

Barred Owl Research Needs and Prioritization in California

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EXECUTIVE SUMMARY

Barred owls (*Strix varia*) have reached high densities within the range of the northern spotted owl (*S. occidentalis caurina*) and are rapidly increasing in number within the range of the California spotted owl (*S. o. occidentalis*). Encroaching populations of barred owls pose a significant competitive threat to the viability of both spotted owl subspecies in California. In response, the Director of the California Department of Fish and Wildlife (CDFW) convened the California Barred Owl Science Team (BOST) to identify and address the threat posed by barred owls to spotted owls in California. BOST is composed of subject matter scientists with a goal to provide objective scientific review and recommendations to CDFW to promote the recovery and conservation of spotted owls in California.

In this document, BOST identifies, describes, and prioritizes key research needs for barred owls that have the potential to benefit the conservation of spotted owls in California. Key research needs were identified from multiple in-person and remote meetings of BOST, with considerable input from attending representatives from state and federal natural resource agencies. BOST and liaisons recognize that periodic updates of this document will likely be required as more is learned about the ecology of barred owls in California and research needs and priorities evolve.

Research that BOST deemed the most likely to provide a rigorous scientific basis for reducing barred owl populations included experimental removals, along with ecological studies expected to generate information that would provide avenues for the effective management of barred owls. Other high priority research needs include research using biological samples obtained during experimental removals to better understand the ecology of barred owls and the threats they pose to spotted owls and associated wildlife. We conclude the document with a discussion of how projects are related to the State Wildlife Action Plan. In Appendix I, we discuss considerations for maximizing the success of proposed removal experiments and ecological research on barred owls.

BARRED OWL RANGE EXPANSION AND THREAT TO SPOTTED OWLS IN CALIFORNIA

The range expansion of barred owls into western North America is well documented (Dark et al. 1998, Kelly et al. 2003, Livezey 2009). Initial colonization was variable among regions, but barred owls now appear to outnumber northern spotted owls throughout the Pacific Northwest (Wiens et al. 2014, Dugger et al. 2016). Competition with established populations of barred owls has emerged as a prominent and complex threat to the long-term persistence of the northern spotted owl. Indeed, the expansion of the barred owls appears to be a major factor contributing to declines in populations of northern spotted owls, including those in northwestern California (Kelly et al. 2003, Forsman et al. 2011, USFWS 2011, Diller et al. 2016, Dugger et al. 2016). For example, populations of northern spotted owls declined by 77% on the Cle Elum Spotted Owl Demography Study Area in Washington between 1985 and 2013 in association with expanding barred owl populations. Even in southern Oregon and northern California where the expansion is more recent, spotted owl populations declined by 30 to 50% since the arrival of barred owls (Diller et al. 2016, Dugger et al. 2016).

Barred owls expanded their range into the Sierra Nevada, California relatively recently (Dark et al. 1998, Seamans et al. 2004, Keane 2017). As the Sierra Nevada contains the largest population of California spotted owls, there is concern that barred owls will soon begin to negatively impact this subspecies. Most detections of barred owls over the past 5 – 10 years have occurred in the northern Sierra Nevada, but more recent detections indicate barred owls may now be increasing in the central and southern Sierra Nevada (Figure 1; also see Keane 2017:212).

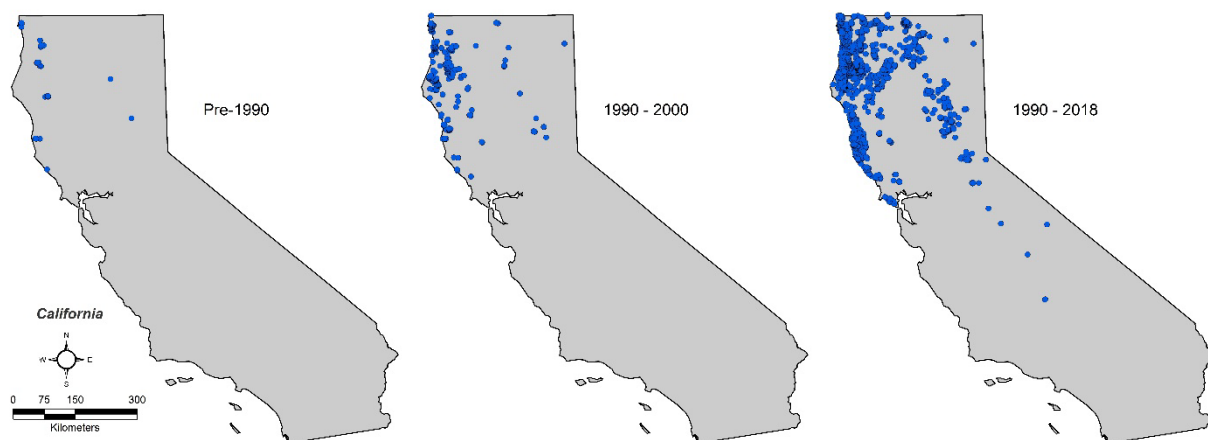
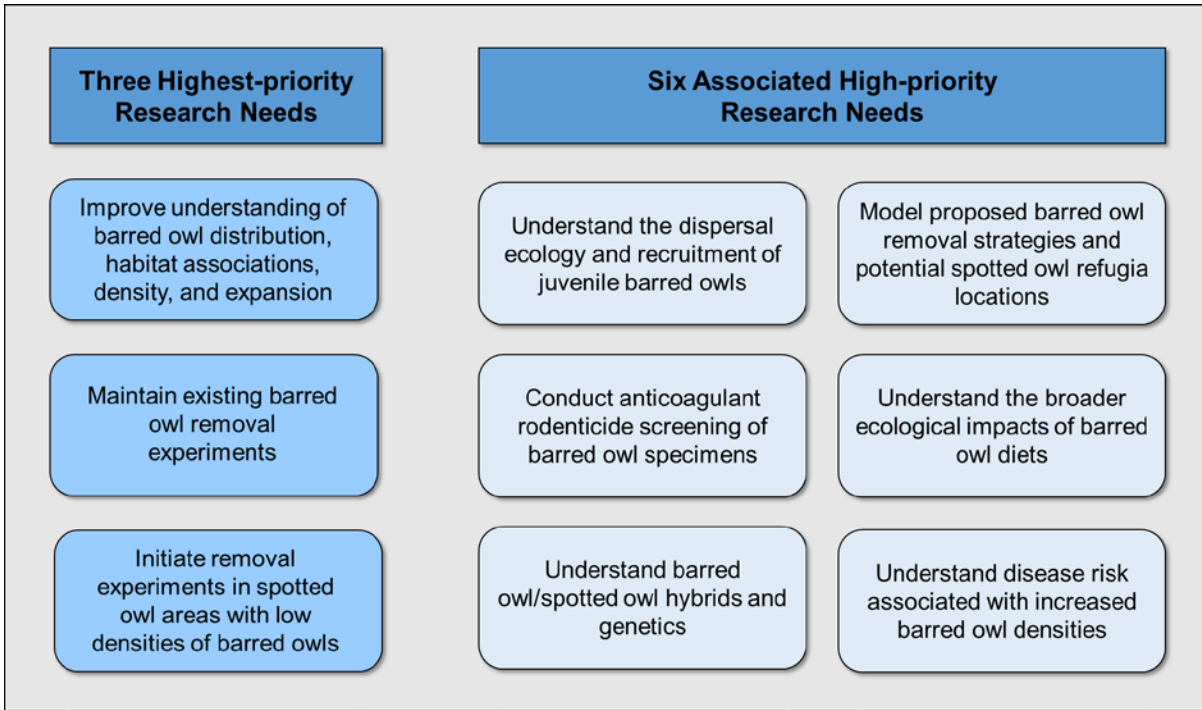


Figure 1. Detections of barred owls and spotted-barred owl hybrids documented in California from 1978 to 2018. Data from the California Department of Fish and Wildlife barred owl database. A portion of the increase in number of detections over time can be attributed to an increase in survey effort. Detections do not necessarily reflect abundance or density.

