Northwestern Pond Turtle (*Actinemys marmorata*)

Northern California Climate Change Vulnerability Assessment Synthesis

An Important Note About this Document: *This document represents an initial evaluation of vulnerability for northwestern pond turtles 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.*

Vulnerability scores and peer review for this document were provided by Don Ashton, McBain Associates, Applied River Sciences (review); David Germano, California State University, Bakersfield (review); Jeffrey Lovich, U.S. Geological Survey (review); and Kathryn Purcell, U.S. Forest Service (scores, review). Additional comments on the climate change vulnerability of this species were provided by Upper Lake workshop participants.

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Species Description

There are two species of western pond turtles (*Actinemys marmorata*, *A. pallida*), of which only one is found within the northern California study region: the northwestern pond turtle (*A. marmorata*; also called the northern Pacific pond turtle; Turtle Taxonomy Working Group 2017). Within the northern California study area, this semi-aquatic freshwater species is primarily found within the Sacramento Valley and surrounding foothills, as well as in the North Coast Range and Klamath Basin (Barela & Olson 2014). Its full range extends throughout the Central Valley and north to Washington, though few observations have been reported in Washington over the past 150 years (Barela & Olson 2014).[1]

Northwestern pond turtles are a medium-sized semi-aquatic freshwater species (Bury et al. 2012). They have variable coloring (olive brown to black) on their carapace and faint light reticulations often radiate from its scutes (i.e., shields; Hallock et al. 2017). Carapace length for adults in the northern part of the species' distribution can range from 15 to 24 cm (6 to 9.1 in; (Lubcke & Wilson 2007; Vuln. Assessment Reviewers, pers. comm., 2018), while the southern subspecies (*Actinemys marmorata pallida*) tends to be slightly smaller and rarely exceeds 17 cm (6.7 in.; e.g., Goodman 1997).

As omnivorous predators and scavengers (Bury 1986), northwestern pond turtles forage and mate in a variety of intermittent and permanent aquatic habitats during the spring and summer breeding season, including rivers, streams, lakes, ponds, wetlands, and vernal pools (Bury & Germano 2008; Bury et al. 2010). In northern California, this species makes extensive use of terrestrial habitats for nesting and estivation (i.e., a dormancy state used to thermoregulate in hot or dry conditions) during the breeding season (Reese & Welsh 1997; Pilliod et al. 2013). Northwestern pond turtles residing in lotic habitats (i.e., rivers and streams) or seasonal lentic habitats (i.e., intermittent ponds) tend to overwinter concealed in the duff layer, leaf litter, soft soil, or seed bank crevices on shoreline banks or in upland areas (Holland & Goodman 1996; Reese & Welsh 1997; Pilliod et al. 2013). Turtles inhabiting permanent lentic habitats (i.e., perennial ponds and small lakes) in northern California may overwinter on land or in the mud under water or ice (Holland 1994; Reese 1996).

Executive Summary

The relative vulnerability of northwestern pond turtles 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 adaptive capacity.

Northwestern Pond Turtle	**Rank**	**Confidence**
Sensitivity	Moderate-High	Moderate
Future Exposure	Moderate-High	Moderate
Adaptive Capacity	Moderate	Moderate
Vulnerability	**Moderate-High**	**Moderate**

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[1] The southwestern pond turtle (A. pallida) generally occurs south of San Francisco Bay excluding the San Joaquin Valley (Spinks et al. 2014; Thomson et al. 2016). Some research on the this species is included where applicable to *Actinemys* turtles in general.

Sensitivity & Exposure Summary	*Climate and climate-driven factors*: • Precipitation amount and timing, drought, streamflow, air temperature, water temperature, heat waves, sea level rise *Disturbance regimes*: • Wildfire, flooding *Non-climate stressors*: • Invasive and/or problematic species; roads/highways/railways/trails, residential and commercial development, agriculture, dams and water diversions, pollution, hunting/trapping/fishing

Northwestern pond turtles are vulnerable to a broad array of climate stressors that impact terrestrial and aquatic habitats, including changes in precipitation amount and timing, increasing drought, altered streamflow, warmer air and water temperatures, heat waves, and sea level rise. While this species can tolerate dry conditions periodically, high rates of mortality can occur during severe and/or multi-year drought. Coupled with wildfire, increased frequency and severity of drought may threaten the survival of small, isolated populations, especially those in ephemeral aquatic environments. Changes in hydrology and warmer air and water temperatures are likely to impact turtle growth, recruitment, and survival in complex ways; for instance, warm, slow-flowing pools may provide additional habitat for juveniles, while more significant increases in air and water temperature could have detrimental effects on the food web, egg survival and sex ratios, and other factors. Sea level rise may pose an additional threat to pond turtles in coastal habitats affected by inundation and saltwater intrusion into freshwater areas. Severe flooding can reduce adult survival and increase nest failure, while both wildfire and flooding degrade turtle habitat and food resources. Northwestern pond turtles are also sensitive to many non-climate stressors that degrade habitat or elevate mortality.

Adaptive Capacity Summary	*Factors that enhance adaptive capacity*: + Long life span and potential for rapid maturation under ideal conditions + High levels of phenotypic and behavioral plasticity in response to environmental change + Use of diverse habitats, including artificial water bodies (e.g., stock tanks) + Widespread public interest in turtle conservation *Factors that undermine adaptive capacity*: – Dispersal limited by habitat loss and fragmentation in the region, and dispersing turtles are vulnerable to predation – Increased vulnerability to extirpation in isolated populations due to restricted gene flow – Slow to recover from population declines under stressful conditions

Habitat loss and fragmentation as a result of development, dams, and water diversions in northern California limit movement of northwestern pond turtles. However, their utilization of artificial water bodies (e.g., stock tanks, small reservoirs) and their ability to migrate in response to extreme environmental conditions increase the potential for survival during severe drought. Northwestern pond turtles exhibit some phenotypic and behavioral plasticity in response to environmental change and are able to make use of some human-created habitats, which may aid adaptation to changing climate conditions and anthropogenic stressors. Genetic diversity has likely declined due to increasing habitat fragmentation, and restricted gene flow in isolated populations increases vulnerability to extirpation. The long lifespan and potential for rapid maturation under ideal conditions can result in high lifetime reproductive output in this species. Conversely, elevated mortality and slower growth and maturation under more stressful conditions can result in slow recovery from population declines. Awareness and support for turtle conservation is generally high, and the increasingly visible impacts of drought on northwestern pond turtle habitat may spark interest and action in managing habitat to allow turtle populations to survive in a changing climate. Managing for northwestern pond turtle protection and recovery will likely focus on protecting, enhancing, and managing terrestrial and aquatic habitats (e.g., lessening terrestrial disturbance during nesting, managing dam releases to provide low-velocity conditions and favorable water temperatures).

Sensitivity and Exposure

Northwestern pond turtles were evaluated by regional experts as having moderate-high 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 northwestern pond turtles as having moderate-high sensitivity to climate and climate-driven factors (moderate confidence in evaluation), with an overall moderate-high future exposure to these factors within the study region (low confidence). Key climatic factors that affect northwestern pond turtles include precipitation amount and timing, drought, streamflow, air temperature, water temperature, heat waves, and sea level rise.[2]

Precipitation amount and timing and drought

Changes in the amount and timing of precipitation and increased duration and/or severity of drought have the potential to reduce food sources and perennial aquatic habitat availability for pond turtles in California (Lovich et al. 2017; Purcell et al. 2017). In northern California, turtles occupying streams that dried up during periods of summer drought were more likely to have smaller body sizes at 10 years of age compared to turtles in perennial streams (Bondi & Marks 2013). Although this study was unable to determine the cause of the size disparity, possibilities include impacts on turtle growth rates and/or increased selective pressure to mature at smaller sizes due to limited resource availability (Bondi & Marks 2013). Turtles from intermittent reaches also spent less time overall in the water and had lower body condition compared to those from the perennial reaches (Bondi & Marks 2013). As aquatic habitats dry up, pond turtles exhibit estivation behavior during which they burrow into upland habitats to thermoregulate (Reese 1996; Reese & Welsh 1997).

