# United States Department of the Interior

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OCT - 3 2017

Dear Interested Reader:

Last winter, the Sacramento Fish and Wildlife Office began an effort to develop range-wide conservation objectives for the California spotted owl (CSO), in order to inform collective efforts of partners working to conserve the species. This Conservation Objectives Report (COR) assesses and summarizes the needs of CSO, describes broad conservation objectives, and makes recommendations to reduce and/or ameliorate stressors to the species. This report is not meant to be prescriptive, but rather to inform range-wide, mixed-ownership and multiple-use land conservation strategies.

The California spotted owl was petitioned for listing under the Endangered Species Act; initial evaluation by the U.S. Fish and Wildlife Service (Service) found that the petition presented substantial scientific or commercial information indicating that the petitioned action may be warranted and the species will undergo a full status review, with a listing decision due before September 30, 2019. Ecologically relevant objectives can help guide the development of proactive conservation efforts that would occur prior to a listing decision. The final, peer-reviewed COR (attached here) delineates such objectives, based upon the best scientific and commercial data available at the time of its release.

Since the early 1990s, CSO have declined in several study areas on national forests; the only stable population appears to be in a national park. California spotted owls also nest and forage on private timberlands, although population trends in these areas remain unknown. The most consistently identified habitat elements important for CSO are large trees in areas with high canopy cover. In general, CSO thrive in areas of structurally complex mature forest embedded within a spatially heterogeneous forest, as would be maintained under a natural fire regime.

There are a number of stressors to CSO, including habitat loss to uncharacteristically large, high-severity fires and increasing large-tree mortality. These stressors are likely to be exacerbated by climate change. Certain forest management practices that remove large trees and other habitat components are also a stressor to CSO. The COR identifies a need to move management of the forest towards healthier conditions that would include a more natural fire regime. Further, the barred owl, a known threat in northern spotted owl range, is likely to become a significant stressor to CSO, along with increasing rodenticide contamination.

The COR identifies objectives for each of the stressors assessed, as well as a number of areas of uncertainty, including information regarding CSO population trends outside of the primary demographic study areas. Where possible, conservation measures were developed to further identify conservation actions.

The development of the COR reflects an effort to proactively conserve the California spotted owl. Achieving these objectives will require collaboration among stakeholders. The Service appreciates the interest and information shared by parties such as yourself, species experts, and peer reviewers in contributing to the development and review of this report.

Sincerely,

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Field Supervisor

# California Spotted Owl
## (*Strix occidentalis occidentalis*)
# Conservation Objectives Report
# October 2017

Photo by Tim Demers. Used with permission.

**US Fish and Wildlife Service**
**Sacramento Fish and Wildlife Office**
**Pacific Southwest Region**

## PREFACE

This report delineates reasonable objectives and measures, based upon the best scientific and commercial data available at the time of its release, for the conservation of the California spotted owl. The report is provided to help focus efforts of federal land management agencies and others in proactive conservation of this species, prior to and separate from a listing decision. This report is intended to provide guidance only and is not a regulatory document; identification of conservation objectives and measures does not create a legal obligation beyond existing legal requirements. The objectives in this report are subject to modification as dictated by new findings, changes in species' status, and the completion of conservation actions.

Development, review, and editing of this document was conducted by U.S. Fish and Wildlife Service. External peer review was conducted in Summer 2017, prior to finalization of the report. We would like to thank the external peer-reviewers for their thoughtful feedback.

Recommended citation:
U.S. Fish and Wildlife Service. 2017. California spotted owl (*Strix occidentalis occidentalis*) Conservation Objectives Report. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Sacramento, CA. October 2017.

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## 1. BACKGROUND AND PURPOSE

The California spotted owl (*Strix occidentalis occidentalis*) occurs on public forestlands and private timberlands throughout the Sierra Nevada and southern forests in California. In 2015, the U.S. Fish and Wildlife Service received two petitions to list the California spotted owl (CSO) under the Endangered Species Act of 1973, as amended. The Service's initial evaluation in our 90-day finding, published in the Federal Register on September 18, 2015, found that the petitions presented substantial information indicating that the petitioned action may be warranted. The species will undergo a full status review, with a listing decision due before September 30, 2019. The Service and other agencies are currently working on multiple CSO conservation efforts, including the development of the U.S. Forest Service's Draft Proposed Framework for CSO Conservation Strategy and a proposed spotted owl habitat conservation plan on private timberlands. To assist in informing these efforts, the Service developed this California spotted owl Conservation Objectives Report (COR).

The goal of this Conservation Objectives Report is to describe the ecological needs of CSO, identify and summarize the current and future stressors to viability of the species, and develop broad range-wide conservation objectives to assist in the development of ongoing and future conservation efforts. For the most recent thorough scientific assessment of CSO and its stressors, please refer to the U.S. Forest Service Pacific Southwest Research Station's Conservation Assessment (Gutiérrez et al. 2017). In addition to primary literature, this COR includes emerging research and information received in response to our March 17, 2017, letters sent via email to a wide range of interested parties requesting current information relevant to CSO. The goal of this COR is not to be prescriptive, but rather to identify ecologically relevant goals to guide the development of regional conservation strategies and other conservation efforts for CSO.

## 2. CALIFORNIA SPOTTED OWL ECOLOGY

### 2.1 Range and distribution

California spotted owls are continuously distributed throughout the forests of the western Sierra Nevada mountains in California, from Shasta County south to the Tehachapi Pass (Verner et al. 1992). The drier eastern side of the Sierras supports limited amounts of CSO habitat and relatively fewer CSO than the western slopes. California spotted owls also occur in southern and central coastal California (hereafter referred to as southern California), with a gap in their distribution between the Sierras and southern California forests (Verner et al. 1992). The CSO can be found at 1,000 – 7,700 ft. elevation in the Sierras, and up to 8,400 ft. in southern California (Verner et al. 1992). Just north of Lassen Peak to south of the Pit River, the range of the CSO transitions into that of the Northern spotted owl (NSO) (Barrowclough et al. 2011).

The American Ornithological Union currently recognizes three genetically distinct subspecies of spotted owl: California spotted owl (*Strix occidentalis occidentalis*), Northern spotted owl (*Strix occidentalis caurina*), and Mexican spotted owl (*Strix occidentalis lucida*) (Haig et al. 2004, Funk et al. 2008) (Figure 1). Relative to the other two subspecies, CSO exhibit low genetic variation (Barrowclough et al. 1999), although no negative effects of inbreeding have been found (Funk et al. 2008). Additionally, the Sierra populations are differentiated from the southern California populations due to a lack of gene flow (Barrowclough et al. 1999, Haig et al. 2004, Barrowclough et al. 2005). California spotted owls in southern California are assumed to function as a metapopulation, though little movement has been recorded between isolated mountain populations (LaHaye et al. 1994, Barrowclough et al. 2005, LaHaye and Gutiérrez 2005). Because the three subspecies of spotted owls share many habitat and behavioral characteristics, for the purposes of this COR "spotted owl" refers generally to all three subspecies.

In the Sierras, CSO are primarily found in mature, multi-layered mixed-conifer and yellow pine forest (80-90% of known sites), but also in red fir and riparian/hardwood forests (Verner et al. 1992). About half of known territories are within or adjacent to the wildland-urban interface specified in the U.S. Forest Service Sierra Nevada Framework (Blakesley et al. 2010). In southern California, habitat availability is more restricted and fragmented, so CSO are more frequently found in forests other than mixed-conifer, likely because mixed-conifer is only present at the highest elevations (Verner et al. 1992).

**Figure 1.** Approximate ranges for the three spotted owl subspecies (from NatureServe data).

## 2.2 Territoriality and reproduction

The spotted owl is a medium-sized brown owl with a mottled appearance, round face, large pale brown facial disks, dark brown eyes, and a yellowish green bill. Like most raptors, females are slightly larger than males (19-27 oz. vs. 17-24 oz., Verner et al. 1992). First and second year adults (subadults) can be distinguished by the tips of tail feathers, which are white and taper to a sharp point (Gutiérrez et al. 1995).

Spotted owls are long-lived species (can live over 15 years in the wild), with high adult survival and low reproduction; as a result, they are slow to recover from population declines (Keane 2014). They have a monogamous mating system, remaining with the same mate from year to year, although occasionally mates will separate, or "divorce." A pair occupies and defends a territory from neighbor and stranger individuals (Gutiérrez et al. 1995, Waldo 2002). In the central Sierra, breeding territories are approximately 1000 acres (Seamans and Gutiérrez 2007a, Tempel et al. 2014a) based on a radius equal to half the "mean-neighbor distance" between the centers of adjacent owl sites (1.1 km). As central place foragers, spotted owls spend a disproportionate amount of time near their territory center, or core (Carey et al. 1992, Carey and Peeler 1995). When available, radio-telemetry has been used to approximate territory size, resulting in some variation in size estimates (Bingham and Noon 1997). Home ranges include all habitat required for nesting, roosting, foraging, and other life functions. Home ranges will overlap each other and their size varies by latitude and study area (~1500-5400 acres), being smaller in the southern Sierras, where oaks are dominant (Verner et al. 1992). An individual typically begins exhibiting territorial behavior in 1-4 years. Those individuals that have not yet established a territory (mostly subadults) are referred to as floaters, and little is known about their habitat requirements (Franklin 1992). The presence of conspecifics and an open territory determines settlement as owls are more likely to settle in territories that were occupied the previous year (LaHaye et al. 2001).