Incidental detections of where barred owls were first observed during surveys of northern spotted owls suggest a rate of invasion of approximately 14 km per year (Hollenbeck et al. 2018). Once barred owls reach high numbers, they may become difficult to effectively remove and maintain at low numbers. For example, in areas with high barred owl numbers, territories were quickly recolonized by barred owls after previous occupants were removed (Wiens et al. 2018). Displaced spotted owls may remain in the general area for several years as non-territorial floaters but could also have lower survival than territorial owls. In areas with a relatively long history of barred owl presence (e.g., >10 years), few spotted owl floaters may be available to recolonize territories after barred owls are removed (e.g., Cle Elum, WA; Wiens et al. 2018). Therefore, managers have a limited time to react to the invasion of barred owls as these owls continue to expand their populations southward into California. Without timely, science-based efforts to curb barred owls, they could threaten the persistence of both subspecies of spotted owls in California.

RESEARCH NEEDS FOR BARRED OWLS IN CALIFORNIA

In the sections below, we identify and describe nine areas of research focus for barred owls in California. While all proposed studies are important, barred owl removal experiments could provide the most direct insight into how to most effectively manage the barred owl threat to both subspecies of spotted owls in California. We recognize that some projects have overlapping objectives, but our intent was to delineate research needs in a manner most consistent with individually fundable research projects.



IMPROVE UNDERSTANDING OF BARRED OWL CURRENT DISTRIBUTION, DENSITY, HABITAT ASSOCIATIONS, AND EXPANSION

General Objectives of the Research:

- *Characterize the distribution and density of barred owls in California*
- *Evaluate habitat associations of barred owls in California*
- *Determine whether certain areas are colonized first and whether these areas can be described based on environmental conditions*
- *Estimate the recent rate of spread of barred owls in California*

To achieve the research objectives described in this document, it is necessary to understand the current distribution, density, and habitat associations of barred owls in California relative to the ranges of both spotted owl subspecies. One approach to addressing these questions includes the estimation of occupancy dynamics based on systematic, species-specific surveys at predefined spatial scales (see Wiens et al. 2011, 2016, 2018, Zipkin et al. 2017). Such approaches provide information on barred owl distribution, occupancy patterns, habitat use, and most importantly, the processes driving those patterns (i.e., colonization and local extinction rates) that are of primary importance for understanding the barred owl invasion process (Yackulic et al. 2015, Yackulic 2017). Conducting barred owl-specific surveys, however, is both time-consuming and expensive, and survey coverage of the entire range of both spotted owl subspecies in California would be difficult or impossible because of ownership patterns in the state. However, alternative methods may be useful for monitoring barred owls at regional scales.

A project using autonomous recording units and passive survey methods to detect California spotted owls and barred owls is currently underway in the northern Sierra Nevada (Wood et al. *in press*). This program surveys owls multiple times each season in randomly-selected grid cells distributed across the study area, providing data for use in dynamic occupancy modeling (Bailey et al. 2009, Yacklic et al. 2012, 2014, Dugger et al. 2016). It has provided preliminary estimated occupancy rates of 0.09 (SE = 0.09) for barred owls and 0.43 (SE = 0.10) for spotted owls based on 72 sites surveyed twice in 2017. These initial results indicate that passive acoustic surveys are a valid technique for systematically assessing the occupancy dynamics of barred owls at regional scales. The project could be implemented across the Sierra Nevada in the near future. Acoustic survey methods are also being tested in high-density barred owl areas within the range of the northern spotted owl (*D. Wiens personal communication*). Current studies using acoustic surveys should yield additional information on how these methods compare with traditional call-broadcast surveys in terms of cost and effort.

Surveys of spotted owls in California have recorded large numbers of incidental detections of barred owls, especially within the range of the northern spotted owl. Many of these detections have been compiled in a database curated by CDFW (Figure 1). There may be challenges associated with using the CDFW database for research purposes, but the data could be useful for addressing basic questions about barred owl distributions and invasion dynamics in California. Barred owl detection locations, along with habitat information, could also be used to evaluate the species' landscape-level habitat relationships in California (e.g., Seamans and Gutiérrez 2007, Dugger et al. 2011). Large-scale empirical modeling (e.g., Neubert and Parker 2004, With 2004, Arim et al. 2006) may help identify the risk of barred owl invasion in areas currently unoccupied by the species. Fitting of theoretical models (see review in Hastings et al. 2005), can further contribute to the understanding possible source habitats of barred owls in California – an important aide in targeting removal efforts.

MAINTAIN EXISTING BARRED OWL REMOVAL EXPERIMENTS

General Objectives of the Research:

- *Determine the effect of experimental removal of barred owls on site-occupancy dynamics, reproduction, survival, and population trends of northern spotted owls.*
- *Evaluate the response of barred owl populations to experimental removals.*
- *Characterize the amount of effort and cost required to optimize numbers of remaining barred owls while achieving positive effects on vital rates of spotted owls.*

A pilot removal study on Green Diamond Resource Company lands in northern California conducted from 2009 to 2013 demonstrated a rapid, positive effect on spotted owl survival and rate of population change (Diller et al. 2016, Dugger et al. 2016). However, the Green Diamond study was conducted in the early stages of the barred owl expansion into California, and the feasibility and effectiveness of removals in high-density areas and during later stages of the barred owl invasion process remain uncertain. Additional studies testing the benefits of experimental removal of barred owls to northern spotted owls have been initiated on four study areas within the northern spotted owl's geographic range, including one in northern California (Higley and Carlson 2017), two in western Oregon, and one in central Washington (Wiens et al. 2018). These studies will provide valuable information on differences in spotted owl and barred

owl responses to experimental removals under a variety of different forest conditions. At the inception of the study, barred owls were already well established in all four of these study areas and numbers of spotted owls were relatively low (2 – 13 pairs per treatment area; Wiens et al. 2018). If experimental removal of barred owls as part of current studies increases territory occupancy and population trends of spotted owls, sustained removals in localized areas could provide source populations that improve regional demographics of northern spotted owls. Existing studies will provide a better understanding of the response of northern spotted owls to experimental removals of barred owls in a variety of forest types, with implications for research, management, and policy decisions for both subspecies of spotted owls in California. Therefore, we consider these studies to have considerable value for informing conservation of spotted owls in California.

