



Vulnerability Assessment and Conservation Recommendations for the Northern Spotted Owl in Marin County, California



Northern Spotted Owl (*Strix occidentalis caurina*) in Marin County, California

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Vulnerability assessment and conservation recommendations for the northern spotted owl in Marin County, California

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Abstract

Vulnerability assessments are a common approach to identifying conservation priorities for species and informing resource management decisions by evaluating species' exposure (spatial extent and frequency/intensity) and sensitivity (whether and how a species will respond) to a threat. We assessed the vulnerability of the Northern Spotted Owl (NSO; *Strix occidentalis caurina*) in Marin County to eight distinct threats: 1) competition with Barred Owls (*S. varia*); 2) climate change; 3) wildfire; 4) sudden oak death (SOD); 5) other habitat loss/disturbance, specifically from urban development or fuels management; 6) noise disturbance; 7) rodenticide poisoning; and 8) disease. Specifically, we reviewed evidence from published literature for the relative vulnerability of NSOs to each potentially relevant threat in the region; surveyed local experts on the relative vulnerability of NSOs to each potential threat; ranked the vulnerability of NSOs to each threat in Marin County; and made conservation recommendations. We identified three threats to which NSOs are currently most vulnerable in Marin County: climate change, competition with Barred Owls, and wildfire (specifically high-severity fires); exposure to each of these threats is expected to increase over the next 30–50 years. We identified rodenticides and SOD as moderate threats, and habitat loss (from urban development and fuels management), noise disturbance, and disease were identified as the lowest relative threats. However, except for urban development, the local experts' confidence in their assessment of the sensitivity of NSOs to the lower-ranked threats was low, suggesting a need for further research. Conservation recommendations include: continued habitat protections that consider NSOs and dusky-footed woodrat (*Neotoma fuscipes*) habitat on a landscape scale; management of Barred Owls to maintain the current low level of exposure; continued avoidance of noise disturbance to nesting NSOs; and community education and outreach efforts to help reduce the threat of rodenticides, noise, and other types of human disturbance. We identified research needs and uncertainties including evaluating the response of NSOs and their prey in Marin County to: weather and climate, including extreme events; habitat change including to fuels management and SOD; and noise and other human disturbance. Conservation actions to protect NSOs and the habitat and prey on which they depend, and outreach to local communities and land managers will be an essential part of the future health of this population.

Executive Summary

The effective conservation and management of species requires understanding the threats they face, and how those threats might change over time. Vulnerability assessments are a common approach to identifying conservation priorities and informing resource management decisions by evaluating species' exposure (spatial extent and frequency/intensity) and sensitivity (whether and how a species will respond) to a threat. We assessed the vulnerability of the Northern Spotted Owl (NSO; *Strix occidentalis caurina*) in Marin County to eight distinct threats: 1) competition with Barred Owls; 2) climate change; 3) wildfire; 4) sudden oak death (SOD); 5) other habitat loss/disturbance, specifically from urban development or fuels management; 6) noise disturbance; 7) rodenticide poisoning; and 8) disease. Marin County, California supports one of the highest known densities of NSOs within their range and is currently relatively stable—unlike in most other areas across their range—making this an area of particular conservation interest. Our objectives were to 1) review evidence from published literature for the relative vulnerability of NSOs to each potentially relevant threat in the region; 2) survey local experts on the relative vulnerability of NSOs to each potential threat; 3) rank the vulnerability of NSOs to each threat in Marin County; and 4) make conservation recommendations. We considered the vulnerability of NSOs for the entire county—rather than on National Park Service (NPS) lands only as is more typical for reports in this NPS Natural Resources Report series—because the influence of conservation actions or management of this small population extends beyond NPS boundaries. Additionally, regional long-term monitoring and partnerships among agencies and non-profit organizations in Marin County have resulted in our ability to assess NSOs on a broader scale more relevant to their conservation than limiting the study to any single land ownership.

Combining data from the expert survey with evidence from the scientific literature, we identified three threats to which NSOs are currently most vulnerable in Marin County: climate change, competition with Barred Owls, and wildfire (specifically high-severity fires); each of these threats is expected to increase over the next 30–50 years. We identified rodenticides and SOD as moderate threats, and habitat loss (from urban development and fuels management), noise disturbance, and disease were identified as the lowest relative threats. However, except for urban development, the local experts' confidence in their assessment of the sensitivity of NSOs to the lower-ranked threats was low. Experts expected NSOs in Marin County to have stable or increasing exposure to all the threats we considered in the future, with the possible exception of rodenticides to which future exposure was expected to be stable or decreasing.

Conservation recommendations include: continued habitat protections that consider NSOs and dusky-footed woodrat habitat on a landscape scale; management of Barred Owls to maintain the current low level of exposure; continued avoidance of noise disturbance to nesting NSOs; and community education and outreach efforts to help reduce the threat of rodenticides, noise, and other types of human disturbance. Research needs and uncertainties include evaluating the response of NSOs and their prey in Marin County to: weather and climate, including extreme events; habitat change including to fuels management and SOD; and noise and other human disturbance. We also recommend testing any dead NSOs or Barred Owls for rodenticides to help understand their exposure

to this threat. Past and continued protection of the mosaic of habitats that are essential to NSOs and their prey, the low number of Barred Owls, and disturbance-avoidance during the nesting season have likely contributed to the stable population in this region. Monitoring programs such as the cross-agency long-term program in Marin County is essential to our understanding of this species' local status, and to detect early warning signs of declines. Conservation actions to protect NSOs and the habitat and prey on which they depend, and outreach to local communities and land managers will be an essential part of the future health of this population.

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Introduction

The Northern Spotted Owl (NSO; *Strix occidentalis caurina*) is a subspecies of the Spotted Owl associated with mature coniferous forests (Forsman et al. 1984) that ranges from southern British Columbia to Marin County, California. The NSO was listed by the U.S. Fish and Wildlife Service (USFWS) as a federally threatened subspecies in 1990, with declines mostly attributed to habitat loss, and due to continued declines (Forsman et al. 2011, Dugger et al. 2016), is also listed as state threatened in California. The USFWS now identifies habitat loss—including lag effects of past loss and continued timber harvest and wildfire—and competition from the Barred Owl (*S. varia*) as the primary threats to the continued survival of the NSO (USFWS 2023a). The historic range of the Barred Owl was once limited to the forests of eastern North America, but after a range expansion westward that now includes the entire range of the NSO, their presence has caused displacement of NSOs, competition with NSOs for space and food, and negative impacts on NSO demographics (Gutiérrez et al. 2007, USFWS 2011, Wiens et al. 2014, Franklin et al. 2021). The Barred Owl is now considered to be an invasive species in the NSO range by the USFWS (USFWS 2023b).

Long-term monitoring of NSOs in Marin County, at the southernmost edge of their range, began in 1999 as local public land agencies began to track long-term trends in occupancy and reproductive success on their lands and adjacent properties. The Marin County study area supports one of the highest known densities of NSOs within their range (Chow 2001, Blakesley et al. 2004, Stralberg et al. 2009) and is currently relatively stable (Brown et al. 2023, Ellis 2020), making this an area of particular conservation interest. However, NSOs in Marin County face a distinct combination of conservation concerns from elsewhere in their range. For example, they are not impacted by commercial tree harvesting operations as in many other parts of their range, and instead, habitat loss and disturbance is more likely to come from their proximity to the wildland-urban interface and residential areas (Stralberg et al. 2009). They are primarily found in second growth and old growth coast redwood (*Sequoia sempervirens*), Douglas fir (*Pseudotsuga menziesii*), and bishop pine (*Pinus muricata*) habitats, but some are also found in mixed evergreen hardwood forests, a forest type not typically associated with NSOs nor as common in other parts of their range (Stralberg et al. 2009, Lesmeister et al. 2018). Similar to other parts of the NSO range in California and southwest Oregon (Gutiérrez et al. 2020), the primary prey for NSOs in this area is the dusky-footed woodrat (*Neotoma fuscipes*; Chow and Allen 1997, Fehring 2003). The NSO population in Marin is genetically isolated from populations to the north (Barrowclough et al. 2005) possibly due to a gap in contiguous forest coverage, which may also contribute to the relatively low number of Barred Owls to date. Additionally, the NSO population in Marin is relatively small, with approximately 140 territories identified so far, and though much of the potential habitat is included in the long-term monitoring efforts, there is potential habitat on both private and public lands that has either never been surveyed to determine whether NSOs are present or is not surveyed annually.

The effective conservation and management of species requires understanding their life histories, the threats they face, and how those threats might change over time. Vulnerability assessments are a common approach to identifying conservation priorities and informing resource management decisions by evaluating a species' exposure, sensitivity, and adaptive capacity to a given threat

(Williams et al. 2008, Foden et al. 2018). Exposure represents the magnitude of the threat, such as the frequency or intensity with which a species experiences the threat, and sensitivity and adaptive capacity represent the species' ability to withstand the threat (Still et al. 2015). Recent vulnerability assessments in conservation have frequently aimed to compare species' vulnerability to a common threat, like climate change (Gardali et al. 2012, Still et al. 2015), while a vulnerability assessment for a single species comparing multiple threats can help identify which threat(s) a species may be most vulnerable to, and where management actions may be most effective.

Range-wide threats to NSOs have been described previously (Noon and Blakesley 2006, Lesmeister et al. 2018, Wan et al. 2018), but the unique habitat associations of NSOs in Marin County, their location at the edge of the range, their relative isolation from other populations of NSO, and their association with the wildland-urban interface warrant an independent vulnerability assessment to inform local conservation and management decisions. Here, we report on the results of a vulnerability assessment for NSOs in Marin County. Although this vulnerability assessment was driven by an initial interest in threats to NSOs within the Golden Gate National Recreation Area (GGNRA), Point Reyes National Seashore (PRNS), and Muir Woods National Monument (MUWO) specifically, because this population is relatively small and threats to any portion of the county's NSO population could have impacts on the NSOs within NPS lands, we considered threats to NSOs for the entire county. Specifically, our objectives were to 1) review evidence from published literature for the relative vulnerability of NSOs to a range of potential threats relevant in the region; 2) survey local NSO experts on the relative vulnerability of NSOs to each potential threat; 3) rank the vulnerability of NSOs to each threat in Marin County; and 4) make conservation recommendations for land managers and others invested in NSO conservation in the county.

Methods

Study Area

The study area for this vulnerability assessment is at the southernmost extent of the NSO range in Marin County, California (Figure 1). NSO habitat in Marin County is under many different land managers and ownerships, including California State Parks (CSP), Marin County Parks (MCP), Marin Water, NPS (including PRNS and the GGNRA which includes MUWO), local municipalities, and private landowners. The climate is characterized by cool, rainy winters, and warmer, dry summers. Vegetation at study sites included forests of Douglas fir (*Pseudotsuga menziesii*), coast redwood (*Sequoia sempervirens*), bishop pine (*Pinus muricata*), and mixed evergreen hardwood forests including bay laurel (*Umbellularia californica*), tanoak (*Notholithocarpus densiflorus*), and coast live oak (*Quercus agrifolia*); the coniferous forests often also have a hardwood component of the previously mentioned species.

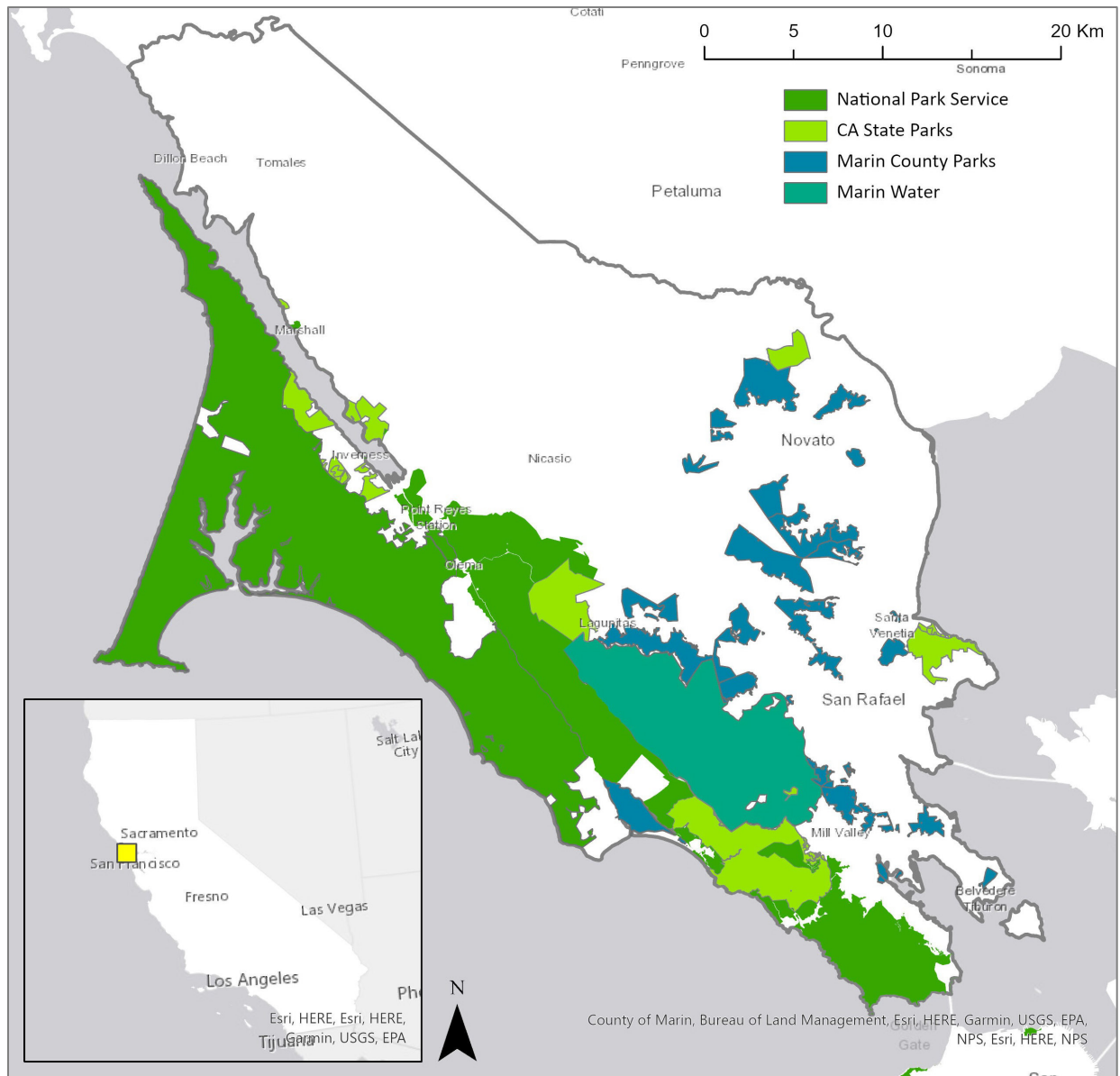


Figure 1. Marin County study area showing the major public landowners in the county where most Northern Spotted Owl monitoring occurs: National Park Service (Point Reyes National Seashore, Golden Gate National Recreation Area, including Muir Woods National Monument), California State Parks, Marin County Parks, and Marin Water. The county boundary is outlined in dark grey. Inset map of California shows the extent of the larger map in yellow.

Assessing Vulnerability

We assessed the vulnerability of NSOs in Marin County to eight distinct threats: 1) competition with Barred Owls; 2) climate change; 3) wildfire, with a focus on high-severity fire; 4) sudden oak death; 5) other habitat loss/disturbance, specifically from urban development or fuels management (i.e., fuels reduction); 6) noise disturbance; 7) rodenticide poisoning; and 8) disease, including Highly Pathogenic Avian Influenza (HPAI). Threats were determined based on the expert opinions of the authors and based on previously identified threats to NSO (e.g., Courtney et al. 2004, Lesmeister et

al. 2018) and specifically for Marin County (Cormier et al. 2023). We considered both their sensitivity and exposure to each threat when evaluating vulnerability. We defined sensitivity as whether NSO populations are likely to be affected by exposure to a given threat in Marin County, and if so, how (e.g., impacts to their survival, reproduction, habitat availability, or prey). Exposure considers the magnitude, frequency, and spatial extent over which NSOs experience each of these potential threats in Marin County, both now and in the future.

We assessed their sensitivity and exposure to each threat by 1) conducting a literature review of known impacts to NSOs from each threat, and 2) surveying local NSO experts on their assessments of the sensitivity and exposure of each threat to NSOs, specifically in Marin County. In addition to sensitivity and exposure, a third major component of vulnerability assessments is adaptive capacity (Wade et al. 2016), the ability of a species or population to cope with or adapt to a threat or change. When vulnerability assessments are designed to compare the relative vulnerability of different species or populations to a given threat, the factors considered to influence a species' adaptive capacity include those that could increase or compound their vulnerability (e.g., small population size, limited genetic diversity, limited dispersal ability, narrow dietary requirements) or those that could buffer impacts or allow them to adjust to a given threat (e.g., phenotypic plasticity which could allow the species to respond to changes in timing of important resources, such as a shift in peak prey availability; Foden et al. 2018). In this vulnerability assessment, we are not comparing the relative vulnerability of different species, and although the adaptive capacity of NSOs in Marin to individual threats is uncertain, the factors that influence their adaptive capacity are expected to be relatively constant across the county, regardless of the threat under consideration. Therefore, we did not address adaptive capacity for each threat for NSOs, only their adaptive capacity as a whole.

Literature Review

To synthesize the scientific literature on NSOs and each of the 8 potential threats we identified, we adapted a protocol for rapid evidence assessment (Varker et al. 2015). For each threat, we conducted a separate rapid evidence assessment of the scientific literature, following a consistent process of defining the search strategy, screening the literature using predetermined criteria for inclusion or exclusion, and extracting information.

Specifically, we first identified candidates for inclusion in our literature review by using Google Scholar's "Advanced Search" in the fall of 2023 with "Northern Spotted Owl" entered into the "with the exact phrase" field and other search terms we identified for each threat entered into the "with at least one of the words" field (Table 1). We used Google Scholar's search algorithm to identify the 100 most relevant results for each threat for further screening, using predefined criteria for inclusion or exclusion:

- **Scope:** Studies focused on impacts to NSOs by the potential threat were included. Impacts could include changes in population dynamics (e.g., occupancy, reproduction, survivorship), behavior (e.g., vocalizations, maintenance), prey availability, or habitat availability.
- **Study Type:** Peer-reviewed articles describing meta-analyses, reviews, and empirical studies with field observations were included. Formally refereed technical reports (e.g., General Technical Reports) were also included. We only included modeling studies if the threat under

investigation was otherwise difficult to empirically assess. We excluded conference proceedings, white papers, and book chapters which are not typically peer-reviewed and can be difficult to access online. In some cases, we included relevant dissertations or master's theses if the work was not also published in a peer-reviewed article, or the article was published but not available (see below).

- **Geography & Subspecies:** We prioritized studies of NSOs in California. If studies were lacking for NSOs in California, we included studies from anywhere in the range from the original 100 most relevant results, reviewing and drawing first from NSO research outside of California, next from research related to California Spotted Owls (CSO; *S. o. occidentalis*), and then Mexican Spotted Owls (MSO; *S. o. lucida*), but kept the focus when possible on published literature specific to NSOs.
- **Time Period:** We did not limit the publication years in our search.
- **Language:** We intended to limit results to studies written in English, to allow the project team to interpret accurately, although all the studies in our search results were in English.
- **Availability:** We limited results to publications whose full text was available through the UC Davis library system.

Table 1. Search terms in Google Scholar for the literature review for each pre-selected threat in the vulnerability assessment for Northern Spotted Owls in Marin County, California. Terms were entered using the Advanced Search option; “Northern Spotted Owl” was entered into the “with the exact phrase” field and other listed search terms were entered into the “with at least one of the words” field.

Potential Threat	Search Terms
Barred Owls	Barred Owl
Climate Change	Rain, temperature, drought, atmospheric river, extreme weather, heat, precipitation
Disease	Highly Pathogenic Avian Influenza, West Nile Virus, parasite, avian malaria, disease
Habitat Loss/Disturbance (urban development, fuels management)	Urban development, fuel reduction, fuel break, prescribed fire
Noise Disturbance	Noise disturbance, noise pollution, noise level, anthropogenic noise
Rodenticide Poisoning	Rodenticide, poison
Sudden Oak Death	Sudden oak death, <i>Phytophthora ramorum</i>
Wildfire	Wildfire, burn severity

After the initial screening, we then re-reviewed titles and abstracts, and read the full text as needed to further evaluate which papers were suitable for inclusion, for which we extracted the following information from each paper:

- **Study Area:** The location where the study occurred.
- **Subspecies:** NSO, CSO, or MSO.

- **Study Type:** The general study methodology, such as meta-analysis, review paper, or empirical study.
- **Aim of study:** Stated goal of the study.
- **Impact of the threat:** \pm or no evidence of an effect.
- **Overall conclusion:** stated by study authors.
- **Notes on methodology:** years of data collection, sample size, other relevant field or analytical notes.

In a few cases, we added additional papers when the initial search did not include a relevant paper, if there was one that was known to the authors or cited in a paper from the original search.

