Chapter 9: Synthesis and Interpretation of California Spotted Owl Research Within the Context of Public Forest Management

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Introduction

In this chapter, we synthesize the information presented in the preceding chapters of this assessment of the California spotted owl (*Strix occidentalis occidentalis*) and provide a scientific appraisal of its implications for forest management and owl conservation. We focus on the key scientific findings since the 1992 California spotted owl technical assessment (CASPO) (Verner et. al. 1992) and discuss priorities for future research that could enhance the successful conservation of California spotted owls and their habitat. Throughout this chapter, we acknowledge when uncertainty limits well-founded conclusions and articulate differences in interpretation of the scientific literature, where such differences exist. The development of a spotted owl conservation strategy will require additional, careful analysis and deliberation to arrive at specific and scientifically defensible management guidelines (sensu CASPO; Verner et al. 1992).

Implications of Recent Research for Spotted Owl Conservation

The greatest challenge for managers charged with maintaining a viable population of spotted owls on National Forest System (NFS) lands in the Sierra Nevada may be to embed effective, long-term owl conservation practices within an overall management strategy aimed at restoring resilient forest structure, composition, and function. We discuss how and when spotted owl conservation and forest ecosystem restoration are compatible based on our current understanding of the

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scientific literature. Conversely, we identify circumstances in which reducing fuels and restoring desired forest structure and composition may pose significant risks to spotted owls so that managers and policymakers can make informed decisions about relevant tradeoffs.

A number of species of conservation concern exists within the Sierra Nevada in addition to California spotted owls, including American marten (*Martes americana*), northern goshawk (*Accipiter gentilis*), black-backed woodpecker (*Picoides arcticus*), great gray owl (*S. nebulosa*), and particularly Pacific fisher (*Pekania pennanti*). The cumulative effects of meeting the current habitat conservation needs of each of these species may increase the challenge of achieving ecosystem management and ecological restoration objectives. However, a comprehensive old-forest management strategy that promotes large trees and canopy complexity within a landscape-scale mosaic of forest conditions could benefit many species of conservation concern, not just the California spotted owl.

Conservation of Spotted Owls in the Context of Ecosystem Restoration

Meeting the dual objectives of conserving spotted owls and promoting resilience of Sierra Nevada forests will require restoring some semblance of historical wildfire regimes without endangering already declining spotted owl populations. Conserving spotted owl populations and restoring ecosystem resilience are complementary objectives when management activities reduce the loss of old forest and owl habitat to drought and large high-severity fires. To do so will require reducing small-tree densities and promoting "natural" fire regimes in Sierra Nevada forests while maintaining a sufficient amount and distribution of suitable habitat to support viable owl populations (a key uncertainty is the amount and distribution of habitat that is sufficient). Thus, a reasonable guiding philosophy is to manage Sierra Nevada forests in ways that combine the objectives of spotted owl conservation, fuels management, and drought resilience while also recognizing that forests are dynamic ecosystems that will support a range of vegetation types and structures that vary over space and time. In practice, however, implementing effective fire management and ecosystem restoration programs that do not also pose risks to spotted owls will be challenging. In some cases, conserving habitat elements known to be important to spotted owls may lead to dense stands with high fuel loadings that are at risk from high-severity fire and other stressors such as drought, insects, pathogens, and air pollution (chapters 5 and 7). Conversely, fuel reduction and forest restoration strategies that reduce canopy cover, the complexity of forest structure, or large-tree density can potentially affect spotted owl populations negatively in both the short and long term (chapters 2, 3, 4, and 7). Determining the appropriate pace, scale, and intensity of treatments as well as the type of treatment is complicated by scientific uncertainty of the potential impacts of a suite of threats including some types of mechanical treatments on spotted owls (chapters 3 and 7; see also the "Research Implications" section below).

Two different paradigms emerged as part of this assessment regarding tradeoffs between the potential short-term negative impacts and possible long-term benefits of fuel and restoration treatments on spotted owls. One paradigm holds that treatments within spotted owl habitat pose risks to spotted owls because owls have declined significantly on some NFS lands in the Sierra Nevada and southern California over the past two decades (chapters 4 and 8). Although the cause of these recent declines is uncertain, the large reduction in abundance observed on the Eldorado National Forest study area cannot be attributed to barred owl (*Strix varia*) or fire, as estimated declines occurred before the King Fire, and very few barred owls have been detected on the Eldorado. Certainly non-habitat-related factors (e.g., climate) could have contributed to recent declines (Jones et al. 2016a), but there is concern that habitat features known to be important to spotted owls (e.g., forests with vertical structure and complex canopies) have declined during demographic studies as a result of forest management activities on both public and private lands, recognizing that these potential effects have been difficult to detect as part of demographic studies (chapters 4 and 7). There is also concern that the removal of large trees as hazards (e.g., road- and trail-side tree removal) and salvage logging affect owl habitat suitability and could be affecting spotted owl populations in the Sierra Nevada. Finally, and perhaps most importantly, pre-CASPO changes to owl habitat from historical even-age timber harvesting and the selective removal of large and "defect" trees may be contributing to recent population declines (via long-term "legacy" effects) as well as longer term (unmeasured) declines.

The conclusion from this interpretation of the published literature is that current spotted owl populations may be small relative to historical levels and limited by the spatial extent of old forest and forests containing legacy elements in the Sierra Nevada (chapter 4). There is recognition that high-severity fire and other ecosystem stressors pose threats to California spotted owls (Jones et al. 2016b), but there is also concern that the expansion of treatments that simplify forest structure and decrease forest tree canopy cover in owl habitat could exacerbate population declines and increase the probability of extirpation of owls from the region. Moreover, whether fuel treatments will protect spotted owl habitat from high-severity fire sufficiently to compensate for potential short-term impacts to populations is unknown. This paradigm suggests that conserving and promoting a sufficient amount of forest dominated by large trees, complex forest structure, and closed canopies at sites known to be used by spotted owls—particularly in owl nest stands, activity centers, and territories—is likely to enhance owl habitat and populations. Nevertheless, fuels and restoration treatments are considered to be an important component of an overall strategy intended to restore resilience to Sierra Nevada forests at larger spatial scales (chapter 5). Thus, under this paradigm, treatments would occur primarily in areas of the landscape dominated by younger forests with high small-tree density and be designed to enhance foraging habitat and foster growth rates of larger, retained trees to enhance resilience to fire when possible. Finally, it is a well-established principle of wildlife management ("Declining Population Paradigm") that halting and reversing substantial recent population declines of a species of concern, like the spotted owl, is an essential component of a conservation program (Caughley 1994). Doing so will be challenging, likely requiring restoration of habitat conditions as well as the implementation of studies carefully designed to identify the cause of recent population declines more precisely (and thus facilitate effective and specific management actions; see below).

