Frogs
Northern California Climate Change Vulnerability Assessment Synthesis

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

Peer reviewers for this document included Anonymous (University of California, Davis), Sam Cuenca (U.S. Forest Service), Sarah Kupferberg (University of California, Berkeley), and Deanna H. Olson (U.S. Forest Service). Vulnerability scores were provided by Patrick Kleeman (U.S. Geological Survey). Upper Lake workshop participants provided additional comments on the climate change vulnerability of this species group.

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Species Group Description

This assessment includes the foothill yellow-legged frog (*Rana boylii*), northern red-legged frog (*R. aurora*), Cascades frog (*R. cascadae*), and coastal tailed frog (*Ascaphus truei*). All four of these species breed in aquatic habitat, but they vary in geographic range and habitat requirements in northern California (Hayes et al. 2016; Thomson et al. 2016).[1]

The foothill yellow-legged frog is the most widely distributed of the three species, and occurs from central Oregon west of the crest of the Cascades southward into central California in the foothills of the Coast Range and along the western slopes of the Sierra Nevada, with robust populations still occurring in the North Coast Range (Hayes et al. 2016). This species is found mostly in foothill and lowland streams from sea level up to approximately 2,000 m (6,500 ft; Elliott et al. 2009; Hayes et al. 2016). In northern California, they are more likely to be present in habitat without large dams, and recent abundance estimates show similar population levels in coastal and inland montane watersheds (Kupferberg et al. 2012). In some North Coast sites, such as on the Mad River and South Fork Eel, foothill yellow-legged frog densities are among the highest recorded in the state (Kupferberg et al. 2012).

The northern red-legged frog is distributed from Vancouver Island and the adjacent mainland coast of British Columbia south along the western side of the Cascade Crest through Mendocino County in California (Stebbins 2003). This species is a coastal pond- and stream-breeder whose distribution in northwestern California is limited to lowlands and foothills between the coast and inland mountains (Elliott et al. 2009). They spend more time in terrestrial habitats than the other frogs considered in this assessment, and may be found far from breeding habitat in damp or wet upland vegetation (Elliott et al. 2009). Within forested areas, northern red-legged frogs are more common in mature and old-growth forests, though they are not restricted to these habitats (Aubry & Hall 1991).

The Cascades frog is distributed from northern California through Oregon and Washington (Jennings & Hayes 1994; Blaustein et al. 1995; Stebbins 2003), with an elevational range from 230–2,500 m (750–8,200 ft; (Jennings & Hayes 1994). They are near extirpation in the southern Cascades portion of their range in California, but remain fairly widespread in the Klamath Mountains (Pope et al. 2014). Cascades frogs are a montane species and breed primarily in lentic habitats, including wet meadows, lakes, and ponds, though they can also breed in adjacent slow-flowing streams (Pope et al. 2014).

Finally, the highly aquatic coastal tailed frog (also known as Pacific tailed frog) is one of two species of tailed frog in the western United States (Elliott et al. 2009). They are distributed from British Columbia to northern California, mostly west of the Cascade Mountains (Stebbins 2003; Thomson et al. 2016). Within the study region, which occurs at the southern limit of the species' range, they occur along the coast from the Oregon border through Mendocino County and east to Shasta County (Salt 1952; Bury 1968; Welsh 1985). Coastal tailed frogs are more abundant in harvested or older forests compared to harvest or younger stands (Bury & Corn

[1] Note that there is much more information available for foothill yellow-legged frogs than for the other species, and much of that is based on studies from the Sierra Nevada. Differences in habitat preferences, life history characteristics, and other factors prevent conclusions from research on foothill yellow-legged frogs from being universally applied to other species or other geographies. This highlights the importance of further research for under-studied species (Vuln. Assessment Reviewer, pers. comm., 2019).

1988; Corn & Bury 1989; Welsh 1990; Gomez & Anthony 1996; Welsh & Lind 2002; Ashton et al. 2006). However, they are found in younger forests nearer to the coast (mostly within 30 km [18.6 mi]) likely due to the buffering effect of the maritime climate (Bury 1968; Diller & Wallace 1999).This extreme habitat specialist occupies cold, fast-flowing streams and has several unusual adaptations to breeding in swift-flowing waters, including its "tail," which is actually a reproductive organ used for internal egg fertilization (Elliott et al. 2009).

Executive Summary

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

Frogs	**Rank**	**Confidence**
Sensitivity	Moderate	Moderate
Future Exposure	Moderate-High	Low
Adaptive Capacity	Moderate	Moderate
Vulnerability	**Moderate**	**Moderate**

Sensitivity & Exposure Summary	*Climate and climate-driven factors*: • Water temperature, streamflow, precipitation amount and timing, drought *Disturbance regimes*: • Flooding, disease, wildfire *Non-climate stressors*: • Dams and water diversions (e.g., flow regulation), pollution/poisons, invasive species, roads/highways/trails, timber harvest, agriculture, mining, and development

Frogs are sensitive to factors that disrupt seasonal hydrological patterns and sediment transport in aquatic habitats. Climate-driven changes in hydrology (including altered flooding regimes) can have deleterious effects on egg and larvae survival, aquatic food webs, and habitat quality and availability. Increased disease risk in a warming climate presents an additional threat to frog populations and has been implicated in frog species declines in other areas, although the level of risk to individual species in northern California is unclear. Altered wildfire regimes (e.g., uncharacteristically large and/or severe fires) may increase the risk of decline or extirpation for small, isolated, or stressed (e.g., from drought, reduced prey availability, or disease) frog populations. Additionally, fungal diseases and parasites are contributing to increased morbidity and mortality in many frog species, and chytridiomycosis, in particular, appears to interact with other stressors (e.g., introduced fish) and has been linked to declines in the Cascades frog. Many non-climate stressors further exacerbate the potential effects of climate stressors and changing disturbance regimes on frogs. For instance, frogs are vulnerable to changes in hydrological regimes due to regulated flows on dammed rivers. Invasive species (i.e., introduced fish and American bullfrogs [*Lithobates catesbeianus*]) increase predation, compete for food, and are associated with enhanced vulnerability to disease. Frogs are also highly sensitive to contaminants, which can increase mortality across all life stages.