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

Several studies have documented pond turtle mortality and the extirpation of isolated populations during periods of severe drought, particularly for turtles living in ephemeral aquatic habitats that may remain dry during multi-year droughts (Leidy et al. 2016; Lovich et al. 2017; Purcell et al. 2017). Although pond turtles are adapted to the frequent periods of drought that characterize the region, estivation or travel over land to seek out habitat refugia also increases their vulnerability to starvation, dehydration, and predation (Purcell et al. 2017). Additionally, the risk of wildfire is greatly enhanced during periods of severe drought (Abatzoglou & Williams 2016; McKenzie & Littell 2017), which can accelerate population declines due to starvation following loss of habitat and food sources (Lovich et al. 2017).

Regional Precipitation & Drought Trends[3]	
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)[4] • 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. 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

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[3] Trends in climate factors and natural disturbance regimes presented in this and subsequent summary tables are not species-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.

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

Regional Precipitation & Drought Trends[3]	
	and once-in-a-century drought will occur once every 20 years (Pierce et al. 2018)
Summary of Potential Impacts on Species *(see text for citations)*	
• Reduced habitat extent and food availability under drier conditions • High rates of turtle mortality and potential population declines during periods of severe drought • Increased terrestrial emigration as ponds and other water sources dry up, increasing the risk of turtle mortality	

Streamflow

Changes in stream hydrology affect northwestern pond turtle habitat availability and quality, and have the potential to impact recruitment, growth, and survival (Reese & Welsh 1998a; Bury et al. 2012; Bondi & Marks 2013). Lower flows may reduce habitat availability, particularly if streams dry up completely during the summer months (Bondi & Marks 2013; Leidy et al. 2016). However, increased area of warm, shallow water could provide additional habitat for juvenile turtles (Reese 1996; Reese & Welsh 1998a) and reduce time spent basking (Ashton et al. 2011). *See below for discussion of water temperature and the impacts of changes in stream hydrology due to dams and water diversions.*

Regional Streamflow Trends	
Historical & current trends: • Shift towards earlier spring peak flows in snowmelt-dominated basins (Stewart et al. 2005; Pierce et al. 2018) • In rain-dominated coastal rivers in northern California, minimum annual flows have decreased and late summer recession rates have increased over the past 40-80 years (Sawaske & Freyberg 2014; Asarian & Walker 2016; Klein et al. 2017) • September streamflow declined at 73% of undammed sites in northern California and southwest Oregon (Asarian & Walker 2016)	*Projected future trends:* • Generally, wet season flows are projected to increase and dry season flows are projected to decrease (Leng et al. 2016; Grantham et al. 2018) • Overall increase in flow variability and earlier timing of spring peak flows (by up to 30 days; Stewart et al. 2005) • As a result of more extreme dry conditions, the lowest streamflow per decade is projected to be 30–40% lower by 2100 (Pierce et al. 2018)
Summary of Potential Impacts on Species *(see text for citations)*	
• Changes in habitat availability and quality, potentially affecting recruitment, growth, and survival	

Air temperature

Air temperature influences northwestern pond turtle incubation time, sex determination, and, in combination with other factors, juvenile growth rates. Generally, incubation time decreases as temperatures increase, although very high or low temperatures can result in extended incubation (Christie & Geist 2017) and reduced hatching success (Hays et al. 1999; Geist et al. 2015; Christie & Geist 2017). In addition, warmer egg incubation temperatures produce higher ratios of females to males per clutch (Ewert et al. 1994; Geist et al. 2015; Christie & Geist 2017), with temperatures. Studies of daily temperature fluctuations within pond turtle nests in northern California have found that temperatures can regularly vary by up to 20°C (36°F; Geist et al. 2015; Christie & Geist 2017), with peak temperatures well over the threshold considered lethal for headstarted turtles incubated at a constant temperature (lethal range 30°C [86°F] and above; Geist et al. 2015). Additionally, eggs at the bottom of the nest experience less variation in temperatures compared to eggs near the top of the nest (Geist et al. 2015). These patterns suggest that temperature fluctuations play an important role in determining sex ratios, while also limiting the length of exposure to potentially lethal temperatures (Geist et al. 2015). Some studies suggest the potential for skewed sex ratios as a result of warmer future temperatures (e.g., Christie & Geist 2017). However, nesting females can compensate by finding cooler microsites in which to nest, and the presence of this species over geologic time scales suggests that populations are likely to persist even under warmer conditions (Vuln. Assessment Reviewers, pers. comm., 2018).

In addition to their impacts on reproduction, warmer air temperatures could degrade pond turtle habitat, particularly when combined with other stressors (Hallock et al. 2017). For instance, higher air temperatures in conjunction with increased drought can lead to drying of aquatic habitat and reduced food availability, increasing predation associated with terrestrial emigration to new habitats (Ihlow et al. 2012; Hallock et al. 2017; Purcell et al. 2017).

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 Species *(see text for citations)*	
• Possible decreases in hatching success and reduced hatchling energy stores • Reduced availability of aquatic habitats and food resources, increasing predation associated with terrestrial emigration to new habitats • Unknown impacts of temperature on long-term population dynamics (e.g., changing sex ratios)	

Water temperature

Changes in water temperature influence juvenile growth rates and age at sexual maturity for northwestern pond turtles, and these two life history traits are linked in complex ways (Hallock et al. 2017). In general, juvenile turtles grow more quickly in warmer water (Ashton et al. 2015; Snover et al. 2015). However, turtles growing in cooler water become sexually mature at a smaller body size and greater age than those growing in warmer habitats (Snover et al. 2015).

Increased water temperatures are likely to reduce aerial basking time, which could allow more time for feeding (Ashton et al. 2011; Hallock et al. 2017) and reduce exposure to predators (Bury et al. 2012). In some turtle species, warmer water temperatures allow turtles to assimilate more energy by increasing the rate at which they are able to digest food (Kepenis & McManus 1974; Parmenter 1980; Congdon 1989; Parmenter & Avery 1990). Although little is known about how warmer water temperatures will affect pond turtle food sources (Vuln. Assessment Reviewers, pers. comm., 2018), it is possible that primary productivity (e.g., plants, algae, some bacteria) will increase (Petchey et al. 1999; O'Connor et al. 2009). However, the impacts of potential increases in primary productivity on food webs is highly uncertain due to complex interactions among species that occur at the ecosystem level (Petchey et al. 1999).

Regional Water Temperature Trends	
Historical & current trends: • ~0.1°C (0.2°F) per decade increase in mean August stream temperatures in northwestern California from 1976–2015 (Isaak et al. 2017) ○ Corresponds to a 0.4°C (0.7°F) increase in air temperature and 5.3% decrease in discharge per decade	*Projected future trends:* • 0.4–0.8°C (0.7–1.4°F) per decade increase in mean August stream temperatures in northwestern California by the 2080s (Isaak et al. 2017) ○ Corresponds to a 3.6°C (6.5°F) increase in air temperature and 1.2% decrease in stream discharge • 1–3°C (1.8–5.4°F) increase in the temperature of the Sacramento River by 2100 (Cloern et al. 2011)
Summary of Potential Impacts on Species *(see text for citations)*	
• Possible increase in foraging opportunities and reduced exposure to predators due to decreased aerial basking time • Unknown impacts on food webs, including turtle food sources	

Heat waves

Exposure to high maximum temperatures, as occurs during heat waves, may impact turtle reproduction (Ewert et al. 1994; Spinks et al. 2003; Christie & Geist 2017) by leading to skewed sex ratios (i.e., a greater proportion of females), decreased hatching success, and possibly lower energy stores for hatchlings due to increased incubation duration (Christie & Geist 2017). Increases in heat wave frequency could stress northwestern pond turtle embryos that are already developing at temperatures close to their thermal limits (Christie & Geist 2017). Five summers of visual surveys by kayak on the Trinity River has also revealed a marked decrease in aerial basking during heat waves, decreasing detectability (D. Ashton, pers. obs. following USGS protocol [Snover & Adams 2016]).

In northern California, late summer and fall heat waves are also frequently associated with very high wildfire risk (Schroeder et al. 1964), with high temperatures increasing fire size, rate of spread, and severity (Sharples 2009; Estes et al. 2017). Extreme fire conditions can occur when the high pressure system also produces warm, dry east winds (i.e. foehn winds; Schroeder et al. 1964).