Barred Owl Mapping

For the Barred Owl threat, in addition to the literature review, we also compiled and mapped Barred Owl detection location data from Marin County and nearby Sonoma and Napa counties to better understand their spatial distribution on a regional scale because these areas are a potential source of Barred Owl dispersal into Marin County. We accessed NSO observations through the California Natural Diversity Database (CNDDDB; CDFW 2023) and CNDDDB Barred Owl observations were shared by California Department of Fish and Wildlife staff via email (ds8, version 33 updated April 28, 2023). We also acquired Barred Owl data from the Global Biodiversity Information Facility (GBIF; GBIF 2023), eBird (eBird Basic Dataset 2023), and iNaturalist (iNaturalist Community 2023). For each of these databases, we queried for observations of Barred Owls in California from all years, downloaded datasets, and filtered for data from Marin, Napa, and Sonoma Counties. Data submitted through eBird are automatically subjected to evaluation, particularly for unusual observations (e.g., rare species), and for iNaturalist data, we included only Barred Owl records that met criteria for research grade status, meaning the observer included a date, coordinates, a photo or recording, and at least 2/3 observers agreed with the identification of the species. Since GBIF contains data submitted through eBird and iNaturalist (also research grade), there is significant overlap in these datasets; however, GBIF also contains unique records from other sources (e.g., California Academy of Sciences), and several submissions to eBird and iNaturalist were absent from GBIF at the time of download. We also accessed Breeding Bird Survey data to check for Barred Owl detections in that dataset for the two routes in Marin County (Fairfax and Point Reyes), three routes in Sonoma County (Bodega Bay, Fish Rock, and Mark West), and three routes in Napa County (Glenn Ellen 2, Glenn Ellen, and Rumsey—the latter two routes are no longer active) and found no detections of Barred Owls in this dataset. We requested additional Barred Owl data from seven biologists conducting NSO surveys in this region. Of the four groups who shared their data, two had overlapping datasets from their collaborative work in the region. In total, we received contributing datasets from D. Hofstadter (unpublished data), The Wildlands Conservancy’s Jenner Headlands Preserve (unpublished data), and Environmental Resource Solutions, Inc (unpublished data). The date that each dataset was downloaded or received, and the time period of each dataset is presented in Appendix A.

We mapped all Barred Owl observations (1989–2023) alongside NSO observations (1900–2023) in Marin, Napa, and Sonoma Counties. We further evaluated each record from the community science sources (eBird, iNaturalist, GBIF) to confirm the species identification for inclusion in the map. We omitted detections of Unknown *Strix* species (4 records) and feathers-only detections (2 records). We included two suspected Spotted x Barred Owl hybrids (one in Marin, one in Sonoma) with the Barred Owl observations. Due to the nature of the data sources, the locations submitted with each record may be approximate rather than exact (e.g., eBird hotspots or NSO survey call stations). However, approximate locations are adequate for assessing the general distribution and abundance of Barred Owls in the region as a threat to NSOs in Marin. We scaled maps in accordance with CNDDB guidelines that require owl location data be displayed at a scale no more zoomed-in than 1:350,000 (CDFW 2011).

Expert Survey

To gather additional input on the relative sensitivity and exposure of NSOs to each threat in Marin County, we independently surveyed 13 individuals with local expertise on NSOs and their habitats, including the 6 authors of this report. We structured the survey to assess the relative sensitivity and exposure of NSOs to each threat, with some threats broken down into multiple components so they could be assessed separately. For example, climate change was broken down into separate more-specific threats of extreme temperatures, extreme storms (e.g., atmospheric rivers), and extreme drought, while for habitat disturbance, experts were asked separately about potential impacts of urban development, and forest health and fuels management.

When taking the survey, experts were first given a short summary of threats to review (Appendix B) and asked if there were any other threats that should be considered in our vulnerability assessment. Second, experts were asked to rank the relative sensitivity of NSO populations to each threat, in terms of how often they expected that exposure to the threat would result in negative impacts to each of five sensitivity factors: survival, nesting likelihood, fecundity, prey availability, and habitat availability. Experts ranked each threat for each sensitivity factor using a defined scale representing the likelihood of a negative impact from exposure to the threat: 1 = impacts uncommon (<10% of exposures expected to result in a negative impact), 2 = impacts common (10–50% of exposures), or 3 = impacts frequent (>50% of exposures). Third, experts were asked to score the current and anticipated future exposure of NSOs to each potential threat specifically in Marin County. The current exposure to each threat was scored in terms of both spatial extent and frequency/intensity using a similar scale as for the sensitivity factors. For exposure based on spatial extent, experts scored threats as: 1 = limited (<10% of NSO territories exposed), 2 = moderate (10–50%), and 3 = widespread (>50%). For exposure based on frequency/intensity, experts scored threats as: 1 = mild/infrequent (exposure in <10% of years), 2 = moderate/common (10–50%), and 3 = intense/frequent (>50%). Future exposures were scored in terms of whether experts expected the spatial extent or frequency/intensity of each potential threat to change over the next 30–50 years: –1 = decreasing, 0 = stable/little change, and 1 = increasing. In addition, at the end of each of the sensitivity and exposure components of the survey, experts were also asked to rank their overall confidence in their ratings for each potential threat: 1 = very uncertain/little known, 2 = mostly uncertain, 3 = mixed uncertainty/confidence, 4 = mostly confident, and 5 = very confident/well

understood. The survey was implemented as a Google Form, sent to each expert, and completed online in November and December 2023 without access to other experts' results. For each survey question, we summarized survey results by calculating the frequency of each response as well as the mean and standard error (SE) of the expert scores. We generally represented the consensus across experts by rounding the mean value to the nearest rank score (i.e., impacts from exposure were expected to be "uncommon" if the mean was $<10\%$), except where experts were clearly divided.

Ranking Each Threat

To represent the overall vulnerability of NSOs to each threat, we first summarized the scores from the expert survey. Because we found that the mean scores for exposure to each threat in terms of spatial extent was highly correlated with the mean scores for exposure in terms of frequency/intensity, for both current exposure (Pearson's $r = 0.84$, $p = 0.001$) and expected future exposure (Pearson's $r = 0.96$, $p < 0.001$), we simplified current and future exposure scores for each threat as the mean of the scores for spatial extent and frequency/intensity. We then scored the current vulnerability of each NSO sensitivity factor to each threat as the product of the mean sensitivity score and mean current exposure score, such that scores could range from a minimum possible value of 1 to a maximum possible value of 9.

To then summarize the overall vulnerability of NSOs to each threat, including all sensitivity factors, we took the mean of their individual vulnerability scores. However, because climate change was represented by multiple component threats, we first scored the current vulnerability of each NSO sensitivity factor to climate change as the maximum of the individual component scores. We recognized that by taking the mean of the scores for each sensitivity factor, we treated each factor as having equal importance to the NSO population, even though as a long-lived species, changes in survival are expected to have a greater influence on population dynamics than reproductive success. We considered giving each sensitivity factor a different weight, but it was unclear how to weigh impacts to habitat or prey availability relative to survival or reproduction. Therefore, it is possible that the relative rankings of these threats could be further refined to account for the varying importance of each sensitivity factor.

We divided the final overall vulnerability scores for all threats into three equal intervals representing relatively low, moderate, or high threats to NSO populations according to local experts. To represent how exposure to each of these threats may change in the future, we also grouped mean future exposure scores into four groups representing stable to decreasing, stable, stable to increasing, or increasing; none were estimated to be definitively decreasing. We then compared our rankings from the survey data to the results from the literature review to look for differences between the two approaches.

Results

A total of 123 papers met our inclusion criteria in the literature review (n=2–40 for each threat, some of which were repeated across more than one threat). Because we do not cite each paper that met the inclusion criteria in the summary of the literature below, we provide a list of the full literature dataset in Appendix C. In reviewing the literature and the survey data from local experts, we found general alignment and consistency in the assessments of NSO sensitivity to each threat. There was unanimous consensus among experts in their sensitivity and exposure ratings for some threats (e.g., impacts to NSO habitat availability from exposure to high-severity wildfire were expected to be frequent, and increasing exposure of NSOs to climate change in the future), while others had a broader distribution of ratings, but none of the survey results indicated a clear division among experts in their assessment (Appendix D). We found variation among the five sensitivity factors considered in the expert survey in their sensitivity, exposure, and overall relative vulnerability to each threat; none of the threats for any sensitivity factor received the highest possible current vulnerability score of 9 (i.e., with frequent or widespread exposures that would also frequently result in a negative impact; Figure 2).

Based on these survey results and our literature review of each potential threat, we identified three threats to which NSOs are currently most vulnerable, and for which we expect exposure to be increasing in the future: climate change, competition with Barred Owls, and wildfire (specifically high-severity fires; Table 2). We ranked NSO vulnerability to rodenticides and sudden oak death (SOD) as relatively moderate, although local experts had lower confidence in their assessment of the sensitivity of NSOs to SOD (Appendix D, Figure 7), and rodenticides were expected to be stable to decreasing, while SOD was expected to be stable to increasing in the future. The threats we ranked NSOs as relatively least vulnerable to in Marin County were disease, habitat loss due to either fuels management or urban development, and noise disturbance; however, except for urban development, the confidence of the local experts in their assessment of the sensitivity of NSOs to these lower-ranked threats was relatively low (Table 2). In addition, local experts expected NSOs in Marin County to have stable or increasing exposure to almost all the threats we considered in the future (Table 2); they did not expect exposure to any threats to decrease, with the possible exception of rodenticides (Appendix D, Figure 6).

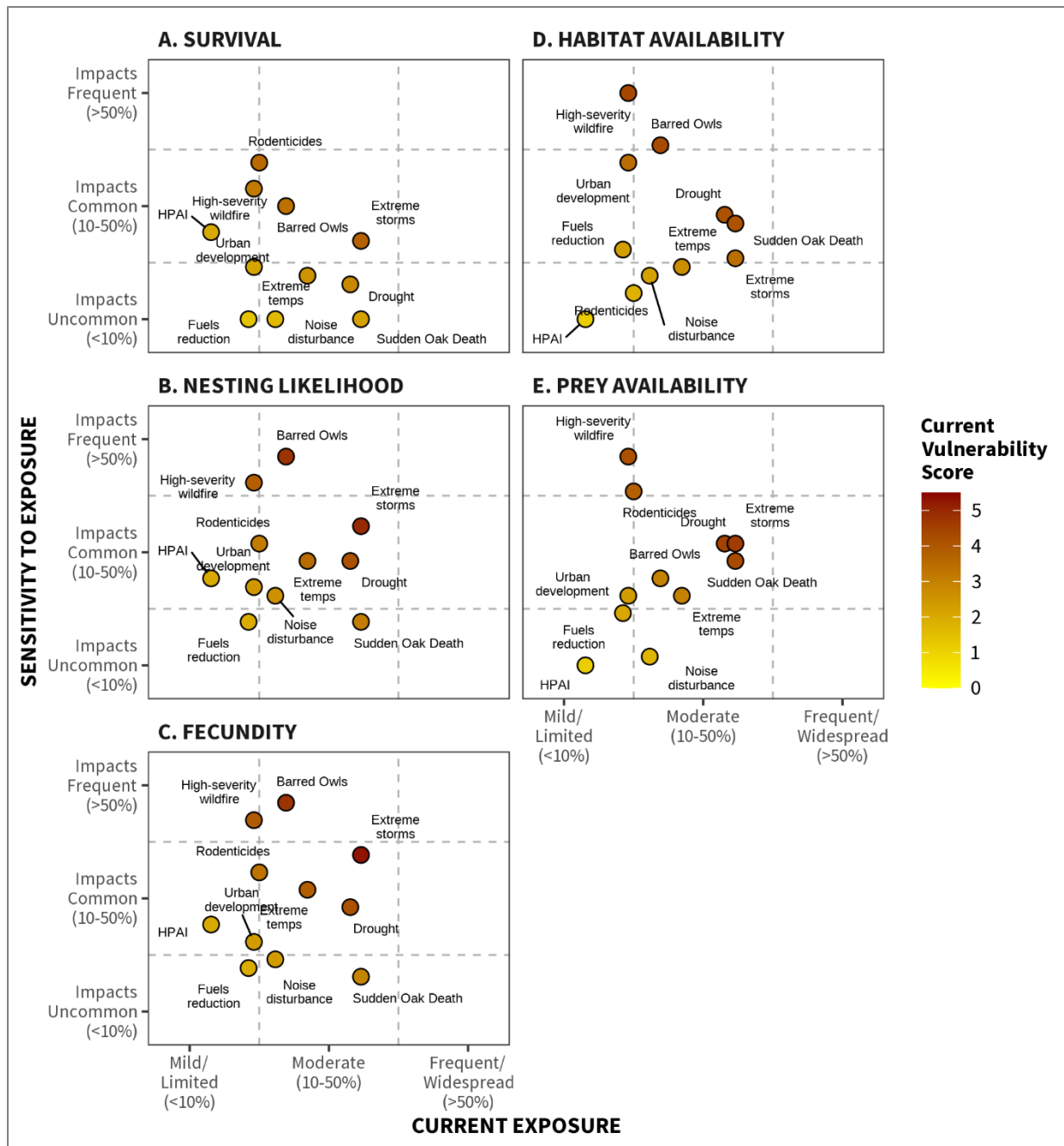


Figure 2. Current vulnerability score presented by each threat to each sensitivity factor for Northern Spotted Owls in Marin County, California, as assessed by local experts (n=13): (A) Survival, (B) Nesting Likelihood, (C) Fecundity, (D) Habitat Availability, and (E) Prey Availability. For each sensitivity factor (A–E), each point represents the mean sensitivity and exposure scores for each threat (see Appendix D, Figures 5–6), and the color represents the current vulnerability score, calculated as the product of sensitivity and exposure scores. Higher values (with darker red color) represent threats to which NSOs are more frequently exposed and/or are more likely to have a negative impact.

Table 2. Relative vulnerability ratings and expected future exposure of Northern Spotted Owls to threats in Marin County, California. Scores are based on a survey of local experts and literature review of each threat. Vulnerability and exposure scores with relatively low confidence scores are shown in brackets.

Potential Threat	Current Vulnerability Rating for Marin County	Expected Future Exposure for Marin County
Barred Owls	High	Increasing
Climate Change	High	Increasing
Disease	[Low]	[Stable]
Noise Disturbance	[Low]	Stable to Increasing
Other Habitat Loss (Fuels Management)	[Low]	Increasing
Other Habitat Loss (Urban Development)	Low	Stable to Increasing
Rodenticides	Moderate	Stable to Decreasing
Sudden Oak Death	[Moderate]	Stable to Increasing
Wildfire	High	Increasing

In the following sections, we summarize the results of the literature review and expert survey for each individual threat, providing evidence for the sensitivity of NSOs to the threat, information about their current and future exposure to the threat in Marin County, and a brief discussion of the relative vulnerability of NSOs to the threat in Marin County. We also folded in discussion of additional threats mentioned by local experts in the survey where they fell under one of the existing threat categories identified. Additional threats mentioned by local experts but not specifically addressed by this vulnerability assessment included: (1) disturbance related to local recreation, including large hiking or cycling events; (2) interactions with dogs, specifically with respect to grounded NSO young; (3) information about NSO locations being shared publicly, leading to frequent visitors to NSO territories; and (4) vehicle strikes.

Barred Owls

Evidence for Sensitivity

Since their listing as a federally threatened subspecies, competition with Barred Owls has emerged as one of the most prominent threats to NSOs (USFWS 2011, Lesmeister et al. 2018). We found evidence in the literature of negative impacts by Barred Owls on many aspects of NSO population dynamics, including survival, occupancy, recruitment rates, breeding dispersal distances, and the overall rate of population change. In range-wide studies from long-term demography sites, the effects of negative impacts from Barred Owls on NSO survival have become more evident over time: Anthony et al. (2006) found evidence of negative impacts to survival in 3 of 14 study areas, Dugger et al. (2016) later found strong evidence of negative impacts to survival in 10 of 11 study areas (three study areas had been dropped since Anthony et al. 2006), and Franklin et al. (2021) found Barred Owl presence to be the primary factor impacting survival of NSOs. Further, removal of Barred Owls from study areas across the NSO range resulted in a strong positive response in NSO survival (Wiens et al. 2021), and NSOs at sites with Barred Owl removals in northern California had higher survival

than at sites without removals (Diller et al. 2016). In some cases, the same banded individual NSOs were found to re-occupy a site after Barred Owl removals (Diller et al. 2016).

In several occupancy analyses, site extinction rates for NSOs were generally higher and/or colonization rates lower at sites with Barred Owls in many study areas across the range (Olson et al. 2005, Kroll et al. 2010, Dugger et al. 2011, Sovern et al. 2014, Diller et al. 2016, Dugger et al. 2016, Franklin et al. 2021). Overall occupancy rates have also been negatively impacted by Barred Owl presence: in a study in Oregon, Kelly et al. (2003) found that occupancy was lower if Barred Owls were detected within 0.8 km of the NSO territory center (for sites not occupied by NSOs, the territory center was from the most recent occupied year), and there were marginal declines in occupancy if Barred Owls were 0.8–2.4 km away. In addition, recruitment rates were negatively impacted by Barred Owl presence (Glenn et al. 2010, Franklin et al. 2021); and breeding dispersal distance for NSOs (i.e., the movement of individuals between successive breeding locations) was positively associated with Barred Owls (Jenkins et al. 2019, Jenkins et al. 2021), which may have been due to the need for NSOs to go farther to find mates (Jenkins et al. 2021). However, in a study from Oregon and Washington, Hollenbeck et al. (2018) did not find any influence of Barred Owls on the dispersal distance of young birds from their natal site to their first attempted breeding location.

The effects of Barred Owls on NSO reproduction have been somewhat more variable. For example, in northern California, Diller et al. (2016) found no evidence for differences in fecundity (number of young per female) between treated sites (where Barred Owls were removed) and untreated sites, although more young overall were produced in the treated areas due to a higher number of occupied sites. There was also little evidence for an impact of Barred Owls on fecundity in a range-wide study (Dugger et al. 2016), but breeding rates and the probability of successful reproduction have been negatively associated with Barred Owl presence in other studies spanning the NSO range (Glenn et al. 2011a, Mangan et al. 2019, Rockweit et al. 2023). Further, in a study in Oregon, Wiens et al. (2014) found that the number of NSO fledglings increased with increasing distance to Barred Owl territory centers, and all ($n = 5$) nesting attempts within 1.5 km of a Barred Owl territory center failed. Barred Owl presence was the primary factor that negatively impacted the rate of population change in the most recent range-wide demographic study (Franklin et al. 2021); and in a range-wide Barred Owl removal experiment, the rate of population change for NSOs in areas without Barred Owl removals was -12% per year, while in removal areas, the rate stabilized (0.2% decline per year; Wiens et al. 2021).

There is also evidence that habitat availability and prey availability are being impacted by Barred Owls through competition for limited resources (Wiens et al. 2014). For example, the probability of a location being used by NSOs in Oregon was substantially lower if the location was near or within a Barred Owl's core-use area (Wiens et al. 2014), and in areas with Barred Owls, NSOs in California and Oregon foraged at greater distances from streams, at greater distances from their nest sites, and on steeper and warmer slopes compared to NSOs in areas with no or few Barred Owls (Irwin et al. 2019). Wiens et al. (2014) also found that survival rates of both species were positively associated with the amount of old forest in their home ranges, which suggested that the availability of old forest may be a limiting resource in the competitive relationship between NSOs and Barred Owls. In terms

of prey competition, Barred Owl diet studies in Oregon and Washington have found overlap in prey species that are of primary importance to NSOs, although Barred Owls also consume more species than NSOs and there are differences in the relative proportions of species consumed by the two species (Wiens et al. 2014, Baumbusch 2023). Despite these differences, Baumbusch (2023) suggested that NSO prey are still likely consumed at higher frequencies across the landscape as Barred Owls replace NSOs due to Barred Owls' smaller territories (Hamer et al. 2007) and higher densities, larger body size, and larger brood sizes. Similarly, Wiens et al. (2014) noted the high potential for exploitative competition—depleting shared resources—in times of low prey abundance or when the individuals from the two species have overlapping foraging areas. There is also evidence that Barred Owls are dominant during interactions between Barred Owls and NSOs: when presented with artificial agonistic interspecies interactions (i.e., playback and a taxidermy mount of the opposite species), Barred Owls called more frequently and had more trials that resulted in a strike than NSOs exposed to Barred Owls, and NSOs also had a stronger response to other NSOs than to Barred Owls (Van Lanen et al. 2011). Thus, Wiens et al. (2014) suggested that NSOs may be reducing the potential for these interactions with Barred Owls through spatial avoidance, resulting in the changes they observed in habitat use, movements, and reduced fitness (e.g., reproductive success) for NSOs in areas with Barred Owls.

Other possible threats to NSOs from the Barred Owl invasion include hybridization (Hamer et al. 1994) and changes to parasite community dynamics (Lewicki et al. 2015). However, there is evidence that hybridization is not very common and has not had substantial impacts to date (Kelly and Forsman 2004, Hanna et al. 2018).

Local experts were “mostly confident” to “very confident” about their assessments of NSO sensitivity to Barred Owls (Appendix D, Figure 7), which included that if exposed to Barred Owls, impacts to NSO survival and prey availability would be common and impacts to habitat availability would be common to frequent (Figure 2). Local experts were also more consistent than the literature review suggests in estimating that impacts to nesting likelihood and fecundity from exposure to Barred Owls would be frequent.

