Riparian-Nesting Birds

Northern California Climate Change Vulnerability Assessment Synthesis

***An Important Note About this Document:** This document represents an initial evaluation of vulnerability for riparian-nesting birds 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 (Klamath Bird Observatory), Chad Roberts (Tuleyome), and Nathaniel Seavy (Point Blue Conservation Science). Vulnerability scores were provided by Redding workshop participants. Upper Lake workshop participants provided additional comments on the climate change vulnerability of this species group.

Table of Contents

Species Group Description....1

Executive Summary....2

Sensitivity and Exposure....3
- *Sensitivity and future exposure to climate and climate-driven factors....4*
- *Sensitivity and future exposure to changes in natural disturbance regimes....8*
- *Dependency on habitat and/or other species....11*
- *Sensitivity and current exposure to non-climate stressors....11*

Adaptive Capacity....13
- *Species group extent, integrity, connectivity, and dispersal ability....13*
- *Intraspecific/life history diversity....14*
- *Resistance and recovery....15*
- *Management potential....15*
  - Public and societal value....15
  - Management capacity and ability to alleviate impacts....15
  - Ecosystem services....16

Recommended Citation....17

Literature Cited....17

Vulnerability Assessment Methods and Application....25

Species Group Description

Riparian areas associated with rivers, streams, wet meadows, and other wetlands are typically dominated by woody vegetation, although riparian habitat structure and composition vary widely from herbaceous grasses and sedges to dense shrub-dominated thickets and closed-canopy forests with large trees (National Research Council 2002; RHJV 2004). Riparian areas support diverse wildlife communities, and have long been recognized as one of the most significant wildlife habitat element in forested western landscapes (Thomas et al. 1979; RHJV 2004). Riparian-associated bird species depend on these habitats for nest sites, cover, and/or abundant seed and insect food sources (RHJV 2004). This assessment focuses on a number of riparian-nesting birds typical in the study area, which includes northwestern California and the Sacramento River Valley. These include the Yellow Warbler (*Setophaga petechia*), Yellow-breasted Chat (*Icteria virens*), Wilson's Warbler (*Cardellina pusilla*), Common Yellowthroat (*Geothlypis trichas*), MacGillivray's Warbler (*G. tolmiei*), Warbling Vireo (*Vireo gilvus*), Willow Flycatcher (*Empidonax traillii*), Yellow-billed Cuckoo (*Coccyzus americanus*), Song Sparrow (*Melospiza melodia*), Lincoln's Sparrow (*M. lincolnii*), White-crowned Sparrow (*Zonotrichia leucophrys nutalli*), Black-headed Grosbeak (*Pheucticus melanocephalus*), Blue Grosbeak (*Passerina caerulea*), Downy Woodpecker (*Picoides pubescens*), and Bald Eagle (*Haliaetus leucocephalus*; Vuln. Assessment Workshop, pers. comm., 2017). These species occupy a wide variety of niches within riparian habitats, depending on nest site preferences and foraging strategy (Motroni 1984; RHJV 2004; Rodewald 2015). Many are Neotropical migrants that winter in western Mexico and Central and South America, though a few species migrate shorter distances or reside in the area year-round (e.g., Downy Woodpecker; Rodewald 2015).

Executive Summary

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

Riparian-Nesting Birds	**Rank**	**Confidence**
Sensitivity	Moderate-High	High
Future Exposure	Moderate-High	Moderate
Adaptive Capacity	Moderate-High	High
Vulnerability	**Moderate-High**	**Moderate**

Sensitivity & Exposure Summary

Climate and climate-driven factors:
- Precipitation, drought, air temperature, heat waves

Disturbance regimes:
- Wildfire, disease

Non-climate stressors:
- Invasive and other problematic species, agriculture, pollution, livestock grazing, dams and water diversions

Riparian-nesting birds are likely to be impacted by climate stressors and climate-driven changes in disturbance regimes that increase physiological stress and/or cause mortality (e.g., heat waves, disease). Increases in air temperature may also contribute to phenological mismatches between insect prey emergence and the timing of avian migration and breeding. Warmer air temperatures, changes in precipitation, increased drought, and altered fire regimes may also alter the structure and composition of riparian vegetation, potentially reducing their suitability for riparian bird nesting and foraging. Key non-climate stressors for riparian-nesting birds include invasive and other problematic species, agriculture, pollution, livestock grazing, and dams and water diversions. These contribute to habitat loss and fragmentation, alter riparian vegetation composition and structure, reduce insect prey availability, and increase nest predation.

Adaptive Capacity Summary

Factors that enhance adaptive capacity:

+ Represents wide variety of families, foraging guilds, and life history strategies
+ Some species able to shift migration timing and/or route, nest site selection, and foraging strategy in response to climate conditions and habitat loss
+ Highly mobile, which confers resistance to changing conditions and disturbances

Factors that undermine adaptive capacity:

– Population declines and/or reduced breeding range in many species, largely due to habitat loss and brood parasitism

Riparian-nesting birds have been significantly impacted by habitat loss and fragmentation of riparian areas in northern California over the past 150 years, and many species have experienced population declines and/or range reductions. Because many of these species are migratory, habitat loss or degradation in their wintering grounds and on migratory stopover sites can also contribute to population declines. However, this species group exhibits a wide variety of life history strategies. Many species have high genetic diversity or behavioral flexibility (e.g., Song Sparrow), demonstrating the ability to shift migration timing and/or route, nest site location, and foraging strategy in response to changing climate conditions and habitat loss. The high mobility of this species group also increases resistance to climate change by allowing individuals to avoid disturbances and seek out higher-quality habitat. Many riparian-nesting birds are federally- or state-listed, and the scientific literature suggests that a number of management strategies could increase the resilience of riparian-nesting birds to climate change, including habitat restoration, protection of riparian corridors, Brown-headed Cowbird control, and grazing management.

Sensitivity and Exposure

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

Warmer, drier conditions over the coming century are likely to contribute to changes in the location and/or size of breeding and wintering ranges in riparian-nesting species (Stralberg et al. 2009; National Audubon Society 2013; Veloz et al. 2013; Langham et al. 2015). Range shifts are likely as bird species adapted to warmer climate regimes extend their range boundaries into formerly colder regions (VanDerWal et al. 2013; Princé & Zuckerberg 2015). For many species, northwards shifts are likely to occur in response to increasingly unsuitable climatic conditions within their current ranges (National Audubon Society 2013; Veloz et al. 2013; Langham et al. 2015). However, projections of elevational and latitudinal range shifts are heterogeneous among species (Tingley et al. 2012; Langham et al. 2015). Projections of habitat loss and range shifts also vary depending on factors such as the modeling method, climate projections, and timeframe. For example, some distribution models show the Wilson's Warbler experiencing significant losses (76%) of climatically suitable area within their current breeding range (National Audubon Society 2013). Other studies show more variable results for this species, with both population declines and increases anticipated depending on the climate scenarios projected (Veloz et al. 2013). Additionally, Veloz et al. (2013) found that Yellow Warblers and Willow Flycatchers are expected to decrease in abundance across all five climate models by 2070, and Warbling Vireo populations are projected to decline according to three out of five climate models applied.

Because individual species ranges shift independently in response to a combination of climate variables (e.g., temperature, precipitation), community composition will likely change in riparian bird communities (Stralberg et al. 2009). By 2070, novel community assemblages may occur across 10-57% of the state's land area, potentially altering ecological dynamics such as predator/prey interactions and interspecific competition for resources such as food and nesting sites (Stralberg et al. 2009). In northern California, the most significant changes in species composition are projected to occur in the southwestern foothills of the Cascades (along the northern edge of the Sacramento Valley) and, to a lesser degree, within the North Coast region (Stralberg et al. 2009).

Riparian ecosystems are generally considered more resilient to climate change than surrounding upland areas (Seavy et al. 2009; Capon et al. 2013). For instance, these areas are likely to buffer the impacts of higher temperatures and more limited water availability under future climate conditions, and are also adapted to recover rapidly from disturbances such as flooding (Seavy et al. 2009). As a result, riparian-nesting birds may be less likely to experience extreme climatic changes compared to many other groups of birds (Gardali et al. 2012; DiGaudio et al. 2015).

