



Late-Successional-Dependent Species

Northern California Climate Change Vulnerability Assessment Synthesis

An Important Note About this Document: This document represents an initial evaluation of vulnerability for late-successional-dependent species in northern California based on expert input and existing information. Specifically, the information presented below comprises vulnerability factors selected and scored by regional experts, relevant references from the scientific literature, and peer-review comments and revisions (see end of document for a glossary of terms and brief overview of study methods). The aim of this document is to expand understanding of habitat vulnerability to changing climate conditions, and to provide a foundation for developing appropriate adaptation responses.

Peer reviewers for this document included Anonymous (Conservation Biology Institute; partial review only), Michelle Reilly (U.S. Fish and Wildlife Service), Gregory Schrott (U.S. Fish and Wildlife Service), and Jody Tucker (U.S. Forest Service). Vulnerability scores were provided by Eureka and Redding workshop participants. Upper Lake workshop participants provided additional comments on the climate change vulnerability of this species group.

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Species Group Description

Late-successional-dependent species (hereafter referred to as LSD species) selected by workshop participants and considered collectively in this assessment include Pacific fisher (*Pekania pennant pacifica*), Humboldt marten (*M. caurina humboldtensis*), Sierra marten (*M. c. sierrae*), and northern spotted owl (*Strix occidentalis caurina*). Terrestrial vulnerabilities of the

marbled murrelet (*Brachyramphus marmoratus*) were also considered briefly in this assessment, but this species is covered in more detail within a separate chapter.

LSD species are characterized by their dependence on mature and late-seral forest stands for some portion of their life cycle. Late-seral forests supply unique habitat features, primarily cavities in large-diameter and decadent trees, snags, and logs, which these species use for nesting/denning, and resting (Meyer et al. 2004; Slauson et al. 2007; Golightly et al. 2009; Kirk & Zielinski 2009; Hamlin et al. 2010; Purcell et al. 2012; Aubry et al. 2013; CDFW 2015, 2016). Although old-growth stands occur in drier forest types, including ponderosa pine (*Pinus ponderosa*) and mixed conifer (Kaufmann et al. 2007; Leonzo & Keyes 2010), they are most common within mixed evergreen (Spies et al. 2006) and coastal redwood forests (Mahony & Stuart 2000; Michels & Russell 2016). Preferred forest type varies by species (see table below) but include a majority of forest types found in the northern California study region.

Species	Characteristics
Pacific fisher	<ul style="list-style-type: none"> • Carnivorous mammal • Occupies mixed conifer/hardwood forest types from 1,067–3,134 m [3,500–7,000 ft] • Commonly utilizes Douglas-fir (<i>Pseudotsuga menziesii</i>) and black oak (<i>Quercus kelloggii</i>) for denning and resting
Humboldt marten	<ul style="list-style-type: none"> • Carnivorous mammal • Within California, occurs primarily in late-successional moist Douglas-fir forests; also occurs to a lesser degree in moist conifer forest types on serpentine soils within 30 km (18.6 miles) of the coast (likely represents marginal habitat) • Occupied areas typically feature a dense, extensive shrub layer
Sierra marten	<ul style="list-style-type: none"> • Carnivorous mammal • Occupies late-seral coniferous forest types from 1,372–3,048 m [4,500–10,000 ft]
Northern spotted owl	<ul style="list-style-type: none"> • Predatory bird • Occupies a variety of mature and late-seral forest types, including mixed conifer/hardwood forests, coniferous forests, and coast redwood forests
Marbled murrelet	<ul style="list-style-type: none"> • Seabird • Primarily nests in coast redwood (<i>Sequoia sempervirens</i>) forests on nesting platforms of moss, ferns, or other epiphytes on branches and broken treetops
Source(s): Meyer et al. 2004; Zielinski et al. 2004; Slauson et al. 2007; Golightly et al. 2009; Kirk & Zielinski 2009; Hamlin et al. 2010; Purcell et al. 2012; Aubry et al. 2013; CDFW 2015, 2016; Slauson et al. 2019	

Executive Summary

The relative vulnerability of LSD species in northern California was evaluated as moderate-high by regional experts due to moderate-high sensitivity to climate and non-climate stressors, moderate exposure to projected future climate changes, and low-moderate adaptive capacity.

Late-Successional-Dependent Species	Rank	Confidence
Sensitivity	Moderate-High	High
Future Exposure	Moderate	Low
Adaptive Capacity	Low-Moderate	High
Vulnerability	Moderate-High	Moderate

Sensitivity & Exposure Summary	<p><u>Climate and climate-driven factors:</u></p> <ul style="list-style-type: none"> Air temperature, heat waves, precipitation amount and timing, drought, snowpack, timing of snowmelt and runoff, storms <p><u>Disturbance regimes:</u></p> <ul style="list-style-type: none"> Wildfire <p><u>Non-climate stressors:</u></p> <ul style="list-style-type: none"> Fire suppression, roads/highways/trails, timber harvest, poisons, invasive and/or problematic species
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LSD species are sensitive to a variety of climatic changes and disturbance regimes. Direct climate impacts include changes in animal physiology, behavior, reproductive success, recruitment, and survival. For example, warmer air temperatures and heat waves will reinforce thermoregulatory behaviors and utilization of thermal refugia, but may also increase northern spotted owl recruitment. Reduced snowpack and shifts in snowmelt timing may alter fisher and Sierra marten competition and Sierra marten winter survival. As habitat specialists and predators, LSD species are also indirectly vulnerable to climate changes and disturbance regimes that alter late-seral habitat availability, quality, connectivity or prey availability. Shifts in air temperature, precipitation, drought, storms, and wildfire regimes are also likely to impact habitat structure (including critical habitat features) and the landscape distribution of regional forest types, potentially impacting LSD species distributions. For instance, uncharacteristically large and/or severe wildfires can fragment and/or eliminate late-seral habitats. Changes in precipitation and snowpack will influence regional food webs, affecting foraging opportunities, recruitment, and survival.

LSD species are also vulnerable to a variety of non-climate stressors. Several stressors contribute to direct mortality (e.g., poisons, vehicle collisions), while others negatively impact habitat availability, quality, connectivity, and utilization. For example, busy roads and highways act as dispersal barriers, while roadsides and trails can facilitate both hunting and predator travel and presence. Timber harvest can result in the removal of critical habitat features (e.g., snags, ground cover) and increases habitat fragmentation. Like roads, timber harvest can increase both prey availability and predation risk. Many non-climate stressors also exacerbate climate change impacts by reducing refugia or accelerating rates of change. For example, fire

suppression has altered forest structure and composition in ways that frequently enhance the risk of uncharacteristically severe wildfire. In addition to the above stressors, northern spotted owls are vulnerable to competitive exclusion by the invasive barred owl (*Strix varia*).

Adaptive Capacity Summary	<p><u>Factors that enhance adaptive capacity:</u></p> <ul style="list-style-type: none"> + Behavioral plasticity (e.g., thermoregulatory behaviors, using non-traditional habitats) + Some regulatory and legislative support for species management <p><u>Factors that undermine adaptive capacity:</u></p> <ul style="list-style-type: none"> – Declining regional populations – Small, isolated populations vulnerable to extirpation or genetic bottlenecks – Recovery limited by low reproductive potential and reliance on late-seral stand conditions
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LSD species populations have declined in northern California due to habitat loss and fragmentation. Northern spotted owl declines have been further exacerbated by interactions with invasive barred owls. Small and isolated populations are vulnerable to extirpation from genetic bottlenecks and stochastic events, such as wildfire. Recovery potential for this species group is limited by reliance on late-seral stand conditions, which can take centuries to develop, as well as by low reproductive potential (i.e., few young, limited annual breeding events). However, LSD species do exhibit some behavioral plasticity (e.g., thermoregulatory behaviors, use of non-traditional habitats) that may facilitate adaptation to changing conditions. There is some regulatory and legislative support for managing individual species and late-seral habitat through the federal and state Endangered Species Acts and the Northwest Forest Plan.

Sensitivity and Exposure

LSD species were evaluated by regional experts as having moderate-high overall sensitivity (high confidence in evaluation) and moderate overall future exposure (low confidence) to climate and climate-driven factors, changes in disturbance regimes, and non-climate stressors.

In general, it is difficult to project how climate change will affect LSD species distributions, as their habitat niches are influenced by numerous factors, including physiology, vegetation characteristics, topography, and competition (Spencer et al. 2015b). In the absence of disturbance, changes in late-seral forest composition and structure are likely to lag climatic changes, which may buffer LSD species if climate impacts do not directly affect their physiology (Carroll 2010; Long et al. 2014). Alternatively, rapid changes in forest structure and composition (e.g., due to wildfire) could compound climate-driven range reductions for LSD species (USFWS 2009; Carroll 2010). Microrefugia created by interactions between diverse topography (e.g., cold-air pooling or inversion areas), weather, and vegetation will also likely play an important role in buffering climate impacts on LSD species both now and in the future (Spencer et al. 2015b; Frey et al. 2016; Jones et al. 2016). These could include riparian areas, valley bottoms, north-facing slopes with higher shading, and high-elevation sites with more precipitation (USFWS 2011; Olson et al. 2012).

Future changes in Pacific fisher distribution are difficult to predict because conditions in their lower-elevation forest habitats are affected by both anthropogenic and climate factors (Spencer et al. 2015b). Both increases and decreases in fisher distribution have been projected by the end of the 21st century, depending on the climate model used (Spencer et al. 2015b). In general, declines in snowpack and projected upslope expansion of mixed conifer-hardwood forests may allow range expansion (Lawler et al. 2012; Spencer et al. 2015b; Zielinski et al. 2017). However, this may not occur if increasing temperatures force upward migration faster than forests can transition, or if increasing fire severity and size eliminates preferred late-seral habitat characteristics (Long et al. 2014; Zielinski et al. 2017).