Breeding season begins in mid-February and can last through mid-September, starting earlier in southern California and at lower elevations throughout its range, with the peak of egg-laying in mid-April (Verner et al. 1992). Pairs divide the nesting roles; the male CSO provisions the female while she sits on the nest (Gutiérrez et al. 1995). Females lay 1-3 eggs, but survival of the offspring is highest when two young fledge (Peery and Gutiérrez 2013). Eggs take approximately 30 days to hatch, and owlets fledge about 35 days later. Fledglings will "branch out," leaving the nest before they can fly and roosting near the nest and their parents. During this early developmental stage, juvenile owls rely on multi-layered forest structure to move about above the forest floor. Within several weeks, juveniles are able to fly and will generally disperse in the fall.

Spotted owls appear to follow a bet-hedging strategy of reproduction (Stearns 1976, Franklin et al. 2000). In good years with sufficient resources, they attempt a nest, but in poor years they do not. This often leads to an even-odd pattern of reproduction, where a majority of pairs will nest one year but not the next (Blakesley et al. 2010, Forsman et al. 2011). Importantly though, lack of reproduction at any given site for a few years does not necessarily mean the site itself is of poor habitat quality, but rather may reflect overall poor environmental or climatic conditions in those years (Stoelting et al. 2014). Annual mean reproductive output for the spotted owl is the lowest among North American owls (Johnsgard 1988), with 0.555-0.988 young/female CSO (Franklin et al. 2004, Blakesley et al. 2010).

Reproductive success is particularly dependent upon local weather conditions, especially during the previous winter or early in the nesting season (e.g. MacKenzie et al. 2012). Colder temperatures and greater precipitation early in the breeding season (March to May) was negatively correlated with reproductive success in Sierra National Forest and Sequoia-Kings Canyon National Park (North et al. 2000). Also, in Eldorado National Forest, El Niño events, which result in warm, wet winters, negatively influenced reproduction (Seamans and Gutiérrez 2007b). Northern spotted owls have also shown similar patterns in response to cold (Franklin et al. 2000). Cold temperatures during nesting may increase energetic requirements, risk of egg exposure, or interfere with foraging, resulting in decreased nesting success (Franklin et al. 2000, Rockweit et al. 2012).

California spotted owls have high site fidelity, returning to the same territory year after year. However, a small percentage of adults (7-9%) (Blakesley et al. 2006, Seamans and Gutiérrez 2007a) will disperse each year, often due to events such as the loss or change of configuration of their nest tree or a mate replacement (Berigan et al. 2012). Dispersing owls tend to be younger, and either join a mate or move to an adjacent territory of higher quality (Seamans and Gutiérrez 2007a, Gutiérrez et al. 2011). Although spotted owls are non-migratory, some will move downslope during winter (Laymon 1988, Verner et al. 1992, Gutiérrez et al. 1995). Downslope movement occurs in October to mid-December, can be from 9-40 miles, and a change in elevation of 1640-4921 feet (Gutiérrez et al. 1995). Little is known about habitat use during the non-breeding season, but movements are presumably to access more favorable weather conditions and/or greater prey abundance found at lower elevations and particular habitats (Bond et al. 2010, Ganey et al. 2014). Pairs return to their territory in late February to late March. Juveniles undergo natal dispersal in September, averaging 6-10 miles, though based on recaptures of banded birds dispersal distance can range between 2-47 miles (LaHaye et al. 2001, Blakesley et al. 2006).

In contrast to relatively low reproductive rates, spotted owls have apparent high adult survival in the Sierras (0.810-0.891), and male survival is slightly higher than female (Blakesley et al. 2010, Tempel et al. 2014b). Juvenile survival is more difficult to measure because of natal dispersal

and emigration. However, the few studies that have estimated juvenile survival found it to be substantially lower than adult survival (0.368 in San Bernardino National Forest, LaHaye et al. 2004; 0.333 in Lassen National Forest, Blakesley et al. 2001).

Temporal variation in survival is not as well-explained by weather covariates as reproduction is. However, survival does appear to have a quadratic relationship with the Southern Oscillation Index so that survival is greatest in years not dominated by either El Niño or La Niña weather patterns (mild, intermediate winters) (Seamans and Gutiérrez 2007b). Spotted owls can be preyed upon by great horned owls (*Bubo virginianus*), as well as northern goshawks (*Accipiter gentilis*) and red-tailed hawks (*Buteo jamaicensis*) (Gutiérrez et al. 1995). There has also been one instance of a likely predation by a barred owl (*Strix varia*) (Leskiw and Gutiérrez 1998). Variability in the population growth rate is driven by both reproductive rate and survival. However, because reproductive output varies more than survival, it can be more influential to population growth (Blakesley et al. 2001, Seamans and Gutiérrez 2007a). Juvenile survival provides the smallest contribution to changes in the population growth rate (Tempel et al. 2014b).

2.3 Habitat requirements

Spotted owls prefer residual old growth forest with high structural diversity (Laymon 1988, LaHaye et al. 1997, Moen and Gutiérrez 1997, Seamans and Gutiérrez 2007a). The nest tree itself is critical for CSO success, and is typically **the oldest, largest live or dead tree** with many defects like cracks or decaying wood (Verner et al. 1992, Blakesley et al. 2005). Spotted owls are frequently cavity nesters, using live trees and snags, broken top trees, platforms (mistletoe brooms), debris platforms, and even old raptor or squirrel nests. In the Sierras, the average mixed-conifer nest tree is >45 in. diameter at breast height (dbh) and >100 ft. tall (Verner et al. 1992, North et al. 2000). In hardwood forests, the typical nest tree is ~30 in. dbh and 55 ft. tall (Verner et al. 1992). California spotted owls prefer nest trees that are located further from forest edges with sharp contrast between habitat types (Phillips et al. 2010).

The habitat structure immediately above and near the nest site has been the focus of a considerable amount of research and is important to CSO occupancy, fecundity, and survival. In general, CSO nesting habitat consists of dense overhead canopy cover and closure, large trees, a high basal area (total cross-sectional area of all trees at 4.5 ft. above ground, 185-350 $ft^2$/ac), multiple canopy layers, and an abundance of limbs and large logs on the ground (Bias and Gutiérrez 1992, Verner et al. 1992, Moen and Gutiérrez 1997, North et al. 2000, Blakesley et al. 2005, Chatfield 2005, Seamans 2005, Roberts et al. 2011). Many studies fail to distinguish between canopy cover and closure, but for the purposes of this report, we have attempted to use terminology consistent with Jennings et al. (1999). Canopy cover refers to the proportion of the forest floor covered by tree crowns, whereas canopy closure is the proportion of the sky obscured

by vegetation viewed from a single point (Jennings et al. 1999). Canopy cover can be estimated from remotely sensed data, and is typically broken into three classes: high (≥70%), moderate (40-69%), and low (<40%) (Tempel et al. 2016). For tree size definitions, we refer to standard categories of very large (≥36 in. dbh), large (≥24 in.), medium (12-23.9 in.), and small (<12 in.) (Tempel et al. 2014a). Reproduction in particular has been associated with **high canopy cover** at multiple scales (Hunsaker et al. 2002, Tempel et al. 2014a). On Lassen National Forest, reproductive success was correlated with forests dominated by high canopy cover and medium or large trees, and negatively correlated with non-forest or forest dominated by small trees (Blakesley et al. 2005). On Eldorado National Forest, a larger area of hardwoods within a territory negatively influenced reproduction (Tempel et al. 2014a). At the immediate nest area (0.12 acre), productivity is also positively correlated with foliage volume above the nest site (North et al. 2000). Additionally, large trees have been shown to be particularly important for NSO within 400 m of the nest (Irwin et al. 2012). Besides nesting success, high canopy closure may also be important for post-fledging rearing, as juveniles tend to roost within 800 m of their nest (Whitmore 2009). The complex vertical structure is important for shading and avoidance of overheating in the hot summers (Barrows 1981, Weathers et al. 2001). Recent analyses used LiDAR imagery to identify canopy cover at different height strata and found that high canopy cover in tall trees (>48 m) was highly selected for by CSO, while cover in lower strata (2-16 m) was avoided compared to the availability on the landscape (North et al. in press).

Territories have greater habitat heterogeneity than nest stands, but occupancy, colonization, adult survival and reproductive success are still positively associated with the proportion of structurally complex conifer forest with large trees and moderate-high canopy cover (Blakesley et al. 2005, Seamans and Gutiérrez 2007a, Tempel et al. 2014a, Tempel et al. 2016). Recent evidence suggests that the most important predictor of occupancy is forests characterized by **both high canopy cover and large trees** (G.M. Jones and M.Z. Peery, pers. comm. 2017). Additionally, recent work using aerial imagery of Plumas National Forest found that areas of high canopy cover are more extensive today compared to 1941, suggesting that CSO habitat as characterized primarily by high canopy cover may have been less abundant on the landscape in the mid-1900s (S. Stephens, pers. comm. 2017). This finding may be further evidence that high canopy cover alone (i.e. without large, old trees) may not support sustainable CSO populations. **Spatial heterogeneity including small gaps** or openings within the territory is thought to be particularly important for the development of a sufficient prey base. Northern spotted owls have been found to maximize fitness within territories that are heterogeneous in forest stages, presumably due to increased prey availability (Franklin et al. 2000). Preliminary analyses conducted at the territory scale across the CSO Sierra study areas indicate that moderate canopy cover positively influences productivity, whereas moderate or high canopy cover positively influences survival (J.D. Wolfe and J.J. Keane, pers. comm. 2017). Tempel et al. (2016) did not find an effect of territory heterogeneity on CSO occupancy, although this study did not examine fitness. There does appear to be evidence that once a certain amount of high canopy cover is

reached, additional moderate canopy cover can similarly benefit occupancy (Tempel et al. 2016). Thus, areas of both high and moderate canopy cover can be important. However, a territory with overall <40% canopy cover is of lower quality (Tempel et al. 2016). California spotted owls will forage primarily in contiguous patches of moderate to high canopy cover, but will also use edge habitats (Williams et al. 2011, Eyes 2014). Riparian habitats can be particularly important for prey (Irwin et al. 2007, 2012, Bond et al. 2016). The presence of large **residual trees** (those that are significantly larger or older than the contemporaneous stand) also greatly increases the likelihood of CSO use for foraging activities (Bias and Gutiérrez 1992, Moen and Gutiérrez 1997, Williams et al. 2011). Furthermore, CSO will forage in and on the edge of areas that have been burned at a range of severities, including some high severity patches, so wildfire can provide valuable foraging habitat and heterogeneity within territories (Bond et al. 2009, Bond et al. 2016, Eyes et al. 2017).