The alternative paradigm that emerged from the assessment holds that increases in the spatial extent of high-severity fire and other disturbances to forests (e.g., prolonged drought, insects, and disease), resulting from over a century of fire suppression and now climate change, pose the primary proximate threat to spotted owl population persistence, owl habitat, and forest ecosystems in the Sierra Nevada. Current fuels and other restoration treatments are intended to retain and promote large-tree development, but their pace and scale is small (on national forests in the Sierra Nevada <12 141 ha/year (<30,000 ac/year) of mechanical thinning and <3642 ha/year (<9,000 ac/year) of prescribed fire occur, compared to 196 677 ha/year (486,000 ac/year) that historically burned [North et al. 2012]) such that any detrimental effects to owls are likely to be local and short lived. In contrast, recent and projected wildfire and drought-related mortality, exacerbated by the fire deficit, affect a significantly greater area, and often kill the largest trees while also drastically reducing canopy cover. Actions consistent with this paradigm could include, for example, fuel- and density-reduction treatments strategically placed with less consideration of owl habitat impacts and an emphasis placed on reducing the spatial extent of high-severity fire effects and drought-induced mortality.

This paradigm suggests that working with dynamic forest processes would be more effective for reducing risks to owls and the forests upon which they depend than a strategy focused on conserving and enhancing existing owl habitat. Underlying this interpretation of risk is uncertainty about historical (i.e., pre-Euro-American) spotted owl populations when forest conditions were significantly different than they are today. Recent analyses of historical datasets and efforts to reconstruct stand structure prior to the fire-suppression era (chapter 5) suggest that average canopy cover was lower in landscapes with an active fire regime. Modern forests, by contrast, have far fewer large trees, and defect structures have declined while high canopy cover conditions have become more widespread. It is unclear how these changes have influenced owl population declines that have been documented in three of the four Sierra Nevada demographic studies. Furthermore, it is uncertain whether and to what degree observed population declines may be a result of either recent management practices that created a more homogeneous forest, a legacy of more extensive and intensive management practices in previous decades (e.g., the logging of large trees and snag removal), or a change in a population that is currently higher than was supported under historical forest conditions. In light of these uncertainties, it is possible that restoring forest conditions where high canopy cover conditions are aligned with productive sites will support an owl population equilibrated to forest conditions and resilient to dynamic processes even as the climate changes.

The underlying uncertainties associated with past, present, and future conditions will present challenges to spotted owl conservation and forest management. However, there was consensus about new findings presented in this assessment that are relevant to both owl conservation and forest restoration in the Sierra Nevada. These include:

- Spotted owls have declined in abundance on some NFS lands in the Sierra Nevada over the past two decades (chapter 4).
- The density of large and defect trees has declined in Sierra Nevada forest as a result of historical (pre-CASPO) timber harvesting (chapter 5), and these habitat elements may well be contributing to recent spotted owl population declines.
- A century of fire exclusion has led to an increase in the size of high-severity fires owing to the accumulation of surface and ladder fuels (chapter 5). Habitat loss resulting from large high-severity fires and other stressors poses an increasing risk both to spotted owls and forest ecosystems, and these risks will likely increase with climate change over coming decades (Jones et al. 2016b).
- Restoring low- to moderate-severity fire regimes to the mixed-conifer zone could help achieve both spotted owl conservation and forest restoration goals.

- Habitat conditions in some spotted owl territories may not be viable in the long term because they are located in areas that have high burn probabilities or low drought tolerance. Conservation and restoration of owl habitat (large trees, moderate stem density, and canopy cover) in areas that could support these conditions (i.e., higher actual evapotranspiration and lower climatic water deficit rates) may align the distribution of owl habitat with forest restoration goals.

These key findings and points of consensus suggest that the viability of spotted owls in the Sierra Nevada depends on carefully balancing fuel and restoration treatments with the maintenance and enhancement of existing owl habitat. However, as discussed above, developing a specific set of management guidelines as part of owl conservation efforts that will simultaneously achieve these objectives will be complicated by scientific uncertainty about the potential risks and rewards posed by fuel and restoration treatments. Thus, conservation planning efforts would benefit from a quantitative risk assessment, which would require close coordination among wildlife ecologists, forest and fire ecologists, and remote-sensing scientists, as well as the development of an integrated model that links fire behavior, forest conditions, and spotted owl habitat/demography at the appropriate spatial and temporal scales. Moreover, the success of future conservation planning efforts also would benefit from the development of a robust feedback loop that generates and incorporates new information and learning through implementation, for example by monitoring the impacts of management actions on both forest structure and owl population response. Possible approaches for evaluating the short- and long-term impacts of fire and restoration treatments, as well as possible components of an adaptive management strategy, are described in more detail below.

Desired Conditions for Areas of Ecological Importance

Research summarized in chapters 2 through 8 indicates that different ecological (e.g., habitat) features are important to spotted owls at each of several spatial scales, and that considering these scale-specific requirements will facilitate the development of forest conditions that minimize risk to owls and promote resilient forest ecosystems. The scales of greatest importance are the owl's activity center, territory, and home range, embedded within the broader forested landscape. In general, owl territory occupancy and demographic rates are likely to fare better with a gradient of less intensive to more intensive forest management activities within owl habitat as a function of distance from activity centers. Maintaining key habitat elements within activity centers and territories will likely promote population growth in the short term, whereas reducing risk from high-severity fire and other threats within owl home ranges and the broader landscape could promote population viability in the long term. Given that owls are central-place foragers and exhibit strong nesting site fidelity (see chapter 2), and new nesting habitat (primarily old forest) develops over long time scales, maintaining existing nesting habitat (particularly at sites that have a history of use) is likely to promote viable populations while forest and restoration treatments designed to reduce risks from high-severity fire and other environmental stressors are implemented at larger spatial scales. The retention of large trees (particularly old trees with structural defects) and the accelerated development of additional large trees is likely to be beneficial at all scales, given that such trees have declined on the landscape and are important for both forest resilience and spotted owls. Desired conditions for each scale of ecological importance, as well as the implications of recent research for achieving these conditions via forest management, are described as follows:

- **Activity-center scale**: Maintaining high-quality nesting and roosting habitat (i.e., old forest) at known spotted owl activity centers (defined as the areas of long-term nesting and roosting use within an owl territory) will likely enhance occupancy and demographic performance. Forest structural characteristics known to be important at this scale are more likely to be maintained or even enhanced through low-intensity vegetation treatments when forest management is implemented with the intent of reducing the risk of high-severity fire and drought-induced large tree mortality.
- **Territory scale (outside of activity centers)**: Within territories, spotted owl occupancy and fitness appear to be positively related to the acreage of high-quality habitat (i.e., forests dominated by large trees and particularly high canopy cover), and a landscape populated by territories containing a sufficient amount of these habitat conditions will likely promote viable spotted owl populations. However, given climate change predictions and the likely increase in large high-severity fires and drought-induced tree mortality, reducing these risks to forests within territories will likely benefit spotted owl populations.
- **Home range scale (outside of territories)**: Spotted owl home ranges characterized by heterogeneous forests containing a mosaic of vegetation conditions, including patches of old forest and a mix of stand ages will likely confer sufficient high-quality nesting, roosting, and foraging habitat. At this scale, there is an opportunity to place greater emphasis on fuels management and forest restoration, particularly approaches that enhance

forest resilience, landscape heterogeneity, and spotted owl foraging habitat. Maintaining and increasing the prevalence of large trees could be particularly effective for restoring forest resilience and improving owl foraging habitat at this scale.