Sensitivity and future exposure to climate and climate-driven factors

Regional experts evaluated riparian-nesting birds 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 riparian-nesting birds include precipitation, drought, air temperature, and heat waves.[1]

Precipitation and drought

Reduced vegetation cover and productivity as a result of precipitation declines and drought may result in a loss of food resources (e.g., seeds, berries, insects) and cover for riparian-nesting birds (Chase et al. 2005; Bolger et al. 2005; Albright et al. 2010; Ackerman et al. 2011; Dybala et al. 2013; Ferger et al. 2014). In Song Sparrows, drought has been associated with

---

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

decreased nest survival and shorter breeding seasons (Chase et al. 2005; Ackerman et al. 2011), likely due to reduced insect prey availability and decreased herbaceous cover (Chase et al. 2005). Drought has been associated with changes in the abundance, richness, and composition of songbird communities, with the most significant changes noted in long-distance migrants (Albright et al. 2010). Over the coming century, altered precipitation is projected to be one of the most important variables impacting abundances of Downy Woodpecker, Swainson's Thrush (*Catharus ustulatus*), Warbling Vireo, Yellow Warbler, and Wilson's Warbler populations (Veloz et al. 2015; Alexander et al. 2017).

Precipitation declines and drought also affect riparian vegetation composition and structure (Perry et al. 2012), potentially favoring colonization of drought-tolerant species to become established in riparian areas and, in some cases, reducing overall habitat heterogeneity (Glenn & Nagler 2005; Stromberg et al. 2010). Reduced vigor within water-stressed trees significantly increases vulnerability to mortality from disturbances such as insect outbreaks, drought (Fettig et al. 2013; Young et al. 2017) and high-severity wildfire (van Mantgem et al. 2013), particularly during "hotter droughts" (Allen et al. 2015). Drought may also drive an increase in the risk of large-scale disturbance events (e.g., insect outbreaks, disease, wildfire; Fettig et al. 2013; Millar & Stephenson 2015). For instance, periods of drought are strongly correlated with increased fire activity (e.g., fire size, rate of spread), largely due to reductions in fuel moisture (Littell et al. 2009; Abatzoglou & Kolden 2013; McKenzie & Littell 2017).

Regional Precipitation Trends[2]	
Historical & current trends: • 2.6–9.4 cm (1.0–3.7 in) increase in mean annual precipitation between 1900 and 2009 for the Northwestern California, Southern Cascade, and Great Valley 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) • 2012–2014 drought set records for lowest precipitation, highest temperatures, and most extreme drought indicators on record (Griffin & Anchukaitis 2014; Diffenbaugh et al. 2015)	*Projected future trends:* • 23% decrease to 38% increase in mean annual precipitation by 2100 (compared to 1951–1980) for the North Coast, Northern Coast Range, Northern Interior Coast Range, Klamath Mountain, Southern Cascade, and Great Valley ecoregions (Flint et al. 2013; Flint & Flint 2014)[3] • Seasonal changes are projected to be more 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.

---

[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.

[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 Trends[2]	
	2018; Swain et al. 2018) - 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 *(see text for citations)*
- Reduced reproductive success due to a loss of food resources and cover for breeding birds - Decreased habitat suitability due to changes in vegetation structure, composition, and productivity

Air temperature

Warming temperatures may impact the timing of seasonal patterns related to migration and breeding in North American passerines (Gordo 2007; Ackerman et al. 2011; Mayor et al. 2017; Halupka & Halupka 2017; Furnas & McGrann 2018), and are associated with changes in abundance for many riparian-nesting species such as the Willow Flycatcher (Veloz et al. 2015; Alexander et al. 2017). Warmer temperatures have been correlated with earlier spring arrival in many migratory bird species (Mayor et al. 2017; Furnas & McGrann 2018), as well as changes in the onset of breeding behavior and the length of the breeding season (Halupka & Halupka 2017; Furnas & McGrann 2018). However, the direction and magnitude of observed changes varies depending on the species (Mayor et al. 2017; Halupka & Halupka 2017; Furnas & McGrann 2018). For instance, species that produce multiple broods per year, such as Song Sparrows, appear to have increased the length of their breeding season by 4 days per decade over the past 45 years, while the breeding season of single-brood species has generally become shorter by 2 days per decade (Halupka & Halupka 2017). Changes in the timing of invertebrate development and emergence may also impact reproductive success by causing phenological mismatches between the timing of spring arrival and peak food availability (Bale et al. 2002; Both et al. 2006).

Regional Air Temperature Trends	
Historical & current trends: - 0.03°C (0.05°F) decrease to 0.5°C (0.9°F) increase in the average annual temperature between 1900 and 2009 for the Northwestern California, Southern Cascade, and Great Valley	*Projected future trends:* - 2.2–6.1°C (4.0–11.0°F) increase in the average annual temperature by 2100 (compared to 1951–1980) for the North Coast, Northern Coast Range, Northern Interior Coast Range,

Regional Air Temperature Trends	
ecoregions (Rapacciuolo et al. 2014) ○ No seasonal temperature trends available	Klamath Mountain, Southern Cascade, and Great Valley ecoregions (Flint et al. 2013; Flint & Flint 2014) ○ 1.9–5.8°C (3.4–10.4°F) increase in average winter minimum temperatures ○ 2.0–6.8°C (3.6–12.2°F) increase in average summer maximum temperatures
Summary of Potential Impacts on Species Group *(see text for citations)*	
• Earlier spring arrival in migratory species and changes in the onset of breeding behavior and/or length of the breeding season • Potential mismatches between the timing of spring arrival and insect emergence, impacting food availability	

Heat waves

Extreme temperatures can result in dehydration and possible mortality in birds (Albright et al. 2017; Zhang et al. 2017). Thus, changes in the frequency and/or severity of heat waves may reduce survival and reproductive success (Jiguet et al. 2006; Albright et al. 2017). Small songbirds are more vulnerable to heat waves than are larger birds because they lose water at a higher rate, increasing the potential for dehydration on hot days when evaporative cooling demands are greater (Albright et al. 2017). A study of montane songbirds in northern California showed that Neotropical migrants were less likely than resident species and altitudinal migrants to reduce vocal activity on hot days during the breeding season, potentially increasing their vulnerability to heat stress given that singing is energetically expensive (McGrann & Furnas 2016). Studies also suggest that species distributed across narrower thermal ranges may be more likely to experience population declines, possibly because they tend to nest and forage within more specialized microenvironments in the landscape (Jiguet et al. 2006). Similarly, birds breeding near the upper limits of a species' thermal range also exhibit lower rates of population growth, regardless of latitude (Jiguet et al. 2010).

Regional Heat Wave Trends	
Historical & current trends: • 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)	*Projected future trends:* • 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 *(see text for citations)*	
• Reduced survival and reproductive success, potentially resulting in population declines for vulnerable species	

Sensitivity and future exposure to changes in natural disturbance regimes

Regional experts evaluated riparian-nesting birds as having moderate sensitivity to changes in natural disturbance regimes (moderate confidence in evaluation), with an overall moderate-high future exposure to these stressors within the study region (moderate confidence). Key natural disturbance regimes that affect riparian-nesting birds include wildfire and disease.[4]

Wildfire

Most of the forested landscape in northern California historically experienced variable fire return intervals, with shorter intervals and higher severities on south- and west-facing slopes and ridgetops (Taylor & Skinner 1998; Skinner et al. 2009). On lower slopes, longer fire-return intervals and lower severities were more common, particularly on northern and eastern aspects (Taylor & Skinner 1998; Skinner et al. 2009). Fire dynamics in the region changed following Euro-American settlement in the 1850s and then the widespread implementation of fire suppression practices in the mid- to late-20th century (Skinner et al. 2009; Steel et al. 2015; Taylor et al. 2016). Fires in the region are now larger and dominated primarily by mixed-severity fire regimes, which include irregular patches of low-, moderate-, and high-severity fire (Perry et al. 2011; Halofsky et al. 2011; Hessburg et al. 2016). These changes, in combination with intensive forest management, have significantly impacted bird populations by altering habitat structure and species composition across most forests and shrublands in the region and across the western U.S. (Huff et al. 2005; NABCI 2016).

While research is insufficient to make widely applicable conclusions about fire regimes in riparian areas, existing data suggest that historically they generally burned at frequencies and intensities similar to those of surrounding upland forests (Dwire & Kauffman 2003; Van de Water & North 2010, 2011). When instream flows are sufficient to maintain relative humidity and adequate soil moisture for riparian vegetation, riparian forests may resist burning, resulting in longer fire return intervals compared to adjacent upland stands (Dwire & Kauffman 2003; Skinner 2003; Olson & Agee 2005; Van de Water & North 2010; Bendix & Commons 2017). Fire may alter the subsequent species composition of riparian areas (e.g., by favoring colonization by exotic species; RHJV 2004). However, the availability of abundant instream flows in subsequent growing seasons favors rapid reestablishment of riparian-related plant species, often dominated by the same species present prior to burning (Kobziar & McBride 2006; Halofsky & Hibbs 2009).