Exposure in Marin County

There have been relatively few, but regular, recent detections of Barred Owls in Marin County (Figure 3). The first Barred Owl detection in Marin County was in 2002 (Jennings et al. 2011) and the number of individuals known to be present in any given year (2002–2023) has ranged from zero to eight. Thirteen Barred Owl individuals were collected in Marin County as part of research studies between 2015–2023 (Ellis 2017, Hofstadter, unpublished data); it is possible these removals have slowed the spread of Barred Owls in Marin County by preventing these individuals, some of which included established pairs, from breeding. If Barred Owl occupancy in Marin County increased, it is likely that most of the habitat suitable for NSOs would also be suitable habitat for them (Wiens et al. 2014). So far, Barred Owls have mostly been detected in the southern end of the county, and in the Olema Valley in the southwest of the county (Figure 4), which may reflect their current preferred habitat in Marin. Due to the higher number of Barred Owls in Sonoma County (Figure 3), there is potential for an increase of Barred Owls in Marin from southward immigration, a similar pattern to

what has been documented throughout the range (Livezey 2009). This dispersal may be partially limited by the presence of the Petaluma Gap—an area of non-forest separating owl habitat in both counties. Local experts were “mostly confident” in their assessment of NSO exposure to Barred Owl impacts (Appendix D, Figure 7), including that the current spatial extent of exposure of NSO territories to Barred Owl impacts was moderate (10–50% of territories) and that the current frequency/intensity of exposure was mild to moderate (Appendix D, Figure 6). Experts in our survey also expected that the future spatial extent and frequency/intensity of Barred Owls would increase in Marin County (Appendix D, Figure 6).

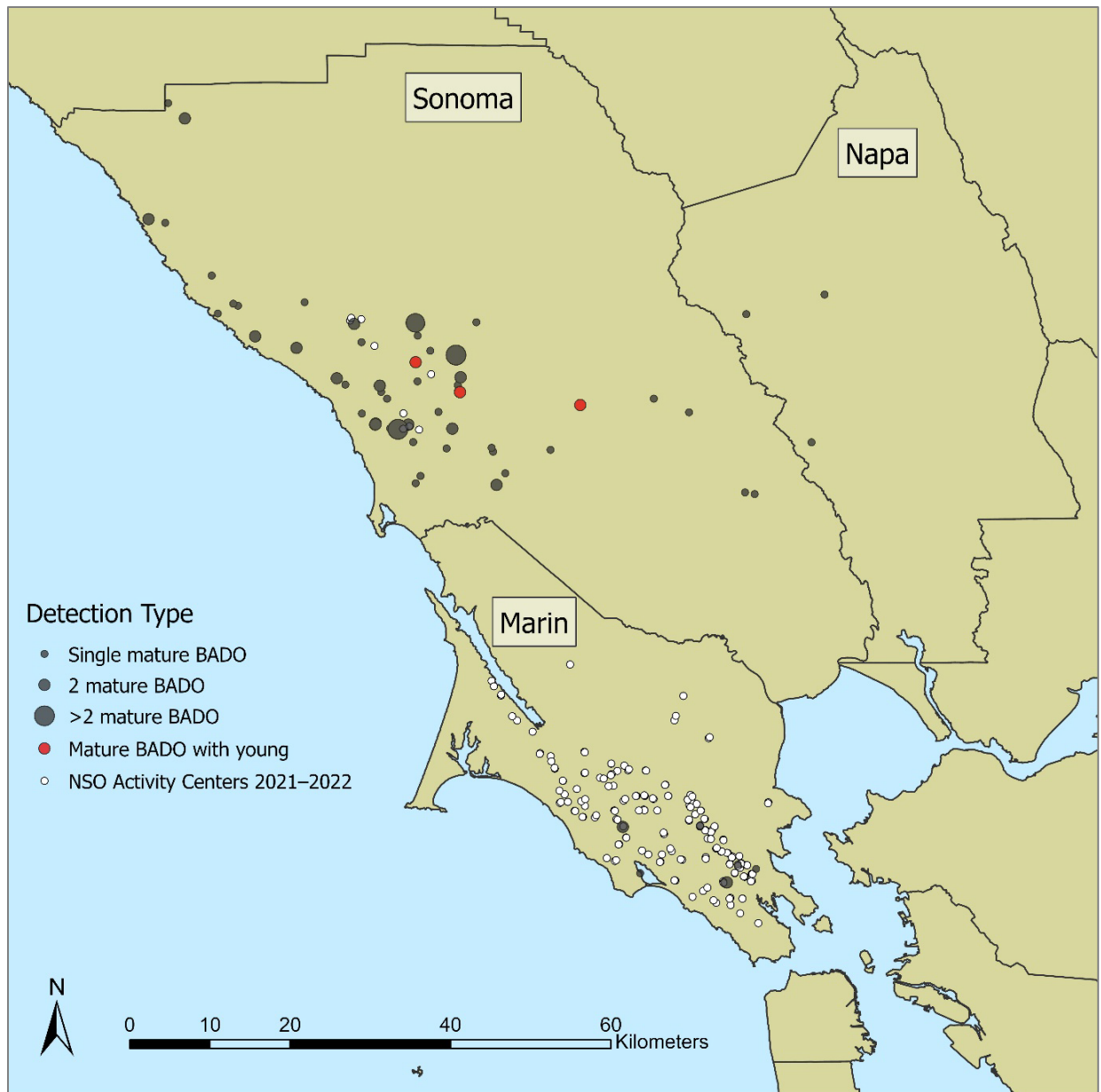


Figure 3. Barred Owl (BADO) detections (grey and red dots) from 2022–2023 in Sonoma, Napa, and Marin counties. Northern Spotted Owl (NSO) activity centers from 2021–2022 are shown in white (most NSO 2023 data from this region was not yet available). Detections do not necessarily reflect abundance or density since not all areas are surveyed every year. Some Barred Owl individuals mapped may have been removed through ongoing research in the study area (Hofstadter, unpublished data); Barred Owl data from 2023 are not for the full year and vary depending on the date the data were acquired from each source (Appendix A).

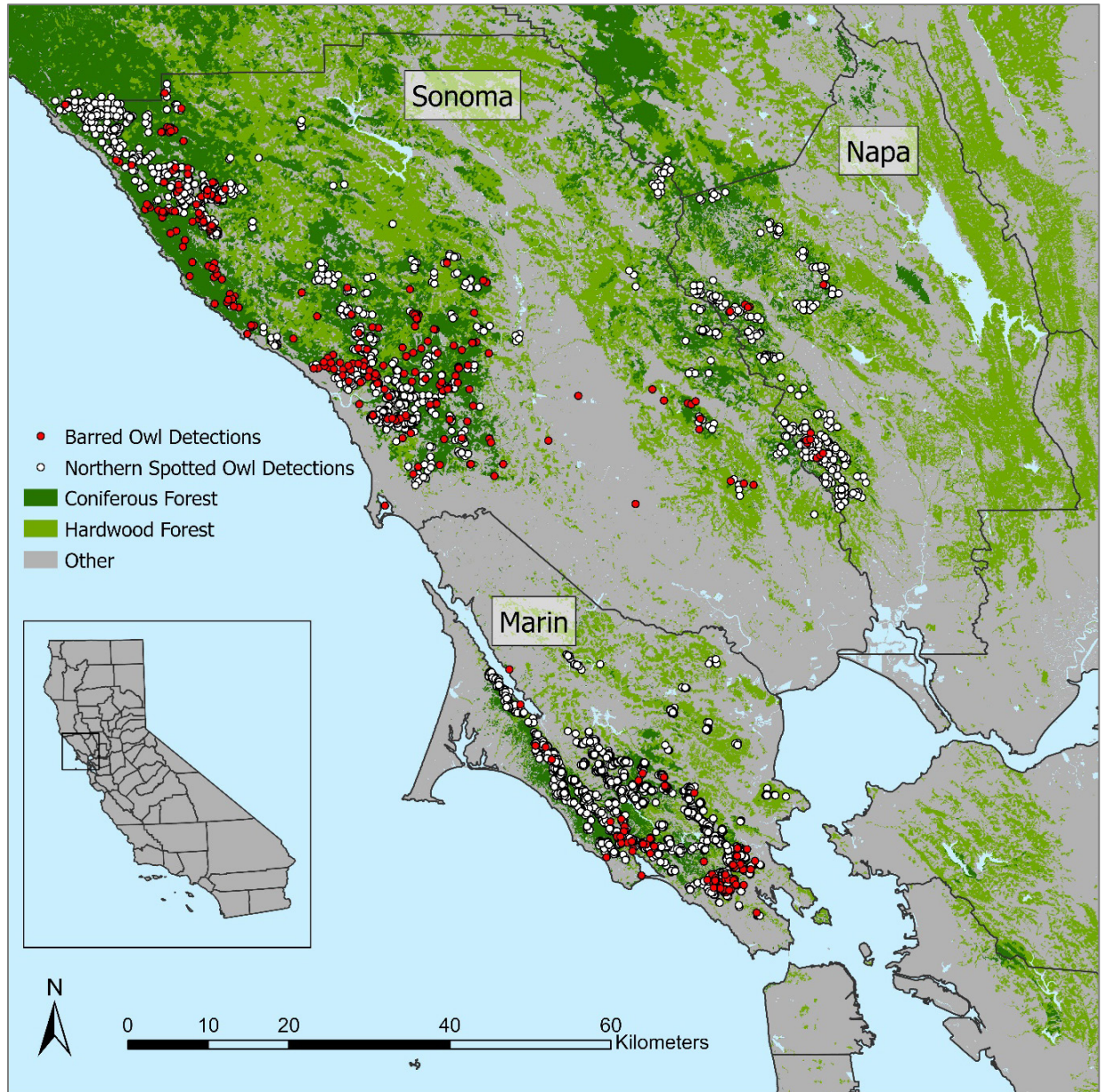


Figure 4. Barred Owl and Northern Spotted Owl detections in Sonoma, Napa, and Marin counties. Detections of Barred Owls (red circles) are from 1989–2023, while Northern Spotted Owl detections (white circles) range from 1900–2023. Each symbol represents the presence of at least one individual and some points likely represent repeated detections of the same individual(s). Detections do not necessarily reflect abundance or density since not all areas are surveyed every year; data from 2023 are not for the full year and vary by dataset (Appendix A). Vegetation data are from the California Department of Forestry and Fire Protection (CalFire 2015).

Relative Threat Level in Marin County: High and Increasing

We estimated Barred Owls as currently posing a high threat to NSOs in Marin (Table 2), second only to climate change. The results from our literature review and expert survey indicate that NSOs are vulnerable to the impacts of Barred Owls through all the sensitivity factors we considered (Figure 2).

Local experts assessed nesting likelihood, fecundity, and habitat availability as the most sensitive factors, but impacts of Barred Owls on NSO reproduction in the literature have been mixed, and even moderate impacts to survival for this long-lived species could have larger impacts to overall population growth in Marin County, as demonstrated by other studies (Forsman et al. 2011, Franklin et al. 2021). Thus, it will be important to understand the impacts of Barred Owls on local NSO population dynamics. In addition, Barred Owls currently pose a high threat even though current exposure to Barred Owls was estimated as limited to moderate. An increase in the exposure to Barred Owls in the future would be expected to pose a significant threat to the NSO population in Marin County, as it has elsewhere throughout the range (Wiens et al. 2014, Franklin et al. 2021), and subsequent expected negative impacts to NSOs may depend on whether management of Barred Owls occurs in Marin County (Diller et al. 2016, Dugger et al. 2016, Wiens et al. 2021) and in adjacent areas from where immigration would be possible (Figure 4; Hofstadter et al. 2022).

Climate Change

Evidence for Sensitivity

Climate change has the potential to impact NSO populations through changes in weather, their habitat, disturbance processes, prey availability, and interactions with other threats. We found evidence in the literature that NSO survival, recruitment rates, fecundity, and rate of population change are sensitive to weather conditions during the winter and breeding season. For example, in a range-wide study, Dugger et al. (2016) found that NSO mean adult (>1 year old) survival was higher across all study areas when the Pacific Decadal Oscillation (PDO) was in a warming phase (warmer winters) and the Southern Oscillation Index (SOI) was negative (dry). In a northern California study, Franklin et al. (2000) also found that survival was associated with warm and dry springs (March–April). At two California sites in their study, Dugger et al. (2016) also found that survival was associated with dry conditions during early spring (March–April), but the effects of early-spring temperature differed between sites. Conversely, in Oregon and Washington, Glenn et al. (2010, 2011b) found that survival and the rate of population change were positively associated with wetter than normal conditions during the growing season (May–October), which they attributed to more abundant prey. Rate of population change in Oregon and Washington was also negatively associated with cold, wet winters and breeding seasons, as well as with the number of hot summer days (Glenn et al. 2010).

Winter and spring weather also affected juvenile recruitment rates in several studies. Dugger et al. (2016) found range-wide recruitment was highest when the previous winter was cold and dry, and lowest when the previous winter was cold and wet. However, Franklin et al. (2000) found recruitment in their northern California study was highest in years with wetter springs and speculated that because wetter springs provided poor conditions for adult survival, that may have allowed floaters—non-territorial, non-breeding individuals—to fill new vacancies. If a population lacks sufficient floaters, this hypothesis suggests overall declines might be expected in wetter springs.

The effects of weather conditions on reproduction are more variable throughout their range (Franklin et al. 2000, Olson et al. 2004, Dugger et al. 2005, Glenn et al. 2011a) and in some cases without strong support of an effect (Dugger et al. 2016, Franklin et al. 2021). However, in a range-wide

study, effects of weather on fecundity included a negative association with early nesting-season temperature (i.e., lower fecundity with warmer spring temperatures) at one California site, and the opposite relationship at three other sites in Washington and Oregon (Forsman et al. 2011). In Mount Rainier National Park in Washington, the probability of occupancy by Spotted Owls that reproduced was higher when early nesting season (March–April) temperatures were higher (Mangan et al. 2019). In two studies in Oregon, fecundity was negatively associated with the amount of precipitation in the previous winter (September–April; Wagner et al. 1996) or with breeding season (March–June) precipitation (Zabel et al. 1996). Across multiple study sites in Oregon and Washington, the stress-associated hormone corticosterone was higher in NSO juveniles when precipitation and temperatures were higher; while this increase in corticosterone was most pronounced during the fledging period when rainfall amounts were low (0–8.6 mm), the strong effect in hormone response may have been due it already being an energetically demanding time for the birds (Mikkelsen et al. 2021).

In addition to the direct effects of weather conditions on NSO survival and reproduction, weather can indirectly affect NSO populations through its effects on habitat suitability, quality, and prey (Franklin et al. 2000, Sakai and Noon 1993). In a study spanning sites from Washington to northern California, Carroll (2010) found that vegetation best explained the distribution of NSOs, but that of the climate variables in their models, a negative relationship with winter precipitation was the most important factor determining habitat suitability. Likewise, in the redwood coast ecoregion of California, Hysen et al. (2023) found that January rainfall was an important predictor of suitable NSO nesting habitat. Franklin et al. (2000) found that while forest cover patterns explained a high amount of spatial variation in fitness-related traits among Spotted Owls in northern California, climate variables explained most of the year-to-year variation.

Although the direct and indirect effects of weather on survival, recruitment, reproduction, and habitat quality have been relatively small and variable throughout the NSO range, climate change may play a larger role in the future. For example, the risk of wildfires is increasing, and the proportion of the NSO range that has burned is also projected to increase (Wan et al. 2019), which could change the amount of suitable habitat and prey (see fire section). Potential loss of forest cover due to large high severity wildfires and/or increased tree mortality from higher temperatures and increased drought (Van Mantgem et al. 2009) may be particularly important for NSOs. An increase in extreme storms could also reduce hunting efficiency and prey activity, which could negatively impact NSOs. NSO biologists in Marin County have also observed nest failures immediately after spring rainstorms in some years (NPS and Point Blue, unpublished data), and while the exact cause of individual nest failures is rarely known, it is possible that females exposed to heavy rain while on a nest or fewer hunting opportunities during storms are causal factors in some cases. Additionally, prevalence of disease and/or parasites may also change with a changing climate and could have impacts on NSOs; for example, Young et al. (1993) found higher densities of hippoboscids on NSOs to be associated with warmer fall and cooler summer temperatures, and in years with decreased winter precipitation. Additionally, NSOs have also been found to exhibit signs of stress when roost temperatures reached 27–31°C (Barrows 1981), which may be reached more regularly throughout their range in a changing climate.

Local experts expected that the exposure of NSO pairs or territories to extreme temperatures, storms, and drought would commonly (10–50% of exposures) result in negative impacts to nesting likelihood, fecundity, and prey availability. Impacts to survival were expected to be common only from exposure to extreme storms, and impacts to habitat availability were expected to be common only from exposure to drought. None of these three climate change threats were expected to have frequent (>50% of exposures) impacts (Figure 2). Experts felt “mixed uncertainty and confidence” with regard to these expectations for extreme temperatures and drought, but were “mostly confident” about these expectations for extreme storms.

Exposure in Marin County

Local experts estimated that the current spatial extent of exposure to extreme temperatures and drought was moderate (10–50% of NSO territories), the spatial extent of exposure to extreme storms was widespread (>50%), and the current frequency/intensity of exposures to all three threats was moderate (Appendix D, Figure 6).

The climate in Marin County is expected to become significantly warmer and generally more arid, with an increase in the frequency and severity of drought punctuated by extreme storms (Ackerly et al. 2018). In addition, large areas of Marin may also become less suitable for evergreen conifer forests and more favorable for chaparral and grasslands as a result of these changes in climate (GGNPC 2023). In alignment with the literature, local experts felt “mostly confident” in their expectations that future exposure to extreme temperatures, storms, and drought would increase. We expect that climate change would generally impact NSOs similarly throughout the county, although there may be some variation from coastal to inland sites and with elevation due to gradients in temperature, precipitation, and wildfire risk.

Relative Threat Level in Marin County: High and Increasing

We estimated climate change as currently presenting the highest threat to NSOs in Marin, specifically due to extreme events (drought, storms, and extreme temperatures). The results of our literature review and expert survey indicate NSO populations are vulnerable to the impacts of weather conditions through all of the sensitivity factors we considered. We estimated current exposure to extreme temperatures, storms, and drought as moderate, and thus likely to already be affecting NSO populations. In addition, we expect exposure to this threat to increase over the next 30–50 years. While the results of our literature review indicated that projections of warmer and drier conditions in the future may have a positive benefit to NSO survival in Marin, because Marin County is already drier and has warmer winter temperatures than in many other parts of the NSO range, it is possible that NSOs would respond differently to changes in climate here since their response to weather has been geographically variable. There also may be thresholds in warm and dry conditions that have not yet been exceeded in other studies, but beyond which NSO survival is reduced. In addition, while local experts expected extreme temperatures, storms, and drought to directly affect NSO nesting likelihood and fecundity, the effects of weather on reproduction in the literature was variable across sites, and effects in Marin County are unknown; thus, it is important to understand the local impacts of weather and climate on NSOs. Warmer and drier conditions will also affect NSOs through their habitat and prey. An increasing risk of high-severity wildfire (see wildfire section

below) and climate conditions favoring chaparral and grasslands over evergreen forests are likely to impact the extent and quality of available habitat. Changes to prey populations may also occur, but how those populations will change is unknown. While our survey was focused on extreme storms, extreme temperatures, and drought, and most of the literature has focused on NSO response to current climate and weather metrics, the local experts generally agreed that NSOs would be sensitive to climate change in Marin County—consistent with the literature that NSOs are sensitive to changes in weather and climate—and there was strong agreement and confidence among experts that exposure would increase.

Disease

Evidence for Sensitivity

The USFWS (2011) NSO Recovery Plan states that there is no imminent threat to the NSO from disease, but that it is important to continue to monitor for diseases and pathogens. We found evidence that NSOs are susceptible to a range of diseases and parasites, with limited evidence of impacts to survival and no evidence or studies of impacts to reproduction, habitat availability, or prey availability, though we did not specifically search the literature for disease impacts to dusky-footed woodrats or other prey.

Avian influenza viruses circulate naturally among birds, and wild birds can be infected with HPAI and show no signs of illness. However, the strain of H5N1 currently in circulation has caused illness and death in a higher diversity of wild bird species than during previous avian influenza outbreaks (Klassen and Wille 2023). The current strain of HPAI has been detected in almost every U.S. state, including in California and in Marin County. The birds at highest risk of HPAI are waterfowl, other waterbirds, and the birds that prey or scavenge on these species (CDFW 2024). No Spotted Owls have been confirmed as being infected by H5N1 to date, but other owl species have, including Barred Owls and Great Horned Owls (USDA 2024, updated 02 January 2024).

Several studies documented the prevalence of blood parasites in NSOs, which can cause mild symptoms in most bird species, but severe anemia has been reported in some species of raptors and owls (Remple 2004). For example, NSOs from throughout the range and CSOs were found to have more *Haemoproteus* spp. blood parasites than other Strigidae owl species examined, and this study also documented the first case of a NSO infected with a *Plasmodium* sp. (avian malaria), though they found no evidence of change over time in prevalence for NSOs (1994–1996 versus 2004–2005; Ishak et al. 2008). They also found that Spotted Owls (NSO, CSO) had the highest diversity of *Leucocytozoon* lineages compared to other owl species, including many that were unique to the species; lineages that have coevolved with a specific host are thought to be less virulent than those that are not constrained to one host (Ishak et al. 2008). In another study of blood parasites, NSOs had greater parasite diversity of *Haemoproteus* spp. and a higher probability of infection compared to sympatric Barred Owls, supporting the “enemy release” hypothesis where the Barred Owl hosts benefit from parasite loss in their invasive range (Lewicki et al. 2015). In a study of all three Spotted Owl subspecies, including NSOs from northern California (n=22), Gutiérrez (1989) found all NSOs were infected by at least one species of blood parasite, and half were infected by at least two species. The effects of the parasites on NSOs were not determined in any of these studies.