- **Landscape scale (matrix between home ranges)**: A landscape of heterogeneous forests containing a mosaic of vegetation conditions including patches of old forest will likely provide opportunities for recruitment of new spotted owl territories in the context of dynamic forest conditions and confer broad-scale ecosystem resilience. Thus, fuels and restoration treatments—in conjunction with prescribed and managed fire—that promote landscape heterogeneity in forest conditions and reduce risks for high-severity fire and other stressors will likely benefit spotted owls and forest resilience in the longer term.

The Science Behind Scale-Specific Desired Conditions: Implications for Forest Management

Here, we review the scientific basis for the above-described desired conditions and discuss how the knowledge accumulated about California spotted owls and forest ecosystems in the Sierra Nevada since CASPO could inform forest management at each of these scales in more detail.

Activity-center scale—

California spotted owl activity centers are typically characterized by old-forest conditions (i.e., large trees, complex structure; chapter 3) and maintaining such conditions within activity centers is likely important for promoting owl reproduction and population viability. Protected activity centers (PACs) were designed as part of the CASPO strategy to protect 120 ha (300 ac) of the “best available” nesting and roosting habitat (i.e., activity centers) within known spotted owl territories and appear to have been a useful management construct based on research demonstrating long-term use of these areas by owls (Berigan et al. 2012; chapter 2). Moreover, Blakesley et al. (2005) demonstrated that reproductive success in California spotted owls was correlated with vegetation types characterized by high-canopy and medium/large trees at the approximate scale of a PAC (see chapter 4 for more details). These observations, coupled with observed significant declines in owl populations on NFS lands (chapter 4), suggest that fuels and restoration treatments that substantially affect these habitat attributes within spotted owl activity centers could affect spotted owl populations adversely. Limiting treatments to approaches designed to avoid impacts to existing spotted owl habitat such as prescribed burning and hand removal of small trees are more likely to provide a balance between habitat conservation and fuels management than prescriptions that appreciably affect forest overstory structure at this scale.

Territory scale—

The quality of nesting, roosting, and foraging habitat at the territory scale is inevitably a complex function of many variables such as the density of large trees (including snags), vertical forest structure, canopy complexity, and large woody debris, as well as forest heterogeneity (chapter 3). Consideration of the range of forest conditions the literature suggests is important to owls at this scale will facilitate management of spotted owl habitat in a manner that promotes viable populations (chapter 5). Many of these characteristics, however, have proven difficult to map with sufficient accuracy and resolution at the territory scale, particularly with a large enough sample size of territories to understand how they affect owl occupancy and fitness, and thus population viability (chapter 6). In contrast, canopy cover has been relatively tractable to map at this scale and has proven to be a reasonably strong predictor of spotted owl territory occupancy and fitness (chapter 4). Recent research on the Eldorado study area indicates that occupancy and territory fitness (i.e., λ or annual population growth rates at the territory scale) (Franklin et al. 2000) are higher in territories (400-ha [988-ac] circles centered on activity centers) that contain relatively large extents of closed-canopy forest (≥70 percent cover) (Tempel et al. 2014), and that owls occupying high-elevation territories appear to be more sensitive to reductions in this forest type (Jones et al. 2016a). To date, these studies provide the most rigorous quantitative assessment of the association (particularly the directionality and the shape of the relationship) between the acreage of high-canopy forest and spotted owl demographics and provide the best available information for management of owl habitat at the territory scale. Although from a management perspective it would be valuable to understand what acreage of high-canopy cover forest is expected to lead to stable population growth at the territory scale, the absolute estimate of territory fitness (see fig. 4 in Tempel et al. 2014) is biased low owing to territory switching by owls and because recruitment into territories was not considered in the analysis by Tempel et al. (2014). As a result, decisions about how much high-canopy cover forest to retain within territories, based on this analysis, will be, to a certain extent, subjective (but see below). Tempel et al. (2014) suggested that 100 to 150 ha (247 to 370 ac) of high-canopy cover forest might provide a reasonable balance between perceived tradeoffs associated with maintaining owl habitat quality and promoting forest resilience. However, the mean area of high-canopy-cover forest in the declining Eldorado "population" was about 137 ha (338 ac), and thus a population of territories each containing only 100 ha (247 ac) of high-canopy-forest is expected to decline even more rapidly given the association between high-canopy-cover forest and spotted owl population growth rates. By extension, a landscape populated by territories containing only 50 ha (123 ac) of forests >70 percent canopy cover—the mathematical inflection point in the nonlinear relationship between territory fitness and the area of high-canopy-cover forest—will likely lead to even more rapid population declines, at least in the short term. Importantly, ongoing research based on all four demographic study areas will provide more precise estimates of how much high-canopy-cover forest (as well other canopy cover types) is required to yield stable population growth rates at the territory scale.

Although consistent empirical evidence supports the short-term conservation value of retaining high-canopy-cover forest (i.e., most owls are found in these forests), the amount of canopy cover necessary to allow owl persistence remains uncertain. The topography and past, active fire regimes of the Sierra Nevada created a diverse array of patches at different scales (i.e., patchy tree patterns within patches; successional patchworks within local landscapes; and life form, cover type, and structural patchworks within ecoregions). Consequently, many existing stands having high canopy cover are likely the result of past logging and fire suppression rather than locations that would normally support high canopy cover with a historical fire regime (chapter 5). For mixed-conifer forests, historical estimates of canopy cover generally ranged from 15 to 30 percent for forests with active fire regimes (Collins et al. 2011, 2015; Lydersen et al. 2013; Stephens et al. 2015), 19 to 49 percent for modern old growth with restored fire regimes (Lydersen and North 2012), and 60 to 65 percent for modern forests having fire-suppressed regimes (Lydersen et al. 2013), with lower values for pine-dominated stands (Stephens and Fry 2005, Taylor 2010). Particular locations, such as a group of tall trees or a grove of large trees supporting a dense cluster of codominant trees within the grove matrix, may have high canopy closure, but a stand-level average canopy cover of 70 percent appears to have been rare in historical forests (Collins et al. 2015, Stephens et al. 2015). Thus, although 70-percent canopy cover may be a desired condition for owls, in some locations it will be difficult to achieve and harder to maintain because such stand conditions usually have high surface and ladder fuel loading, high stem density, and associated water stress that increases large tree mortality.