Cultural burning practiced by tribes within the region for centuries has largely maintained short fire return intervals within riparian habitats, particularly at lower elevations (Fry & Stephens 2006; Skinner et al. 2009; Norgaard et al. 2016; Karuk Tribe 2019). Cultural burning practices generally benefit riparian-nesting birds by enhancing vegetation structure and composition in riparian areas (Hankins 2013; Norgaard et al. 2016; Karuk Tribe 2019). Specifically, frequent low- to moderate-intensity fire maintains the dominance of willow (*Salix* spp.) and cottonwood (*Populus* spp.), on which many riparian-nesting birds depend, while removing encroaching conifers that compete for water and light (Hankins 2013; Norgaard et al. 2016; Karuk Tribe

---

[4] All disturbance regimes presented were ranked as having a moderate or higher impact on this species group.

2019). Fires also create cavities and snags used by riparian birds for foraging and nesting (Kotliar et al. 2002; Hutto 2006; Norgaard et al. 2016).

Wildfire can reduce survival and reproductive success in riparian-nesting birds on an immediate basis, particularly when they occur right before or during the nesting season (Stephens & Alexander 2011; Norgaard et al. 2016). However, longer-term responses to habitat changes resulting from fire vary widely depending on species and fire severity (Huff et al. 2005; Fontaine et al. 2009; Stephens & Alexander 2011; Fontaine & Kennedy 2012). For instance, canopy nesting and foliage-gleaning species tend to decline as a result of habitat loss resulting from high-severity fire, while shrub- and snag-nesting species (e.g., White-crowned Sparrow, woodpeckers) increase in abundance (Fontaine & Kennedy 2012). Because individual species response to fire is so variable, it is likely that mixed-severity fire regimes play a role in maintaining high levels of bird diversity on a landscape scale by supporting forests in multiple stages of succession (Fontaine et al. 2009; Fontaine & Kennedy 2012; Stephens et al. 2015).

Regional Wildfire Trends

Historical & current trends:

- 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):
  - 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 proportion of high-severity fire were documented in northwestern CA forests from 1984–2008 (Miller et al. 2012; Parks et al. 2015; Law & Waring 2015; Keyser & Westerling 2017)
  - The relatively short period of record for fire severity data may obscure long-term trends

Projected future trends:

- 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)
  - 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)
  - 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. 2019)
- 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

Regional Wildfire Trends	
○ To date, there are no peer-reviewed studies on trends in northern California fire severity that include data from the last ten years	are likely to increase over the coming century (Westerling 2018) ○ 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 *(see text for citations)*
• *Immediate*: ○ Mortality and reduced reproductive success in riparian-nesting birds, particularly when fire occurs just before or during nesting season ○ Altered habitat suitability for riparian-nesting birds where complex riparian habitat is lost • *Short-term (~2-year)*: ○ Maintenance of early-successional habitat composition and structure utilized by many riparian-nesting species ○ Increased abundance of cavities and snags used for feeding and nesting • *Long-term*: ○ Increased bird diversity where mixed-severity fire regimes maintain landscape-scale heterogeneity

Disease

Riparian-nesting birds are sensitive to infectious diseases such as West Nile virus, which was introduced to California in 2003 (Reisen et al. 2004) and is spread through mosquito (*Culex* spp.) vectors (Rochlin et al. 2019). West Nile virus can cause significant mortality in birds, though most species do not show significant population declines as result of this disease (Kilpatrick & Wheeler 2019). This is likely due, in part, to high spatial and temporal variability in patterns of vector abundance and disease transmission (Kilpatrick & Wheeler 2019), which are impacted by variables such as vector density, avian migration, weather, land use, and topography, among others (Marra et al. 2004; Owen et al. 2006; Gibbs et al. 2006; Wang et al. 2011; Tam et al. 2014; Rochlin et al. 2019). The primary climatic variables associated with the prevalence of West Nile virus are temperature and precipitation (Epstein 2001; Gibbs et al. 2006; Wang et al. 2011; Tam et al. 2014). Specifically, mild winters followed by high spring temperatures and hot, dry summers favor the transmission of West Nile virus and many other mosquito-borne diseases (Epstein 2001; Johnson & Sukhdeo 2013). In the western U.S., low rainfall in the previous year has also been associated with increased incidence of West Nile virus in humans (Landesman et al. 2007). Over the coming century, warmer temperatures are expected to alter patterns of disease distribution by increasing the rate of vector survival during colder months, lengthening mosquito breeding season, and enhancing pathogen reproductive rates (Epstein 2001; Dohm et al. 2002; Marra et al. 2004; Tam et al. 2014).

Regional Disease Trends	
Historical & current trends: • Northwards expansion of West Nile virus in California since its detection in 2003 (Reisen et	*Projected future trends:* • Northwards range expansion as temperatures increase (Epstein 2001; Marra et al. 2004)

Regional Disease Trends	
al. 2004)	• Changes in patterns of disease prevalence and/or severity, depending on site conditions and limiting factors of the disease (Marra et al. 2004)
Summary of Potential Impacts on Species Group *(see text for citations)*	
• Increased avian mortality	

Dependency on habitat and/or other species

Regional experts evaluated riparian-nesting birds as having high dependency on sensitive habitats (high confidence in evaluation), high dependency on prey or forage species (high confidence), and high dependency on the availability of migratory stopover and winter habitats (high confidence).

Riparian-nesting birds are generally dependent on structurally-complex riparian habitats, with species occupying different niches depending on life history characteristics (Motroni 1984; RHJV 2004; Rockwell & Stephens 2018). Broadleaved habitat types dominated by willow, cottonwood, and alder (*Alnus* spp.) are critical foraging and nesting habitats for many riparian-nesting birds species, particularly where understory cover is dense (Motroni 1984; RHJV 2004; Rockwell & Stephens 2018). The presence of mature trees and snags are also important for Downy Woodpeckers and other cavity-nesting species (Motroni 1984; RHJV 2004). Many riparian-nesting birds are migratory, and these species are dependent on habitat availability and quality in their breeding habitat and wintering grounds, as well as at migratory stopover sites (Dolman & Sutherland 1995; Small-Lorenz et al. 2013). Habitat loss or degradation in any of these areas can contribute to population declines (Dolman & Sutherland 1995; NABCI 2016).

During migration and breeding, birds require protein-rich invertebrate prey, and many species have evolved migration timing to take advantage of peak insect abundance in riparian areas (Laymon 1984; Morrison et al. 1994). Shifts in the timing of insect development and emergence could cause a phenological mismatch for migratory riparian birds, potentially impacting survival and reproductive success (Bale et al. 2002; Both et al. 2006).

Sensitivity and current exposure to non-climate stressors

Regional experts evaluated riparian-nesting birds 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 (moderate confidence). Key non-climate stressors that affect riparian-nesting birds include invasive and other problematic species, agriculture, pollution, livestock grazing, and dams and water diversions.[5]

---

[5] 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 energy production/mining and dams/water diversions.

Invasive and other problematic species

Brown-headed Cowbirds (*Molothrus ater*) are brood parasites that lay their eggs in the nests of other songbirds, including many riparian-nesting species such as the MacGillivray's Warbler, Warbling Vireo, Blue Grosbeak, Yellow Warbler, Yellow-breasted Chat, Wilson's Warbler, Willow Flycatcher, and Song Sparrow (Tewksbury et al. 2002; RHJV 2004). Many Brown-headed Cowbird host species are long-distance migrants common in fragmented landscapes (Tewksbury et al. 2002), and reduced reproductive success as a result of brood parasitism has contributed to population declines in many of these species (RHJV 2004). Some species, such as Yellow Warblers and Blue Grosbeaks, are able to raise their own young in addition to Brown-headed Cowbird nestlings (Tewksbury et al. 2002; RHJV 2004). However, others (e.g., Warbling Vireo, MacGillivray's Warbler) often experience complete brood loss when parasitized (Tewksbury et al. 2002).

Harmful invasive plant species that colonize northern California riparian associations include fig (*Ficus carica*), tamarisk (*Tamarix* spp.), and giant reed (*Arundo donax*; Vuln. Assessment Reviewer, pers. comm., 2018). Following establishment, these species can reduce nesting and foraging habitat quality for birds by altering the structure and composition of riparian vegetation (Herrera & Dudley 2003; RHJV 2004). Many areas dominated by harmful invasive plants experience reduced structural complexity and lower understory plant density and diversity (Herrera & Dudley 2003). Habitat structural alterations may reduce nesting habitat suitability for riparian-nesting birds, many of which prefer nesting in willow, cottonwood, and other native hardwood species (Ellis 1995; Lynn et al. 1998; RHJV 2004). Studies have also demonstrated that areas dominated by giant reed have lower invertebrate diversity and abundance compared to patches dominated by native willows, reducing the availability of insect prey for riparian-nesting birds (Herrera & Dudley 2003).

