Freshwater Marshes

Northern California Climate Change Vulnerability Assessment Synthesis

An Important Note About this Document: *This document represents an initial evaluation of vulnerability for freshwater marshes 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 Sam Flanagan (Bureau of Land Management) and Nina Hemphill (Bureau of Land Management). Vulnerability scores were provided by Nathaniel Seavy (Point Blue Conservation Science). Upper Lake workshop participants provided additional comments on the climate change vulnerability of this habitat.

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Habitat Description

Freshwater marshes occur where water is present for most or all of the growing season, often on the margins of ponds, lakes, or rivers (Kramer 1988; CDFW 2015). They are characterized by perennial herbaceous plants such as rushes (*Juncus* spp.), bulrushes or tule (*Bolboschoenus*, *Schoenoplectus*, and *Scirpus* spp.), cattails (*Typha* spp.), common reed (*Phragmites australis*), and sedges (*Carex* spp.; Kramer 1988; CDFW 2015). Where water is over 3 ft (1 m) in depth, aquatic plants such as water lilies (*Nymphaeaceae*), duckweed (*Lemna* spp.), and pondweed

(*Potamogeton* spp.) may occur (Kramer 1988; Thorne et al. 2016). Species composition is also dependent on hydroperiod (i.e., timing and length of inundation; Kramer 1988; Thorne et al. 2016), which is strongly influenced by the dominant sources of water (e.g., snowpack, precipitation, surface flows, groundwater discharge; Poff et al. 2002). Wetland plants also provide habitat structure that supports many taxonomic groups, including epiphytic bacteria, invertebrates, fish, birds, and mammals.

In California, freshwater marshes primarily occur below 2,270 m (7,450 ft) and may be flooded seasonally or permanently (Kramer 1988). Significant acreage of freshwater wetlands occur within the Klamath Basin, which historically flooded when the Klamath River overflowed its banks in the spring (Mayer 2005). Freshwater marshes are also important within and around the Sacramento Valley (CVJV 2006). In the Klamath Basin and Sacramento Valley, wetland water supply is highly managed through a system of canals, dikes, and other water-control structures (Mayer 2005; CVJV 2006). Smaller marshes are common around the edges of alpine lakes of alpine drainages in the Trinity Alps, as well as around Dry Lagoon and other coastal areas in northern California (Duffy et al. 2016).

Executive Summary

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

Freshwater Marshes	**Rank**	**Confidence**
Sensitivity	Moderate	Moderate
Future Exposure	Moderate-High	Moderate
Adaptive Capacity	Moderate-High	High
Vulnerability	**Moderate**	**Moderate**

Sensitivity & Exposure	
	<u>*Climate and climate-driven factors*</u>: • Precipitation amount and timing, soil moisture, drought, snowpack, air temperature <u>*Disturbance regimes*</u>: • Wildfire <u>*Non-climate stressors*</u>: • Agriculture, residential and commercial development, invasive species, dams and water diversions

Freshwater marshes are sensitive to climate stressors that alter hydrologic and thermal regimes, including changes in precipitation patterns and snowpack, increased drought, and warmer air temperatures. Relatively small changes in water inputs or evaporation and transpiration rates are enough to alter wetland extent and/or convert wetlands to upland habitats. Changes in precipitation patterns are also likely to reduce habitat availability for many wildlife and plant species and drive changes in wetland structure and function. Periodic fire can be beneficial in maintaining wetland habitat structure and hydrologic regimes, but altered fire regimes (e.g., increased extent and/or frequency of high-severity fire) may degrade habitat quality and contribute to the loss of native species. Non-climate stressors such as agriculture, livestock grazing, residential and commercial development, and dams and water diversions can further alter wetland hydrology, water quality, and connectivity.