Our assessment of the scientific literature indicates that reconciling perceived differences in desired conditions for spotted owls and Sierra Nevada forests at the territory scale—particularly with respect to canopy cover—is one of the more significant challenges facing management intended to maintain viable owl populations and promote resilient forests. However, at least three general principles for simultaneously achieving both objectives are emerging from ongoing scientific research. First, aligning high-canopy-cover stands with locations capable of supporting these forest types (e.g., north-facing slopes and drainage bottoms) will likely increase the resilience of both forest ecosystems and owl habitat to predicted increases in fire and drought severity under climate change. While desired conditions for the distribution of high-canopy-cover areas within spotted territories are uncertain, ongoing research using light detection and ranging (LiDAR) and studies of actual evapotranspiration and climatic water deficit are investigating these issues from a forest-restoration perspective. Second, if other attributes of spotted owl habitat, such as the prevalence of large defect trees, can be enhanced via forest management, it may be possible to maintain viable owl populations with less high-canopy forest present within territories than has been estimated in recent studies (Tempel et al. 2014). Third, emerging research suggests that once a certain amount of high-canopy forest is present within territories (presumably to meet nesting and roosting requirements), gains in medium (40 to 70 percent) canopy forest provide similar benefits to expected territory occupancy rates as gains in high canopy cover forests (Tempel et al., in press). While additional research is needed to develop desired conditions likely to confer both resilient forests and high-quality spotted owl habitat at the territory scale, these findings collectively suggest that achieving seemingly incompatible objectives may be possible.

When developing management guidelines based on studies of spotted owl demography and canopy cover conditions at the territory (and other) ecological scales, it is important to recognize that canopy cover is often estimated using different techniques in research and management applications. For example, canopy cover was estimated using aerial photointerpretation in Tempel et al. (2014) and Landsat imagery in Tempel et al. (2016), both mapping products being informed by ground-based vegetation measurement taken with spherical densitometers. By contrast, many forest management applications use Forest Vegetation Simulator-derived canopy cover values (Dixon 2002), which generally yield lower estimates (particularly when canopy cover is high) and do not necessarily indicate that desired conditions are not being met (Fiala et al. 2006). Determining whether desired conditions are being met requires developing appropriate calibration equations or “cross-walking” exercises.

Home range scale—

Heterogeneous forests containing a mosaic of vegetation conditions within spotted owl home ranges (but outside of the territory scale) could both enhance the resilience of Sierra Nevada forests and benefit owl populations (chapters 3 and 5). In particular, forest restoration practices that promote the maintenance/recruitment of old-forest conditions within a heterogeneous matrix of other forest and vegetation types would likely increase resilience to changing climate and other stressors. Moreover, the promotion of wildfire regimes characterized by a range of burn severities and that produce a mosaic of vegetation conditions, including unburned refugia, can potentially enhance spotted owl foraging habitat and prey resources (chapter 3). Mast-producing trees, particularly oaks, within mixed-conifer forests may also benefit owl prey species, particularly woodrats (*Neotoma* spp.) (chapter 3). However, diet studies of California spotted owls suggest that management intended to benefit prey populations would ideally be tailored to specific elevations (chapter 2). Shrubs and early seral stage forest may benefit the primary prey species at lower elevations (woodrats), whereas at higher elevations, older forests will more likely benefit the primary prey species (flying squirrels). Promoting woodrat habitat at the expense of suitable spotted owl nesting habitat (e.g., converting older forest to brush or early seral stands) could adversely affect owls. Moreover, as is current practice, we suggest that the scale at which spotted owl home range areas are managed vary along a latitudinal gradient because home ranges are smaller in the southern Sierra Nevada than in the northern Sierra Nevada.

Identifying spotted owl home ranges (as well as sites within individual home ranges) that would most benefit from fuel and restoration treatments would help balance the potential short-term impacts and long-term benefits of such treatments. Specifically, treatments in home ranges containing relatively poor spotted owl habitat and dominated by dense stands of shade-tolerant trees species on south slopes or ridgetops (i.e., fire prone) could be particularly beneficial (chapters 3 and 5). Conversely, treatments in home ranges containing habitat conditions known to promote reproduction, survival, and territory occupancy, and where forests did not depart appreciably from the “natural range” of variability are likely to be more detrimental to owl populations. An important issue to resolve when developing an owl habitat management strategy is that California spotted owl fitness appears to benefit from prevalent closed-canopy forests, conditions that can also increase the risk of high-severity fire and susceptibility to climate change and related stressors. A key issue is that home ranges that contribute disproportionately to population growth and stability may not be readily identified. It might be possible to mitigate this uncertainty, to some extent, by emphasizing the retention and promotion of other habitat features known to be important to spotted owls in all home ranges, such as large and old trees (especially ones with defects that are used as nest sites), large oaks, large coarse woody debris, and other features in treated areas. Emerging remote sensing technologies will likely improve the ability to characterize spotted owls habitat features at home range (and landscape) scales and thus provide opportunities to develop habitat targets based on more than simply canopy cover (chapter 6 and see below).

Landscape scale—
Similar to the home-rangescale, landscape-scale heterogeneity in forest conditions, shaped by a range of burn severities, could increase both the resilience of Sierra Nevada forests and spotted owl population viability. Thus, restoration activities intended to promote historical fire regimes and forest heterogeneity at broad spatial scales would be consistent with owl conservation objectives, particularly when implemented in areas where fire risk is high and the density of owl sites is low. Wildland fire (managed wildfire and prescribed fire) is an option, in conjunction with mechanical treatments to reduce fuel loads, for reducing risk of high-severity fire in the broader landscape. In addition to restoring historical fire regimes, landscape-scale fuel and restoration treatments could be designed to reduce risks to owl territories, particularly in highly productive ones. Nevertheless, some “protected” habitat will inevitably be lost to high-severity fire and the recruitment of nesting habitat outside of home ranges (e.g., via the protection and enhancement of large trees) through strategic management approaches will likely be needed to maintain a well-distributed spotted owl population. Such an approach explicitly recognizes and embraces the inherent spatial and temporal variability of forest conditions that is characteristic of a dynamic forest landscape. A habitat monitoring program, similar to the one developed for Pacific fisher, and discussed in more detail below, could be an effective means to account for the losses and gains in suitable habitat and to increase confidence that sufficient habitat is being maintained or restored at landscape scales to promote viable owl populations.

Landscape-scale conservation of spotted owl habitat is complicated by the fact that climate change will continue to alter the structure and composition of forests, as well as other environmental factors (e.g., microclimates and prey communities) that may affect California spotted owls (chapters 5 and 7). Projections of future climate suggest that pine-oak, mixed-conifer, and red fir forests, which comprise the majority of spotted owl habitat, are expected to shift upward in elevation but remain in locations where soils and topographic features maintain relatively suitable growing conditions and microclimates (chapter 5). Thus, the conservation, restoration, and promotion of old-forest conditions at appropriate sites on north-facing slopes and in steep drainages within the current range are likely to benefit spotted owls in both the short and long term. In addition, spotted owl habitat may develop at sites where it is currently not present (e.g., by promoting old-forest characteristics at higher elevations in montane conifer and red fir forests), and these sites could be particularly important in the future if owl populations track suitable climate conditions and that of the forests they tend to occupy. The establishment and growth of large-diameter trees at sites where they presently do not occur will take many decades and perhaps centuries depending on current forest conditions. Long-term planning would be required to identify such sites and implement management activities that will promote habitat features required by owls in a timely manner.

