

Species Status Assessment (SSA) Report
For the
Cascades Frog (*Rana cascadae*)
26 January 2022
Version 1.0



Photo Bridgette Moran, U.S. Fish and Wildlife Service



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EXECUTIVE SUMMARY

This report summarizes the results of a species status assessment (SSA) conducted for Cascades frog (*Rana cascadae*). This status review is in response to a petition to list the Cascades frog as an endangered or threatened species due to population declines in all or part of its range. The objective of this SSA report is to describe the viability of the Cascades frog based on the best scientific and commercial information available. The Cascades frog was first described in 1939 from the Elysian Fields in Mount Rainier National Park, Washington. This ranid species was described at the time as greenish brown with many dark spots and green-brown mottled sides; however, there is variation among frogs in spot appearance. Body size varies by elevation and latitude, likely in relation to the length of the growing season, and Cascades frogs also exhibit sexual dimorphism in which females typically grow larger than males.

This species is associated with montane and subalpine habitats at middle to high elevations (approximately 400 to 2,500 meters (1,312 to 8,202 feet) elevation) across most of its range with the exception of a few low elevation populations on the west slope of the Olympic Mountains (down to 48 meters (157 feet) elevation). It occurs on both slopes of the Cascade Mountain Range from Washington, in the vicinity of the U.S. and Canada border, south through Washington and Oregon to California, just south of Lassen Peak. Two disjunct populations are known from the Olympic Mountains of Washington and the Klamath Mountains of California. The Cascades frog generally remains well distributed throughout its historical range; however, local extirpations and population declines have been reported, especially in the Southern portion of the range. Cascades frogs are primarily aquatic, inhabiting a variety of perennial and ephemeral aquatic habitats including lakes, ponds, wet meadows, and streams. These aquatic habitats are maintained by cold winters with deep snowpack and spring snowmelt and breeding habitats must hold water long enough to allow for development through metamorphosis. Cascades frogs are vulnerable to fish predation, and typically breed in water bodies absent of fish. After the breeding season, many ephemeral aquatic features dry out, leading to a reduction in available habitat. In this post-breeding period, Cascades frogs use lakes, ponds, wet meadows, and streams, where they are often found along shorelines or on emergent rocks or logs. Cascades frogs overwinter within aerobic sediments at the bottom of lakes, ponds, springs, and streams.

To assess viability, we first determine what the species needs to support resilient populations, then assess its current condition in terms of those needs, and finally project its future condition under plausible future scenarios. In conducting this analysis, we consider the likely changes that are happening in the past, current, and future environment to help us understand what factors drive the viability of the species. For the purpose of this assessment, we define viability as the ability of the Cascades frog to sustain populations in their natural habitat over time (current to 2069). Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time. Using the SSA framework, we considered what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation.

We used the best scientific and commercial data available to analyze and describe past and ongoing changes in the species' habitat, demographic parameters, and distribution at a regional scale. We assess the factors that impact the Cascades frog in the SSA. Three primary stressors are discussed in detail here and include non-native trout, *Batrachochytrium dendrobatidis* (chytrid fungus), and climate change. Other factors that were not carried forward as primary stressors include: other diseases, meadow contraction,

water management/withdrawal, livestock grazing, roads, potential invasive predators (other than non-native trout), contaminants, UV-B radiation, wildfire, fire prevention and suppression, recreation, timber harvest, and hybridization (detailed discussion in Appendix II).

A healthy Cascades frog population is defined in terms of its abundance, reproductive and recruitment rates, juvenile and adult survival, and site connectivity for individual movement and genetic exchange. We use a combination of demographic and habitat factors to create four condition metrics to assess current conditions. These include the demographic factors, connectivity and site occupancy, and the habitat factors, aquatic features and precipitation. We combined all four factors using a weighted average, with aquatic features weighted twice as important relative to the other categories because water availability is dependent on climate and is critically important to successful recruitment.