Although riparian areas are particularly suitable for colonization by non-native plants because of available moisture, many non-native plants do not significantly alter either avian species richness or habitat structure (Stohlgren et al. 2006; Stohlgren 2011) and some can provide benefits to riparian birds (e.g., cover; RHJV 2004; Rockwell & Stephens 2018). For instance, Himalayan blackberry (*Rubus armeniacus*) is now considered naturalized and ineradicable in California riparian areas (Vuln. Assessment Reviewer, pers. comm., 2019), where it is preferentially used for nesting by Yellow Warblers (Rockwell & Stephens 2018) and Tricolored Blackbird (*Agelaius tricolor*; (Meese & Simmons 2010; Meehan et al. 2019). Himalayan blackberry is also used as a food source for many wintering bird species (Motroni 1984; Dybala et al. 2015).

Agriculture and pollution

Land use conversion to agriculture is particularly high in riparian and floodplain ecosystems, especially on privately-owned lands at lower elevations, and results in significant habitat losses for riparian-nesting birds (Tewksbury et al. 2002; RHJV 2004). Remnant riparian habitats are often highly fragmented, which exposes nests to higher rates of predation and parasitism (Tewksbury et al. 2002; RHJV 2004). Pesticides used in agricultural areas also impact riparian-nesting birds by reducing invertebrate prey availability and degrading foraging habitat (RHJV 2004). Mercury contamination of wetlands is another concern for riparian-nesting birds (Vuln. Assessment Reviewer, pers. comm., 2019), as even sub-lethal levels of mercury can contribute to physical, neurological, developmental, reproductive, and behavioral problems (Wolfe et al. 1998; Scheuhammer & Sandheinrich 2007; Eagles-Smith et al. 2016).

Livestock grazing

Riparian habitats associated with streams and montane wet meadows are often used for livestock grazing, particularly on private lands, because they provide shade and a source of water for cattle (Campbell & Allen-Diaz 1997; Tewksbury et al. 2002; RHJV 2004). However, livestock can directly disturb riparian birds during the breeding season by knocking over nests in willow thickets and other shrubby areas and/or trampling the eggs of ground-nesting birds such as the Lincoln’s sparrow (Sanders & Flett 1989; RHJV 2004). Grazing also impacts riparian-nesting birds indirectly through vegetation removal and soil compaction, which results in changes in riparian habitat composition and structure and associated declines in the quality and availability of nesting and foraging habitat (Sanders & Flett 1989; Campbell & Allen-Diaz 1997; RHJV 2004). Grazed areas are associated with reduced avian abundance and altered community composition, with impacts varying depending on grazing intensity (Tewksbury et al. 2002; Alexander et al. 2008). The most significant impacts are often noted among long-distance migratory, shrub- and ground-nesting, and/or foliage-gleaning species (Sanders & Flett 1989; Tewksbury et al. 2002; Alexander et al. 2008).

Adaptive Capacity

Riparian-nesting birds were evaluated by regional experts as having moderate-high overall adaptive capacity (high confidence in evaluation).

Species group extent, integrity, connectivity, and dispersal ability

Regional experts evaluated riparian-nesting birds as having a high geographic extent (high confidence in evaluation), low-moderate overall health and functional integrity (moderate confidence), and a moderate-high degree of connectivity between populations (moderate confidence). Regional experts evaluated riparian-nesting birds as having a high dispersal ability (high confidence in evaluation), and no barriers to dispersal were identified.

Over 20,000 hectares (49,400 acres) of habitat supports riparian-nesting birds in northern California, with the majority of that area found in montane riparian zones and wet meadows (RHJV 2004). However, 85% of the riparian habitat along northern coastal streams has likely been lost over the past 150 years, and continued habitat loss and fragmentation threaten much of the remaining area, especially at lower elevations (RHJV 2004). Many riparian-nesting species are currently in decline and/or have already experienced significant reductions in their breeding range, including the Yellow Warbler, Yellow-breasted Chat, Wilson’s Warbler, Warbling Vireo, Willow Flycatcher, and Yellow-billed Cuckoo, among others (RHJV 2004; NABCI 2016). Even on federal lands in northwestern California covered by the Aquatic Conservation Strategy of the

Northwest Forest Plan, riparian management is focused on maintaining habitat values for aquatic species (Reeves et al. 2018) but not for birds (Vuln. Assessment Reviewer, pers. comm., 2019).

Habitat loss and fragmentation are among the primary drivers of declining populations in riparian-nesting birds (RHJV 2004), with species-specific impacts depending on patch size, heterogeneity, and spatial configuration, as well as the condition of the surrounding landscape (Tewksbury et al. 2002; Stephens et al. 2003). Even though birds are highly mobile and can travel long distances to reach suitable habitat and food resources (Dolman & Sutherland 1995), smaller and/or more isolated patches are likely to limit dispersal and gene flow across the landscape (Bélisle & St. Clair 2001; Stephens et al. 2003; RHJV 2004). This may be due, in part, to increased abundance of Brown-headed Cowbirds and predators in highly fragmented landscapes (Tewksbury et al. 2002; Stephens et al. 2003; RHJV 2004).

Intraspecific/life history diversity

Regional experts evaluated riparian-nesting birds as having moderate life history diversity (low confidence in evaluation), moderate genetic diversity (low confidence), low-moderate behavioral plasticity (low confidence), and low phenotypic plasticity (low confidence).

Riparian-nesting birds in northern California are a diverse group, representing a wide array of families, foraging guilds, and life history strategies (Motroni 1984; RHJV 2004; DiGaudio et al. 2015). For instance, migration distance is highly variable, with some species wintering in Central or South America and others residing in northern California year-round (Rodewald 2015; NABCI 2016). However, more than half the species studied in the western United States include populations that are "altitudinal" or short-distance migrants within the region, including species in virtually every bird family in California (Boyle 2017). Riparian plant associations have been shown to provide essential habitat for distinctly different species groups in the winter and the nesting season, as well as for residents that occupy riparian areas throughout the annual cycle (Motroni 1984; Dybala et al. 2015).

In general, species with higher levels of genetic variation, phenotypic diversity, and/or behavioral plasticity are more likely to shift migration timing and/or route in response to changing climate conditions and habitat loss (Dolman & Sutherland 1995; Ackerman et al. 2011; Gilroy et al. 2016; Mayor et al. 2017; Bay et al. 2018). Several studies suggest greater potential for greater phenological mismatches in long-distance migrants (Pulido & Widmer 2005; Gilroy et al. 2016; Mayor et al. 2017). However, some Neotropical migrants show evidence of behavioral plasticity in response to environmental conditions. For instance, Black-headed Grosbeaks arrive on their breeding grounds earlier during El Niño years (Ackerman et al. 2011). Still other species have demonstrated behavioral flexibility in nest-site preferences (e.g., Song Sparrow, Blue Grosbeak; Chase 2002; RHJV 2004), and seasonal foraging strategy (Motroni 1984).

Resistance and recovery

Regional experts evaluated riparian-nesting birds as having low-moderate resistance to climate stressors and natural disturbance regimes (high confidence in evaluation). Recovery potential was evaluated as moderate (high confidence) for the species group as a whole. However, the response of individual species is highly varied.

The high mobility of riparian-nesting birds confers resistance to changing conditions by allowing individuals to avoid disturbances, seek out higher-quality habitat, shift their range, and/or change their migration strategy (Dolman & Sutherland 1995; Mayor et al. 2017; Porzig et al. 2018). For migratory species, however, dependence on habitat availability in disparate locations increases the risk that one or more sites will be affected by climate and/or non-climate stressors (Dolman & Sutherland 1995; Small-Lorenz et al. 2013). Shifts in the timing of migration and breeding may also be unable to keep up with rapid shifts in plant and insect phenology (Both et al. 2006; Leech & Crick 2007; Mayor et al. 2017). By contrast, population recovery is largely dependent on reproductive rates (Vuln. Assessment Workshop, pers. comm., 2017). Thus, species that can re-nest following the loss of eggs and chicks and/or those that produce multiple broods in a single year may be less vulnerable to disturbance and extreme climatic conditions (Halupka & Halupka 2017).

Management potential

Public and societal value

Regional experts evaluated riparian-nesting birds as having moderate-high public and societal value (high confidence in evaluation).

Some riparian-nesting birds receive some regulatory protection through federal- or state-listings, including the Willow Flycatcher and Yellow-billed Cuckoo (RHJV 2004). Many riparian bird species are also California Department of Fish and Wildlife species of management concern, an administrative designation that encourages conservation of declining species before they meet California Endangered Species Act criteria (Shuford & Gardali 2008).

Indirectly, the Aquatic Conservation Strategy of the Northwest Forest Plan increases support for riparian-nesting birds by explicitly establishing planning objectives for riparian habitat areas in northwestern California National Forests (Reeves et al. 2018).

