Executive Summary

Introduction

The California spotted owl (*Strix occidentalis occidentalis*) occurs in the Sierra Nevada, the mountains of central coastal California, and the peninsula and Transverse Ranges of southern California. It is a species of conservation concern because of the potential impacts of forest management and high-severity fire on its habitat—primarily closed-canopy forest. The first California spotted owl technical assessment "The California Spotted Owl: A technical Assessment of it's current status" (CASPO) was published in 1992. It was developed to help guide forest management in the Sierra Nevada and southern California mountains. Since CASPO, much has been learned about the ecology of California spotted owls, but the complexity of managing owl habitat, forests, and wildlife also has increased because of declining forest health, climate change, diseases, and invasive species. Moreover, the population status of owls in the Sierra Nevada is no longer uncertain—populations are declining on national forests.

This document represents a comprehensive overview of the current knowledge about the ecology, habitat use, and population dynamics of the California spotted owl as well as existing and potential threats to its viability. For this assessment (as in CASPO), we divided the range of the California spotted owl into two major physiographic provinces: the Sierra Nevada and the mountains of southern California (including the Transverse Ranges of southern California and portions of the Coast Range of central California). Tehachapi Pass was used as the demarcation between the regions. The majority of new information pertains to the Sierra Nevada population, so all but chapter 8 primarily address the Sierra Nevada population. The science team that produced the assessment was assembled to provide expertise in owl biology and other relevant disciplines (experts in climate change, fire and fuels management, forest ecology, remote sensing, and vegetation ecology). Ideally, this assessment will help inform future options for management and activities ranging in scales from site-specific projects to large landscapes to the entire range of the owl.

Biology and Ecology

The three subspecies of the spotted owl are recognized by the American Ornithologists' Union: northern (*S. o. caurina),* California (*S. o. occidentalis*), and Mexican *(S. o. lucida*). The ranges of the northern and California spotted owls are parapatric (ranges immediately adjacent). For purposes of owl management and conservation, Pit River has been recommended as the management dividing line

between these two subspecies although there is evidence that both subspecies occur on either side of the river.

Spotted owls have a monogamous mating system, with territorial pairs forming relatively long-term pair bonds and occupying large home range areas. Spotted owls sometimes break pair bonds (i.e., "divorce"); birds that break pair bonds or whose mate has died form new pair bonds with other birds, often in different territories. Spotted owls are territorial (i.e., exclude other pairs or individuals from the core of their home range) and exhibit strong fidelity to their territory. The territory is typically smaller than a home range. Although the sizes of territories have not been estimated, home ranges are relatively large (about 400 to 1200 ha [1,000 to 3,000 ac]), and home ranges of adjacent owls often overlap.

Spotted owls are primarily active at night when they hunt, defend, socialize, and conduct exploratory movements. They sleep, conduct self-maintenance, and guard young during the day while roosting in complex-structured forests. These forests provide thermal and protective cover, and the same roost sites are often used consistently over many years. The areas around nest and roost sites serve as the center of activity for spotted owls. An owl can forage anywhere within its home range.

Owls have evolved long lifespans and low reproductive rates as mechanisms to mitigate the negative effects of short-term, unpredictable environmental conditions (such as weather variability and disturbance frequency). Annual reproduction by California spotted owls is extremely variable, ranging from no young produced within an area to nearly all birds producing young. These biological features have led some scientists to suggest that the owl exhibits a "bet hedging" life history strategy, meaning that the lack of reproduction at a site for one or more years does not necessarily reflect low site quality, but rather it could reflect temporarily poor environmental conditions that cause owls to postpone reproduction until conditions improve.

Spotted owls prey primarily on medium-sized small mammals, particularly dusky-footed and big-eared woodrats (*Neotoma* spp.) at lower elevations and flying squirrels (*Glaucomys sabrinus)* at higher elevations. However, they prey on many other species, such as mice, pocket gophers, voles, birds, lizards, and insects.

Predators of spotted owls include the great horned owl (*Bubo virginianus*), northern goshawk (*Accipiter gentilis*), and red-tailed hawk (*Buteo jamaicensis*). The invasion of the barred owl (*Strix varia*) in western North America has been of substantial concern for spotted owl conservation because it is a dominant competitor.