Other factors that degrade frog habitat and/or act as barriers to movement include roads, agriculture, development, timber harvest, and mining.

Adaptive Capacity Summary	*Factors that enhance adaptive capacity*: + Relatively mobile taxa (i.e., can move to new habitats in response to changing conditions) + Healthy, connected populations in some areas, which maintain gene flow and can serve as source populations following stochastic events *Factors that undermine adaptive capacity*: – Fragmented and/or isolated populations in many areas, which limits genetic diversity – Dispersal barriers (e.g., large rivers, roads, mountain ridges, xeric uplands) preclude movement and limit ability to respond to changing environmental conditions – High habitat specificity in some species (e.g., coastal tailed frogs) – Limited behavioral plasticity in response to rapidly changing climate conditions – Lack of public awareness of threat to species group and corresponding reduced capacity of wildlife agencies to invest in frog conservation actions

Although relatively little information is available on population trends in northern California (particularly for northern red-legged and coastal tailed frogs), frog populations are declining more generally in the western U.S. and globally. However, northern California likely provides refugia for some species. Frogs show some behavioral plasticity in response to environmental stress by seeking microrefugia or emigrating to new habitats, however it is unclear whether this trait will protect frog populations in a changing climate. Management efforts to address climate impacts on native frogs may focus on identifying places where aquatic and terrestrial habitat connectivity has been disrupted and increasing connectivity where possible (i.e., via habitat restoration to provide shading, ground structures, and microclimate refugia in uplands; also, reintroduction and/or assisted migration); lessening impacts of human land use and management practices; and increasing understanding of basic frog ecology and responses to stressors.

Sensitivity and Exposure

Frogs were evaluated by regional experts as having moderate overall sensitivity[2] (moderate confidence in evaluation) and moderate-high overall future exposure (low confidence) to climate and climate-driven factors, changes in disturbance regimes, and non-climate stressors.

Habitat refugia will be particularly important for frog survival in a changing climate (Blaustein et al. 2010; Thomson et al. 2016; Catenazzi & Kupferberg 2017). Coastal habitats in northern California may serve as climate refugia for some frog populations as long as they are able to migrate from inland habitats (Thomson et al. 2016; Vuln. Assessment Workshop, pers. comm., 2017). Groundwater-fed streams and wetlands may also be more resilient to climate change,

[2] Climate sensitivity assessments of the foothill yellow-legged frog, northern red-legged frog, and coastal tailed frog in Oregon also assigned rankings of moderate sensitivity, based on an analysis of area of occupancy, geographic rarity, and variation in climate metrics at known sites, relativized across all Oregon amphibian taxa (Mims et al. 2018).

representing possible refugia for northern California frogs (Vuln. Assessment Reviewer, pers. comm., 2019).

Sensitivity and future exposure to climate and climate-driven factors

Regional experts evaluated frogs as having moderate sensitivity to climate and climate-driven factors (high confidence in evaluation), with an overall moderate-high future exposure to these factors within the study region (low confidence). Key climatic factors that affect frogs include water temperature, streamflow, precipitation amount and timing, and drought.[3]

Water temperature

Temperature is one of the primary factors influencing the onset of oviposition in foothill yellow-legged frogs, with earlier oviposition occurring at warmer sites in both the Sierra Nevada (Kupferberg 1996; Catenazzi & Kupferberg 2013) and northwestern California (Wheeler et al. 2015, 2018). Water temperature is also associated with the onset of calling behavior and the number of calls detected (Wheeler et al. 2018). The pattern of earlier breeding activity in warmer waters has also been found in other anurans (i.e., frogs and toads; Fukuyama & Kusano 1992; Oseen & Wassersug 2002; Saenz et al. 2006). Water temperature also impacts other aspects of physiology and behavior, such as egg and tadpole development and growth rates (Olson 1988; Hutchison & Dupré 1992; Blouin & Brown 2000). Cold water appears particularly important for coastal tailed frogs; for example first-year larvae occur in streams <10°C (18°F) (Blaustein et al. 1995; Brown 2005), whereas foothill yellow-legged frogs can breed in streams ranging from 10-20°C (Olson & Davis 2009; Wheeler et al. 2018). However, there are no known studies that have directly considered the impacts of increasing water temperatures on frogs in the context of climate change.

Increasing water temperatures can also contribute to shifts in aquatic periphyton communities away from palatable species, potentially reducing food resources for grazing tadpoles and influencing insect populations eaten by adult frogs (Furey et al. 2014; Vuln. Assessment Reviewer, pers. comm., 2019). Unusually warm water temperatures also allow toxic algae blooms that can have negative consequences for all consumers at higher trophic levels (Power et al. 2015), though there are no studies that explicitly document impacts on frogs. Warmer water temperatures also favor species such as smallmouth bass (*Micropterus dolomieui*) and bluegill (*Lepomis macrochirus*) that prey on frog larvae (Vuln. Assessment Reviewer, pers. comm., 2019).

[3] Climate and climate-driven factors presented are those ranked as having a moderate or higher impact on this species group; additional climate and climate-driven factors that may influence the species group to a lesser degree include timing of snowmelt/runoff and storms.

Regional Water Temperature Trends[4]	

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 Group *(see text for citations)*	
• Earlier timing of breeding activity associated with warmer water temperatures, which also impact egg and tadpole development and growth • Possible shifts in periphyton communities away from palatable species, affecting food availability	

Streamflow

Stream-breeding frogs in northern California are adapted to high and variable flows in fall through spring and lower, more stable flows in the summer (Hayes et al. 2016; Thomson et al. 2016). For instance, the foothill yellow-legged frog varies the timing of breeding activities such as calling and oviposition in response to water depth conditions that maximize reproductive success (Wheeler et al. 2018). Seasonal flow variability also governs the re-assembly of riverine algal-based food webs (Power et al. 2008, 2015), of which frogs are an integral part (Vuln. Assessment Reviewer, pers. comm., 2019).