Potential Changes in Species Group Distribution

- *Pacific fisher*: Potential upslope expansion as snowpack declines and mixed conifer-hardwood forests expand; however, the potential for range shifts depends in part on whether climate conditions outpace forest transitions
- *Sierra marten*: Overall range contractions due to loss of snowpack at lower elevations within the species' range
- *Humboldt marten*: Reduced habitat availability as coastal forests contract
- *Northern spotted owl*: Likely shift northwards and into higher-elevation areas, with potential loss of isolated coastal populations
- *Marbled murrelet*: Potential reduction in suitable nesting habitat due to loss of climatically-suitable habitat for coastal forests

Source(s): USFWS 2009; Carroll 2010; Lawler et al. 2012; Purcell et al. 2012; Spencer et al. 2015b; Zielinski et al. 2017; Slauson et al. 2019

Sierra martens are uniquely adapted to and dependent upon snowy environments, and are likely to track upward shifts of the snowline (Spencer et al. 2015b; Zielinski et al. 2017). Because marten currently utilize the forested habitat at the highest elevations, overall distribution is likely to be severely reduced as the snowline shifts upslope (Spencer et al. 2015b). Population extirpations may occur where upward migration is not possible (Purcell et al. 2012; Zielinski et al. 2017). Although species-specific distribution modeling under future climate conditions is not available for the Humboldt marten, projected contraction of coastal forest types is likely to reduce suitable habitat availability and connectivity, especially at the current southern and inland edge of their range (Fernández et al. 2015; Thorne et al. 2016, 2017; DellaSala et al. 2018; Slauson et al. 2019).

Climatically-suitable habitat for northern spotted owls is projected to shift northward as future conditions become warmer and drier conditions (Carroll 2010). Climate-driven reductions in coastal habitat suitability may increase owl reliance on late-successional habitats at higher elevations, potentially leading to extirpations of isolated coastal populations already impacted by habitat loss and fragmentation (Carroll 2010). Potential climatically-suitable habitat for coastal forests may also impact the availability of nesting habitat for marbled murrelets (USFWS 2009). However, the dependent of this species on both terrestrial and marine habitats makes projecting future changes in distribution more difficult, as they are also likely to be affected by changes in marine prey availability.

Sensitivity and future exposure to climate and climate-driven factors

Regional experts evaluated LSD species as having moderate-high sensitivity to climate and climate-driven factors (high confidence in evaluation), with an overall moderate-high future exposure to these factors within the study region (moderate confidence). Key climatic factors that affect LSD species include air temperature, heat waves, precipitation amount and timing, drought, snowpack, timing of snowmelt and runoff, and storms.¹

Air temperature and heat waves

Increasing air temperatures and heat waves are likely to have direct behavioral and physiological impacts on LSD species. For example, fishers avoid daily high temperatures by resting in cool, shaded forests (i.e., temperature microrefugia) and foraging during cooler periods of the day (Aubry et al. 2013). Northern spotted owls also rely on shady structures during warm periods, as they are vulnerable to heat stress when temperatures exceed 27.2°C (81°F; (USFWS 2011). Hotter temperatures and heat waves may increase thermal avoidance behaviors and reliance on temperature microrefugia, potentially limiting foraging opportunities (Glenn et al. 2010; Lofroth et al. 2010; Aubry et al. 2013), which can have subsequent impacts on LSD species survival, recruitment, and population stability (Glenn et al. 2010). Populations in interior areas may experience more severe heat impacts or be forced to behaviorally thermoregulate more frequently than populations in more moderate coastal climates (Ting 1998 cited in CDFW 2016). However, although the most extreme temperatures are likely to occur within the interior, the most significant changes are projected to occur in coastal areas, particularly during humid nighttime heat waves (Gershunov & Guirguis 2012). While warmer summer temperatures are likely to be problematic for many LSD species, warmer temperatures during the winter breeding and spring nesting season may benefit northern spotted owls by reducing the risk of cold-related mortality (USFWS 2011; Dugger et al. 2016).

Warmer temperatures are likely to alter LSD species distributions (Safford 2006; Jones et al. 2016). Impacts will likely be greatest for cold-adapted species such as Sierra martens. For example, a study in the southern Sierra Nevada found that Sierra marten rarely occurred in areas where minimum temperatures were greater than 4°C (39.2°F; Zielinski et al. 2017). Comparatively, fishers occupied in areas with warmer minimum temperatures (up to 8.8°C [47.8°F]; Zielinski et al. 2017). However, fishers still prefer relatively cool environments, so warming will likely cause upslope movements of fisher by the end of the century, potentially by 150–300 m (500–1,000 ft; Safford 2006). Warmer temperatures may also change the habitat features selected and utilized by LSD species within their current range (Safford 2006; Aubry et al. 2013).

Warmer temperatures are have indirect impacts on LSD species by affecting prey distribution and availability, though exact changes and resulting impacts on LSD species are difficult to predict (Safford 2006; USFWS 2011; Jones et al. 2016). Similarly, warmer conditions increase evapotranspiration in forest habitats, enhancing water stress with potential impacts on forest

¹ All climate and climate-driven factors presented were ranked as having a moderate or higher impact on this species group.

composition, structure, distribution, and vulnerability to disturbance (i.e., fire, insects, disease; van Mantgem et al. 2009; Das et al. 2013; van Mantgem et al. 2013; van Mantgem & Sarr 2015; McIntyre et al. 2015; Young et al. 2017). These changes may affect habitat availability, quality, and connectivity for LSD species (USFWS 2009, 2011). For example, increases in climatic water deficit as a result of rising air temperatures during the 20th century have increased mortality of old-growth trees in California and beyond (McDowell & Allen 2015; McIntyre et al. 2015; Young et al. 2017). Warmer temperatures may also drive increases in hardwood productivity, potentially allowing upslope expansion of hardwoods into areas currently dominated by conifers (Lenihan et al. 2008). Increases in hardwoods could increase denning and resting habitat for fishers, while reducing habitat suitability for marten and marbled murrelets (Safford 2006; USFWS 2009). Hardwoods are also important habitat features for many prey species utilized by northern spotted owls and fishers (Raphael 1987; Irwin et al. 2013), so increases in hardwood productivity under future climate conditions could be associated with increased prey availability (Vuln. Assessment Reviewer, pers. comm., 2019).

However, LSD species may experience lower rates and magnitudes of temperature change by living in late-seral and old-growth habitats (Franklin et al. 2000; USFWS 2011; Frey et al. 2016). Old-growth stands significantly buffer air temperature increases relative to more homogenous mature forest plantations (Frey et al. 2016). Specifically, a study in the Oregon Cascade Mountains found that old-growth Douglas-fir forests with high biomass, complex vertical structure, and heterogeneous canopies were up to 2.5°C (4.5°F) cooler than Douglas-fir mature Douglas-fir plantations with simplified structures, suggesting that old-growth stands can function as temperature microrefugia (Frey et al. 2016). Temperature refugia benefits were also correlated with higher elevation, topographic diversity, and proximity to the coast (Vanwalleghem & Meentemeyer 2009; Frey et al. 2016). However, increasing habitat fragmentation could enhance LSD species exposure to rising air temperatures (Frey et al. 2016), as smaller forest patches experience more drastic changes in temperature (Vanwalleghem & Meentemeyer 2009).

Regional Air Temperature & Heat Wave Trends²	
<p><i>Historical & current trends:</i></p> <ul style="list-style-type: none"> • 0.03°C (0.05°F) decrease to 0.2°C (0.4°F) increase in the average annual temperature between 1900 and 2009 for the Northwestern California and Southern Cascade ecoregions (Rapacciuolo et al. 2014) <ul style="list-style-type: none"> ○ No seasonal temperature trends available 	<p><i>Projected future trends:</i></p> <ul style="list-style-type: none"> • 2.2–5.5°C (4.0–9.9°F) increase in the average annual temperature by 2100 (compared to 1951–1980) for the North Coast, Northern Coast Range, Northern Interior Coast Range, Klamath Mountain and Southern Cascade ecoregions (Flint et al. 2013; Flint & Flint 2014)

² Trends in climate factors and natural disturbance regimes presented in this and subsequent summary tables are not species group-specific; rather, they represent broad trends and future projections for the study region. The precipitation, temperature, climatic water deficit, and snowpack projections for this project are derived from the Basin Characterization Model, which uses modified Jepson ecoregions (Flint et al. 2013; Flint & Flint 2014). Projections for all other factors are based on a review of relevant studies in the scientific literature. For this project, exposure was evaluated by calculating the magnitude and direction of projected change within the modified Jepson ecoregions that include habitat distribution within the study geography.

Regional Air Temperature & Heat Wave Trends ²	
<ul style="list-style-type: none"> • Increase in the frequency of humid nighttime events over the past several decades (Gershunov & Guirguis 2012) • High interannual and interdecadal variability in heat waves (Gershunov & Guirguis 2012) 	<ul style="list-style-type: none"> ○ 1.9–5.8°C (3.4–10.4°F) increase in average winter minimum temperatures ○ 2.2–6.7°C (4.0–12.1°F) increase in average summer maximum temperatures • Increased heat waves, with the greatest increase in humid nighttime heat waves and in coastal areas (Gershunov & Guirguis 2012) • 2–6°C (3.6–10.8°F) increase in the temperature of the hottest day of the year by 2100 (Pierce et al. 2018)
Summary of Potential Impacts on Species Group <i>(see text for citations)</i>	
<ul style="list-style-type: none"> • Reinforcement of thermal avoidance behaviors and increased reliance on temperature refugia, potentially limiting foraging opportunities and affecting recruitment and survival • Enhanced northern spotted owl survival and recruitment in the breeding and nesting seasons • Altered species distributions, especially for cold-adapted marten • Altered prey availability and distribution (exact impacts uncertain) • Altered habitat availability, quality, and connectivity due to changes in late-seral forest habitat distribution, species composition, condition, and vulnerability to disturbance 	

Precipitation amount/timing and drought

Northern spotted owls are sensitive to wet and cold conditions during the winter breeding season and early spring nesting season (Franklin et al. 2000; USFWS 2011; Dugger et al. 2016). Wet winters and heavy nesting season precipitation have both been correlated with reduced owl recruitment, while higher recruitment occurs following drier winters (Glenn et al. 2010; Dugger et al. 2016). Nestlings are vulnerable to mortality from chilling, and cold, wet conditions increase the risk of starvation in adults and nestlings due to reduced foraging success (Franklin et al. 2000; Glenn 2009 cited in U.S. Fish and Wildlife Service 2011). Wet and cold spring conditions limit recruitment by reducing the annual number of fledged young and limiting juvenile survival during dispersal periods (Franklin et al. 2000; Glenn 2009 cited in USFWS 2011).

