to resources and conditions, such as habitat, weather, prey, and competitors, that influence population dynamics. Maintaining viable populations of owls requires consideration and management of landscape vegetation conditions and dynamics. Primary conservation and management concerns at the population-landscape scale include managing for a distribution of high-quality territories that support high adult survival and high reproduction (= high quality) and facilitate successful dispersal and recruitment. Management efforts would benefit from considering the nested structure of spotted owl habitat associations at multiple scales, ranging from patches/stands used by individual owls for nesting, roosting, and foraging, to territories required to support a pair of owls, and up to landscapes necessary to support viable populations. These different spatial scales are important to consider in formulating strategies to promote forest restoration, resilience, and fire management, and they are consistent with current forest management proposals advocating a multiscale perspective that encompasses a patch-scale focus to increase vegetation heterogeneity nested within a landscape-scale focus that considers topography, elevation, latitude, and natural disturbance regimes.

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Tom Munton

Figure 1—California spotted owl.

Population Distribution, Status, Trends, and Genetics

Historical and Current Distribution

Little is known about the historical distribution, abundance, and habitat associations of California spotted owls in the Sierra Nevada (Gutiérrez 1994, Verner et al. 1992). Early inventory and survey efforts are described in Verner et al. (1992). The first systematic efforts to survey California spotted owls occurred in 1973 and 1974, followed by broad efforts to inventory California spotted owls across the Sierra Nevada during the late 1980s and early 1990s. More recently, inventory and survey efforts have largely consisted of project-level surveys, generally conducted for 1 to 2 years in support of project implementation, and demographic study area-level surveys at four study sites where consistent annual monitoring has occurred over a much longer time period (Blakesley et al. 2010, Franklin et al. 2004).

Verner et al. (1992) found no evidence of range contractions or expansions of California spotted owls in the Sierra Nevada. However, they identified 11 areas of concern where potential gaps in distribution may become an issue owing to fragmentation or bottlenecks in the distribution of owls or their habitat if the status of the owl in the Sierra Nevada were to deteriorate. No research has addressed the status of owls or their habitat in these areas of concern since the publication of CASPO in 1992. Anecdotal observations of California spotted owls suggest that they are still widely distributed across their historical range in the Sierra Nevada.

Population Status and Trends

The most recent estimate of population size for California spotted owls in the Sierra Nevada reported 1865 owl sites, with 1,399 sites on National Forest System (NFS) lands, 129 owl sites on National Park Service (NPS) lands, 314 sites on private lands, 14 sites on Bureau of Land Management lands, 8 on state of California lands, and 1 on Native American lands (USFWS 2006). Care should be used interpreting these estimates of population numbers as they represent a compilation of all sites where California spotted owls have been recorded over the past 30 to 40 years; they should not be interpreted as an accurate estimate of current population size because the proportion of sites still occupied by owls at the current time is not known, and there is evidence for recent population declines in the Sierra Nevada (see below). Demographic monitoring from four study areas from 1990 to 2011 provides the sole source of empirical data on the status of and trends in California spotted owl populations in the Sierra Nevada. Three of the demographics studies are conducted on NFS lands (on the Lassen, Eldorado and Sierra National Forests), and the fourth study is located on NPS lands (Sequoia–Kings Canyon National

Parks). Two meta-analysis workshops have been conducted to analyze California spotted owl demographics and population trends across the four studies (Blakesley et al. 2010, Franklin et al. 2004). Recent research of population trends provides evidence for population declines on the three studies on NFS lands and a stable/increasing population in the NPS study area, and it is providing new approaches for evaluating spotted owl population trends and interpreting the probability of population declines (Conner et al. 2013; Tempel and Gutiérrez 2013). Tempel and Gutierrez (2013) reported declines in both territory occupancy and rate of population change measured by realized population change for the Eldorado National Forest study area. Conner et al. (2013) used a Bayesian approach for estimating the probability of different levels of population decline using realized population change and reported probabilities of decline of 93 percent and 78 percent for the Lassen and Sierra National Forests study areas, respectively, and an 8 percent probability of a stable or increasing population for the Sequoia-Kings Canyon study area. The factors driving these population trends are not known.

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Population Genetics

Population genetics studies support the recognition of three subspecies of spotted owls based on both microsatellites (Funk et al. 2008) and mitochondrial DNA (Barrowclough et al. 1999, 2005, 2011; Haig et al. 2001, 2004). Early descriptions of spotted owl distribution based on limited numbers of specimens and records suggested that the range of northern and California spotted owls did not overlap (Grinnell and Miller 1944). More recent extensive survey and inventory efforts have documented a continuous distribution of spotted owls between the subspecies, and initial genetic analyses indicated the boundary between subspecies to be in northern California or southern Oregon (Barrowclough et al. 2005, Funk et al. 2008). Based on these initial genetic assessments, Gutiérrez and Barrowclough (2005) proposed the Pit River as a geographical boundary between the subspecies because it was located approximately halfway between populations known to consist largely of pure northern spotted owl haplotypes near Mount Shasta and largely pure California spotted owl haplotypes near Lassen Peak. However, recent research has refined understanding of genetic variation across this region and indicates that a hybrid zone exists from approximately 94 km north of Mount Shasta to southeast of Lassen Peak, and that a more appropriate place to designate a boundary between northern and California spotted owls would be between the Pit River and Lassen Peak (Barrowclough et al. 2011).