Although less is known about minimum habitat requirements at the scale of a home range, CSO still consistently use areas that contain greater abundance of large trees and greater proportion of mature forest than the average forest composition on the landscape (Call et al. 1992, Moen and Gutiérrez 1997, Williams et al. 2011). As heterogeneity increases, so does the size of a CSO home range, so there may be a negative effect if too much heterogeneity exists within CSO habitat (Williams et al. 2011, Eyes 2014). In managed landscapes, studies on CSO habitat use may be influenced and limited by the habitat types that are available, so the findings may not reflect optimal CSO habitat (Roberts 2017).

In southern California, most CSO live in forests other than mixed-conifer because that forest type is restricted to the highest elevations in the isolated mountain ranges (Verner et al. 1992). These forests include riparian/hardwood forests and woodlands, live oak/big cone-fir forest, and redwood/California laurel forest. In San Bernardino National Forest, the most used cover types are canyon live oak/big cone fir (Smith et al. 2002). This habitat might be preferred due to high densities of prey in the chaparral that surrounds it (LaHaye et al. 1997). Even with less access to mature forest, owls select for more closed canopy and less non-forest at four different scales up to the size of a territory (Smith et al. 2002), and still select for large trees and higher basal area at nest sites (LaHaye et al. 1997).

### 2.4 Foraging and diet

Because spotted owls are central place foragers, they concentrate most of their foraging and activity around the nest or roost, and their activity declines further out from the nest (Carey et al. 1992, Ward et al. 1998). Spotted owls rarely fly above the forest canopy, except for dispersal (Gutiérrez et al. 1995). As perch and pounce predators, spotted owls are agile but not particularly fast fliers. Spotted owls are primarily active at night, but will also hunt during the day, especially

when they have young to feed (Verner et al. 1992). Later in the nesting season, owls may also forage further from the nest to feed growing fledglings.

Although CSO will eat a variety of prey, they are considered to be small mammal specialists because they select a few key species for the majority of their diet. At upper elevations (above 4,000 feet) in the Sierra Nevada conifer forests, northern flying squirrels (*Glaucomys sabrinus*) are the primary prey (Laymon 1988, Munton et al. 2002). At lower elevations in the Sierras, as well as in southern California, where oak woodlands and riparian-deciduous forests are dominant, CSO prey more on woodrats (*Neotoma* spp.) (Verner et al. 1992, Smith et al. 1999, Munton et al. 2002). Flying squirrels dominate CSO diet at about 75% of known owl sites (Verner et al. 1992). California spotted owls have low metabolic rates relative to other birds and would require one flying squirrel every 1.8 days or one woodrat every 3.7 days (Weathers et al. 2001). Individuals tend to have smaller home ranges where woodrats are the prey base compared to flying squirrels, presumably because woodrats provide a higher caloric gain per successful spotted owl foraging bout and occur in higher densities (Zabel et al. 1995). By biomass, pocket gophers (*Thomomys* sp.) are the second largest component of a CSO diet, replacing woodrats at higher elevations and flying squirrels at lower elevations (Munton et al. 2002). Pocket gophers were also the most important prey item for CSO four years after a fire in the southern Sierras (Bond et al. 2013). Although CSO will prey upon some birds, reptiles, amphibians, and insects, mammals make up the most biomass (Munton et al. 2002).

Flying squirrels are found more in closed-canopy forests (Pyare and Longland 2002, Meyer et al. 2005, Roberts et al. 2015). A moderate to high canopy closure, large trees, thick litter layer and sparsely distributed large coarse woody debris are particularly important for developing a good prey base in these habitats (Waters and Zabel 1995, Pyare and Longland 2002, Meyer et al. 2005, 2007, Kelt et al. 2014, Roberts et al. 2015). **Coarse woody debris** is critical, but does not need to be overly dense (Knapp et al. 2005). Riparian habitat and other relatively mesic sites in particular yields truffle and arboreal lichen (e.g. *Bryoria fremontii*), which are important to flying squirrel diet (Smith 2007, Meyer et al. 2008).

Woodrats are found more often in open habitats, oak woodlands, and early seral-stage forests (Innes et al. 2007). Specifically, at lower elevations, woodrats (both dusky-footed and big-eared) and brush mouse are associated with oak (especially, California black oak) cover and the density of large oaks >13 in. dbh (Innes et al. 2007, Roberts et al. 2008, Kelt et al. 2014). Heterogeneous forest conditions often provide higher primary productivity than homogenous closed canopy forests and thus, may enhance habitat for small mammals (Jones et al. 2016b, Sollmann et al. 2016). Transitional areas (habitat with conifer stands and a significant hardwood component) where prey distributions overlap offer a rich and diverse prey base (Verner et al. 1992). Small mammal diversity may be enhanced by increased structural heterogeneity at large spatial scales

and development of mature forest structure, particularly as created by natural and managed fire (Kelt et al. 2014, Roberts et al. 2015).

## 3. CURRENT CONDITION

The California Department of Fish and Wildlife (CDFW) maintains a record of CSO locations and activity centers (areas of repeated detection, nesting/roosting areas) in the California Natural Diversity Database (CNDDB). Although many sightings have not been reconfirmed outside of ongoing study areas, since 1993, 1,416 unique CSO activity centers have been recorded, the majority of which are in the Sierras (Figure 2). Rather than estimating overall population size, then, most of our knowledge of the status of CSO is derived from population trends in four long-term demography studies in the Sierras, and one in southern California. In the Sierras, data collection began in 1986 on the Eldorado National Forest and in 1990 on the Lassen National Forest, Sierra National Forest, and Sequoia-Kings Canyon National Park. In southern California, the San Bernardino National Forest was studied from 1987-2010, with some gaps in sampling. Multiple meta-analyses have utilized different techniques to analyze the population trends of CSO in these study areas. The nuances of these techniques are beyond the scope of this discussion (see Tempel et al. 2017 for a full comparison), but the overall trends are consistent and we focus on the most recent analyses here.

On Forest Service lands, since the early 1990s, CSO nesting sites have been managed as Protected Activity Centers (PACs), which include ~300 acres of the "best available" contiguous habitat. This scale has proven to be a useful management tool and biologically relevant because habitat characteristics at this scale are related to demographic parameters (occupancy, reproduction, and survival) (Blakesley et al. 2005), and CSO have repeatedly used these areas over the long-term (Berigan et al. 2012). Most data analysis relies on trends in the occupancy of territories or trends in the abundance of a study area.

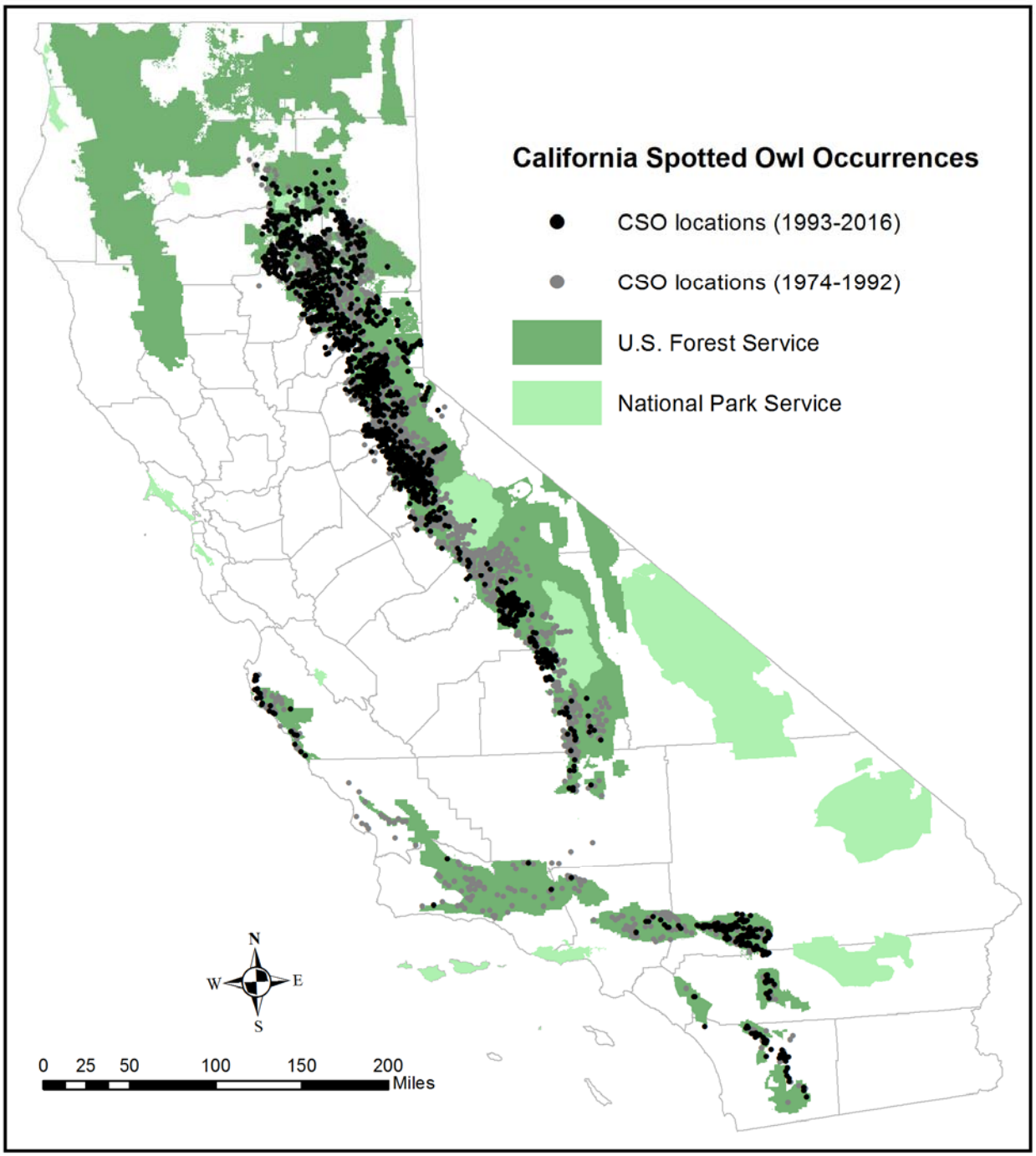


**Figure 2.** Map of California spotted owl activity centers from CNDDB, before and after 1993. Shown with federal lands.