Adaptive Capacity Summary	*Factors that enhance adaptive capacity*: + High species and structural diversity and unique transitional role between terrestrial and aquatic habitats + High public awareness of the importance of marshes and wetlands + Protection of wetland habitats under the federal Clean Water Act *Factors that undermine adaptive capacity*: – Significant loss of freshwater marshes over the last century due to land-use conversion and altered hydrology – Fragmentation due to land use and geologic factors limits movement of wetland plants in response to temperature and water level changes – Resistance to changing precipitation regimes is reduced in wetlands invaded by non-native species

Freshwater marshes are distributed throughout a wide elevational range in northern California, although their current extent has been drastically diminished from historical levels. These wetland types are rich in plant and animal diversity, reflecting diverse topographic and hydrological settings with component plant species ranging from widespread to endemic. However, habitat migration opportunities in the face of climate change are limited by barriers (e.g., roads and buildings) and land uses (e.g., dams/water diversions and livestock grazing) that fragment habitat and/or dispersal corridors. The scientific literature suggests multiple management actions that can help build adaptive capacity in wetland habitats, including maintaining or restoring hydrologic regimes, conducting prescribed burning to reduce woody species encroachment, reintroducing beaver (*Castor canadensis*) to raise water table levels and increase water storage, and managing invasive species. These wetlands also provide critical ecosystem services including surface water storage and infiltration, flood protection, and wildlife habitat for many culturally and ecologically important species.

Sensitivity and Exposure

Freshwater marshes were evaluated by regional experts as having moderate overall sensitivity (moderate 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.

Sensitivity and future exposure to climate and climate-driven factors

Regional experts evaluated freshwater marshes as having moderate-high sensitivity to climate and climate-driven factors (moderate confidence in evaluation), with an overall high future exposure to these factors within the study region (moderate confidence). Key climatic factors that affect freshwater marshes include precipitation amount and timing, soil moisture, drought, snowpack, and air temperature.[1]

Precipitation amount and timing, soil moisture, and drought

The vulnerability of freshwater marshes to climate change depends largely on the source(s) and volume of water over their annual cycle (Poff et al. 2002). For freshwater marshes, winter precipitation (e.g., rain or snow) or managed water deliveries strongly influences wetland extent (Duffy & Kahara 2011; Reiter et al. 2018). Drier conditions due to changes in the amount and/or timing of precipitation and associated decreases in soil moisture may result in substantial drying during the summer months, reduced water levels, shortened wetland hydroperiods, and conversion of permanent wetlands to intermittent or seasonal systems (Lee et al. 2015; Reiter et al. 2015, 2018; Thorne et al. 2016; Schaffer-Smith et al. 2017). During severe multi-year droughts, open water habitat in the Sacramento Valley (which includes freshwater marshes, flooded cropland, and ponds) can decrease by up to 69% (Reiter et al. 2018). Freshwater marshes associated with rivers and lakes may also be impacted by precipitation-driven changes in streamflow (Poff et al. 2002).

Changes in soil moisture associated with shifts in precipitation regimes and increased drought are likely to impact vegetation composition, structure, and functioning (Poff & Zimmerman 2010). For instance, drier conditions and/or changes in the timing of spring drawdown can disrupt seed production and germination in seasonal wetlands (Naylor 2002).

Regional Precipitation, Soil Moisture, & Drought 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) • No trends available for soil moisture • Drought years have occurred twice as often over the last two decades compared to the previous century (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

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

[2] Trends in climate factors and natural disturbance regimes presented in this and subsequent summary tables are not habitat-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, Soil Moisture, & Drought Trends[2]	
• 2012–2014 drought set records for lowest precipitation, highest temperatures, and most extreme drought indicators on record (Griffin & Anchukaitis 2014; Diffenbaugh et al. 2015)	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) • Overall, interannual variability is expected to increase (Pierce et al. 2018; Swain et al. 2018) • Decreased top-level soil moisture is likely even if precipitation increases due to temperature-related changes in evaporative demand (Pierce 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 Habitat *(see text for citations)*
• Decreased wetland hydroperiod, depth, and area due to overall drier conditions, particularly in wetlands dependent on precipitation as their primary (or only) water source • Encroachment of upland plant species at fringes of drying wetlands • Changes in vegetation composition, structure, and functioning due to decreased soil moisture

Snowpack amount

Reduced snowpack at high elevations is expected to reduce water availability in wetlands (Poff et al. 2002; Yarnell et al. 2010; Dwire et al. 2018), particularly for higher-elevation wetlands in snow-driven systems of the Klamath Mountains, Trinity Alps, Yolla Bolly Mountains, and southern Cascades (Vuln. Assessment Reviewer, pers. comm., 2019). As a result of reduced aquifer recharge and streamflows, freshwater wetlands fed by snowmelt may experience lower water levels, shortened hydroperiods, and increased probability of drying (Poff et al. 2002; Yarnell et al. 2010; Dwire et al. 2018).