Multiple studies have found that altered streamflow regimes can disrupt breeding phenology and alter or eliminate aquatic habitat for frogs (Thomson et al. 2016). For example, rapid streamflow declines can leave eggs vulnerable to desiccation and strand tadpoles (Carey & Alexander 2003). Adults are also subject to desiccation during very low flows due to high rates of water loss via the skin and respiratory systems (Carey & Alexander 2003). Reduced streamflows, combined with warm water temperatures, can lead to outbreaks of diseases and parasites, elevating frog morbidity and mortality (Kupferberg et al. 2009a; Adams et al. 2017). Shifts in flow volume and timing may also lead to a mismatch between the timing of breeding with necessary stream conditions and food resources (Furey et al. 2014; Power et al. 2015; Catenazzi & Kupferberg 2017), affecting the growth and development of early life stages

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

(Catenazzi & Kupferberg 2013, 2018; Wheeler et al. 2015). For instance, shifts towards earlier spring peak flows in snowmelt-dominated streams could limit reproductive success in foothill yellow-legged frogs by washing away egg masses and increasing the need for tadpoles to seek refuge (Kupferberg et al. 2009b).

<table>
<tr><th colspan="2">Regional Streamflow Trends</th></tr>
<tr><td>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)</td><td>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)</td></tr>
<tr><th colspan="2">Summary of Potential Impacts on Species Group (see text for citations)</th></tr>
<tr><td colspan="2">• Reduced availability of aquatic habitat and greater rates of desiccation and tadpole stranding during periods of very low flows
• Potential mismatch in the timing of breeding and necessary flow conditions, limiting reproductive success
• Increased incidence of disease outbreaks and parasites</td></tr>
</table>

Precipitation amount/timing and drought

Amphibian dependence on hydrological conditions for reproduction makes them vulnerable to precipitation variability (Carey & Alexander 2003). Changes in the amount and/or timing of precipitation that alters depth, velocity, or hydroperiod can dramatically affect the yearly reproductive output of frog populations (Carey & Alexander 2003). For instance, heavy precipitation after foothill yellow-legged frog egg masses have been deposited and/or during larval development can result in mortality, significantly reducing recruitment (Lind et al. 1996; Kupferberg et al. 2009b, 2012). Because frogs lay eggs in ponds, stream riffles or pools (Thomson et al. 2016), eggs and larvae are also vulnerable to desiccation in times of low precipitation, when these water bodies may shrink (Carey & Alexander 2003; Garwood 2009). For instance, for northern red-legged frogs to successfully breed, water must be retained in lentic habitats from breeding (between December and February) through the end of the larval period in mid- to late-summer in order to facilitate successful metamorphosis (McAllister & Leonard 2005; Ostergaard et al. 2008). Dry conditions can also impact larvae indirectly by affecting food supply and predator distribution (Pearman 1995). Furthermore, increased evaporation during warm weather, coupled with low precipitation, can concentrate pollutions and poisons with toxic effects on larvae (Carey & Bryant 1995).

Adult frog survivorship can also be impacted by water availability (Carey & Alexander 2003; Thomson et al. 2016). Periods of low precipitation leave terrestrial adult frogs vulnerable to water loss from the skin and respiratory systems (Carey & Alexander 2003). During periods of prolonged drought, extensive mortality of adult frogs could occur if they are unable to find or access moist microclimates (Carey & Alexander 2003). Survivorship may be also be reduced if lack of moisture compromises functioning, such as ability to forage and evade predators (Carey & Alexander 2003).

Changes in precipitation amount and timing and increased drought will likely reduce available aquatic breeding habitat, potentially restricting frog distribution (Carey & Alexander 2003). However, drier conditions could benefit some native frogs by reducing populations of non-native fish and bullfrogs in some perennial ponds that begin to dry out periodically (Adams 2000; Adams & Pearl 2007). Any potential benefit from reduced predator populations would be lost, though, if the hydroperiod becomes too short for the completion of larval development by native species (Vuln. Assessment Reviewer, pers. comm., 2019).

Regional Precipitation & Drought Trends	
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)[5] • 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 decrease (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

[5] 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	
	years will occur once every 10 years by 2100 and once-in-a-century drought will occur once every 20 years (Pierce et al. 2018)

Summary of Potential Impacts on Species Group *(see text for citations)*
• Reduced reproductive success due to increased egg/larval mortality during heavy precipitation events or periods of drought • Decreased aquatic habitat availability and quality, potentially restricting frog distribution • Increased adult frog mortality during periods of extended and/or severe drought

Sensitivity and future exposure to changes in natural disturbance regimes

Regional experts evaluated frogs as having moderate sensitivity to changes in natural disturbance regimes (moderate confidence in evaluation), with an overall moderate-high future exposure to these stressors within the study region (low confidence). Key natural disturbance regimes that affect frogs include flooding, disease, and wildfire.[6]

Flooding

California frogs are adapted to periodic flooding typical of the region. For example, foothill yellow-legged frogs breed after peak spring flows have subsided to avoid scouring that can wash away egg masses and tadpoles (Kupferberg et al. 2009b; Wheeler et al. 2018). However, changes in flood timing, frequency, or magnitude may impact reproductive success (i.e., when they occur during or after oviposition; Kupferberg 1996; Lind et al. 1996; Kupferberg et al. 2012). Decreased flood disturbance in streams and rivers, either due to flow regulation or climate change, can also allow non-native predators and competitors of native amphibians to establish, proliferate, and migrate further upstream (Kupferberg 1997; Doubledee et al. 2003; Fuller et al. 2011). Many of the non-native aquatic vertebrates (e.g. American bullfrogs, bass) that have negative effects on California frogs are better suited to lentic conditions and less able to persist when flooding events are frequent (Vuln. Assessment Reviewer, pers. comm., 2019).