Postfire Management

Recent research indicates that California spotted owls persist in territories that experience low- to moderate- severity and mixed-severity (i.e., low to moderate fire regimes with inclusions of high-severity fire patches) wildfire and that small patches of high-severity fire may enhance foraging conditions for spotted owls (chapters 3 and 7). Salvage harvesting within such landscapes, particularly high-intensity salvage (removal of most snags), could negatively affect spotted owl habitat via the removal of snags and ultimately the reduction of coarse woody debris on the forest floor (chapter 5 and 7). However, site occupancy after fire is more likely to be affected when large areas of forest are burned at high severity (chapters 3 and 7). While salvage harvesting may have few short-term (<10 year) ecological benefits in such landscapes, over the long term (>30 years), judicious salvage practices (e.g., leaving some snags) followed by reforestation based on goals for desired restoration of historical conditions may help promote a return to mature conifer forest more quickly than an intensively burned area that is not harvested or replanted. Replanting trees in intensively burned landscapes, particularly large burns far from seed sources, will likely increase the rate at which spotted owl habitat is regenerated (chapter 5). However, forests resulting from reforestation efforts will be a function of planting design (e.g., density of tree planting) and subsequent management; large areas planted using conventional plantation prescriptions (i.e., high densities of equally spaced seedlings and homogeneous thinning) (chapter 5) could lead to delayed or poor habitat conditions for spotted owls, high risk to wildfire, and a reduction in landscape-scale diversity in vegetation conditions. In sum, spatial scale and planting practices are both important considerations when balancing tradeoffs among salvage harvesting, restoration, and spotted owl conservation. Salvage within low-moderate and mixed-severity burned areas can potentially affect spotted owls negatively, whereas the inability to replant large patches of high-severity burned forest could result in the long-term loss of owl habitat (chapter 5).

Barred Owl Range Expansion, Monitoring, and Control

Barred owls have recently expanded their range into the northern Sierra Nevada, and a small but increasing number of barred owls are being detected in the central and southern Sierra Nevada (chapter 7). Given the apparently profound impacts that they have had on northern spotted owls (*S. o. caurina*), control measures would likely be most effective while barred owls still occur at low densities in the Sierra Nevada (Dugger et al. 2016). As is the case generally for invasive species, the momentum of range expansion and abundance is expected to increase exponentially once barred owls have reached a critical, as yet unknown, density. The control of barred owls throughout forest areas in the Sierra Nevada will be difficult, if not impossible, when such a critical density is reached. If barred owls reach a critical density, as they have in the range of the northern spotted owl, we can expect a rapid increase in their numbers, interspecific competition, predation, and other impacts to spotted owls (Gutiérrez et al. 2007).

The primary control strategy for barred owls being tested in the range of the northern spotted owl is lethal removal. Barred owls are easy and cost-effective to remove from known locations (Diller et al. 2014). In the southern Cascades and Sierra Nevada, known barred owls could likely be removed in one or two field seasons by small crews of technicians using current techniques (Diller et al. 2014). An effective regional strategy could include a comprehensive survey and removal protocol that targets some specified degree of coverage and detection probability, and then the removal of barred owls wherever they occur in the Sierra Nevada. The success of such a program could be gauged based on how effectively it maintained barred owl numbers near their current low levels and prevented the rapid and sustained increases that were observed within the range of the northern spotted owl.

The development of barred owl monitoring and control measures could be an important topic for the conservation of the California spotted owl. Development and implementation of these measures would likely benefit from an integrated effort by several natural resource agencies, including the USFS, U.S. Fish and Wildlife Service, National Park Service, and California Department of Fish and Wildlife, as well as the cooperation of private landowners with property in the forest matrix.

Establishing Benchmarks for Conservation Success

Conservation of California spotted owls in the Sierra Nevada will require maintaining a well-distributed population of owls of sufficient abundance that the population will be resilient to the effects of climate change and other environmental stressors. A set of "conservation benchmarks" would be valuable to indicate the status of California spotted owl populations; such benchmarks could be used to evaluate monitoring results and gauge whether management activities have accomplished their intended objective of conserving spotted owls, or whether additional conservation measures need to be implemented, within an adaptive management framework. Establishing population and habitat benchmarks could reduce conflicts in interpretation of monitoring results and improve management responsiveness, at least to the extent that stakeholders agree on a set of predefined conservation benchmarks. Potential demographic metrics of spotted owl population status upon which conservation benchmarks could be based include abundance, population trends, and geographic distribution. Demographic metrics of population status could be feasible and cost effective to monitor and are generally indicative of the viability of California spotted owls in the Sierra Nevada. Habitat-based metrics, such as those currently under development as part of the Pacific Fisher Conservation Strategy, also have merit (see above) particularly at regional scales that are outside of existing spotted owl demographic study areas. However, such metrics cannot replace population-based metrics because spotted owls may decline for many reasons (e.g., barred owls, disease, etc.). In contrast, changes in habitat metrics only reflect changes in distribution and abundance of habitat.

Quantifiable benchmarks based on demographic metrics could include, for example: (1) the number (n) of spotted owls that represent different levels of probability of long-term persistence in the Sierra Nevada; (2) population trends that represent stable, increasing, or declining populations with given degrees of confidence; and (3) the number of owl territories that must be occupied in each geographic zone (perhaps as defined by clusters of ranger districts) to achieve different levels of probability of long-term persistence. Establishing scientifically defensible benchmarks for demographic metrics is challenging, and the minimum viable population size (MVP) concept, for example, has been criticized on the grounds that no single "magic" population size guarantees population persistence and that modeling frameworks for estimating MVPs are not exact (Flather et al. 2011). Nevertheless, as a practical matter, quantifiable conservation benchmarks are important to trigger management decisions—whether they indicate problems and trigger conservation "triage" efforts, or they indicate positive conditions and validate that management activities have had either a positive or neutral effect. Exploring extinction risk across a range of possible benchmarks and identifying thresholds below which extinction risk is increasingly likely can circumvent some of the perils associated with estimates of "absolute" conservation benchmarks. The California spotted owl is rare among species of conservation concern because there is a significant body of demographic data available to inform the development of conservation benchmarks for a population viability analysis perhaps guided by expert opinion. In addition, genetic analyses described below could provide historical context for conservation benchmarks developed as part of such a modeling exercise.