Evidence is clear that CSO have declined in both occupancy and abundance in the study areas on the three national forests in the Sierras (Lassen, Eldorado, and Sierra), as well as in southern California. In the Sierras, CSO have experienced a decline in abundance of 31% on Sierra National Forest, 44% on Lassen National Forest, and 50% on Eldorado National Forest (Tempel

et al. 2014b, Conner et al. 2016). San Bernardino National Forest has seen a similar decline of 50% from 1989-2010 (Eliason and Loe 2011) in territory occupancy, and a 9% per year decline in abundance from 1987-1998 (LaHaye et al. 2004). The only stable or increasing CSO population on public lands appears to be in Sequoia-Kings Canyon National Park, the only national park with a long-term CSO demography study (Conner et al. 2013, 2016, Table 1).

**Table 1.** California spotted owl population trends from 5 long-term demography studies.

| Study Area | Pop. change | *95% CI* | Time Period | Area ($km^2$) | Citation |
|---|---|---|---|---|---|
| Eldorado | -50% | *-62%, -46%* | 1990-2012 | 355 | Tempel et al. 2014b |
| Lassen | -44% | *-61%, -21%* | 1993-2013 | 1,254 | Conner et al. 2016 |
| Sierra | -31% | *-50%, -4%* | 1993-2013 | 562 | Conner et al. 2016 |
| Sequoia-Kings Canyon | +25% | *-15%, +85%* | 1993-2012 | 182 | Conner et al. 2016 |
| San Bernardino | -65% | *not estimated* | 1987-1998 | 2,140 | LaHaye et al. 2004 |

Although there is no information regarding either historical population sizes or estimates for minimum viable population sizes, CSO populations have declined in the national forest study areas since the early 1990s, but not in the national park study area. The causes of the CSO population declines have not been conclusively identified, but researchers suggest they may be due to differences in habitat between the national forests and national parks resulting from differences in forest management and fire activity. Sequoia-Kings Canyon National Park historically experienced minimal logging and has a more restored natural fire regime than the national forests, and also contains giant sequoia groves and an abundance of oaks (Seamans and Gutiérrez 2007a, van Wagtendonk 2007, Blakesley et al. 2010, Tempel et al. 2014a). Furthermore, recent work comparing the CSO populations suggests that rather than current management practices on national forests, the declines may partly be the result of a lag effect from the past removal of large trees prior to the early 1990s, that has contributed to current habitat differences (G.M. Jones and M.Z. Peery, pers. comm. 2017). Although the populations are declining, reproduction seems to be relatively constant in all study areas in the Sierras except Eldorado, where measured parameters continue to be highly variable between years (Blakesley et al. 2010). Additionally, on national forests, the proportion of territories occupied by single CSO rather than pairs appears to be increasing (Tempel and Gutiérrez 2013). Thus, in analyzing population trends, territory occupancy may not detect population changes as well as mark-recapture models that track individual birds (e.g. Pradel model, Conner et al. 2016).

Information regarding CSO populations on private lands comes from five study areas on mixed ownership lands scattered through the northern half of the Sierras. From 2012-2016, systematic surveys found a high proportion of occupied territories each year that remained occupied during the study period (Roberts et al. 2017). Additionally, CSO crude densities (the number of CSO sites per unit area) reported on the private timberlands were similar or higher than those on

public lands (Roberts et al. 2017, Table 2). Crude densities may not be a reliable indicator of habitat quality because an area could be a population sink supported by continued immigration from more productive source habitats (Pulliam 1988). Additionally, given the short duration of this survey effort and because CSO are long-lived and exhibit high site fidelity, returning to the same territories year after year, it is difficult to ascertain population trends from this survey data at this time. However, of 45 CSO territories documented prior to 1996, all 45 were occupied at least once during the study period (2012-2016). These preliminary results warrant further monitoring and analysis with demographic data on individually marked owls if we are to determine if there is a difference in current CSO status between public and private lands.

**Table 2.** California spotted owl crude densities in study areas (most recent estimates). Primary land ownership is defined by >60% of study area, otherwise labeled as mixed ownership.

| Study Area | Crude density | Study area size ($km^2$) | Primary land ownership | Citation |
|---|---|---|---|---|
| Fall River | 0.056 | 89 | Private | Roberts et al. 2017 |
| Lassen | 0.051 | 355 | National Forest | Gutiérrez et al. 2017 |
| Chalk Bluff | 0.152 | 86 | Mixed | Roberts et al. 2017 |
| Eldorado | 0.16 | 1,254 | National Forest | Gutiérrez et al. 2017 |
| Stumpy Meadows | 0.035 | 115 | Private | Roberts et al. 2017 |
| South Fork Cosumnes River | 0.141 | 137 | Private | Roberts et al. 2017 |
| South Fork Mokelumne River | 0.071 | 122 | Mixed | Roberts et al. 2017 |
| Sierra | 0.151 | 562 | National Forest | Gutiérrez et al. 2017 |
| Sequoia-Kings Canyon | 0.184 | 182 | National Park | Gutiérrez et al. 2017 |
| San Bernardino | *No recent estimate* | 2,140 | National Forest | Gutiérrez et al. 2017 |

Most forest types have been defined by California Wildlife Habitat Relations (CWHR) categories with existing vegetation classification and mapping (EVEG). In the Sierras, 4M or greater CWHR translates to ≥40% canopy cover and trees ≥12 in. dbh, which include potential habitats used by CSO. Currently, there are approximately 4.9 million acres of 4M or greater CWHR in the Sierras, just over half of which is Sierra mixed conifer forest (North et al. 2017). Of this habitat, 75% is on national forestlands, 7% on national parklands, and 18% on private or other lands. In the southern California national forests, there are only about 400,000 acres of 4M or greater CWHR, about 16% of which is Sierra mixed conifer; however there are about 1.2

million acres of general habitat types in which CSO have been known to reproduce (Stephenson and Calcarone 1999). The realized amount of suitable habitat is likely far less though, in particular after major losses from wildfire and drought over the last decade and a half.

## 4. SUMMARY OF STRESSORS

*Large, high-severity fires*

Historically, the natural fire regime in the Sierra Nevada and southern California forests included frequent fires at primarily mixed-severity (mostly low-moderate, with patches of high-severity) (Van de Water and Safford 2011, Mallek et al. 2013). Past forest management, namely fire suppression and loss of large trees, however, has led to dense forests with high fuel load conditions and shade-tolerant trees, resulting in an increased proportion and patch size of high-severity fires (Miller et al. 2009, Mallek et al. 2013, McIntyre et al. 2015, Steel et al. 2015). In defining fire severity, in general, low-severity fire consumes surface fuels but not canopy trees (<25% upper canopy layer is lost or <25% basal area mortality); moderate-severity fire kills small trees (up to 75% canopy layer or basal area mortality); and high-severity fire consumes all surface fuels and kills nearly all mature plants (>75% canopy or basal area mortality) (Key and Benson 2005, Barrett et al. 2010). Prior to Euro-American settlement, frequent low-moderate severity fires occurred every 5-15 years (Van de Water and Safford 2011, Mallek et al. 2013). In areas with high fuel loads or during hot, dry weather patterns, some high-severity patches likely burned too, but were generally limited in size. In mixed-conifer forest in the Sierras, any given fire would not have included more than 5-10% high-severity fire (Miller and Safford 2017). The patches of high-severity fire averaged only 10 acres in size, with a maximum historic patch size of 250 acres (Collins and Stephens 2010, Miller and Safford 2012, Safford and Stevens in press).

Consequently, forests were likely made up of an abundance of large, fire resistant trees at a lower density (Taylor 2004, Scholl and Taylor 2010, Collins et al. 2011a). Basal area for historical conditions in the Sierras ranged from 91-235 $ft^2$/acre, depending on site productivity, with a mean of 150 $ft^2$/acre (Safford and Stevens in press). Additionally, snags in today's forest are significantly smaller and at a higher density (Agee 2002), resulting in an overall denser and more homogenous forest that is more susceptible to large, high-severity fire (Hessburg et al. 2005). Recent work has demonstrated that in spite of differences in logging, such changes have occurred on both national parks and national forests, although large trees are less common on national forestlands (S. Stephens, pers. comm. 2017).

In southern California shrub-dominated landscapes, patches of high-severity fire have always been more common than in the Sierras (Steel et al. 2015). However, the area impacted by fires in southern California has also been increasing recently, in part due to continued human population growth and the conversion of cover types to grasses (Syphard et al. 2017). Although temperature

is clearly a factor related to the area burned in higher elevation forests, prior-year precipitation is more strongly related to fire activity in the Sierra foothills and southern California (Keeley and Syphard 2017).