Habitat Associations

Patch/Stand Scale

Nest and roost habitat—

Nest and roost site habitat requirements are the best studied aspect of California spotted owl habitat associations. Spotted owls nest in cavities, on tops of broken trees, and on platforms located in older, large-diameter live conifers, oaks, and snags. Conifer nest trees average about 110 cm (45 in) diameter at breast height (dbh) in the Sierra Nevada (Verner et al. 1992). Large conifers, oak trees, and snags are key habitat elements for California spotted owls, and large, downed logs resulting from these trees are important habitat elements for key prey species. Nests and roosts are typically located in stands that have ≥ 70 percent total canopy cover and contain one or several large trees of declining vigor and multiple canopy layers resulting from mixtures of differently aged trees.

Foraging habitat—

Recent telemetry studies of spotted owl foraging habitat use consistently indicate that owls use a broader range of vegetation conditions for foraging than they do for nesting and roosting (Ganey et al. 2003, Glenn et al. 2004, Irwin et al. 2007, Williams et al. 2011). California spotted owl foraging habitat use across all forest types and vegetation conditions remains a poorly understood aspect of their ecology. Use of a broader range of vegetation conditions for foraging is likely governed by the abundance and availability of important prey species. Northern flying squirrels (*Glaucomys sabrinus*) and dusky-footed woodrats (*Neotoma fuscipes*) dominate the biomass of owl diets in the Sierra Nevada, with deer mice (*Peromyscus maniculatus*), pocket gophers (*Thomomys* spp.), and other small mammals, birds, and insects also a component of the diet (Verner et al. 1992). Williams et al. (1992) synthesized the available ecological and habitat association information for key California spotted owl prey species. Given the importance of prey to spotted owls, much research has focused on small mammal ecology and habitat associations (Coppeto et al. 2006, Innes et al. 2007, Lehmkuhl et al. 2006, Meyer et al. 2007) and the effects of forest treatments on small mammals (Amacher et al. 2008). Results from studies of small mammal habitat associations demonstrate the species-specific importance of vegetation type, stand characteristics, and specific habitat elements (e.g., shrubs, downed logs, snags, truffles), and that habitat associations may vary in different parts of the Sierra Nevada. Fontaine and Kennedy (2012) and Stephens et al. (2012) provide recent reviews of fuels treatment effects on wildlife. A full review of the literature on habitat associations and forest management effects

on key California spotted owl prey species is beyond the scope of this review. However, given the importance of prey to California spotted owls and other carnivores in the Sierra Nevada, a future synthesis of scientific information on small mammal habitat associations and effects of forest management on their populations and habitat is needed. This information may inform and help tailor development of future forest management treatments and desired landscape conditions to different parts of the Sierra Nevada, as well as identify important information and research gaps.

Core Area/Home Range/Territory Scale

The size of California spotted owl home ranges is highly variable; it appears to vary with latitude and elevation, and likely in response to the availability and arrangement of vegetation types and dominant prey species (Gutiérrez et al. 1995). Across the Sierra Nevada, home range sizes are smallest in low-elevation, hardwood-dominated sites, where dusky-footed woodrats are the dominant prey species; intermediate in mixed-conifer forests; and largest in true fir forests of the northern Sierra Nevada, where northern flying squirrels are the dominant prey species (Zabel et al. 1995). A number of studies have reported that the proportion of older forest is the best predictor of home range size, with smaller home ranges having higher proportions of older forest (Glenn et al. 2004, Gutiérrez et al. 1995). Recently, Williams et al. (2011) reported that the number of vegetation patches (a measure of habitat heterogeneity) is the best predictor of home range size for California spotted owls in the central Sierra Nevada, with larger home ranges associated with greater habitat heterogeneity. Whether owls were selecting home ranges for vegetation heterogeneity, or simply using more heterogeneous home ranges that reflected habitat availability or increased travel distances associated with the lack of large areas of older forest within the study area, was uncertain (Williams et al. 2011).

Recent research includes observational studies that describe associations between habitat and spotted owl occurrence, occupancy, and demographic parameters (survival, reproduction, habitat fitness potential) at the core area and home range scales (Blakesley et al. 2005; Dugger et al. 2005, 2011; Franklin et al. 2000; Gaines et al. 2010; Irwin et al. 2004; Kroll et al. 2010; Lee and Irwin 2005; McComb et al. 2002; Olson et al. 2004; Seamans and Gutiérrez 2007a). Although the size of the analysis areas varied across studies, habitat associations were generally assessed at similar spatial scales (core areas or home range scales) around spotted owl nests and roost or activity centers. Vegetation classifications and habitat definitions also varied across studies, but the studies generally defined spotted owl habitat as stands with large trees and high canopy cover (hereafter referred to as mature forest; see individual studies for specific definitions of habitat used in each).