Occupied sites from 1999 to 2020 with overlapping 5 km (3.10 mi) buffers were merged into a single unit, creating a total of 73 analytic units (AUs). We divided the current range of the species into five representative units, Washington Olympics, Washington Cascades, Oregon Cascades, California North and California South based on factors that may contribute to the adaptive capacity of the species including genetic information, habitat, distribution of occurrences, connectivity, natural geological and elevational gaps in the range of the species, and management considerations.

The current condition analysis finds that in all but one of the representative units where occupancy has been investigated and abundance information is available, the frog continues to occupy historical sites and maintain historical abundance and appears to be relatively stable. However, in the California South Representative Unit, the resiliency, redundancy, and representation of this representative unit is currently low and at risk of extirpation because there are so few occupied sites, there are few AUs remaining, and the abundance of Cascades frogs is relatively low at all but two sites.

To determine how future climate conditions will impact the resiliency of AUs, we considered the direct and indirect effects of several climate variables on suitable habitat. These variables included maximum temperature, minimum temperature, precipitation, snow water equivalent, soil moisture, and potential evapotranspiration. Future climate projection data were modeled using 2 emission scenarios (RCP 4.5 and 8.5) and two time periods (2010 to 2039 and 2040 to 2069), across the United States. This resulted in 4 future scenarios: Near-term 1 (reduced emissions), near-term 2 (status quo emissions), long-term 1 (reduced emissions), and long-term 2 (status quo emissions).

Our analysis shows that future resiliency of the majority of the 73 AUs declines under near-term and long-term climate projections. Overall, there is an increase in the number of AUs that were once suitable habitat shifting to null condition (not considered suitable habitat) as emissions increase over time. The overall future declines in suitable habitat will impact resiliency of localized populations due to reduced connectivity, decreasing both the potential for gene flow and the ability to withstand stochastic events. Projected reductions in winter snowpack and increased temperatures will result in earlier pond drying with shorter hydroperiods on average, reducing available aquatic habitat necessary to support the species through all of its life history needs.

The number of AUs projected to remain on the landscape (redundancy) in the future suggests that the species will likely be capable of withstanding most catastrophic events under the low and high emissions scenarios both in the near-term (2039) and the long-term (2069). However, due to reduced availability of suitable habitat, some populations could experience extirpation resulting in reduced genetic diversity and

viability across the range. Given the species' extensive range and distribution, a catastrophic event is unlikely to impact viability across the entire range. However, under our future scenarios, resiliency is projected to decline along with available suitable habitat, particularly in the Washington Olympics, Oregon Cascades, and California North and half of the California South representative unit; this could decrease potential connectivity for local populations and could result in some extirpations.

With respect to representation, the AUs of three representative units (Washington Olympics, Oregon Cascades, and California North) are likely to decline in habitat suitability by 2039 and continue to decline through 2069. Given the genetic differentiation and isolation of the Washington Olympics from other populations, declines in habitat suitability may increase vulnerability to any losses of AUs. The Washington Cascades AUs are projected to remain similar in amount of suitable habitat by 2039 but then decline becomes more evident by 2069 but appears to occur more slowly than the above representative units. While the California South representative unit is currently in danger of being extirpated, under our climate scenarios, the AUs are projected to roughly maintain a similar balance of suitable habitat into the future though the configuration may change. It is imperative to maintain the few remaining populations so that Cascades frogs are present to return to higher elevation unoccupied suitable habitat in the future.

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LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

Symbol, Abbreviation, or Acronym	Meaning
3Rs	Resiliency, redundancy, and representation
°C	Degrees Celsius
°F	Degrees Fahrenheit
AU	Analytic Unit
<i>Bd</i>	<i>Batrachochytrium dendrobatidis</i>
BLM	Bureau of Land Management
CA	California
CESA	California Endangered Species Act
CDFW	California Department of Fish and Wildlife
cm	Centimeter(s)
cm/s	Centimeter(s) per second
CNDDDB	California Natural Diversity Database
DNA	Deoxyribonucleic acid
eDNA	Environmental DNA
EDDI	Evaporative Demand Drought Index
Eds.	Editors
<i>et al.</i>	<i>Et alia</i> ("and others")
Etc.	<i>Et cetera</i> ("and other similar things" or "and so forth")
FERC	Federal Energy Regulatory Commission
ft.	Foot/feet
ft./s	Feet per second
g	Gram(s)
GIS	Geographic Information Systems
HCP	Habitat Conservation Plan
HSM	Habitat Suitability Model
HUC	Hydrologic Unit Code
in.	Inch(es)
IPCC	Intergovernmental Panel on Climate Change
km	Kilometer(s)
LUCAS	Land Use and Carbon Scenario Simulator model (Sleeter <i>et al.</i> 2019)
LVNP	Lassen Volcanic National Park
m	Meter(s)
MDAT	Maximum 30-day average water temperature
mi	Mile(s)
mm	Millimeter(s)
MRNP	Mount Rainier National Park
mtDNA	Mitochondrial DNA
n	Number