Regional Snowpack Trends	
Historical & current trends: • 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)	*Projected future trends:* • Decreases in April 1 SWE by 2100 (compared to 1951–1980; Flint et al. 2013; Flint & Flint 2014): ○ 86–99% decrease on the North Coast

Regional Snowpack Trends	
	○ 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
Summary of Potential Impacts on Habitat *(see text for citations)*	
• Reduced water availability for snow-fed wetlands, resulting in lower water levels, shorter hydroperiods, and increased probability of drying	

Air temperature

Warmer air temperatures increase evapotranspiration (Flint et al. 2013; Thorne et al. 2015), and are likely to contribute to general drying trends in wetlands that could result in reduced habitat extent and the decline of species in isolated wetlands that are near their thermal tolerance limits (Poff et al. 2002). Increasing air temperatures and the resulting increase in water temperatures are also likely to increase plant and invertebrate growth and productivity in marshes and wetlands (Poff et al. 2002; Greig et al. 2012). While warming aquatic environments could benefit some species, it is also likely to lead to changes in plant composition and structure and altered food webs that may ultimately lead to a decline in ecosystem functioning (Greig et al. 2012). For example, warmer water temperatures are associated with increased growth of harmful algal blooms in nutrient-rich waters, which deplete dissolved oxygen, reduce water clarity, alter the food web, and produce toxins that can harm fish, wildlife, pets, and humans (Visser et al. 2016).

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 ecoregions (Rapacciuolo et al. 2014) ○ No seasonal temperature trends available	*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, 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 Habitat *(see text for citations)*	
• Increased growth of undesirable algae • Possible range shifts in wetland plants northwards and/or towards higher elevations, with possible extirpation for populations in isolated habitats	

Sensitivity and future exposure to changes in natural disturbance regimes

Regional experts evaluated freshwater marshes as having low-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).

Wildfire

The frequency and intensity of wildfire in wetlands is highly dependent on hydroperiod and system productivity, which influence fuel availability and moisture (Bixby et al. 2015). Although perennial marshes are very unlikely to burn, they may be influenced by increases in large, uncharacteristically severe fires in upland habitats within the same watershed. For example, the loss of upland vegetation typically mobilizes nutrients, increases runoff and erosion, and alters microclimates in the short-term (Coombs & Melack 2013; Bixby et al. 2015). Over longer time scales fires can enhance aquatic productivity and alter water chemistry by increasing organic matter and nutrient inputs into aquatic habitats (Earl & Blinn 2003).

However, increasing drought may enhance the risk of fire within marshes that dry out. Tule vegetation, in particular, becomes very flammable as it dries out, increasing the risk of wildfire within the marsh itself (Vuln. Assessment Reviewer, pers. comm., 2019).

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)
	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

Regional Wildfire Trends	
• No significant trends in the average areal proportion of high-severity fire were documented in northwestern CA 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 ○ To date, there are no peer-reviewed studies on trends in northern California fire severity that include data from the last ten years	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 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 Habitat *(see text for citations)*	
• Increased erosion and nutrient runoff following large high-severity fires within the watershed, impacting water quality and aquatic productivity	

Sensitivity and current exposure to non-climate stressors

Regional experts evaluated freshwater marshes as having high sensitivity to non-climate stressors (moderate confidence in evaluation), with an overall moderate-high current exposure to these stressors within the study region (moderate confidence). Key non-climate stressors that affect freshwater marshes include agriculture, residential and commercial development, invasive species, and dams and water diversions.[4]

Agriculture and residential/commercial development

Land-use conversion to agriculture and development has resulted in the loss of many freshwater marshes in the region (Gilmer et al. 1982; Suchanek et al. 2003; CVJV 2006). Land-use conversion damages and fragments wetlands directly through draining, vegetation removal, channel incision, and loss of floodplain connectivity (Gilmer et al. 1982; CVJV 2006; Vuln. Assessment Reviewer, pers. comm., 2019).