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)

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

Regional Flooding Trends
Summary of Potential Impacts on Species Group *(see text for citations)*
• Reduced reproductive success due to changes in the timing, frequency, or magnitude of flooding • Increased establishment of non-native predators/competitors where flood disturbance decreases

Disease

Population declines in foothill yellow-legged frogs and Cascades frogs have been linked to both fungal diseases (e.g., chytridiomycosis, caused by the chytrid fungus *Batrachochytrium dendrobatidis* (*Bd*) and parasites, which increase morbidity and mortality (Kupferberg et al. 2009a; Piovia-Scott et al. 2011, 2015; Adams et al. 2017). The chytrid fungi can be carried by disease-tolerant host species, some of which are highly invasive such as the African clawed frog (*Xenopus laevis*; Vredenburg et al. 2013) and the American bullfrog (*Rana catesbeiana*; Huss et al. 2013), as well as by the native Pacific chorus frog (*Pseudacris regilla*; Reeder et al. 2012). In foothill yellow-legged frogs, chytrid infections do not appear to significantly reduce adult survival on its own, though it does suppress growth of recently metamorphosed individuals by approximately 40% (Davidson et al. 2007). However, chytridiomycosis may increase mortality to a greater degree in foothill yellow-legged frog populations also stressed by factors such as altered hydrology and the presence of American bullfrogs (Adams et al. 2017). In the Klamath Mountains, chytridiomycosis has been linked to dramatic declines in juvenile Cascades frogs (Piovia-Scott et al. 2015). Follow-up laboratory experiments found that specific phenotypic and genotypic characteristics of the pathogen can vary, resulting in greater virulence on the sites associated with steep populations declines (Piovia-Scott et al. 2015). Increased temperatures in terrestrial habitat have been associated with reduced fungal impacts in frogs, which may reduce the impact of *Bd* on some frog populations during the summer (Piovia-Scott et al. 2011; Adams et al. 2017). Skin peptides present in the foothill yellow-legged frog may also provide some protection from chytridiomycosis (Davidson et al. 2007).

Parasites, such as the copepod *Lernaea cyprinacea*, cause malformations in young foothill yellow-legged frogs (Kupferberg et al. 2009a), and climate change is likely to affect disease dynamics related to parasite abundance (Thomson et al. 2016). For example, outbreaks of non-native parasitic copepods in foothill yellow-legged frogs occurred during two warm years at a long-term study site, resulting in morphological abnormalities and smaller sizes at metamorphosis (Kupferberg et al. 2009a). The outbreak was likely caused by increased summer water temperature and/or decreased daily stream discharge (Thomson et al. 2016).

Regional Disease Trends	
Historical & current trends: • No trends available for disease	*Projected future trends:* • Expansion of the projected future climate niche for *Bd* in northern temperate ecosystems (Xie et al. 2016)

Regional Disease Trends
Summary of Potential Impacts on Species Group *(see text for citations)*
• Increased illness and mortality, particularly in stressed individuals

Wildfire

Direct impacts of wildfire on frogs can include mortality within both terrestrial and aquatic habitats (Hossack & Pilliod 2011). In aquatic life stages, mortality could occur from thermal stress or rapid changes in water chemistry (Spencer & Hauer 1991; Hossack & Pilliod 2011). The impacts of wildfire on frogs vary across habitats and spatial scales (Hossack & Pilliod 2011). Individual frogs or small populations may respond to disturbances at the microhabitat level, where fires eliminate or alter cover through burning of understory vegetation and woody debris or deposit ash and sediment in aquatic substrates (Hossack & Pilliod 2011). At the macrohabitat level (e.g. lake, pond, and stream), fires may increase solar radiation and water temperatures, alter hydroperiods and nutrient cycling, and enhance productivity in aquatic systems (Hossack & Pilliod 2011). In general, frogs that have narrow geographic distributions, are closely tied to specific microhabitat conditions (e.g., water temperatures), or occur in areas that historically experienced long fire-return intervals (such as cool, mesic forests) are likely to be most affected by altered wildfire regimes (Pilliod et al. 2003; Hossack & Pilliod 2011). Frogs stressed by drought or disease may also be more vulnerable to decline or extirpation (Hossack & Pilliod 2011). In addition, the sensitivity of frogs to wildfire likely varies among life stages, populations in different geographic regions, and species, depending on life history characteristics (e.g., reproduction timing, larval duration, adult mobility, desiccation resistance; Pilliod et al. 2003).

The season in which the wildfire occurs also plays a role in the severity of impact on frog populations (Hossack & Pilliod 2011). Most wildland fires in the Pacific Northwest occur in the late summer when conditions are driest, and many frog species are underground or near aquatic habitat (Pilliod et al. 2003). However, wildfire season in northern California has been starting earlier in the year (Westerling 2016), beginning as early as May and June in the Klamath National Forest compared to more traditional July/August timeframes (Vuln. Assessment Reviewer, pers. comm., 2019). Fires occurring earlier in the season may impact frogs to a greater degree, particularly if they occur during periods of migration to or dispersal from breeding sites (Pilliod et al. 2003). Similarly, fires burning unusually late in the season (e.g., such as the 2018 Camp Fire that occurred in November) could also have impacts on immediate food availability for adult frogs, leading to reduced fitness and reproduction (Vuln. Assessment Reviewer, pers. comm., 2019).

Rapid increases in stream temperatures can occur during wildfire from fuel combustion or post-fire from increased solar radiation due to the loss of riparian vegetation (Minshall et al. 1997; Hossack & Pilliod 2011). Changes in daily and seasonal water temperature profiles can have negative effects on frog development and survival, particularly for cold-adapted stream species (Hossack & Pilliod 2011). Even if streams do not reach species' thermal tolerance levels during or after a fire, sublethal or lethal stress may result from exposure to elevated temperatures over time (Hossack & Pilliod 2011).