Removal experiments in the northern spotted owl's range also inform research and management strategies for barred owls within the range of the California spotted owl. Initial results from these studies show that recolonization rates of barred owls following experimental removals are highly variable within and among different study regions (Wiens et al. 2018). Spatial data on colonization patterns of barred owls following removals permits researchers to identify and map the physiographic composition of colonization “hotspots” (i.e., landscape conditions that are attractive to, and positively selected by, dispersing barred owls). Identifying, mapping, and concentrating removal efforts on colonization hotspots could facilitate suppression of barred owls, especially at the leading edge of their range expansion.

INITIATE REMOVAL EXPERIMENTS IN SPOTTED OWL AREAS WITH LOW DENSITIES OF BARRED OWLS

General Objectives of the Research:

- *Evaluate the extent to which barred owl populations can be reduced in areas where barred owl populations are still at relatively low densities, particularly at regional scales.*
- *Quantify spatial and temporal patterns of recolonization by barred owls following experimental removals.*

The context for research on barred owls in areas with relatively low densities differs from that of northern regions where densities are much higher. In low-density areas, such as the Sierra Nevada and Marin County, barred owls have likely not yet had major impacts on spotted owl populations (Wood et al. *in press*). Studies in the redwood zone indicate that removing barred owls from low-density areas is tractable and can benefit spotted owls at local spatial scales (Diller et al. 2014, 2016), but it is unclear whether such efforts are practical to “scale up” to entire bioregions. Experiments designed to evaluate the feasibility of regional-scale barred owl removals are high priority. Developing a scientific basis for regional-scale barred owl management will be particularly important for preventing impacts to California spotted owls and maintaining viable populations of this subspecies in the Sierra Nevada. A secondary benefit of regional-scale experimental removals in low-density areas would be reduction of barred owls at the leading edge of the population expansion, providing more time to develop management strategies before barred owls become a major component of the landscape.

Monitoring landscape occupancy of barred owls, including site-specific rates of colonization and extinction before and after experimental removals, could be used to quantify the effectiveness of removal efforts and provide insight on implementing regional-scale management of barred owls. First, before-after monitoring would yield a test of the effectiveness of experimental barred owl removals by providing estimates of changes in density or site occupancy, and thus an assessment of the feasibility of regional-scale management. Second, monitoring barred owl population growth from recolonization or *in situ* demographic processes following experimental removals would provide estimates of when, and how often, removal is required to suppress barred owls. Third, post-removal monitoring would provide a means to study barred owl colonization relative to habitat conditions and thereby facilitate targeted removals as part of future management efforts. New removal experiments in the Sierra Nevada could leverage two existing monitoring programs: (i) long-term spotted owl demographic studies in the Sierra Nevada that provide opportunities for monitoring barred owl populations at local scales (Tempel et al. 2014, Conner et al. 2016); and (ii) ongoing regional spotted owl and barred owl monitoring with passive acoustic survey techniques (e.g., Wood et al. *in press*). Simulation analyses indicate that a passive acoustic monitoring framework with 100 sites surveyed three times per season will have high (>80%) statistical power to detect modest ($\geq 4\%$) annual changes in occupancy of barred owls over a 10-year period across the Sierra Nevada region (Wood et al. *in press*).

Delays in implementation of barred owl removal studies will likely result in larger barred owl populations in the study areas. If barred owl populations begin to rapidly increase in the study areas, the opportunity to study the effect of removal on low-density barred owl populations will be reduced. Moreover, delaying experimental removal, and allowing the barred owl population to increase, could require the removal of greater numbers of barred owls over the course of the study compared to studies initiated in the early stages of the expansion. Removal of barred owl populations at early stages may also be a less expensive approach to prevent barred owl populations from becoming entrenched. Finally, we note that, in developing removal experiments within the range of the northern spotted owl, the USFWS (2013, pp 46-51) examined options to gather information with no, or limited, removal of barred owls, as well as non-lethal removal approaches. None of these options were financially or ecologically feasible (for details see USFWS 2013).

UNDERSTAND THE DISPERSAL ECOLOGY AND RECRUITMENT OF JUVENILE BARRED OWLS

General Objectives of the Research:

- *Characterize movements and first-year dispersal distances of juvenile barred owls at different stages of the invasion process (i.e., in settled areas versus leading edge of invasion)*
- *Estimate juvenile (first-year) survival rates of barred owls*
- *Evaluate habitat use by dispersing juvenile barred owls.*

Management of barred owls will require an understanding of the mechanisms that regulate demographic processes of this species. Dispersal, in particular, plays a central role in range expansion and population growth of barred owls. The distance and direction of juvenile

movement may differ at the leading edge of the range expansion and in areas with established, more abundant source populations. Variable dispersal patterns could have important implications for understanding the rate of spread of barred owls into California and the rate at which areas with removal efforts are subsequently recolonized by barred owls. Currently, the only information available on dispersal movements by barred owls in the western U.S. is limited to approximately 10 band recoveries (see Baumbusch 2016:8). No information exists on the timing of juvenile dispersal from natal territories or movement during the first year of life, nor on survival rates during this period. Data on movement behavior and dispersal distance are also needed to parameterize population models used to forecast the spread of barred owls and optimize potential removal strategies (e.g., Perlman 2017; also see “Population Modeling to Assess Barred Owl Removal Strategies and Spotted Owl Refugia” below). Information on the extent and range of dispersal movements of barred owls will also help determine the spatial extent over which removals will be most effective in minimizing immigration from uncontrolled source populations.

Fledgling barred owls could be captured and equipped with GPS/satellite tags so that their movements, and possibly survival, could be monitored during the first 1–2 years of life. Dispersal and movement studies of tagged fledgling barred owls would provide information on forest conditions and terrain used by juveniles during dispersal, especially when comparing successful versus unsuccessful recruitment of those juveniles into the breeding population. Tracking studies near the leading edge of the range expansion in California could provide information on forest conditions and movement paths used during dispersal in areas with low numbers of barred owls. Fledglings could also be marked with GPS units in close proximity to existing removal experiments to determine how experimental removals influence dispersal patterns of spatially associated barred owls in landscapes with greater numbers of barred owls.

Characterizing the dispersal dynamics of juvenile barred owls with GPS or telemetry approaches in low-density areas may be relatively challenging because of the paucity of known nests sites and information on reproductive status of known pairs, which are needed for locating juveniles on which to attach transmitters. Genomic approaches that characterize the spatial distribution of related individuals across the landscape are powerful tools for characterizing patterns of dispersal and could be particularly suitable for low-density areas (Peery et al. 2008, Fountain et al. 2018). This approach could be used in combination with removal studies, where samples would be obtained from birds collected during removals. Other genetic methods, such as population assignment tests (Paetkau et al. 2004), could be used to identify the origin of potential immigrants into areas of interest and could potentially be applied to both high- and low-density areas. Such a project, however, would require greater sampling of barred owls across multiple California regions before we can assess whether population structure will be useful for assigning birds to different populations.