Habitat Characteristics and Use

Spotted owls are habitat specialists that are strongly associated with mature forests that are multistoried or complex in structure and have larger trees, higher canopy cover, and more coarse woody debris than does the general landscape. Several hypotheses have been generated to explain why owls select old/mature forests (such as nest site requirements, ambient temperature moderation, or prey availability). They use large, old trees and snags as structures for nests. Here they nest in cavities, broken tree tops, and occasionally on debris platforms such as nests of other species or mistletoe brooms. In mixed-conifer forests, the average nest tree is 124 cm (49 in) in diameter at breast height (d.b.h.) and 31 m (103 ft) tall with an average nest height of 23 m (74 ft). Nests trees in hardwood forests have an average diameter of 76 cm (30 in) and an average nest height of 12 m (38 ft). Owl site occupancy and adult survivorship increase when there is a greater proportion of area of the nest stand containing high canopy cover and high basal area in an owl territory.

Spotted owls are central-place foragers so they concentrate their activities in a "core area" around nests and roosts, with foraging activity decreasing as distance increases from nests or roosts. The "core area" refers to the area that contains the nesting, roosting, and foraging habitat that is essential to each pair's survival and reproductive success. It is commonly considered to be consistent with the territory and is often portrayed in analyses as a circle with a radius that is half the average distance between adjacent nests (i.e., nearest neighbor distance). Occupancy, site colonization, adult survival, and reproductive success are positively associated with the proportion of the core area containing structurally complex conifer forest with large trees and high canopy cover. Concomitantly, reproductive success is negatively correlated with the proportion of nonforested areas and forest types that are not used by owls for nesting or foraging.

Current management on the National Forest System (NFS) centers on protection of 121 ha (300 ac) of high-quality habitat (protected activity center [PAC]) around the nest site as a means of maintaining average habitat conditions within the core use area. One study showed that the current size specified for spotted owl PACs may be adequate to maintain occupancy of territories. Another study showed that mechanical tree removal on ≥20 ha (49 ac) of a PAC was negatively correlated with site colonization and occupancy. Because of the limited number of studies, the contribution of PACs to owl conservation still needs study.

Spotted owl foraging habitat is characterized by a mosaic of vegetation types and seral stages including but not limited to mature forest. Spotted owls often forage in areas having high-contrast edges as well as in interior forest patches (i.e., with few edges). The juxtaposition of mature closed-canopy forest with other cover types is correlated with higher reproductive output and intermediate survival rates in northern spotted owls, which in turn may reflect higher prey diversity and abundance where there is a mosaic of cover types available to owls.

Habitat characteristics of most spotted owl prey have remained largely unstudied in the Sierra Nevada. In general, the dominance of flying squirrels in the diet increases as elevation increases—the reverse is true for woodrats. In the Sierra Nevada, northern flying squirrels are associated with mature forest stands with patches of moderate-to-high canopy closure (>70 percent), large live or dead trees (>75 cm d.b.h. [>30 in]), thick litter layers (≥2.5 cm [≥0.1 in]), and sparsely distributed coarse woody debris or understory cover. In lower elevation forests, woodlands, and shrublands of the west-side Sierra Nevada, woodrats are positively associated with oak cover or large oak density (>32 cm [>13 in] d.b.h.).

A home range is the area used by an individual to meet its requirements for survival and reproduction—consistently, owl home ranges contain a greater abundance of large trees and greater proportion of mature forest than is available on the landscape. Generally, California spotted owl home ranges are larger in the northern Sierra Nevada ([>1000 ha [>2,500 ac]) and smaller in the southern Sierra Nevada (<1000 ha). Owl home ranges contain a mosaic of cover types; however, home range size increases as heterogeneity increases, suggesting that high cover type heterogeneity can negatively affect habitat quality. Data sources to describe habitat characteristics across large geographic areas such as home ranges have proven to be inaccurate and inconsistent among studies, making it difficult to derive specific and reliable home range characteristics to inform management.

Population Distribution and Trends

As reported in CASPO, there appear to be no significant gaps in distribution of owls in the Sierra Nevada. The majority of owls occur within the mid-elevation, mixed-conifer forests on the west slope of the Sierra Nevada. We could not determine the relative population density or size between public and private land in the Sierra Nevada because there has been no published estimate of the number of owls occupying private land in the Sierra Nevada.

Since CASPO, data collected on five long-term California spotted owl study areas have provided substantial empirical data on demographic rates and population trends. Of these five study areas, four were in the Sierra Nevada—three on national forests (Lassen, Eldorado, and Sierra) and one within Sequoia and Kings Canyon National Parks. Meta-analyses of these data have shown substantial variation in reproductive rates (number of young fledged per territorial female for which reproduction was assessed) among the four areas. Reproduction has declined over time on the Eldorado but has been relatively constant on the other study areas.