Loss of vegetation from wildfires often results in accelerated soil erosion and overland flow, particularly on steeper slopes (Pettit & Naiman 2007). During storms and periods of snowmelt after wildfire, heavy sediment loads entering streams can alter channel substrate and morphology, negatively impacting aquatic biota (Newcombe & MacDonald 1991), including frogs. Sedimentation from post-fire runoff in streams could result in decreased growth and development of tadpoles (Gillespie 2002) as well as adverse effects on frogs that use the interstitial spaces between rocks to lay eggs, forage, and hide from predators (Hossack & Pilliod 2011). However, the introduction of sediment and debris into streams can also increase habitat complexity and enhance aquatic food production (Pilliod et al. 2003). Aquatic habitat extent may increase due to a reduction of forest density and canopy that increases water yield into aquatic habitats (Hayes et al. 2016).

There are currently few studies that examine the impact of wildfire on native frogs in northern California (Vuln. Assessment Reviewer, pers. comm., 2019) or elsewhere (Hossack & Pilliod 2011). However, researchers are currently examining the effects of the 2018 Camp Fire (affected the Feather River) and 2018 Eel Fire (affected the mainstem and Rice Fork of the Eel River) on foothill yellow-legged frogs (Vuln. Assessment Reviewer, pers. comm., 2019). Fall surveys on the Eel River indicate that the frogs survived and produced metamorphs, even in places where intense fire burned all the way to the water's edge (Vuln. Assessment Reviewer, pers. comm., 2019). However, whether the population will survive over the long term depends on the extent of debris flows and sediment transport in the tributaries and mainstem channels (Vuln. Assessment Reviewer, pers. comm., 2019). Anecdotal reports indicate that fire opened up breeding habitats in some places, such as on Bull Meadow Creek (a tributary of the Clavey River) where alder canopy was very dense (Vuln. Assessment Reviewer, pers. comm., 2019). Populations appeared to be most impacted in tributaries used for pumping water during the fire, as well as where extensive bulldozing occurred for the construction of a fire break (Vuln. Assessment Reviewer, pers. comm., 2019).

<table>
<tr><th colspan="2">Regional Wildfire Trends</th></tr>
<tr><td>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):</td><td>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</td></tr>
</table>

Regional Wildfire Trends

- 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

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 Group *(see text for citations)*

- *Immediate*:
  - Increased mortality in both aquatic and terrestrial habitat due to the direct effects of fire and/or changes in habitat availability and quality that affect survivability
- *Short-term (~2-year)*:
  - Increased sediment and debris in streams during post-fire precipitation events, potentially altering substrate, channel morphology, habitat complexity, and food web production
- *Long-term*:
  - Possible increases in habitat complexity

Dependency on habitat and/or other species

Regional experts evaluated frogs as having low-moderate dependency on sensitive habitats (moderate confidence in evaluation) and low dependency on prey or forage species (moderate confidence). Frogs also have a low-moderate dependency on other factors, including stream flow levels (i.e., flows that do not strand egg masses or scour egg masses) and light that allows algae growth for larvae to feed on (moderate confidence).

All four frog species included in this assessment breed in aquatic habitat and spend time in terrestrial habitat, largely forested uplands (Jones et al. 2005). The northern red-legged frog is the most terrestrial of the three species, and is associated with lentic habitats including off-channel pools, and breeds in shallow areas that often have emergent vegetation (McAllister & Leonard 2005). Aspects of microhabitat habitat complexity such as wetland bays and proximity to upland forest are positively associated with the occurrence of this species, while it is negatively associated with upland impervious areas in urban settings (Ostergaard et al. 2008). Cascades frogs are also found in lentic habitats, but at higher elevations compared to the northern red-legged frog. They breed primarily in wet meadows, lakes, and ponds, though they can also breed in adjacent slow-flowing streams (Pope et al. 2014).

The foothill yellow-legged frog breeds in streams large enough to develop bar and backwater habitats (Hayes et al. 2005), and spends more time in riparian habitat than the coastal tailed frog (Hayes et al. 2016; Thomson et al. 2016). As the most aquatic of the species considered in this assessment, coastal tailed frogs are associated with streams in forested uplands, and are often found in higher elevation, fast-flowing streams within old-growth forest conditions (Brown 2005). Larvae require rocky stream substrates for foraging on diatoms, while juveniles and adult tailed frogs use streams and stream banks (Brown 2005). This species has several adaptations to live (e.g., ventral sucker) and breed (i.e., their "tail") successfully in fast-moving water (Elliott et al. 2009).

Sensitivity and current exposure to non-climate stressors

Regional experts evaluated frogs as having moderate sensitivity to non-climate stressors (high confidence in evaluation), with an overall moderate current exposure to these stressors within the study region (high confidence). Key non-climate stressors that affect frogs include dams and water diversions, pollution and poisons, invasive species, roads/highways/trails, timber harvest, agriculture, mining, and development.[7]

Dams and water diversions

Negative impacts (i.e. altered flow volume and timing) downstream of impoundments have been documented for foothill yellow-legged frogs and northern red-legged frogs (Kupferberg et al. 2012; Yarnell et al. 2015; Courcelles 2016), though most research is focused on foothill yellow-legged frogs and no studies were found for the coastal tailed frog and Cascades frog.

Flow alterations result in reduced distribution and abundance of breeding frog populations below dams (Lind 2005; Kupferberg et al. 2012). Rapid increases in flow volume that occur after oviposition can displace foothill yellow-legged frog egg masses, reducing clutch survival (Lind et al. 1996; Kupferberg et al. 2012). Uncharacteristically low flows, by contrast, increase the risk of egg mass and tadpole desiccation and predation (Kupferberg 1996; Kupferberg et al. 2011). Loss of flow variability and reduced flows may also have longer-term impacts on riparian vegetation, sediment transport, and stream channel morphology, reducing habitat suitability (Lind et al. 1996; Courcelles 2016; Hayes et al. 2016). Even small dams can increase fine sediment and alter the primary productivity of streams, which is associated with reduced tadpole density in coastal tailed frogs (Courcelles 2016).