Between 2011 and 2015, three dead NSOs from Marin County and two dead CSOs were determined to have been infected with avian trichomonosis, and symptoms from this parasite (*Trichomonas gallinae*) range from asymptomatic to severe disease resulting in mortality in different bird species (Rogers et al. 2016). While the source of these particular infections was unclear, the cases coincided spatially and temporally with trichomonosis epidemics in Band-tailed Pigeons (*Patagioenas fasciata*), and the owls may have become infected by feeding on this species, which is susceptible to mortality from trichomonosis (Rogers et al. 2016).

West Nile virus (WNV) was identified as a potential threat to NSOs (Courtney et al. 2004), and one captive Spotted Owl was confirmed to have died from WNV (Gancz et al. 2004). Other studies of owls and WNV in California found low to no prevalence of the disease, and study authors suggested that either infection rates were very low, sampling methods did not detect the disease, or that the mortality rate was sufficiently high that surviving individuals were not found (Hull et al. 2010, Captanian et al. 2017).

A single dead NSO in Washington was diagnosed with fatal Spirochetosis caused by a *Borrelia* sp. bacteria, though the significance, and prevalence in NSOs and other species, remains unknown (Thomas et al. 2002). Another bacterium (either *Frenkelia* sp. or *Sarcocystis* sp.) was documented in a single dead NSO in Oregon, but not linked to its death, though some species of *Sarcocystis* may cause disease or death in some raptors (Hoberg et al. 1993).

Ecto-parasites have also been documented for NSOs, specifically hippoboscids, which could reduce NSO fitness, or act as vectors for blood parasites or other pathogens (Hunter et al. 1994). In a California study, relative densities of hippoboscids were greater when fall temperatures were higher, winter precipitation was lower, and summers were cooler (Young et al. 1993).

Local experts expected that if exposed to HPAI and other diseases, impacts to NSO survival, nesting likelihood, and fecundity would be common, and that impacts to habitat or prey would be uncommon (Figure 2), with “mixed uncertainty and confidence”.

Exposure in Marin County

Studying exposure to disease and determining the cause of death or impacts from disease to fitness in wild animals can be difficult to measure. Local experts estimated the current spatial extent and frequency/intensity of exposure to disease was limited and mild, and that the future spatial extent and frequency/intensity of exposures would remain relatively stable, although local experts were least confident of any threat about their assessments of exposure (Appendix D, Figure 7).

Relative Threat Level in Marin County: Low and Stable

We estimated disease as presenting a relatively low threat to NSOs in Marin, but with relatively low confidence in assessments of both current vulnerability and expected future exposure (Table 2). The results of our literature review indicated some NSO mortality due to disease, but there was limited information about impacts to reproduction, and more study is needed. We estimated future exposure of NSOs to disease in Marin County to be low, but how these stressors might change with climate change, the progression of the current HPAI outbreak, or an increase in Barred Owls is uncertain. It

is also possible that NSOs in Marin County may be exposed to different pathogens than in other parts of their range.

Noise Disturbance

Evidence for Sensitivity

Noise disturbance has the potential to negatively impact nesting NSOs and is regulated by the USFWS (USFWS 2020). Studies evaluating NSO response to noise disturbance were limited. However, Hayward et al. (2011) found that NSOs in northern California near noisy roads (from off-highway vehicles [OHV]) fledged significantly fewer young than those near quieter roads, and that NSOs had short-term stress response (indicated by increased glucocorticoid metabolites) to acute exposure to OHV traffic noise. We did not find any studies that evaluated impacts of noise to NSO survival, habitat availability or use, or prey availability. In their review of threats to NSOs, Lesmeister et al. (2018) suggested that further research was needed on both acute and prolonged exposure to environmental stressors, including human-caused disturbance. Local experts were “mixed” to “mostly confident” that if exposed to noise disturbances, impacts to NSO survival, fecundity, habitat availability, and prey availability would be uncommon, but that impacts to nesting likelihood would be common (Figure 2).

Exposure in Marin County

Noise disturbance varies across NSO sites in the county, with some NSO sites close to busy roads, trails, and residential areas. Traffic noise can be heard at many sites, including from some of the busiest roads in the county (e.g., Sir Francis Drake Boulevard); in residential areas, noise from traffic and landscaping equipment are especially prevalent. However, there is also widespread and intentional avoidance of noise during the nesting season to protect NSOs, especially by the largest land management agencies in the county (e.g., CSP, MCP, Marin Water, and NPS; Figure 1). Local experts estimated the current spatial extent and intensity/frequency of noise disturbance as moderate (Figure 2). In the future, it is possible that the number of sites exposed to more frequent noise disturbance could increase due to development. At the same time, the replacement of gas-powered vehicles and landscaping tools with electric versions could decrease noise levels at some sites. Local experts felt “mostly confident” in their estimate of the future spatial extent of noise disturbance in Marin as stable to increasing and the future frequency/intensity of noise disturbance as stable (Figure 2 and Figure 7 in Appendix D).

Relative Threat Level in Marin County: Low and Stable to Increasing

We estimated noise disturbance as currently presenting a relatively low threat to NSOs in Marin. The results of our literature review and expert survey indicate some sensitivity of reproduction to noise, but found no evidence nor studies for impacts to survival, habitat availability, or prey. We estimated current exposure to noise disturbance in Marin as moderate, and due to the nature of many sites being located near the wildland-urban interface, it is likely a greater threat here compared to most other parts of the NSO range. An ongoing study that includes data from sites in Marin County seeks to evaluate stress hormones in NSOs throughout their range in relation to urban areas (Pekrul, unpublished data), and may provide additional insight into this threat.

Other Habitat Loss or Disturbance (Urban Development / Fuels Management)

Evidence for Sensitivity

Habitat loss has been a primary threat to NSOs throughout much of their range (USFWS 2011), with commercial timber harvest identified as a leading cause, but there is currently no commercial timber harvest in Marin County. Instead, habitat loss and disturbance in Marin is more likely to be related to urban development or land management in the wildland-urban interface, where many NSO territories in Marin are located. We only found one study that evaluated the impacts of urban development on NSOs, and it was from Marin County where NSO nest sites were negatively associated with the proportion of urban development within 200 m (Stralberg et al. 2009). In this same study, nest sites were also negatively associated with the amount of habitat fragmentation within 200–800 m, measured as the amount of woodland edge, which was primarily edge between forest and urban areas or non-native grassland (Stralberg et al. 2009).

Another potential source of NSO habitat disturbance is the growing interest in forest health and fuels management to improve overall forest health and reduce the risk of high-severity wildfire in California, including in Marin County. These management actions can include thinning trees, pile burns of downed wood and debris, and prescribed fire (GGNPC 2023). A number of studies on the potential impacts of fuels management activities on NSOs indicated a need for more research on both short- and long-term impacts, and that there may be trade-offs between negative impacts to habitat or prey from fuels reduction, and having a lower risk of potential habitat loss from high severity fires (Lehmkuhl et al. 2007, Ganey et al. 2017, Lesmeister et al. 2018, Wan et al. 2018). We did not find any empirical studies that evaluated impacts of fuels management on NSOs, but 10 GPS-tracked CSOs in a landscape that was recently modified from fuels reduction activities in the Sierra Nevada of California were found to forage in areas with a lower proportion of gaps in the canopy (gaps were defined as areas with a maximum vegetation height of 2m); the authors suggested that fuels reduction treatments that created higher proportions of gaps may reduce foraging habitat for CSO (Gallagher et al. 2019). In addition, we found several studies that modeled impacts of fuels management to NSO habitat. For example, Ager et al. (2007) modeled estimates of habitat loss in central Oregon using wildfire simulation methods to assess the risk probability under different fuel treatment scenarios and found that fuels treatment on 20% of the forested landscape in non-NSO habitat reduced the projected NSO habitat loss from wildfire by 44%. In another modeling study, Bailey et al. (2015) assessed tradeoffs between fuel treatment options and maintaining NSO habitat in dry forests of the eastern Cascades in Washington, and found that while the “no fuels treatment” scenario was best for maintaining suitable roosting and nesting NSO habitat—at least in the short-term—it also had the highest potential fire risk, though that depended on adjacent fuel conditions. They also found that heavier treatments (which included removing most trees that were 8–10 inches in diameter at breast height [dbh]; some 10–20” dbh trees, and a few 20–24” dbh trees) degraded NSO habitat and took longer to recover to ideal NSO conditions. Bailey et al. (2015) recommended creating a mosaic of structural conditions on multiple spatial scales through a mix of lighter and more aggressive treatments in some areas, and no fuels treatments in other areas.

Local experts were “mostly confident” that if exposed to urban development, impacts to NSO nesting likelihood, fecundity, habitat availability, and prey availability would be common, and that impacts

to survival would be uncommon (Figure 2). Local experts had “mixed uncertainty and confidence” that if exposed to forest health and fuels management actions, impacts to NSO survival, nesting likelihood, fecundity and prey availability would be uncommon, and impacts to habitat availability would be common (Figure 2).

Exposure in Marin County

Exposure to urban development and fuels management varies across NSO sites in the county; some NSO sites are on the edges of or embedded in residential areas and fuels reduction work has increased throughout the county in recent years by local agencies and private landowners. Local experts were “mostly confident” in their estimate that the current spatial extent of both urban development and fuels management is limited to moderate, and that the intensity/frequency is mild (Figure 2). Local experts felt “mostly confident” that the future spatial extent and frequency/intensity of NSO exposure to urban development in Marin County would be stable to increasing, and that the future spatial extent and frequency/intensity of NSO exposure to fuels management in Marin County would increase (Appendix D, Figure 6).

Relative Threat Level in Marin County: Low and Stable to Increasing

We estimated habitat loss or disturbance from urban development and forest health/fuels management as currently presenting a relatively low threat to NSOs in Marin due to the relatively limited exposure and low sensitivity of NSO survival and reproduction to these threats. However, the results of our literature review indicate a significant amount of uncertainty, particularly with regard to impacts of fuels reduction efforts on NSO habitat availability, and the need to understand trade-offs between habitat disturbance from fuels management with future habitat losses from wildfire. We also do not know how comparable/similar the scale and actions of fuels treatments in the literature are to those that have occurred and are planned for Marin County.

Rodenticides

Evidence for Sensitivity

Exposure to rodenticides is a common conservation concern for wildlife that may prey on poisoned rodents. We found few studies documenting incidence of NSO exposure to anticoagulant rodenticides (AR) through the presumed ingestion of poisoned prey, and in those studies, impacts from the ARs to the NSOs were not known. In northern California, one NSO found dead within 1.4 km of seven different marijuana growing operations (MGO) tested positive for AR, although the role of the AR on the death of the NSO was unclear (Franklin et al. 2018). There were several additional studies that assessed incidence of ARs in Barred Owls that were lethally collected in the NSO range during research to evaluate competition with NSOs; the Barred Owl samples were used as a potential surrogate for understanding effects to NSOs. For example, in a study from northern California, 70% (n=10) of NSOs that were found dead, and 40% (n = 84) of collected Barred Owls, tested positive for ARs; in this study, three of the dead NSOs were killed by vehicle strikes, two were emaciated with undetermined infectious etiology, one was killed by a predator, and the cause of death of the others was unknown (Gabriel et al. 2018). Rates of AR in Barred Owls and Barred x Spotted Owl hybrids ranged from 48% (n=40) in Oregon and Washington (Wiens et al. 2019) to 62% (n=127) in a different northern California study, which also found 100% (n=7) of female Barred Owl ovaries

positive for ARs (Hofstadter et al. 2021). Additionally, Barred Owls that were in areas closer to the wildland-urban interface had higher rates of ARs in a recent northern California study (Hofstadter et al. 2021). While none of the owls from these studies were known to have been directly killed by the ARs, the effects of sublethal doses of ARs are not well understood and may cause decreased fitness or an increased risk of mortality from other causes (Rattner et al. 2012, Salim et al. 2014). Local experts were “mostly confident” that if exposed to rodenticides, impacts to NSO prey availability would be frequent, and impacts to survival, nesting likelihood, and fecundity would be common, while impacts to habitat availability would be uncommon (Figure 2).

Exposure in Marin County

Extent of exposure to rodenticides is not known for Marin County but may be more likely near sites in the wildland-urban interface, as was found in Barred Owls in northern California (Hofstadter et al. 2021). Six dead Marin County NSOs tested positive for ARs in 2012–2014 and one tested positive in 2019 (WildCare, unpublished data) and one of the Barred Owls that was lethally collected in Marin County tested positive for ARs (W. Merkle, personal communication, January 2024), though not all collected individuals were tested nor is every dead NSO. Several laws have been passed to attempt to reduce harm to wildlife from ARs. For example, in 2014, a new California law enacted some restrictions on second-generation ARs (SGARs are more toxic and have a longer half-life than first-generation ARs [FGAR]). Due to the 2014 law, certain products are only permitted for use by professional exterminators, and they are no longer permitted on store shelves; further restrictions on SGARs were enacted in 2020, and in January 2024, diphacinone, a FGAR, was also banned. While we know of no studies that have evaluated incidence of ARs in wildlife before and after these laws to evaluate their effectiveness, the Department of Pesticide Regulation reported high rates of ARs in non-target wildlife between 2014 and 2018, including from 276 wild animals that were tested from WildCare (a Marin County wildlife rehabilitation center) between 2014–2016 (in all 3 years, > 70% of the animals tested positive for SGARs, and in 2015, >90% tested positive; DPR 2018). In this report, the authors noted that it was likely too soon after the 2014 law went into effect to expect changes to the rate of SGARs from the WildCare data due to the prolonged half-lives of the SGARs (DPR 2018). Some studies found ARs to be prevalent near sites with illegal marijuana cultivation (Franklin et al. 2018, Gabriel et al. 2018), which have also been confirmed in Marin County, but are probably less prevalent than in NSO study areas farther north in California (Wengert et al. 2021). With “mixed uncertainty/confidence”, local experts estimated the current spatial extent of exposure to rodenticides in Marin County as moderate and the current intensity/frequency of exposure to rodenticides as mild, with little change or possibly a decrease expected in the future (Appendix D, Figure 7).

Relative Threat Level in Marin County: Moderate and Stable to Decreasing

We estimated rodenticides as currently presenting a moderate threat to NSOs in Marin. While the literature lacked studies on the impacts of rodenticides to NSO individuals and populations, we found evidence that NSOs range-wide are being exposed to rodenticides, it has been documented locally, and local experts estimated that impacts to survival, reproduction and prey from rodenticide exposure would be common. We estimated current exposure to rodenticides in Marin as moderate, and due to the nature of many sites being located near the wildland-urban interface, it may be a greater threat

here than in some other parts of the NSO range (Hofstadter et al. 2021). It is possible that state laws created to reduce negative impacts of ARs to non-target wildlife could help reduce future exposure of NSOs in Marin County.

Sudden Oak Death

Evidence for Sensitivity

Sudden oak death (SOD)—caused by the pathogen *Phytophthora ramorum*—was first documented in the United States in Marin County in 1995 (Garbelotto and Rizzo 2005) and has caused the mortality of tens of thousands of trees in the county since then (Edson et al. 2016). In an evaluation of the status of the NSO shortly after documentation of SOD in the U.S., Courtney et al. (2004) noted the uncertainties of how SOD might impact NSOs, and suggested that possible threats included changes in forest structure and species composition from tree mortality (with potential subsequent impacts on thermal cover, vertical structure, hunting perches, and density of ground cover plants), loss of potential nest trees, and changes in prey availability. We did not find any studies that directly evaluated the impacts of SOD on NSOs, although we found several studies relevant to their habitat and prey. In Marin County, there have been reductions in canopy cover, and regeneration of tanoaks—the main affected species in NSO habitats in the county and an important source of food and shelter for their primary prey, the dusky-footed woodrat—at least initially was insufficient to re-occupy the growing space (Ramage 2011). Further, dusky-footed woodrat abundance was negatively correlated with SOD in Marin County, although deer mice (*Peromyscus maniculatus*)—another prey species of NSOs, though to a lesser extent—were positively correlated (Swei et al. 2011). Due to increased fuel loads created by SOD in Marin County, models of fire behavior in diseased stands indicated longer flame lengths, higher rates of spread, and more intense surface fire compared to healthy stands (Forrestel et al. 2015), potentially increasing risk of NSO habitat loss (see fire section). Local experts expected that if exposed to SOD, impacts to NSO survival, nesting likelihood, and fecundity would be uncommon, and that impacts to their habitat and prey availability would be common (Figure 2), but their confidence level was “mixed uncertainty/confidence.”

Exposure in Marin County

The extent of NSO exposure to areas impacted by SOD in Marin County has been widespread, although it varies among sites (Ramage 2011). Local experts had “mixed uncertainty and confidence” that the current spatial extent and frequency/intensity of NSO territories exposed to SOD in Marin County was moderate. While we do not know how SOD will change in Marin County, Haas et al. (2016) found that warmer and wetter rainy-season conditions in consecutive years increased the risk of SOD infection. Winters are expected to become warmer in Marin County, and precipitation is predicted to be more variable (see climate change section), so it is possible SOD infections could change accordingly, but the amount of precipitation could influence whether there is an increase or decline in infections in our study area. Experts in our survey estimated that the future spatial extent may increase, but that the frequency/intensity of SOD would be relatively stable (Appendix D, Figure 6).

Relative Threat Level in Marin County: Moderate and Stable to Increasing

We estimated SOD as currently presenting a moderate threat to NSOs in Marin (Table 2). The results of our literature review and expert survey indicate some sensitivity of habitat and prey availability, but little to no evidence for impacts to survival and reproduction metrics, though we found no studies that evaluated NSO response to SOD. We estimated current exposure to SOD in Marin as moderate, and that it will either remain stable or increase in the future.

Wildfire

Evidence for Sensitivity

We found evidence for the sensitivity of NSO occupancy, survival, and recruitment to wildfire in the literature that often depends on burn severity. In addition, we also provide some results from studies of CSOs, since much of the research on Spotted Owl response to wildfire has been done with this subspecies. However, we caution that the differences in the ecology of these subspecies and differences in geography, climate, and historical fire regimes between Marin County and other parts of the NSO and CSO ranges may result in variable responses to wildfire (Ganey et al. 2017).

In a study of NSO occupancy after a mixed-severity fire in Oregon, Clark et al. (2013) found a greater probability of site extinction (i.e., going from occupied to unoccupied) after the fire and a decline in occupancy of nesting territories, which they attributed to a combination of post-fire salvage logging, past logging, and high-severity fire (high severity in this study was defined as forests with >70% of the canopy removed by fire and, while the definitions can vary by study, generally >70% to >75% canopy mortality). For CSOs, high-severity fire has been negatively associated with site colonization (Temple et al. 2014, Temple et al. 2022), and positively associated with site extinction rates (Temple et al. 2022), with a lack of recolonization at abandoned sites after six years post-fire, although sites with a mosaic of burn severities were more likely to persist (Jones et al. 2021). After the 2014 King Fire that burned over 39,000 ha in the Sierra Nevada, half of which burned at high severity, the probability of extirpation by CSOs in territories where over 50% of the habitat burned at high severity was seven times higher after the fire (0.88) compared to before the fire (0.12; Jones et al. 2016). However, Lee et al. (2012) did not find an effect of fire on occupancy in CSOs, nor an effect on occupancy from the amount of high-severity fire, although the proportion of suitable CSO habitat they identified that burned at high-severity fire in the territories they examined ranged from 0.001–0.932 (mean = 0.32).

NSO survival and recruitment responses varied among fires with different characteristics in a study from northern California that used long-term NSO data before and after wildfire. Mixed-severity fires that burned mostly at low severity were associated with minimal impacts to survival and recruitment, while a fire that burned mostly at high severity was associated with a large drop in survival and little effect on recruitment, and mixed moderate and high-severity fires were associated with a reduction in survival and increased recruitment (Rockweit et al. 2017). Survival for 23 NSOs in Oregon was found to be lower in burned areas 3–5 years after fire, and lower for NSOs that had been displaced by fire compared to NSOs whose territories were unburned but were located adjacent to burned areas; they did not find an effect of burn severity in their study (Clark et al. 2011). For

CSOs, Bond et al. (2002) found similar survival rates one year after fire compared to reported annual adult survival rates for the species.

Habitat suitability for NSOs may change after fire. NSOs in Oregon favored disturbances that created diffuse edge habitat (e.g., low and mixed-severity fire) as opposed to abrupt boundaries created by high-severity disturbance (Comfort et al. 2016). CSOs in the Sierra Nevada used small patches of high-severity burn, but used a broader range of habitat patch sizes burned at low and moderate severity; they also showed a preference for habitat edges that were created by fire (Eyes et al. 2017); and after the King Fire, CSOs used forests burned at low severity in proportion to their availability (Jones et al. 2016). CSOs have also been shown to avoid larger areas of high-severity fire (Jones et al. 2016, Jones et al. 2020a, Schofield et al. 2020, Kramer et al. 2021) but selected for high-severity patches in one study if their home range contained only a small amount (<5%; Jones et al. 2020a). In another study, CSOs foraged in forests burned across the range from low to high severity and to a greater extent in high-severity burned areas but avoided moderate- and high-severity burns for roosting during the breeding season (Bond et al. 2010). Lee and Bond (2015a) did not find CSOs to avoid high-severity burned areas, and occupancy remained high in their study. In southern California, both fire and post-fire logging had impacts on CSO occupancy, but impacts were greater at sites where CSOs did not breed in the previous year, compared to those that did (Lee and Bond 2015b).