Reproductive rates have been correlated with both climatic conditions and habitat characteristics. Reproductive rates were negatively correlated with higher precipitation and colder temperatures during the previous winter or early nesting season and positively correlated with the presence of closed-canopied forest, respectively. Key vital rates—reproductive rates at both the nest and territory scales, as well as the survival of adults—appear to be closely tied to habitat characteristics, namely a positive association with the amount of forest with dense canopy and larger trees.

All studies published since CASPO have demonstrated that owl populations on national forests in the Sierra Nevada have declined over the past 20 years. Both the finite rate of a population increase (λ) and the realized rate of change (Δ_t) have shown negative trends over the past 20 years. The greatest population declines have occurred on the Lassen and Eldorado National Study Areas. However, one study in two national parks, Sequoia and Kings Canyon, showed a stable population. These findings removed the uncertainty expressed in CASPO about the status of population trends in the California spotted owl.

Sierra Nevada Forest Conditions

Most of the California spotted owl's habitat is concentrated in mid-elevation forests of the Sierra Nevada, which are made up primarily of ponderosa pine, mixed-conifer, white fir, and mixed-evergreen forest types. The majority of the range of California spotted owl is occupied by NFS lands, with private lands and national parks making up almost all the rest. These forests have changed substantially since the arrival of Europeans. Management practices (fire suppression, logging, and grazing) on national forests and private lands have largely shaped current forest conditions in the Sierra Nevada. There are five national parks in the Sierra Nevada and southern Cascades covering 1.74 million ac that contain substantial suitable spotted owl habitat. Management of these parks is directed toward building ecosystem resilience to cope with changing climates, primarily using prescribed fire and managed wildfire to accomplish conservation objectives.

Until 1990, similar management objectives and silvicultural prescriptions were used on both NFS and private lands. Prior to 1900, logging occurred mainly near mining operations and communities, with most logging occurring on private lands. Timber harvest in the Sierra Nevada peaked in the post-World War II years and then stabilized starting in the 1960s. The CASPO report noted four key changes in forest conditions that occurred from 1850 to 1992: (1) the loss of old, large-diameter trees and associated large downed logs; (2) a shift in species composition toward shade-tolerant, fire-sensitive tree species (i.e., from pines to fir and cedar); (3) increases in fuel loads associated with the mortality of small-diameter trees; and (4) the presence of fuel ladders (ground to canopy) that facilitate crown fire. We found no new information that was contrary to this historical view (but see climate change effects below).

With the adoption of the California spotted owl guidelines following CASPO, management of national forest and private forests diverged significantly in the mid-1990s. Timber harvest dramatically decreased on NFS lands such that private lands produced more than 80 percent of the timber volume from 1990 to 2013. Nearly 400 000 ha [1 million ac] were logged on private land between 1990 and 2013 in the Sierra Nevada, with most logging occurring in the southern Cascades and northern Sierra Nevada. In contrast, about (265 000 ha [665,000 ac]) were logged during about the same time on national forests, with most logging occurring in the northern Sierra Nevada.

Current estimates are (about 4.9 million ac [2 million ha]) of suitable habitat, with about 75 percent, 7 percent, and 18 percent occurring on NFS, national parks, and either private or other government lands, respectively. About half of all suitable habitat is classified as the Sierra Nevada mixed-conifer vegetation type, and this type is mostly (about 75 to 80 percent) on NFS lands, which demonstrates the critical role of NFS lands for owl conservation in the Sierra Nevada.

The preponderance of evidence suggests forests have a considerably higher density of trees than forests of presettlement times because of fire exclusion and logging that allowed the regrowth of dense tree stands. Moreover average canopy cover of presettlement forests has been estimated to be as low as 22 percent but ranging from 8 to 37 percent. However, a less accepted estimate of presettlement forests based on Forest Inventory and Analysis data and on historical tree data suggests that presettlement forests had greater density than suggested by others. Despite these differences, most studies suggest presettlement forests were spatially complex across landscapes, including the presence of early seral vegetation (e.g., dense conifer regeneration, and shrubs) and denser mature forest stands within a

matrix of generally low-density stands. Numerous studies have demonstrated that high frequency (5- to 15-year return intervals) of low-severity fire maintained low-density stands across much of the landscape, resulting in the dominance of large, fire-resistant trees. This is particularly the case for yellow pine (*Pinus ponderosa* and *P. jeffreyi*) and mixed-conifer forest types within the Sierra Nevada.