<table>
<tr><th colspan="2">Regional Heat Wave Trends</th></tr>
<tr><td>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)</td><td>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)</td></tr>
<tr><th colspan="2">Summary of Potential Impacts on Species (see text for citations)</th></tr>
<tr><td colspan="2">• Potential reduction in reproductive success due to skewed sex ratios, lower hatchling energy stores, and/or decreased hatchling success
• Altered behavior patterns, including reduced aerial basking
• Increased likelihood of extreme fire conditions</td></tr>
</table>

Sea level rise

Most pond turtle populations live in elevated terrain away from the coast; however, inundation and saltwater intrusion into freshwater habitats may occur for those inhabiting coastal habitats (Agha et al. 2018). Although little information is available, pond turtles have been observed in brackish tidal sloughs, suggesting they exhibit some level of tolerance for saline environments (Agha et al. 2018).

<table>
<tr><th colspan="2">Regional Sea Level Rise Trends</th></tr>
<tr><td>Historical & current trends:
• At the Crescent City station, sea levels decreased by an average of 0.08 cm (0.03 in) per year from 1933–2018 (equivalent to a decrease of 0.08 m [0.26 ft] in 100 years; NOAA/National Ocean Service 2019)
• At the Humboldt Bay (North Spit) station, sea levels increased by an average of 0.49 cm (0.19 in) per year from 1977–2018 (equivalent to an increase of 0.49 m [1.6 ft] in 100 years; NOAA/National Ocean Service 2019)
• At the Arena Cove station, sea levels increased by an average of 0.08 cm (0.03 in) per year from 1978–2018 (equivalent to a change of</td><td>Projected future trends:
• Sea level rise trends by 2100 (compared to 2000), based on likelihood of occurrence (range includes projections linked to low-, moderate-, and high-emissions scenarios; Kopp et al. 2014; Griggs et al. 2017; Sweet et al. 2017; Anderson 2018):
○ For the Crescent City station, 66% probability of 0.03–0.65 m (0.1–2.1 ft), 0.5% probability of 1.25–1.55 cm (4.1–5.1 ft), and extreme scenario (representing ice sheet collapse) of 2.79 m (9.1 ft)
○ For the Humboldt Bay (North Spit) station, 66% probability of 0.62–1.24 cm (2.0–4.1 ft), 0.5% probability of 1.83 to 2.15 m (6.0–</td></tr>
</table>

Regional Sea Level Rise Trends	
0.08 m [0.27 ft] in 100 years; NOAA/National Ocean Service 2019)	7.0 ft), and extreme scenario (representing ice sheet collapse) of 3.37 m (11.0 ft) ○ For the Arena Cove station, 66% probability of 0.21–0.94 m (0.7–3.1 ft), 0.5% probability of 1.65–2.04 m (5.4–6.7 ft), and extreme scenario (representing ice sheet collapse) of 3.02 m (9.9 ft)

Summary of Potential Impacts on Species *(see text for citations)*
• Inundation and saltwater intrusion into coastal freshwater habitats, likely resulting in habitat loss

Sensitivity and future exposure to changes in natural disturbance regimes

Regional experts evaluated northwestern pond turtles as having moderate-high 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 northwestern pond turtles include wildfire and flooding.[5]

Wildfire

Climate-driven changes in fire regimes, including possible increases in fire extent and the incidence of extreme fire behavior (Westerling 2018), may result in significant turtle mortality events (Lovich et al. 2017; Vuln. Assessment Workshop, pers. comm., 2017). Direct mortality in more likely in overwintering turtles and hatchlings as they cannot move quickly enough to retreat to water bodies (Bury et al. 2012). Estivating turtles are also especially vulnerable to fire mortality where water has dried up due to drought (Lovich et al. 2017). Turtles may be more able to survive fires that occur in the late summer because they are more likely to be in aquatic habitats (Vuln. Assessment Reviewer, pers. comm., 2018). Wildfire can also drastically reduce the availability of insulative cover (e.g. duff, litter, woody debris, shrubs) used by overwintering turtles in terrestrial areas (Vuln. Assessment Reviewer, pers. comm., 2019). However, anecdotal evidence in the year or two following the 2013 Rimm Fire in Yosemite suggests that there may be some temporary benefits to recruitment where wildfire clears vegetation from nesting benches and reduces population of nest predators (D. Ashton, pers. comm., 2019).

In particular, high-intensity wildfire may act synergistically with other stressors (e.g., drought) to significantly degrade or eliminate aquatic habitat and food sources and reduce persistence of pond turtle populations (Lovich et al. 2017). This type of multiple-impact habitat degradation followed a large, severe wildfire that occurred at a southern California lake containing southwestern pond turtles during the 2012–2016 drought (Lovich et al. 2017). Following the fire, water quality impacts contributed to the collapse of aquatic food webs, leading to high turtle mortality from starvation and dehydration (Lovich et al. 2017). Turtle populations already suffering from prolonged drought impacts (such as reduced habitat extent and food availability)

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

can be too physiologically impaired to emigrate to new habitats following wildfire (Lovich et al. 2017).

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 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

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 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 *(see text for citations)*

- Immediate mortality of turtles and hatchlings in terrestrial habitats
- Reduced water quality in aquatic habitats, resulting in potential collapse of the food web and subsequent starvation

Flooding

Changes in flooding frequency and/or intensity may affect northwestern pond turtle reproduction, physical condition, behavior, and survival. For instance, northwestern pond turtle nests in upland habitat may be inundated during floods (Holte 1998; Bury et al. 2012), which can lead to the loss of eggs or hatchlings (Feldman 1982). Flooding also increases sedimentation impacts in rivers, lakes, and ponds (Vuln. Assessment Workshop, pers. comm. 2017; Vincent 2009), reducing water quality and feeding opportunities (Reese & Welsh 1998a). During severe floods, turtles may experience mortality or be washed downstream (Vuln. Assessment Reviewer, pers. comm., 2018).

Flooding impacts on pond turtle behavior and survival vary depending on habitat type (Holland 1994; Bury et al. 2012; Pilliod et al. 2013). In lakes and permanent ponds, northwestern pond turtles tend to overwinter in mud under ice, making them less exposed to flooding impacts in winter (Bury et al. 2012). In riverine habitats, northwestern pond turtles tend to concentrate in side-channels, oxbows, or other adjacent wetland habitats to avoid scouring flows during periods of flooding and return to central river channels when high flows decrease (Holland 1994). Pond turtles also move overland between riverine or small pond habitats to avoid high flows (Holland 1994; Pilliod et al. 2013). Overwintering in upland habitat may be an adaptation to high winter flows (Reese 1996; Goodman 1997; Reese & Welsh 1997). In the spring, pond turtles are known to congregate in vernal pools before returning to rivers, likely because these pools provide warmer and more productive habitat than rivers that are still experiencing high flow or flooding conditions (Pilliod et al. 2013).

Regional Flooding Trends	
Historical & current trends: • No trends available for flooding	*Projected future trends:* • More frequent/severe winter flooding due to an increase in extreme precipitation events (Dettinger 2011; AghaKouchak et al. 2018; Swain et al. 2018; Grantham et al. 2018) • State-wide, 200-year floods are expected to increase in frequency by 300–400%, becoming 50-year floods (Swain et al. 2018)
Summary of Potential Impacts on Species *(see text for citations)*	
• Increased nest failure following inundation of upland habitat • Increased sedimentation in aquatic habitat, reducing water quality and feeding opportunities • Increased mortality or displacement of individuals washed downstream	

Dependency on habitat and/or other species

Regional experts evaluated northwestern pond turtles as having moderate dependency on sensitive habitats (high confidence in evaluation) and moderate dependency on prey or forage species (low confidence). In general, northwestern pond turtles were evaluated as having a moderate degree of specialization (high confidence).