Changing precipitation patterns and drought also alter influence the food web by altering plant productivity, affecting prey availability for LSD species and potentially driving changes in fitness, foraging, recruitment, and survival (Safford 2006; Lofroth et al. 2010; USFWS 2011; Zielinski et al. 2017). For example, declines in prey availability may require fishers to expand their home range and foraging distances to secure food (Lofroth et al. 2010), force them to use less suitable habitats at higher elevations (Zielinski et al. 2017), and reduce reproductive fitness (e.g., fewer breeding attempts, less successful breeding, reduced litter sizes, reduced survival; Fuller & Sievert 2001; Spencer et al. 2015a; Green et al. 2018). For northern spotted owls, summer drought conditions may limit prey availability, which has been linked with decreased survival in other raptor species (Franklin et al. 2000; Glenn 2009 cited in U.S. Fish and Wildlife Service 2011). Comparatively, increases in late spring or summer precipitation could help maintain prey

availability and enhance LSD species fitness, survival, and recruitment (USFWS 2011). For example, in the Pacific Northwest, the rate of northern spotted owl population change was positively associated with wetter-than-normal growing seasons from 1990–2005 (Glenn et al. 2010).

Drier conditions and longer, more severe drought periods may to change the structure and composition of forest types used by LSD species (Safford 2006; Lofroth et al. 2010; van Mantgem & Sarr 2015). For example, increased moisture stress is likely to limit growth across forest types, particularly on drier sites (Carroll et al. 2014; Restaino et al. 2016). Shifts in species composition may occur along moisture gradients, with a possible increase in the dominance of drought-tolerant oaks and a decline in conifers (McIntyre et al. 2015; Serra-Diaz et al. 2016). Reduced vigor within water-stressed trees also increases vulnerability to disturbances, including drought-related tree mortality (Allen et al. 2015; McDowell & Allen 2015; Young et al. 2017) and high-severity wildfire (Millar & Stephenson 2015; Gergel et al. 2017; McKenzie & Littell 2017). Large trees and/or dense stands are particularly vulnerable to drought stress (McDowell & Allen 2015; Young et al. 2017).

Altered forest structure, composition, and tree mortality rates are likely to affect LSD species denning, resting, and nesting habitat as well as prey availability (Safford 2006; USFWS 2009; CDFW 2016), potentially elevating stress and reducing fitness (Kordosky 2019). For example, a study in the Sierra Nevada found that levels of drought-related tree mortality in a fisher’s home range significantly influenced cortisol levels, which are indicative of physiological stress (Kordosky 2019). Altered forest conditions may also drive changes in species distribution due to shifts in the availability of suitable habitat (USFWS 2011; Falxa & Raphael 2016), including the presence of features preferred by LSD species such as tree cavities, snags and logs (Safford 2006; Lofroth et al. 2010). For example, dry conditions may limit epiphyte growth in coastal redwoods, decreasing suitable nesting habitat for marbled murrelets (Malt & Lank 2007). Drought-related impacts on habitat availability may include the loss of late-seral forest areas to increased wildfire activity (e.g., fire size, rate of spread, severity; (USFWS 2009), which is associated with reductions in fuel moisture (Littell et al. 2009; Abatzoglou & Kolden 2013; Parks et al. 2014, 2016; McKenzie & Littell 2017).

Regional Precipitation & Drought Trends	
<p><i>Historical & current trends:</i></p> <ul style="list-style-type: none"> • 7.2–9.4 cm (2.8–3.7 in) increase in mean annual precipitation between 1900 and 2009 for the Northwestern California and Southern Cascade ecoregions (Rapacciuolo et al. 2014) • Drought years have occurred twice as often over the last two decades compared to the previous century (Diffenbaugh et al. 2015) 	<p><i>Projected future trends:</i></p> <ul style="list-style-type: none"> • 20% decrease to 34% increase in mean annual precipitation by 2100 (compared to 1951–1980) for the North Coast, Northern Coast Range, Northern Interior Coast Range, Klamath Mountain, and Southern Cascade ecoregions (Flint et al. 2013; Flint & Flint 2014)³ • Seasonal changes are projected to be more

³ Projections for changes in annual and seasonal precipitation by ecoregion can be found in the full climate impacts table (<https://bit.ly/2LHgZaG>).

Regional Precipitation & Drought Trends	
<ul style="list-style-type: none"> • 2012–2014 drought set records for lowest precipitation, highest temperatures, and most extreme drought indicators on record (Griffin & Anchukaitis 2014; Diffenbaugh et al. 2015) 	<p>significant as the wet season becomes wetter and shorter (i.e., later onset of fall rains and earlier onset of summer drought) and the dry season becomes drier and longer (Pierce et al. 2018; Swain et al. 2018)</p> <ul style="list-style-type: none"> • Overall, interannual variability is expected to increase (Pierce et al. 2018; Swain et al. 2018) • Drought years are twice as likely to occur over the next several decades due to increased co-occurrence of dry years with very warm years (Cook et al. 2015) • 80% chance of multi-decadal drought by 2100 under a high-emissions scenario (Cook et al. 2015) • Severe droughts that now occur once every 20 years will occur once every 10 years by 2100 and once-in-a-century drought will occur once every 20 years (Pierce et al. 2018)
Summary of Potential Impacts on Species Group <i>(see text for citations)</i>	
<ul style="list-style-type: none"> • Enhanced adult and juvenile mortality, reduced recruitment, and restricted juvenile dispersal if heavy precipitation/ cool conditions occur during northern spotted owl nesting season • Altered food web dynamics and reduced prey availability during periods of low precipitation/drought, affecting foraging success, fitness, recruitment, and survival • Altered habitat availability and quality due to drought-related changes in forest distribution, composition, and structure, which may reduce fitness and/or force range shifts • Enhanced creation of preferred habitat features (e.g., cavities) as drought interacts with tree disease and insect pressure • Limited epiphyte growth due to dry conditions, reducing nesting habitat for marbled murrelet 	

Snowpack and timing of snowmelt and runoff

Shifts in snowpack are likely to alter the distribution of Sierra martens and Pacific fishers, with range contractions likely at lower elevations within their range (Zielinski et al. 2005, 2017, 2017; Kirk & Zielinski 2009). In areas where they are currently limited by snow (e.g., southern Cascades), fishers may be able to expand to higher elevations if forest conditions support upward migration (Lofroth et al. 2010; Zielinski et al. 2017). However, this could result in increased range overlap and competition between these species, with possible extirpation of Sierra martens if they are displaced by fishers (Purcell et al. 2012; Zielinski et al. 2017).

Reduced snowpack and shifts in snowmelt timing may also have behavioral or physiological impacts on LSD species. For example, reduced snowpack could increase fisher winter and early spring activity by allowing easier travel and hunting (Lofroth et al. 2010). However, Sierra martens require thermal cover provided by snow in montane environments, and reduced snowpack could increase mortality due to cold exposure (Halofsky et al. 2011). Prey availability

may also be decreased, as many common winter prey species require deep snow and subnivean cavities to survive (Zielinski et al. 1983). Finally, reduced snowpack may limit marten use of marginal habitat areas (e.g., open and simplified forest stands), reducing functional connectivity (Moriarty et al. 2015).

Regional Snowpack & Snowmelt Trends	
<p><i>Historical & current trends:</i></p> <ul style="list-style-type: none"> • 15–39% decrease in April 1 snow water equivalent (SWE) between 1951 and 2010 for the Northwestern California and Southern Cascade ecoregions (Flint et al. 2013) • 15–40-day shift towards earlier date of 90% snowmelt across the western U.S. since 1915 (Hamlet et al. 2005) 	<p><i>Projected future trends:</i></p> <ul style="list-style-type: none"> • Decreases in April 1 SWE by 2100 (compared to 1951–1980; Flint et al. 2013; Flint & Flint 2014): <ul style="list-style-type: none"> ○ 86–99% decrease on the North Coast ○ 82–99% decrease in the Northern Coast Range ○ 99–100% decrease in the Northern Interior Coast Range ○ 72–94% decrease in the Klamath Mountains ○ 61–89% decrease in the Southern Cascades • Likely 5–15-day shift towards earlier timing of snowmelt-driven runoff in northern California by 2100 (up to 60-day shift across the western U.S.; Stewart et al. 2004; Rauscher et al. 2008)
Summary of Potential Impacts on Species Group <i>(see text for citations)</i>	
<ul style="list-style-type: none"> • Increased potential for range overlap and competition between fisher and Sierra marten where fishers move upwards in elevation • Increased winter mortality risk for Sierra marten without snowpack insulation • Reduced winter prey availability for Sierra marten, enhancing starvation risk or reducing fitness • Overall decreased habitat suitability and connectivity for Sierra marten 	

Storms

Stormy winter and spring conditions may directly affect northern spotted owl recruitment by altering prey availability and foraging success during the breeding and nesting season (Glenn et al. 2010; USFWS 2011). Additionally, windy conditions paired with low temperatures can increase egg exposure to heat loss, particularly in suboptimal nesting sites (CDFW 2016).