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Although recent studies are geographically and spatially varied, they share many key themes. Results consistently reinforce original findings of the strong association between spotted owls and mature forest habitat in core areas around nest sites. Modeling of habitat conditions with survival and occupancy shows that important habitat metrics at core area and home range scales include the total amounts of mature forest or the amounts of interior mature forest (defined as the amount of mature forest greater than some distance from an edge). Adult spotted owl survival is positively associated with the amount of mature forest (Blakesley et al. 2005; Dugger et al. 2005, 2011; Franklin et al. 2000; Olson et al. 2004). Territory occupancy is also positively related to the amounts of mature forest at core area scales for both California and northern spotted owls, with higher colonization rates and lower extinction rates associated with territories with more mature forest (Blakesley et al. 2005, Dugger et al. 2011, Seamans and Gutiérrez 2007a). Dugger et al. (2011) reported that northern spotted owl extinction and colonization rates were negatively associated with the degree of fragmentation of mature forest across the larger home range.

Spotted owl reproduction exhibits high annual variation. Franklin et al. (2000) reported that 43 percent of annual variation in reproduction is explained by habitat covariates; however, most studies report little influence of habitat on variation in reproduction (Blakesley et al. 2005, Dugger et al. 2005, Olson et al. 2004). Weather may directly influence spotted owls, but it may also indirectly influence them by affecting the abundance or availability of prey. In general, annual variation in reproduction has been shown to be associated with weather (the importance of specific weather metrics differs among studies), owl age/experience, reproduction in the previous year, and the presence of barred owls nearby (Blakesley et al. 2005; Dugger et al. 2005, 2011; Kroll et al. 2010; MacKenzie et al. 2012; Olson et al. 2004; Seamans et al. 2001).

Three studies have investigated territory habitat quality and its association with habitat amounts and patterns (Dugger et al. 2005, Franklin et al. 2000, Olson et al. 2004). For the purposes of these studies, habitat quality was defined as habitat fitness potential, an integrative metric that incorporates territory-specific estimates of survival and reproduction to generate a territory-specific estimate of lambda. Lambda is the annual rate of population growth. A lambda value of 1.0 indicates a stable population, lambda values >1 indicate an increasing population, and lambda values <1.0 indicate a declining population. In terms of territory-specific lambda estimates, values >1.0 indicate territories with combinations of owl survival and reproduction that result in positive population growth. In all three studies, habitat fitness potential values (indicating high-quality territories) were highest for habitat conditions containing mature forest interspersed with a mix of other vegetation types.

Several consistent patterns emerge from recent research efforts devoted to understanding the factors that contribute to high-quality owl habitat at core area and home range spatial scales (i.e., forest conditions that support viable territories). First, spotted owl occurrence and survival are significantly related to mature forest habitat. Second, higher owl survival and reproduction are also associated with areas that have a mix of different vegetation types and edge between mature forest and other vegetation types. Third, weather is an important factor influencing spotted owl demographics, particularly reproduction. Finally, spotted owl population dynamics are likely governed by both habitat and weather.

Landscape Scale

Spotted owls are a territorial species with each pair defending an exclusive territory, and they appear to exhibit an ideal despotic distribution where dominant individuals occupy the highest quality sites (Franklin et al. 2000, Seamans and Gutiérrez 2006, Zimmerman et al. 2003). In addition to habitat factors, the presence of other spotted owls in adjacent territories may also be a factor associated with the probability of a territory being selected (Seamans and Gutiérrez 2006). At the landscape scale, spotted owl territories tend to be more regularly spaced than randomly distributed. Little information is available at larger landscape scales on the relationship between landscape vegetation patterns and California spotted owl population density or number of territories, especially comparative information to assess how the number of territories varies across landscapes with different amounts and patterns of vegetation. Limited information suggests that the number of spotted owl territories may be related to landscape-scale habitat availability (Zabel et al. 2003). Additionally, creation of large gaps or large areas of low-quality habitat may affect dispersal of young and adult owls and successful colonization of unoccupied territories. Understanding of the relationships between landscape-scale vegetation condition and spotted owl territory density and dispersal behavior is a high priority for further research, as current forest fuels, restoration, and wildfire strategies are focused on larger landscape scales.

Effects of Forest Management and Wildfire

Forest Management

Two general approaches have been used to investigate the effects of forest management on spotted owls: (1) modeling, which is used to project the effects of forest treatments on spotted owls and their habitat; and (2) field-based studies, which measure the response of spotted owls to forest management effects. Simulation modeling suggests that landscape-scale fuels treatments on a small proportion of

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the landscape can minimize effects to owl habitat and reduce risk of habitat loss to wildfire (Ager et al. 2007, Lehmkuhl et al. 2007). Some treatments may also reduce fire risk within core areas with minimal effects on owl reproduction (Lee and Irwin 2005). Simulation modeling indicates that the long-term benefits of wildfire risk reduction may outweigh the short-term effects of treatments on spotted owl habitat (Roloff et al. 2012). Models have been developed to spatially integrate fuels treatments with protection of spotted owl habitat within landscape-scale restoration efforts (Ager et al. 2012, Gaines et al. 2010, Prather et al. 2008). Results from simulation modeling also suggest that fuels treatments can be effectively used to reduce wildfire risk and support restoration efforts while providing spotted owl habitat at home range and landscape scales.