Although the majority of literature supports this historical fire regime and forest structure for the Sierras, a few studies have challenged the predominant view. These studies suggest that historical forests were denser and experienced greater proportions of large, high-severity fires than currently (e.g. Baker 2012, Williams and Baker 2012, Hanson and Odion 2013, Baker 2014, Odion et al. 2014, Hanson and Odion 2016). Recent literature describes some issues that could undermine the validity of this argument (e.g. Fulé et al. 2014, Stevens et al. 2016, Miller and Safford 2017, North et al. 2017, Safford and Stevens in press), but these contrary findings are under continued discussion in the scientific community. Debating the nuances of this argument is beyond the scope of this report. However, regardless of the historical fire regime, we can discuss CSO habitat and behavior in the context of current and future fire severities and extents.

Given that spotted owls evolved in forests that frequently experienced fire, it is not surprising that both CSO and NSO will readily use habitat that has been subject to low-moderate and mixed severity fire (Bond et al. 2002, Clark 2007, Lee et al. 2012, Eyes 2014). However, large patches of high-severity fire significantly reduce colonization, occupancy, and use (Roberts et al. 2011, Eyes 2014, Tempel et al. 2014a). The year after the King Fire (2014 in El Dorado county), the probability of CSO site extirpation was seven times higher in severely burned sites (when greater than half the territory burned at high-severity) than others (Jones et al. 2016a). Another study conducted the year after the Rim Fire (2013 in Tuolumne and Mariposa counties), however, did not find an effect of high-severity fire on CSO occupancy (Lee and Bond 2015a). These seemingly conflicting results may be due to differences in the configuration of the remaining habitat, as the Rim Fire resulted in a more spatially heterogeneous distribution of high-severity burns (Jones et al. 2016a). There is likely some threshold of high-severity fire owls can tolerate within their territory, although the exact size and configuration is unknown. In southern California, when patches of high-severity exceeded 123.5 acres (of a 500 acre territory), territory extinction probability increased (Lee et al. 2013). Additionally, lower quality sites (as defined by non-reproductive the previous year) showed a greater negative effect of fire on occupancy than higher quality sites (Lee and Bond 2015b). High-severity fire has also been shown to negatively affect survival of NSO (Rockweit et al. 2017). Northern spotted owls showed an increased turnover of territory occupancy in response to high-severity fire, suggesting that continued occupancy of the territories may be temporary and overall quality of the territory is reduced (Rockweit et al. 2017).

While CSO will forage in habitat subject to a variety of burn severities, they still tend to use primarily low and moderate severity patches, avoiding the interior of large, high-severity areas (Jones et al. 2016a, Eyes et al. 2017). The size and configuration of the patch of high-severity

fire appears to be critical. Some work suggests that CSO will use high severity patches in proportion to availability 3-4 years after the fire (Bond et al. 2009, 2016), although the sizes of the foraging patches in these studies were not reported. In Yosemite National Park, the mean size of a high severity patch used for foraging was 16 acres (Eyes 2014). Additionally, CSO were found to selectively forage in fire-created edge habitats, rather than contiguous edges (Eyes et al. 2017). Many prey species important to CSO are negatively correlated with fire severity including flying squirrels and deer mice (Roberts et al. 2008, 2015). Landscapes with restored fire regimes (such as Yosemite National Park) show greater small mammal species evenness, which could promote stability and resilience in CSO prey populations (Roberts et al. 2015). So while it appears that often California spotted owls will avoid large, high-severity patches, smaller patches and mixed severity can be beneficial because they support the prey base.

Habitat loss to large, high-severity fire is a substantial threat to CSO persistence. Within the next 75 years, based on fire activity trends, the amount of nesting habitat burned at moderate or high-severity fire will likely exceed the total existing habitat in the Sierras, and therefore there is a critical need to avoid losses of older forests (Stephens et al. 2016b). Closed canopy forests (such as those in PACs) do tend to have uncharacteristically large and severe fires (Agee and Skinner 2005). However, from 1993-2013, 88,000 acres of CSO PACs burned, 28% of which were at high-severity, which was a similar proportion to the overall landscape (Keane 2017). So while PACs themselves are not necessarily more vulnerable to high-severity fire than the surrounding landscape is, the proportion of PACs burned at high-severity is greater than would be expected under a natural fire regime (<5-15% Mallek et al. 2013). California spotted owls are similarly losing habitat in southern California, which has experienced increasing widespread wildfires, particularly in the early 2000s (Keeley et al. 2009). Repeated high-severity fires in the same area can convert the type of habitat, resulting in long-term habitat loss for CSO (Stephens et al. 2013). Addressing the potential effects of large, high-severity fires on owl habitat will require collaborative landscape-level efforts.

*Forest management practices*

The effects of specific forest management practices on spotted owls are not well understood. Some practices may act as stressors on spotted owls, while others may improve habitat. Commercial timber harvest no longer occurs within the CSO range in southern California on public lands (Eliason and Loe 2011), though it continues to occur on private lands, and is conducted in the Sierras on both public and private lands. Verner et al. (1992) identified habitat loss due to timber harvest as a primary threat to CSO. As a result, management on national forestlands diverged from private lands, and 83.4% of timber volume harvested in the Sierras from 1994-2013 came from private lands (North et al. 2017). Additionally, in order to reduce the likelihood of high severity fires, fuels reduction activities on public lands have been slowly implemented. Forest fuels are typically split into four categories: ground (material that has begun

to degrade), surface (downed wood, herbaceous vegetation and shrubs), ladder/bridge (small trees and larger shrubs), and aerial/crown fuels (within the crowns of standing trees, separated from surface fuels) (Jenkins et al. 2014). Management for fuels reduction in the forest includes reducing surface fuels, increasing the height to the live crown (reducing ladder fuels and removing small trees), decreasing crown densities, and retaining/recruiting large fire-resistant tree species (Agee and Skinner 2005). Data on the effects of various fuel treatments on owls has been mixed, due to minimal experimentally designed studies, confounding factors, and a lack of consistency in defining types of treatments. For the purposes of discussion we broadly classified the methods of fuels reduction into prescribed fire, hand thinning, and mechanical treatments. For the most part, prescribed fire that has the potential to lead to low or moderate severity fires, or mixed severity with small patches of high-severity fires can be good for owl habitat. Additionally, hand thinning of smaller trees does little to disturb CSO. These small scale treatments typically leave high canopy cover and large trees, which are important to spotted owl nesting. Chainsaws and helicopter noises do not appear to decrease reproductive success (Delaney et al. 1999) nor increase stress hormones like corticosterone (Tempel and Gutiérrez 2003, 2004). However, NSO nesting near loud roads have lower reproductive success than those near quiet roads (Hayward et al. 2011), and males show higher levels of corticosterone (Wasser et al. 1997), suggesting there may be some non-lethal effects from noise-causing human disturbances.

For the purposes of this discussion, we have categorized forest management practices into three groups: mechanical thinning, salvage logging, and clearcutting. These categories are not mutually exclusive, nor are an exhaustive list, but rather one way to consider potential stressors for CSO.

*Forest management: mechanical thinning*

Owl response to mechanical treatments appears to rely on scale and intensity of the treatments. Mechanical treatments (or thinning) refer to machine-based fuels reduction for purposes of reducing large fires and tree harvest (North et al. 2015a). Generally, territories with greater amounts of mature conifer forest have a higher probability of colonization by CSO (Seamans and Gutiérrez 2007a), so actions that alter mature forest to a large degree could result in a less desirable territory. Specifically, converting mature conifer forest from high to moderate canopy cover was negatively correlated with CSO demographic parameters in one meta-analysis (Tempel et al. 2014a). However, while the canopy conversions in this study could have been from mechanical treatments for fuels reduction, they also could have been caused by other activities. Additionally, in an earlier study, CSO territories with >50 acres of altered mature forest showed a 2.5% decline in occupancy and an increase in dispersal (Seamans and Gutiérrez 2007a). In this study, fire and treatment disturbances were combined, so we cannot isolate out the impacts from

mechanical treatments. A study on NSO and CSO found minimal effects two years after territories were partially harvested (Irwin et al. 2015). Modeling projected over a 30 year time frame suggested that while treatments can reduce the risk of high-severity fire to CSO, in the absence of fire, such treatments could have a negative effect on fitness (Tempel et al. 2015). At the landscape-scale, a study that examined the effects of mechanically-produced wide shaded fuel breaks (Defensible Fuel Profile Zones) on CSO found that the fuel breaks were avoided for 1-2 years after treatments (Stephens et al. 2014). Additionally, occupied territories declined by >40% within four years after treatment, and the remaining individuals used larger areas. Mechanical thinning that results in widely and regularly spaced trees tend to be avoided by CSO (Gallagher 2010). However, the most recent meta-analysis of the long-term demography studies in the Sierras did not find negative impacts to occupancy from mechanical thinning (Tempel et al. 2016), and in fact some populations exhibited small positive effects, confirming the variability in responses to mechanical treatments.

*Forest management: salvage logging*

Salvage logging refers to the removal of dead or damaged trees to recover economic value that would otherwise be lost (Society of American Foresters' Dictionary). It typically occurs after a fire, or large tree mortality event, and can be a controversial activity (Long et al. 2014). Salvage logging has few short-term ecological benefits (Wagenbrenner et al. 2015), though longer term trade-offs are less clear (Peterson and Dodson 2016). Because CSO can persist in low-moderate severity fires, salvage logging of remaining suitable habitat may negatively affect occupancy (Peery et al. 2017). In high-severity fires, salvage logged CSO sites had a slightly lower probability of being occupied than sites that only burned and did not undergo salvage logging treatment (Lee et al. 2013, Lee and Bond 2015b). Recent work on NSO found that high severity-fire interacts with salvage logging to jointly contribute to declines in site occupancy (Clark et al. 2013). Salvage logging may reduce the quality of foraging habitat through the removal of legacy snags in particular, although it is difficult to disentangle the effects of salvage logging from high-severity fire.