Storms also play an important role in shaping late-seral habitat conditions and availability. For example, storm-related lightning and wind facilitates cavity development in mature trees by damaging trunks or limbs (Lofroth et al. 2010). This promotes infection by heart-rot fungi, eventually forming hollows or cavities used by LSD species (Lofroth et al. 2010). In coastal redwood forests, wind damage can allow sprouting and the development of reiterated branches and trunks in the resulting canopy gaps (Sawyer et al. 2000; Sillett & Van Pelt 2007; Van Pelt et al. 2016). The resulting complex structure is able to support the development of arboreal soil and promote epiphyte growth, increasing the availability of potential nesting sites for marbled murrelets (Sillett & Van Pelt 2007; Sillett et al. 2018). However, wind storms can also temporarily reduce late-seral habitat availability by causing windthrow, particularly at the

edge of clearcuts (Sinton et al. 2000) and/or in waterlogged soils (Olson et al. 1990; Lorimer et al. 2009). This, along with flooding, landslides, and other disturbances associated with winter storms, may cause the loss of mature trees in late-seral forests (USFWS 2009; Raphael et al. 2018; DellaSala et al. 2018).

Regional Storm Trends	
<p><i>Historical & current trends:</i></p> <ul style="list-style-type: none"> • Decline in the frequency of extreme two-day precipitation events between 1950 and 2009, with a slight decrease in the amount of precipitation received during extreme two-day events (Mass et al. 2010) • No trends available for storm-related wind events 	<p><i>Projected future trends:</i></p> <ul style="list-style-type: none"> • Increase in storm intensity and duration, resulting in greater maximum precipitation rates and volume (Dettinger 2011; Shields & Kiehl 2016; Prein et al. 2017) • Slight to moderate increase in storm frequency (up to 30% increase in atmospheric river days, or ~2.5 days per year; Dettinger 2011) • Projected statewide increases in daily extreme precipitation values of 5–20% by 2100 (Pierce et al. 2018) • No projections available for storm-related wind events
Summary of Potential Impacts on Species Group <i>(see text for citations)</i>	
<ul style="list-style-type: none"> • Reduced northern spotted owl recruitment and survival during breeding and nesting season • Enhanced development of cavities and reiterated branches and trunks following tree injuries • Potential loss of mature trees and/or limbs due to storm-related damage 	

Sensitivity and future exposure to changes in natural disturbance regimes

Regional experts evaluated LSD species as having moderate sensitivity to changes in natural disturbance regimes (high confidence in evaluation), with an overall moderate future exposure to these stressors within the study region (low confidence). Wildfire is the key natural disturbance regime that affects LSD species.⁴ To a lesser degree, insect- and disease-related tree mortality can contribute to habitat loss and fragmentation, reduced availability of breeding and rest structures, reduced thermal cover, and changes in predator/prey populations (Slauson et al. 2019; Vuln. Assessment Reviewers, pers. comm., 2019).

Wildfire

Wildfire has variable impacts on LSD species depending on fire frequency, severity, and size, and when comparing short- versus long-term outcomes. In the short-term, fire can temporarily reduce habitat suitability by removing ground cover, logs, and shrub canopy (Slauson et al. 2009; Lesmeister et al. 2019). However, over longer time scales fire plays an important role in creating and maintaining a forest structure that provides critical habitat features for LSD species (Safford 2006; Lofroth et al. 2010; CDFW 2016). For example, low- and moderate-severity fire in drier forests and mixed-severity fires in mesic forest types fosters the retention

⁴ This disturbance regime was ranked as having a moderate or higher impact on this species group.

of large mature trees, promotes landscape-scale diversity in forest stand age and structure, and facilitates the development of complex forest structures that include snags, logs, and tree cavities (Safford 2006; Lofroth et al. 2010; Long et al. 2016; Rockweit et al. 2017). A study of mixed-severity fires in northwestern California found that fires that burn at predominantly low severity have little effect on northern spotted owl survival and recruitment, while post-fire habitat quality is more likely to decline in areas territories that burn at moderate to high severities (Rockweit et al. 2017). Burned areas within the landscape can also benefit LSD species by increasing prey associated with early-successional habitats or open areas (e.g., woodrats; Lesmeister et al. 2018).

Changes in natural wildfire regimes following Euro-American settlement of the region around 1850 have increased the risk of negative wildfire impacts on old-growth stands in many areas (Taylor & Skinner 2003; Spies et al. 2006; USFWS 2011; CDFW 2016; Safford & Stevens 2017). For instance, fire suppression activities prevalent since the early 1900s have significantly altered fuel structure and availability (Spies et al. 2006; Leonzo & Keyes 2010; Safford & Stevens 2017). Impacts are particularly significant where fire exclusion followed the removal of large trees during timber harvest, contributing to a general trend toward denser, even-aged forests dominated by a greater proportion of small trees (Strothmann & Roy 1984; Skinner 1995; Hunter 1997; Colombaroli & Gavin 2010; Sensenig et al. 2013; Odion et al. 2014; McIntyre et al. 2015).⁵ Additionally, some studies have suggested that insect-related tree mortality could impact fire behavior (e.g., spread, intensity, severity) over the following 1–3 decades by adding insect-killed biomass to the forest floor, altering fuel structure and increasing fuel availability (Hicke et al. 2012; Stephens et al. 2018). However, no consistent relationship between insect outbreaks and increased fire activity or severity has been demonstrated in western U.S. forests (Bond et al. 2009; Harvey et al. 2013; Donato et al. 2013; Meigs et al. 2015, 2016; Hart et al. 2015; Reilly & Spies 2016). It is possible that insect-related tree mortality can and does impact fire behavior at local scales, but the complex interactions between weather, disturbance history, and numerous other factors likely obscure any consistent relationship across broader spatial and temporal scales.

Large, high-severity fires can eliminate late-seral forest habitats and associated habitat features utilized by LSD species for nesting, denning, and resting (USFWS 1992, 2011; Safford 2006; Purcell et al. 2012; CDFW 2015, 2016; Norgaard et al. 2016; Zielinski & Gray 2018; Lesmeister et al. 2019). For example, a southwestern Oregon study found that 93% of pre-fire northern spotted owl habitat in patches that were burned at high severity had become unsuitable for nesting and roosting in a survey conducted two months following the fire (Lesmeister et al. 2019). Reduced canopy cover over large areas can also reduce prey availability and increase predation risk (Safford 2006). Overall, larger and high severity fires can reduce late-seral habitat connectivity, availability, and quality (Purcell et al. 2012; Lesmeister et al. 2019) and increases risk of direct mortality (CDFW 2016), potentially limiting population connectivity and driving population declines or local extirpations of LSD species (Purcell et al. 2012). For example, large

⁵ Refer to the section on non-climate stressors for a more complete discussion of the impacts of fire suppression and timber harvest on LSD species.

fires in 2008 are thought to have contributed to a 42% decline in Humboldt marten habitat occupancy relative to pre-fire conditions, likely because dense shrub understories were removed, eliminating cover required by these species (Slauson et al. 2009). A recent survey following two fires that burned portions of the study area for a long-term fisher monitoring program in the Klamath-Siskiyou region found that the number of fishers in the study area declined by 40% within the first year following the fires and declines persisted for at least two more years (D. Green, pers. comm., 2019). Across the Klamath-Siskiyou Ecoregion, 4% of the fisher population has been exposed to forest fire at varying levels of severity between 2015 and 2017 (D. Green, pers. comm., 2019).

Late-seral forest habitats can take centuries to recover and develop following stand-replacing disturbance, resulting in long-term shortages in habitat availability, connectivity, and suitability for LSD species (Safford 2006; Zielinski & Gray 2018). Under future climate conditions, increased risk of uncharacteristically large and/or severe fires has the potential to alter habitat availability for LSD species at a much faster rate than projected shifts in vegetation due to warmer temperatures and changes in precipitation (CDFW 2016). In combination with changing temperature and moisture regimes, wildfire (particularly repeated fires) may also drive vegetative type conversions (Airey Lauvaux et al. 2016), eliminating recovery of critical habitat even over longer-than-usual time scales (USFWS 2011).

Regional Wildfire Trends	
<p><i>Historical & current trends:</i></p> <ul style="list-style-type: none"> • 85% of U.S. Forest Service lands in northern California are burning less frequently compared to pre-1850 fire return intervals, largely due to fire suppression (Safford & Van de Water 2014) • Fire size and total area burned increased on U.S. Forest Service lands in northwestern California between 1910-2008, with the highest values occurring after 2000 (Miller et al. 2012) • Changes in large fires (over 400 ha) in the inland northern California/Sierra Nevada region since the 1970s (Westerling 2016): <ul style="list-style-type: none"> ○ 184–274% increase in frequency ○ 270–492% increase in total area burned ○ 215% increase in length of the fire season • Changes in fire size, area burned, and fire frequency over the past several decades remain well below historical tribally-influenced frequency and extent of burning in California (Stephens et al. 2007) • No significant trends in the average areal proportion of high-severity fire were 	<p><i>Projected future trends:</i></p> <ul style="list-style-type: none"> • State-wide, up to 77% increase in mean annual area burned and 50% increase in the frequency of extremely large fires (>10,000 ha) by 2100 (Westerling 2018) <ul style="list-style-type: none"> ○ Greatest increases in burned area (up to 400%) occur in montane forested areas in northern California (Westerling et al. 2011; Westerling 2018) ○ Less significant increases or possible decrease along the North Coast (Westerling et al. 2011) • Little projected change in fire severity in northwestern California by 2050 in models based solely on historical fire-climate relationships (Parks et al. 2016) <ul style="list-style-type: none"> ○ However, human activity and fuel buildup from decades of fire suppression have altered historical fire-climate relationships (Taylor et al. 2016; Syphard et al. 2017; Wahl et al. 2019), and projections that incorporate these factors suggest that more significant increases in fire severity and size may occur (Mann et al. 2016; Wahl et al.