Fire is a critical ecosystem process throughout the Sierra Nevada, but that process is changing because of fire exclusion and climate change. Current trajectories of fire size and impact, along with a predicted doubling of the likelihood of future fires, suggest a future in which the frequency and proportion of stand-replacing fires in the Sierra Nevada will exceed both current and past levels. Such changes have the potential to reduce forest regeneration.

Estimates of the effects of climate change predict an upward elevation shift of plant species and communities, an expansion of grassland, savannah and shrub-dominated ecosystems, and a general reorganization of forested ecosystems. Increases in tree stress and large-tree mortality are expected among these vegetation changes. Climate projections also suggest the potential for conversions of all vegetation type with increasing warmer and drier future climate scenarios, including the forests upon which California spotted owls currently depend.

Forest heterogeneity in the Sierra Nevada is strongly influenced by water availability and fire. Mesic and riparian sites are dominated by the greatest densities of large overstory trees, have high basal area and canopy cover, and have an abundance of large snags and logs. Slope steepness and slope position (e.g., ridgetop, midslope, valley bottom) influence forest heterogeneity because they affect the reception and retention of water. While overstory forest patterns are closely associated with climatic water deficit, understory conditions are strongly shaped by fire.

Heterogeneity within forest types that are fire adapted (historically affected by frequent fires) can be characterized by the interspersion of individual trees, clumps of trees, and openings or gaps (i.e., ICO structure). The small-scale heterogeneity characteristic of historical forest conditions are hypothesized to confer multiple desirable functions: openings may inhibit crown fire spread under most weather conditions and may be as effective as fuel breaks with regularly spaced trees with wide crown separations; and the variable microclimate and vegetation conditions between the three conditions may enhance forest drought resilience and provide greater habitat diversity for both plants and animals. Intentionally creating these conditions by either mechanical treatments or prescribed fire is likely to be challenging.

Mapping Forest Conditions Past, Present, and Future

Mapped data are essential to public land managers and researchers to identify and characterize wildlife habitat across scales, to monitor species and habitat change, and to predict and plan for future scenarios. National forest managers in the Sierra Nevada use maps to aid conservation planning for sensitive species. They require the ability to estimate important habitat metrics accurately across spatial scales to account for variation in a species' needs. However, creating accurate maps can be challenging because landscapes exhibit great variability in composition, cover, and topography, and reflect a complex legacy of fire and logging effects.

Aerial photographs provide spatially detailed records and remain a valuable data source for habitat despite the increase in the number and types of digital sensors available to managers and scientists. Aerial photographs predate satellite imagery; in California, imagery archives include images from the 1930s onward. Further, the spatial detail provided by aerial photography is high, even when analog photographs are digitized. Finally, when digitized, aerial photographs (e.g., digital orthophoto quadrangles) can be analyzed with powerful image analysis techniques.

Approaches to mapping wildlife habitat have been varied. Data used to create maps describing owl habitat have been gathered from field surveys; black and white or color air photos; or digital aerial imagery, and other maps such as timber survey; Landsat-derived vegetation; and fire-severity maps. Remotely sensed imagery at both fine spatial resolution (e.g., 1 m [3 ft]) and moderate resolution (e.g., 30 m [98 ft]) has also been used to create maps.

Vegetation maps derived from Landsat data have been used widely to study California spotted owl habitat. The broad spatial coverage of Landsat and the spectral detail of its sensors have been found useful to map species groups and canopy cover but cannot detect the residual tree component of forests in forests dominated by the medium-sized trees necessary for owls to use these forests. Additional sources of vegetation data useful to create maps of owl habitat are color infrared aerial photographs, National Agricultural Imagery Program (NAIP) imagery, and Google Earth, but have yielded varying levels of success. Some studies have shown that some Landsat maps have error rates that can lead to erroneous conclusions about changes in habitat conditions. The NAIP imagery has shown greater promise for accurately mapping tree size, canopy cover, and vegetation type.

LiDAR (Light Detection and Ranging) is a laser-based technology that provides detailed, extensive, and accurate vegetation structure data, which are key elements of species' habitats. LiDAR provides data suitable to estimate many vegetation characteristics typically associated with California spotted owl habitat.