There has been substantial debate in the scientific literature about the study designs, analyses, and interpretations of the effects of high-severity fire on Spotted Owls (e.g., Hanson et al. 2009, Spies et al. 2010, Hanson et al. 2010, Hanson et al. 2018, Lee 2018, Jones et al. 2019, Peery et al. 2019 [webpanel 1], Jones et al. 2020b, Lee 2020), contributing to the apparent variation in NSO responses described above. However, most studies have not assessed long-term impacts of fire on NSOs, and studies evaluating impacts to demography are limited (Rockweit et al. 2017). While NSOs may use forest burned at high severity, the size of the high-severity patches, spatial patterns of burned areas in the landscape, and cumulative impacts of subsequent fires all have the potential to threaten NSOs (Ganey et al. 2017). Local experts were specifically asked about high-severity wildfire and were “mostly confident” in their expectation that if exposed to high-severity wildfire, impacts to NSO nesting likelihood, fecundity, habitat and prey availability would be frequent, and that negative impacts to their survival would be common (Figure 2).

Exposure in Marin County

Hysen et al. (2023) identified parts of Marin County as having a high concentration of NSO nesting habitat at a very high risk of experiencing high-severity wildfires, especially areas set back from the coast. Parts of Marin County were identified as having a greater probability of large wildfire than expected by chance (Davis et al. 2011), and areas of higher risk were similar to those shown in Hysen et al. (2023). There have been two significant fires that included NSO habitat in Marin County in recent decades, though the proportion of known NSO sites in the county impacted by these fires is low: the 1995 Vision Fire burned approximately 5,000 ha, primarily on NPS lands in PRNS, and the 2020 Woodward Fire burned almost 2,000 ha, also in PRNS (about 500 ha burned in both fires). NSO survey data were limited prior to the Vision Fire, and most known sites were outside of the fire perimeter (Chow and Allen 1997), which remains the case today (NPS, unpublished data). Six NSO

sites had significant parts of their territories that burned in the Woodward Fire, and while a formal analysis has not been conducted, occupancy of sites appears to be similar to before the fire and NSO have been found roosting and nesting in unburned areas of their partially-burned territories (NPS, unpublished data, T. Ellis personal communication, January 2024). Local experts were “mostly confident” in their assessment that the current spatial extent of exposure to high-severity wildfire in Marin County was moderate, and that the current frequency/intensity of exposure was mild. In their models predicting future burned areas, Wan et al. (2019) found that the annual percent area burned in the NSO range was projected to increase to 0.4% in the 2040s, and to 2.1% in the 2080s, though Marin County did not appear to be as high of risk as some other parts of the NSO range. All experts in our survey estimated that the future spatial extent and future frequency/intensity of high-severity wildfire would increase in Marin County.

Relative Threat Level in Marin County: High and Increasing

We estimated wildfire as currently presenting a high threat to NSOs in Marin. The results of our literature review and expert survey indicate some sensitivity of NSOs to high-severity wildfire (and possibly moderate-severity fires in some cases), though additional studies are needed, including continued monitoring NSO sites burned by previous fires in Marin County. We estimated current exposure to wildfire in Marin as moderate, and we expect exposure to this threat to increase over the next 30–50 years. While the results of our literature review indicated that the risk of wildfire, including high-severity wildfire, is expected to increase in Marin County, the impacts to NSOs will depend on size, severity, and patchiness of any future fires.

Discussion

The Marin County NSO population is relatively stable and has not experienced the declines seen in other long-term study areas throughout their range (Ellis et al. 2020, Franklin et al. 2021, Brown et al. 2023). Falling under a patchwork of land ownerships, a large proportion of the NSOs in the county has been monitored and protected by local land management agencies and private landowners for decades, who continue to be committed to their conservation and seek to maintain a stable local population. This vulnerability assessment identifies the threats that are most likely to have a significant impact on the Marin County NSO population, informs conservation strategy, and highlights research needs.

None of the threats we considered in this vulnerability analysis were assessed to be simultaneously widespread, frequently occurring, and frequently impacting NSO survival, reproduction, habitat or prey in Marin County (Figure 2), likely contributing to the local population's stability. However, we identified climate change, Barred Owl competition, and high-severity wildfires as the threats to which NSOs in Marin County are currently most vulnerable, and of particular concern is that NSO exposure to all of these threats is expected to increase in the next 30–50 years (Table 2). Climate change scored as the highest current threat, which was primarily because current exposure to extreme temperatures, extreme storms, and drought was already estimated as moderate, and local experts assessed NSO survival, reproduction, habitat, and prey as commonly impacted by exposure to one or more aspects of these climate factors (Figure 2). Climate change also has the potential to change and interact with other threats that were evaluated separately (e.g., wildfire, sudden oak death, disease), and in some cases, exacerbate their impacts (Wan et al. 2019). While the impacts of climate change are expected to increase over the next 30–50 years, the magnitude of this increase will depend on local, national, and international efforts to reduce greenhouse gas emissions and enact climate-smart conservation, restoration, and management strategies to improve ecosystem resilience.

Local experts also assessed NSO survival, reproduction, habitat, and prey as commonly to frequently impacted by exposure to Barred Owls, for which there was also strong evidence in the literature, but the current exposure to Barred Owls is relatively low in Marin. As with climate change, while local experts expected the future exposure of NSOs to Barred Owls in Marin will increase over the next 30–50 years, the future abundance of Barred Owls in Marin will likely depend on whether Barred Owl management occurs in Marin and adjacent counties (Wiens et al. 2021); and given the number of different landownerships in the county, the effectiveness of management of Barred Owls will also depend on the spatial coverage and the participation of the various land managers and private entities throughout the county. For the Barred Owl mapping (Figures 3 and 4), although we compiled as many observations as possible from various sources, the data were limited to what was reported and/or shared with us (Appendix A). The detections represent known locations of NSOs and Barred Owls in this region, but the absence of detections in a given area does not confirm absence of either species. Most Barred Owls in our dataset were observed incidentally, either detected during formal NSO surveys (i.e., data from CNDDDB and contributing biologists) or by members of the public (i.e., data from eBird and iNaturalist), so it is possible that others may have gone undetected. Further, not all areas with potential Barred Owl habitat are surveyed each year, and in at least one case, a

biologist was unable to share their Barred Owl data due to the lack of resources to compile and share data. Lastly, while biologists conducting NSO surveys are experienced in identifying NSO from other owl species, including Barred Owls, and iNaturalist observations require a photo or recording where the identification could be confirmed, eBird data does not require documentation; therefore it is possible that some Barred Owl observations may represent mis-identified birds, although we expect this would be a very small portion of our full dataset. Despite these limitations, the known number of Barred Owls in Sonoma County, and the low, but regular detections of Barred Owls in Marin County suggest that this species is capable of becoming established in Marin at numbers higher than we have experienced to date, similar to what has been observed across the range of the NSO.

We also identified high-severity wildfire as one of the highest threats to NSO in Marin County, which was primarily because local experts assessed high-severity fire as having frequent impacts on NSO habitat, prey, and reproduction when exposed (Figure 2). While the literature review indicated substantial debate about the variable NSO responses to fires with different characteristics (e.g., patch size of high-severity burned areas), we expect that a larger high-severity fire where larger portions of their habitat is no longer suitable for roosting or nesting would have negative impacts on NSOs in Marin. There was also agreement between the local experts who expected future exposure to high-severity wildfire would increase in Marin County, and the literature that predicted high fire risk for Marin County NSO habitat (Hysen et al. 2023). The risk of wildfire is also linked to other threats. For example, longer, drier, and hotter summers due to climate change have increased the risk of larger and higher-severity wildfires in Marin (Fire Safe Marin 2020; GGNPC 2023), and increased fuel loads created by SOD (Forrestel et al. 2015) could increase the risk of NSO habitat loss from fire. In response, local land managers including Marin Water and Marin County Parks have recognized the need for increased efforts to reduce fuels and the risk of high-severity wildfire (May & Associates, Inc. 2015, Panorama Environmental Inc. 2019). The recently published Marin Regional Forest Health Strategy represents a coordinated multi-agency effort to improve forest health and resilience in Marin County through active stewardship, including forest thinning and prescribed fire (GGNPC 2023). Although these treatments may also disturb NSO habitat, they are expected to help decrease the risk of high-severity fire; it will be important to consider the need to balance the reductions of fuels with habitat protections for NSO and other species (Ager et al. 2007).

We identified rodenticides and sudden oak death as moderate threats to NSO in Marin County, and habitat loss (from urban development and fuels management), noise disturbance, and disease were identified as the lowest relative threats. However, these threats should not be ignored since they may exacerbate, or be exacerbated by, other threats to NSOs (see above), and the cumulative impacts from multiple threats can have significant impacts on species. In addition, threats like rodenticides, one of the threats most likely to affect NSO survival (Figure 2), could have been ranked higher if we had given more weight to threats to NSO survival. Because the population dynamics of long-lived species are often most influenced by small changes to survival (e.g., Forsman et al. 2011, Franklin et al. 2021), even a small increase in rodenticide exposure and NSO mortality could impact the Marin population more than short-term impacts of other threats to reproductive success. Furthermore, there was greater uncertainty and often less research on the impacts of these lower-scored threats, so it is

possible the lack of information for some of these risks has resulted in an underestimation of their potential impacts.

Local experts also identified additional threats that we did not specifically address in our assessment, including impacts from recreational activities, interactions between grounded NSO juveniles and dogs, and vehicle strikes. At least two NSOs were struck by vehicles in 2023 in Marin County, and while one was able to be released after being treated for injuries at the local wildlife rehabilitation hospital, the other had injuries that were too severe, and had to be euthanized (WildCare, unpublished data).

Another important consideration for a vulnerability assessment is to consider the attributes that could influence a species' adaptive capacity to a threat, such as its phenotypic plasticity, dispersal ability, and evolutionary capacity (Foden et al. 2018). For example, if an area becomes unsuitable for NSO (e.g., because the habitat has become unsuitable, or due to exclusion by a competitor), their ability to adapt to the threat would depend on 1) their intrinsic ability to disperse to a new area, 2) extrinsic limitations to dispersal (this could include physical barriers created by the lack of suitable dispersal habitat), 3) the availability of required resources at the new site, and 4) proliferation (species who reach reproductive maturity faster and/or that produce more young will have a higher potential for dispersing offspring) (Foden et al. 2018). NSOs are capable of breeding as young as one year old (Gutiérrez et al. 2020) and dispersing long distances (Hollenbeck et al. 2018) including the distances within the geographic area of Marin County (assuming extrinsic limitations to dispersal are not unsurmountable), but as a dietary and habitat specialist, their successful dispersal would also depend on availability of suitable resources elsewhere (Foden et al. 2018), including areas not already occupied by other NSOs. Because NSOs are associated with older complex forests, it can take decades to recover from past habitat loss (Yackulic et al. 2019). Thus, the availability of their required resources would also depend on the spatial and temporal scale of a changing threat; for example, if habitat conversion was on a slower temporal scale (e.g., decades), adaptation may be more likely if the succession of other forested habitats in the county were becoming suitable for NSOs as other forest was lost. The ability of NSOs in Marin County to recover from a decline in their population size would also be a challenge because Marin NSOs are known to be genetically isolated from NSOs to the north (Barrowclough et al. 2005). This genetic isolation is likely to be the result of low rates of immigration and emigration between Marin and counties to the north, suggesting that recovery may largely depend on successful reproduction within Marin County. In addition, this genetic isolation may contribute to reduced genetic diversity within Marin County, and therefore reduced evolutionary capacity to adapt to changing conditions. These intrinsic attributes of NSOs in Marin mean their adaptive capacity is inherently limited, so that their vulnerability to all threats is inherently elevated, making it even more important to reduce their exposure to threats and prevent population declines in the first place.

Conservation Recommendations

There are conservation actions that can be taken in response to these threats to NSOs in Marin County. While preventing the most severe impacts of climate change will require effective policies and laws to be enacted by state, federal, and international government bodies, local habitat

conservation and management actions can also directly support the resilience of NSO populations to growing threats of climate change and high-severity wildfire. For example, the impacts of extreme heat can be mitigated by preserving and maintaining older forests with a high level of canopy cover that provide cooler roost locations for NSO on warmer days (Barrows 1981) and are generally important for providing NSO habitat (Carroll 2010, Hysen et al. 2023). Further, protecting large blocks of older forest may help to reduce the likelihood of high-severity fire, as was found in a study in Oregon where under most fire conditions, NSO nesting forest (i.e., forest with high canopy cover and large live trees) burned at lower severity than other forest types (Lesmeister et al. 2019, 2021). In Marin County, much of the potential NSO habitat is protected by NPS and other local land management agencies (e.g., CSP, MCP, and Marin Water), but identifying the most suitable older forests throughout the county could help to determine where any additional habitat protections would help protect NSOs. In addition, forest management practices, such as prescribed burns or mechanical fuels reduction treatments, may also help protect NSO habitat by reducing the risk of high-severity fire. However, we recommend prioritizing these practices in areas with the highest likelihood of high-severity fire, ensuring active nests are not disturbed, and implementing these practices cautiously to balance wildfire risk against the potential negative impacts of these practices on NSO habitat quality and prey (see research needs below; Lehmkuhl et al. 2007, Gainey et al. 2017, Lesmeister et al. 2018, Wan et al. 2018). In addition, we recommend any habitat conservation and management strategy consider a landscape approach since NSOs are adapted to a mosaic of successional stages that provides an adequate amount of closed-canopy forest, as well as earlier-seral habitat capable of supporting abundant prey (Zabel et al. 1995, Ward et al. 1998, Franklin et al. 2000, Olson et al. 2004, Gaines et al. 2010, Lesmeister et al. 2018).

Habitat protection and management alone will not address the threat of competition from Barred Owls. While the current exposure to Barred Owls is low, we expect that if the number of Barred Owls in Marin increased, we would observe large declines in the local NSO population similar to those that have been documented elsewhere throughout the NSO range (Franklin et al. 2021). Experimental removals of Barred Owls have been successful at stabilizing declining populations of NSOs (Wiens et al. 2021) and intervention during the early phase of invasion by removing Barred Owls in the CSO range was successful in greatly reducing the threat in the Sierra Nevada (Hofstadter et al. 2022). We suggest that because Marin County is still in the early stages of invasion, with none to a few individuals detected per year (Figure 4), removal of Barred Owls in Marin and areas immediately to their north (Sonoma and Napa Counties) as they are detected would be more effective than waiting until they have become more established in the county, thereby reducing the risk of a much larger challenge to NSOs here (Simpson et al. 2009, USFWS 2023b). This recommendation is in alignment with the draft Barred Owl Management Strategy proposed by the USFWS (2023b) that states that Barred Owls in Marin and Sonoma Counties should be removed anywhere in the county, regardless of NSO presence or historic use of the site, as long as landowners and land managers are willing. In areas where Barred Owls have been removed in Marin County to date, we have observed NSO recolonization and successful nesting in several areas where NSO pairs had not been detected while the Barred Owl(s) were present at the site (Point Blue and NPS, unpublished data). Currently, research permits will allow for the removal of Barred Owls detected in the county in the near-future, and the effectiveness of any future removal efforts in the county will depend on the support of local

land managers and private landowners. Any lethal removal of Barred Owls in Marin County should evaluate the ethics of such a program (Lynn 2018), follow protocols outlined by the USFWS (2023b) to be as humane as possible, and be evaluated on a regular basis, especially as any non-lethal options are developed.

We also expect that community education and outreach efforts could help reduce the threat of rodenticides, noise disturbance, and other threats resulting from the proximity of NSOs to human communities in Marin. While knowledge of NSOs is not uncommon among local residents, we recommend efforts to increase awareness of their nesting season, sensitivity to noise, and potential harmful exposure to rodenticides. We also recommend testing all dead NSOs to gain a better understanding of exposure; sharing reports of owls that test positive for rodenticides could also help to increase awareness in the risk of rodenticide use here and reduce the use of these products. We recommend non-chemical rodent control whenever possible. We recommend the continued avoidance of noise disturbance in NSO habitat during the breeding season. It is possible that noise disturbance was ranked low because it is a threat that the major land managers and some private landowners of Marin County have been actively managing (i.e., avoiding noise) around nesting NSOs for years. Given the potential for lower reproductive output due to noise disturbance (Hayward et al. 2011), increased efforts to educate the public and smaller municipalities on the risks of noise disturbance to NSOs may increase participation in reducing noise around NSO nest sites and could further reduce the risk. Additionally, local experts highlighted several other types of human disturbance as threats to Marin NSOs that we did not evaluate, such as from pets and recreational activities; community outreach may also be useful in reducing any negative impacts from these activities.

Finally, while additional conservation recommendations are likely to emerge from research that aims to address the uncertainties identified in this report (see below), we recommend convening a cross-jurisdictional group to review these recommendations and work together to address knowledge gaps and develop an actionable conservation strategy for NSOs in Marin County.

Uncertainties and Research Needs

Effects of Weather and Climate

Due to geographic variation throughout the NSO range in studies that evaluated response to weather and climate (Glenn et al. 2010, Dugger et al. 2016, Franklin et al. 2021), local evaluation of the impacts of these variables on NSO occupancy and reproduction in Marin County would help to predict how NSO may respond to climate change here. Additionally, NSO habitat in Marin County has and will continue to respond to climate change, but we lack data on how the owls have and will respond to these changes.

Effects of Wildfire, Fuels Management, and Other Habitat Change

While the Woodward Fire that burned in PRNS in 2020 only overlapped with a small number of NSO sites (n=6), all of which were also monitored before the fire (Ellis 2020), evaluating the short- and long-term impacts to NSO occupancy and reproduction at burned and unburned sites would help to inform how NSO in Marin County respond to mixed-severity fire. Additionally, while there are only a couple of NSO territories near the periphery of the Vision Fire footprint and most of the

habitat within the footprint is not currently suitable NSO habitat, it would be informative to conduct inventory surveys in the areas within the fire perimeter that have more complex forest structure with larger trees to determine if they have become occupied by NSO. We also lack predictions for how NSO and their prey will respond to the different levels of fire predicted in the county (Hysen et al. 2023) and conducting dusky-footed woodrat surveys in unburned and burned areas—in areas that experienced different fire severities—would help inform these predictions and understand current NSO prey response to fires in Marin.

The literature on NSO response to fuels management (Bailey et al. 2015, Ganey et al. 2017, Gallagher et al. 2019) suggests variability in NSO response depending on the treatment, and there is still a lot of uncertainty around this topic (Wan et al. 2018). Studying short- and long-term impacts of fuels management to NSOs and their prey in Marin is an important component to making recommendations that will help land managers meet their goals for increasing resilience to wildfires, while also promoting practices that provide long-term benefits to NSO and other wildlife.

Marin County forests have changed substantially from SOD, though, it is unclear how these changes in habitat may have affected NSOs and their prey (but see Swei et al. 2011). Studies that assess the response of NSO and their prey to a range of SOD intensities could help inform forest management practices as they relate to SOD, and NSO conservation.

Barred Owls

Currently, when Barred Owls are detected and collected in Marin County, there is ongoing research to identify prey species consumed by Barred Owls and to assess the feasibility of removing Barred Owls and document NSO response to removals in Marin County. Stomach contents are collected from lethally removed individuals for future work that will develop, test and apply genetic (“meta-barcoding”) methods to identify prey species. This research is being led by researchers at the University of Wisconsin in partnership with NPS, including coordination with Point Blue and other local land managers. The diet study will inform our understanding of the impacts to other species from Barred Owls, beyond their impacts to NSOs.

Barred Owls in Marin County are usually first detected in the county during NSO surveys or by birders and other members of the public who directly report their observations to NSO biologists in the county, or via community science applications like eBird and iNaturalist. There are also Automated Recording Units (ARU) deployed on NPS lands that can detect both NSOs and Barred Owls, though data processing can delay the knowledge of each species’ presence in an area. Additional surveys that are specific to Barred Owls may increase the likelihood of early detection of this species, especially in areas not surveyed annually for NSOs.

Understanding the origins of Barred Owls in Marin County (e.g., whether they are offspring of a local pair or immigrated from elsewhere) would increase our understanding of how to manage this species. Collecting data on Barred Owl immigration and genetics would benefit the local conservation of NSOs.

Rodenticides

Due to high rates of rodenticides reported in dead wildlife from Marin County's local wildlife rehabilitation center (DPR 2018), including for NSOs (WildCare, unpublished data), studies that aim to understand the impacts of rodenticides to NSOs are warranted. While we recommend testing all dead NSO for rodenticides, these wild animals are not selected randomly and are taken to WildCare because they are distressed; these data are still valid and can be used evaluate rodenticides, but exposure rates may not reflect the rates in the wild NSO population of Marin County (DPR 2018). Thus, we also recommend testing Barred Owls that are removed for management purposes (USFWS 2023b), as an indicator species for rodenticide exposure in NSOs (e.g., Hofstadter et al. 2021), even if this is only represented by a few individuals; with the Barred Owl AR data, there is the potential to evaluate rates of ARs at sites relative to their proximity to the wildlife-urban interface. Additionally, testing NSOs and Barred Owls for exposure to bromethalin—a non-anticoagulant neurotoxic rodenticide that may be used as an alternative to ARs (Murray and Cox 2023)—would further increase our understanding of NSO exposure to rodenticides in Marin County.

Human Disturbance

In Marin County where a significant proportion of sites are near the wildland-urban interface, there is a unique opportunity to evaluate differences between sites closer to human-inhabited areas, and those that are more remote. Studies that assess impacts of noise, recreation, or other human disturbances on reproduction or prey species composition and availability relative to the proximity to human inhabited areas would all help to inform this under-studied area of NSO conservation. Additionally, there is also potential in Marin County for social science studies, such as how best to engage the public in voluntarily reducing their potential impacts to NSOs.