*Forest management: clearcutting*

Timber harvest can cover all types of tree removal, which would include some fuels reduction activities as well as salvage logging. In addition to outright habitat loss, timber harvest can eliminate important CSO habitat elements such as old, large trees and large downed logs (McKelvey and Weatherspoon 1992). Clearcutting is one form of timber harvest that can take various shapes and sizes, though in general tends to leave large, regularly shaped patches with clean edges (Tempel et al. 2014a). The overstory trees that

remain in commercial thinning prior to a clearcut tend to be regularly spaced with little forest floor and understory diversity, and low heterogeneity in stand structure (Knapp et al. 2012). No research has explicitly examined CSO response to an even-aged management strategy that utilizes clearcuts (Keane 2017). However, loss and adverse modification of suitable habitat resulting from timber harvest was identified as one of the main threats to NSO in the Service's 1990 listing decision. California spotted owls have been observed avoiding private lands (Thrailkill and Bias et al. 1989), and tend to forage on private lands proportionately less than the amount of private lands available on the landscape in mixed ownership landscapes (Williams et al. 2014). These observations were not linked to management practices in these studies. However, CSO do nest on private timberlands in the Sierras. Additionally, crude density estimates of CSO territories are similar across public and private lands (Roberts et al. 2017), although, as discussed above, there is limited information regarding population trends on private lands. While some gaps in canopy cover can be beneficial for the prey base, current clearcutting practices probably do not create the collection of patches observed in spotted owl territories with high-fitness (Franklin et al. 2000).

*Tree mortality*

Tree mortality has substantially increased throughout the Sierras, particularly in the southern Sierra region (van Mantgem et al. 2009, Asner et al. 2015). In 2015 in the southern Sierra, about 345 trees/km$^2$ died (Young et al. 2017), and very large trees in general are disproportionately affected by this tree mortality (Smith et al. 2005). Drought combined with dense forest conditions have led to severe water stress (Asner et al. 2015, Young et al. 2017). This stress interacts with pathogens, insects and air pollution to contribute to tree mortality events (Lutz et al. 2009, McIntyre et al. 2015). Bark beetles in particular are exacerbated by climatic conditions (Bentz et al. 2010), and measures of stand density are correlated with levels of mortality attributed to bark beetles, suggesting the density of trees (and indirectly competition) is a contributing factor (Hayes et al. 2009). The full extent of the mortality and effects on CSO is unknown, but the extensive large-tree mortality is likely to contribute to habitat loss.

*Barred owls*

Barred owls were historically confined to eastern North America, but have expanded west over the past century (Livezey 2009). Whether barred owl expansion is human-caused is uncertain, but it is thought to be a combination of settlement of the central plains combined with climate change. Currently barred owls threaten NSO in parts of its range. They use a broader suite of vegetation, though still show a preference for old growth, large trees, and high canopy cover like spotted owls (Wiens et al. 2014). Because barred and spotted owls use similar habitat, natural segregation and coexistence is unlikely (Yackulic et al. 2012, 2014). Barred owls are

competitively superior and have a smaller home range (2-4 times smaller), probably due to a broader diet (Wiens et al. 2014). Barred owls can thus live at substantially higher densities than spotted owls.

Where barred owls occur in the NSO range, they decrease NSO occupancy by increasing territory extinction and lowering colonization (Olson et al. 2005, Dugger et al. 2011, Yackulic et al. 2014). Northern spotted owls show a lower overall probability of habitat use (Van Lanen et al. 2011) and lower nesting success; barred owls produced 4.4 times more young over a three year study period (Wiens et al. 2014). Furthermore, because barred owls can live at higher densities and consume a wider variety of prey species than spotted owls, their expansion has the potential to alter the prey on the landscape and affect a variety of other native species (Holm et al. 2016). In the range of NSO, there are ongoing removal experiments that suggest NSO may reoccupy a site within one year after barred owls are removed; however 1-4 years after the initial removal, barred owls again occupied some sites (Diller et al. 2012). These removal experiments are being conducted in areas of relatively high barred owl densities. In the range of CSO, however, barred owl detections have been low, suggesting the edge of barred owl expansion is just at the northern extent of CSO range.

A barred owl was first detected in the northern Sierras in 1989 and in the central and southern Sierras in 2004 (Steger et al. 2006). As of 2013, there were 51 barred owls detected in the Sierras (Keane 2017). Currently there are over 140 barred owl detections recorded in CNDDB, although these records do not necessarily reflect unique individuals. However, no systematic surveys have been conducted and all detections are incidental, therefore, they may be at a low density throughout the region (Dark et al. 1998, Keane 2014). There have also been a number of sparred owl detections, hybrids between the two species. As their range continues to expand, barred owls will likely become a significant threat to CSO (Gutiérrez et al. 2007). If control measures were to be implemented, they are more likely to be successful now, while the densities of barred owls are still low in CSO range (Dugger et al. 2016).

*Contaminants*

Although they have not yet been found in CSO, environmental contaminants may be an emerging threat. Rodenticides associated with illegal marijuana cultivations have been found in barred owls in northern California (Keane 2017). In the southern Sierra, large amounts of rodenticides and other pesticides have been found in national forests (Thompson et al. 2013), and fishers (*Pekania pennanti*) are experiencing high rates of exposure (Gabriel et al. 2012). Given that CSO share similar habitats and prey with fisher and barred owl, CSO are likely to be affected by rodenticides as well (Keane 2017).

*Climate change*

Current predictions suggest there will be a 3-6 °C increase in temperature in the Sierras within the 21st century, and although changes in precipitation patterns are less certain, winter snowpack will likely decrease with a corresponding increase in ecosystem moisture stress during the dry, hot summer months (Cayan et al. 2013, Pierce et al. 2013). The direct effects of such climate changes on spotted owls will be complex as they exhibit population-specific demographic responses to local weather and regional climates (Franklin et al. 2000, Glenn et al. 2010, 2011, Peery et al. 2012). Additionally, spotted owls tend to only attempt nests in years with sufficient resources, following a bet-hedging strategy (Franklin et al. 2000). Drought and high temperatures in the previous summer can result in lower survival and recruitment (Franklin et al. 2000, Seamans et al. 2002, Glenn et al. 2011, Jones et al 2016b). Warm, dry springs, on the other hand increase reproductive success (Glenn et al. 2010, 2011, Peery et al. 2012, Jones et al. 2016b). Potential projected decreases in precipitation will likely reduce the plant production important for spotted owl prey (Seamans et al. 2002, Olson et al. 2004, Glenn et al. 2010, 2011).

While large scale forest changes are projected under warmer and drier future climate scenarios, fine scale uncertainty suggests there may be refugia for cooler, moister forest types (North et al. 2017). Additionally, mixed-conifer forests, like many communities, are projected to advance upslope, which could develop habitat for CSO where none now exists (Peery et al. 2012). While these changes in habitat may mitigate some effects of climate change, the creation of new habitat will likely not keep pace with the loss (Stephens et al. 2016b). Climate change is likely to exacerbate the risk of large, high-severity fires and drought-induced tree mortality (Miller and Safford 2012, Mallek et al. 2013), which both have negative impacts on CSO habitat. The effects of climate change on fire activity, however, will likely vary across landscapes. Lower elevations and latitudes (e.g. southern California), where fire is more limited by ignition than climate, will be less likely to experience an increase in fire activity with hotter and drier conditions (Keeley and Syphard 2016).

## 5. CONSERVATION FRAMEWORK

Our conservation framework consisted of 1) identifying CSO population and habitat status and stressors, 2) defining broad conservation goals, and 3) developing conservation objectives and measures for ameliorating stressors and addressing CSO needs. We used three parameters: population and habitat representation, redundancy, and resilience (Shaffer and Stein 2010, Redford et al. 2011), as broad guiding concepts in developing our conservation objectives. Redundancy is multiple, geographically dispersed populations and habitats across the species' range that helps species withstand catastrophic events; representation is the retention of various types of diversity (genetic, ecological, etc.) of the species so that the adaptive capacity of the species is conserved; and resilience is the ability to recover from stochastic environmental

variation and disturbances. In this COR, we relied on the best available science, including the latest Conservation Assessment (Gutiérrez et al. 2017), recent emerging scientific research, information received related to our March 17, 2017, letter soliciting new information from interested parties, and expert elicitation.

## 5.1 Conceptual model

In general, species are likely to be more resilient if large populations exist in large blocks of high quality habitat across the breadth of environmental variability to which the species is adapted (Redford et al. 2011). Most of the studies on CSO have yielded information regarding habitat requirements at the territory and population level. Thus, recognizing that many CSO habitat requirements vary based on scale, we have developed a conceptual model to examine how factors interact to influence the resiliency of CSO populations (Figure 3). Some of the objectives then take these concepts further to address redundancy and representation across the species, including the need for additional landscape-level analyses. The model for CSO population resilience includes population parameters that are typically measured for CSO, important broad habitat requirements, as well as the potential stressors discussed above. Red arrows indicate one factor decreases another, blue arrows indicate the factor increases another, and purple indicates it may increase or decrease depending on other parameters. Thicker lines suggest a stronger relationship, and dashed lines indicate some uncertainty of the relative strength. This model is not quantitative, but rather an illustrative tool examining the interactions between important potential influences on CSO populations.