Dams alter water temperatures downstream for many kilometers, affecting the aquatic food web on which frogs depend and impacting tadpole growth and survival (Kupferberg et al. 2011; Catenazzi & Kupferberg 2013; Furey et al. 2014). Water temperatures are often

[7] All non-climate stressors were ranked as having a moderate or higher impact on this species group.

uncharacteristically warm when summer base flows are artificially low due to dams, increasing thermal stress on tadpoles and frogs (Catenazzi & Kupferberg 2013). By contrast, the release of cold water from deep reservoirs can result in unusually cold water temperatures, reducing tadpole growth and potentially delaying metamorphosis in foothill yellow-legged frogs (Lind et al. 1996; Catenazzi & Kupferberg 2013, 2017, 2018). Both thermal and hydrological changes in regulated rivers and streams can also shift phytoplankton productivity and composition, potentially reducing food availability for tadpoles (Catenazzi & Kupferberg 2013; Furey et al. 2014). For example, dams can increase the spread of the invasive benthic diatom, *Didymosphenia geminata*, which is associated with cool summer water temperatures (Kirkwood et al. 2009; Kumar et al. 2009). This diatom can displace more nutritious algal taxa required for robust growth of foothill yellow-legged frog tadpoles (Kupferberg et al. 2011; Furey et al. 2014). Reservoirs create habitat for introduced species, including invasive fish (Moyle 2002) and the American bullfrog (Fuller et al. 2011). Lastly, impoundments fragment riverine habitat and disrupt dispersal routes for juvenile and adult frogs (Hayes et al. 2016); genetic diversity of foothill yellow-legged frog populations in dammed rivers has been found to be lower than in undammed rivers (Peek 2010; Peek et al. 2018).

Water diversions may cause streams to dry up more rapidly or may make streams less lotic (Hayes et al. 2016). Even small operations, such as those used to divert water for growing cannabis (*Cannabis sativa, C. indica*), may have significant impacts on foothill streams with limited summer flows (Bauer et al. 2015; Carah et al. 2015). Suspected direct effects of water diversions on foothill yellow-legged frogs include removal of adults, tadpoles, and egg masses by water pumps and mutilation of animals on pump screens (Hayes et al. 2016). Diversions used for inter-basin movement of water may introduce fish and other invasive predators, or transfer disease-bearing vectors and disease-contaminated water (Hayes et al. 2016).

<u>Pollution and poisons</u>

Amphibians are vulnerable to pollutions and poisons due to their permeable skin (Thomson et al. 2016). Agricultural activities, such as cannabis and lily bulb production in Humboldt and Del Norte Counties, can introduce pesticides, herbicides, and fungicides into frog habitat (Thomson et al. 2016). Ranids appear to be more sensitive to pesticides than many other genera, with up to 90% tadpole mortality occurring in the Cascades frog, northern red-legged frogs and foothill yellow-legged frog following acute exposure to some insecticides (Hammond et al. 2012). Sublethal contaminant concentrations may also affect frogs indirectly by altering food webs or increasing susceptibility to pathogens such as *Bd* (Davidson et al. 2007; Blaustein et al. 2011).

Legacy and present-day mining can also introduce pollutants such as mercury into frog habitat (Alpers et al. 2001; Hayes et al. 2016). Frogs may also be sensitive to contaminants related to human recreation (e.g., camping) such as detergent, sunscreen, insect repellent components, and excess nitrogen from human waste (Rouse et al. 1999).

<u>Invasive species</u>

Frog populations in northern California are negatively affected by the presence of non-native fish species such as brown trout (*Salmo trutta*), green sunfish (*Lepomis cyanellus*), smallmouth bass, bluegill, and carp (*Cyprinus carpio*), as well as American bullfrogs and several species of crayfish (Hayes & Jennings 1986; Kupferberg 1997; USFWS 2002; Fuller 2008; Olson et al. 2009; Hayes et al. 2016). Both American bullfrogs and introduced fish can reduce frog recruitment and foraging activity (Vredenburg 2004; Olson et al. 2009). Breeding populations of foothill yellow-legged frogs can be an order of magnitude smaller when American bullfrogs are present (Kupferberg 1997). American bullfrog tadpoles likely compete for food with tadpoles from other frog species (Kupferberg 1997), while adult American bullfrogs prey on adults of native frog species (USFWS 2002; Hothem et al. 2009). The impacts of bullfrogs on northern red-legged frogs appears to be mediated by the distribution of food resources, with clumped resources intensifying interspecific competition compared to areas with more evenly scattered resources (Kiesecker et al. 2001). Impacts on the growth and development of northern red-legged frog larvae also appear to be greater when both bullfrogs and smallmouth bass are present (Kiesecker & Blaustein 1998). American bullfrogs also spread the chytrid fungus (Huss et al. 2013), which has impacted native amphibian populations in California (Kupferberg et al. 2009a; Piovia-Scott et al. 2011, 2015; Adams et al. 2017).

<u>Roads, highways, and trails</u>

Roads, highways, and trails reduce frog populations through road-kill mortality (Hamer & McDonnell 2008), alter and eliminate habitat, introduce sediments and pollutants, and increase frog population fragmentation in northern California (Hayes et al. 2016; Thomson et al. 2016). For example, road-building activities can increase sedimentation in aquatic habitat (Spellerberg 1998; Trombulak & Frissell 2000). High concentrations of suspended sediment may reduce growth of invertebrate food sources (Newcombe & MacDonald 1991; Waters 1995) and suffocate frog egg masses (Thomson et al. 2016). Road construction, in association with timber harvesting, has led to coastal tailed frog declines and location extirpations (Welsh & Ollivier 1998; Welsh et al. 2005) primarily through increased sedimentation, increased stream temperatures, and habitat fragmentation (Thomson et al. 2016). Northern red-legged frogs are increasingly impacted by road-building related to cannabis cultivation, which dewaters streams and other wetlands for irrigation and introduces pesticides and herbicides to frog habitat (Vuln. Assessment Reviewer, pers. comm., 2019). Additionally, vehicular emissions and road runoff contain chemical pollutants (e.g., heavy metals, salt, ozone, nutrients; Trombulak & Frissell 2000) that can reduce survival, cause deformities, elevate levels of stress hormones, and inhibit growth and metamorphosis (Mahaney 1994; Welsh & Ollivier 1998). Roads also fragment habitat and restrict foothill yellow-legged frog movement and migration. Many populations of foothill yellow-legged frogs are already small and fragmented, so further fragmentation of habitat from roads may lead to population declines (Hayes et al. 2016).