MODEL PROPOSED BARRED OWL REMOVAL STRATEGIES AND POTENTIAL SPOTTED OWL REFUGIA LOCATIONS

General Objective of the Research:

- *Develop two-species population models to explore effectiveness and costs and benefits of proposed barred owl removal strategies.*
- *Use spatially explicit population modeling to explore potential refugia locations for spotted owls in California.*

The development of management programs for barred owls would benefit from a better understanding of the relative effectiveness of different removal strategies in maintaining low numbers of barred owls. Data on distribution and occupancy have informed management decisions about population control programs for other species (e.g., Goldstein et al. 2016, Pacioni et al. 2018), and could be used to address questions related to removal intensity and frequency needed to manage populations of barred owls in California. Spatially explicit population models, which combine landscape composition and structure data with simulated metapopulation dynamics, are one tool that can be used to explore the relative effectiveness of coupling barred owl control efforts with refugia design options for spotted owls. This type of approach has been used to assess critical habitat configurations for northern spotted owls (USFWS 2012, Schumaker et al. 2014), and, more recently, extended to include simulated populations of barred owls (Perlman 2017).

We note that empirical data on basic vital rates and movement are currently lacking for barred owls, which can impart bias and imprecision to conclusions drawn from population models. It is also unclear whether there are forest habitat characteristics that promote use by northern spotted owls (or California spotted owls) over barred owls (also see Wiens et al. 2014). Differences between species in habitat associations, and how those differences translate to demographic processes, are important for inferences drawn from two-species population models. Moreover, recent attempts to develop spatially-explicit population models for barred owls highlight the need for accurate information on movement, dispersal, and survival of barred owls (Baumbusch 2016, Perlman 2017; also see *Barred Owl Dispersal Movements* above). As such, efforts to model population dynamics of barred owls are closely tied to research priorities identified elsewhere in this document (e.g. estimating juvenile dispersal and survival rates).

Two-species occupancy modeling that incorporates habitat characteristics and effects of the presence of each owl species on the other can be another useful tool for investigating questions regarding how the persistence of spotted owls be mediated by interactions between barred owls and forest habitat conditions (Yackulic et al. 2014, Dugger et al. 2016). Harvest theory and decision analysis provide another approach for assessing the removal effort required to maintain low densities of barred owls. For example, Runge et al. (2009) developed a modeling framework for assessing and setting allowable levels of take in populations of migratory birds. This type of approach could be used to determine numbers of barred owls that need to be removed to destabilize localized barred owl populations and stabilize spotted owl populations. As with all conceptual models, testing of predictions and alternatives with empirical data is critical to evaluate the effectiveness of these models in providing robust strategies to manage barred owls.

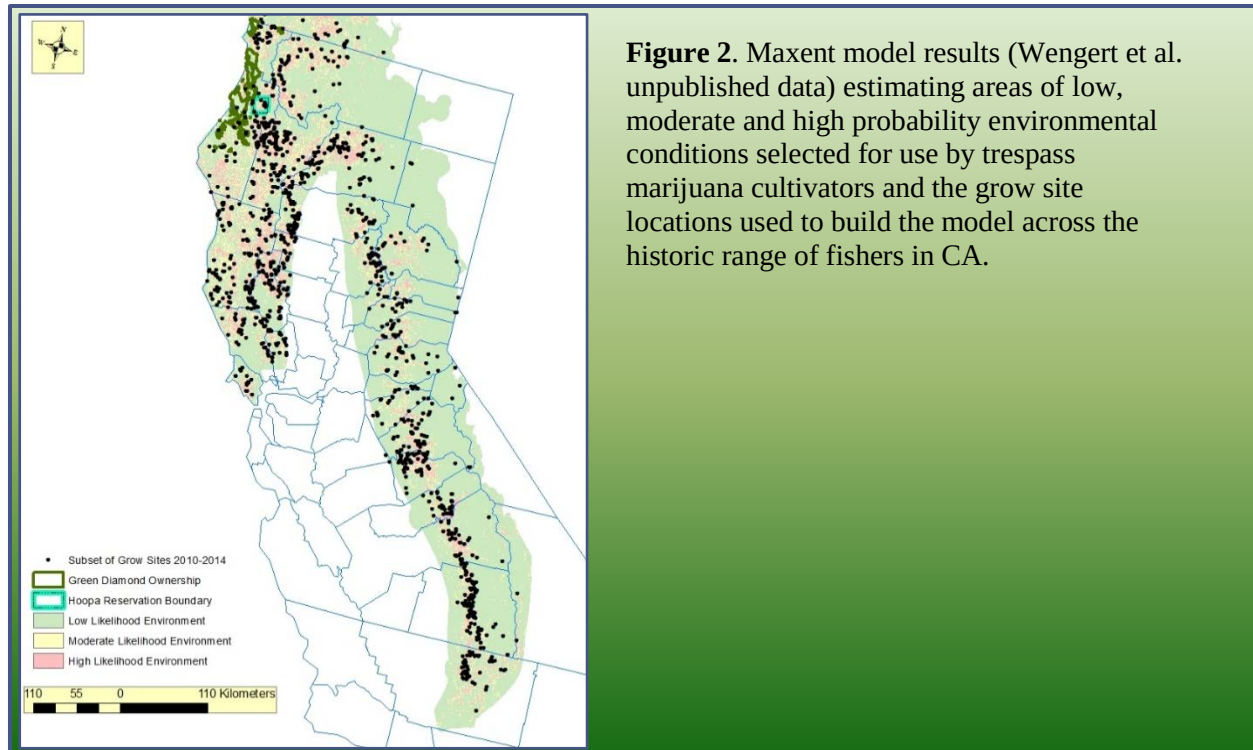
CONDUCT ANTICOAGULANT RODENTICIDE SCREENING OF BARRED OWL SPECIMENS

General Objectives of the Research:

- *Use barred owls as a proxy for exposure to anticoagulant rodenticides in spotted owls.*
- *Opportunistically screen barred owls removed in conjunction with experimental removal studies for anti-coagulant exposure rates, and systematically screen barred owls across different regions.*

Non-target wildlife near agricultural areas, rural or urban communities are frequently exposed to anticoagulant rodenticides (ARs) (Eason et al. 2002, Erickson and Urban 2004). However, it has recently been confirmed that wildlife inhabiting remote, forested environments are being exposed to ARs at a very high rate due to their use in clandestine trespass marijuana cultivation sites (MCS) on public, private and tribal lands (Gabriel et al. 2012, Thompson et al. 2014, Gabriel et al. 2018). Barred and northern spotted owls have been exposed to one or more ARs at relatively high rates in northern California (40% and 70% respectively; Gabriel et al. 2018). Moreover, in 2017, a freshly dead resident female northern spotted owl was found with measurable amounts of brodifacoum (a highly toxic, second-generation AR) in both her liver tissue and blood, and this sub-lethal brodifacoum exposure likely contributed to the owl's death (Franklin et al. 2018). A dead northern spotted owl was also recovered in Mendocino County with evidence of AR exposure (Calforests 2014).