Management capacity and ability to alleviate impacts[6]

Regional experts evaluated the potential for reducing climate impacts on riparian-nesting birds through management as moderate-high (high confidence in evaluation).

The scientific literature identifies several management approaches that are likely to increase the resilience of riparian-nesting birds to changes in climate stressors and disturbance regimes

---

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

by increasing habitat availability and connectivity (Dolman & Sutherland 1995; DiGaudio et al. 2015; Dybala et al. 2018; Rockwell & Stephens 2018), reducing brood parasitism (RHJV 2004), and protecting potential climate refugia (Seavy et al. 2009; Veloz et al. 2015; Alexander et al. 2017). To be effective, management activities account for multiple factors, including nest site availability, food resources, microclimate conditions, predation risk, land use in adjacent upland habitats, and connectivity (Stephens et al. 2003; RHJV 2004; Seavy et al. 2009). Protecting and restoring riparian areas, in particular, has been demonstrated as an effective way to increase habitat availability, enhance connectivity, and create climate refugia (Gardali et al. 2006a; Seavy et al. 2009; DiGaudio et al. 2015; Dybala et al. 2018; Rockwell & Stephens 2018). Tools such as the Conservation Ranking Map within the Pacific Northwest Climate Change Avian Vulnerability tool can assist managers in identifying areas where riparian conservation work should be prioritized (Veloz et al. 2013, 2015; Alexander et al. 2017).[7]

Riparian restoration often focuses on restoring natural hydrological processes through dam removal or the management of dam releases that try to imitate natural flooding cycles (RHJV 2004; Rockwell & Stephens 2018), followed by planting and/or invasive species removal to increase native shrub and canopy cover, plant diversity, and vertical heterogeneity (Gardali et al. 2006b; DiGaudio et al. 2015; Dybala et al. 2018; Rockwell & Stephens 2018). Other strategies that may ameliorate the impacts of habitat loss and other anthropogenic stressors for riparian-nesting songbirds include management of foraging areas in adjacent upland habitats, reducing the abundance of Brown-headed Cowbirds (Sanders & Flett 1989; RHJV 2004), and eliminating or delaying grazing in riparian areas until after the breeding season (Sanders & Flett 1989). Restoring natural disturbance regimes within riparian forests and adjacent upland habitats through prescribed fire (see Table 1) or floodplain reconnection is also likely to increase the resilience of habitats utilized by this species group (Norgaard et al. 2016; Alexander et al. 2017; Karuk Tribe 2019).

Table 1. Effects of prescribed burning on riparian-nesting birds 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
• Takes avian life cycles into account and avoids burning while birds are most vulnerable to mortality from fire	• Increases habitat suitability following disturbances that allow willow, cottonwood, and other species to thrive	• Maintains habitat suitability by promoting early-seral vegetation in riparian areas
Source(s): Norgaard et al. 2016; Karuk Tribe 2019		

Ecosystem services

Riparian-nesting birds provides a variety of ecosystem services, including:

---

[7] The Climate Change Avian Vulnerability tool is available from https://www.avianknowledgenorthwest.net/dsts/interactive-maps/1-pnw-models.

- Provisioning of genetic resources;
- Regulation of pests and disease (Kross et al. 2016);
- Cultural/tribal uses for spiritual/religious purposes, educational values, aesthetic values, sense of place, cultural heritage, inspiration, and recreation (RHJV 2004; Vuln. Assessment Workshop, pers. comm., 2017).

Recommended Citation

Hilberg LE, Reynier WA, Kershner JM. 2019. Riparian-Nesting Birds: Northern California Climate Change Vulnerability Assessment Synthesis. Version 1.0. EcoAdapt, Bainbridge Island, WA.

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

Literature Cited

Abatzoglou JT, Kolden CA. 2013. Relationships between climate and macroscale area burned in the western United States. International Journal of Wildland Fire **22**:1003–1020.

Ackerman JT, Herzog MP, Salas L, Gardali T, Ballard G, Loughman D, Yarris G, Eadie JM. 2011. Avian breeding demographic response to climate change: a multi-species and multi-landscape approach to synthesizing risk factors. Summary Report. U.S. Geological Survey, Western Ecological Research Center, Davis, CA; PRBO Conservation Science, Petaluma, CA; California Waterfowl Association, Sacramento, CA; University of California, Davis, CA.

Albright TP, Mutiibwa D, Gerson AR, Smith EK, Talbot WA, O'Neill JJ, McKechnie AE, Wolf BO. 2017. Mapping evaporative water loss in desert passerines reveals an expanding threat of lethal dehydration. Proceedings of the National Academy of Sciences **114**:2283–2288.

Albright TP, Pidgeon AM, Rittenhouse CD, Clayton MK, Flather CH, Culbert PD, Wardlow BD, Radeloff VC. 2010. Effects of drought on avian community structure. Global Change Biology **16**:2158–2170.

Alexander JD, Stephens JL, Seavy NE. 2008. Livestock utilization and bird community composition in mixed-conifer forest and oak woodland in southern Oregon. Northwest Science **82**:7–17.

Alexander JD, Stephens JL, Veloz S, Salas L, Rousseau JS, Ralph CJ, Sarr DA. 2017. Using regional bird density distribution models to evaluate protected area networks and inform conservation planning. Ecosphere **8**:e01799.

Allen CD, Breshears DD, McDowell NG. 2015. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere **6**:1–55.

Bale JS et al. 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology **8**:1–16.

Bay RA, Harrigan RJ, Underwood VL, Gibbs HL, Smith TB, Ruegg K. 2018. Genomic signals of selection predict climate-driven population declines in a migratory bird. Science **359**:83–86.

Bélisle M, St. Clair CC. 2001. Cumulative effects of barriers on the movements of forest birds. Conservation Ecology **5**:9.

Bendix J, Commons M. 2017. Distribution and frequency of wildfire in California riparian ecosystems. Environmental Research Letters **12**:075008.

Bolger DT, Patten MA, Bostock DC. 2005. Avian reproductive failure in response to an extreme climatic event. Oecologia **142**:398–406.

Both C, Bouwhuis S, Lessells CM, Visser ME. 2006. Climate change and population declines in a long-distance migratory bird. Nature **441**:81–83.

Boyle WA. 2017. Altitudinal bird migration in North America. The Auk **134**:443–465.

Campbell CG, Allen-Diaz B. 1997. Livestock grazing and riparian habitat water quality: an examination of oak woodland springs in the Sierra Foothills of California. Pages 339–346 in N. H. Pillsbury, J. Verner, and W. D. Tietje, editors. Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues; 19–22 March 1996; San Luis Obispo, CA. Gen. Tech. Rep. PSW-GTR-160. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, CA.

Capon SJ et al. 2013. Riparian ecosystems in the 21st century: hotspots for climate change adaptation? Ecosystems **16**:359–381.

Chase MK. 2002. Nest site selection and nest success in a song sparrow population: the significance of spatial variation. The Condor: Ornithological Applications **104**:103–116.

Chase MK, Nur N, Geupel GR. 2005. Effects of weather and population density on reproductive success and population dynamics in a song sparrow (*Melospiza melodia*) population: a long-term study. The Auk: Ornithological Advances **122**:571–592.

Cook BI, Ault TR, Smerdon JE. 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances **1**:e1400082.

Diffenbaugh NS, Swain DL, Touma D. 2015. Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences **112**:3931–3936.

DiGaudio RT, Kreitinger KE, Hickey CM, Seavy NE, Gardali T. 2015. Private lands habitat programs benefit California's native birds. California Agriculture **69**:210–220.

Dohm DJ, O'Guinn ML, Turell MJ. 2002. Effect of environmental temperature on the ability of *Culex pipiens* (Diptera: Culicidae) to transmit West Nile virus. Journal of Medical Entomology **39**:221–225.

Dolman PM, Sutherland WJ. 1995. The response of bird populations to habitat loss. Ibis **137**:S38–S46.

Dwire KA, Kauffman JB. 2003. Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management **178**:61–74.

Dybala KE, Eadie JM, Gardali T, Seavy NE, Herzog MP. 2013. Projecting demographic responses to climate change: adult and juvenile survival respond differently to direct and indirect effects of weather in a passerine population. Global Change Biology **19**:2688–2697.

Dybala KE, Engilis A, Trochet JA, Engilis IE, Truan ML. 2018. Evaluating riparian restoration success: long-term responses of the breeding bird community in California's Lower Putah Creek watershed. Ecological Restoration **36**:76–85.

Dybala KE, Truan ML, Engilis A. 2015. Summer vs. winter: examining the temporal distribution of avian biodiversity to inform conservation. The Condor: Ornithological Applications **117**:560–576.