Regional Wildfire Trends	
<p>documented in northwestern CA from 1984–2008 (Miller et al. 2012; Parks et al. 2015; Law & Waring 2015; Keyser & Westerling 2017)</p> <ul style="list-style-type: none"> ○ The relatively short period of record for fire severity data may obscure long-term trends ○ To date, there are no peer-reviewed studies on trends in northern California fire severity that include data from the last ten years 	<p>2019)</p> <ul style="list-style-type: none"> ● The majority of impacts to natural and human ecosystems come from extreme fire events (i.e., fires that have a low probability of occurring in any given place and time), which are likely to increase over the coming century (Westerling 2018) <ul style="list-style-type: none"> ○ Generally, these patterns are not well-represented in studies that evaluate indices of mean fire size, intensity/severity, etc.
Summary of Potential Impacts on Species Group <i>(see text for citations)</i>	
<ul style="list-style-type: none"> ● <i>Immediate:</i> <ul style="list-style-type: none"> ○ Mortality of some individuals, with possible extirpation of small, isolated populations ○ Temporary reduction in key habitat features (e.g., ground cover, existing logs) ● <i>Short-term (~2-year):</i> <ul style="list-style-type: none"> ○ Enhanced predation risk and possible prey reductions due to reduced canopy cover, although burned areas provide enhanced hunting for fishers ○ Development of key habitat features (e.g., cavities, snags, logs) ● <i>Long-term:</i> <ul style="list-style-type: none"> ○ Maintenance of critical late-successional habitat features (e.g., snags, downed logs, complex vertical structure) and promotion of landscape-scale habitat heterogeneity in areas maintained by low- to moderate-severity and/or mixed-severity fire regimes ○ Elimination and/or severe reductions in late-seral habitat availability and connectivity where uncharacteristically large, severe fires alter the landscape (particularly if repeated) 	

Dependency on sensitive habitat and/or other species

Regional experts evaluated LSD species as having high dependency on sensitive habitats (high confidence in evaluation) and moderate-high dependency on prey or forage species (high confidence).

Habitat dependencies

At the landscape scale, LSD species are generally associated with mid- to late-seral forest habitat with large patch sizes, moderate to high canopy cover (60-80% for northern spotted owl, >60% for fisher, >30% for Sierra marten), and complex vertical and horizontal forest structure (USFWS 1992; Slauson et al. 2007, 2019; Kirk & Zielinski 2009; Hamlin et al. 2010; Lofroth et al. 2010; Purcell et al. 2012; Weir et al. 2012; Aubry et al. 2013; Long et al. 2014; CDFW 2016). In addition to general association with late-seral forest habitat, individual species also have more specific habitat requirements. For example, northern spotted owls also require forest edges and more diverse forest composition and structure for foraging (CDFW 2016). Martens and fishers are commonly found occupying areas adjacent to the riparian zone (Long et al. 2014).

At the home range scale, habitat features are more closely tied with forest structure than tree species composition (USFWS 1992; Zielinski et al. 2004; Safford 2006; Purcell et al. 2012; Weir et al. 2012; Long et al. 2014; Green 2017). Generally, these species require large-diameter, decadent trees and/or snags with cavities, deformities, and platforms for resting and reproduction (USFWS 1992; Zielinski et al. 2004; Purcell et al. 2012; CDFW 2016; Slauson et al. 2019). Many LSD species also prefer habitats with downed logs, decaying tree boles, stumps, and diverse vertical structure and ground cover that provides predator protection and thermal cover, such as dense shrub cover, abundant lower tree branches, and coarse woody debris (Zielinski et al. 2004; Hamlin et al. 2010; CDFW 2016). In areas with suboptimal tree size, dwarf mistletoe broom (*Arceuthobium douglassi*) allows northern spotted owls to nest in stands with smaller and younger trees (CDFW 2016). Similarly, epiphytes in coast redwood crowns are a required nesting habitat element for marbled murrelets (Meyer et al. 2004; Golightly et al. 2009). Development of these unique late-seral stand conditions can take centuries to develop, meaning suitable habitat can be eliminated much faster than it can be created (Zielinski & Gray 2018).

Many LSD species also exhibit some sensitivity to patch size. For example, marbled murrelets select for habitat areas with larger patch sizes (USFWS 1992). Similarly, marten and fisher require fairly large areas of contiguous late-seral conditions (Slauson et al. 2007; Kirk & Zielinski 2009; Hamlin et al. 2010; Long et al. 2014). Declines in habitat quality require these species to expand their home range size to meet specific life history needs, which can increase energetic costs (Hamlin et al. 2010). Forest simplification and creation of forest openings can also reduce functional connectivity between habitat patches and alter marten movement patterns (Moriarty et al. 2015, 2016).

Prey/forage dependencies

As predators, LSD species are very sensitive to climate-driven shifts in prey availability and/or distribution (Franklin et al. 2000; Lofroth et al. 2010; Purcell et al. 2012). For example, demographic patterns in northern spotted owls are tightly linked with prey availability, which is influenced by regional climatic patterns (Franklin et al. 2000; CDFW 2016). In the Klamath and coastal region of northern California, northern spotted owls prey primarily on dusky-footed woodrats (*Neotoma fuscipes*), while in interior areas, their diet is composed of either woodrats or flying squirrels (*Glaucomys sabrinus*; CDFW 2016). Due to high prey specificity, climate-driven changes in prey abundance could affect northern spotted owl population stability. For example, woodrats prefer early-seral shrub and forest habitat (Hamm & Diller 2009; CDFW 2016), which may become more abundant in the short-term due to increased wildfire risk and disease-related disturbances (CDFW 2016). Longer-term trends are more uncertain, as overall declines in forest health and integrity may lead to declines in groundcover and food (i.e., mast and leaves) used by woodrats (CDFW 2016). Additionally, the woodrat genus (*Neotoma*) exhibits changes in body size in response to temperature changes, with higher air temperatures driving smaller body size (Smith & Betancourt 2006). This could reduce the energetic benefits per kill, potentially requiring more frequent foraging or larger foraging areas to meet energetic needs (Smith & Betancourt 2006). Warmer, drier conditions and altered fire regimes may also impact food sources utilized by prey species. For instance, a recent study found that lichen, which is an

important food source for flying squirrels (Weigl 1978; Maser et al. 1986), demonstrated little recolonization in the hotter, drier microclimates of forests impacted by moderate- to high-severity fire in the Sierra Nevada (Miller et al. 2018).

In California, fishers consume a variety of medium- to small-sized mammals and birds, despite being dietary specialists in more northern parts of their range where they prey on snowshoe hares (*Lepus americanus*) and porcupines (*Erethizon dorsatum*; Zielinski et al. 1999; Golightly et al. 2006; Lofroth et al. 2010). However, their smaller-bodied prey base in California is energetically less efficient, which may act as a limiting factor for population growth and increase vulnerability to climate-driven shifts in prey availability (Fuller & Sievert 2001; Spencer et al. 2015a; Green et al. 2018). Both Sierra martens and Humboldt martens consume a variety of small mammals, birds, insects, and fruits (Zielinski et al. 1983; Zielinski & Duncan 2004; Hamlin et al. 2010; Long et al. 2014). However, the winter diet of Sierra martens is more specialized, focusing on only a few small mammals associated with late-seral forest habitat (e.g., red-backed voles [*Clethrionomys californicus* and *C. gapperi*], Douglas squirrels [*Tamias sciurus douglasii*]; Zielinski et al. 1983; Zielinski & Duncan 2004; Hamlin et al. 2010; Long et al. 2014).

Sensitivity and current exposure to non-climate stressors

Regional experts evaluated LSD species as having high sensitivity to non-climate stressors (high confidence in evaluation), with an overall moderate current exposure to these stressors within the study region (high confidence). Key non-climate stressors that affect LSD species include fire suppression, roads/highways/trails, timber harvest, poisons, and invasive and/or problematic species (barred owls).⁶

Fire suppression

Fire suppression has occurred in most northern California forests since the early 1900s, following Euro-American settlement and subsequent logging (Skinner et al. 2006; Steel et al. 2015; Safford & Stevens 2017). The exclusion of fire from regional forests has resulted in greater densities of small and medium-sized trees, simplifying forest structure and composition at the landscape level (see Table 1; Taylor & Skinner 2003; Spies et al. 2006; Leonzo & Keyes 2010; Perry et al. 2011; Safford & Stevens 2017). Decreased tree vigor in dense stands increases competition for resources (e.g., soil moisture, light), making stressed trees more vulnerable to mortality from drought, insects, and disease (van Mantgem et al. 2004; Leonzo & Keyes 2010; Fettig et al. 2013; Safford & Stevens 2017; Slack et al. 2017). Cumulatively, these changes often increase risk of late-seral and mature forest habitat loss to severe fires or other disturbances (Hamlin et al. 2010; Lofroth et al. 2010; CDFW 2016). These changes also degrade habitat conditions preferred by LSD species, including the development of diverse stand structure with large trees (Hamlin et al. 2010; Lofroth et al. 2010; CDFW 2016). Fire exclusion may also reduce the availability of prey species associated with early-successional forests and open areas (Norgaard et al. 2016).

⁶ Non-climate stressors presented are those ranked as having a moderate or higher impact on this species group; additional non-climate stressors that may influence the species group to a lesser degree include recreation.

Fire suppression activities (e.g., backburning, fire line construction, safety mitigation activities) can also damage mature trees directly (Lake 2007; Norgaard et al. 2016). For instance, trees with existing cavities that pose a hazard to firefighters may be felled (Long et al. 2016; Norgaard et al. 2016). The opening of fire breaks may also increase exposure to predators, particularly where they are adjacent to high-quality habitat for LSD species (Vuln. Assessment Reviewer, pers. comm., 2019).

Table 1. Impacts of fire suppression on the resilience of LSD species to climate stressors and climate-driven changes in fire regimes (table adapted from Norgaard et al. 2016).