Over longer periods of time, agricultural practices also reduce water supplies, alter runoff and erosion/sedimentation patterns, and introduce contaminants (e.g., fertilizers, herbicides, pesticides, heavy metals) into freshwater marshes, affecting wetland hydrology and vegetation (Carpenter et al. 1998; Duffy & Kahara 2011; CDFW 2015). For instance, vineyards require large amounts of water during the growing season and are prone to erosion, resulting in the introduction of large amounts of sediment in adjacent wetlands (CDFW 2015). Cannabis cultivation also has a significant impact on aquatic systems by reducing water supplies and water quality (Bauer et al. 2015; Wang et al. 2017). Excess nutrients, in particular, can increase algae production and invasive species abundance (Carpenter et al. 1998). With expanded water conservation measures, growing urban populations would further reduce water availability for

[4] All non-climate stressors presented were ranked as having a moderate or higher impact on this habitat type.

wetland habitats by placing additional stress on highly-regulated water supplies in the Sacramento Valley region (Medellín-Azuara et al. 2007; Kahara et al. 2012).

Invasive species

Invasive aquatic plants (e.g., perennial pepperweed [*Lepidium latifolium*]) can degrade native freshwater marshes by displacing native species, altering nutrient cycles, and reducing water quality, particularly where they form dense stands (Okada et al. 2009; Duffy et al. 2016). While hydrologically-intact wetlands are resistant to terrestrial invasives, degraded systems are also vulnerable to invasion by drought-tolerant species such as giant reed (*Arundo donax*) and salt cedar (*Tamarix* spp.), which drive further changes in hydrology and biodiversity as well as increased fire frequency (Duffy et al. 2016).

Dams and water diversions

Large-scale dams and water diversions are common throughout the North Coast and Klamath Range region for flood control, water supply, and hydropower (CDFW 2015). The region also has many smaller-scale dams and water diversions for local agricultural irrigations (CDFW 2015; Bauer et al. 2015). Dams and water diversions can lower regional groundwater tables, reduce water supplies, and alter the timing of seasonal high- and low flows (CDFW 2015). Dams and water diversions can also restrict sediment supply to aquatic habitats and raise water temperatures that favor algal growth (CDFW 2015). Freshwater marshes that are hydrologically connected to riparian or lacustrine systems affected by dams and water diversions are most likely to be impacted by reduced and variable flows (CDFW 2015).

Adaptive Capacity

Freshwater marshes were evaluated by regional experts as having moderate-high overall adaptive capacity (high confidence in evaluation).

Habitat extent, integrity, continuity, and permeability

Regional experts evaluated freshwater marshes as having a moderate geographic extent (moderate confidence in evaluation), moderate structural and functional integrity (moderate confidence), and low-moderate continuity (high confidence).

Landscape permeability for freshwater marshes was evaluated as moderate (moderate confidence). Land use conversion and roads/highways/trails were identified as the primary barriers to habitat continuity and dispersal across the study region.[5]

The presence of freshwater marshes within the study region has declined dramatically since the turn of the 20th century, primarily due to drainage and land conversion to urban development and agriculture (Gilmer et al. 1982; Suchanek et al. 2003). Land-use conversion to urban or agricultural use continue to result in the loss and fragmentation of the region's freshwater marshes, particularly in more populated areas on the coast and in the Sacramento Valley (Duffy

[5] All barriers presented were ranked as having a moderate or higher impact on this habitat type.

& Kahara 2011). Infrastructure associated with development (e.g., roads, water storage/delivery systems) further fragment wetland habitats, hindering the movement and dispersal of native plants and animals (Gilmer et al. 1982; Poff et al. 2002). Non-native plant species may further interfere with the dispersal of native wetland plants (Galatowitsch et al. 1999). Altered hydrology due to climate change or anthropogenic causes can also reduce the structural and functional integrity of freshwater marshes by contributing to floodplain disconnection, channel incision, lowered groundwater tables, and reduced wetland area (Poff et al. 2002; Vuln. Assessment Reviewer, pers. comm., 2019).

Habitat diversity

Regional experts evaluated freshwater marshes as having moderate-high physical and topographical diversity (moderate confidence in evaluation), high component species diversity (high confidence), and high functional diversity (high confidence).