Given that the spotted owl diet contains a higher percentage of rodents by biomass than barred owls and spotted owl home ranges are larger than barred owls (Wiens et al. 2014) it is likely that spotted owls have a higher risk of exposure to ARs than do barred owls. Barred owls however, should serve as a good, albeit conservative, surrogate for estimating potential exposure rates of spotted owls to ARs. Thus far, barred owl liver samples from Green Diamond Resource Company lands and the Hoopa Valley Indian Reservation in Humboldt and Del Norte Counties along the northern California coast and northeastern Humboldt County have been tested for ARs. These areas represent areas of low (Green Diamond Land) and high (Hoopa) probability of selection for use by trespass growers (Figure 2). Trespass grow sites are likely prevalent throughout the ranges of the northern and California spotted owl in California (Figure 2), so it is also likely that spotted owls are being exposed to ARs at a high rate in the state. The northern Sierra Nevada would be an important area to focus on given the number of barred owls and known historic MCS.



UNDERSTAND THE BROADER ECOLOGICAL IMPACTS OF BARRED OWL DIETS

General Objectives of the Research:

- *Characterize the diets of barred owls in various portions of their expanded range in California.*
- *Evaluate dietary overlap with spotted owls.*
- *Identify rare and at-risk native species that may be affected by barred owl predation.*

As an invading apex predator capable of achieving extraordinarily high densities, barred owls have the capability to trigger significant changes in the native prey community, food webs, and old-forest ecosystem processes (Holm et al. 2016). Identifying the diets of barred owls in different portions of their newly expanded range into California is a key first-step towards understanding their potential impacts to prey populations and associated trophic linkages. The removal of barred owls provides an unprecedented opportunity to study the diet of barred owls in the western United States. Barred owl stomach contents analyzed using standard morphological methods to date have shown different diet components and proportions than analyses done with pellets (Higley, Dumbacher, and Medina, unpublished data; Wiens, Dugger, Baumbusch, unpublished data). A detailed analysis of both pellet and stomach data could more accurately quantify the diet and niche of western barred owls and allow a comparison of niche separation and overlap with spotted owls. These approaches could also be supported with environmental DNA (eDNA) analyses to detect and identify rare or difficult to detect prey species in diets of

barred owls collected recently in Oregon and Washington (D. Wiens *personal communication*). Collectively, more diet data will help: (i) assess the impacts of barred owls on other species, including salamanders, other birds, and freshwater species; and (ii) identify areas where spotted owls may be able to persist or outcompete barred owls.

UNDERSTAND BARRED OWL-SPOTTED OWL HYBRIDS AND GENETICS

General Objectives of the Research:

- *Characterize genetic and phenotypic characteristics of barred/spotted owl hybrids, and identify visual and auditory cues for field identification of barred/spotted owl hybrids.*
- *Determine the fate of hybrid genes and hybrid owls in the population to assess potential risks to spotted owls posed by hybridization.*

The occurrence of hybrid barred and spotted owls has been well documented in the western range of the barred owl (Haig et al. 2014). Hybrids appear to be more numerous and demographically significant when barred owls are relatively rare, during which time barred owls may resort to mating with unpaired spotted owls rather than foregoing a mating season. In addition, many barred owls in California are phenotypically distinct from eastern barred owls, which could be a sign of hybridization with spotted owls. To understand how hybridization may be affecting populations of western barred and spotted owls and facilitate hybrid management, we need to know more about phenotypic and genotypic characteristics of hybrid individuals, the frequency of hybridization, when and why it occurs, and assess its impact on the parent species. To aid in these studies, there is now a relatively complete and well-assembled full genome of northern spotted owl and barred owl to use as a reference, as well as effective tools for whole-genome analysis of hybridization between these two species (Hanna et al. 2017).

Rapidly and accurately identifying hybrids in the field using visual and auditory cues is important for assessing the prevalence of hybrid pairings and for identifying hybrids for potential removal. This work will require samples from a series of barred and spotted owls, as well as samples and sequences from known and suspected hybrids, including individuals with unusual western phenotypes. Ideally, samples will include F1 hybrids (first generation 50:50 barred/spotted owls), as well as F2 hybrids (second generation hybrids that may be backcrossing with parental species, that are 75% species 1 and 25% species 2). With birds along this hybrid spectrum, we can use genetic sequence data to accurately identify the hybrid history and pedigree and document the phenotypes of each type of hybrid. Phenotypic data should include the vocal recordings of hybrids, as well as plumage and morphometrics, so that hybrids can be accurately identified by both sound and sight.

Studying the fates of hybrid genes and hybrid owls is a key to understanding the impacts of hybridization and introgression on spotted owls. Previous studies suggest that, although hybrids may be more common where barred owls are rare, they are uncommon once barred owl numbers increase (Haig et al. 2014, Keane 2017). There are multiple possibilities of what happens to these hybrid birds. Hybrids may be unfit or strongly selected against, such that they truly do disappear. In this case, hybrids may have little impact on spotted owls genetically, but they may still have

significant demographic impacts, as they may displace or compete with pure spotted owls while they are alive, and thus may still contribute to the decline in spotted owls. Assessing the demographic impacts of hybridization will require estimating the number of barred owls present with some hybrid parentage and quantifying the impacts of introgression on both spotted and barred owl populations, perhaps in conjunction with spotted owl demography studies. If the hybrids backcross and offspring are viable, then hybrid genes may persist, even if at lower percentages, in the genomes of barred owls, spotted owls, or both. Backcrossed descendants may not be readily identifiable as hybrid offspring, but these genes may have important impacts (positive or negative) on the populations that carry them.

UNDERSTAND DISEASE RISK ASSOCIATED WITH HIGH DENSITIES OF BARRED OWLS

General Objectives of the Research:

- *Compile background information and resources on transmission of pathogens and parasites in barred owls.*
- *Identify and rank potential risks of transmission of pathogens and parasites from barred owls to spotted owls.*
- *Collect and preserve relevant samples from barred owls collected in removal experiments.*

Invasive species can negatively impact conspecifics in their non-native ranges through the introduction of novel parasites and pathogens (PAP) (Telfer and Brown 2012, Young et al. 2017). One concern is whether founding populations of barred owls have carried PAP from their native range into the range of spotted owls that can negatively impact spotted owl populations through *co-invading PAP* (those which have been co-introduced and then spread to new, native hosts; Lymbery et al. 2014). Disease risk to spotted owls will also depend on the general mode of transmission for PAP from barred to spotted owls (Figure 3). Direct contact may be considered low-risk, while vector-borne PAP transmission (e.g., blood parasites) may be considered higher risk, depending on the PAP being transmitted (Ishak et al. 2008, Lewicki et al. 2015).