Population parameters include CSO territory occupancy, as well as fecundity and survival. Habitat requirements are broadly categorized into areas with both high canopy cover and large trees, very large trees, residual trees/snags, coarse woody debris, and small forest gaps/spatial heterogeneity. Some characteristics, such as high canopy cover and large trees affect all population parameters. Other habitat components like coarse woody debris and forest heterogeneity are primarily habitat characteristics necessary to maintain a sufficient prey base, and thus are more likely to affect fecundity than other parameters. Most potential stressors can affect multiple habitat components or population parameters as well as interact with each other. The most substantial stressor to habitat is large, high-severity fire, which may be modulated somewhat by various forest management practices. However, depending on scale and implementation, these same practices could also decrease certain habitat components. Tree mortality is also likely to become an important stressor to habitat. Additionally, barred owls are likely to emerge as a significant stressor to CSO resiliency by decreasing CSO occupancy. Finally, although we know little about contaminants as a stressor to CSO, we suspect the negative effects of contaminants have been going undetected thus far, and could become a more significant stressor to CSO. Managing for the interaction of these stressors will require a comprehensive region-wide conservation strategy and forest-specific plans.

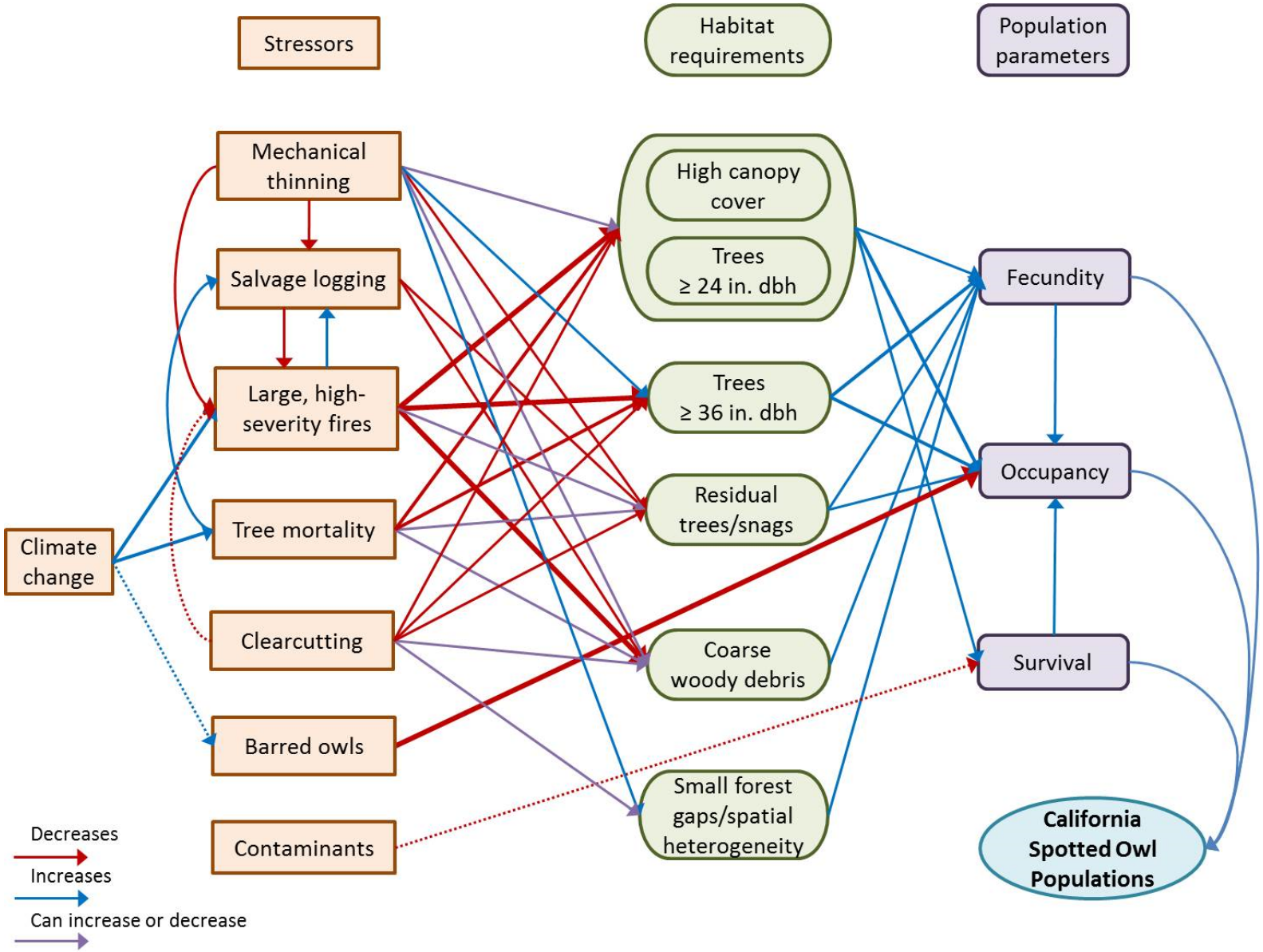


**Figure 3.** Conceptual model illustrating relationships among primary habitat needs, stressors, and California spotted owl populations.

5.2 Conservation Goal

Our goal is the long-term conservation of CSO and its habitat throughout its range by maintaining viable, connected, and well-distributed populations and habitats through amelioration of stressors and conservation of key habitat components.

## 6. CONSERVATION OBJECTIVES

6.1 General conservation objectives

***Reduce the population declines of California spotted owl***
There is now substantial evidence that populations on national forests have declined significantly over the past two decades. Recent evidence suggests that these declines may be a result of previously altered habitat, notably the loss of large trees (G.M. Jones and M.Z. Peery, pers. comm. 2017). To that end, we need to continue to investigate the causes of the declines, and in the meantime preserve habitat elements we know are critical for CSO conservation. Stopping a population decline is an important part of any conservation strategy (Caughley 1994). Because PACs have been demonstrated as useful for CSO management in national forests (Berigan et al. 2012), focusing on maintaining a network of similar protected areas for important habitat elements throughout the range of CSO should be emphasized.

***Manage habitat for spotted owl use and the long-term establishment of natural fire regimes***
Among CSO and forest ecology experts there is an ongoing discussion about the need to balance the protection of CSO habitat elements with the reduction of the likelihood of large scale fires (Peery et al. 2017). The only known stable CSO population on public lands appears to be in Sequoia Kings Canyon National Park, which has not only more large trees but more of a restored fire regime (Blakesley et al. 2010, Tempel et al. 2014a). California spotted owls generally use high canopy cover, large trees, and complex forest structure, which can coincide with high fuel loads (Peery et al. 2017). Any proposed conservation actions need to be strategic in balancing these seemingly conflicting needs. Mechanical manipulation of PACs or protected areas should be avoided as much as possible, but territories can tolerate more habitat heterogeneity. It will be a challenge to balance enhancing habitat heterogeneity with maintaining sufficient mature closed canopy forest (Kane et al. 2013, Stephens et al. 2014), but managing forests sustainably will be necessary to support the long-term conservation of CSO. Short term losses of high canopy cover in some habitat, for example, may be necessary for reducing fuel loads, but could be acceptable to CSO persistence if other critical elements like large trees remain (Tempel et al. 2016). Specific fuel reduction activities should be designed in relation to known CSO territories, but also elevation, latitude, and forest site productivity. Managed wildfire should be considered whenever practicable (Hessburg et al. 2016). Mechanical treatment on its own will not achieve fire resilient landscape conditions, as it can be implemented on less than half of the productive

forestlands in the Sierras regardless (North et al. 2015a). The massive tree mortality in the southern Sierras may also make this goal more challenging. However, efforts to move the broader landscape toward a more natural fire regime will be important for long-term persistence (Stephens et al. 2016a).

***Develop and encourage voluntary conservation actions***

About 75% of CSO habitat and territories are on national forests or parks, with the rest on private timberlands. To conserve CSO and habitat resilience, redundancy, and representation, federal and state agencies and other stakeholders should work together to develop plans that include clear mechanisms for addressing the threats to CSO. In developing conservation plans, we encourage entities to coordinate closely with the Service. Implementation of mechanisms to conserve CSO will benefit from stakeholder participation in conservation planning across land ownership boundaries.

***Create a region-wide monitoring program and develop adaptive management plans***

Ensuring active monitoring and reporting is critical for understanding region-wide and population-specific changes. The existing long-term demography studies have provided an abundance of information, but key knowledge gaps remain, particularly CSO distribution between study areas and viable population sizes. The development and implementation of a robust range-wide monitoring program could expand upon the few existing long-term demography studies. Such a system would benefit from standardized data collection across forests and land ownerships. The current demography studies could be compared across landownerships as well to understand the nuances of CSO responses to forest management practices. Without this information, it is difficult to measure the benefit of conservation activities and there would be limited capacity to adaptively manage if current management is ineffective and new science emerges.

***Prioritize and support research to address additional uncertainties***

In spite of the breadth of research, there are a number of uncertainties that remain about CSO. Most notably, although recent work is beginning to understand the causes of the declines on national forestlands, such causes of CSO declines have not been conclusively determined. We also require more information about the southern California populations in particular, as well as dispersal and recruitment dynamics across a larger landscape. Understanding such parameters across the landscape would help set more specific targets for population sizes and habitat connectivity. Designing experimental studies to test sensitivities to different fuels reduction treatments, as well as different habitat uses and prey availability on private and public lands would aid in habitat management. Additionally, the future effects from recent tree mortality on spotted owl habitat and use is largely uncertain. Finally, there is insufficient data regarding the CSO that live on the eastern side of the Sierras to develop relevant objectives for these owls at

this time. Effective amelioration of stressors can only be accomplished if we understand how they affect CSO resilience, redundancy, and representation.