Progress on CASPO Uncertainties and Remaining Knowledge Gaps

Inventory

The CASPO technical assessment identified deficiencies in inventory (i.e., surveys to assess spotted owl occurrence and abundance) as one of the major uncertainties about California spotted owls (Verner and Taylor 1992). Specifically, they mentioned three parts of the owl's range where basic information on owl locations and habitat use is needed: (1) the mountains of southern California; (2) the foothill woodlands of the western Sierra Nevada; and (3) the Coast Ranges, particularly the region from the Santa Cruz area northward to San Mateo County. Extensive surveys in southern California were conducted on the San Bernardino demographic study area (San Bernardino and San Jacinto Mountains) from 1987 through 2000 and as part of a regional U.S. Forest Service (USFS) monitoring program from 2003 through 2012 (see chapter 8). The information gained from these surveys suggests that owl populations in southern California have declined in the past 20 years and that little, if any, connectivity exists between owl populations in the various mountain ranges in southern California. However, based on an inspection of the California spotted owl databases from the California Department of Fish and Wildlife (CDFW) and the Pacific Southwest Region of the USFS (see figs. 4-1 and 4-2), it appears that very few spotted owl surveys have been conducted in other mountain ranges of southern California, the foothills of the western Sierra Nevada, and the Coast Ranges (particularly north of Monterey Bay) since CASPO. Some surveys may have been conducted on private timberlands within these geographic areas, but not incorporated into the CDFW database. Nonetheless, considerable uncertainty remains about the owl's distribution and winter ranges in these areas, and the significance of these local and regional owl populations to the species' rangewide persistence.

Monitoring

The CASPO recommendations included the formal adoption of demographic approaches for monitoring California spotted owls in the Sierra Nevada by continuing and expanding four demographic studies recently established at that time. The rationale for a demographic, as opposed to an occupancy-based, strategy stemmed from concern over potentially low statistical power to detect declines in territory occupancy using methods developed for northern spotted owls. Moreover, demographic studies provide more insight into the mechanisms behind changes in populations, and they are likely better able to contend with lag effects associated with the owl's long lifespan. These ongoing demographic studies have now yielded reasonably precise estimates of population trends and indicate that two of three study populations occurring primarily on national forests are declining in abundance, and the third is likely declining (chapter 4).

From a statistical perspective, conclusions about population trends are limited to the areas encompassed by the four demographic study areas because the areas were not randomly selected. However, because study areas are large, span the length of the Sierra Nevada, have long-term (20+ years) data, and have similar study designs, they likely reflect the trends in California spotted owl populations throughout NFS lands on the west side of the Sierra Nevada. To achieve a regional-scale inference based on sampling of owls, monitoring would have to occur at a much larger scale using a lower intensity approach that did not sacrifice the statistical rigor of the demography study areas. Subsequent to CASPO, formal approaches based on presence/absence data (i.e., occupancy analysis) were developed to provide a statistical framework for estimating changes in occupancy over space and time while accounting for imperfect detection probabilities. For example, a recent analysis of territory occupancy data for the Eldorado Study Area found that annual rates of change in occupancy were similar to rates of change in abundance estimated with demographic methods (reverse-time mark-recapture models). Although this congruence is encouraging, developing an occupancy-based monitoring program outside of the demographic studies (i.e., a regionwide scale of monitoring) would involve beginning a new monitoring program with no prior information. Moreover, given the species' long lifespan, detecting trends in spotted owl populations can take many years, even decades (as was the case with the existing demography studies). Nonetheless, a regional-scale, occupancy-based monitoring program would be highly complementary to the information provided by the demographic monitoring and would facilitate the assessment of barred owl impacts and serve as a valuable component of a barred owl management strategy (see below).

Research

One major knowledge gap identified in CASPO involved "habitat capability" as little to no information existed on relationships between fitness (survival and reproduction) and habitat features. As described in chapter 4, significant progress has been made in this regard as several studies have investigated correlations between habitat features and owl demographic rates such as reproduction, survival, and occupancy across a range of spatial scales. A general picture has emerged where individual fitness and territory occupancy appear to be linked to the availability of closed-canopy forest with complex vertical structure. Other vegetation types (e.g., montane chaparral) distributed within a mosaic of forest types may constitute important foraging habitat, particularly when juxtaposed with closed-canopy forests, and may confer fitness benefits to spotted owls; however, such linkages have not been demonstrated conclusively for California spotted owls.

Priority Research Needs

The synthesis of information in each chapter, as well as progress made on knowledge gaps identified as part of the CASPO process, indicate that a paradox exists with respect to our understanding of the California spotted owl's ecology and life-history needs. On the one hand, many aspects of its ecology have been studied intensively, and consequently, we have a reasonable understanding of population trends within specific demography study areas as well as habitat associations at a variety of spatial scales. On the other hand, many important uncertainties remain; two of the most important being (1) the environmental and anthropogenic causes of observed population declines, and (2) the short- and long-term effects of forest fuels and restoration management and wildfire regimes on spotted owls. Reducing these two uncertainties, as well as others described below, would be facilitated by creative research approaches that integrate emerging advances in animal tracking technology, remote sensing-based habitat mapping, and population genomic and other molecular approaches. Below, we highlight priority research needs for the coming years and briefly point to possible new research approaches that could be employed to reduce outstanding uncertainties.

Identifying Environmental Causes of Population Declines

Spotted owls are declining in abundance on some NFS lands in the Sierra Nevada (chapter 4). The identification of environmental factor(s) responsible for population declines is essential for halting and reversing wildlife population declines. Understandably, much research on California spotted owls has focused on habitat associations and, more recently, the influence of habitat quality and wildfires on populations in an effort to inform managers of forest lands (see chapters 2, 3, and 4). However, studies explicitly attempting to diagnose causes of the decline and discriminate among candidate environmental factors are lacking given the inherent challenges in conducting such work, and mechanism(s) behind observed declines thus remain uncertain. Tempel et al. (2014) suggested that reductions in the amount of closed-canopy forests may have contributed to observed declines in spotted owl abundance in the central Sierra Nevada, but the study area-level decline in owl habitat (about 8 percent) was considerably less than the decline in owl numbers (about 50 percent) over a two-decade period. The population decline may have exceeded the recent reduction in habitat because of lag effects related to historical habitat change, nonlinear effects of habitat loss, and changes in other, unmeasured habitat elements. However, factors unrelated to habitat could also be contributing to the decline (see chapter 7), and carefully designed studies are needed to understand the relative importance of potential threat factors. Moreover, multiple environmental factors could be responsible for observed population declines, and they could be acting synergistically (interacting) such that cumulative effects exceed the impacts of stressors when considered individually and even additively. Clearer understanding of these processes would facilitate the effective allocation of conservation resources and improve the likelihood of halting and reversing declines.

Several conceptual frameworks have been developed to diagnose causes of decline in species of conservation concern (e.g., Peery et al. 2004). These frameworks can include comparing populations experiencing different levels of potential threat factors, comparing population trends before and after a threat factor emerges, and direct experiments designed to manipulate threat factors and measure an appropriate response. Carefully designed experimental studies constitute the most rigorous way to test hypotheses about causes of declines (e.g., effects of forest treatments) in spotted owls (chapter 7), but are challenging to implement because of the owl's long lifespan and large spatial requirements, and previous attempts have met with limited success. Controlling the many factors influencing owl population performance, while testing specific hypotheses, is immensely difficult on landscapes with significant environmental variability and diverse historical conditions. Moreover, the owl is currently declining, and additional losses of habitat under the auspices of "experimentation" need to be carefully vetted with consideration for potential detrimental effects on the species. Successful research would also require experimental control over large geographic areas, something that has proven to be very difficult to execute.