NCNP	North Cascades National Park
NHD	National Hydrography Dataset
NPS	National Park Service
OCAMP	Oregon Connectivity Assessment and Mapping Project
ODFW	Oregon Department of Fish and Wildlife
OR	Oregon
ORBIC	Oregon Biodiversity Information Center
oz.	Ounce(s)
pers. comm.	Personal communication
pers. obs.	Personal observation
PIT	Passive Integrated Transponder
PVA	Population Viability Analysis
SD	Standard deviation
Service/USFWS	U.S. Fish and Wildlife Service
SSA	Species Status Assessment
SUV	Snout-urostyle length (similar measure of body length as SVL)
SVL	Snout-vent length
unpl.	unpublished
U.S.	United States
USFS	United States Forest Service
USGS	United States Geological Survey
WA	Washington
WDFW	Washington Department of Fish and Wildlife
YOY	Young-of-year

1.0 INTRODUCTION

1.1 Background

This report summarizes the results of a species status assessment (SSA) conducted for Cascades frog (*Rana cascadae*). This status review is in response to a petition to list the Cascades frog as an endangered or threatened species in all or part of its range. The Center for Biological Diversity petitioned the Service to list 53 amphibian and reptile species, including the Cascades frog, under the Federal Endangered Species Act (Act) as amended, July 11, 2012. In July 2015, the Service found the petition provided substantial information that listing the species may be warranted (80 FR 37573, July 1, 2015), and subsequently committed to completing a 12-month finding for the Cascades frog in 2022.

This SSA Report is intended to provide the biological information to support a decision on whether the Cascades frog meets the definition of threatened or endangered under the Act, as amended. The SSA Report does not result in a decision by the Service on whether this taxon should be proposed for listing as a threatened or endangered species but instead provides a review of the available information strictly related to the biological status of the Cascades frog. A listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the Federal Register, with appropriate opportunities for public input.

1.2 Analytical Framework

The SSA report, the product of conducting an SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, if the Cascades frog is listed under the Act, the SSA report will be a living document upon which other documents such as recovery plans and 5-year reviews will be based, supporting future decisions about the species' listing status and, eventually, a post-delisting monitoring plan.

The objective of this SSA report is to thoroughly describe the viability of the Cascades frog based on the best scientific and commercial information available. Through our assessment, we determined what the species needs to support viable populations, its current condition in terms of those needs, and its forecasted future condition under plausible future scenarios. In conducting this analysis, we took into consideration the likely changes that are happening in the environment – past, current, and future – to help us understand what factors drive the viability of the species. For the purpose of this assessment, we define viability as the ability of the Cascades frog to sustain populations in their natural habitat over time (approximately 50 years based on future scenarios). Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time (USFWS 2016, p. 9). Using the SSA framework (Figure 1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (USFWS 2016, entire; Wolf et al. 2015, entire).

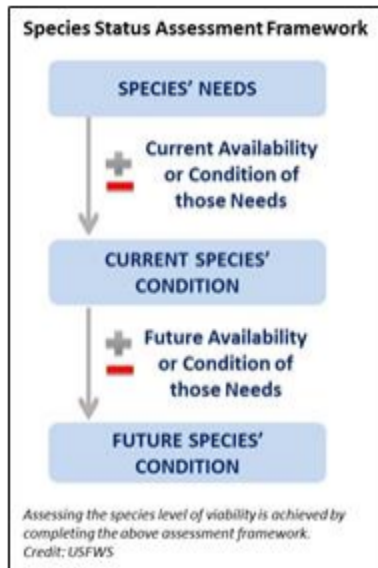


Figure 1. Species Status Assessment Framework.