Eagles-Smith CA et al. 2016. Mercury in western North America: a synthesis of environmental contamination, fluxes, bioaccumulation, and risk to fish and wildlife. Science of The Total Environment **568**:1213–1226.

Ellis LM. 1995. Bird use of saltcedar and cottonwood vegetation in the Middle Rio Grande Valley of New Mexico, U.S.A. Journal of Arid Environments **30**:339–349.

Epstein PR. 2001. West Nile virus and the climate. Journal of Urban Health **78**:367–371.

Ferger SW, Schleuning M, Hemp A, Howell KM, Böhning-Gaese K. 2014. Food resources and vegetation structure mediate climatic effects on species richness of birds. Global Ecology and Biogeography **23**:541–549.

Fettig CJ, Reid ML, Bentz BJ, Sevanto S, Spittlehouse DL, Wang T. 2013. Changing climates, changing forests: a western North American perspective. Journal of Forestry **111**:214–228.

Flint LE, Flint AL. 2014. California Basin Characterization Model: a dataset of historical and future hydrologic response to climate change (Ver. 1.1, May 2017). U.S. Geological Survey Data Release. Available from https://doi.org/10.5066/F76T0JPB.

Flint LE, Flint AL, Thorne JH, Boynton R. 2013. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. Ecological Processes **2**:25.

Fontaine JB, Donato DC, Robinson WD, Law BE, Kauffman JB. 2009. Bird communities following high-severity fire: response to single and repeat fires in a mixed-evergreen forest, Oregon, USA. Forest Ecology and Management **257**:1496–1504.

Fontaine JB, Kennedy PL. 2012. Meta-analysis of avian and small-mammal response to fire severity and fire surrogate treatments in U.S. fire-prone forests. Ecological Applications **22**:1547–1561.

Fry DL, Stephens SL. 2006. Influence of humans and climate on the fire history of a ponderosa pine-mixed conifer forest in the southeastern Klamath Mountains, California. Forest Ecology and Management **223**:428–438.

Furnas BJ, McGrann MC. 2018. Using occupancy modeling to monitor dates of peak vocal activity for passerines in California. The Condor: Ornithological Applications **120**:188–200.

Gardali T, Holmes AL, Small SL, Nur N, Geupel GR, Golet GH. 2006a. Abundance patterns of landbirds in restored and remnant riparian forests on the Sacramento River, California, U.S.A. Restoration Ecology **14**:391–403.

Gardali T, Holmes AL, Small SL, Nur N, Geupel GR, Golet GH. 2006b. Abundance patterns of landbirds in restored and remnant riparian forests on the Sacramento River, California, U.S.A. Restoration Ecology **14**:391–403.

Gardali T, Seavy NE, DiGaudio RT, Comrack LA. 2012. A climate change vulnerability assessment of California's at-risk birds. PLoS ONE **7**:e29507.

Gershunov A, Guirguis K. 2012. California heat waves in the present and future. Geophysical Research Letters **39**:L18710.

Gibbs SEJ, Wimberly MC, Madden M, Masour J, Yabsley MJ, Stallknecht DE. 2006. Factors affecting the geographic distribution of West Nile virus in Georgia, USA: 2002–2004. Vector-Borne and Zoonotic Diseases **6**:73–82.

Gilroy JJ, Gill JA, Butchart SHM, Jones VR, Franco AMA. 2016. Migratory diversity predicts population declines in birds. Ecology Letters **19**:308–317.

Glenn EP, Nagler PL. 2005. Comparative ecophysiology of *Tamarix ramosissima* and native trees in western U.S. riparian zones. Journal of Arid Environments **61**:419–446.

Gordo O. 2007. Why are bird migration dates shifting? A review of weather and climate effects on avian migratory phenology. Climate Research **35**:37–58.

Griffin D, Anchukaitis KJ. 2014. How unusual is the 2012–2014 California drought? Geophysical Research Letters **41**:9017–9023.

Halofsky JE, Hibbs DE. 2009. Controls on early post-fire woody plant colonization in riparian areas. Forest Ecology and Management **258**:1350–1358.

Halupka L, Halupka K. 2017. The effect of climate change on the duration of avian breeding seasons: a meta-analysis. Proceedings of the Royal Society B: Biological Sciences **284**. Available from https://doi.org/10.1098/rspb.2017.1710 (accessed December 5, 2018).

Hankins DL. 2013. The effects of indigenous prescribed fire on riparian vegetation in central California. Ecological Processes **2**:24.

Herrera AM, Dudley TL. 2003. Reduction of riparian arthropod abundance and diversity as a consequence of giant reed (*Arundo donax*) invasion. Biological Invasions **5**:167–177.

Huff MH, Seavy NE, Alexander JD, Ralph CJ. 2005. Fire and birds in maritime Pacific Northwest. Studies in Avian Biology **30**:46–62.

Hutto RL. 2006. Toward meaningful snag-management guidelines for postfire salvage logging in North American conifer forests. Conservation Biology **20**:984–993.

Jiguet F, Devictor V, Ottvall R, Turnhout CV, Jeugd HV der, Lindström Å. 2010. Bird population trends are linearly affected by climate change along species thermal ranges. Proceedings of the Royal Society of London B: Biological Sciences **277**. Available from https://doi.org/10.1098/rspb.2010.0796 (accessed November 21, 2017).

Jiguet F, Julliard R, Thomas CD, Dehorter O, Newson SE, Couvet D. 2006. Thermal range predicts bird population resilience to extreme high temperatures. Ecology Letters **9**:1321–1330.

Johnson BJ, Sukhdeo MVK. 2013. Drought-induced amplification of local and regional West Nile virus infection rates in New Jersey. Journal of Medical Entomology **50**:195–204.

Karuk Tribe. 2019. Karuk Climate Adaptation Plan. Karuk Tribe, Orleans, CA. Available from https://karuktribeclimatechangeprojects.com/climate-adaptation-plan/ (accessed August 22, 2019).

Keyser A, Westerling AL. 2017. Climate drives inter-annual variability in probability of high severity fire occurrence in the western United States. Environmental Research Letters **12**:065003.

Kilpatrick AM, Wheeler SS. 2019. Impact of West Nile virus on bird populations: limited lasting effects, evidence for recovery, and gaps in our understanding of impacts on ecosystems. Journal of Medical Entomology **56**:1491–1497.

Kobziar LN, McBride JR. 2006. Wildfire burn patterns and riparian vegetation response along two northern Sierra Nevada streams. Forest Ecology and Management **222**:254–265.

Kotliar NB, Hejl SJ, Hutto RL, Saab V, Melcher C, McFadzen ME. 2002. Effects of fire and post-fire salvage logging on avian communities in conifer-dominated forests of the western United States. Studies in Avian Biology **25**:49–64.

Kross SM, Kelsey TR, McColl CJ, Townsend JM. 2016. Field-scale habitat complexity enhances avian conservation and avian-mediated pest-control services in an intensive agricultural crop. Agriculture, Ecosystems & Environment **225**:140–149.

Landesman WJ, Allan BF, Langerhans RB, Knight TM, Chase JM. 2007. Inter-annual associations between precipitation and human incidence of West Nile virus in the United States. Vector-Borne and Zoonotic Diseases **7**:337–343.

Langham GM, Schuetz JG, Distler T, Soykan CU, Wilsey C. 2015. Conservation status of North American birds in the face of future climate change. PLoS ONE **10**:e0135350.

Law BE, Waring RH. 2015. Carbon implications of current and future effects of drought, fire and management on Pacific Northwest forests. Forest Ecology and Management **355**:4–14.

Laymon SA. 1984. Riparian bird community structure and dynamics: Dog Island, Red Bluff, California. Pages 587–597 in R. E. Warner and K. M. Hendrix, editors. California riparian systems: ecology, conservation, and productive management. University of California Press, Berkeley, CA.

Leech DI, Crick HQP. 2007. Influence of climate change on the abundance, distribution and phenology of woodland bird species in temperate regions. Ibis **149**:128–145.

Littell JS, McKenzie D, Peterson DL, Westerling AL. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications **19**:1003–1021.

Lynn S, Morrison ML, Kuenzi AJ, Neale JCC, Sacks BN, Hamlin R, Hall LS. 1998. Bird use of riparian vegetation along the Truckee River, California and Nevada. The Great Basin Naturalist **58**:328–343.

Mann ML, Batllori E, Moritz MA, Waller EK, Berck P, Flint AL, Flint LE, Dolfi E. 2016. Incorporating anthropogenic influences into fire probability models: effects of human activity and climate change on fire activity in California. PLoS ONE **11**:e0153589.

Marra PP, Griffing S, Caffrey C, Kilpatrick MA, McLean R, Brand C, Saito E, Dupuis AP, Kramer L, Novak R. 2004. West Nile virus and wildlife. BioScience **54**:393–402.