Freshwater wetlands are unique because of their role as transitional ecotones between aquatic and terrestrial ecosystems, and shallow marshy areas are particularly important for their biological diversity and as habitat for rare species. Wetlands vary in size, water depth, and hydroperiod, resulting in dynamic and productive ecosystems with diverse structural characteristics and biological communities (Kramer 1988; Poff et al. 2002). The heterogeneity in topography, water depth, and other hydrological and physical attributes allows freshwater wetlands in northern California and the Central Valley to support up to 200 species of dabbling ducks, wading birds, raptors, aerial insectivores, and songbirds (Kahara et al. 2012). They also provide food, water, and cover for numerous amphibians, reptiles, mammals, and invertebrates (Kramer 1988; CDFW 2015), such as the California newt (*Taricha torosa*), northern red-legged frog (*Rana aurora*), California red-legged frog (*Rana draytonii*), river otter (*Lontra canadensis*), and American beaver (CDFW 2015).

Resistance and recovery

Regional experts evaluated freshwater marshes as having moderate-high resistance to climate stressors and natural disturbance regimes (moderate confidence in evaluation) and moderate-high recovery potential (moderate confidence).

In general, wetland habitats supported primarily by surface water are likely to have less resistance to precipitation declines and warming temperatures compared to groundwater-supplied marshes (Winter 2000; Poff et al. 2002).

Within freshwater marshes, bulrushes appear more able to withstand and recover from drought compared to sedges and rushes (Rejmánková et al. 1999). Water lilies have very intolerant of drought, but recover more rapidly than bulrushes, rushes, and sedges. These differences suggest that life history of dominant marsh species may be important in determining wetland responses to future drought conditions (Rejmánková et al. 1999).

Management potential

Public and societal value

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

There is regulatory support for wetland habitats through the Federal Clean Water Act of 1972 (33 U.S.C. §§1251-1387).

Management capacity and ability to alleviate impacts[6]

Regional experts evaluated the potential for limiting climate impacts on freshwater marshes through management as moderate-high (high confidence in evaluation).

Because freshwater marshes provide many critical ecosystem services (e.g., water filtration, floodwater storage, support of biodiversity), restoration of degraded wetlands can provide a suite of benefits to natural and human communities (Duffy & Kahara 2011). Restoration activities often focus on restoring natural hydrology, retaining water, and managing vegetation through planting, burning, mowing, disking, or grazing (Duffy & Kahara 2011). Many of these activities will remain relevant over the coming century, but monitoring and adaptive management will be required as conditions change (Lawler et al. 2010). Other management activities that may become increasingly important over the coming century include removing barriers to reconnect fragmented wetlands (Vuln. Assessment Workshop, pers. comm., 2017) and promoting the presence of beavers to increase water storage (Baldwin 2015).

Multiple studies have demonstrated the effectiveness of incentive programs that pay farmers and landowners to remove environmentally-sensitive wetlands from active agricultural use (Kahara et al. 2012; DiGaudio et al. 2015; Reiter et al. 2018). For example, the Wetlands Reserve Program (WRP) was created by the Natural Resources Conservation Service (NRCS) as part of the 1990 Farm Bill and is designed around conservation easements that compensate landowners for converting flood-prone farmland to wetland (Kahara et al. 2012). These incentive programs are particularly beneficial during periods of severe drought, when reduced water availability in the region can discourage the management of wetlands that provide vital staging areas for migrating and wintering waterfowl (Kahara et al. 2012; Matchett & Fleskes 2017).

Ecosystem services

Freshwater marshes provide a variety of ecosystem services, including:

- Provisioning of food, fiber, genetic resources, and fresh water;
- Regulation of climate/microenvironments, flood/erosion control, water purification, pest/disease regulation, and natural hazard regulation;

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

- Support of primary production, oxygen production, soil formation/retention, nutrient cycling, water cycling, carbon storage; and
- Cultural/tribal uses for spiritual/religious purposes, knowledge systems, educational values, aesthetic values, social relations, sense of place, cultural heritage, inspiration, and recreation (Vuln. Assessment Workshop, pers. comm., 2017).

Wetlands are recognized as a globally important ecosystem that provide a number of important ecosystem services, such as flood protection, water filtration, and critical habitat for resident and migratory birds, fish, amphibians, and mammals (Poff et al. 2002; Duffy & Kahara 2011; Colloff et al. 2016).