Resiliency is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford et al. 2011, p. 40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. We can best gauge resiliency by evaluating population level characteristics such as: demography (abundance and the components of population growth rate — survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity.

Redundancy is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely (Mangal and Tier 1993, p. 1083). We can best gauge redundancy by analyzing the number and distribution of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale, or for narrow-ranged species, at the species level.

Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments—referred to as adaptive capacity—is essential for viability, as species need to continually adapt to their continuously changing environments (Nicoitra et al. 2015, p. 1269). We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of the species' morphology, habitat characteristics within the geographical range, or both.

A species with a high degree of resiliency, representation, and redundancy (the 3Rs) is better able to adapt to novel changes and to tolerate environmental stochasticity and catastrophes. In general, species

viability will increase with increases in resiliency, redundancy, and representation (Smith et al. 2018, p. 306).

2.0 SPECIES INFORMATION

2.1 Species Description

The Cascades frog is one of a group of similar appearing species of true frogs of the genus *Rana* in western North America. The Cascades frog's general coloration was first described as greenish brown with many dark spots approximately 3 millimeters (mm) (approx. 0.12 inches (in)) in diameter, light brown dorsolateral folds (ridges of skin down the sides of the frog's back), and green-brown mottled sides with black fading to light yellow on the ventral (underside) surface (Slater 1939, entire). Additional key visual identification features include a yellow upper jaw (lip) stripe extending almost to the shoulder, and outward oriented eyes (Nussbaum et al. 1983, p. 166; Olson in Jones et al. (Eds.) 2005, p.186). The frog's ventral color is cream to yellow and ventral hind limbs are yellow to honey colored (Nussbaum et al. 1983, p. 166; Olson in Jones et al. (Eds.) 2005, p.186) (Figure 2 and 3). When first hatched, larvae are dark brown to black, but over time, they lighten to brown to brownish black with silver to gold flecking on their sides and ventral surface (Olson in Jones et al. (Eds.) 2005, p. 186) (Figures 4 and 5).

Cascades frogs are considered a medium sized ranid (*Ranidae*) frog that exhibits sexual size dimorphism with adult females larger than males (Figure 3a); however, there are differences in size by elevation and latitude likely varying per length of growing season (Slater 1939, p. 146; Nussbaum et al. 1983, p. 170). In studies with larger sample sizes, adult females have averaged approximately 62 to 71 mm (2.44 to 2.8 in) snout-urostyle length (SUL) and 30 to 45.9 grams (g) (1.06 to 1.62 ounces (oz.)) while males were 53 to 56 mm and 18 g (0.63 oz.) (Briggs and Storm 1970, pp. 290-298; Olson 1988, p. 240; Garwood and Welsh 2007, p. 20). Table 1 shows average adult Cascades frog length and weight data from three studies across their range.

Table 1. Adult Cascades frog mean length and weight reported from regional studies. Numbers in parentheses indicate the range.

Location	Female Length (mm)	Female Weight (g)	Male Length (mm)	Male Weight (g)	Elevation	Citation
Klamath Mountains, CA (n=324)	68 mm (58-81 mm)	30 g (18-57 g)	56 mm (50-67 mm)	18.5 g (10-27 g)	1,976-2,226 m 6482-7303 ft.	Garwood and Welsh. 2007, p. 20
Cascades, OR (n=48)	62.3 mm (59-66 mm)	Not reported	Approx. 53mm (49-58 mm)	Not reported	1,285 m 4,216 ft.	Briggs and Storm 1970, pp. 290-298
Cascades, OR (n=70)	71mm (n=13)	45.9 g (n=10)	55 mm (n=57)	18.1 g (n=55)	1,190 m 3,904 ft.	Olson 1988, p. 240