Numerous observational studies have described spotted owl habitat associations (see review above), but very few studies have directly assessed the effects of fuels and forest treatments on spotted owls and their habitat. Researchers have long advocated for experimental studies to evaluate the effects of forest management on spotted owls (Lee and Irwin 2005, Noon and Franklin 2002), and a lack of controlled experiments to test important hypotheses for forest management effects on spotted owls contributes to continuing controversy (Noon and Blakesley 2006). To date, no experiments using before-after control-impact (BACI) designs have been conducted, with the exception of a study of forest treatment effects on owl foraging on the Eldorado National Forest. These BACI studies are scientifically challenging to design, logistically difficult to implement, and expensive to conduct. Given the inherent variability in spotted owl populations, large numbers of individual owls or owl pairs in experimental and control groups may be necessary to have adequate statistical power to detect effects. Planning regulations, regulatory requirements (e.g., the National Environmental Policy Act), and legal challenges make it logistically difficult to implement extensive treatments across space and time to meet rigorous scientific design requirements. In lieu of experimental studies, passive adaptive management approaches (sensu Kendall [2001]) have been used to investigate the effects of forest management on California spotted owls. Under a passive adaptive management framework, managers dictate the implementation of treatments in time and space governed by management priorities. Researchers attempt to establish a baseline and monitor changes in owl response using models to evaluate the evidence for treatment effects on observed responses. Inferences from these quasi-experimental, passive adaptive management approaches are weaker than those from BACI designs because observed responses may result from other uncontrolled factors. Under a BACI design, or active adaptive management (sensu Kendall [2001]), treatments and controls are implemented in space and time to meet rigorous experimental design criteria as governed by

research priorities. Nevertheless, these passive adaptive management approaches may be the best option in situations where true experiments are not scientifically, logistically, or financially possible, or where political will may be lacking.

Seamans and Gutiérrez (2007a) reported that California spotted owl territories with more mature forest had higher probabilities of being colonized and lower probabilities of becoming unoccupied. Alteration of ≥ 20 ha of mature forest in these spotted owl territories may decrease the probability of colonization. It is unclear whether breeding dispersal or other factors, such as lower survival, are associated with variability in the probability of a territory becoming unoccupied. Nor is it clear if the probability of a territory becoming unoccupied is related to the amount of mature forest within or among territories (Seamans and Gutiérrez 2007a).

Three ongoing studies may provide further insight into the effect of forest management on California spotted owls. Twenty years of demographic monitoring at four study sites distributed across the Sierra Nevada have provided an unparalleled long-term data set on owl occupancy and demographics. Efforts are underway to develop post-hoc annual vegetation maps for each study area that can facilitate a retrospective meta-analysis to assess habitat associations and investigate the effects of forest management on California spotted owl occupancy, survival, and reproduction across the four study areas. Results from the Plumas-Lassen Study and the Sierra Nevada Adaptive Management Project will also provide further modeling and monitoring of forest treatment effects on California spotted owls. These ongoing efforts will further understanding of forest treatment and wildfire effects on California spotted owls and their habitat in the Sierra Nevada.

Wildfire

Current information indicates that California spotted owls will occupy landscapes that experience low- to moderate-severity wildfire, as well as areas with mixed-severity wildfire that includes some proportion of high-severity fire. Bond et al. (2002) reported that first-year postfire adult survival and site fidelity were similar at 11 territories that had experienced wildfire compared to unburned sites across the range of northern, Mexican, and California spotted owls. In contrast, Clark et al. (2011) reported lower adult owl survival 1 to 4 years postfire in eastern Oregon. However, their results were likely affected by past logging effects and postfire salvage logging that resulted in low overall amounts of remaining suitable habitat after the wildfires. Jenness et al. (2004) reported no effects of mixed-severity wildfire on Mexican spotted owls at burned sites that experienced an average of 16 percent high-severity fire. However, Jenness et al. (2004) stated that the statistically nonsignificant higher occupancy and higher reproduction observed at unburned sites (31 sites) compared to burned sites (33 sites) were suggestive of a

biologically significant effect. They recommended that their results, which indicate that wildfires do not affect spotted owls, should be interpreted cautiously because of concerns that limited sample sizes and high variability in both burn extent and severity across their burned sites may have limited ability (i.e., low statistical power) to detect biologically meaningful differences between burned and unburned sites. In Yosemite National Park, Roberts et al. (2011) estimated that spotted owls had similar occupancy and density between unburned (16 sites) and recently burned (16 sites) (<15 years since burn) montane forests that burned primarily at low to moderate fire severity. Lee et al. (2012) reported no difference in owl occupancy between unburned and burned territories from six fire areas in the Sierra Nevada. Further, Lee et al. (2012) concluded that the proportion of high-severity fire (an average of 32 percent of suitable vegetation burned within analysis areas) had no effect on postfire occupancy by spotted owls in the Sierra Nevada, although the amount of high-severity fire was not included in models of occupancy, colonization, and extinction and was only qualitatively assessed relative to burned sites. Recently, Lee et al. (2013) found no statistically significant effects of wildfire or salvage logging on California spotted owls in the mountains of southern California. Although not statistically significant, occupancy rates declined by 0.062 in burned sites in the first year after wildfire, and postfire salvage logging reduced occupancy by an additional 0.046 relative to burned sites without salvage logging. Differences in occupancy between unburned versus burned and burned-salvage logged sites increased over time. Colonization was positively associated, and extinction negatively associated, with the amount of suitable habitat within 203-ha core areas around owl sites, and extinction probability was significantly higher when >50 ha of suitable habitat burned at high severity within burned sites compared to unburned sites (Lee et al. 2013).