Northwestern pond turtles require a mosaic of connected aquatic and terrestrial habitat niches for survival and successful reproduction (Hallock et al. 2017), although they can occupy a wide variety of habitats (Holland 1994; Germano & Bury 2001; Germano 2010; Bury et al. 2012; Lovich et al. 2017). Specifically, feeding, mating, and basking are restricted to aquatic habitats, while nesting and estivation occur on land (Bury 1986; Bury et al. 2012). In their aquatic habitat, this species is typically associated with deep water that moves at a low velocity and the presence of underwater cover or refugia (Reese & Welsh 1998b; Germano & Bury 2001). Northwestern pond turtles use sunny banks and fields up to a few hundred meters from water for estivation in the warmest months of the year (Reese & Welsh 1997; Hays et al. 1999) and overwinter in friable soil and duff within upland habitats (Holland & Goodman 1996; Reese & Welsh 1997; Pilliod et al. 2013). They also must have connected terrestrial habitat with no major barriers to movement for dispersal in response to environmental or resource changes, although overland travel may expose them to increased predation pressure (Purcell et al. 2017).

Pond turtles can also be locally abundant in human-made water impoundments, including reservoirs, canals, and ponds associated with wastewater treatment, livestock, and logging operations (Holland 1994; Germano & Bury 2001; Germano 2010; Bury et al. 2012; Lovich et al. 2017). However, in many areas they are less abundant than in natural water bodies and/or primarily use human-created sites during times of environmental stress (Purcell et al. 2017). Poor water quality also has the potential to impair pond turtle health (Polo-Cavia et al. 2010). Overall, the dependence of northwestern pond turtles on multiple habitat types across their life history likely increases their vulnerability to major stressors (e.g., flooding, drought, wildfire, pollution) within any of these (Vuln. Assessment Workshop, pers. comm., 2017).

Although they are omnivorous generalists, pond turtles are particularly dependent on aquatic habitat for feeding because they can only swallow their prey in water (Bury 1986). While they prefer live prey, pond turtles also scavenge carrion and browse on vegetation (Holland 1994). Prey items include small aquatic invertebrates and foothill yellow-legged frog (*Rana boylii*) tadpoles and egg masses; carcasses of mammals, birds, reptiles, amphibians, and fish; and plant materials (tule [*Scirpus* sp.], cattail [*Typha latifolia*] roots, willow [*Salix* spp.] and alder [*Alnus* spp.] catkins, ditch grass inflorescences, and green filamentous algae; Holland 1994). Diets of male, female, and juvenile pond turtles differ in prey size and proportions of food items, which may reduce intraspecific competition between age and sex classes (Bury 1986).

Sensitivity and current exposure to non-climate stressors

Regional experts evaluated northwestern pond turtles as having moderate-high sensitivity to non-climate stressors (moderate confidence in evaluation), with an overall moderate current exposure to these stressors within the study region (low confidence). Key non-climate stressors that affect northwestern pond turtles include roads/highways/railways/trails, residential and commercial development, agriculture, dams and water diversions, pollution, and hunting/trapping/fishing.[6]

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

Invasive and/or problematic species

Several invasive and/or non-native species are known predators of pond turtles and their eggs, including American bullfrogs (*Rana catesbeiana*) and largemouth bass (*Micropterus salmoides*; Moyle 1973; Hays et al. 1999; Haegen et al. 2009; Hallock et al. 2017). Observations suggest that introduced turtles (e.g., red-eared slider [*Trachemys scripta elegans*]) may also have a negative impact on pond turtle populations in and around urban areas, possibly by competing for food and/or basking sites (Spinks et al. 2003). However, both red-eared sliders and northwestern pond turtles have co-existed in and around Clear Lake since introduction of the red-eared slider in that area in 1968, suggesting that pond turtles may be relatively resilient to this non-native species outside of urban areas (Hayes et al. 2018).

Roads, highways, railways, and trails

The presence and use of roads, highways, railways, and trails impact all northwestern pond turtle life stages by increasing direct mortality during crossings (Bury et al. 2012). Turtles can be attracted to puddles and wet tire tracks on dirt roads, increasing their exposure to traffic (Bury et al. 2012). Female turtles are often disproportionally affected by traffic due to greater likelihood of movement through areas containing roads during travel to terrestrial nesting habitats (Steen & Gibbs 2004; Aresco 2005). Vehicular and pedestrian activity on trails can inhibit basking behavior and/or alarm turtles from their basking sites, reducing time for thermoregulation (Nyhof & Trulio 2015).

Roads, highways, and railways also introduce pollutants and contaminants to aquatic habitats through surface runoff (Hamer & McDonnell 2008). Truck and train transportation along waterways also increases the risk of toxic chemical spills into rivers, which can severely degrade turtle habitat (Bury et al. 2012). For example, northwestern pond turtle habitat in the Trinity River near State Highway 299 is vulnerable to toxic spills from vehicular traffic in areas where the road runs alongside the river; impacts from a spill in these areas could lead to high mortality rate for turtle populations in the river (Bury et al. 2012). More than a mile downstream of a spill of diesel fuel into Hayfork Creek, a tributary to the Trinity River, deleterious effects were observed in northwestern pond turtles and other semi-aquatic herpetofauna (Bury 1972).

Residential and commercial development

Residential and commercial development eliminates aquatic and terrestrial habitat (Spinks et al. 2003), and there is often high development pressure on land adjacent to waterways (Reese & Welsh 1997). Development in terrestrial habitat can fragment areas for nesting, overwintering, estivating, and emigration for pond turtles (Spinks et al. 2003; Bury et al. 2012). In addition, development and associated land management actions can reduce shade in nesting habitat, increasing exposure of eggs to periods of high incubation temperature (Christie & Geist 2017). Aquatic habitats in urbanized areas are likely to experience increased channelization and sedimentation, a reduction in aquatic vegetation, and fewer or less desirable basking sites (Spinks et al. 2003). Residential development near pond turtle habitat may also result in increased predation from raccoons, skunks, foxes, coyotes, and domestic dogs (Holland 1994;

Bury & Germano 2008; Bury et al. 2012). This can occur both through meso-predator release (e.g., Soulé et al. 1988) and/or predator subsidies (Mitchell & Klemens 2000).

Agriculture

In the Central Valley, the pond turtle has lost much of its habitat to agricultural activities, flood control, and urbanization (Germano & Bury 2001; Bury et al. 2012). However, in some cases pond turtles are able to occupy livestock ponds and other artificial water bodies with good water quality (Reese & Welsh 1997; Purcell et al. 2017).

Dams and water diversions

Dams and water diversions impact northwestern pond turtle habitat availability and quality by altering stream hydrology (Reese & Welsh 1998a; Bury et al. 2012; Bondi & Marks 2013). River reaches below dams typically have increased water depth and velocity, more sedimentation, and lower water temperatures due to cold water releases (Reese & Welsh 1998b; Olden & Naiman 2010; Hallock et al. 2017). Altered channel morphology is common in dammed reaches as a result of hydrologic changes (Reese & Welsh 1998b; Bondi & Marks 2013), and overall aquatic habitat heterogeneity is typically lower (Reese & Welsh 1998b). Damming increases deep water and promotes undercut banks frequently utilized by turtles, but the loss of low-velocity flows and colder water temperatures result in reduced habitat suitability (Reese & Welsh 1998a).

Comparisons of turtles in dammed and free-flowing rivers have highlighted slower growth rates, delayed sexual maturity, and smaller sizes at maturity in individuals occupying dammed reaches (Ashton et al. 2015; Snover et al. 2015). Terrestrial estivation behavior may also increase in response to unseasonably cold water releases from dams (Goodman 1997), raising terrestrial predation risk (Ultsch 2006). Altered water levels and cooler water temperature from dams may also create habitat for invasive predators (CDFW 2015) and increases amount of time spent basking (Ashton et al. 2011). Hydrological changes from damming decreases shallow edgewater habitat in downstream reaches, reducing slow-flow habitat areas required by juveniles (Reese 1996; Reese & Welsh 1998a). Additionally, reduced densities of hatchlings and juveniles in dammed reaches suggest lower population recruitment rates (Bondi & Marks 2013). Dams also increase sedimentation, filling deep water pools, which reduces cover and food sources (Bury & Germano 2008). Culverts and other water diversions also alter hydrology and create areas of increased flow, thereby reducing turtle movement and availability of basking sites (Hays et al. 1999; Hallock et al. 2017).