In particular, the ability to map individual trees, tree sizes, and canopy cover are enhanced by analysis of LiDAR data.

An essential step in map development is assessing the map's accuracy. The best method for doing this is to compare classified map values against field-verified values (creating an error matrix). Using field validation methods, spotted owl researchers generally have created maps with greater than 80 percent accuracy using aerial photography and 76 percent accuracy using Landsat. But all such large-scale maps of owl habitat thus far created have not contained the "residual tree" component that appears critical for owls. Mapping technology has been and will continue to be critical to understanding owl habitat relationships and inform their conservation.

Population and Habitat Threats

The CASPO provided four factors as either threats or potential threats to the viability of California spotted owl populations: (1) timber harvest and forest management, (2) wildfire, (3) development of gaps in owl distribution across the Sierra Nevada, and (4) human population growth and development. Since then, most of these conditions persist or have worsened, while additional factors have emerged as threats to California spotted owl population viability: invasion of the barred owl (*Strix varia*) into the Sierra Nevada; climate change that could affect owls and their habitat; and disease, parasites, and contaminants (namely rodenticides) that could lead to owl mortality.

Three studies have explicitly addressed the threat of timber harvest and wildfire at territory and landscape spatial scales with mixed results. Whereas multiple studies have shown the importance of critical amounts of mature conifer forest for owls, they have been mixed in their ability to elucidate their cause-and-effect relationships. For example, one study showed that loss of ≥20 ha (50 ac) of mature forest within a territory resulted in a decline in the probability of territory occupancy. Further, territories with greater amounts of mature conifer forest had higher probabilities of being colonized and lower probability of being unoccupied relative to territories with lower amounts of mature conifer forest. Another study was unable to relate habitat change due to fire or logging directly to owl vital rates, but the amount of mature, high canopy cover forest was positively related to owl survival, reproduction, population growth rate, and occupancy. There is only a single published study on the effects of logging on the owl, which showed a 43 percent reduction in occupied owl sites. Although causative linkages have not been established, these high rates of decline are coincident with the greater amount and extent of logging on public and private lands.

Studies relating owl demographic parameters to habitat patterns indicate the importance of territory-scale habitat conditions such as the amount of complex-structured mature forest present and an intermediate amount of habitat edge between forest and other vegetation types. This pattern has also been reported for owls whose territories have been affected by mixed-severity fires, including low amounts of stand-replacing fires. However, there is significant uncertainty about the amounts of edge and fine-scale heterogeneity that might be beneficial to owls or how best to achieve this heterogeneity.

Recent research indicates that California spotted owls can persist on territories burned by low-moderate severity and mixed-severity (i.e., low-moderate fires with inclusions of high severity) wildfire. The amount of high-severity fire that owls can tolerate within their territory is unknown. Occupancy of sites by owls after fire appears to be a function of the amount of suitable habitat remaining after fire, the amount of suitable habitat burned at high severity, and whether postfire salvage logging was conducted. Postfire salvage logging may negatively affect postfire habitat suitability and confounds our understanding of owl response to fire.

Development of gaps in owl distribution in the Sierra Nevada could have negative demographic effects because dispersal among geographic areas likely would be reduced. Spotted owls in the Sierra Nevada have low genetic diversity so fragmentation and isolation of owl populations in the future could lead to increased risk to long-term viability. The CASPO had a list of eight land areas of concern (AOCs) within the Sierra Nevada where potential gaps in the distribution could develop because (1) naturally fragmented distribution of habitat and owls occurs, (2) populations become isolated, (3) habitat becomes highly fragmented, and (4) areas occur where crude density of owls becomes low. Evidence indicates that the threat of gaps in distribution has likely increased since CASPO as a function of habitat loss and fragmentation. Documented owl population declines in Lassen and Eldorado National Forests (AOCs 2 and 4, respectively), along with uncertainty about the status of owls in the northern Lassen, Tahoe, Stanislaus, and Sequoia National Forests (AOCs 1, 3, 5, and 8, respectively) where extensive forest management treatments have occurred contribute to the increased threat of gaps developing in the distribution of owls.

Human population continues to grow in the main area of owl distribution on the west slope of the Sierra Nevada, which has raised the risk to owl habitat. Wildland-urban interface (WUI) zones are typically heavily managed to reduce fuels and the risk of fire to protect communities. About 50 percent of known owl sites occur within areas designated as WUIs. Disturbance resulting from human recreation and management activities also can potential affect California spotted

owls. Impacts from recreation can range from the presence of hikers near owl nests and roosts to loud noises made by motorized vehicles. Research studies have varied in their findings about the effects of disturbances on owls.