Little information is available on patch-scale habitat use in postfire landscapes. Bond et al. (2009) reported that owls nested and roosted in unburned or low- to moderate-severity patches of forest, and, 4 years after fire, they foraged selectively in high-severity burn patches that were located within larger home ranges that generally burned at low to moderate severities. Patches of early-successional vegetation recovering from high-severity fire may provide access to early-successional associated prey, such as woodrats and gophers, within the mosaic of mixed fire severity landscapes. Additional information is needed on habitat use by spotted owls in postfire landscapes. Further, it is important to know if the owls using the postfire landscapes are the original occupants or whether the postfire site was colonized by different owls to more fully understand the effects of wildfire on spotted owls.

Recent findings indicate that California spotted owls in the Sierra Nevada are able to persist in landscapes that experience low- to moderate-severity and mixed-severity wildfires. However, several key uncertainties remain regarding long-term occupancy and demographic performance of spotted owls at burned sites. Specifically, uncertainty exists regarding how increasing trends in the amounts and patch sizes of high-severity fire will affect California spotted owl occupancy, demographics, and habitat over longer timeframes. Additionally, further information is needed on the effects of postfire salvage logging on spotted owl habitat.

Additional Ecological Stressors

Barred Owls

Barred owl (*Strix varia*) range expansion has posed a significant threat to the viability of the northern spotted owl (Gutiérrez et al. 2007). Barred owls are native to eastern North America but have expanded their range westward into Washington, Oregon, and northern California in the past 40 years and are now found throughout the entire range of the northern spotted owl. During initial colonization, barred owls may hybridize with spotted owls to produce hybrids (i.e., “sparred” owls). As barred owl numbers increase in a local area, they pair with their own species. Compared to spotted owls, barred owls are larger, are active both day and night, consume a broader diet, have smaller home ranges, and occur at higher population densities. These factors render them competitively dominant over spotted owls, and they have displaced or replaced northern spotted owls over many portions of their range. Inferences regarding barred owl effects on spotted owls must be tempered by the fact that studies to date are based on observational and correlational studies and require confirmation through experimental assessment of barred owl effects. Results to date suggest two key findings: first, barred owls have replaced or displaced northern spotted owls over large areas of their range through the hypothesized mechanism of interference competition (Dugger et al. 2011); and second, although little information is available on how forest management affects spotted-barred owl interactions, there is recent evidence suggesting habitat patterns can influence occupancy and colonization dynamics (Dugger et al. 2011, Yackulic et al. 2012).

Barred owls are an increasing risk factor for California spotted owls in the Sierra Nevada. Barred owls were first recorded within the range of the California spotted owl in 1989 on the Tahoe National Forest. Two sparred owls were reported in the Eldorado Demographic Study Area during 2003 and 2004 (Seamans et al. 2004), and one of these sparred owls is still present on the study area. Barred owls were first recorded in the southern Sierra Nevada in 2004 (Steger et al.

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2006). Ongoing research has documented 73 records of barred or sparrowed owls in the Sierra Nevada to date, with the majority of records from the northern Sierra Nevada (Tahoe, Plumas, and Lassen National Forests). Of note, five new records of barred owls were documented in the Stanislaus and Sierra National Forests in 2012, indicating further range expansion of barred owls in the southern Sierra Nevada.

Barred owl numbers are likely higher than documented in the Sierra Nevada, as there have been no systematic surveys for them to date. Rather, barred owls are recorded during spotted owl surveys or reported by the public. Spotted owl surveys are conducted annually within the four demographic study areas; however, outside of these study areas, spotted owl survey efforts are limited and sporadic over space and time in response to local project survey requirements. Thus, it is likely that additional barred owls are present in the Sierra Nevada given limited spotted owl survey work outside of the demographic study areas. Further, species-specific survey methods are required to account for differences in response behavior and imperfect detection between spotted and barred owls (Wiens et al. 2011).

Climate Change

Across their range, spotted owls exhibit population-specific demographic relationships with local weather and regional climates (Glenn et al. 2010, 2011; Peery et al. 2012). Based solely on projections of climate change (i.e., not incorporating other factors such as habitat, etc.), this population-specific variation is anticipated to result in population-specific responses to future climate scenarios, which could range from little effect to potentially significant effects. These population-specific responses could result in high vulnerability. For California spotted owls, Seamans and Gutiérrez (2007b) reported that temperature and precipitation during incubation most affected reproductive output, and conditions in winter associated with the Southern Oscillation Index (SOI) most affected adult survival on the Eldorado National Forest. Weather variables explained a greater proportion of the variation in reproductive output than they did for survival. Further, these two weather variables were also included in the best models predicting annual population growth rate (Seamans and Gutiérrez 2007b). MacKenzie et al. (2012) found that SOI or other weather variables explained little variation in annual reproduction for this same population of owls. Unlike results for California spotted owls in southern California reported in Peery et al. (2012), subsequent analyses testing for effects of weather variables on demographic parameters showed no clear temporal associations for owls on the Eldorado National Forest in the Sierra Nevada.²

² Gutiérrez, R.J. 2013. Personal communication. Professor, Department of Fisheries, Wildlife, and Conservation Biology, University of Minnesota, 2003 Upper Buford Circle, St. Paul, MN 55108.