Prior to Fire	During Fire	After Fire
<ul style="list-style-type: none"> • Reduced availability of prey species associated with early-successional forest and open areas • Increased risk of high-severity fire due to high tree density and fuel loads • Reduced habitat suitability due to simplified forest structure 	<ul style="list-style-type: none"> • Loss of snags utilized for denning during fire suppression activities • Opening or re-opening of linear fuelbreaks that may increase exposure to predators where adjacent to high-quality habitat 	<ul style="list-style-type: none"> • Removal of standing wood during post-fire fuels management and/or salvage logging
Source(s): Lake 2007; Hamlin et al. 2010; Lofroth et al. 2010; Zielinski et al. 2010; CDFW 2016; Norgaard et al. 2016; Rockweit et al. 2017; Lesmeister et al. 2018		

Roads, highways, and trails

Fishers, martens, and dispersing juvenile northern spotted owls are vulnerable to mortality from vehicle collisions when crossing roads and highways (Hamlin et al. 2010; Lofroth et al. 2010; Long et al. 2014; CDFW 2016; Sweitzer et al. 2016b; Slauson et al. 2019). Roads and trails also enhance predation risk by providing travel corridors for predators (e.g., coyotes, bobcats, mountain lions; (Slauson et al. 2019). However, they also increase prey availability and facilitate hunting, and quiet roads and trails have been associated with increased recruitment in northern spotted owls (Hayward et al. 2011).

Larger roads and highways fragment habitat, reducing fisher and marten habitat connectivity and limit species dispersal (Garroway et al. 2011; Tucker et al. 2017), especially for females (Tucker et al. 2017). For example, Highway 101 likely limits Humboldt marten dispersal to suitable habitat in Prairie Creek Redwood State Park (Slauson et al. 2019). Larger roads also are associated with lower recruitment rates in northern spotted owls nesting within 100 meters (328 ft), likely due to the stress of traffic noise (Hayward et al. 2011).

Timber harvest

Depending on harvest method, timber harvest can reduce late-successional forest stand area, degrade stand conditions, and/or increase habitat fragmentation, decreasing habitat suitability

for and survival of LSD species (USFWS 1992, 2011; Hamlin et al. 2010; Purcell et al. 2012; Long et al. 2014; Moriarty et al. 2015, 2016; Falxa & Raphael 2016). Timber harvest activities that reduce overstory (e.g., clear-cuts), remove key habitat features used by LSD species (e.g., snags), reduce old-growth stand patch size, or reduce stand complexity (e.g., via removal of small-diameter trees and downed logs) are most likely to reduce habitat suitability and species utilization (Slauson et al. 2009; USFWS 2011; Long et al. 2014; Moriarty et al. 2015, 2016; Zielinski & Gray 2018). For example, studies in the Sierra Nevada, southern Cascades, and Oregon have found that marten typically do not occupy landscapes with more than 25–30% of mature forest cover removed, that they avoid stands subjected to partial, selection, or regeneration cuts (Slauson et al. 2009; USFWS 2011; Long et al. 2014; Moriarty et al. 2015, 2016; Zielinski & Gray 2018), and that they do not perceive simplified stands as functionally connected habitat (Odion et al. 2004; Moriarty et al. 2015, 2016). Similarly, Humboldt marten occupancy in northern California appears most stable in old-growth stands with a larger patch size (Slauson et al. 2009, 2019). In some cases, fragmentation as a result of timber harvest may preclude access to and use of remnant suitable habitat patches, limiting overall habitat availability and recovery potential of depressed LSD species populations (Hamlin et al. 2010; Moriarty et al. 2015, 2016).

Altered forest structure or increased fragmentation as a result of timber harvesting may alter LSD species behavior, such as foraging patterns and required foraging distance, which can impact population density (Long et al. 2014). Timber harvest can also increase vulnerability to predation by reducing cover and refuge areas while increasing predator access (e.g., via reduced patch size or increased edge effects; (USFWS 1992; Slauson et al. 2009; Hamlin et al. 2010; Moriarty et al. 2016). However, the same factors that increase predation risk can increase the availability of prey (e.g., dusky-footed woodrats) for northern spotted owls (Hamm & Diller 2009; Irwin et al. 2013). Increasing fragmentation and simplified stand structure as a result of timber harvest can also reduce microrefugia or exacerbate climate impacts, such as susceptibility to rising air temperatures (Vanwalleghem & Meentemeyer 2009; Sweitzer et al. 2016a; Frey et al. 2016). Exposure to timber harvesting is localized in the study region (Vuln. Assessment Workshop, pers. comm., 2017), and is higher on private lands relative to federal- or state-owned lands (Hamlin et al. 2010; USFWS 2011; Falxa & Raphael 2016). Timber harvest and land-use conversion for cannabis (*Cannabis sativa*, *C. indica*) cultivation elevates regional exposure to forest loss and fragmentation (Gabriel et al. 2015; CDFW 2016; Wang et al. 2017).

Poisons

Mortality of fishers, martens, and northern spotted owls is likely increasing as a result of exposure to rodenticides and pesticides used by illegal cannabis farms (Gabriel et al. 2012, 2015, 2018; Sweitzer et al. 2016b). For example, studies by Gabriel et al. (2018) and Gabriel et al. (2015) found that 70% of sampled northern spotted owls and 85% of sampled fishers, respectively, had been exposed to one or more anticoagulant rodenticides. These species are vulnerable to direct ingestion of poisoned trap bait and secondary poison exposure from eating poison-contaminated prey (Gabriel et al. 2012, 2018). Even at sub-lethal doses, poisons can impair fitness and function, indirectly increasing mortality risk (Gabriel et al. 2012, 2018; Sweitzer et al. 2016b). For example, anticoagulant rodenticide may impair fisher blood clotting,

increasing mortality risk from minor wounds encountered when hunting or escaping predators (Gabriel et al. 2012). Poison exposure may also reduce resilience to environmental variability (e.g., temperature changes) and impact prey availability (Gabriel et al. 2012). Additionally, additive mortality from poison exposure can limit recovery of small populations, even when suitable habitat is available (Gabriel et al. 2015).

Invasive and/or problematic species

Barred owls directly compete with northern spotted owls for breeding, sheltering, and foraging resources, reducing northern spotted owl recruitment, survival, and site occupancy (USFWS 2011; CDFW 2016; Dugger et al. 2016). Competitive exclusion from remnant late-seral habitats is problematic given the limited habitat available to this species (USFWS 2011; CDFW 2016). Barred owls are habitat and prey generalists, which may give them advantages over northern spotted owls under variable climatic conditions (USFWS 2011). Barred owls occupy all areas currently inhabited by northern spotted owls, but are particularly abundant in northern portions of the owl’s range (USFWS 2011), potentially reducing access to or viability of refugia.

Northern spotted owls are vulnerable to genetic diversity losses via hybridization with barred owls, particularly in areas where northern spotted owls are rare and barred owls are abundant (CDFW 2016). Barred owls can also introduce or increase parasitic infection risk (CDFW 2016). Additionally, barred owl presence may increase northern spotted owl exposure to rodenticide poisoning as they visit more contaminated sites as their range expands in response to competitive interactions (Gabriel et al. 2018).

Adaptive Capacity

LSD species were evaluated by regional experts as having low-moderate overall adaptive capacity (high confidence in evaluation).

Species group extent, integrity, connectivity, and dispersal ability

Regional experts evaluated LSD species as collectively having a low-moderate geographic extent (high confidence in evaluation), low overall health and functional integrity (high confidence), and a low-moderate degree of connectivity between populations (high confidence), although all factors vary by species (see table below).

Species	Geographic extent	Population health and functional integrity	Population connectivity
Pacific fisher	Moderate-high	Low	Low
Humboldt marten	Low	Low	Low
Sierra marten	Moderate-high	Low-moderate	Moderate-high
Northern spotted owl	Moderate-high	Low	Low-moderate
Marbled murrelet	Moderate	Low	Moderate-high

Regional experts evaluated LSD mammals as having low dispersal ability while birds (e.g., northern spotted owl, marbled murrelet) were evaluated as having high dispersal ability (moderate confidence in evaluation). Barriers to dispersal were evaluated as having a high collective impact on the species group (high confidence). Roads/highways/trails, timber harvest (including clear-cuts), and cannabis cultivation were identified as the primary barriers to dispersal, in addition to high dependence on specialized habitat characteristics.⁷ Roads, highways, and trails are particularly problematic barriers for fisher and marten (Vuln. Assessment Workshop, pers. comm., 2017), and Humboldt marten dispersal may be additionally limited by major rivers (e.g., the Klamath River; Slauson et al. 2018).⁸ For northern spotted owls, the presence of barred owls was identified as an additional barrier to dispersal (Vuln. Assessment Workshop, pers. comm., 2017).

LSD species populations have declined across northern California, largely due to the impact of human activities and past or present management practices on habitat conditions and availability (Zielinski et al. 2005; Slauson et al. 2009; Hamlin et al. 2010; Lofroth et al. 2010; CDFW 2016; Falxa & Raphael 2016). For the northern spotted owl, population declines have also been strongly influenced by the presence of barred owls (USFWS 2011; CDFW 2016). Several of the species considered in this assessment are federally- and/or state-listed as threatened or endangered, including the northern spotted owl (USFWS 2011; CDFW 2019), Humboldt marten (CDFW 2019), and marbled murrelet (USFWS 1992; CDFW 2019). Additionally, the Pacific fisher is currently proposed for federal listing as a threatened species (USFWS 2019).

The largest of the two remaining native fisher populations in the state occurs in northwestern California/southern Oregon (Lofroth et al. 2010). Recent estimates gauge this population at roughly 3,200 individuals, with population density peaking 40–80 km (24.8–49.7 miles) from the coast and between 39–41.5 degrees latitude (Furnas et al. 2017). Northwestern California fishers are isolated from the only other California population, found in the southern Sierra Nevada, by over 400 km (248 miles; Zielinski et al. 2005; Safford 2006; Tucker et al. 2012). Recent analysis of genetic evidence indicates that isolation of these two populations likely pre-dates European settlement of California (Knaus et al. 2011; Tucker et al. 2012). Northwestern California fishers also remain isolated from populations that are being reintroduced into the northern Nevada and southern Oregon Cascades (Furnas et al. 2017). The maximum dispersal distances for individual fishers in California is 100 km (62 miles), undermining potential population connectivity (Safford 2006 and citations therein).