Pollution

Northwestern pond turtles in both urbanized and more remote habitats are frequently exposed to contaminants from current and past agricultural and mining practices, sewage treatment, road runoff, and firefighting (Germano 2010; Meyer et al. 2014, 2016). These pollutants run off into aquatic habitats, where they can be directly toxic to turtles and/or can alter habitat suitability and food resources as water quality declines. For instance, sublethal concentrations of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) can cause immunosuppression, chromosomal damage, genotoxicity, loss of secondary sex characteristics, decreased reproductive and endocrine function, and hormone disruption in turtles (de Solla 2010; Polo-Cavia et al. 2010). Agricultural and sewage treatment operations impact water quality by increasing nutrients, pesticides, and sediment, although pond turtles have successfully reproduced in sewage settling ponds (Germano 2010).

Pond turtles can bioaccumulate mercury and toxic PCBs from their aquatic prey in areas impacted by industrial activities and legacy mining (Hays et al. 1999; Meyer et al. 2014, 2016), particularly given their long lives and higher trophic position (Rowe 2008; Meyer et al. 2016). For example, in the Whiskeytown Creek National Recreation Area high levels of PCBs were detected in turtle plasma, likely a result of legacy PCB pollution from an historical sawmill located upstream (Meyer et al. 2016). PCBs have been also been found in pond turtle egg shells (Henny et al. 2003), and are associated with hatchling abnormalities, altered sex ratios, and increased juvenile mortality (Bishop et al. 1991; Bergeron et al. 1994; Eisenreich et al. 2009; Matsumoto et al. 2014). Mercury can also impair endocrine and thyroid activity in pond turtles (Meyer et al. 2014). In Six Rivers National Forest, PAHs and PCBs were also found in sediment, macroinvertebrates, and turtle plasma, highlighting that northwestern pond turtles are even exposed to pollution in remote protected areas (Meyer et al. 2016).

Hunting, trapping, and fishing

Humans have direct impacts on turtle populations through hunting, fishing bycatch, and poaching for the pet trade (Holland 1994; Bury et al. 2012). For instance, southwestern pond turtles have been observed to swallow fish hooks (Lovich et al. 2017), which has also been observed in other freshwater turtle species (Steen et al. 2014).

Adaptive Capacity

Northwestern pond turtles were evaluated by regional experts as having moderate overall adaptive capacity (moderate confidence in evaluation).

Species extent, status, connectivity, and dispersal ability

Regional experts evaluated northwestern pond turtles as having a high geographic extent (high confidence in evaluation), declining population status (high confidence), and a moderate degree of connectivity between populations (moderate confidence).

Regional experts evaluated northwestern pond turtles as having a moderate dispersal ability (moderate confidence in evaluation). Barriers to dispersal were evaluated as having a high impact on the species (high confidence). Land-use conversion, geologic features, agriculture, and roads/highways/railways/trails were identified as the primary barriers to dispersal.[7]

Northwestern pond turtles remain fairly common in southern Oregon and northern California (Bury & Germano 2008; Bury et al. 2012; Barela & Olson 2014). However, isolated populations are particularly vulnerable to climate stressors such as severe drought (Purcell et al. 2017).

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

Artificial habitats may become more important for habitat connectivity and survival as climate change increases the frequency and duration of periodic drying of naturally occurring aquatic habitats (Vuln. Assessment Reviewer, pers. comm., 2018; Vincent 2009).

Home range size varies by sex and age class (Hays et al. 1999); for instance, in a stream habitat in northern California, northwestern pond turtles had approximate home ranges of 1 ha (2.47 ac) for adult males, 0.25 ha (0.62 ac) for adult females, and 0.4 ha (1 ac) for juveniles (Bury 1979; Hays et al. 1999; Bury & Germano 2008). Dispersal capacity for pond turtles is somewhat limited by their slow movement and continued habitat loss and fragmentation (Hays et al. 1999). However, long dispersal distances are being documented, particularly in pond-dwelling turtles that move long distances as their isolated aquatic habitats dry up (Purcell et al. 2017; Vuln. Assessment Reviewer, pers. comm., 2018). This species' ability to increase migratory behavior in response to extreme environmental conditions (e.g., drought) may be a factor in its survival where its habitat is connected over the landscape (Lovich et al. 2017; Purcell et al. 2017), as is its ability to temporarily use human-created habitats, including reservoirs, water treatment ponds, and agricultural ponds (Hays et al. 1999; Germano & Bury 2001).

Intraspecific/life history diversity

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

Genetic diversity has likely declined in northwestern pond turtles, and restricted gene flow among isolated populations suggests increased vulnerability to extirpation (Gray 1995). While the southwestern pond turtles demonstrate considerable genetic variability among populations, the northwestern pond turtles does not appear to exhibit strong genetic distinction among populations (Spinks & Shaffer 2005; Spinks et al. 2014).

Pond turtles exhibit high levels of phenotypic and behavioral plasticity in response to habitat type and changing environmental conditions (Lubcke & Wilson 2007; Bury & Germano 2008; Bondi & Marks 2013; Snover et al. 2015). Like other turtle species, northwestern pond turtles show fairly wide geographic variation in life history and morphological traits across environmental gradients (Bondi & Marks 2013; Snover et al. 2015). For instance, adult body size and age of maturation is variable across populations due to the strong influence of environmental conditions such as water temperature on growth (Lubcke & Wilson 2007; Germano & Bury 2009; Ashton et al. 2015; Snover et al. 2015), although males tend to mature slightly quicker and at a smaller size (Bury et al. 2012). In environments with rapid growth, northwestern pond turtles can mature in as little as 3 or 4 years, but in many populations, 6 to 10 years is commonly reported (Snover et al. 2015). In environments where growth is very slow, maturation may be delayed an addition dozen years, which may have reproductive consequences for turtles by reducing lifetime reproductive output (Snover et al. 2015). Additionally, smaller body size and more time on land increases exposure to gape-limited predators (Vuln. Assessment Reviewer, pers. comm., 2018).

Researchers have also shown that timing of departure from and return to aquatic habitat, distances traveled over land, and habitats used during terrestrial movements are highly variable among individual pond turtles, even from the same population (Pilliod et al. 2013). Under drought conditions, Purcell et al. (2017) found high variability in distances moved from a drying pond, with some pond turtles remaining close to the home pond and others moving long distances in search of alternate aquatic habitat. Thus, behavioral plasticity appears to strongly influence drought survival, with surviving individuals showing unique movement patterns (Purcell et al. 2017).

Resistance and recovery

Regional experts evaluated northwestern pond turtles as having low resistance to climate stressors and natural disturbance regimes (moderate confidence in evaluation). Population recovery potential (i.e., recruitment rate) was evaluated as low-moderate (moderate confidence).

Pond turtles evolved with periodic drought conditions and exhibit drought-protective behaviors, such as the ability to estivate (i.e., enter a prolong state of dormancy or torpor instigated by hot or dry conditions; (Bury et al. 2012), fast for long time periods in terrestrial habitats (Bury 1986; Holland 1994; Hays et al. 1999; Purcell et al. 2017), and travel overland to other water bodies (Holland 1994; Pilliod et al. 2013). However, they have low resistance to periods of prolonged and/or severe drought, especially if migration to new aquatic habitats is constrained by habitat degradation, fragmentation, or wildfire (Lovich et al. 2017; Purcell et al. 2017). Northwestern pond turtles also have limited resistance to prolonged high temperatures during incubation (Geist et al. 2015; Christie & Geist 2017) and low plasticity in the timing of their first nesting excursion compared to the previous year (St. John 2015). It is unknown whether turtles will be able to compensate for warmer mean and maximum temperatures in the future through phenotypic responses in timing of nesting or nest site selection (Schwanz & Janzen 2008; Mitchell & Janzen 2010).

The long lifespan of pond turtles (30–40 years, and in some cases up to 70 years; Holland 1994; Bury et al. 2012) and potential for rapid maturity under ideal conditions (Snover et al. 2015) can result in potentially high lifetime reproductive output (Vuln. Assessment Reviewer, pers. comm., 2018). However, they also have relatively small clutch sizes (3–7 eggs) (Lovich & Meyer 2002; Bury & Germano 2008) and survival of younger turtles is often low, resulting in slow recovery of small populations (Vuln. Assessment Reviewer, pers. comm., 2019). It is not clear whether reproductive capacity will be sufficient to compensate for elevated mortality from increasing stressors and disturbances, particularly in populations that are already declining (Holland 1994; Hays et al. 1999; Christie & Geist 2017). In addition, population declines may be masked by the presence of long-lived turtles that are not successfully reproducing (Vuln. Assessment Reviewer, pers. comm., 2018).