Comparing populations experiencing different levels of threats (e.g., amounts of habitat loss, disease incidence, prevalence of barred owls) is a potentially powerful approach. For instance, comparisons of population growth rates among the four Sierra Nevada demographic study areas (owls on the three NFS study areas are declining, whereas owls on the National Park Service [NPS] study area appear stable; chapter 4) suggest that past and current management differences between NFS lands and NPS lands could be responsible for spotted owl declines in the former. However, ecological and other anthropogenic differences between NFS and NPS lands could be responsible for differences in population trends between land ownerships. For example, the NFS study areas contain a large amount of private land managed for commercial timber production, whereas the NPS study area does not. Inference about causes of declines can be strengthened by considering individual owls or territories as the sampling unit and relating spatiotemporal variation in demographic parameters (e.g., survival, reproduction, and occupancy) to variables that reflect potential threat factors. In fact, population-level research has thus far shown that the individual/territory is the key sampling level for attempting to partition the complex and interacting mechanisms behind the observed population declines in the long-term and spatially extensive monitoring demographic study areas. However, a key gap here involves a dearth of individual- and territory-level information (other than relatively coarse-scale habitat metrics) that can be used to explain variation in the demographic rates. Greater emphasis on collecting information about prey availability, competitor and predator abundance (particularly barred owls—at this time they are only a potentially important consideration within the Lassen Study Area), and diseases within the demographic study areas could help elucidate the causes of declines. Some of this information can readily be collected as part of captures (e.g., health parameters) or surveys (e.g., presence/absence of predators or competitors) that are already part of the monitoring activities conducted for each demographic study. Although correlative associations (i.e., observational studies) between owl demographic rates and environmental variables do not necessarily identify causative mechanisms behind population declines, concordance in results across study areas greatly strengthens inferences about causes. Moreover, once reasonably well-supported correlations between environmental factors and demographic rates have been identified, simple population models can be used to estimate the sensitivity of population growth to each variable. Environmental variables with a strong influence on population growth (i.e., high sensitivity) and that are amenable to manipulation would then be likely candidates for management intervention. Although some information (notably prey availability) may be impractical to collect at a sufficiently large number of territories, there are smaller scale opportunities and indirect methods for studying prey as a limiting factor (see below). The research approach described here would benefit from maintaining the three demographic study areas on NFS lands and restoring the NPS study area (Sequoia and Kings Canyon), as doing so would facilitate both broad- and fine-scale assessment of relationships between owl population and changes in environmental conditions.

Effects of Fuel Treatments and Wildfire on Population Viability

Greater understanding of the effects of fuel and restoration treatments and wildfire on California spotted owls is needed to inform forest management that is intended to recover owl populations and restore ecosystem resilience in Sierra Nevada forests (chapters 3 and 7). Fuel and restoration treatments may confer long-term benefits to spotted owls by reducing the risk of large high-severity fires (chapter 5), but it is unknown under what circumstances potential long-term benefits outweigh more certain short-term impacts to owls if treatments substantially change forest structure. In short, for fuel and restoration treatments to confer a net benefit to spotted owls, the following conditions all must be met:

- Large high-severity fires have a negative effect on owl habitat and populations.
- Fuel and restoration treatments effectively reduce the frequency and size of high-severity fires and water-stress mortality that are detrimental to spotted owl habitat.
- Treatment changes to forest structure do not lead to the extirpation of spotted owls or to such low abundances that owls cannot recover to realize the benefits of restored fire regimes.

High-severity fires—

Until recently, the effects of high-severity fire on spotted owls has remained uncertain, in part, because studies had been predicated on a limited number of territories experiencing extensive high-severity fire, potential fire effects have been confounded by the effects of salvage logging, and the lack of marked individuals makes it difficult to interpret the occupancy status of territories (chapters 3 and 7). However, the King Fire of 2014 provided an unprecedented opportunity to understand the impacts of a large high-severity fire on California spotted owls given its impact on the Eldorado demography study area in the form of a natural “before, after, control, impact” experiment. Spotted owl occupancy declined markedly at severely burned sites 1-year postfire, and the large patch of severely burned forest was strongly avoided for foraging by global positioning system (GPS)-tagged individuals whose territories were at the perimeter of the fire (Jones et al. 2016b). Because fire impacts were not confounded by salvage harvesting, this study thus provided compelling evidence that high-severity fire can negatively affect spotted owls when burn patch size is large. In contrast, occupancy did not appear to decline in the first breeding season following the Rim Fire (Bond and Lee 2015); however, caution is advisable when interpreting results after only 1 year given the high site fidelity of spotted owls and without knowledge of the distribution, size, and severity of burned forest patches. Caution is also appropriate because owls were not individually marked and movements among territories by unmarked individuals can give the appearance of occupancy in vacant territories. Additional opportunities will likely emerge for studying the effects of severe fire on spotted owls by taking advantage of these opportunities through monitoring responses after fires and using radiotelemetry or GPS tagging when feasible to augment our understanding of owl responses to fire.

Fuel treatments—
In terms of fuel treatment effectiveness, model-based and empirical evidence indicate that fuel treatments can reduce fire severity and spread, and that combining fuel treatments (e.g., Strategically Placed Landscape Treatments [SPLATs] or topography-based variable-density reduction) with prescribed and managed fire can effectively reduce the extent of high-intensity fires in the Sierra Nevada under most conditions (chapter 5). In some recent wildfires (e.g., Rim, King, Valley, Butte), fire behavior has exceeded current model predictions, producing large patches of high-severity effects, including areas with recent (<15 years) fuels treatments. It is not always clear what is driving this extreme behavior, but some observations and early analyses (Lydersen et al. 2013) suggest two likely factors: (1) heavy fuel loads sufficient for the wildfire to generate its own extreme weather, and (2) increasingly efficient early suppression of past fires, which has effectively selected for fewer, high-severity large wildfires that “escape” containment during more extreme weather than occurred historically (North et al. 2015). Fuels treatments, such as some combination of mechanical thinning, prescribed burning and managed wildfire, will likely only be effective in the absence of extreme fire behavior.