The Sierra marten occurs from the Salmon-Trinity Mountains east to the Cascade Mountains, and south into the Sierra Nevada (Hamlin et al. 2010). Surveys indicate that Sierra marten

⁷ All barriers presented were ranked as having a moderate or higher impact on this species group.

⁸ U.S. Fish and Wildlife (Yreka Field Office) and the Conservation Biology Institute are currently collaborating to evaluate functional connectivity for fisher and marten species in the Klamath Basin:

<https://consbio.org/products/projects/klamath-basin-ecological-connectivity>

populations in the southern Cascades and Sierra Nevada have declined and distributions have significantly contracted over time (Zielinski et al. 2005; Kirk & Zielinski 2009; Moriarty 2009; Moriarty et al. 2011). Extant populations are now concentrated in areas with limited human impacts, including lower levels of timber harvest and road access and greater prevalence of high elevation mature forest (Zielinski et al. 2005; Kirk & Zielinski 2009). However, fragmentation as a result of timber harvest or other human activity can severely curtail Sierra marten movement (Zielinski et al. 2005; Kirk & Zielinski 2009). Studies of coastal marten populations suggest that juvenile dispersal distances are typically low in Alaska/British Columbia (15.5 km [9.5 mi]; Pauli et al. 2012) and California (10.8 km [6.7 mi]; Slauson 2017).

Due to historical trapping and ongoing habitat modifications (Slauson et al. 2019), the Humboldt marten currently occupies less than 5% of its historical range in California (Slauson et al. 2009). The species now exists in four isolated populations in northwestern California and coastal Oregon, separated by distances of 20–40 km (12.4–24.8 miles; Slauson et al. 2019). The largest extant population is patchily distributed across an area of roughly 62,700 acres of northern Humboldt and Del Norte Counties, comprising less than 100 individuals in 2008 (Slauson et al. 2009). A smaller population occurs near the California-Oregon border in northeast Del Norte County (Slauson et al. 2019), and two additional small populations occur along the central and southern Oregon coast (Linnell et al. 2018). Functional connectivity for Humboldt martens is restricted by degraded landscape conditions associated with severe wildfire, urbanization, and logging (Moriarty et al. 2016; Slauson et al. 2019).

The northern spotted owl occurs from Marin County in northern California north along the Pacific Coast to southwest British Columbia, Canada, occupying coastal ranges and ranging inland as far as the Cascade Range (Carroll 2010; USFWS 2011; CDFW 2016). From 1990–2011, northern spotted owl populations in California declined 31–55% depending on location; (Forsman et al. 2011), with lower rates of decline occurring in areas where barred owls are being removed (Dugger et al. 2016; Diller et al. 2016; Wiens et al. 2017). Recent studies indicate that the rate of northern spotted owl population decline may be accelerating in California, with declines in both fecundity and survival (Dugger et al. 2016). At the same time, suitable habitat is stable or increasing for barred owls, suggesting that spotted owl declines are at least, in part, attributable to interspecific competition (Dugger et al. 2016; Lesmeister et al. 2018). Juvenile dispersal distances of up to 111 km (69 mi) have been recorded, but average distances range between 14.6 km and 45 km (9.1–28 mi); (Gutiérrez et al. 1985; Forsman et al. 2002). Northern spotted owl dispersal is negatively affected by loss and fragmentation of old, closed-canopy forests (Forsman et al. 2011; USFWS 2011), and small changes in landscape connectivity can have significant, population-wide impacts (Schumaker et al. 2014).

The marbled murrelet occurs from central California to Alaska, spending the majority of its life in the marine environment but utilizing coastal late-successional forest habitats to nest (USFWS 1992; Falxa & Raphael 2016). Over the past century, marbled murrelet nesting habitat has declined by over 80% due to logging, and this has been a major factor in observed population declines across the species' range (USFWS 1997; Falxa & Raphael 2016; Raphael et al. 2018). However, there is some indication that California populations have stabilized or increased

modestly since implementation of the Northwest Forest Plan in 1994 (Lynch et al. 2016). Although adult murrelets can travel very long distances (up to 750 km [466 mi]) up and down the coast (Adrean et al. 2018), juveniles typically do not disperse very far inland for nesting (17.7–35.4 km [11–22 miles]; USFWS 1992).

Intraspecific/life history diversity

Regional experts evaluated LSD species as having low life history diversity (high confidence in evaluation), low genetic diversity (low confidence), moderate-high behavioral plasticity (low confidence), and low phenotypic plasticity (low confidence).

Both martens and fishers exhibit behavioral plasticity in habitat selection, which may enhance their resilience to environmental stress, including climate impacts (Zielinski et al. 2017; Matthews et al. 2019). For instance, fishers in northwestern California appear to select reproductive dens that offer thermoregulatory benefits (i.e., buffering of low temperatures) (Matthews et al. 2019). Northern spotted owls also utilize a variety of forest types if roosting and nesting structures (i.e., residual mature trees) are available, and additionally exhibit behavioral adaptations to heat stress (CDFW 2016). Similarly, Sierra and Humboldt martens forage in regenerating stands if denning/resting structures (i.e., large snags, logs, stumps) are available (Purcell et al. 2012). Humboldt martens will also use lower-quality habitat if necessary, including rocky serpentine areas with interstitial spaces, which potentially provide similar function to wood cavities (Slauson et al. 2007, 2009). However, marten occupancy tends to be more transitory on serpentine sites, individuals have larger home ranges (indicating lower prey availability), and populations appear to be male-biased and have low breeding activity (Slauson et al. 2019). Overall, it is unclear if serpentine areas can provide for year-round habitat needs (Purcell et al. 2012).

Small and/or isolated populations present significant genetic challenges for LSD species. Fewer opportunities for genetic exchange contribute to reduced genetic diversity (Knaus et al. 2011; Tucker et al. 2012), which limits the potential for adaptation to rapid environmental changes (Hamlin et al. 2010; CDFW 2016). Genetic bottlenecks in small populations also increase the risk of extirpation (Hamlin et al. 2010; CDFW 2016).

Resistance and recovery

Regional experts evaluated LSD species as having low resistance to climate stressors and natural disturbance regimes (high confidence in evaluation). Recovery potential was evaluated as low (high confidence).

LSD species are generally not very resistant to landscape-scale changes in habitat availability and quality (USFWS 1992; Zielinski et al. 2005; Hamlin et al. 2010; Lofroth et al. 2010; CDFW 2015, 2016). Additionally, their reliance on late-successional forest characteristics slows population recovery following severe disturbances, as late-seral habitat characteristics can take centuries to develop (DellaSala et al. 2015; Zielinski & Gray 2018). Habitat fragmentation can further reduce reproductive potential and recovery rates in many species by increasing

predation risk (USFWS 1992; Hamlin et al. 2010; Long et al. 2014; CDFW 2016; Sweitzer et al. 2016b).

Both fishers and martens beginning breeding at 2–3 years of age and only have a few kits per litter; fishers also do not breed every year (Hamlin et al. 2010; Lofroth et al. 2010; Green et al. 2018). Similarly, martens typically do not successfully breed until 3 years old, have only one litter per year, and have less than 3 kits per litter on average (Hamlin et al. 2010). Northern spotted owl breeding and recruitment are highly influenced by local weather, regional climatic conditions, exposure to barred owls, prey availability, and overall habitat condition and quality (CDFW 2016; Dugger et al. 2016; Lesmeister et al. 2018). Reproductive rates are very low for marbled murrelets, which typically do not have more than one egg per nest and don't breed every year (De Santo & Nelson 1995; Hamer & Nelson 1995). However, recovery of these species following disturbance or population declines is likely dependent primarily on adult survival rather than reproductive rates (Vuln. Assessment Reviewer, pers. comm., 2019).

Management potential

Public and societal value

Regional experts evaluated LSD species as having moderate-high public and societal value (high confidence in evaluation).

While wildlife and birds are generally valued by the public more than plant species, regional public opinion and value of LSD species ranges from hostility to support (Vuln. Assessment Workshop, pers. comm., 2017). There is some legislative and regulatory support for management of LSD species and their associated habitats, particularly for species listed under the federal ESA such as the northern spotted owl and the marbled murrelet (USFWS 1990, 1992). Following the listing of these two species in 1990 and 1992, respectively, political tensions over how to balance timber harvest with protection of old-growth habitat for these species ultimately resulted in the creation and implementation of the Northwest Forest Plan (NWFP) in 1994 (Spies et al. 2018). Both northern spotted owls and marbled murrelets are considered flagship species under the NWFP; thus, protection of old-growth habitat for LSD species is heavily factored into forest management across the Pacific Northwest, including northern California (Spies et al. 2018). However, some societal groups associate or blame LSD species for reductions in timber harvest/resource extraction and associated economic limitations (Charnley et al. 2008). Additionally, the ability for managers to actually undertake work that would enhance the climate resilience of LSD species is limited due to the extensive consultation processes required under the federal ESA and Northwest Forest Plan (Vuln. Assessment Reviewers, pers. comm., 2018). There is some proactive management occurring on private lands to avoid having additional LSD species listed as threatened or endangered species (Vuln. Assessment Workshop, pers. comm., 2017).

Management capacity and ability to alleviate impacts⁹

Regional experts evaluated the potential for reducing climate impacts on LSD species through management as moderate (moderate confidence in evaluation).

Although management options to mitigate climate impacts (e.g., precipitation impacts on prey forage availability) are relatively limited, there is greater potential for addressing the impact of non-climate stressors on LSD species (Vuln. Assessment Workshop, pers. comm., 2017). For example, to reduce vulnerability to road kill, road culverts can be maintained and cleared of debris to facilitate reduce fisher vulnerability to road kill and facilitate movement across the landscape (Sweitzer et al. 2016b). Underpass and overpass structures could also be designed and installed to increase habitat connectivity (Sweitzer et al. 2016b). Timber harvest could be concentrated in areas not typically preferred by these species (e.g., low slope profiles, warmer areas) and could be conducted in ways that minimize loss of mature old-growth trees while maintaining existing logs and snags (Aubry et al. 2013). Management activities such as limiting unnecessary road and skid trails, maintaining canopy cover, and retaining structural understory diversity can reduce risk of enhanced predator overlap with LSD species (Sweitzer et al. 2016b). Additionally, there is on-going range-wide research on using barred owl removal as a conservation action for northern spotted owls (Dugger et al. 2016; Diller et al. 2016; Wiens et al. 2017).