Hypotheses concerning mechanisms of pathogen transmission from invasive to native species include: (i) the *Enemy Release (Escape) hypothesis*, where invasive hosts leave behind a fraction of their natural PAP when invading a new range and thereby obtain a competitive advantage over native species, (ii) the *Enemy of My Enemy hypothesis* where invasive hosts introduce novel PAP to naïve native hosts, and (iii) the *Parasite Spillover hypothesis* where invasive hosts act as new reservoirs that either amplify PAP with negative consequences to native hosts, or dilute PAP with positive consequences for native hosts (Amsellem et al 2017, Young et al. 2017, Lewicki et al. 2015).

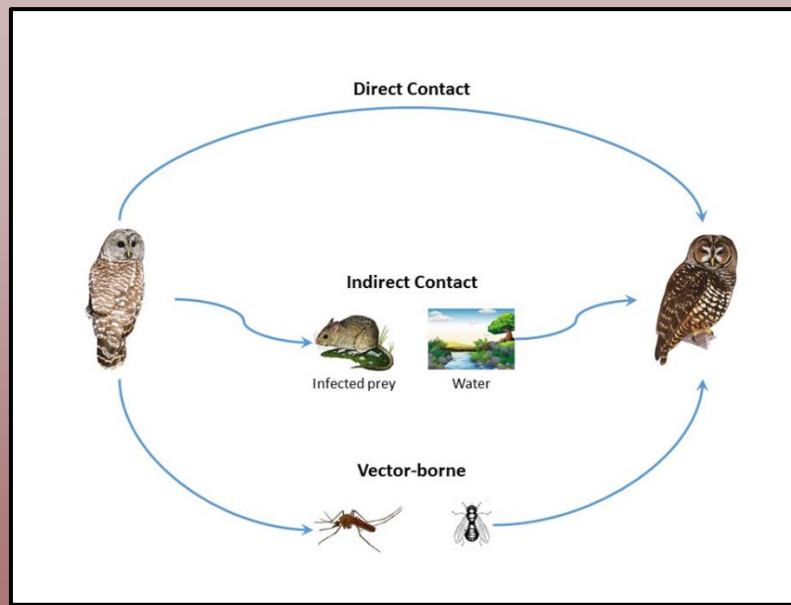


Figure 3. Major transmission pathways for pathogens and parasites (PAP) from barred to spotted owls. Transmission through direct contact involves transmission through physical contact between barred and spotted owls, such as through pairing or agonistic encounters. Indirect contact involves contamination of the environment from barred owls, such as fecal contamination that infects shared resources. Vector-borne pathways involve a vector, such as mosquitoes, that acquire PAP from barred owls through blood meals and subsequently infect spotted owls.

Given these proposed mechanisms, the following research questions could elucidate the potential effects of PAP originating from invasive barred owls:

- *What PAP are unique to barred owls in eastern populations that could have co-invaded with barred owls into the West?* Addressing this question involves identifying the existing literature on PAP relevant to barred and spotted owls, and identifying retrospective and contemporary specimens available for investigating potentially shared and novel PAP. Museum collections offer retrospective samples to further identify PAP in eastern barred owls for comparison with western barred owl populations, especially PAP of concern.
- *What PAP pose a high risk of affecting spotted owl populations, if PAP co-invaded?* Using compiled information, PAP can be prioritized in terms of risk, based on criteria such as mode of transmission, pathogenicity, host effects, etc. (see Tefler et al. 2012, Hwang et al. 2018). The approach by Hwang et al. (2018) may be useful for systems with limited information because it couples expert opinion with Bayesian analysis to rank risks from a variety of PAP.

The above questions form the foundation for research that can inform management of spotted owls in the face of novel disease threats. Critical questions of management concern include:

- *If barred owls have introduced novel, high-risk PAP into the range of spotted owls, have they spilled-over into spotted owls?*
- *If so, what are the effects on spotted owl populations in terms of survival, reproduction, and ultimately, rates of population change?*

- *As spotted owl populations decline from competitive effects of barred owls, will the effect of novel PAP on smaller spotted owl populations become more severe?*

Identification of samples to collect in order to address these research questions is critical because removal of barred owls provides an opportunity for collection of samples to identify potential PAP. Currently, blood and tissue samples are being collected from barred owls during removals and preserved in museum collections. However, the types of samples taken and how they are preserved are often specific to the PAP of interest and may need to be refined in future collections.

ALIGNMENT OF RESEARCH NEEDS WITH THE CALIFORNIA STATE WILDLIFE ACTION PLAN

When developing projects to meet the research needs described herein, project objectives, settings, and tasks should be aligned with the California State Wildlife Action Plan 2015 Update (SWAP 2015) to the extent possible. SWAP 2015 was developed to address the highest conservation priorities of the state, offering a blueprint of conservation actions necessary to sustain the integrity of California's diverse ecosystems. SWAP approaches conservation from ecosystem and regional perspectives, identifying strategies to improve habitat conditions for Species of Greatest Conservation Need (SGCN), including northern and California spotted owls. SWAP 2015 provides scope and direction for allocating federal funds during 2016–2025 for the state of California through the State and Tribal Wildlife Grants Program. The vision of SWAP 2015 notes that CDFW will seek to “provide resources and coordinate efforts with partners to eradicate or control invasive species and prevent new introductions.” A conservation action identified in SWAP for conifer forests in the Sierra Nevada is to “sustain ongoing relevant monitoring and resources assessment work” to meet the conservation objectives of documenting baseline conditions and monitoring trends of SGCN and the conifer forest ecosystem in general (SWAP 2015 Section 5.4).

While the barred owl could be studied with regard to a single targeted species (i.e. spotted owls), project developers are encouraged to consider the species in relevant ecosystems and regional contexts whenever possible. For example, projects could consider barred owl influences on species assemblages or richness (see *Californian–Vancouverian Montane and Foothill Forest*, Appendix D: Table D-21), influences of climate change and projection scenarios to the speed and severity of the barred owl's expansion (Appendix F), or synergetic impacts of barred owls, climate change, large, severe wildfires, or large-scale tree mortality to spotted owls (SWAP 2015; also see <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=109227&inline>). Collaborative opportunities with other conservation efforts should also be explored while scoping potential projects. For example, project developers should examine if the data are valuable for other programs or if the sampling design can be coordinated with other projects. In sum, project proponents are encouraged to develop their proposals to contribute to overall ecosystem improvements and other conservation efforts, as well as species-specific conservation.