Recommended Citation

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

Literature Cited

Baldwin J. 2015. Potential mitigation of and adaptation to climate-driven changes in California's highlands through increased beaver populations. California Fish and Game **101**:218–240.

Bauer S, Olson J, Cockrill A, van Hattem M, Miller L, Tauzer M, Leppig G. 2015. Impacts of surface water diversions for marijuana cultivation on aquatic habitat in four northwestern California watersheds. PLoS ONE **10**:e0120016.

Bixby RJ, Cooper SD, Gresswell RE, Brown LE, Dahm CN, Dwire KA. 2015. Fire effects on aquatic ecosystems: an assessment of the current state of the science. Freshwater Science **34**:1340–1350.

Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications **8**:559–568.

CDFW. 2015. California State Wildlife Action Plan, 2015 Update: a conservation legacy for Californians. Prepared with assistance from Ascent Environmental, Inc. California Department of Fish and Wildlife, Sacramento, CA.

Colloff MJ, Lavorel S, Wise RM, Dunlop M, Overton IC, Williams KJ. 2016. Adaptation services of floodplains and wetlands under transformational climate change. Ecological Applications **26**:1003–1017.

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

Coombs JS, Melack JM. 2013. Initial impacts of a wildfire on hydrology and suspended sediment and nutrient export in California chaparral watersheds. Hydrological Processes **27**:3842–3851.

CVJV. 2006. Central Valley Joint Venture implementation plan: conserving bird habitat. U.S. Fish and Wildlife Service, Central Valley Joint Venture, Sacramento, CA. Available from http://www.centralvalleyjointventure.org/assets/pdf/CVJV_fnl.pdf (accessed May 29, 2019).

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.

Duffy WG, Garone P, Grewell BJ, Kahara SN, Fleskes JP, Helm B, Moyle PB, Records R, Silveira J. 2016. Wetlands. Pages 669–692 in H. A. Mooney and E. S. Zavaleta, editors. Ecosystems of California. University of California Press, Oakland, CA.

Duffy WG, Kahara SN. 2011. Wetland ecosystem services in California's Central Valley and implications for the Wetland Reserve Program. Ecological Applications **21**:S18–S30.

Dwire KA, Mellmann-Brown S, Gurrieri JT. 2018. Potential effects of climate change on riparian areas, wetlands, and groundwater-dependent ecosystems in the Blue Mountains, Oregon, USA. Climate Services **10**:44–52.

Earl SR, Blinn DW. 2003. Effects of wildfire ash on water chemistry and biota in south-western USA streams. Freshwater Biology **48**:1015–1030.

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.

Galatowitsch SM, Anderson NO, Ascher PD. 1999. Invasiveness in wetland plants in temperate North America. Wetlands **19**:733–755.

Gilmer DS, Miller MR, Bauer RD, LeDonne JR. 1982. California's Central Valley wintering waterfowl: concerns and challenges. Pages 441–452 in K. Sabol, editor. Transactions of the Forty-seventh North American Wildlife and Natural Resources Conference. U.S. Fish and Wildlife Service, Washington, D.C.

Greig HS, Kratina P, Thompson PL, Palen WJ, Richardson JS, Shurin JB. 2012. Warming, eutrophication, and predator loss amplify subsidies between aquatic and terrestrial ecosystems. Global Change Biology **18**:504–514.

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

Kahara SN, Duffy WG, DiGaudio R, Records R. 2012. Climate, management and habitat associations of avian fauna in restored wetlands of California's Central Valley, USA. Diversity **4**:396–418.

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.

Kramer G. 1988. Fresh emergent wetland. In K. E. Mayer and W. F. Laudenslayer Jr., editors. A guide to wildlife habitats of California. California Department of Fish and Game, Sacramento, CA. Available from https://www.wildlife.ca.gov/Data/CWHR/Wildlife-Habitats.

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.

Lawler JJ et al. 2010. Resource management in a changing and uncertain climate. Frontiers in Ecology and the Environment **8**:35–43.

Lee SY, Ryan ME, Hamlet AF, Palen WJ, Lawler JJ, Halabisky M. 2015. Projecting the hydrologic impacts of climate change on montane wetlands. PLoS ONE **10**:e0136385.