Management potential

Public and societal value

Regional experts evaluated northwestern pond turtles as having moderate-high public and societal value (moderate confidence in evaluation).

Given their charismatic nature, pond turtles are generally well-liked by the public, though many people are unaware of the conservation challenges associated with this species (Vuln. Assessment Workshop, pers. comm., 2017). Additionally, the very visible impacts of prolonged drought on this species may be a catalyst for further public interest and support for conservation efforts (Vuln. Assessment Workshop, pers. comm., 2017).

Although the northwestern pond turtle is considered a Species of Special Concern in California (Thomson et al. 2016), that designation does not necessitate protection of its habitat (Bury & Germano 2008). A limited amount of pond turtle habitat is protected under the Wild and Scenic Rivers Act (Bury & Germano 2008), the Clean Water Act (i.e., wetlands habitat; Hallock et al. 2017), and in some state and federal parks in northern California (Bury & Germano 2008). However, in many areas the majority of northwestern pond turtle habitat is on privately-owned land (Vuln. Assessment Reviewer, pers. comm., 2018). Private landowners generally appreciate turtles but may not understand the impacts of stocking ponds with bass and other species, and they often consider bullfrogs as desirable (Vuln. Assessment Reviewer, pers. comm., 2018).

Management capacity and ability to alleviate impacts[8]

Regional experts evaluated the potential for reducing climate impacts on northwestern pond turtles through management as moderate (moderate confidence in evaluation). Local interest to implement a management approach for species conservation is high, but there is little dedicated funding (Vuln. Assessment Workshop, pers. comm., 2017).

Although the detailed impacts of climate change on pond turtles are not yet well-known, there are a number of management actions suggested in the scientific literature that focus on enhancing and protecting terrestrial and aquatic habitat (Reese 1996; Reese & Welsh 1998b; Pilliod et al. 2013), providing drought refugia (Purcell et al. 2017), and managing the impacts of invasive/problematic species (Corkran & Thoms 2006). Potential actions include:

- Increasing natural structural and hydrologic features on dammed river reaches to provide areas with low-velocity flows, warmer water temperatures, and basking areas (Reese & Welsh 1998b);
- Limiting development and human activity in riparian corridors and around seasonally inundated ponds to protect connectivity between aquatic habitats and upland nesting areas (Bodie 2001; Pilliod et al. 2013);

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

- Managing isolated aquatic habitats within a single watershed as a group in order to maintain population connectivity, allowing colonization of isolated wetlands from source populations and limiting the loss of genetic diversity (Reese 1996);
- Creating or maintaining persistent water sources in drought-prone areas, including artificial water bodies (e.g., livestock troughs) that may allow individuals to survive during prolonged periods of drought (Vuln. Assessment Reviewer, pers. comm., 2018);
- Avoiding the creation of habitat that allows proliferation of American bullfrogs (Corkran & Thoms 2006); and
- Managing urban and suburban water bodies with high public visibility as interim habitats in order to provide drought refugia and raise awareness about pond turtle conservation (Roe et al. 2011).

Ecosystem services

Northwestern pond turtles provide a variety of ecosystem services, including:

- Regulation of water quality (Vuln. Assessment Workshop, pers. comm., 2017);
- Support of nutrient/mineral cycling (from aquatic to terrestrial habitats) and biomass conversion (invertebrates to vertebrates; Lovich et al. 2018);
- 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).

Turtles make substantial contributions to the biomass of the ecosystems they occupy due to their long lives, generalist diets, overlapping generations, and low energetic demands (Lovich et al. 2018). The historically high biomass and density of turtles has given them an ecologically important role as both consumers (i.e., predators, scavengers) and prey, and loss of turtle populations could have serious consequences on ecosystem structure and function (Lovich et al. 2018).

Turtles also serve as biosentinels (i.e., key indicators of environmental contaminants), in part because their long lives and relatively high trophic position in aquatic systems allows them to accumulate significant levels of heavy metals and other pollutants (Rowe 2008; Lovich et al. 2018).

Recommended Citation

Sims SA, Hilberg LE, Reynier WA, Kershner JM. 2019. Northwestern Pond Turtle (*Actinemys marmorata*): 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, Williams AP. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences **113**:11770–11775.

Agha M, Ennen JR, Bower DS, Nowakowski AJ, Sweat SC, Todd BD. 2018. Salinity tolerances and use of saline environments by freshwater turtles: implications of sea level rise. Biological Reviews **93**:1634–1648.

AghaKouchak A, Ragno E, Love C, Moftakhari H. 2018. Projected changes in California's precipitation intensity-frequency curves. California's Fourth Climate Change Assessment. Publication Number: CCCA4-CEC-2018-005. California Energy Commission, Sacramento, CA.

Anderson JK. 2018. Sea level rise in the Humboldt Bay region. Update 1: March 2018. Prepared for the California State Coastal Conservancy and Coastal Ecosystems Institute of Northern California. Northern Hydrology & Engineering, McKinleyville, CA.

Aresco MJ. 2005. The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles. Biological Conservation **123**:37–44.

Asarian JE, Walker JD. 2016. Long-term trends in streamflow and precipitation in northwest California and southwest Oregon, 1953-2012. Journal of the American Water Resources Association **52**:241–261.

Ashton D, Bettaso J, Welsh HH. 2015. Changes across a decade in size, growth, and body condition of western pond turtle (*Actinemys marmorata*) populations on free-flowing and regulated forks of the Trinity River in Northwest California. Copeia **103**:621–633.

Ashton DT, Bettaso JB, Welsh HH. 2011. Comparative ecology of western pond turtle (*Actinemys marmorata*) populations on the free-flowing South Fork and regulated Main Fork Trinity River: demography, size and body condition comparisons, thermal ecology, and spatial dynamics. Final Report to the Trinity River Restoration Program. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Barela KL, Olson DH. 2014. Mapping the western pond turtle (*Actinemys marmorata*) and painted turtle (*Chrysemys picta*) in western North America. Northwestern Naturalist **95**:1–12.

Bergeron JM, Crews D, McLachlan JA. 1994. PCBs as environmental estrogens: turtle sex determination as a biomarker of environmental contamination. Environmental Health Perspectives **102**:780.

Bishop CA, Brooks RJ, Carey JH, Ng P, Norstrom RJ, Lean DR. 1991. The case for a cause-effect linkage between environmental contamination and development in eggs of the common snapping turtle (*Chelydra s. serpentina*) from Ontario, Canada. Journal of Toxicology and Environmental Health **33**:521–547.

Bodie JR. 2001. Stream and riparian management for freshwater turtles. Journal of Environmental Management **4**:443–455.

Bondi CA, Marks SB. 2013. Differences in flow regime influence the seasonal migrations, body size, and body condition of western pond turtles (*Actinemys marmorata*) that inhabit perennial and intermittent riverine sites in northern California. Copeia **2013**:142–153.

Bury RB. 1972. Small mammals and other prey in the diet of the Pacific giant salamander (*Dicamptodon ensatus*). American Midland Naturalist **87**:524–526.

Bury RB. 1979. Population ecology of freshwater turtles. Pages 571–602 in M. Harless and H. Morlock, editors. Turtles: research and perspectives. John Wiley & Sons, New York, NY.

Bury RB. 1986. Feeding ecology of the turtle, *Clemmys marmorata*. Journal of Herpetology **20**:515–521.

Bury RB, Germano DJ. 2008. *Actinemys marmorata* (Baird and Girard 1852 -- Western pond turtle, Pacific pond turtle. Pages 001.1-001.9 in A. G. J. Rhodin, P. C. H. Pritchard, P. P. van Dijk, R. A. Saumure, K. A. Buhlmann, and J. B. Iverson, editors. Conservation biology of freshwater turtles and tortoises: a compilation project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist

Group. Chelonian Research Monographs, No. 5. Chelonian Research Foundation, Lunenburg, MA.