Treatment changes to forest structure do not lead to the extirpation of spotted owls—
Little direct information exists about the short-term influence of fuel treatments on owls. Tempel et al. (2014) found a small negative effect on reproductive output related to “medium-intensity” timber harvests that included, but was not limited to, SPLATs and SPLAT-like thin-from-below prescriptions with relatively even spacing

among the remaining trees and found no effect on territory occupancy or individual survival. Stephens et al. (2014) reported a decline in the number of territorial owl sites 3 to 4 years following implementation of a landscape fuels management strategy primarily consisting of defensible fuels profile zones and forest thinning treatments. The potential effects of actual SPLATs or "newer" fuels reduction and restoration treatments that vary forest conditions with topography (North et al. 2009) have not been assessed. Further, studies of the potential long-term benefits of restoring historical fire regimes (reducing the extent of high-severity fire) to spotted owls have remained in their infancy. Recently, the Sierra Nevada Adaptive Management Project (SNAMP) investigated this question at the "fireshed" scale (tens of square kilometers) within an interdisciplinary framework. Results from this project suggest that SPLATs can reduce the risks of high-severity fire to spotted owls on the fireshed scale over a 30-year timeframe (Tempel et al. 2015). In the absence of fire, SPLATs had a persistent negative effect on spotted owl fitness over the modeling period (Tempel et al. 2015). Thus, additional research will be needed that incorporates absolute risks of fire into model-based evaluations of fuel treatments effects in order to examine relative risks in greater detail. Moreover, similar studies conducted at landscape scales will be needed to fully assess the effects of implementation of fuel treatments on the spotted owl population throughout the Sierra Nevada. Ultimately, rigorous characterization of the short- and long-term effects of fuel and restoration treatments on spotted owls will be possible with the development of a spatially explicit population model that could be used as a decision-support tool to help evaluate the potential effects of alternative forest management actions (see above).

Historical (Pre-Euro-American) Abundance of California Spotted Owls

The California spotted owl is unusual among species of concern because more than 20 years of detailed demographic data have been collected at multiple sites, whereas most threatened species do not have such a wealth of information to guide managers. However, our insight into factors affecting population trends is limited to recent decades although wildfire suppression and timber harvesting have altered the composition and structure of Sierra Nevada forests since the late 19th century (chapters 4 and 5). As discussed above, unavoidable uncertainty exists about population trends over the past 150 years and the full suite of factors that influenced populations. Several hypotheses have been suggested about this early history of owls, but these cannot be tested with information from demographic studies, and existing genetic information does not provide definitive information regarding historical population size. However, emerging genetic-based methods provide exciting opportunities to evaluate demographic history in California spotted owls (chapter 4). Populations that have dramatically declined (i.e., effective population size) tend to lose genetic diversity (e.g., heterozygosity and allelic diversity) because of genetic drift. When historical specimens from museums are available, direct comparisons of genetic diversity (and thus effective population size) can be made between historical and modern sampling times, but few such samples are available for California spotted owls. However, the recent advent of next-generation-sequencing (NGS) has revolutionized researchers' ability to characterize demographic history using genetic samples collected at a single point in time (chapter 4). Indeed, NGS approaches now allow for the screening of tens of thousands of loci (as opposed to tens of loci) and thus the evaluation of competing models of demographic history (e.g., population expansion or contraction over relatively short periods of time) and estimation of important population parameters (e.g., pre-Euro-American population size and subsequent trends in population size). As such, "genomic" methods could provide considerable potential for understanding the combined effects of forest management activities on spotted owls in the 20th century. Answering the question of whether spotted owls are more abundant currently or historically would provide insight into how resilient owl populations might be to future population perturbations as a function of climate, fire, management, or combinations thereof.

Enhancing Foraging and Prey Habitat

Evidence is mounting that California spotted owls forage in heterogeneous forests containing a mosaic of vegetation types and seral stages (including patches of old forest) because complex landscapes support a diversity and abundance of small mammal prey (chapter 3). Indeed, the juxtaposition of mature conifer forests containing a hardwood component with other vegetation types may enhance foraging opportunities and confer fitness benefits to owls (chapter 3). However, greater understanding of the vegetation conditions that shape the abundance and distribution of important prey species in the Sierra Nevada would facilitate the development of effective stand- and landscape-scale forest management strategies to enhance spotted owl foraging habitat. Pairing such forest management activities with carefully designed field studies (ideally within an experimental framework) could provide a rigorous means for evaluating the potential benefits of efforts to enhance spotted owl prey and foraging habitat. Assessments of forest management intended to improve foraging habitat quality would also benefit from the integration of pellet-based diet analyses, prey and vegetation sampling, as well as the use of fine-scale tracking of radio- or GPS-marked owls. Ultralight GPS loggers are now sufficiently small (5 to 10 g [0.2 to 0.4 oz]) to be deployed safely on owls, can generate precise locations at rapid intervals, and would provide an effective tool for determining the use of different vegetation types for foraging. Such studies could be enhanced by the use of isotopic tracers applied to prey occurring in the target patches, which would allow for the estimation of the contribution of prey captured in different habitats to the total biomass of prey consumed by marked owls.

Impacts of Climate Change to Spotted Owls and Their Habitat

Climate change will inevitably alter the structure and composition of Sierra Nevada forests and thereby the suitability and configuration of spotted owl habitat (chapter 5). Thus, it will be important to identify sites that are most likely to continue to support suitable habitat, as well as sites that are likely to transition into suitable habitat as the climate changes, and to actively manage and conserve priority sites (e.g., by reducing fire risk and promoting old-forest conditions). Existing habitat areas that are likely to retain suitability into the future are generally predicted to occur in cooler, north-facing areas with high topographic relief, and existing models of forest vulnerability provide a tool for predicting the specific locations of likely refugia on the landscape (chapter 5). Although plants and animals in montane systems are generally expected to make upslope shifts in distributions as the climate warms, novel vegetation communities are likely to emerge, and changes in the distribution of owl habitat and prey will likely be influenced by soil conditions and topographic features (chapter 5). A recent climate change-modeling study based on 20 years of spotted owl occupancy data from the Eldorado demography study area suggests that maintaining viable spotted owl populations is most likely to be achieved by managing for owl habitat at high-elevation territories (Jones et al. 2016a). This analysis constitutes a novel and useful first attempt to project the effects of climate change on spotted owl distribution in the Sierra Nevada; however, it does not explicitly consider projected changes in forests or fire regimes in this region. Future studies could further our understanding of potential climate change effects by linking expected changes in owl distribution to shifts in vegetation communities and change in fire dynamics—an effort that would benefit from integrative efforts involving wildlife, forest, and fire ecologists.

Habitat Evaluation Tools

Accurate and high-resolution mapping of the California spotted owl habitat elements across landscapes will enhance the effectiveness of many aspects of owl habitat conservation, including monitoring the effect of management actions on habitat quality. As described in chapter 6, most previous map-based studies of California spotted owl habitat associations have made use of moderate-resolution Landsat imagery that cannot discern some key structural elements (e.g., high concentrations of residual trees or multilayered canopy) that are important to spotted owls. Emerging remote sensing methods such as LiDAR will continue to improve our ability to characterize habitat quality for spotted owl habitat at landscape scales and hopefully provide the spatiotemporal vegetation data needed to understand the effects of forest management and natural disturbance on owls. Despite improvements in habitat mapping provided by LiDAR and other high-resolution sensors, there are many outstanding needs for mapping of wildlife habitat, including the mapping of snags, large trees, and large broken-top trees; development of improved metrics to quantify vertical canopy structure; and development of tree species distributions in mixed-conifer forests. The integration of various LiDAR techniques with other optical imagery may overcome some of these hurdles and improve the mapping of wildlife habitat in the near future, particularly to the extent that simple, field-validated remote sensing metrics can be linked to management goals (chapter 6).

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