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.

Matchett EL, Fleskes JP. 2017. Projected impacts of climate, urbanization, water management, and wetland restoration on waterbird habitat in California's Central Valley. PLoS ONE **12**:e0169780.
Mayer TD. 2005. Water-quality impacts of wetland management in the Lower Klamath National Wildlife Refuge, Oregon and California, USA. Wetlands **25**:697–712.
Medellín-Azuara J, Harou JJ, Olivares MA, Madani K, Lund JR, Howitt RE, Tanaka SK, Jenkins MW, Zhu T. 2007. Adaptability and adaptations of California's water supply system to dry climate warming. Climatic Change **87**:75–90.
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.
Naylor LW. 2002. Evaluating moist-soil seed production and management in Central Valley wetlands to determine habitat needs for waterfowl. Master of Science thesis. University of California, Davis, CA.
Okada M, Grewell BJ, Jasieniuk M. 2009. Clonal spread of invasive *Ludwigia hexapetala* and *L. grandiflora* in freshwater wetlands of California. Aquatic Botany **91**:123–129.
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.
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.
Poff NL, Brinson MM, Day JW Jr. 2002. Aquatic ecosystems and global climate change: potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Prepared for the Pew Center on Global Climate Change.
Poff NL, Zimmerman JKH. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology **55**:194–205.
Rapacciuolo G et al. 2014. Beyond a warming fingerprint: individualistic biogeographic responses to heterogeneous climate change in California. Global Change Biology **20**:2841–2855.
Reiter ME, Elliott N, Veloz S, Jongsomjit D, Hickey CM, Merrifield M, Reynolds MD. 2015. Spatio-temporal patterns of open surface water in the Central Valley of California 2000-2011: drought, land cover, and waterbirds. Journal of the American Water Resources Association **51**:1722–1738.
Reiter ME, Elliott NK, Jongsomjit D, Golet GH, Reynolds MD. 2018. Impact of extreme drought and incentive programs on flooded agriculture and wetlands in California's Central Valley. PeerJ **6**:e5147.
Rejmánková E, Rejmánek M, Djohan T, Goldman CR. 1999. Resistance and resilience of subalpine wetlands with respect to prolonged drought. Folia Geobotanica **34**:175–188.
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.
Schaffer-Smith D, Swenson JJ, Barbaree B, Reiter ME. 2017. Three decades of Landsat-derived spring surface water dynamics in an agricultural wetland mosaic: implications for migratory shorebirds. Remote Sensing of Environment **193**:180–192.
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.

Suchanek TH et al. 2003. Evaluating and managing a multiply-stressed ecosystem at Clear Lake, California: a holistic ecosystem approach. Pages 1239–1271 in D. J. Rapport, B. L. Lasley, D. E. Rolston, N. O. Nielsen, C. O. Qualset, and A. B. Damania, editors. Managing for healthy ecosystems. Routledge, Abingdon, UK.

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.

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.

Thorne JH, Boynton RM, Flint LE, Flint AL. 2015. The magnitude and spatial patterns of historical and future hydrologic change in California's watersheds. Ecosphere **6**:1–30.

Thorne JH, Boynton RM, Holguin AJ, Stewart JAE, Bjorkman J. 2016. A climate change vulnerability assessment of California's terrestrial vegetation. California Department of Fish and Wildlife, Sacramento, CA.

Visser PM, Verspagen JMH, Sandrini G, Stal LJ, Matthijs HCP, Davis TW, Paerl HW, Huisman J. 2016. How rising CO_2 and global warming may stimulate harmful cyanobacterial blooms. Harmful Algae **54**:145–159.

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 IJ, Brenner JC, Butsic V. 2017. Cannabis, an emerging agricultural crop, leads to deforestation and fragmentation. Frontiers in Ecology and the Environment **15**:495–501.

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.

Winter TC. 2000. The vulnerability of wetlands to climate change: a hydrologic landscape perspective. Journal of the American Water Resources Association **36**:305–311.

Yarnell SM, Viers JH, Mount JF. 2010. Ecology and management of the spring snowmelt recession. BioScience **60**:114–127.

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),[7] 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.[8]

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

[8] 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

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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.