Bury RB, Germano DJ, Bury GW. 2010. Population structure and growth of the turtle *Actinemys marmorata* from the Klamath–Siskiyou ecoregion: age, not size, matters. Copeia **2010**:443–451.

Bury RB, Welsh HH, Germano DJ, Ashton DT. 2012. Western pond turtle: biology, sampling techniques, inventory and monitoring, conservation, and management. Society for Northwestern Vertebrate Biology, Olympia, WA.

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.

Christie NE, Geist NR. 2017. Temperature effects on development and phenotype in a free-living population of western pond turtles (*Emys marmorata*). Physiological and Biochemical Zoology **90**:47–53.

Cloern JE et al. 2011. Projected evolution of California's San Francisco Bay-Delta-River System in a century of climate change. PLoS ONE **6**:e24465.

Congdon JD. 1989. Proximate and evolutionary constraints on energy relations of reptiles. Physiological Zoology **62**:356–373.

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

Corkran CC, Thoms C. 2006. Amphibians of Oregon, Washington and British Columbia: a field identification guide. Lone Pine Publishing, Auburn, WA.

de Solla SR. 2010. Organic contaminants in reptiles. Pages 289–324 in D. W. Sparling, G. Linder, C. A. Bishop, and S. Krest, editors. Ecotoxicology of amphibians and reptiles, 2nd edition. CRC Press, Boca Raton, FL.

Dettinger M. 2011. Climate change, atmospheric rivers, and floods in California – a multimodel analysis of storm frequency and magnitude changes. Journal of the American Water Resources Association **47**:514–523.

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.

Eisenreich KM, Kelly SM, Rowe CL. 2009. Latent mortality of juvenile snapping turtles from the upper Hudson River, New York, exposed maternally and via the diet to polychlorinated biphenyls (PCBs). Environmental Science & Technology **43**:6052–6057.

Estes BL, Knapp EE, Skinner CN, Miller JD, Preisler HK. 2017. Factors influencing fire severity under moderate burning conditions in the Klamath Mountains, northern California, USA. Ecosphere **8**:e01794.

Ewert M, Jackson DR, Nelson CE. 1994. Patterns of temperature-dependent sex determination in turtles. Journal of Experimental Zoology **270**:3–15.

Feldman M. 1982. Notes on reproduction in *Clemmys marmorata*. Herpetological Review **13**:10–11.

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.

Geist NR, Dallara Z, Gordon R. 2015. The role of incubation temperature and clutch effects in development and phenotype of head-started western pond turtles (*Emys marmorata*). Herpetological Conservation and Biology **10**:489–503.

Germano D, Bury R. 2001. Western pond turtles (*Clemmys marmorata*) in the Central Valley of California: status and population structure. Transactions of the Western Section of The Wildlife Society **37**:22–36.

Germano DJ. 2010. Ecology of western pond turtles (*Actinemys marmorata*) at sewage-treatment facilities in the San Joaquin Valley, California. The Southwestern Naturalist **55**:89–97.

Germano DJ, Bury RB. 2009. Variation in body size, growth, and population structure of *Actinemys marmorata* from lentic and lotic habitats in southern Oregon. Journal of Herpetology **43**:510–520.

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

Goodman RH Jr. 1997. The biology of the southwestern pond turtle (*Clemmys marmorata pallida*) in the Chino Hills State Park and the West Fork of the San Gabriel River. Master of Science thesis. California State Polytechnic University, Pomona, CA.

Grantham TEW, Carlisle DM, McCabe GJ, Howard JK. 2018. Sensitivity of streamflow to climate change in California. Climatic Change **149**:427–441.

Gray EM. 1995. DNA fingerprinting reveals a lack of genetic variation in northern populations of the western pond turtle (*Clemmys marmorata*). Conservation Biology **9**:1244–1255.

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

Griggs G, Árvai J, Cayan D, DeConto R, Fox J, Fricker HA, Kopp RE, Tebaldi C, Whiteman EA. 2017. Rising seas in California: an update on sea-level rise science. California Ocean Science Trust, Oakland, CA.

Haegen WMV, Clark SL, Perillo KM, Anderson DP, Allen HL. 2009. Survival and causes of mortality of head-started western pond turtles on Pierce National Wildlife Refuge, Washington. The Journal of Wildlife Management **73**:1402–1406.

Hallock LA, McMillan A, Wiles GJ. 2017. Periodic status review for the Western Pond Turtle in Washington. Washington Department of Fish and Wildlife, Olympia, WA.

Hamer AJ, McDonnell MJ. 2008. Amphibian ecology and conservation in the urbanising world: a review. Biological Conservation **141**:2432–2449.

Hayes FE, Turner DG, Weidemann DE. 2018. Relative abundance of invasive red-eared sliders (*Trachemys scripta elegans*) and native western pond turtles (*Emys marmorata*) at Clear Lake, Lake County, California. Chelonian Conservation and Biology **17**:309–313.

Hays DW, McAllister KR, Richardson SA, Stinson DW. 1999. Washington state recovery plan for the western pond turtle. Washington Department of Fish and Wildlife, Olympia, WA.

Henny CJ, Beal KF, Bury RB, Goggans R. 2003. Organochlorine pesticides, PCBs, trace elements and metals in western pond turtle eggs from Oregon. Northwest Science **77**:46–53.

Holland DC. 1994. The western pond turtle: habitat and history. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. Available from http://relicensing.pcwa.net/documents/Library/PCWA-L%20450.pdf (accessed June 15, 2018).

Holland DC, Goodman RH. 1996. *Clemmys marmorata* (western pond turtle): terrestrial habitat use. Herpetological Review **27**:198.

Holte DL. 1998. Nest site characteristics of the western pond turtle, *Clemmys marmorata*, at Fern Ridge Reservoir, in west central Oregon. Master of Science thesis. Oregon State University, Corvallis, OR.

Ihlow F, Dambach J, Engler JO, Flecks M, Hartmann T, Nekum S, Rajaei H, Rödder D. 2012. On the brink of extinction? How climate change may affect global chelonian species richness and distribution. Global Change Biology **18**:1520–1530.

Isaak DJ et al. 2017. The NorWeST summer stream temperature model and scenarios for the western U.S.: a crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams. Water Resources Research **53**:9181–9205.

Kepenis V, McManus JJ. 1974. Bioenergetics of young painted turtles, *Chrysemys picta*. Comparative Biochemistry and Physiology Part A: Physiology **48**:309–317.

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.

Klein RD, McKee T, Nystrom K. 2017. Shrinking streamflows in the Redwood Region. Pages 187–197 in R. B. Standiford and Y. S. Valachovic, editors. Coast Redwood Science Symposium—2016: past successes and future direction. Gen. Tech. Rep. PSW-GTR-258. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Kopp RE, Horton RM, Little CM, Mitrovica JX, Oppenheimer M, Rasmussen DJ, Strauss BH, Tebaldi C. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future **2**:2014EF000239.

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.

Leidy RA, Bogan MT, Neuhaus L, Rosetti L, Carlson SM. 2016. Summer die-off of western pond turtle (*Actinemys marmorata*) along an intermittent coast range stream in central California. The Southwestern Naturalist **61**:71–74.

Leng G, Huang M, Voisin N, Zhang X, Asrar GR, Leung LR. 2016. Emergence of new hydrologic regimes of surface water resources in the conterminous United States under future warming. Environmental Research Letters **11**:114003.

Lovich J, Meyer K. 2002. The western pond turtle (*Clemmys marmorata*) in the Mojave River, California, USA: highly adapted survivor or tenuous relict? Journal of Zoology **256**:537–545.

Lovich JE, Ennen JR, Agha M, Gibbons JW. 2018. Where have all the turtles gone, and why does it matter? BioScience **68**:771–781.

Lovich JE, Quillman M, Zitt B, Schroeder A, Green DE, Yackulic C, Gibbons P, Goode E. 2017. The effects of drought and fire in the extirpation of an abundant semi-aquatic turtle from a lacustrine environment in the southwestern USA. Knowledge & Management of Aquatic Ecosystems **418**:18.

Lubcke GM, Wilson DS. 2007. Variation in shell morphology of the western pond turtle (*Actinemys marmorata* Baird and Girard) from three aquatic habitats in northern California. Journal of Herpetology **41**:107–115.

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.