Barred owls have invaded the range of both northern and California spotted owls. Because barred owls are having a major negative impact on northern spotted owls, it is predicted they will have a similar impact on spotted owls in California. Competition between barred and spotted owls occurs because of broad overlap in habitat use, similar diets, and choice of nests. Barred owls are behaviorally dominant. Through 2013, 51 barred and 27 "sparred" (hybrids between the two species) owls, and 1 unknown have been detected in the Sierra Nevada. No barred owls have been reliably documented in either southern or central coastal California. Experiments are occurring to test the effects of barred owl removal on northern spotted owls and to assess whether removal is a feasible management strategy to reduce competition with spotted owls. If left unchecked, barred owls have the potential to extirpate spotted owls from the Sierra Nevada.

Climate change is projected to have significant effects on Sierra Nevada forests, which in turn would affect spotted owls. Increases in temperature and changes in precipitation patterns may have direct effects on spotted owl physiology, survival, reproduction, recruitment, and population growth. Climate change may also precipitate indirect effects through mechanisms such as (1) changes in habitat distribution, abundance, and quality; (2) increasing high-severity wildfire; (3) increasing mature/large-tree mortality caused by drought, insects, and disease; (4) changes in prey distribution, abundance, and population dynamics; (5) changes in interspecific interactions with competitors and predators; and (6) changes in disease dynamics associated with changing temperature and precipitation patterns.

Although little information exists on the threat of disease, parasites, and contaminants on spotted owl populations, the potential for impacts from these elements is concerning. The primary threats are West Nile Virus, ectoparasites, and endoparasites. West Nile virus is primarily a mosquito-borne flavivirus that has recently invaded North America and is highly lethal to owls. Several species of ectoparasites and endoparasites have been identified in spotted owls. Diseases and parasites can interact with other stressors to affect either the condition or survival of individuals. Environmental contaminants have not been identified as current ecological stressors on California spotted owls; however, recent reports of high exposure rates of fisher (*Pekania pennanti*) to rodenticides across the southern Sierra Nevada are likely to have implications for spotted owls because they feed on rodents. For example, 62 percent (44 of 71 owls) of barred owls tested positive for rodenticides on the Hoopa Reservation in northern California.

The Spotted Owl in Southern and Central Coastal California

Spotted owls in southern and central coastal California have received much less attention than those inhabiting the Sierra Nevada because of economic (effect of habitat conservation measures on timber harvest) and social issues (community desire for naturally functioning ecosystems). Yet there has been continued concern over the status of owl populations in this region since CASPO. The owl in this region is distributed from Monterey County and Tehachapi Pass south through the coastal, Peninsular, and Transverse Ranges to Mount Palomar near the Mexican border. The presumption is that owls in the Sierra San Pedro Martir in Baja California Norte are California spotted owls as well.

There are four major cover types used by spotted owls in southern California: riparian/hardwood forests and woodlands, live oak (*Quercus chrysolepis* Liebm.)/big cone-fir (*Pseudotsuga macrocarpa* (Vasey) Mayr) forests, mixed-conifer forests, and redwood (*Sequoia sempervirens* (Lamb. ex D. Don) Endl.)/ California laurel (*Umbellularia californica* (Hook. & Arn.) Nutt.) forests. Unlike in the Sierra Nevada, most owls occur in cover types other than mixed-conifer forest because mixed-conifer forest is only found at the highest elevations in most of these isolated mountain ranges. Thus, they are found over gradients of habitat within these mountain ranges. Yet, site-specific characteristics of territories and nest sites follow patterns seen in the Sierra Nevada owl habitat selection.

The spotted owl in southern California is unique among west coast spotted owl populations because it occurs as a presumed metapopulation—distinct populations that function independently, yet their dynamics are interrelated because of dispersal among populations. Metapopulation structure is presumed, but there is a lack of documented movement among populations to confirm this presumption. One analysis in CASPO revealed key properties of this theoretical metapopulation. One property was that the San Bernardino population was critical to the persistence of the entire metapopulation because the many small populations in the region would benefit from having this large population be a source of immigrants. A later simulation study suggested that the metapopulation would likely either go extinct within the next 30 to 40 years or would undergo a substantial decline but not go extinct. If there is little or no dispersal among populations, as current studies indicate, the risk of local population extinctions increases.