<u>Timber harvest, agriculture, mining, and development</u>

Other anthropogenic disturbances such as timber harvest, agriculture, mining, and residential/commercial development degrade habitats required by northern California frogs. Two studies of foothill yellow-legged frogs in Oregon and California found that they were less likely to occur in areas with more agriculture and urban development (Lind 2005; Olson & Davis 2009). Both mining and recreation activities were also noted as potentially having adverse effects on foothill yellow-legged frogs in Oregon streams (Olson & Davis 2009).

Negative effects of timber harvest are noted for both northern red-legged frogs and coastal tailed frogs (Blaustein et al. 1995). Coastal tailed frogs are considered old-growth forest associates and multiple studies have documented immediate declines in coastal tailed frog abundance following clearcuts, likely due to siltation and elevated stream temperatures (Blaustein et al. 1995; Dupuis & Steventon 1999; Bury et al. 2002; Matsuda & Richardson 2005). In a retrospective study, Stoddard and Hayes (2005) found coastal tailed frogs were more likely to occur in forested streams buffered by riparian zones >46 m wide, when clearcutting occurred upslope. Such streamside buffers likely protected stream habitats from both siltation and elevated temperatures. Although clearcutting on federal land ceased following implementation of the Northwest Forest Plan in 1994 (Phalan et al. 2019), historical logging practices have extirpated this species from many parts of its previous range (Thomson et al. 2016). Reduced abundance of northern red-legged frogs have also been detected in younger stands, even though they are not restricted to old-growth forests (Aubry & Hall 1991). Streamside buffers likely project

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Adaptive Capacity

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

Species group extent, integrity, connectivity, and dispersal ability

Regional experts evaluated frogs as having a low-moderate geographic extent (high confidence in evaluation), low-moderate overall health and functional integrity (high confidence), and a moderate degree of connectivity between populations (moderate confidence).

Regional experts evaluated frogs as having a moderate dispersal ability (moderate confidence in evaluation). Barriers to dispersal were evaluated as having a moderate impact on the species group (moderate confidence). Land-use conversion and dams/water diversions were identified as the primary barriers to dispersal.[8]

Although ranges of the species considered in this assessment extend outside of California, all have experienced population declines and, in some cases, extirpations over the past several decades (Jennings & Hayes 1994; Blaustein et al. 1995; Stebbins 2003; Thomson et al. 2016). Estimates suggest that the foothill yellow-legged frog was extirpated from over half of its historical range in California by the mid-1990s (Davidson et al. 2002). Declines have been occurring in Cascades frog populations since the 1980s (Fellers & Drost 1993; Jennings & Hayes 1994; Fellers et al. 2008); recent surveys have documented this species in less than a dozen sites in the southern Cascades (Fellers et al. 2008; citations in Pope et al. 2014) though they remain relatively widespread in the Klamath Mountains (Piovia-Scott et al. 2011). Northern red-legged frogs have also undergone drastic population declines in recent decades (Moyle 1973;

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

Hayes & Jennings 1986), and coastal tailed frogs have been extirpated from large parts of their historic range due to forestry disturbance (Thomson et al. 2016). Several researchers have projected continuing declines in frog populations due to a combination of climate change, anthropogenic disturbances (e.g., habitat loss and fragmentation), non-native species, and disease (Corn & Bury 1989; Dupuis & Steventon 1999; Welsh & Lind 2002; Ashton et al. 2006; Olson et al. 2007). Small and/or isolated populations are particularly vulnerable to extirpation following stochastic events (e.g., severe drought, wildfire), and the chances of recolonization are significantly reduced in fragmented landscapes (Pope et al. 2014).

Successful frog movement and dispersal through both aquatic and terrestrial ecosystems varies by life stage and species, and from physical (e.g., dams, development) and physiological (e.g., water temperature and levels) barriers (Garwood 2009; Olson et al. 2009; Thomson et al. 2016). For instance, the absence of forested landscapes, whether due to natural or anthropogenic changes, can be a key restrictor of habitat connectivity and genetic diversity within coastal tailed frog populations (Spear & Storfer 2008). However, studies conducted within the Mount St. Helens volcanic blast zone in Washington documented coastal tailed frog movement across regenerating forests (Spear et al. 2012). In Oregon, small numbers of frogs have also been found along headwater streams in harvested forests where this species does not typically occur, suggesting stream networks may help serve as dispersal habitat (Olson & Weaver 2007). In Cascades frogs, a detailed study of frog movement in the Trinity Alps Wilderness found that distances traveled among juvenile and adult frogs range widely, but can span distances of several kilometers and occur across ridgelines, allowing gene flow among larger metapopulations (Garwood 2009).

Intraspecific/life history diversity

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

Foothill yellow-legged frogs show behavioral plasticity in the timing of breeding activity in response to changing hydrological conditions and water temperature, maximizing reproductive success (Kupferberg 1996; Wheeler et al. 2015, 2018; Catenazzi & Kupferberg 2017). Breeding activity in this species can vary by several weeks, and the onset of breeding activity is closely correlated with streamflow, water depth, and water temperature (Kupferberg 1996; Lind et al. 1996; Wheeler et al. 2015, 2018). For instance, calling and oviposition in six northwestern California populations occurred earlier at sites with warmer, shallower water (Wheeler et al. 2018). Foothill yellow-legged frog tadpoles have also shown behavioral plasticity in adjusting to water temperature changes in dammed rivers (Catenazzi & Kupferberg 2017). While there are no known studies investigating breeding phenology for other northern California frog species, surveys of anurans (i.e., frogs and toads) in other areas have found that abiotic factors such as temperature and precipitation impact the timing of breeding behaviors (e.g., Saenz et al. 2006).