2a



2b

Figures 2a and 2b. 2a, Adult Cascades frog (Siskiyou Co., CA); 2b, Adult Cascades frog showing cream to yellow ventral color (Pierce Co., WA). Photo credits Gary Nafis, CaliforniaHerps.com



3a



3b

Figures 3a and 3b. Adult Cascades frogs in amplexus showing size dimorphism (larger female on bottom) (Kittitas Co., WA); Adult male at breeding site (Kittitas Co., WA). Photo credits Gary Nafis, CaliforniaHerps.com



4a



4b



4c

Figures 4a, 4b, and 4c. 4a: Cascades frog egg mass (Clackamas Co., OR); 4b: egg mass and adult (Kittitas Co., WA); 4c: egg masses *in situ* (Kittitas Co., WA). Photo credits Gary Nafis, CaliforniaHerps.com



5a



5b

Figures 5a and 5b. 5a: Cascades frog larva or tadpole (Siskiyou Co., CA); 5b: recently metamorphosed or young-of-year (YOY) juvenile (unknown location). Photo credits Gary Nafis, CaliforniaHerps.com

2.2 Taxonomy & Genetics

Cascades frog was first described in 1939 from the Elysian Fields in Mt. Rainier National Park, Washington (Slater 1939, entire). Cascades frog was later considered to be a subspecies of red-legged frog (*Rana aurora*) (Dunlap 1955, pp. 314). Several studies identified Cascades frog as a distinct species based on combinations of morphology, range, chromosomal and DNA analyses (Dunlap 1955, p. 330; Dumas 1966, p. 71; Haertel et al. 1974, entire; Green 1986, entire). A phylogenetic study of the New World true frogs used sequences from the mitochondrial genome to group Cascades frog in the western North American anuran clade (foothill yellow-legged frog (*R. boylei*) species group) also including northern red-legged frog (*R. aurora*), mountain yellow-legged frog (*R. muscosa*), Oregon spotted frog (*R. pretiosa*), and Columbia spotted frog (*R. luteiventris*) (Hillis and Wilcox 2005, pp. 304-308); within this group, Cascades frogs are most closely related to northern red-legged frog.

Currently, the Cascades frog is widely accepted as a distinct species based on morphology and genetic studies as described above. We therefore accept the current taxonomy as follows (ITIS 2021):

Phylum: Chordata

Class: Amphibia

Order: Anura

Family: Ranidae

Genus: *Rana*

Species: *Rana cascadae* Slater (1939)

Several studies provide evidence of genetic divergence between geographic regions throughout its range. A study comparing mitochondrial (mtDNA) and microsatellite data to assess Cascades frog across its range indicated that gene flow in Cascades frog is restricted to short distances and occurs in a stepping-stone fashion (with individuals moving between discrete waterbodies) with strong isolation by distance (Monsen and Blouin 2003, pp. 3280-3281). This study suggested that there are at least two distinct sets of populations, the California populations and the Oregon/Washington populations (Monsen and Blouin

2003, entire). Microsatellite and mtDNA data detected molecular signatures occurring at different timescales regarding the genetic separation of populations from the Olympic Mountains and the Washington Cascade Range; mtDNA suggested that the Olympic Mountains and Washington Cascades populations have been separated for millions of years, while the microsatellite data indicated that isolation occurred more recently (Monsen and Blouin 2003, pp. 3281-3281). Given the physical and geographic isolation of the Olympic Mountains, they suggested the Olympic populations should be managed separately from the Cascade Range populations (Monsen and Blouin 2003, p. 3283).

A recent genomic study focused on Cascades frog in southern Oregon and northern California found genetic divergence between Oregon and California populations, and that genetic variation was lower in California populations than in Oregon populations (Hardy et al. 2021, p. 1). Lower genetic diversity in the California populations could be a result of divergence but is more likely a result of severe population declines due to *Batrachochytrium dendrobatidis* (*Bd*) infections in the region (Hardy et al. 2021, p. 8). California populations formed two genetic clusters: a northern cluster (Klamath Mountains and populations in the southern Cascades north of Lassen Peak) and the southern cluster (populations south of Lassen Peak (Hardy et al. 2021, pp. 4, 7); this is contrary to other studies (Case 1978, p. 305), as well as conservation actions that have separated California populations based on ecoregion (Klamath Mountains and California Cascades) (Pope et al. 2014, p. 37).