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APPENDIX I

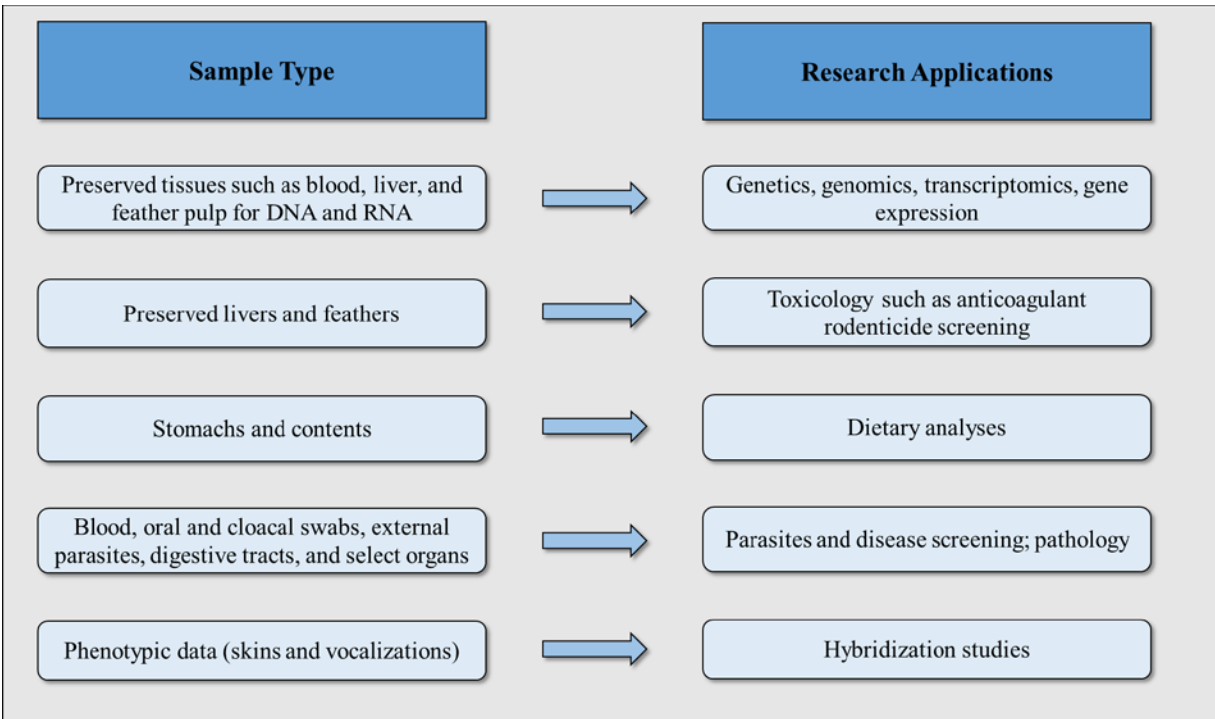
Further Considerations for Experimental Removal of Barred Owls in California

Experimental removals provide unparalleled opportunities to test how barred owls impact spotted owls and to develop management strategies to reduce those effects. They also generate biological samples that provide a unique resource for understanding the ecology of both barred owls and spotted owls, as well as interactions between the two species. However, experimental removals are costly, logistically challenging, and may be opposed by members of the public and stakeholders. Here we outline several steps to address these challenges and ensure the success of experimental removal projects, as well as maximize the information gained.

DEVELOPMENT OF REMOVAL, SPECIMEN COLLECTION, AND POPULATION MONITORING PROTOCOLS FOR BARRED OWLS

Removal Protocols. To better understand the impact of barred owls on northern spotted owl populations, as well as to explore feasible and effective options for managing invasive barred owls, the U.S. Fish and Wildlife Service (USFWS) released a final Environmental Impact Statement (EIS) and Record of Decision approving the experimental removal of barred owls in areas of Washington, Oregon, and northern California (USFWS 2013). Included in the EIS are specific guidelines for experimental removal of barred owls (USFWS 2013, Appendix D). The goals of these guidelines are to ensure safety precautions for humans, humane treatment of all affected barred owls, and to minimize risk of unnecessary injury to barred owls or non-target species. The USFWS (2013) guidelines were subsequently updated when the project was implemented (J.D Wiens, *personal communication*). While the circumstances for future barred owl removal studies in other parts of the spotted owl's range may be different (e.g., changing the rationale for seasonal or hybrid restrictions; *see below*), the aforementioned removal protocols developed for existing studies represent a reasonable starting point for new projects.

Specimen Collection Protocols. Barred owl carcasses obtained from removal experiments provide an unusually comprehensive sample from wild populations of a top predator in the western U.S. As work continues and specimens amass, these collections will become increasingly valuable to ecologists, evolutionary biologists, pathologists, and many other research groups. Thus, there is a responsibility to ensure that representative samples are banked for as many individuals as possible. We recommend that researchers preserve all of the key materials from collected specimens that will potentially be useful for addressing as many research objectives as possible. The development and implementation of standardized sample collection and storage protocols for barred owls will require additional deliberation. Further, the collection of potentially large numbers of barred owls across the range of the spotted owl will inevitably be conducted by multiple research groups, requiring concerted coordination among involved scientists and permitting agencies to ensure the consistency of sample collection and preservation. Finally, the collection of large numbers of barred owls will require identifying research museums capable of archiving and storing large collections.



Population Monitoring Protocols. We recommend development of well-designed monitoring programs that quantify changes in barred owl populations caused by experimental removals. Monitoring designs should have the capability to quantify potential recolonization of barred owls following removal activities. The current approach for monitoring barred owls in the Pacific Northwest involves repeated occupancy surveys within a hexagonal sampling grid overlaid across the area of interest (e.g., Wiens et al. 2011, 2018). This approach is currently being used to track the effects of experimental removals on barred owls within the range of the northern spotted owls using call-broadcast surveys (Wiens et al. 2018), and in the Sierra Nevada portion of the California spotted owl's range using passive acoustic surveys (Wood et al. *in press*). Broadcast calling likely increases detection probabilities, thus reducing the number of surveys required to confirm occupancy, but also requires trained field staff conducting nighttime fieldwork. Passive acoustic surveys, on the other hand, may yield relatively low detection probabilities (depending on deployment duration and the number of recording units deployed), but can be cost-effective at large spatial scales, particularly in the context of monitoring trends in occupancy over time. Additional work is needed to evaluate the relative efficacy of these two approaches for meeting a range of study objectives, including confirming the occupancy of individual sites of interest and occupancy at range of spatial scales.

In practice, monitoring methods will inevitably vary according to study objectives and environmental context, but the standardization of methods – to the extent possible – will enable comparative assessments of project success and integration of comparable data in future meta-analyses. Such an approach has been successful in monitoring northern spotted owl populations across their geographic range (e.g., Dugger et al. 2016). Moreover, the landscape-scale monitoring of barred owls is challenging, and future projects would benefit from the careful consideration of survey design. Pilot studies and statistical power analyses would help ensure that studies are efficient and have a high probability of success.

SEASONAL AND HYBRID RESTRICTIONS IN REMOVAL EXPERIMENTS

Seasonal Restrictions. Current protocols for the experimental removal of barred owls prohibit collection of nesting barred owls with dependent young (USFWS 2013). Because of difficulties and additional costs in determining nesting status of barred owls, current experiments are limited to conducting removals primarily during the nonbreeding season (approximately September–March). As specified by USFWS (2013), however, removal of non-nesting barred owls is permitted during the breeding season in cases where observers have high confidence in determining nesting status of individuals detected. Accordingly, current studies have begun conducting spatially limited removals of barred owls during the breeding season at sites where rapid (2–3 week) recolonization by barred owls is followed by removals conducted during the peak in colonization in early spring (March–April; Wiens et. al. 2018).