Future responses to climate change are likely to be governed by complex interactions of factors that directly affect spotted owls and their habitat, as will indirect factors that can affect habitat (e.g., insect pests, disease, increased fire risk, etc.). Carroll (2010) recommended that dynamic models that incorporate vegetation dynamics and effects of competitor species in addition to climate variables are needed for rigorous assessment of future climate change on spotted owls.

Disease and Contaminants

Disease can function as an important ecological limiting factor in wildlife populations, especially in the case of invasive diseases introduced into native populations that have not co-evolved mechanisms to cope with the risk. Little information exists on disease prevalence in California spotted owl populations, and no information exists regarding the effects of disease on individual fitness or population viability. Blood parasite prevalence sampling for California spotted owls in the northern Sierra Nevada documented that 79 percent of individuals were positive for at least one infection, whereas 44 percent of individuals tested positive for multiple infections (Ishak et al. 2008). Gutiérrez (1989) reported 100 percent blood parasite infection rates across all three spotted owl subspecies, suggesting long-term adaptation to high parasitism rates.

West Nile virus (WNV), a mosquito-borne flavivirus, was first detected in eastern North America in 1999 and spread rapidly across the continent. West Nile virus was first detected in southern California in late 2003 and spread throughout California in late summer of 2004 (Reisen et al. 2004). The virus has been demonstrated to have high acute species-specific mortality rates in many raptor species (owls, hawks, and their relatives) (Gancz et al. 2004, Marra et al. 2004). None of the 141 individual California spotted owl blood samples collected from the southern (Sierra National Forest, Sequoia-Kings Canyon National Parks) or northern (Plumas and Lassen National Forests) Sierra Nevada from 2004 to 2008 has tested positive for WNV antibodies, which would indicate exposure and survival (Hull et al. 2010). Adult, territorial California spotted owls have high annual survival (80 to 85 percent) that has been stable across years, and no evidence has been published from the four long-term demographic studies indicating changes in adult owl survival. Nevertheless, although no effects have been documented to date, future outbreaks of WNV may pose a risk to California spotted owls.

Environmental contaminants have not been identified as potential ecological stressors on California spotted owls. However, recent reports of high exposure rates of fisher (*Pekania pennanti*) to rodenticides, likely associated with illegal marijuana cultivation, across the southern Sierra Nevada (Gabriel et al. 2012) may have implications for spotted owls and other forest carnivores, as they feed extensively on rodents.

Human Recreation and Disturbance

Disturbance from human recreation and management activities has the potential for impacts on California spotted owls. Impacts from recreation and disturbance can range from the presence of hikers near owl nests and roosts to loud noises from chain saws or motorized vehicles. Additionally, disturbances can be acute (short term) or chronic (long term) depending on the type of recreational or management activity. Measures of behavioral response or fecal corticosterone hormone levels (hormones that reflect stress) have been used to assess spotted owl response to disturbance.

Mexican spotted owls in canyons on the Colorado Plateau exhibited low behavioral responses to hikers at distances ≥ 55 m from roost sites, and adults and juveniles were unlikely to flush from hikers at distances ≥ 24 m and > 12 m, respectively (Swarthout and Steidl 2001). Additionally, the presence of hikers near nests did not markedly change Mexican owl behavior, although cumulative effects of high levels of recreational hiking near nests may be detrimental (Swarthout and Steidl 2003). No differences in reproductive success were observed between Mexican spotted owl nests exposed to helicopter and chain saw noise; however, owls exhibited behavioral responses to both stimuli, and greater behavioral response to chainsaw noise than helicopter noise (Delaney et al. 1999). Results from this study supported management use of a 400-m disturbance buffer around active Mexican spotted owl nests. Wasser et al. (1997) reported higher corticosterone hormone levels in male northern spotted owls within 0.41 km of roads in Washington, suggesting higher stress levels correlated with proximity to roads. Tempel and Gutiérrez (2003, 2004) found little evidence for disturbance effects from chain saws and roads, as measured by fecal corticosterone hormone levels for California spotted owls on the Eldorado National Forest, California. Recently, Hayward et al. (2011) reported a more complex association among road noise and northern spotted owl response on the Mendocino National Forest in California. They found no association between baseline hormone levels and distance to roads. Rather, owls in this study area exhibited increased corticosterone hormone levels in response to acute traffic exposure, and they found that owl response may vary with owl life history stage (adults versus juveniles) and physiological body condition. Of note, they reported lower reproductive success for owls near roads with loud noise versus owls near quiet roads.

Integration of Current Forest Management With California Spotted Owl Management and Conservation

Recent research suggests that fundamental changes in forest management may be required to promote resilience, given current forest conditions resulting from historical management practices, a changing climate, and an increased focus on wildfire, both as a threat to habitat and human values, as well as the primary natural disturbance agent that historically has shaped vegetation structure and function (Larson and Churchill 2012; North et al. 2009, 2012; Perry et al. 2011). North (2012) and North et al. (2009, 2012) have proposed a conceptual forest restoration framework that focuses management perspective across multiple spatial and temporal scales when identifying future desired conditions. Key operating concepts focus on fine-scale vegetation heterogeneity resulting from the primary role of fire, embedded within landscape vegetation patterns that are influenced by topography, elevation, latitude, and natural fire regimes over longer temporal scales and larger spatial scales. At the core of this framework is the hypothesis that forest resilience may best be realized by approaches that restore or mimic Sierra Nevada forest structure and function under a wildfire-dominated natural disturbance regime, with the goal of reintroducing fire as an important process to these systems where and when possible (North 2012; North et al. 2009, 2012).