Preliminary results from a rangewide genomics study (although excluding the California South population from Hardy et al. 2021), that used similar methodology (Restriction site associated DNA (RAD)-type genomics approach) to support earlier findings of strong isolation-by-distance across its range (Brown et al., WDFW, unpublished data 2021). These early results suggest that Cascades frogs are separated into seven genetic population clusters: California, southern Oregon, northern Oregon, south Washington Cascades, central Washington Cascades, north Washington Cascades, and the Olympic Range. In California, this study only sampled in the area defined as “California Northern” (Hardy et al. 2021, p. 4) and supports the genetic clustering of populations from the Klamath Mountains and those north of Lassen Peak (Brown et al., WDFW, unpublished data 2021). Incorporating the findings of these two studies together, current genetic evidence supports our assumption that Cascades frog exists in at least seven genetic clusters (Brown et al., WDFW, unpublished data 2021) with support for the southern California region (as defined by Hardy et al. 2021, pp. 4, 7) to be considered an eighth cluster across its entire range. These studies notably identify the Olympic Range as its own separate population and indicates high genetic differentiation between disparate geographic regions (e.g., California vs. Cascades North; Brown et al., WDFW, unpublished data 2021). Given the difference in scale between the Brown et al. study and the Hardy et al. study, there are difficulties when comparing divisions between populations and some of the divisions that are present in the individual studies might not be as clear if the species was considered on a range-wide scale (Lambert, WDFW, pers. comm. 2022).

2.3 Habitat

Cascades frogs are primarily aquatic, inhabiting a variety of perennial (wet year-round) and ephemeral (drying each summer) aquatic habitats including lakes, ponds, wet meadows, and streams (Figures 6 and 7). Terrestrial vegetation species composition varies by elevation and latitude within the species’ range and consists of montane and sub-alpine forests (Olson in Jones et al. (Eds.) 2005, p. 189; Bosakowski 1999, p. 66). Cascades frogs are found in forest stands of all ages (Aubry et al. 1991, pp. 330-332).



Figure 6. Cascades frog habitat, King County, Washington (Photo credits Gary Nafis, CaliforniaHerps.com).



Figure 7. Cascades frog habitat, Siskiyou County, California (Photo credits Gary Nafis, CaliforniaHerps.com).

Cascades frogs reproduce in shallow ephemeral and perennial lentic (still or slow moving) habitats including lake margins, ponds, and wet meadows (O'Hara 1981, p. 92; Garwood 2009, p.37; Pope et al. 2011, pp. 6-7) including human altered and created aquatic habitats such as enlarged or dammed springs or streams (Briggs and Storm, 1970, p. 284) and roadside ditches (Tyson, WDFW, pers. comm. 2022). These aquatic habitats often rely on spring snowmelt and must hold water through the summer, allowing time for egg and larval development. Cascades frogs are vulnerable to fish predation, and most often breed in water bodies absent of fish (Welsh et al. 2006, p. 302). Juveniles (> 1 year old) most often inhabit small shallow ponds and streams (Garwood 2009, p. 37). After the breeding season, ephemeral features dry out, often leading to a reduction in available habitat by the end of the summer. In this post-breeding period, Cascades frogs use lakes, ponds, wet meadows, and streams, where they are often found along shorelines or on emergent rocks or logs (Brown 1997, p. 65-66; Garwood 2009, p. 43; Pope et al. 2011, p. 6; Pope et al. 2014, p.7). While moving among habitat patches, they disperse using stream corridors and upland areas. Cascades frogs overwinter within aerobic (oxygenated) sediments at the bottom of lakes, ponds, springs, and streams (Briggs 1987, p. 241; Garwood 2009, p. 43).

Additional habitat information specific to Cascades frog life stages can be found in the Life History section (Section 2.5).