Recent research has found significant genetic differentiation across the range of the foothill yellow-legged frog (McCartney-Melstad et al. 2018). For example, foothill yellow-legged frog populations along the coast of northern California and Oregon represent one of several distinct clades, though the greatest genetic diversity within clades is evident in the southwestern California clade (McCartney-Melstad et al. 2018). However, reduced genetic diversity and greater levels of genetic isolation were observed in populations associated with river regulation (Kupferberg 1996; Lind et al. 1996; Peek et al. 2018). The Cascades frog also harbors significant within-species variation (Monsen & Blouin 2003), but less is known about genetic diversity in northern red-legged and coastal tailed frogs. Genetic diversity in northern red-legged frogs may be affected by fragmentation and disturbance (Spear & Storfer 2008).

Resistance and recovery

Regional experts evaluated frogs as having moderate resistance to climate stressors and natural disturbance regimes (moderate confidence in evaluation). Recovery potential was evaluated as moderate (moderate confidence).

Like many amphibians worldwide (Stuart et al. 2004; Wake & Vredenburg 2008), frog populations are currently declining due to climate change and habitat development and fragmentation (Thomson et al. 2016). In northern California, frogs have likely adapted to interannual variability in environmental conditions (e.g., variable flow volume and timing, periodic droughts, wildfire) through life history traits and behavioral plasticity (Hayes et al. 2016; Thomson et al. 2016; Catenazzi & Kupferberg 2017). However, their limited ability to adapt to major disruptions in hydroperiod or thermal regimes suggests that continued population declines may be likely due to warmer, drier future conditions and more frequent extreme events (Wheeler et al. 2015). More research is needed to fully understand the recovery potential of frogs in northern California, as information on basic life history, habitat use, and distribution is sparse for all four species (Thomson et al. 2016).

Management potential

Public and societal value

Regional experts evaluated frogs as having low-moderate public and societal value (moderate confidence in evaluation).

The 2015 California Wildlife Action Plan lists the foothill yellow-legged frog, coastal tailed frog, and northern red-legged frog among the conservation targets of the Klamath-Northern California Coastal Hydrologic Unit (CDFW 2015). In addition, the foothill yellow-legged frog is a U.S. Forest Service and Bureau of Land Management Sensitive Species, and the state of California considers the foothill yellow-legged frog to be a Species of Special Concern (Thomson et al. 2016).

Management capacity and ability to alleviate impacts[9]
Regional experts evaluated the potential for reducing climate impacts on frogs through management as low-moderate (moderate confidence in evaluation).

Recommended strategies to alleviate impacts on frogs include actions to prevent further loss and degradation of both terrestrial and aquatic habitat as well as reconnecting habitats across the landscape to facilitate dispersal and long-term, regional persistence of frog populations (Hamer & McDonnell 2008). The following approaches may increase the resilience of frog populations to changing climate stressors and disturbance regimes:

- Protect a variety of stream and riparian habitats as well as mature and old-growth forests, with a focus on managing the entire stream network (Saunders et al. 2002; Olson et al. 2007; Bourque 2008; Welsh 2011);
- Retain streamside buffers on harvested lands to help mitigate the effects of logging and road-building (Olson et al. 2007);
- Use timber harvesting methods that leave residual tree patches (Chan-McLeod & Moy 2007);
- Identify and catalog areas where connectivity has been disrupted and develop strategies to protect and/or restore habitat corridors (Olson et al. 2007; Olson & Burnett 2009);
- Where physical reconnection is not possible (e.g., populations separated by dams and reservoirs), consider reintroduction and translocation to restore gene flow and prevent the loss of at-risk populations (Dillingham et al. 2018; Vuln. Assessment Reviewer, pers. comm., 2019);
- Manage the timing and pattern of dam water releases from April through June to minimize egg scouring and stranding (Kupferberg et al. 2009b);
- Include foothill yellow-legged frog habitat requirements when managing rivers for other taxa, such as steelhead trout (*Oncorhynchus mykiss*; Fuller & Lind 1992);
- Avoid creating American bullfrog habitat during land restoration (e.g., remove artificial ponds by restoring linkages to main river channels; (Fuller et al. 2011);
- Expand research related to the protection of native frogs (especially coastal tailed frogs) and their habitats using riparian buffers. Specifically, increased understanding of contemporary riparian buffer practices is needed in the context of streamside protection and upslope harvest activity because not all harvests are clearcut today and not all buffers are no-entry reserve areas (Vuln. Assessment Reviewer, pers. comm., 2019); and
- Raise awareness of frog conservation issues among the general public by using foothill yellow-legged frogs as an example of how dams can disrupt the ecology of fauna living downstream (Vuln. Assessment Workshop, pers. comm., 2017).

Ecosystem services
Frogs provide a variety of ecosystem services, including:

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

- Regulation of aquatic and terrestrial food webs, as well as pests/disease;
- Provisioning of natural medicine;
- Support of nutrient cycling (aquatic and terrestrial) and water cycling; and
- Cultural/tribal uses for spiritual/religious purposes, knowledge systems, educational values, aesthetic values, social relations, sense of place, cultural heritage, inspiration, and recreation (Hocking & Babbitt 2014; Vuln. Assessment Workshop, pers. comm., 2017).

Tadpoles occur in very high densities in some areas, which affects aquatic primary productivity by altering algal and periphyton community structure and biomass (i.e., through grazing; Kiffney & Richardson 2001; Mallory & Richardson 2005; Hocking & Babbitt 2014). Tadpoles may also play a role in reducing disease through mosquito egg destruction (Hocking & Babbitt 2014).

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

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Northern California Climate Adaptation Project:

Vulnerability Assessment Methods and Application

Defining Terms

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

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

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

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

Vulnerability Assessment Model

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

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

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

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

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

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

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

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

Vulnerability Assessment Model Elements

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

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

Sensitivity & Exposure (Applies to Species Groups and Species)

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

Sensitivity & Exposure (Applies to Species ONLY)

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

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

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

Adaptive Capacity (Applies to Habitats ONLY)

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

Adaptive Capacity (Applies to Species Groups, Species)

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

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