Mayor SJ, Guralnick RP, Tingley MW, Otegui J, Withey JC, Elmendorf SC, Andrew ME, Leyk S, Pearse IS, Schneider DC. 2017. Increasing phenological asynchrony between spring green-up and arrival of migratory birds. Scientific Reports **7**:1902.

McGrann MC, Furnas BJ. 2016. Divergent species richness and vocal behavior in avian migratory guilds along an elevational gradient. Ecosphere **7**:e01419.

McKenzie D, Littell JS. 2017. Climate change and the eco-hydrology of fire: will area burned increase in a warming western USA? Ecological Applications **27**:26–36.

Meehan TD, Arthur S, Michel NL, Wilsey CB, Langham GM. 2019. Trends in tricolored blackbird colony size: 2008 through 2017. The Journal of Wildlife Management **83**:1237–1243.

Meese RJ, Simmons SB. 2010. Safe and effective methods for trapping and color banding tricolored blackbirds in the Central Valley of California. California Fish and Game **96**:23–35.

Millar CI, Stephenson NL. 2015. Temperate forest health in an era of emerging megadisturbance. Science **349**:823–826.

Miller JD, Skinner CN, Safford HD, Knapp EE, Ramirez CM. 2012. Trends and causes of severity, size, and number of fires in northwestern California, USA. Ecological Applications **22**:184–203.

Morrison ML, Tennant T, Scott TA. 1994. Laying the foundation for a comprehensive program of restoration for wildlife habitat in a riparian floodplain. Environmental Management **18**:939–955.

Motroni RS. 1984. Seasonal variation of bird numbers in a riparian forest, Sacramento Valley, California. Pages 578–586 in R. E. Warner and K. M. Hendrix, editors. California riparian systems: ecology, conservation, and productive management. University of California Press, Berkeley, CA.

NABCI. 2016. The state of North America's birds 2016. KBO-2016-0007. North American Bird Conservation Initiative. Environment and Climate Change Canada, Ottawa, Canada. Available from http://www.stateofthebirds.org/2016 (accessed April 9, 2019).

National Audubon Society. 2013. Developing a management model of the effects of future climate change on species: A tool for the Landscape Conservation Cooperatives. Unpublished report prepared for the U.S. Fish and Wildlife Service. Available from http://climate.audubon.org/sites/default/files/Audubon-USFWS%20LCC%20Climate%20Change%20FINAL%201.1.pdf (accessed April 15, 2016).

National Research Council. 2002. Riparian areas: functions and strategies for management. National Academies Press, Washington, D.C.

Norgaard KM, Vinyeta K, Hillman L, Tripp B, Lake F. 2016. Karuk Tribe climate vulnerability assessment: assessing vulnerabilities from the increased frequency of high severity fire. Karuk Tribe Department of Natural Resources, Orleans, CA.

Olson DL, Agee JK. 2005. Historical fires in Douglas-fir dominated riparian forests of the southern Cascades, Oregon. Fire Ecology **1**:50–75.

Owen J, Moore F, Panella N, Edwards E, Bru R, Hughes M, Komar N. 2006. Migrating birds as dispersal vehicles for West Nile virus. EcoHealth **3**:79.

Parks SA, Miller C, Abatzoglou JT, Holsinger LM, Parisien M-A, Dobrowski SZ. 2016. How will climate change affect wildland fire severity in the western US? Environmental Research Letters **11**:035002.

Parks SA, Miller C, Parisien M-A, Holsinger LM, Dobrowski SZ, Abatzoglou J. 2015. Wildland fire deficit and surplus in the western United States, 1984–2012. Ecosphere **6**:1–13.

Perry DA, Hessburg PF, Skinner CN, Spies TA, Stephens SL, Taylor AH, Franklin JF, McComb B, Riegel G. 2011. The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California. Forest Ecology and Management **262**:703–717.

Perry LG, Andersen DC, Reynolds LV, Nelson SM, Shafroth PB. 2012. Vulnerability of riparian ecosystems to elevated CO_2 and climate change in arid and semiarid western North America. Global Change Biology **18**:821–842.

Pierce DW, Kalansky JF, Cayan DR. 2018. Climate, drought, and sea level rise scenarios for the Fourth California Climate Assessment. California's Fourth Climate Change Assessment. Publication Number: CNRA-CEC-2018-006. California Energy Commission, Sacramento, CA.

Porzig EL, Seavy NE, Eadie JM, Gardali T, Humple DL, Geupel GR. 2018. There goes the neighborhood: White-crowned Sparrow nest site selection and reproductive success as local density declines. The Condor: Ornithological Applications **120**:234–244.

Princé K, Zuckerberg B. 2015. Climate change in our backyards: the reshuffling of North America's winter bird communities. Global Change Biology **21**:572–585.

Pulido F, Widmer M. 2005. Are long-distance migrants constrained in their evolutionary response to environmental change? Causes of variation in the timing of autumn migration in a blackcap (*S. atricapilla*) and two garden warbler (*Sylvia borin*) populations. Annals of the New York Academy of Sciences **1046**:228–241.

Rapacciuolo G et al. 2014. Beyond a warming fingerprint: individualistic biogeographic responses to heterogeneous climate change in California. Global Change Biology **20**:2841–2855.

Reeves GH, Olson DH, Wondzell SM, Bisson PA, Gordon S, Miller SA, Long JW, Furniss MJ. 2018. Chapter 7: The Aquatic Conservation Strategy of the Northwest Forest Plan - a review of the relevant science after 23 years. Pages 461–624 in T. A. Spies, P. A. Stine, R. Gravenmier, J. W. Long, and M. J. Reilly, editors. Synthesis of science to inform land management within the Northwest Forest Plan area. Gen. Tech. Rep. PNW-GTR-966. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Reisen W, Lothrop H, Chiles R, Madon M, Cossen C, Woods L, Husted S, Kramer V, Edman J. 2004. West Nile virus in California. Emerging Infectious Diseases **10**:1369–1378.

RHJV. 2004. The Riparian Bird Conservation Plan: a strategy for reversing the decline of riparian associated birds in California. Version 2.0. Riparian Habitat Joint Venture, California Partners in Flight, Sacramento, CA. Available from http://www.prbo.org/calpif/pdfs/riparian.v-2.pdf (accessed November 21, 2017).

Rochlin I, Faraji A, Healy K, Andreadis TG. 2019. West Nile virus mosquito vectors in North America. Journal of Medical Entomology **56**:1475–1490.

Rockwell SM, Stephens JL. 2018. Habitat selection of riparian birds at restoration sites along the Trinity River, California. Restoration Ecology **26**:767–777.

Rodewald PG, editor. 2015. The Birds of North America. Cornell Lab of Ornithology, Ithaca, NY. Available from https://birdsna.org (accessed December 10, 2018).

Safford HD, Van de Water KM. 2014. Using fire return interval departure (FRID) analysis to map spatial and temporal changes in fire frequency on national forest lands in California. Res. Pap. PSW-RP-266. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Sanders SD, Flett MA. 1989. Montane riparian habitat and Willow Flycatchers: threats to a sensitive environment and species. Pages 262–266 in D. L. Abell, editor. Proceedings of the California Riparian Systems Conference: protection, management, and restoration for the 1990s; 1988 September 22-24; Davis, CA. Gen. Tech. Rep. PSW-GTR-110. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Scheuhammer AM, Sandheinrich MB. 2007. Recent advances in the toxicology of methylmercury in wildlife. Ecotoxicology **17**:67–68.

Seavy NE, Gardali T, Golet GH, Griggs FT, Howell CA, Kelsey R, Small SL, Viers JH, Weigand JF. 2009. Why climate change makes riparian restoration more important than ever: recommendations for practice and research. Ecological Restoration **27**:330–338.

Shuford WD, Gardali T. 2008. California Bird Species of Special Concern: a ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California.

Studies of Western Birds 1. Western Field Ornithologists, Camarillo, CA, and California Department of Fish and Game, Sacramento, CA.

Skinner C, Abbott C, Fry D, Stephens S, Taylor A, Trouet V. 2009. Human and climatic influences on fire occurrence in California's North Coast range. Fire Ecology **5**:76–99.

Skinner CN. 2003. A tree-ring based fire history of riparian reserves in the Klamath Mountains. Pages 116–119 in P. M. Faber, editor. California riparian systems: processes and floodplains management, ecology, and restoration. Riparian habitat and floodplains conference proceedings. March 12-15, 2001, Sacramento, CA. Riparian Habitat Joint Venture, Sacramento, CA.

Small-Lorenz S, Culp LA, Ryder TB, Will TC, Marra PP. 2013. A blind spot in climate change vulnerability assessments. Nature Climate Change **3**:91–93.