2.4 Historical and Current Abundance, Range and Distribution

The Cascades frog is associated with montane and subalpine habitats at middle to high elevations (approximately 400 to 2,500 m (1,312 to 8,202 ft.)) on both the east and west slopes of the north-south oriented Cascade Mountain Range from Washington in the vicinity of the U.S. and Canada border south through Washington and Oregon to California just south of Lassen Volcanic National Park. In addition, Cascades frogs can be found in two large disjunct geographic regions; one in the Trinity Alps, Salmon Mountains, Scott Mountains, Marble Mountains and Trinity Alps Divide within the larger Klamath Mountains (hereafter referred to as the Klamath Mountains) of California, and the other in the Olympic Mountains in Washington (Figure 8) (Dumas 1966, p. 61; Nussbaum et al. 1983, p. 168; Olson *in* Jones et al. (Eds.) 2005, p.186). Cascades frogs were historically and are currently known from a wider range of elevations, but low elevation sites are primarily on the western or coastal side of the Olympic Mountains in Washington. There is a slight latitudinal trend in elevation with Cascades frog occupying higher elevations in the southern extent of its range (California: 691-2484 m (2267-8149 ft.) and lower

elevations at higher latitudes (Oregon: 349-2172 m (1145-7125 ft.) and Washington: 48-2055 m (157-6742 ft.)).

The Cascades frog generally remains well distributed throughout its historical range; however, local extirpations and population declines have been reported (Nussbaum et al. 1983, p. 170; Blaustein and Wake 1990, p. 203; Fellers and Drost 1993, pp. 178-179; Fellers et al. 2007, p. 32; Pearl et al. 2009, p. 166; Pope et al. 2011, pp. 5-6). Some reports of extirpations and declines are supported with monitoring data while others are not. Cascades frog abundance can vary greatly depending on winter precipitation and hydroperiod (how long a wetland retains water) trends. As described in the life history section (Section 2.5), Cascades frogs have the ability to breed prolifically under favorable conditions, although otherwise stable populations may have high interannual variability (McCaffery et al. *in* McCaffery and Jenkins (Eds.). 2018, pp. 231-232). Monitoring abundance of Cascades frogs can be difficult without relatively intensive efforts due to breeding site inaccessibility early in the season, females departing shortly after egg laying, and an overall uncertainty and difficulty in counting adults later in the season. In addition, at a landscape level, ranid frog numbers at individual sites are known to fluctuate and at times, may drop to zero (extirpation), and then may be 'rescued' by recolonization from nearby breeding sites over time (Duarte et al. 2020, p. 1460). Because of the difficulty or insufficient funding for monitoring abundance, occupancy modeling may be used to monitor persistence at larger landscape scales (Pearl et al. 2009, entire; Duarte et al. 2021, entire).

Historically, Cascades frogs were observed to be "...extremely abundant in appropriate habitats" in the Oregon Cascades (Nussbaum et al. 1983, p. 166). One study from 1966 to 1967 of Cascades frog population structure at Bear Springs Pond (315m²), Deschutes National Forest, Oregon, estimated between 1,975 and 3,204 frogs age 1yr+ at a site that was believed to be relatively isolated from immigration and emigration (Briggs and Storm 1970, p. 287). Accounts and museum records from around Lassen Volcanic National Park, recorded from the 1920s to 1970s, document sites supporting abundant Cascades frogs, including one record of 44 frogs being collected from a site in one day (Grinnell et al. 1930, p. 144; *summarized in* Fellers and Drost 1993, p. 179; *detailed review in* Pope et al. 2014, pp.13-16, Appendix 3). However, prolonged periods of drought, likely acting synergistically with other influence factors, can cause significant population declines. Cascades frog abundance and the number of occupied sites was greatly reduced between the 1970s and 1990s in the southern Cascades portion of their range in and around the Lassen National Forest and they have potentially been extirpated from Lassen Volcanic National Park (Fellers and Drost 1993, pp. 178-180; Fellers et al. 2007, p. 32; Pope et al. 2011, p. 5). Initially it was suspected to be the synergistic effects of drought, non-native trout, and habitat loss due to meadow encroachment; however, pesticide drift and disease were also recognized as potential influence factors by the mid-2000s (Fellers and Drost 1993, p. 179; Fellers et al. 2007, pp. 33-35).