Disease

While several studies documented parasites and disease in NSOs (e.g., Ishak et al. 2008, Rogers et al. 2016), most were unable to assess impacts to NSOs, and population-level impacts from disease for this species—in Marin or anywhere in the range—is not known. Given the emergence and rapid spread of highly pathogenic avian influenza, the ability to rapidly detect impacts of new diseases on NSOs may be critical to population's persistence, particularly if treatment or prevention strategies are known. In addition, because exposure or susceptibility to disease could change due to climate change, Barred Owl invasion, or other disturbances (Young et al. 1993, Lewicki et al. 2015), studies that evaluate symptoms, evidence of exposure to or spread of pathogens in the population, and any population-level impacts are warranted.

Gaps in Understanding of Population Dynamics

The banding of NSOs in Marin stopped in 2003 (with the exception of banding birds prior to their release from the local wildlife rehabilitation center), removing our ability to uniquely identify individual owls and measure survivorship; thereafter, survey efforts focused on the continued collection of territory occupancy and fecundity data. Banding or tagging (e.g., GPS, telemetry) juvenile birds would also allow us to measure juvenile survival, and to understand dispersal, and where young birds go while waiting for opportunities to occupy breeding territories. Re-incorporating banding into our monitoring program would allow us to evaluate how these population metrics are impacted by the various threats above (e.g., climate change, wildfire, fuels management).

Conclusion

A vulnerability assessment for a single species can help to identify major threats and identify where management action and additional research may be needed, and it represents a critical step in developing an actionable conservation strategy. The population of the threatened Northern Spotted Owl in Marin County has been relatively stable over recent decades of monitoring, but climate change, competition from Barred Owls, and high-severity fire were identified as the threats to which this population is most vulnerable, with exposure to each of these threats expected to increase over the next 30–50 years. Monitoring programs such as the cross-agency long-term NSO monitoring program in Marin County are essential to our understanding of this species' local status and to our ability to detect early warning signs of declines. Past and continued protection of the mosaic of habitats that are essential to NSO and their prey, the relatively low number of Barred Owls, and efforts to avoid disturbance during the nesting season have likely contributed to the stable population in this region. Conservation actions to protect NSOs and the habitat and prey on which they depend, and outreach to local communities and land managers will be an essential part of the future health of this population. We encourage further collaboration to pursue addressing the uncertainties and research needs identified in this assessment and further developing these conservation recommendations into an actionable conservation strategy for NSOs in Marin County.

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Appendix A: Data sources for Barred Owl and Northern Spotted Owl mapping

Table 3. Data sources for Barred Owl and Northern Spotted Owl (NSO) mapping (Figures 3 and 4) and their respective dates downloaded or received and years of data included in each dataset. CNDDDB = California Natural Diversity Database.

Data Source	Date Downloaded or Received	Years of Data
Breeding Bird Atlas *	3/9/2024	1968–2022
CNDDDB Barred Owl Observations	10/9/2023	1989–2023
CNDDDB NSO Observations	10/4/2023	1900–2023
Global Biodiversity Information Facility	10/2/2023	1995–2023
eBird	10/2/2023	1995–2023
iNaturalist	10/2/2023	2011–2023
Marin County NSO Dataset (NPS/Point Blue) **	10/4/2023	2021–2022
University of Wisconsin–Madison (D. Hofstadter)	2/3/2023	2020–2023
The Wildlands Conservancy	9/25/2023	2013–2023
Environmental Resource Solutions	10/10/2023	2023

* Survey years for the Breeding Bird Atlas dataset varied by route with start dates ranging between 1968 and 2005; two routes in Napa County are currently inactive, ending in 2004 and 2008, respectively.

** Used in Figure 4 only

Appendix B: Summary of potential threats to NSO in Marin County, shared with local experts who completed the survey on the sensitivity and exposure of NSO to various threats.

Climate Change (extreme temperatures, extreme storms, drought)

Relative to other bird species in California, Spotted Owls were not identified as particularly vulnerable to climate change (Gardali et al. 2012), but a number of studies throughout their range have identified positive effects of colder and/or drier winters on recruitment (Dugger et al. 2016, Carroll 2010), negative effects of cold, wet winters on reproductive success at some sites (Glenn et al. 2011a), and impacts of precipitation on survival (Carroll 2010). In the Bay Area over the next several decades, the climate is expected to become significantly warmer and generally more arid, with an increase in the frequency and severity of drought punctuated by extreme storms; these changes may be less suitable for evergreen conifer forests and more favorable for chaparral and grasslands (GGNPC 2023).

High-severity wildfires

Decades of fire suppression combined with longer, drier, and hotter summers due to climate change have increased the risk of larger and higher severity wildfires in Marin (Fire Safe Marin 2020; GGNPC 2023). Throughout the NSO's range, the proportion burned by 2080 has been predicted to increase 10-fold (Wan et al. 2019). California Spotted Owls in the Sierra tend to use low- and moderate-severity burned areas and avoid large patches of high-severity (>75% tree mortality) burned areas, although they have been documented using smaller patches of high-severity burned areas (Kramer et al. 2021, Schofield et al. 2020, Roberts et al. 2011).

Sudden Oak Death (SOD)

This disease, caused by the water mold *Phytophthora ramorum*, affects many species of native trees in Marin and causes widespread die-offs of tanoak and oak species. SOD infestation is patchy and its spread is driven by the structure and composition of contiguous forest stands, with more spreading associated with very wet years (Garbelotto and Frankel 2020). SOD-induced mortality increases surface fuels, affecting wildfire behavior, and changes the structure of forests where NSO and their prey live. Research conducted in Marin County demonstrated a decrease in dusky-footed woodrat abundance with increasing SOD disturbance, likely because the woodrats use oaks for food and shelter (Swei et al. 2011). Low to moderate impacts of SOD that open up the forest understory could make it easier for NSO to hunt, but to our knowledge, this has not been evaluated.

Other habitat disturbance/loss (urban development, forest health & fuels management)

In Marin County, NSO live in a mix of forest types, including Douglas fir (*Pseudotsuga menziesii*), coast redwood (*Sequoia sempervirens*), bishop pine (*Pinus muricata*), and even hardwoods like California bay (*Umbellularia californica*) and oaks. Though much of their habitat in Marin County is on protected lands, NSO also nest in and adjacent to forested residential areas, and both public and private lands have been important in maintaining habitat quality for the owls. Because of the

proximity of NSO to residential areas in Marin, urban development may be a concern. In addition, increasing efforts to manage forest health, reduce surface fuels, and maintain fuel breaks, such as through mechanical thinning or prescribed fire, will affect vegetation structure and composition (Fire Safe Marin 2020; GGNPC 2023). As above, management that opens up the forest understory could make it easier for NSO to hunt, but to our knowledge, this has not been evaluated.

Rodenticides (or other poisons/pollutants)

NSO are at risk of potentially harmful rodenticide poisoning by ingesting poisoned rodents, including owls that live adjacent to residential areas (e.g., Hofstadter et al. 2021). In Marin County, NSO are in contact with residential areas more than in other parts of their range; several individuals tested by WildCare wildlife hospital about a decade ago were determined to have been exposed to rodenticides, but it is unknown what the level of impact the rodenticides had on these individuals, and WildCare's program for testing is no longer active (M. Piazza /WildCare, personal communication, September 2022). However, even NSO in remote areas of California have been exposed to rodenticides, and researchers hypothesized the exposure may be due to illegal marijuana cultivation sites (Gabriel et al. 2018). While less common in Marin County than some other parts of the NSO range in California, illegal cannabis cultivation has been documented on public lands in the county.

Noise disturbance

Noise disturbance from vegetation management, landscaping, traffic, construction and maintenance projects, and other human activities may negatively affect NSO (Hayward et al. 2011). Ongoing monitoring tracks nest locations to help managers avoid disruptive activities near nests on public lands. There are seasonal noise disturbance regulations in place for NSO from February to July (their breeding season), but public knowledge of NSO noise regulations in residential areas is sporadic, so owls in these areas are particularly at risk to disturbance.

Barred Owls

The Barred Owl (*Strix varia*) is a closely-related species that is native to eastern North America but has expanded its range westward and rapidly increased in numbers throughout the Pacific Northwest. The Barred Owl range now overlaps with the entire NSO range, and it is considered an invasive competitor and a primary threat to the NSO (Wiens et al. 2021, USFWS 2011). Negative impacts to NSO from the presence of Barred Owls have been well-documented outside of Marin County, including reductions in territory occupancy rates, recruitment, apparent survival, rate of population change, and potential for extirpation (e.g., Franklin et al. 2021, Wiens et al. 2021, Dugger et al. 2016, Olson et al. 2005). In a recent study, management of the Barred Owl resulted in stabilization of mean annual rates of population change for NSO, while in areas without Barred Owl removals, NSO continued to decline (Wiens et al. 2021). In Marin County, the number of Barred Owls has remained relatively low to date (Cormier & Duncan 2021; Ellis 2020; Jennings et al. 2011).

Highly Pathogenic Avian Influenza (or other diseases)

Although avian influenza viruses circulate naturally among birds and wild birds can be infected with Highly Pathogenic Avian Influenza (HPAI) and show no signs of illness, the strain of H5N1 currently in circulation has caused illness and death in a higher diversity of wild bird species than

during previous avian influenza outbreaks. The current strain of HPAI has been detected in almost every US state, including in California, and Marin County. The birds at highest risk of HPAI are waterfowl, other waterbirds, and the birds that prey or scavenge on these species (CDFW 2024). No Spotted Owls have been confirmed as being infected by H5N1 to date, but other owl species have, including Barred Owl and Great Horned Owls (USDA 2024).

Appendix C: Full list of papers that met inclusion criteria in the literature review.

Table 4. Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Ager, A. A., M. A. Finney, B. K. Kerns, and H. Maffei. 2007. Modeling wildfire risk to northern spotted owl (<i>Strix occidentalis caurina</i>) habitat in Central Oregon, USA. <i>Forest Ecology and Management</i> 246(1):45–56.	–	–	–	–	x	–	–	x
Anthony, R. G., E. D. Forsman, A. B. Franklin, D. R. Anderson, K. P. Burnham, G. C. White, C. J. Schwarz, J. D. Nichols, J. E. Hines, G. S. Olson, S. H. Ackers, L. S. Andrews, B. L. Biswell, P. C. Carlson, L. V. Diller, K. M. Dugger, K. E. Fehring, T. L. Fleming, R. P. Gerhardt, S. A. Gremel, R. J. Gutiérrez, P. J. Happe, D. R. Herter, and J. M. Higley. 2006. Status and trends in demography of Northern Spotted Owls, 1985–2003. <i>Wildlife Monographs</i> 163(1):1–48.	x	–	–	–	–	–	–	–
Bailey, L. L., J. A. Reid, E. D. Forsman, and J. D. Nichols. 2009. Modeling co-occurrence of Northern Spotted and Barred Owls: Accounting for detection probability differences. <i>Biological Conservation</i> 142(12):2983–2989.	x	–	–	–	–	–	–	–
Bailey, J. D., K. Vogler, D. Churchill, and A. Youngblood. 2015. Silvicultural approaches to restoring resilient landscapes for Northern Spotted Owls. Chapter 4 in <i>Silviculture and monitoring guidelines for integrating restoration of dry mixed-conifer forest and Spotted Owl habitat management in the eastern Cascade Range</i> . General Technical Report PNW-GTR-915. U.S. Forest Service, Pacific Northwest Research Station.	–	–	–	–	x	–	–	–
Baker, W. L. 2015. Historical Northern Spotted Owl habitat and old-growth dry forests maintained by mixed-severity wildfires. <i>Landscape Ecology</i> 30:655–666.	–	–	–	–	–	–	–	x
Barrows, C. W. 1981. Roost selection by Spotted Owls: an adaptation to heat stress. <i>Condor</i> 83:302–309.	–	x	–	–	–	–	–	–
Baumbusch, R. C. 2023. Foraging ecology of Barred Owls where they are outcompeting the threatened Northern Spotted Owl. Dissertation. Oregon State University, Corvallis, Oregon.	x	–	–	–	–	–	–	–
Bond, M. L., R. J. Gutiérrez, A. B. Franklin, W. S. LaHaye, C. A. May, and M. E. Seamans. 2002. Short-term effects of wildfires on Spotted Owl survival, site fidelity, mate fidelity, and reproductive success. <i>Wildlife Society Bulletin</i> 30(4):1022–1028.	–	–	–	–	–	–	–	x
Bond, M. L., D. E. Lee, R. B. Siegel, and J. P. Ward Jr. 2010. Habitat use and selection by California Spotted Owls in a postfire landscape. <i>Journal of Wildlife Management</i> 73(7):1116–1124.	–	–	–	–	–	–	–	x
Bond, M. L., T. Y. Chi, C. M. Bradley, and D. A. DellaSala. 2022. Forest Management, Barred Owls, and Wildfire in Northern Spotted Owl Territories. <i>Forests</i> 13:1730.	–	–	–	–	–	–	–	x

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Buchanan, J. B. 2023. Draft periodic status review for the Northern Spotted Owl in Washington. Washington Department of Fish and Wildlife, Olympia, Washington. 26 + iii pp.	x	–	–	–	–	–	–	–
California Department of Fish and Wildlife (CDFW). 2024. Information Sheet: Highly pathogenic avian influenza H5N1. Available at https://nrm.dfg.ca.gov (accessed 06 January 2024).	–	–	x	–	–	–	–	–
Captanian, N., M. G. Hawkins, C. Fiorello, M. Thurber, and W. K. Reisen. 2017. Low prevalence of West Nile virus antibodies in select northern California owl species (2007–2014). <i>Journal of Zoo and Wildlife Medicine</i> 48(4):1239–1241.	–	–	x	–	–	–	–	–
Carroll, C. 2010. Role of climate niche models in focal-species-based conservation planning: assessment of potential effects of climate change on Northern Spotted Owl in the Pacific Northwest, USA. <i>Biological Conservation</i> 143(6):1432–1437.	–	x	–	–	–	–	–	–
Clark, D. A., R. G. Anthony, and L. S. Andrews. 2011. Survival rates of Northern Spotted Owls in post-fire landscapes of southwest Oregon. <i>Journal of Raptor Research</i> 45(1):38–47.	–	–	–	–	–	–	–	x
Clark, D. A., R. G. Anthony, and L. S. Andrews. 2013. Relationship between wildfire, salvage logging, and occupancy of nesting territories by Northern Spotted Owls. <i>Journal of Wildlife Management</i> 77(4):672–688.	–	–	–	–	–	–	–	x
Comfort, E. J., D. A. Clark, R. G. Anthony, J. Bailey, and M. G. Betts. 2016. Quantifying edges as gradients at multiple scales improves habitat selection models for Northern Spotted Owl. <i>Landscape Ecology</i> 31:1227–1240.	–	–	–	–	–	–	–	x
Courtney, S. P., J. A. Blakesley, R. E. Bigley, M. L. Cody, J. P. Dumbacher, R. C. Fleischer, A. B. Franklin, J. F. Franklin, R. J. Gutiérrez, J. M. Marzluff, and L. Sztukowski. 2004. Scientific evaluation of the status of the Northern Spotted Owl. Sustainable Ecosystems Institute Unpublished Report, Portland, Oregon.	–	–	x	–	–	–	x	–
Crozier, M. L., M. E. Seamans, R. J. Gutierrez, P. J. Loschl, R. B. Horn, S. G. Sovern, and E. D. Forsman. 2006. Does the presence of Barred Owls suppress the calling behavior of Spotted Owls? <i>Condor</i> 108(4):760–769.	x	–	–	–	–	–	–	–
Davis, R. J., W. C. Aney, L. Evers, and K. M. Dugger. 2011. Large wildfires within the owl's range. Chapter 4 in Davis, R. J., K. M. Dugger, S. Mohoric, L. Evers, and W. C. Aney. <i>Northwest Forest Plan—the first 15 years (1994–2008): status and trends of Northern Spotted Owl populations and habitats</i> . Gen. Tech. Rep. PNWGTR-850. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 147 p.	–	–	–	–	–	–	–	x
Davis, R. J., K. M. Dugger, S. Mohoric, L. Evers, and W. C. Aney. 2011. <i>Northwest Forest Plan—the first 15 years (1994–2008): status and trends of Northern Spotted Owl populations and habitats</i> . Gen. Tech. Rep. PNWGTR-850. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 147 p.	x	–	–	–	–	–	–	–

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Diller, L., K. Hamm, D. Lamphear, and T. McDonald. 2012. Two Decades of Research and Monitoring of the Northern Spotted Owl on Private Timberlands in the Redwood Region: What do We Know and What Challenges Remain? Pages 399–407 in R. B. Standiford, T. J. Weller, D. D. Piirto, and J. D. Stuart, technical editors. Proceedings of the Coast Redwood Forests in a Changing California: A Symposium for Scientists and Managers. General Technical Report PNW-GTR-238. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Albany, California.	x	–	–	–	–	–	–	–
Diller, L. V., K. A. Hamm, D. A. Early, D. W. Lamphear, K. M. Dugger, C. B. Yackulic, C. J. Schwarz, P. C. Carlson, and T. L. McDonald. 2016. Demographic response of Northern Spotted Owls to Barred Owl removal. Journal of Wildlife Management 80(4):691–707.	x	–	–	–	–	–	–	–
Dugger, K. M., F. Wagner, R. G. Anthony, and G. S. Olson. 2005. The relationship between habitat characteristics and demographic performance of Northern Spotted Owls in southern Oregon. Condor 107:863–878.	–	x	–	–	–	–	–	–
Dugger, K. M., R. G. Anthony, and L. S. Andrews. 2011. Transient dynamics of invasive competition: Barred Owls, Spotted Owls, habitat, and the demons of competition present. Ecological Applications 21(7):2459–2468.	x	–	–	–	–	–	–	–
Dugger, K. M., E. D. Forsman, A. B. Franklin, R. J. Davis, G. C. White, C. J. Schwarz, K. P. Burnham, J. D. Nichols, J. E. Hines, C. B. Yackulic, P. F. Doherty, Jr., L. Bailey, D. A. Clark, S. H. Ackers, L. S. Andrews, B. Augustine, B. L. Biswell, J. Blakesley, P. C. Carlson, M. J. Clement, L. V. Diller, E. M. Glenn, A. Green, S. A. Gremel, D. R. Herter, J. M. Higley, J. Hobson, R. B. Horn, K. P. Huyvaert, C. McCafferty, T. McDonald, K. McDonnell, G. S. Olson, J. A. Reid, J. Rockweit, V. Ruiz, J. Saenz, and S. G. Sovern. 2016. The effects of habitat, climate, and Barred Owls on long-term demography of Northern Spotted Owls. Condor 118(1):57–116.	x	x	–	–	–	–	–	–
Eyes, S. A., S. L. Roberts, and M. D. Johnson. 2017. California Spotted Owl (<i>Strix occidentalis occidentalis</i>) habitat use patterns in a burned landscape. Condor 119(3):375–388.	–	–	–	–	–	–	–	x
Forrestel, A. B., B. S. Ramage, T. Moody, M. A. Moritz, and S. L. Stephens. 2015. Disease, fuels and potential fire behavior: impacts of Sudden Oak Death in two coastal California forest types. Forest Ecology and Management 348:23–30.	–	–	–	–	–	–	x	–
Forsman, E. D., E. C. Meslow, and H. M. Wight. 1984. Distribution and biology of the Spotted Owl in Oregon. Wildlife Monographs 87:3–64.	–	x	–	–	–	–	–	–

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Forsman, E. D., R. G. Anthony, K. M. Dugger, E. M. Glenn, A. B. Franklin, G. C. White, C. J. Schwarz, K. P. Burnham, D. R. Anderson, J. D. Nichols, J. E. Hines, J. B. Lint, R. J. Davis, S. H. Ackers, L. S. Andrews, B. L. Biswell, P. C. Carlson, L. V. Diller, S. A. Gremel, D. R. Herter, J. M. Higley, R. B. Horn, J. A. Reid, J. Rockweit, J. P. Schaberl, T. J. Snetsinger, and S. G. Sovern. 2011. Population demography of Northern Spotted Owls. <i>Studies in Avian Biology</i> 40:1–106.	–	x	–	–	–	–	–	–
Franklin, A. B., D. R. Anderson, R. J. Gutiérrez, and K. P. Burnham. 2000. Climate, habitat quality, and fitness in Northern Spotted Owl populations in northwestern California. <i>Ecological Monographs</i> 70(4):539–590.	–	x	–	–	–	–	–	–
Franklin, A. B., P. C. Carlson, A. Rex, J. T. Rockweit, D. Garza, E. Culhane, S. F. Volker, R. J. Dusek, V. I. Shearn-Bochsler, M. W. Gabriel, and K. E. Horak. 2018. Grass is not always greener: rodenticide exposure of a threatened species near marijuana growing operations. <i>BMC Research Notes</i> 11:94.	–	–	–	–	–	x	–	–
Franklin, A. B., K. M. Dugger, D. B. Lesmeister, R. J. Davis, J. D. Wiens, G. C. White, J. D. Nichols, J. E. Hines, C. B. Yackulic, C. J. Schwarz, S. H. Ackers, L. S. Andrews, L. L. Bailey, R. Bown, J. Burgher, K. P. Burnham, P. C. Carlson, T. Chestnut, M. M. Conner, K. E. Dilione, E. D. Forsman, E. M. Glenn, S. A. Gremel, K. A. Hamm, D. R. Herter, J. M. Higley, R. B. Horn, J. M. Jenkins, W. L. Kendall, D. W. Lamphear, C. McCafferty, T. L. McDonald, J. A. Reid, J. T. Rockweit, D. C. Simon, S. G. Sovern, J. K. Swingle, and H. Wise. 2021. Range-wide declines of Northern Spotted Owl populations in the Pacific Northwest: A meta-analysis. <i>Biological Conservation</i> 259:109168.	x	x	–	–	–	–	–	x
Gabriel, M. W., L. V. Diller, J. P. Dumbacher, G. M. Wengert, J. M. Higley, R. H. Poppenga, and S. Mendia. 2018. Exposure to rodenticides in Northern Spotted and Barred Owls on remote forest lands in northwestern California: evidence of food web contamination. <i>Avian Conservation and Ecology</i> 13(1):2.	–	–	–	–	–	x	–	–
Gaines, W. L., R. J. Harrod, J. Dickinson, A. L. Lyons, and K. Halupka. 2010. Integration of Northern Spotted Owl habitat and fuels treatments in the eastern Cascades, Washington, USA. <i>Forest Ecology and Management</i> 260(11):2045–2052.	–	–	–	–	x	–	–	–
Gaines, W. L., J. B. Buchanan, J. F. Lehmkuhl, K. Halupka, and P. H. Singleton. 2015. Northern Spotted Owl issues and objectives. Chapter 3 in <i>Silviculture and Monitoring Guidelines for Integrating Restoration of Dry Mixed-Conifer Forest and Spotted Owl Habitat Management in the Eastern Cascade Range</i> . General Technical Report PNW-GTR-915. U.S. Forest Service, Pacific Northwest Research Station.	–	–	–	–	x	–	–	–
Gallagher, C. V., J. J. Keane, P. A. Shaklee, H. A. Kramer, and R. Gerrard. 2019. Spotted Owl foraging patterns following fuels treatments, Sierra Nevada, California. <i>The Journal of Wildlife Management</i> 83(2):487–501.	–	–	–	–	x	–	–	–
Gancz, A. Y., I. K. Barker, R. Lindsay, A. Dibernardo, K. McKeever, and B. Hunter. 2004. West Nile virus outbreak in North American owls, Ontario, 2002. <i>Emerging Infectious Diseases</i> 10(12):2135–2142.	–	–	x	–	–	–	–	–