Steel ZL, Safford HD, Viers JH. 2015. The fire frequency-severity relationship and the legacy of fire suppression in California forests. Ecosphere **6**:1–23.

Stephens JL, Alexander JD. 2011. Effects of fuel reduction on bird density and reproductive success in riparian areas of mixed-conifer forest in southwest Oregon. Forest Ecology and Management **261**:43–49.

Stephens JL, Ausprey IJ, Seavy NE, Alexander JD. 2015. Fire severity affects mixed broadleaf–conifer forest bird communities: results for 9 years following fire. The Condor: Ornithological Applications **117**:430–446.

Stephens SE, Koons DN, Rotella JJ, Willey DW. 2003. Effects of habitat fragmentation on avian nesting success: a review of the evidence at multiple spatial scales. Biological Conservation **115**:101–110.

Stephens SL, Martin RE, Clinton NE. 2007. Prehistoric fire area and emissions from California's forests, woodlands, shrublands, and grasslands. Forest Ecology and Management **251**:205–216.

Stohlgren TJ. 2011. Landscape patterns of plant invasions. Pages 422–425 in D. Simberloff and M. Rejmanek, editors. Encyclopedia of biological invasions. University of California Press, Davis, CA.

Stohlgren TJ, Barnett D, Flather C, Fuller P, Peterjohn B, Kartesz J, Master LL. 2006. Species richness and patterns of invasion in plants, birds, and fishes in the United States. Biological Invasions **8**:427–447.

Stralberg D, Jongsomjit D, Howell CA, Snyder MA, Alexander JD, Wiens JA, Root TL. 2009. Re-shuffling of species with climate disruption: a no-analog future for California birds? PLoS ONE **4**:e6825.

Stromberg JC, Lite SJ, Dixon MD. 2010. Effects of stream flow patterns on riparian vegetation of a semiarid river: implications for a changing climate. River Research and Applications **26**:712–729.

Swain DL, Langenbrunner B, Neelin JD, Hall A. 2018. Increasing precipitation volatility in twenty-first-century California. Nature Climate Change **8**:427.

Syphard AD, Keeley JE, Pfaff AH, Ferschweiler K. 2017. Human presence diminishes the importance of climate in driving fire activity across the United States. Proceedings of the National Academy of Sciences **114**:13750–13755.

Tam BY, Martin I, Tsuji LJS. 2014. Geospatial analysis between the environment and past incidences of West Nile virus in bird specimens in Ontario, Canada. GeoJournal **79**:805–817.

Taylor AH, Skinner CN. 1998. Fire history and landscape dynamics in a late-successional reserve, Klamath Mountains, California, USA. Forest Ecology and Management **111**:285–301.

Taylor AH, Trouet V, Skinner CN, Stephens S. 2016. Socioecological transitions trigger fire regime shifts and modulate fire–climate interactions in the Sierra Nevada, USA, 1600–2015 CE. Proceedings of the National Academy of Sciences **113**:13684–13689.

Tewksbury JJ, Black AE, Nur N, Saab VA, Logan BD, Dobkin DS. 2002. Effects of anthropogenic fragmentation and livestock grazing on western riparian bird communities. Studies in Avian Biology **25**:158–202.

Thomas JW, Maser C, Rodiek JE. 1979. Chapter 3: Riparian zones. Pages 40–47 in J. W. Thomas, editor. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agricultural Handbook No. 553. U.S. Department of Agriculture, Forest Service, Washington, D.C.

Tingley MW, Koo MS, Moritz C, Rush AC, Beissinger SR. 2012. The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. Global Change Biology **18**:3279–3290.

Van de Water KM, North MP. 2010. Fire history of coniferous riparian forests in the Sierra Nevada. Forest Ecology and Management **260**:384–395.

Van de Water KM, North MP. 2011. Stand structure, fuel loads, and fire behavior in riparian and upland forests, Sierra Nevada Mountains, USA: a comparison of current and reconstructed conditions. Forest Ecology and Management **262**:215–228.

van Mantgem PJ, Nesmith JCB, Keifer M, Knapp EE, Flint A, Flint L. 2013. Climatic stress increases forest fire severity across the western United States. Ecology Letters **16**:1151–1156.

VanDerWal J, Murphy HT, Kutt AS, Perkins GC, Bateman BL, Perry JJ, Reside AE. 2013. Focus on poleward shifts in species' distribution underestimates the fingerprint of climate change. Nature Climate Change **3**:239–243.

Veloz S, Salas L, Altman B, Alexander J, Jongsomjit D, Elliott N, Ballard G. 2015. Improving effectiveness of systematic conservation planning with density data. Conservation Biology **29**:1217–1227.

Veloz S, Salas L, Altman B, Alexander J, Jongsomjit D, Elliott N, Moody D, Michaile S, Fitzgibbon M, Ballard G. 2013. Projected effects of climate change on the distribution and abundance of North Pacific birds and their habitats. Final report to the North Pacific Landscape Conservation Cooperative. PRBO Conservation Science, Petaluma, CA.

Wahl ER, Zorita E, Trouet V, Taylor AH. 2019. Jet stream dynamics, hydroclimate, and fire in California from 1600 CE to present. Proceedings of the National Academy of Sciences **116**:5393–5398.

Wang J, Ogden NH, Zhu H. 2011. The impact of weather conditions on *Culex pipiens* and *Culex restuans* (Diptera: Culicidae) abundance: A case study in Peel Region. Journal of Medical Entomology **48**:468–475.

Westerling AL. 2016. Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. Philosophical Transactions of the Royal Society B: Biological Sciences **371**:20150178.

Westerling AL. 2018. Wildfire simulations for California's Fourth Climate Change Assessment: projecting changes in extreme wildfire events with a warming climate. California's Fourth Climate Change Assessment. Publication Number: CCCA4-CEC-2018-014. California Energy Commission, Sacramento, CA.

Westerling AL, Bryant BP, Preisler HK, Holmes TP, Hidalgo HG, Das T, Shrestha SR. 2011. Climate change and growth scenarios for California wildfire. Climatic Change **109**:445–463.

Wolfe ME, Schwarzbach S, Sulaiman RA. 1998. Effects of mercury on wildlife: A comprehensive review. Environmental Toxicology And Chemistry **17**:146–160.

Young DJN, Stevens JT, Earles JM, Moore J, Ellis A, Jirka AL, Latimer AM. 2017. Long-term climate and competition explain forest mortality patterns under extreme drought. Ecology Letters **20**:78–86.

Zhang J, Schmidt CJ, Lamont SJ. 2017. Transcriptome analysis reveals potential mechanisms underlying differential heart development in fast- and slow-growing broilers under heat stress. BMC Genomics **18**:295.

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),[8] 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.[9]

---

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

[9] 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:

Vulnerability = [(Climate Exposure*0.5) x Sensitivity] - 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

Literature Cited

EcoAdapt. 2014a. A climate change vulnerability assessment for aquatic resources in the Tongass National Forest. EcoAdapt, Bainbridge Island, WA. 124 pp.

EcoAdapt. 2014b. A climate change vulnerability assessment for resources of Nez Perce-Clearwater National Forests. Version 3.0. EcoAdapt, Bainbridge Island, WA. 398 pp.

Glick P, Stein BA, Edelson NA. 2011. Scanning the conservation horizon: A guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

Gregg RM, editor. 2018. Hawaiian Islands climate vulnerability and adaptation synthesis. EcoAdapt, Bainbridge Island, WA. 284 pp.

Hutto SV, Higgason KD, Kershner JM, Reynier WA, Gregg DS. 2015. Climate change vulnerability assessment for the north-central California coast and ocean. Marine Sanctuaries Conservation Series ONMS-15-02. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 473 pp.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Pages 617–652 in M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, editors. Cambridge University Press, Cambridge, UK.

Kershner JM, editor. 2014. A climate change vulnerability assessment for focal resources of the Sierra Nevada. Version 1.0. EcoAdapt, Bainbridge Island, WA. 418 pp.

Lawler J. 2010. Pacific Northwest Climate Change Vulnerability Assessment. From http://climatechangesensitivity.org

Manomet Center for Conservation Sciences and National Wildlife Federation. 2012. The vulnerabilities of fish and wildlife habitats in the Northeast to climate change. A report to the Northeastern Association of Fish and Wildlife Agencies and the North Atlantic Landscape Conservation Cooperative. Manomet Center for Conservation Sciences, Plymouth, MA.

Moss R, Schneider S. 2000. Towards consistent assessment and reporting of uncertainties in the IPCC TAR. In R. Pachauri and T. Taniguchi, editors. *Cross-Cutting Issues in the IPCC Third Assessment Report*. Global Industrial and Social Progress Research Institute (for IPCC), Tokyo.