Restrictions on the removal of nesting barred owls may present unique challenges in portions of California that receive large amounts of snow and have limited access during the non-breeding season. This problem is particularly acute in the northern Sierra Nevada where barred owls are currently most abundant within the range the California spotted owl. Limiting removals to the non-breeding season (or pairs unlikely to be breeding) in this region may significantly constrain the ability to implement experimental removals and potentially lead to safety issues associated with nighttime, winter work in mountainous terrain. In this case, relaxing breeding season removals may be required to meet the objectives of removal studies (e.g., quantifying barred owl recolonization patterns) in this area.

Hybrid Restrictions. Hybrids between barred owls and northern spotted owls are rare in areas dominated by barred owls and thus, not a target of current removal experiments within the range of the northern spotted owl. However, hybrids are more common in the early stages of barred owl range expansion and are frequently detected within the Sierra Nevada portion of the California spotted owl’s range (Keane 2017). Thus, meeting the objectives of removal studies – such as quantifying recolonization rates of barred owls and understanding the effects of hybridization on spotted owls – may require removal of hybrids in other regions. In addition, samples from hybrids are needed to learn more about hybrid identification and genetics to meet research objectives described above (see *Understanding barred owl/spotted owl hybrids and genetics*).

It is important to note that even first-generation hybrids (one parent of each species) can be difficult to distinguish from barred owls and spotted owls, presenting a challenge for removal. While many first-generation hybrids exhibit intermediate physical or vocal characteristics, these characteristics can be difficult to identify under removal conditions which do not provide an opportunity to inspect individuals “in hand” prior to removal. As such, we recommend the development of a hybrid removal protocol that ensures that only barred owls and hybrids are removed, and that the risk of removing spotted owls is negligible. Moreover, if a removed owl appears to be a hybrid upon examination, the specimen should be tagged for genetic and morphological analyses. All confirmed incidences of the removal of hybrids should be reported to the USFWS as part of required annual reports, which are not considered “take” of spotted owls under the U.S. Endangered Species Act (USFWS 2013).

CONTRIBUTION OF PRIVATE LANDS TO BARRED OWL

RESEARCH AND MANAGEMENT

Within California, private and state lands comprise a substantial portion of the range and potential habitat for both northern and California spotted owls (USFWS 2011, Calforests 2014). In areas containing limited federal ownership, state and private lands may provide areas essential to spotted owl populations and promote population connectivity (USFWS 2011). As such, the development of landscape-scale collaborative conservation efforts, such as integration of barred owl removal experiments across multiple landownerships could benefit spotted owl populations considerably (Romañech et al. 2016). Inclusion of barred owl removal experiments in Habitat Conservation Plans could help achieve objectives in the Northern Spotted Owl Recovery Plan (USFWS 2011). Moreover, the development of Safe Harbor Agreements, as was done in Oregon (USFWS 2017), could foster new partnerships with landowners to participate in landscape-scale experiments that support or attract listed species without the negative effects of future property-use limitations (USFWS 2011). Most broadly, the BOST emphasizes the benefits of maintaining or developing collaborative conservation agreements with private landowners through existing agreements or future opportunities to ensure that removal studies are consistent and comparable across regions and ownerships within California.

PUBLIC AND STAKEHOLDER OUTREACH

Any activity that involves removal of animals from the wild, particularly charismatic species like owls, is controversial, regardless of whether it is for scientific research or conservation purposes. In such cases, outreach to interested stakeholders at the early stages of the proposal is crucial to our ability to implement the actions. While members of the public may be uncomfortable with the concept of removing owls from the wild, they are more likely to accept the necessity of the action if they understand the urgency and importance of the research. Early communication and education of interested stakeholders is a crucial part of implementation of any project involving removal of barred owls from the wild, whether that removal is lethal or non-lethal. Thus, we encourage agencies, if they accept and fund the recommended research needs described herein, to include public outreach as an early and important step in implementation of new experimental removal studies.

PERMITTING CONSIDERATIONS FOR EXPERIMENTAL REMOVALS

Removal of Barred Owls for Scientific Purposes under Federal Law. Barred owls are protected under the Migratory Bird Treaty Act (MBTA) and are included in the Migratory Bird Treaty with Mexico. The law does not specifically distinguish between species within their historical range and those that are found in areas where they did not historically occur, even when they are considered invasive or have been transplanted by humans. Under the MBTA, the USFWS can issue a Migratory Bird Scientific Collecting to authorize collection, transportation or possession of migratory birds, their parts, nests, or eggs for scientific research or educational purposes. The current barred owl removal experiments in the range of the northern spotted owl

operate under such a permit. This is also the appropriate permit for the research described in this document. To issue a Scientific Collection Permit under the MBTA, the USFWS must document: (i) the removal is necessary to meet the research objectives, and that other methods would not suffice and (ii) whether or not the potential benefits of the proposed action outweigh the risks to the human environment identified through the environmental analysis, are scientifically justifiable, and thus warrant approval and implementation.

All permits issued under the MBTA are federal actions, requiring National Environmental Policy Act (NEPA) compliance. NEPA compliance may include categorical exclusions, environmental assessments, or environmental impact statements, depending on the level of impact of the proposed activity. Categorical exclusions are for federal actions that do not have a significant effect on the human environment, have been found to have no such effect, and for which neither an environmental assessment nor an environmental impact statement is required. Categorical exclusions do not require formal public involvement and can be completed in a few weeks. Environmental assessments are used to determine whether the Federal actions will have a significant effect on the human environment. This should be a concise public document that briefly discusses the purpose and need for an action, describes alternatives to such action, and provides sufficient evidence and analysis of impacts to determine whether to prepare an environmental impact statement or finding of no significant impact. Environmental assessments require some public involvement but have fewer steps than an environmental impact statement (EIS). Because of the shorter process and more limited effects, environmental assessments can usually be done in less than one year. For federal actions that may have a significant effect on the human environment, the agency prepares an EIS. An EIS is a detailed written statement analyzing the environmental impacts of a proposed action, adverse effects of the project that cannot be avoided, alternative courses of action, short-term uses of the environment versus the maintenance and enhancement of long-term productivity, and any irreversible and irretrievable commitment of resources. An EIS is the most inclusive NEPA documentation and requires more process steps, including expanded public involvement. Because of the longer process and greater effects requiring analysis, EIS development often takes longer than one year.

Removal of Barred Owls for Scientific Purposes under California State Law. California State law protects all raptors, including barred owls, regardless of whether they were historically not found in California or are invasive. Specifically, California Fish and Game Code states, “[i]t is unlawful to take, possess, or destroy any birds in the orders Falconiformes or Strigiformes (birds-of-prey) or to take, possess, or destroy the nest or eggs of any such bird except as otherwise provided by this code... (§ 3503.5).” In addition, [a]ll birds occurring naturally in California that are not resident game birds, migratory game birds, or fully protected birds are nongame birds. It is unlawful to take any nongame bird except as provided in this code...” (Fish and Game Code, § 3800, subd. (a). There are some exceptions, one being the ability to permit take “through a scientific collecting permit issued for scientific, educational, or non-commercial propagation purposes (Fish and Game Code, § 3800, subd. (a)). For the research priorities describe herein, permits would be issued under this provision.

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