Crude densities (density across the landscape) of owls in southern California are lower than densities in other areas of California, which suggests that there is higher spatial fragmentation of suitable habitat within populations in southern California; however, ecological density (density within suitable

cover types across the landscape) is comparable to at least one population of northern spotted owls prior to its recent decline. This suggests that the habitat in southern California has a similar capacity for supporting spotted owls as the more mesic forests in northwestern California. Like populations in the Sierra Nevada, fecundity of owls is variable among years and influenced by the age of owls (subadults have lower fecundity than adults) and weather. In southern California, survival was related to age (survival higher in older age classes) and precipitation in the preceding winter.

The most complete data on territory occupancy and population trend in southern California exists for the San Bernardino Mountains within the San Bernardino National Forest, and suggests that this key population has declined. This study occurred from 1987 through 1998, with additional monitoring of known owl territories from 2003 through 2011. The San Jacinto population was studied less intensively and sporadically from 1988 through 2011. Both populations have shown significant declines (about 50 percent) in territory occupancy and for the San Bernardino a significant decline based on estimates of vital rates.

Connectivity among populations is critical to the persistence of the spotted owl in this region, and it is a function of barriers and dispersal habitat. In CASPO, urban and suburban development and the loss of riparian areas were reported to be threats to the metapopulation because they were barriers to dispersal among populations. The current situation is worse than at the time of CASPO because development continues unabated within both the Los Angeles Basin and the surrounding deserts. Further, two new types of barriers pose potential threats to dispersal: wind farms and large reservoirs. Many wind turbines have been erected in several areas that could serve as potential dispersal corridors between mountain ranges and between the southern California region and the Sierra Nevada. At the time of CASPO, reservoirs were not specifically considered a barrier to dispersal, but at least one owl drowned in its apparent attempt to cross one in the area between the San Bernardino and San Gabriel Mountains.

Habitat loss could result from fires and salvage logging, as well as habitat loss and disturbance from urban development and recreation. There are as yet no restrictions on logging of trees on private land within the range of the owl other than those imposed by the California Forest Practices Act. Habitat is also being lost or fragmented as a result of primary and secondary (i.e., vacation) home building. However, there is no longer any commercial timber harvest on national forests within the owl's range in southern California. Post-CASPO assessments of riparian

habitat found no evidence for loss of riparian habitat owing to the water diversion threat that was listed as a potential threat in CASPO. Yet such loss remains a potential threat as does the threat of channelization to control waterflow (i.e., flood protection). Wildfire has long been a concern because of its potential impact on owls and their habitat, but its overall effect on owl populations is not clear. Given the loss of habitat owing to other factors (e.g., urbanization and drought), fires are likely a contributing factor to owl declines. A myriad of additional threats to habitat and owls exist in the southern California and coastal populations, including disturbance from human recreation, drought, air pollution, mining, marijuana cultivation, invasive species, disease, cumulative effects of small-scale management actions, and climate change.

Synthesis and Interpretation Within the Context of Public Forest Management

In this final chapter, we identify and discuss key scientific findings that have emerged since the CASPO report in 1992. We also discuss priorities for future research that could enhance the successful conservation of California spotted owls and their habitat, and we acknowledge when uncertainty limits well-founded conclusions and articulate potential differences in interpretation of the scientific literature where such differences exist.

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. Establishing a set of biologically based conservation benchmarks would be valuable to indicate the status of spotted owl populations and to prompt additional or alternate conservation measures.

Maintaining a viable population of spotted owls on public lands in the Sierra Nevada will be an outcome of effective, long-term owl conservation practices embedded in an overall management strategy aimed at restoring resilient forest structure, composition, and function. 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. 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.

Two 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 forest management treatments within spotted owl habitat pose risks to spotted owls because their populations have declined and restoration treatments commonly entail the reduction of canopy cover and canopy complexity, and even the removal of some large trees. Thus, a strategy focused on conserving and enhancing existing owl habitat would be the most effective approach to conservation.
- The alternative paradigm holds that increases in the spatial extent of high-severity fire and other disturbances to forests (e.g., prolonged drought, insects, and disease) pose the primary proximate threat to spotted owl population persistence, owl habitat, and forest ecosystems in the Sierra Nevada. Thus, a strategy that reduces the risk of large, high-severity fires would be the most effective approach to conservation.