## 6.2 Stressor-specific conservation objectives

The following stressor-specific conservation objectives are designed to ameliorate the stressors identified and discussed in this document. These are intentionally broad goals that could be further developed within any agency or landowner-specific conservation plan or strategy. In developing CSO plans and strategies, entities should coordinate with the Service to help ensure the specific conservation plans and strategies adequately address the stressors and conservation needs of the species.

### Large, high-severity fires

***Conservation objective:*** Retain and restore resilient forests throughout the range of California spotted owls.

As a result of a century of fire suppression, CSO habitat is threatened by large, high-severity fires (Stephens et al. 2016b). The majority of areas burned on private and national forest lands occurs as result of wildfire that escape suppression under extreme conditions that are more likely to result in high-severity effects (Lydersen et al. 2014, North et al. 2015b). Thus, moving forests toward landscapes that will be resilient under current and future stressors is necessary to reduce the likelihood of the loss of high quality nesting habitat due to large, high-severity fire.

***Conservation measures:***

1. Increase the use of prescribed and managed fire for low-moderate and mixed severity burn as an active management tool. Mixed-severity fire can reduce surface and ladder fuels, acting as natural fuel breaks. Historically about 486,000 acres a year in the Sierras would burn, mostly at low-moderate severity, with small patches of high-severity (North et al. 2012). Efforts should be made to move the forests towards a more natural fire regime. Restoration of the fire frequency that would mimic pre-settlement rates may not be achievable due to ownership patterns and smoke restrictions (Quinn-Davidson and Varner 2012). However, increasing burning under moderate weather conditions will be beneficial (Schweizer and Cisneros 2014).
2. Develop a quantitative risk assessment of CSO PACs and other habitat for large, high-severity fires. Design and implement fuels reduction activities, prioritizing areas by risk of large, high-severity fire (see *Forest management practices* below for specific recommendations).

3. Focus mechanical fuel reductions outside of CSO PACs. As PACs occupy a relatively small percentage of the landscape anyway, only 5-9% of productive lands, limiting the mechanical alteration of PACs would not hamper an effort to move the landscape towards a natural fire regime (North et al. 2015a).
4. Recruit and preserve new CSO habitat outside of the current PACs. We recognize that habitat conditions in some CSO territories might not be viable long-term because of low drought tolerance or high burn probabilities. As some PACs are likely to be lost to high-severity fire or tree mortality, it will be important to strategically plan for recruiting new CSO habitat suitable under future climate conditions. Such habitat should be focused in topographic positions that will support high canopy cover and large trees under future forest conditions, such as north facing slopes and drainage bottoms (North et al. 2009, Underwood et al. 2010, Lydersen and North 2012, North et al. 2012). Modeling could build upon existing efforts to create a habitat reserve network across CSO range to ensure connectivity among PACs and populations.
5. Coordinate fire management and conservation planning across land ownerships.

<u>Forest management practices</u>

***Conservation objective:*** Utilize forest management tools that are compatible with maintaining essential habitat elements for CSO.

There is a critical need to manage for resilience in our forests while preserving connected CSO habitat. This will require some fuels reduction activities at a landscape level (Stephens et al. 2016a). The development of a regional risk assessment for fire in order to prioritize fuels reduction activities in relation to owl habitat is needed. Generally, overstory forest patterns are most associated with the climatic water deficit (Tague et al. 2009), whereas understory conditions are more shaped by the fire history (Lydersen and North 2012). Loss of habitat or abandonment of territories from certain forest management practices can be a serious concern for CSO persistence. Avoiding primary CSO use areas and maintaining the most important habitat elements can ameliorate the effects of some activities. The effects on CSO from clearcutting and even-aged management practices, as well as salvage logging, likely depend on scale, and some industrial forestlands do have nesting individuals.

***Conservation measures:***

1. Design thinning treatments to minimize loss and/or recruit large (≥24 in) and very large (≥36 in. dbh) trees and snags. Modeling indicates that thinning treatments of trees at 12, 20, and 30 in. dbh could yield a similar reduction in burn probability (Collins et al. 2011b), so removal of smaller trees, rather than larger ones important to CSO habitat, should be prioritized.

2. Manage mechanical thinning toward individual trees, clumps, and openings (ICO) (Lydersen et al. 2013). Some work suggests that at least several hundred acres of high canopy cover forest in a CSO territory could maximize fitness (Tempel et al. 2014a), though a firm target is not identified. In general, contiguous patches of mature closed canopy forest that is embedded with small forest openings and some variable forest composition (such as large oaks, especially California black oak) may promote foraging, and would be consistent with a natural fire regime (van Wagtendonk and Lutz 2007). Heterogeneity may somewhat compensate for decreased canopy cover from fuel treatments in the maintenance of flying squirrels (Sollmann et al. 2016).
3. Focus treatments on fostering the growth rate of larger trees, which are then retained long-term, in areas likely to support these in the future (Stephens et al. 2010). Enhancing important attributes like large and defect trees might be able to maintain viable CSO populations when less high canopy cover is present (Peery et al. 2017).
4. Design some fuels reduction treatments to experimentally test CSO responses. As prior attempts at experimentation have indicated, this is obviously challenging in a long-lived species with high site fidelity, but undertaking more such efforts would improve our understanding of CSO resiliency to particular fuels reduction activities. In spite of some studies, the balance between reducing fire risk and effects on CSO fitness remains unclear.
5. Although it is difficult to disentangle fire and salvage logging effects on CSO, it would be prudent to avoid salvage logging of remaining suitable habitat, where possible. California spotted owls persist in territories that experience low-moderate and mixed severity fire (Bond et al. 2002, Roberts et al. 2011, Lee et al. 2012, Lee et al. 2013, Lee and Bond 2015a). However, in situations where over half a territory has burned at high-severity (Jones et al. 2016a) and individuals have abandoned the territory, astute salvage could be warranted. Such salvage would require leaving large snags and downed logs, as well as subsequent replanting and/or natural regeneration to maximize heterogeneity and habitat restoration.
6. In timber harvest plans that utilize a clearcutting strategy, design harvests to retain essential habitat elements and minimize habitat loss. This would include multiple, non-uniformly distributed and irregularly shaped patches, balancing for old growth and some early seral stage forests to maximize biodiversity (Burnett and Roberts 2015). Such patches on industrial forestlands can enhance small mammal abundance (Gray et al. 2016). For NSO, for example, tree stands at 109-152 $ft^2$/acre had the highest probability of foraging use, particularly when streamside (Irwin et al. 2015). Focus on retaining such riparian habitat.
7. Harvest plans should be strategically designed to maintain CSO habitat for long-term resiliency. Monitoring plans will be required to adequately address any negative or positive effects from management activities.

Tree mortality

***Conservation objective:*** Monitor the effects of tree mortality on CSO.

We do not yet know how the substantial tree mortality will affect CSO. Continued drought and dense forests could lead to additional mortality events. Though direct management options are limited, managing the forests toward more resilient conditions as recommended could aid in reducing the likelihood of tree mortality (van Mantgem et al. 2016). This may include some combination of prescribed fire and thinning treatments. For ponderosa pine stands in northern California, for example, a threshold stand density index (SDI; total basal area of all trees in a stand) of 230-365 ft. SDI has been suggested for ponderosa pine stands (Oliver 1995, Hayes et al. 2009) to avoid drought and stress induced tree mortality.

Barred owls

***Conservation objective:*** Establish and implement a monitoring and management study and/or plan for barred owls.

Barred owls are a threat to NSO, and are set to become an imminent threat to CSO. Current knowledge of barred owl presence in CSO range is primarily incidental. California spotted owls will require a comprehensive monitoring and management plan to address this issue. Ongoing research suggests that while removal of barred owls will allow NSO to reoccupy territories, barred owls may return to some territories within a few years (Diller et al. 2014). Because California spotted owl range is currently at the edge of barred owl expansion, if the expansion is to be slowed or halted, a proactive plan to address the threat of barred owl expansion should be implemented. Control measures would likely be most effective now, while barred owls are still at low densities (Dugger et al. 2016) within the range of CSO. However, advocating removal of one species for another is a controversial decision.

***Conservation measures:***

1. We recommend the immediate development of an active monitoring scheme.
2. Given the substantial effects barred owls have had on NSO, we recommend the development of a comprehensive barred owl management study and/or plan for CSO. Such a plan would be intended to get ahead of this emerging threat before full barred owl expansion occurs within the range of CSO.

Contaminants

***Conservation objective:*** Identify rodenticide exposure rates in California spotted owls.

Little information regarding the exposure rate of contaminants on CSO exists. However, the high exposure rates to rodenticides in barred owls and fisher would suggest CSO rates could be high as well (Gutiérrez et al. 2007, Gabriel et al. 2012). Thus, minimizing exposure to contaminants and beginning to test individuals for rodenticides would be prudent. Working with law enforcement partners to monitor the amount of rodenticides on the landscape will be of importance to long-term conservation of CSO.

Climate change

***Conservation objective:*** Align habitat planning and protection with areas likely to support high canopy cover and large trees under future climate scenarios.

Although CSO might not be among the bird species most vulnerable to direct effects from climate change in the Sierras (Siegel et al. 2014), associated increases in large fires and tree mortality are likely to negatively affect CSO habitat. Thus it will be important not only to protect current habitat, but also to recruit new CSO habitat that aligns with future climate scenarios (North et al. 2017). CSO tend to use topographic areas associated with higher productivity anyway, such as canyon bottoms, lower slopes, and northeast aspect positions, which are likely to support older forests (Underwood et al. 2010). Recent work suggests that managing for greater amounts of closed canopy habitat at higher elevations in particular might be beneficial to ensure available habitat in the long-term (Jones et al. 2016b).

To support long term persistence of California spotted owls, it will be important to manage for forests that are resilient to fire and climate change while still maintaining essential habitat elements.

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