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Ganey, J. L., H. Y. Wan, S. A. Cushman, and C. D. Vojta. 2017. Conflicting perspectives on Spotted Owls, wildfire, and forest restoration. <i>Fire Ecology</i> 13:146–165.	–	–	–	–	x	–	–	x
Glenn, E. M., R. G. Anthony, and E. D. Forsman. 2010. Population trends in Northern Spotted Owls: associations with climate in the Pacific Northwest. <i>Biological Conservation</i> 143(11):2543–2552.	x	x	–	–	–	–	–	–
Glenn, E. M., R. G. Anthony, E. D. Forsman, and G. S. Olson. 2011a. Reproduction of Northern Spotted Owls: The role of local weather and regional climate. <i>Journal of Wildlife Management</i> 75(6):1279–1294.	x	x	–	–	–	–	–	–
Glenn, E. M., R. G. Anthony, E. D. Forsman, and G. S. Olsen. 2011b. Local weather, regional climate, and annual survival of the Northern Spotted Owl. <i>Condor</i> 113(1):159–176.	–	x	–	–	–	–	–	–
Gutiérrez, R. J. 1989. Hematozoa from the Spotted Owl. <i>Journal of Wildlife Diseases</i> 25(4):614–618.	–	–	x	–	–	–	–	–
Gutiérrez, R. J., M. Cody, S. Courtney, and A. B. Franklin. 2007. The invasion of Barred Owls and its potential effect on the Spotted Owl: a conservation conundrum. <i>Biological Invasions</i> 9:181–196.	x	–	–	–	–	–	–	–
Hamer, T. E., E. D. Forsman, A. D. Fuchs, and M. L. Walters. 1994. Hybridization Between Barred and Spotted Owls. <i>Auk</i> 111(2):487–492.	x	–	–	–	–	–	–	–
Hamer, T. E., E. D. Forsman, and E. M. Glenn. 2007. Home range attributes and habitat selection of Barred Owls and Spotted Owls in an area of sympatry. <i>Condor</i> 109(4):750–768.	x	–	–	–	–	–	–	–
Hanna, Z. R., J. P. Dumbacher, R. C. K. Bowie, J. B. Henderson, and J. D. Wall. 2018. Whole-genome analysis of introgression between the Spotted Owl and Barred Owl (<i>Strix occidentalis</i> and <i>Strix varia</i> , respectively; Aves: Strigidae) in western North America. <i>G3</i> 8:3945–3952.	x	–	–	–	–	–	–	–
Hanson, C. T., D. C. Odion, D. A. Dellasala, and W. L. Baker. 2009. Overestimation of fire risk in the Northern Spotted Owl recovery plan. <i>Conservation Biology</i> 23(5):1314–1319.	–	–	–	–	–	–	–	x
Hanson, C. T., D. C. Odion, D. A. Dellasala, and W. L. Baker. 2010. More-comprehensive recovery actions for Northern Spotted Owls in dry forests: reply to Spies et al. <i>Conservation Biology</i> 24(1):334–337.	–	–	–	–	–	–	–	x
Hanson, C. T., M. L. Bond, and D. E. Lee. 2018. Effects of post-fire logging on California Spotted Owl occupancy. <i>Nature Conservation</i> 24:93–105.	–	–	–	–	–	–	–	x
Hanson, C. T., D. E. Lee, and M. L. Bond. 2021. Disentangling Post-Fire Logging and High-Severity Fire Effects for Spotted Owls. <i>Birds</i> 2:147–157.	–	–	–	–	–	–	–	x
Hayward, L. S., A. E. Bowles, J. C. Ha, and S. K. Wasser. 2011. Impacts of acute and long-term vehicle exposure on physiological and reproductive success of the Northern Spotted Owl. <i>Ecosphere</i> 2(6):art65.	–	–	–	x	–	–	–	–

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Hoberg, E. P., G. S. Miller, E. Wallner-Pendleton, and O. R. Hedstrom. 1989. Helminth parasites of Northern Spotted Owls (<i>Strix occidentalis caurina</i>) from Oregon. <i>Journal of Wildlife Diseases</i> 25(5):246–251.	–	–	x	–	–	–	–	–
Hoberg, E. P., R. J. Cawthorn, and O. R. Hedstrom. 1993. Enteric Coccidia (Apicomplexa) in the small intestine of the Northern Spotted Owl (<i>Strix occidentalis caurina</i>). <i>Journal of Wildlife Diseases</i> 29(3):495–497.	–	–	x	–	–	–	–	–
Hofstadter, D. F., N. F. Kryshak, M. W. Gabriel, C. M. Wood, G. M. Wengert, B. P. Dotters, K. N. Roberts, E. D. Fountain, K. G. Kelly, J. J. Keane, S. A. Whitmore, W. J. Berigan, and M. Z. Peery. 2021. High rates of anticoagulant rodenticide exposure in California Barred Owls are associated with the wildland-urban interface. <i>Ornithological Applications</i> 123:1–13.	–	–	–	–	–	x	–	–
Hollenbeck, J. P., S. M. Haig, E. D. Forsman, and J. D. Wiens. 2018. Geographic variation in natal dispersal of Northern Spotted Owls over 28 years. <i>Ornithological Applications</i> 120(3):530–542.	x	–	–	–	–	–	–	–
Hull, J. M., J. J. Keane, L. Tell, and H. B. Ernest. 2010. West Nile virus antibody surveillance in three Sierra Nevada raptors of conservation concern. <i>Condor</i> 112(1):168–172.	–	–	x	–	–	–	–	–
Hunter, J. E., R. J. Gutiérrez, A. B. Franklin, and D. Olson. 1994. Ectoparasites of the Spotted Owl. <i>Journal of Raptor Research</i> 28(4):232–235.	–	–	x	–	–	–	–	–
Hysen, L. B., S. A. Cushman, F. A. Fogarty, E. C. Kelly, D. Nayeri, and H. Y. Wan. 2023. Northern Spotted Owl nesting habitat under high potential wildfire threats along the California coastal redwood forest. <i>Science of the Total Environment</i> 890:1634154.	–	x	–	–	–	–	–	x
Irwin, L. L., D. F. Rock, S. C. Rock, A. K. Heyerly, and L. A. Clark. 2019. Barred Owl effects on Spotted Owl resource selection: a meta-analysis. <i>Journal of Wildlife Management</i> 84(1):96–117.	x	–	–	–	–	–	–	–
Ishak, H. D., J. P. Dumbacher, N. L. Anderson, J. J. Keane, G. Valkiūnas, S. M. Haig, L. A. Tell, R. N. M. Sehgal. 2008. Blood parasites in owls with conservation implications for the Spotted Owl (<i>Strix occidentalis</i>). <i>PloSOne</i> 3(5):e2304.	–	–	x	–	–	–	–	–
Jenkins, J. M. A., D. B. Lesmeister, E. D. Forsman, K. M. Dugger, S. H. Ackers, L. S. Andrews, C. E. McCafferty, M. S. Pruett, J. A. Reid, S. G. Sovern, R. B. Horn, S. A. Gremel, J. D. Wiens, and Z. Yang. 2019. Social status, forest disturbance, and Barred Owls shape long-term trends in breeding dispersal distance of Northern Spotted Owls. <i>Condor</i> 121:1–17.	x	–	–	–	–	–	–	–
Jenkins, J. M. A., D. B. Lesmeister, E. D. Forsman, K. M. Dugger, S. H. Ackers, L. S. Andrews, S. A. Gremel, B. Hollen, C. E. McCafferty, M. S. Pruett, J. A. Reid, S. G. Sovern, J. D. Wiens, and Z. Yang. 2021. Conspecific and congeneric interactions shape increasing rates of breeding dispersal of Northern Spotted Owls. <i>Ecological Applications</i> 31(7):e02398.	x	–	–	–	–	–	–	–

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Jennings, S., R. L. Cormier, T. Gardali, D. T. Press, and W. W. Merkle. 2011. Status and distribution of the Barred Owl in Marin County, California. <i>Western Birds</i> 42:103–110.	x	–	–	–	–	–	–	–
Jones, G. M., R. J. Gutiérrez, D. J. Tempel, S. A. Whitmore, W. J. Berigan, and M. Z. Peery. 2016. Megafires: an emerging threat to old-forest species. <i>Frontiers in Ecology and Evolution</i> 14(6):300–306.	–	–	–	–	–	–	–	x
Jones, G. M., R. J. Gutiérrez, A. Kramer, D. J. Tempel, W. J. Berigan, S. A. Whitmore, M. Z. Peery. 2019. Megafire effects on Spotted Owls: elucidation of a growing threat and a response to Hanson et al. (2018). <i>Nature Conservation</i> 37:31–51.	–	–	–	–	–	–	–	x
Jones, G. M., R. J. Gutiérrez, W. M. Block, P. C. Carlson, E. J. Comfort, S. A. Cushman, R. J. Davis, S. A. Eyes, A. B. Franklin, J. L. Ganey, S. Hedwall, J. J. Keane, R. Kelsey, D. B. Lesmeister, M. P. North, S. L. Roberts, J. T. Rockweit, J. S. Sanderlin, S. C. Sawyer, B. Solvesky, D. J. Tempel, H. Y. Wan, A. L. Westerling, G. C. White, and M. Z. Peery. 2020b. Spotted Owls and forest fire: comment. <i>Ecosphere</i> 11(2): e03312.	–	–	–	–	–	–	–	x
Jones, G. M., H. A. Kramer, S. A. Whitmore, W. J. Berigan, D. J. Tempel, C. M. Wood, B. K. Hobart, T. Erker, F. A. Atuo, N. F. Pietrunti, R. Kelsey, R. J. Guterrez, and M. Z. Peery. 2020a. Habitat selection by spotted owls after a megafire reflects their adaptation to historical frequent-fire regimes. <i>Landscape Ecology</i> 35:1199–1213.	–	–	–	–	–	–	–	x
Jones, G. M., H. A. Kramer, W. J. Berigan, S. A. Whitmore, R. J. Gutiérrez, and M. Z. Peery. 2021. Megafire causes persistent loss of an old-forest species. <i>Animal Conservation</i> 24(6):925–936.	–	–	–	–	–	–	–	x
Kelly, E. G., E. D. Forsman, and R. G. Anthony. 2003. Are Barred Owls displacing Spotted Owls? <i>Condor</i> 105(1):45–53.	x	–	–	–	–	–	–	–
Kelly, E. G., and E. D. Forsman. 2004. Recent records of hybridization between Barred Owls (<i>Strix varia</i>) and Northern Spotted Owls (<i>S. occidentalis caurina</i>). <i>Auk</i> 121(3):806–810.	x	–	–	–	–	–	–	–
Klaassen, M., and M. Wille. 2023. The plight and role of wild birds in the current bird flu panzootic. <i>Nature Ecology and Evolution</i> 7:1541–1542.	–	–	x	–	–	–	–	–
Kramer, A., G. M. Jones, S. A. Whitmore, J. J. Keane, F. A. Atuo, B. P. Dotters, S. C. Sawyer, S. L. Stock, R. J. Gutiérrez, and M. Z. Peery. 2021. California Spotted Owl habitat selection in a fire-managed landscape suggests conservation benefit of restoring historical fire regimes. <i>Forest Ecology and Management</i> 479:118576.	–	–	–	–	–	–	–	x
Kroll, A. J., T. L. Fleming, and L. L. Irwin. 2010. Site occupancy dynamics of Northern Spotted Owls in the eastern Cascades, Washington, USA, 1990–2003. <i>Journal of Wildlife Management</i> 74(6):1264–1274.	x	–	–	–	–	–	–	–
Lee, D. E. M. L. Bond, and R. B. Siegel. 2012. Dynamics of breeding-season site occupancy of the California Spotted Owl in burned forests. <i>Condor</i> 114(4):792–802.	–	–	–	–	–	–	–	x

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Lee, D. E., and M. L. Bond. 2015a. Occupancy of California Spotted Owl sites following a large fire in the Sierra Nevada, California. <i>Condor</i> 117(2):228–236.	–	–	–	–	–	–	–	x
Lee, D. E., and M. L. Bond. 2015b. Previous year’s reproductive state affects Spotted Owl site occupancy and reproduction responses to natural and anthropogenic disturbances. <i>Condor</i> 117(3):307–319.	–	–	–	–	–	–	–	x
Lee, D. E. 2018. Spotted Owls and forest fire: a systematic review and meta-analysis of the evidence. <i>Ecosphere</i> 9(7):e02354.	–	–	–	–	–	–	–	x
Lee, D. E. 2020. Spotted Owls and forest fire: Reply. <i>Ecosphere</i> 11(12):e03310.	–	–	–	–	–	–	–	x
Lehmkuhl, J. F., M. Kennedy, E. D. Ford, P. H. Singleton, W. L. Gaines, and R. L. Lind. 2007. Seeing the forest for the fuel: integrating ecological values and fuels management. <i>Forest Ecology and Management</i> 246(1):73–80.	–	–	–	–	x	–	–	–
Lesmeister, D. B., R. J. Davis, P. H. Singleton, and J. D. Wiens. 2018. Northern Spotted Owl habitat and populations: status and threats. Chapter 4: in T. A. Spies, P. A. Stine, R. Gravenmier, J. W. Long, and M. J. Reilly, technical coordinators. Synthesis of science to inform land management within the northwest forest plan area. General Technical Report PNW-GTR-966. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon.	x	x	x	x	x	–	–	x
Lesmeister, D. B., S. G. Sovern, R. J. Davis, D. M. Bell, M. J. Gregory, and J. C. Vogeler. 2019. Mixed-severity wildfire and habitat of an old-forest obligate. <i>Ecosphere</i> 10(4):e02696.	–	–	–	–	–	–	–	x
Lesmeister, D. B., R. J. Davis, S. G. Sovern, and Z. Yang. 2021. Northern Spotted Owl nesting forests as fire refugia: a 30-year synthesis of large wildfires. <i>Fire Ecology</i> 17:32.	–	–	–	–	–	–	–	x
Lewicki, K. E., K. P. Huyvaert, A. J. Piaggio, L. V. Diller, and A. B. Franklin. 2015. Effects of Barred Owl (<i>Strix varia</i>) range expansion on Haemoproteus parasite assemblage dynamics and transmission in barred and Northern Spotted Owls (<i>Strix occidentalis caurina</i>). <i>Biological Invasions</i> 17:1713–1727.	x	–	x	–	–	–	–	–
Livezey, K. B. 2009. Range expansion of Barred Owls, part I: chronology and distribution. <i>The American Midland Naturalist</i> 161(1):49–56.	x	–	–	–	–	–	–	–
Loehle, C., L. Irwin, J. Beebe, and T. Fleming. 2011. Factors influencing the distribution and Northern Spotted Owls in the eastern Cascades, Washington. <i>Northwestern Naturalist</i> 92:19–36.	–	x	–	–	–	–	–	–
Mangan, A. O., T. Chestnut, J. C. Vogeler, I. K. Breckheimer, W. M. King, K. E. Bagnall, and K. M. Dugger. 2019. Barred Owls reduce occupancy and breeding propensity of Northern Spotted Owl in a Washington old-growth forest. <i>Ornithological Applications</i> 121:1–20.	x	x	–	–	–	–	–	–

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Mikkelsen, A. J., D. B. Lesmeister, K. M. O'Reilly, and K. M. Dugger. 2021. Feather corticosterone reveals developmental challenges in a long-term study of juvenile Northern Spotted Owls. <i>Functional Ecology</i> 36:51–63.	–	x	–	–	–	–	–	–
Morishita, T. Y., J. W. Mertins, D. G. Baker, C. M. Monahan, and D. L. Brooks. 2001. Occurrence and species of lice on free-living and captive raptors in California. <i>Journal of Avian Medicine and Surgery</i> 15(4):288–292.	–	–	x	–	–	–	–	–
Odion, D.C., C. T. Hanson, D. A. DellaSala, W. L. Baker, and M. L. Bond. 2014. Effects of fire and commercial thinning on future habitat of the Northern Spotted Owl. <i>The Open Ecology Journal</i> 7:37–51.	–	–	–	–	–	–	–	x
Olson, G. S., E. M. Glenn, R. G. Anthony, E. D. Forsman, J. A. Reid, P. J. Loschl, and W. J. Ripple. 2004. Modeling demographic performance of Northern Spotted Owls relative to forest habitat in Oregon. <i>Journal of Wildlife Management</i> 68(4):1039–1053.	–	x	–	–	–	–	–	–
Olson, G. S., R. G. Anthony, E. D. Forsman, S. H. Ackers, P. J. Loschl, J. A. Reid, K. M. Dugger, E. M. Glenn, W. J. Ripple. 2005. Modeling of site occupancy dynamics for Northern Spotted Owls, with emphasis on the effects of Barred Owls. <i>Journal of Wildlife Management</i> 69(3):918–932.	x	–	–	–	–	–	–	–
Peery, M. Z., G. M. Jones, R. J. Gutiérrez, S. M. Redpath, A. B. Franklin, D. Simberloff, M. G. Turner, V. C. Radeloff, and G. C. White. 2019. The conundrum of agenda-driven science in conservation. <i>Frontiers in Ecology and Evolution</i> doi:10.1002/fee.2006.	–	–	–	–	–	–	–	x
Ramage, B. S. 2011. Fire and sudden oak death in coast redwood forests: effects of two distinct disturbances. Dissertation. University of California, Berkeley, Berkeley, California.	–	–	–	–	–	–	x	–
Remple, J. D. 2004. Intracellular Hematozoa of raptors: a review and update. <i>Journal of Avian Medicine and Surgery</i> 18(2):75–88.	–	–	x	–	–	–	–	–
Rockweit, J. T., A. B. Franklin, G. S. Bakken, and R. J. Gutiérrez. 2012. Potential influences of climate and nest structure on Spotted Owl reproductive success: a biophysical approach. <i>PLoS One</i> 7(7): e41498.	–	x	–	–	–	–	–	–
Rockweit, J. T., A. B. Franklin, and P. C. Carlson. 2017. Differential impacts of wildfire on the population dynamics of an old-forest species. <i>Ecology</i> 98(6):1574–1582.	–	–	–	–	–	–	–	x
Rockweit J. T., J. M. Jenkins, J. E. Hines, J. D. Nichols, K. M. Dugger, A. B. Franklin, P. C. Carlson, W. L. Kendall, D. B. Lesmeister, C. McCafferty, S. H. Ackers, L. S. Andrews, L. L. Bailey, J. Burgher, K. P. Burnham, T. Chestnut, M. M. Conner, R. J. Davis, K. E. Dilione, E. D. Forsman, E. M. Glenn, S. A. Gremel, K. A. Hamm, D. R. Herter, J. M. Higley, R. B. Horn, D. W. Lamphear, T. L. McDonald, J. A. Reid, C. J. Schwarz, D. C. Simon, S. G. Sovern, J. K. Swingle, J. D. Wiens, H. Wise, C. B. Yackulic. 2023. Range-wide sources of variation in reproductive rates of Northern Spotted Owls. <i>Ecological Applications</i> 33:e2726.	x	–	–	–	–	–	–	–