The following key findings and points of consensus regarding new scientific information are relevant to both owl conservation and forest restoration in the Sierra Nevada:

- Spotted owls have declined in abundance on some national forest lands in the Sierra Nevada over the past two decades.
- The density of large and defect trees has declined in Sierra Nevada forest as a result of historical (pre-CASPO) timber harvesting; these habitat elements may well be contributing to recent spotted owl population declines, and restoring large trees is expected to benefit both spotted owls and forest resilience.
- 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, and a concomitant high risk of habitat loss resulting from large high-severity fires.
- 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 owl territories that are located in areas with high burn probabilities or low drought tolerance may not be viable in the long term—conservation and restoration focused in areas that can sustain suitable habitat conditions may align the distribution of owl habitat with forest restoration goals.

Different habitat features are important to spotted owls at each of several spatial scales, and 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. Desired conditions for each scale of ecological importance, as well as the implications of recent research for achieving these conditions via forest management are as follows:

- **Activity center scale**: Maintaining high-quality nesting and roosting habitat at known spotted owl activity centers will likely enhance occupancy and demographic performance. Forest structural characteristics known to be important at this scale are likely to be maintained or even enhanced through low-intensity vegetation treatments intended to reduce the risk of high-severity fire and drought-induced large-tree mortality.
- **Territory scale (outside of activity centers)**: Spotted owl occupancy and fitness within territories appear to be positively related to the acreage of high-quality habitat. Given climate change predictions and the likely implications for fire and tree mortality, reducing these risks to forests within territories is likely to benefit spotted owl populations.
- **Home range scale (outside of territories)**: Spotted owl home ranges are characterized by heterogeneous forests containing a mosaic of vegetation conditions. At this scale, greater emphasis can be placed on fuels management and forest restoration, particularly approaches that enhance forest resilience, landscape heterogeneity, and spotted owl foraging habitat.
- **Landscape scale (matrix between home ranges)**: A landscape of heterogeneous forests containing a mosaic of vegetation conditions including patches of old forest is likely to promote the recruitment of new spotted owl territories. Fuels and restoration treatments (including prescribed and managed fire) that promote landscape heterogeneity in forest conditions and reduce risks for high-severity fire are likely to be beneficial to spotted owl conservation in the longer term.

Recent research indicates that California spotted owls persist in territories that experience low-moderate severity and mixed-severity wildfire and that small patches of high-severity fire may enhance foraging conditions for spotted owls. However, high-severity fire can also have a negative effects on spotted owls. Salvage harvesting within such landscapes, particularly high-intensity salvage (removal of most snags), could invoke or exacerbate negative impacts on spotted owl habitat via the removal of snags and ultimately the reduction of coarse woody debris on the forest floor.

Barred owl range expansion into the northern Sierra Nevada, particularly given the profound impacts they have had on northern spotted owls, could warrant control measures. Control measures would be most effective while barred owls still occur at low densities in the Sierra Nevada. The momentum of range expansion and abundance is expected to increase exponentially once barred owls have reached a critical, as yet unknown, density.

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 are effectively accomplishing their intended objective of conserving spotted owls, or whether additional conservation measures need to be implemented, within an adaptive management framework. For example, potential demographic metrics of spotted owl population status upon which conservation benchmarks could be based include abundance, population trends, and geographic distribution.

Despite considerable resources devoted to improving our understanding of the ecology and status of the California spotted owl, important uncertainties and knowledge gaps remain that could be addressed through future monitoring or research investments.

- It remains unclear what environmental or anthropogenic factors are responsible for observed population declines of the California spotted owl.
- A greater understanding about 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.
- Considerable uncertainty remains about the owl's distribution and winter ranges in the mountain ranges of southern California, the foothills of the western Sierra Nevada, and the Coast Ranges, and the significance of these local and regional owl populations to the species' rangewide persistence.
- To achieve a regional-scale inference based on sampling of owls, 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.
- Nonforested vegetation (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 (survival and reproduction); however, such linkages have not yet been demonstrated conclusively for California spotted owls.

- A greater understanding of the vegetation conditions that shape the abundance and distribution of important prey species in the Sierra Nevada would inform the development of effective stand- and landscape-scale forest management strategies to enhance spotted owl foraging habitat.
- 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.
- There are many outstanding needs for mapping of wildlife habitat, including the mapping of snags, large trees, and large broken-top trees; the development of improved metrics to quantify vertical canopy structure; and the development of tree species distributions in mixed-conifer forests.