One key measure of success for the proposed forest restoration framework focused on forest resilience will be to sustain biodiversity and well-distributed, viable populations of sensitive, focal wildlife species, such as the California spotted owl, fisher, and marten. Similar to the multiscale management considerations for forests, management of California spotted owls and their habitat has parallel considerations of spatial scales, ranging from patches containing specific habitat elements used for nesting and foraging (e.g., large trees, downed logs) to landscapes capable of supporting high-quality territories and viable populations. For the past 20 years, California spotted owl management has been based on recommendations provided by the California Spotted Owl Technical Report (Verner et al. 1992). This strategy consisted of establishing protected activity centers (PACs) of approximately 300 ac (121.5 ha) for each owl site, and using forest treatments designed to maintain large trees within treatment units. Following the Sierra Nevada Forest Plan Amendment (USDA FS 2004), management was adjusted to include a 1,000-ac (405-ha) home range core, where an additional 700 ac (283.5 ha) outside of the PAC is designated and managed as foraging habitat around core areas. Originally, the PAC concept was adopted as an interim strategy to reduce risk from timber harvest and protect the large trees and mature forest known to be important habitat around spotted owl core areas, as well as large trees throughout treated forest areas,

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until a more comprehensive forest management strategy could be developed. Little evaluation of the PAC strategy, and no evaluation of CASPO forest treatments, has been conducted, but recent work documents that PACs have been successful in protecting important nesting and roosting habitat and that owls use these PACs over very long periods of time (Berigan et al. 2012). However, it is uncertain if a reserve-based PAC strategy can effectively provide habitat to support a viable population of California spotted owls over the long term in the wildfire-structured forests of the Sierra Nevada, given increasing trends in wildfire acres burned and amounts of high-severity wildfire associated with contemporary forest fuel loads and projected future climate change scenarios (Ager et al. 2007, 2012; Gaines et al. 2010; Miller et al. 2009; Roloff et al. 2012).

Recommendations proposed by North et al. (2009) focus on using topography, aspect, elevation, latitude, and desired vegetation conditions more consistent with patterns that would result under a natural disturbance regime structured by wildfire to guide management decisions. Management of denser forest habitat conditions would be targeted for topographic locations where wildfires would have burned less frequently or at lower severities, such as northerly aspects, canyon bottoms, and riparian areas. Conversely, south-facing slopes and ridge tops would be managed for more open vegetative conditions consistent with patterns that would be expected under a more natural fire regime. Nested within the overarching landscape scale, vegetation treatments would focus on generating patch-scale heterogeneity in forest structure and composition thought to be more consistent with conditions generated by a frequent, predominately low- to moderate-severity fire regime. Whether the management strategy proposed by North et al. (2009) can provide for viable populations of California owls is a hypothesis that requires field testing and validation.

No information is available on historical spotted owl distribution, numbers, or habitat associations under pre-Euro-American forest conditions in the Sierra Nevada. California spotted owls were present in these forests, but no information is available to evaluate how they interacted with forest landscapes that were generally less dense, more heterogeneous at multiple spatial scales, and dominated by large trees. Further, there is no information on the population size and densities of California spotted owls that occurred under these historical conditions. Thus, there is no base of historical information to convey how California spotted owls might respond to future conditions that may be more similar to the pre-Euro-American forest conditions in the Sierra Nevada. However, results from recent research on spotted owl habitat associations provides a strong basis for identifying and managing for vegetation types (e.g., mature forest) and habitat elements (i.e., large trees, logs, and snags) important to spotted owls.

Recent empirical studies of spotted owl habitat associations consistently reinforce the importance of large trees and mature forest habitat at the stand, core area, home range, and landscape scales (Dugger et al. 2005, Franklin et al. 2000, Olson et al. 2004). Hence, management to protect and enhance large trees and mature forest habitat and their resilience to wildfire and climate change is an important foundational piece for a successful strategy to maintain viable populations of California spotted owls in the Sierra Nevada. However, recent studies have also indicated that vegetation heterogeneity is a component of high-quality habitat at core area and home range spatial scales, and that owls will forage in a broader range of vegetation conditions relative to nesting and roosting habitat. Simulation modeling studies also project that forest fuels and restoration treatments may be compatible with maintaining spotted owl habitat (Ager et al. 2007, 2012; Lehmkuhl et al. 2007; Roloff et al. 2012).