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Rogers, K. H., Y. A. Girard, L. Woods, and C. K. Johnson. 2016. Avian trichomonosis in Spotted Owls (<i>Strix occidentalis</i>): Indication of opportunistic spillover from prey. <i>International Journal for Parasitology: Parasites and Wildlife</i> 5(3):305–311.	–	–	x	–	–	–	–	–
Roloff, G. J., S. P. Mealey, and J. D. Bailey. 2012. Comparative hazard assessment for protected species in a fire-prone landscape. <i>Forest Ecology and Management</i> 277:1–10.	–	–	–	–	x	–	–	–
Saikai, H. F., and B. R. Noon. 1993. Dusky-footed woodrat abundance in different-aged forests in northwestern California. <i>Journal of Wildlife Management</i> 57(2):373–382.	–	x	–	–	–	–	–	–
Schofield, L. N., S. A. Eyes, R. B. Siegel, and S. L. Stock. 2020. Habitat selection by Spotted Owls after a megafire in Yosemite National park. <i>Forest Ecology and Management</i> 478:118511.	–	–	–	–	–	–	–	x
Singleton, P. H. 2013. Barred Owls and Northern Spotted Owls in the Eastern Cascade Range, Washington. Dissertation. University of Washington, Seattle, Washington.	x	–	–	–	–	–	–	–
Sovern, S. G., E. D. Forsman, G. S. Olson, B. L. Biswell, M. Taylor, and R. G. Anthony. 2014. Barred owls and landscape attributes influence territory occupancy of Northern Spotted Owls. <i>Journal of Wildlife Management</i> 78(8):1436–1443.	x	–	–	–	–	–	–	–
Spies, T. A., J. D. Miller, J. B. Buchanan, J. F. Lehmkuhl, J. F. Franklin, S. P. Healey, P. F. Hessburg, H. D. Safford, W. B. Cohen, R. S. H. Kennedy, E. E. Knapp, J. K. Agee, and M. Moeur. 2010. Underestimating risks to the Northern Spotted Owl in fire-prone forests: Response to Hanson et al. <i>Conservation Biology</i> 24(1):330–333.	–	–	–	–	–	–	–	x
Stralberg, D., K. E. Fehring, L. Y. Pomara, N. Nur, D. B. Adams, D. Hatch, G. R. Geupel, and S. Allen. 2009. Modeling nest-site occurrence for the Northern Spotted Owl at its southern range limit in central California. <i>Landscape and Urban Planning</i> 90(1–2):76–85.	–	–	–	–	x	–	–	–
Stephens, S. L., L. N. Kobziar, B. M. Collins, R. Davis, P. Z. Fulé, W. Gaines, J. Ganey, J. M. Guldin, P. F. Hessburg, K. Hiers, S. Hoagland, J. J. Keane, R. E. Masters, A. E. McKellar, W. Montague, M. North, and T. A. Spies. 2019. Is fire “for the birds”? How two rare species influence fire management across the US. <i>Frontiers in Ecology and the Environment</i> 17(7):391–399.	–	–	–	–	x	–	–	–
Swei, A., R. S. Ostfeld, R. S. Lane, and C. J. Briggs. 2011. Effects of an invasive forest pathogen on abundance of ticks and their vertebrate hosts in a California Lyme disease focus. <i>Oecologia</i> 166:91–100.	–	–	–	–	–	–	x	–
Tempel, D. J., R. J. Gutiérrez, S. A. Whitmore, M. J. Reetz, R. E. Stoelting, W. J. Berigan, M. E. Seamans, and M. Z. Peery. 2014. Effects of forest management on California Spotted Owls: implications for reducing wildfire risk in fire-prone forests. <i>Ecological Applications</i> 24(8):2089–2106.	–	–	–	–	–	–	–	x

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Tempel, D. J., H. A. Kramer, G. M. Jones, R. J. Gutiérrez, S. C. Sawyer, A. Koltunov, M. Slaton, R. Tanner, B. K. Hobart, and M. Z. Peery. 2022. Population decline in California Spotted Owls near their southern range boundary. <i>Journal of Wildlife Management</i> 86(2):e22168.	–	–	–	–	–	–	–	x
Thomas, N. J., J. Bunikis, A. G. Barbour, and M. J. Wolcott. 2002. Fatal Spirochetosis due to a relapsing fever-like <i>Borrelia</i> sp. in a Northern Spotted Owl. <i>Journal of Wildlife Diseases</i> 38(1):187–193.	–	–	x	–	–	–	–	–
U.S. Department of Agriculture (USDA). 2024. 2022–2024 Detections of Highly Pathogenic Avian Influenza in Wild Birds. https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-disease-information/avian/avian-influenza/hpai-2022/2022-hpai-wild-birds (accessed 07 January 2024).	–	–	x	–	–	–	–	–
U.S. Fish and Wildlife Service (USFWS). 2011. Revised Recovery Plan for the Northern Spotted Owl (<i>Strix occidentalis caurina</i>). U.S. Fish and Wildlife Service, Portland, Oregon. xvi + 258 pp.	–	–	x	–	–	–	–	–
Van Mantgem, P. J., N. L. Stephenson, J. C. Byrne, L. D. Daniels, J. F. Franklin, P. Z. Fulé, M. E. Harmon, A. J. Larson, J. M. Smith, A. H. Taylor, and T. T. Veblen. 2009. Widespread increase of tree mortality rates in the western United States. <i>Science</i> . 323(5913): 521–524.	–	x	–	–	–	–	–	–
Van Lanen, N. J., A. B. Franklin, K. P. Huyvaert, R. F. Reiser II, and P. C. Carlson. 2011. Who hits and hoots at whom? Potential for interference competition between Barred and Northern Spotted owls. <i>Biological Conservation</i> 144:2194–2201. Wagner, F. F., E. C. Meslow, G. M. Bennett, C. J. Larson, S. M. Small, and S. DeStefano. 1996. Demography of Northern Spotted Owls in the southern Cascades and Siskiyou mountains, Oregon. <i>Studies in Avian Biology</i> 17:67–76.	x	–	–	–	–	–	–	–
Wagner, F. F., E. C. Meslow, G. M. Bennett, C. J. Larson, S. M. Small, and S. DeStefano. 1996. Demography of Northern Spotted Owls in the southern Cascades and Siskiyou mountains, Oregon. <i>Studies in Avian Biology</i> 17:67–76.	–	x	–	–	–	–	–	–
Wan, H. Y., J. L. Ganey, C. D. Vojta, and S. A. Cushman. 2018. Managing emerging threats to Spotted Owls. <i>The Journal of Wildlife Management</i> 82(4):682–697.	x	x	–	–	x	–	–	x
Wan, H. I., S. A. Cushman, and J. L. Ganey. 2019. Recent and projected future wildfire trends across the ranges of three Spotted Owl subspecies under climate change. <i>Frontiers in Ecology and Evolution</i> 7: article 37.	–	x	–	–	–	–	–	x
Wiens, J. D., R. G. Anthony, and E. D. Forsman. 2014. Competitive interactions and resource partitioning between northern spotted owls and barred owls in western Oregon. <i>Wildlife Monographs</i> 185:1–50.	x	–	–	–	–	–	–	–
Wiens, J. D., K. E. Dilione, C. A. Eagles-Smith, G. Herring, D. B. Lesmeister, M. W. Gabriel, G. M. Wengert, and D. C. Simon. 2019. Anticoagulant rodenticides in <i>Strix</i> owls indicate widespread exposure in west coast forests. <i>Biological Conservation</i> 238:108238.	–	–	–	–	–	x	–	–

Table 4 (continued). Full list of papers that met the inclusion criteria (marked with an “x”) in the literature review (see methods) by threat. Threats: BO = Barred Owls; CC = Climate Change; DI = Disease; ND = Noise Disturbance; OH = Other Habitat Loss (fuels reduction treatments and urban development); RO = Rodenticides; SO = Sudden Oak Death; Wildfire = WI.

Citation	BO	CC	DI	ND	OH	RO	SO	WI
Wiens, J. D., K. M. Dugger, J. M. Higley, D. B. Lesmeister, A. B. Franklin, K. A. Hamm, G. C. White, K. E. Dillione, D. C. Simon, R. R. Bown, P. C. Carlson, C. B. Yackulic, J. D. Nichols, J. E. Hines, R. J. Davis, D. W. Lamphear, C. McCafferty, T. L. McDonald, and S. G. Sovern. 2021. Invader removal triggers competitive release in a threatened avian predator. PNAS 118:No. 31, e2102859118.	x	–	–	–	–	–	–	–
Yackulic, C. B., L. L. Bailey, K. M. Dugger, R. J. Davis, A. B. Franklin, E. D. Forsman, S. H. Ackers, L. S. Andrews, L. V. Diller, S. A. Gremel, K. A. Hamm, D. R. Herter, J. M. Higley, R. B. Horn, C. McCafferty, J. A. Reid, J. T. Rockweit, and S. G. Sovern. 2019. The past and future roles of competition and habitat in the range-wide occupancy dynamics of Northern Spotted Owls. Ecological Applications 29(3): e01861.	x	–	–	–	–	–	–	–
Young, K. E., A. B. Franklin, and J. P. Ward. 1993. Infestation of Northern Spotted Owls by hippoboscids (Diptera) flies in northwestern California. Journal of Wildlife Diseases 29(2):278–283.	–	x	x	–	–	–	–	–
Zabel, C. J., S. E. Salmons, and M Brown. 1996. Demography of Northern Spotted Owls in southwestern Oregon. Studies in Avian Biology 17:77–82.	–	x	–	–	–	–	–	–
Total	38	25	20	2	12	4	4	40

Appendix D: Survey data from local experts on the sensitivity and exposure of Northern Spotted Owls to potential threats in Marin County, California.

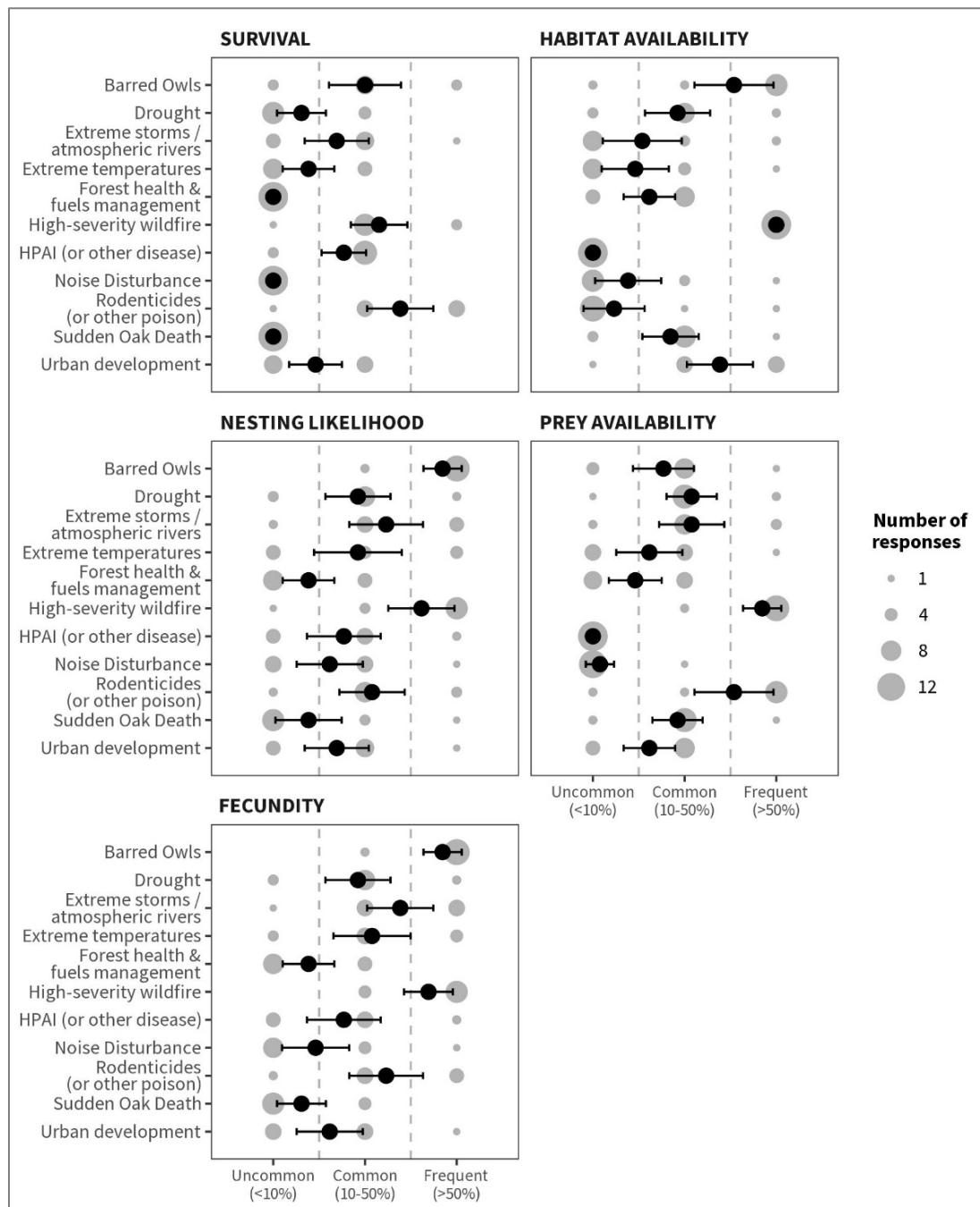


Figure 5. Mean sensitivity scores of Northern Spotted Owls to potential threats to their population in Marin County, as assessed by local experts (n=13). Mean estimates are shown in black \pm SE. Gray dots show the number of responses for uncommon (<10%), common (10–50%), and frequent (>50%) sensitivity.

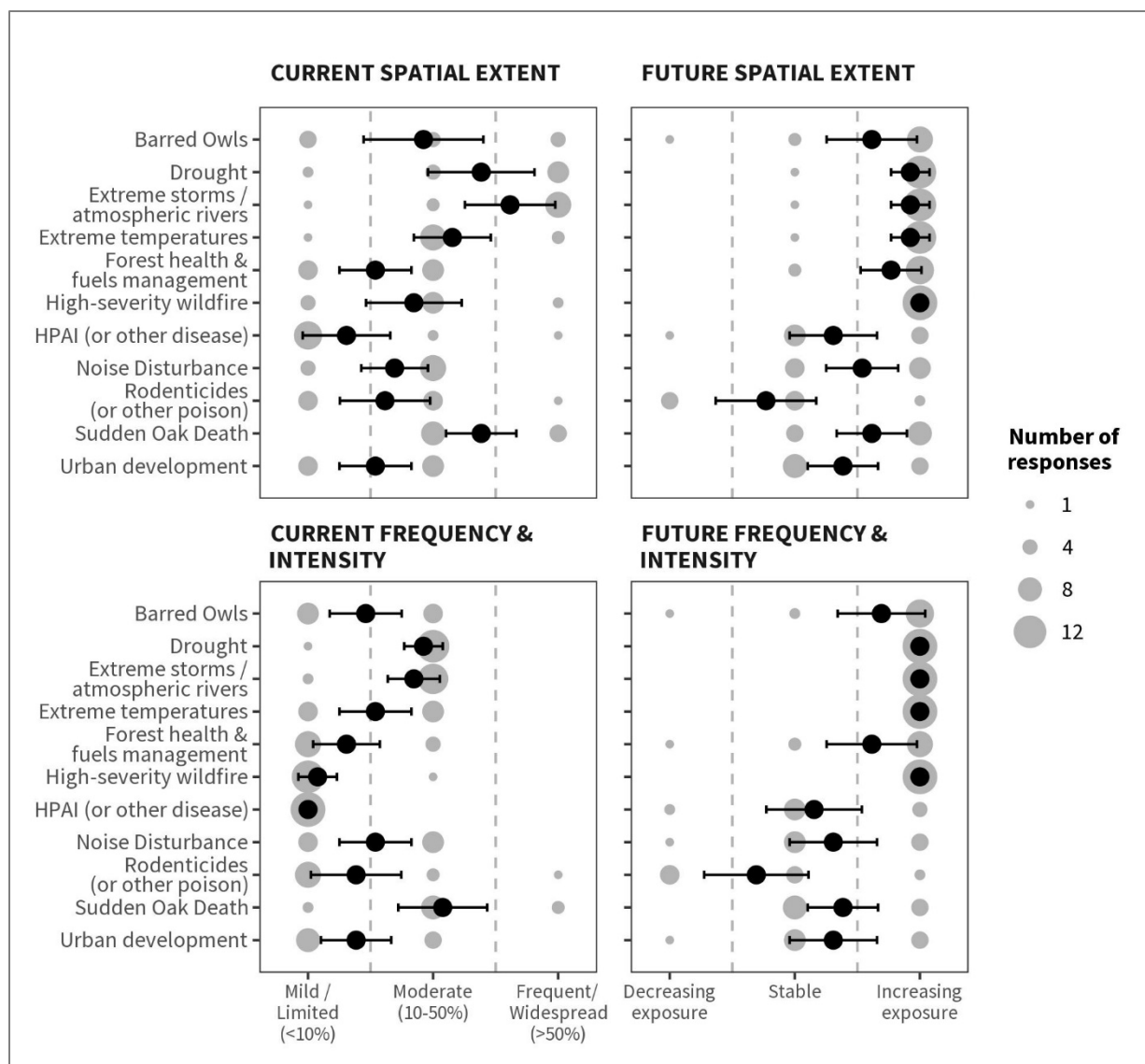


Figure 6. Mean exposure scores of Northern Spotted Owls to potential threats to their population in Marin County, as assessed by local experts (n=13). (Top) Spatial extent. (Bottom) Frequency and intensity. (Left) Current exposure. (Right) Anticipated future exposure. Mean estimates are shown in black \pm SE. For current exposure, gray dots show the number of responses for mild/limited (<10%), moderate (10–50%), and frequent/widespread (>50%) exposure. For future exposure, gray dots show the number of responses for decreasing, stable, or increasing exposure.

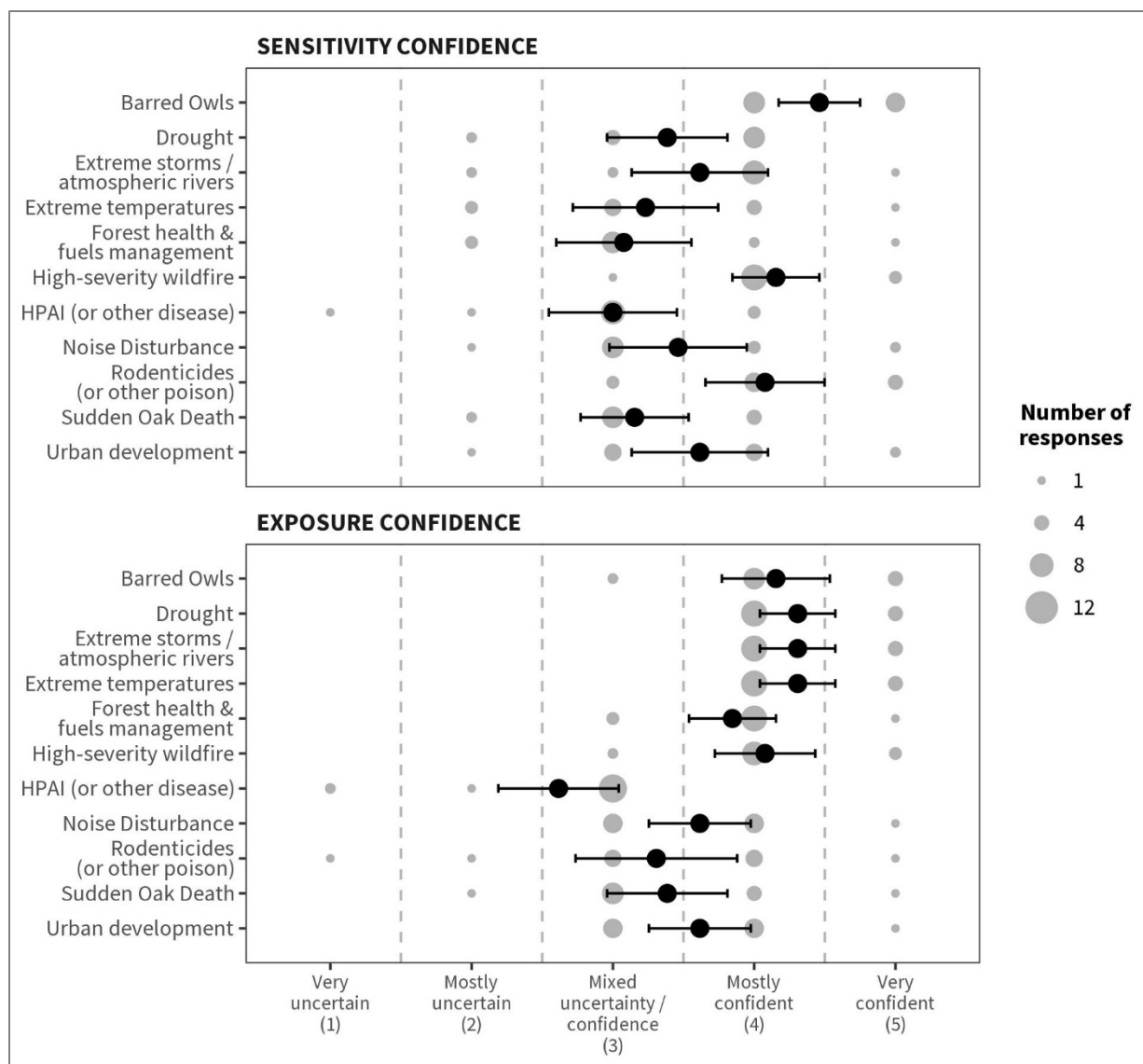


Figure 7. Mean local expert (n=13) confidence in their individual assessments of Northern Spotted Owl sensitivity and exposure (Figures 5 and 6) to potential threats to the population in Marin County. Mean estimates are shown in black \pm SE. Gray dots show the number of responses on the scale from very uncertain to very confident.

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