The scientific literature also identifies some climate-informed management options, such as identifying, protecting, and enhancing microrefugia (Spencer et al. 2015b; Frey et al. 2016; Jones et al. 2016). Species-informed fuel treatments and prescribed burning (see Table 2) could potentially decrease the risk of severe fires in remnant old-growth habitat, while still retaining the habitat structures required by LSD species (Hamlin et al. 2010; Scheller et al. 2011; Long et al. 2014; Spencer et al. 2015a; Moriarty et al. 2015, 2016; Stephens et al. 2016; Karuk Tribe 2019). However, retaining sufficient downed wood and understory vegetation for marten and fisher, or promoting closed-canopy forests for northern spotted owls (which may feature enhanced ladder fuels), may conflict with regional fuel reduction goals and/or enhance regional fire risk (Long et al. 2014; Moriarty et al. 2015, 2016; Jones et al. 2016). Management of required habitat characteristics is made more difficult by the large home ranges of fishers, martens, and northern spotted owls, particularly given variable land ownership in the region (Vuln. Assessment Workshop, pers. comm., 2017). In general, management practices will vary depending on location (e.g., moist vs. dry forests) and will need to be highly site-specific (Hamlin et al. 2010; USFWS 2011; Scheller et al. 2011; Long et al. 2014).

⁹ Further information on climate adaptation strategies and actions for northern California can be found on the project page (<https://bit.ly/31AUGs5>).

Table 2. Effects of prescribed burning on LSD species across time (table adapted from Norgaard et al. 2016). Cultural burning practices, in particular, have played a role in maintaining these species on the landscape over very long time scales.

Immediate	2-Year	Long Term
<ul style="list-style-type: none"> • Avoids burning in known denning areas and protects areas of dense canopy cover through the use of low-intensity fire • Reduced impacts to mothers and juveniles when burns are conducted in the fall • Reduction of fuel loads decreases risk of high severity fire 	<ul style="list-style-type: none"> • Burned areas attract prey for fishers, increasing quality of hunting habitat • Creation of new cavities and/or enhancement of existing cavities following fire 	<ul style="list-style-type: none"> • Creates a mosaic of burned and unburned areas that provides suitable habitat for both hunting and denning • Maintains oak-dominated ecosystems that serve multiple fisher life history requirements
Source(s): Norgaard et al. 2016; Karuk Tribe 2019		

Ecosystem services

LSD species provides a variety of ecosystem services, including:

- Provisioning of genetic resources/services (for very rare species);
- Cultural/tribal uses for spiritual/religious purposes, knowledge systems, educational values, aesthetic values, sense of place, cultural heritage, and inspiration (Vuln. Assessment Workshop, pers. comm., 2017).

Some LSD species hold particular importance for regional Native American tribes. For example, both fisher and marten were traditionally trapped, and their skins were used for ceremonial regalia (Norgaard et al. 2016; Karuk Tribe 2019; Slauson et al. 2019).

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Further information on the Northern California Climate Adaptation Project is available on the project website (<https://tinyurl.com/NorCalAdaptation>).

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Northern California Climate Adaptation Project: Vulnerability Assessment Methods and Application

Defining Terms

Exposure: A measure of how much of a change in climate or climate-driven factors a resource is likely to experience (Glick et al. 2011).

Sensitivity: A measure of whether and how a resource is likely to be affected by a given change in climate or factors driven by climate (Glick et al. 2011).

Adaptive Capacity: The ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011).

Vulnerability: A function of the sensitivity of a particular resource to climate changes, its exposure to those changes, and its capacity to adapt to those changes (IPCC 2007).

Vulnerability Assessment Model

The vulnerability assessment model applied in this process was developed by EcoAdapt (EcoAdapt 2014a; EcoAdapt 2014b; Kershner 2014; Hutto et al. 2015; Gregg 2018),¹⁰ and includes evaluations of relative vulnerability by local and regional stakeholders who have detailed knowledge about and/or expertise in the ecology, management, and threats to focal habitats, species groups, individual species, and the ecosystem services that these resources provide. Stakeholders evaluated vulnerability for each resource by discussing and answering a series of questions for sensitivity and adaptive capacity. Exposure was evaluated by EcoAdapt using projected future climate changes from the scientific literature. Each vulnerability component (i.e., sensitivity, adaptive capacity, and exposure) was divided into specific elements. For example, habitats included three elements for assessing sensitivity and six elements for adaptive capacity. Elements for each vulnerability component are described in more detail below.

In-person workshops were held in Eureka, Redding, and Upper Lake between May and October 2017. Participants self-selected habitat and species group/species breakout groups and evaluated the vulnerability of each resource. Participants were first asked to describe the habitat and/or to list the species to be considered in the evaluation of an overarching species group. Due to limitations in workshop time and participant expertise, multiple resources were not assessed during these engagements. Evaluations for remaining habitats, species groups, and species were completed by contacting resource experts.¹¹

¹⁰ Sensitivity and adaptive capacity elements were informed by Lawler 2010, Glick et al. 2011, and Manomet Center for Conservation Sciences 2012.

¹¹ Resources evaluated by experts included: coastal bluff/scrub habitats, coastal conifer hardwood forest, true fir forest, lakes/ponds, freshwater marshes, vernal pools, seeps/springs, native insect pollinators, native ungulates, salamanders, frogs, native mussels, marbled murrelet, and northwestern pond turtle.

Stakeholders assigned one of five rankings (High, Moderate-High, Moderate, Low-Moderate, or Low) for sensitivity and adaptive capacity. EcoAdapt assigned rankings for projected future climate exposure. Rankings for each component were then converted into scores (High-5, Moderate-High-4, Moderate-3, Low-Moderate-2, or Low-1), and the scores were averaged (mean) to generate an overall score. For example, scores for each element of habitat sensitivity were averaged to generate an overall habitat sensitivity score. Scores for exposure were weighted less than scores for sensitivity and adaptive capacity because the uncertainty about the magnitude and rate of future change is greater. Sensitivity, adaptive capacity, and exposure scores were combined into an overall vulnerability score calculated as:

$$\text{Vulnerability} = [(\text{Climate Exposure} * 0.5) \times \text{Sensitivity}] - \text{Adaptive Capacity}$$

Elements for each component of vulnerability were also assigned one of three confidence rankings (High, Moderate, or Low). Confidence rankings were converted into scores (High-3, Moderate-2, or Low-1) and the scores averaged (mean) to generate an overall confidence score. These approximate confidence levels were based on the Manomet Center for Conservation Sciences (2012) 3-category scale, which collapsed the 5-category scale developed by Moss and Schneider (2000) for the IPCC Third Assessment Report. The vulnerability assessment model applied here assesses the confidence associated with individual element rankings and, from these rankings, estimates the overall level of confidence for each component of vulnerability and then for overall vulnerability.

Stakeholders and decision-makers can consider the rankings and scores presented as measures of relative vulnerability and confidence to compare the level of vulnerability among the focal resources evaluated in this project. Elements that received lower confidence rankings indicate knowledge gaps that applied scientific research could help address.

Vulnerability Assessment Model Elements

Sensitivity & Exposure (Applies to Habitats, Species Groups, Species)

- **Climate and Climate-Driven Factors:** e.g., air temperature, precipitation, freshwater temperature, soil moisture, snowpack, extreme events: drought, altered streamflows, etc.
- **Disturbance Regimes:** e.g., wildfire, flooding, drought, insect and disease outbreaks, wind
- **Future Climate Exposure:** e.g., consideration of projected future climate changes (e.g., temperature and precipitation) as well as climate-driven changes (e.g., altered fire regimes, altered water flow regimes, shifts in vegetation types)
- **Stressors Not Related to Climate:** e.g., tectonic and volcanic events; residential or commercial development; agriculture and/or aquaculture; roads, highways, trails; dams and water diversions; invasive and other problematic species; livestock grazing; fire suppression; timber harvest; mining; etc.

Sensitivity & Exposure (Applies to Species Groups and Species)

- **Dependencies:** e.g., dependencies on sensitive habitats, specific prey or forage species, and the timing of the appearance of these prey and forage species (concern for mismatch)

Sensitivity & Exposure (Applies to Species ONLY)

- **Life History:** e.g., species reproductive strategy, average length of time to reproductive maturity

Adaptive Capacity (Applies to Habitats, Species Groups, Species)

- **Extent, Integrity, and Continuity/Connectivity:** e.g., resources that are widespread vs. limited, structural and functional integrity (e.g., degraded or pristine) of a habitat or health and functional integrity of species (e.g., endangered), isolated vs. continuous distribution
- **Landscape Permeability:** e.g., barriers to dispersal and/or continuity (e.g., land-use conversion, energy production, roads, timber harvest, etc.)
- **Resistance and Recovery:** e.g., *resistance* refers to the stasis of a resource in the face of change, *recovery* refers to the ability to “bounce back” more quickly from the impact of stressors once they occur
- **Management Potential:** e.g., ability to alter the adaptive capacity and resilience of a resource to climatic and non-climate stressors (societal value, ability to alleviate impacts, capacity to cope with impacts)
- **Ecosystem Services:** e.g., provisioning, regulating, supporting, and/or cultural services that a resource produces for human well-being

Adaptive Capacity (Applies to Habitats ONLY)

- **Habitat Diversity:** e.g., diversity of physical/topographical characteristics, component native species and functional groups

Adaptive Capacity (Applies to Species Groups, Species)

- **Dispersal Ability:** i.e., ability of a species to shift its distribution across the landscape as the climate changes
- **Intraspecific/Life History Diversity:** e.g., life history diversity, genetic diversity, phenotypic and behavioral plasticity

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