Considering that California spotted owls evolved within heterogeneous Sierra Nevada forests structured by wildfire as the primary disturbance agent, as well as results from recent empirical and modeling studies, it is reasonable to expect that carefully crafted forest treatments can meet fuels and restoration objectives and provide habitat for California spotted owls. However, several caveats must be considered and uncertainty exists regarding how treatments will affect owl populations and their habitat. First, current understanding of California spotted owl habitat associations is based on studies conducted under contemporary forest conditions in the Sierra Nevada, which are shaped by timber harvest and fire suppression policies and management activities that have resulted in significant reductions in large trees and mature forest, and increases in forest homogeneity across stand and landscape spatial scales. It is uncertain if current habitat conditions are optimal for spotted owls and how owls may respond to future vegetation conditions that shift the landscape vegetation trajectory toward a condition more similar to patterns that would be expected under a natural disturbance regime largely driven by wildfire, but also influenced by other natural disturbances, such as insects, diseases and wind. Second, uncertainty exists regarding what constitutes high-quality spotted owl habitat capable of maintaining territories and viable populations over time. Current ongoing research investigating California spotted owl demography-habitat associations will help address these knowledge gaps.

Current population status and declining population trends of spotted owls on NFS lands in the Sierra Nevada point to the importance of a careful approach to management of California spotted owls and their habitat. Although the causes of the population declines are unknown, it is likely that historical and current vegetation

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Recent research indicates that comprehensive forest management strategies are required to address forest resilience and restoration in the Sierra Nevada, given current vegetation conditions, trends in wildfire, and projected climate change. Considerable scientific uncertainty exists regarding how California spotted owls and their habitat will be affected by the management direction proposed in North et al. (2009).

management practices (primarily timber harvest and fire suppression) are a factor. Additionally, range expansion of the barred owl into the Sierra Nevada is a serious emerging threat to California spotted owl viability. Recent research indicates that comprehensive forest management strategies are required to address forest resilience and restoration in the Sierra Nevada, given current vegetation conditions, trends in wildfire, and projected climate change (North et al. 2009). Considerable scientific uncertainty exists regarding how California spotted owls and their habitat will be affected by the management direction proposed in North et al. (2009). Adaptive management and monitoring of California spotted owls and their habitat will be an important element of a management strategy to address forest resilience and restoration in the Sierra Nevada.

Adaptive Management, Monitoring, and Information Needs

A number of tools and assessments can be used to address current scientific uncertainty about how California spotted owls and their habitat will respond to the management direction proposed in North et al. (2009). Ongoing research will address some of the information needs, whereas other needs can be met by tailoring existing modeling tools and approaches that have been developed for other applications to specifically address California spotted owls in the Sierra Nevada. Key information needs are highlighted below.

1. Integrated conservation planning efforts to synthesize existing and ongoing research efforts and develop adaptive management planning and assessment tools could better inform forest management. Improved habitat models specific to California spotted owls in the Sierra Nevada are a core need to further understand owl-habitat associations and to develop adaptive management tools to assess how owls may respond to management scenarios. The current effort to conduct an integrated meta-analysis to relate over 20 years of California spotted owl demographic data to changes in habitat over 20 years across the four long-term demographic study areas in the Sierra Nevada will provide the most comprehensive assessment of owl habitat associations to date. Models from this effort can be further developed to function as adaptive management tools. Similarly, ongoing research developing patch-scale nesting and foraging models using Forest Inventory and Analysis data can be developed into adaptive management tools for assessing treatment effects.

2. Results from climate change assessments across the three subspecies of spotted owls indicate population-specific associations with weather factors and projected responses to future climate change (Glenn et al. 2010, Peery et al. 2012). Modeling to project how California spotted owl populations in the Sierra Nevada may respond to future climate and habitat scenarios would provide insight into possible future scenarios. The four ongoing demographic studies provide existing long-term data on owl populations across the Sierra Nevada that can inform this assessment.
3. Models at home range and landscape scales are needed to assess tradeoffs between wildfire risk and treatment effects over short and long time periods specific to the Sierra Nevada (e.g., Ager et al. 2012, Lee and Irwin 2005, Roloff et al. 2012, Scheller et al. 2011, Thompson et al. 2011).
4. Improved information on vegetation status, structure, and condition is needed to facilitate development of habitat models and to assess the effects of treatments on California spotted owls and their habitat. Current, widely available vegetation data are not consistent across the Sierra Nevada and vary among forests. At patch scales, existing vegetation data are not adequate to describe the finer scale heterogeneity that will result from the proposed new management direction. New vegetation information is required that describes finer scale heterogeneity that can then be used to model and assess owl habitat and treatment effects. Efforts to develop vegetation information that is better able to capture fine-scale vertical and horizontal heterogeneity, such as LiDAR or WorldView2 imagery, are promising (García-Feced et al. 2011; Hyde et al. 2005, 2006), yet as of now, they are not available and operational enough to be able to conduct patch-to landscape-scale analyses of owl habitat associations.
5. Efforts are needed to assess the distribution and status of barred owls across the Sierra Nevada. Barred owls pose an increasing risk to California spotted owls in the synthesis area and require conservation focus.
6. Additional research is needed on the effects of high-severity fire on California spotted owl occupancy, population dynamics, and habitat given increasing trends in the amounts and patch sizes of high-severity fire in the Sierra Nevada (Miller et al. 2009).

7. Little information is available on how prey affects California spotted owl foraging behavior and population dynamics. Better understanding of California spotted owl-prey associations across different vegetation types and elevations would be beneficial for tailoring treatments and desired landscape conditions across different regions of the Sierra Nevada. Additionally, a synthesis of the literature on small mammal habitat associations in the Sierra Nevada, and comparative information from other western forests, would be valuable for identifying important forest types, stand structure characteristics, and habitat elements important to small mammals that could be used to inform future management.

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