Matsumoto Y, Hannigan B, Crews D. 2014. Embryonic PCB exposure alters phenotypic, genetic, and epigenetic profiles in turtle sex determination, a biomarker of environmental contamination. Endocrinology **155**:4168–4177.

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.

Meyer E, Eagles-Smith CA, Sparling D, Blumenshine S. 2014. Mercury exposure associated with altered plasma thyroid hormones in the declining western pond turtle (*Emys marmorata*) from California mountain streams. Environmental Science & Technology **48**:2989–2996.

Meyer E, Eskew EA, Chibwe L, Schrlau J, Simonich SLM, Todd BD. 2016. Organic contaminants in western pond turtles in remote habitat in California. Chemosphere **154**:326–334.

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.

Mitchell JC, Klemens MW. 2000. Primary and secondary effects of habitat alteration. Pages 5–32 in K. W. Klemens, editor. Turtle conservation. Smithsonian Press, Washington, D.C.

Mitchell NJ, Janzen FJ. 2010. Temperature-dependent sex determination and contemporary climate change. Sexual Development **4**:129–140.

Moyle PB. 1973. Effects of introduced bullfrogs, *Rana catesbeiana*, on the native frogs of the San Joaquin Valley, California. Copeia **1973**:18–22.

NOAA/National Ocean Service. 2019. NOAA Tides and Currents: Sea Level Trends. Available from http://tidesandcurrents.noaa.gov/sltrends/sltrends.html.

Nyhof PE, Trulio L. 2015. Basking western pond turtle response to recreational trail use in urban California. Chelonian Conservation and Biology **14**:182–184.

O'Connor MI, Piehler MF, Leech DM, Anton A, Bruno JF. 2009. Warming and resource availability shift food web structure and metabolism. PLoS Biology **7**:e1000178.

Olden JD, Naiman RJ. 2010. Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. Freshwater Biology **55**:86–107.

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.

Parmenter RR. 1980. Effects of food availability and water temperature on the feeding ecology of pond sliders (*Chrysemys s. scripta*). Copeia **1980**:503–514.

Parmenter RR, Avery HW. 1990. The feeding ecology of the slider turtle. Pages 257–265 in J. Gibbons, editor. Life history and ecology of the slider turtle. Smithsonian Institution Press, Washington, D.C.

Petchey OL, McPhearson PT, Casey TM, Morin PJ. 1999. Environmental warming alters food-web structure and ecosystem function. Nature **402**:69–72.

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.

Pilliod DS, Welty JL, Stafford R. 2013. Terrestrial movement patterns of western pond turtles (*Actinemys marmorata*) in central California. Herpetological Conservation and Biology **8**:207221.

Polo-Cavia N, Engstrom T, López P, Martín J. 2010. Body condition does not predict immunocompetence of western pond turtles in altered versus natural habitats. Animal Conservation **13**:256–264.

Purcell KL, McGregor EL, Calderala K. 2017. Effects of drought on western pond turtle survival and movement patterns. Journal of Fish and Wildlife Management **8**:15–27.

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

Reese DA. 1996. Comparative demography and habitat use of western pond turtles in northern California: the effects of damming and related alterations. Ph.D dissertation. University of California, Berkeley, CA.

Reese DA, Welsh HH. 1997. Use of terrestrial habitat by western pond turtles (*Clemmys marmorata*): implications for management. Pages 352–357 in V. Abbema, editor. Proceedings: Conservation, restoration and management of tortoises and turtles – an international conference. New York Turtle and Tortoise Society, Purchase, NY.

Reese DA, Welsh HH. 1998a. Comparative demography of *Clemmys marmorata* populations in the Trinity River of California in the context of dam-induced alterations. Journal of Herpetology **32**:505–515.

Reese DA, Welsh HH. 1998b. Habitat use by western pond turtles in the Trinity River, California. The Journal of Wildlife Management **62**:842–853.

Roe JH, Rees M, Georges A. 2011. Suburbs: dangers or drought refugia for freshwater turtle populations? The Journal of Wildlife Management **75**:1544–1552.

Rowe CL. 2008. “The calamity of so long life”: life histories, contaminants, and potential emerging threats to long-lived vertebrates. BioScience **58**:623–631.

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.

Sawaske SR, Freyberg DL. 2014. An analysis of trends in baseflow recession and low-flows in rain-dominated coastal streams of the Pacific coast. Journal of Hydrology **519**:599–610.

Schroeder MJ, Glovinsky M, Henricks VF, Hood FC, Hull MK. 1964. Synoptic weather types associated with critical fire weather. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Schwanz LE, Janzen FJ. 2008. Climate change and temperature-dependent sex determination: can individual plasticity in nesting phenology prevent extreme sex ratios? Physiological and Biochemical Zoology **81**:826–834.

Sharples JJ. 2009. An overview of mountain meteorological effects relevant to fire behaviour and bushfire risk. International Journal of Wildland Fire **18**:737–754.

Snover ML, Adams MJ. 2016. Herpetological monitoring and assessment on the Trinity River, Trinity County, California—final report. Open-File Report 2016-1089. U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, OR.

Snover ML, Adams MJ, Ashton DT, Bettaso JB, Welsh HH. 2015. Evidence of counter-gradient growth in western pond turtles (*Actinemys marmorata*) across thermal gradients. Freshwater Biology **60**:1944–1963.

Soulé ME, Bolger DT, Alberts AC, Wrights J, Sorice M, Hill S. 1988. Reconstructed dynamics of rapid extinctions of chaparral-requiring birds in urban habitat islands. Conservation Biology **2**:75–92.

Spinks PQ, Pauly GB, Crayon JJ, Shaffer HB. 2003. Survival of the western pond turtle (*Emys marmorata*) in an urban California environment. Biological Conservation **113**:257–267.

Spinks PQ, Shaffer HB. 2005. Range-wide molecular analysis of the western pond turtle (*Emys marmorata*): cryptic variation, isolation by distance, and their conservation implications. Molecular Ecology **14**:2047–2064.

Spinks PQ, Thomson RC, Shaffer HB. 2014. The advantages of going large: genome-wide SNPs clarify the complex population history and systematics of the threatened western pond turtle. Molecular Ecology **23**:2228–2241.

St. John WA. 2015. Drivers of non-random nest-site selection in an oviparous vertebrate. Master of Science thesis. Sonoma State University, Rohnert Park, CA.

Steen DA, Gibbs JP. 2004. Effects of roads on the structure of freshwater turtle populations. Conservation Biology **18**:1143–1148.

Steen DA, Hopkins BC, Dyke JUV, Hopkins WA. 2014. Prevalence of ingested fish hooks in freshwater turtles from five rivers in the southeastern United States. PLoS ONE **9**:e91368.

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.

Stewart IT, Cayan DR, Dettinger MD. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate **18**:1136–1155.

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

Sweet WV, Kopp RE, Weaver CP, Obeysekera J, Horton RM, Thieler ER, Zervas C. 2017. Global and regional sea level rise scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. National Oceanic and Atmospheric Administration, Silver Spring, MD.

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.

Thomson RC, Wright AN, Shaffer HB. 2016. California amphibian and reptile species of special concern. University of California Press, Oakland, CA.

Turtle Taxonomy Working Group, Rhodin AGJ, Iverson JB, Bour R, Fritz U, Georges A, Shaffer HB, van Dijk PP. 2017. Turtles of the world: annotated checklist and atlas of taxonomy, synonymy, distribution, and conservation status. Pages 1–292 in A. G. J. Rhodin, J. B. Iverson, P. P. van Dijk, R. A. Saumure, K. A. Buhlmann, P. C. H. Pritchard, and R. A. Mittermeier, editors. Conservation biology of freshwater turtles and tortoises: a compilation project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group. Chelonian Research Monographs 7. doi: 10.3854/crm.7.checklist.atlas.v8.2017, 8th edition.

Ultsch GR. 2006. The ecology of overwintering among turtles: where turtles overwinter and its consequences. Biological reviews **81**:339–367.

Vincent WF. 2009. Effects of climate change on lakes. Pages 55–60 in G. E. Likens, editor. Encyclopedia of Inland Waters. Elsevier, Amsterdam.

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.

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.

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),[9] 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.[10]

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

[10] 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.