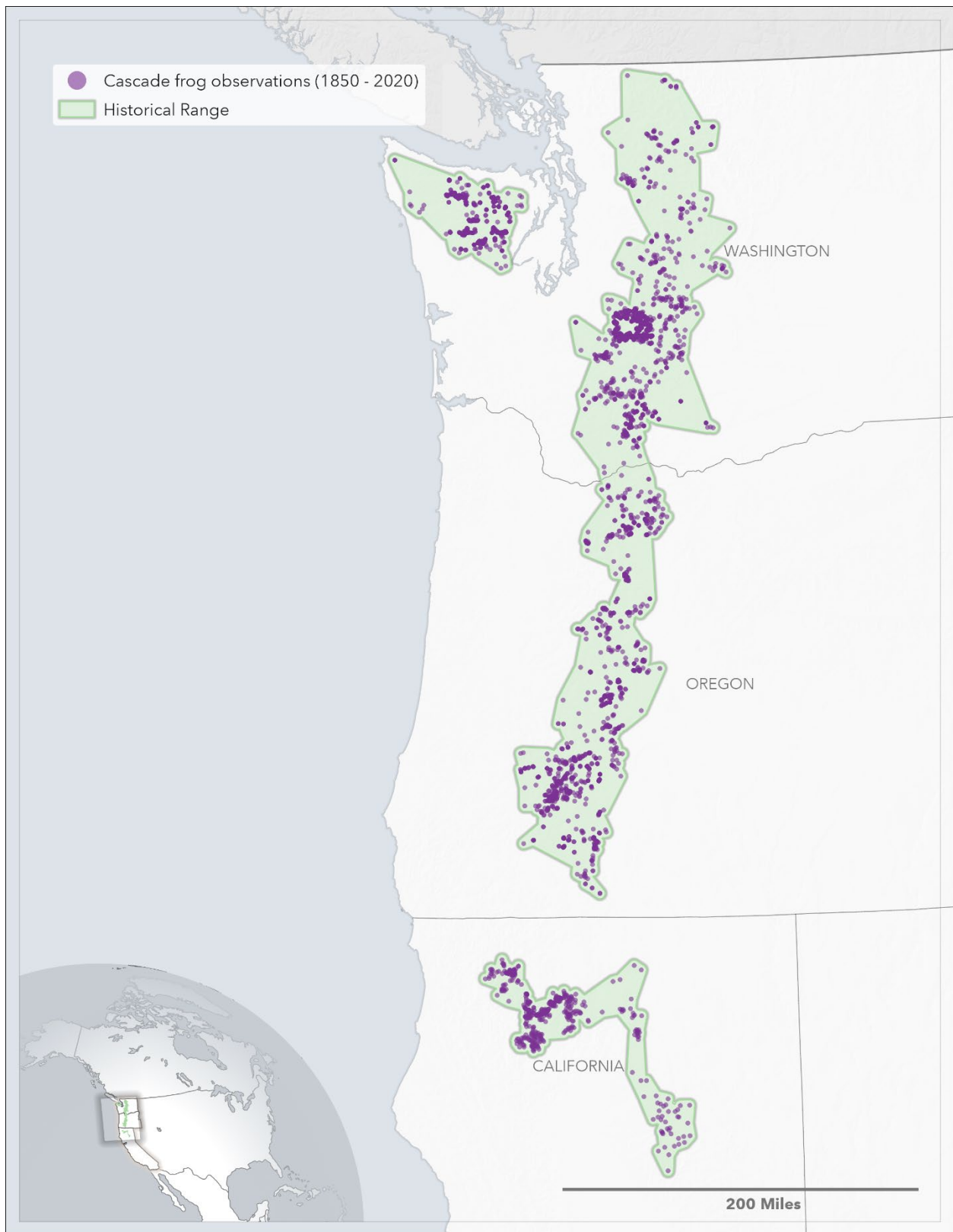


Figure 8. Map of the historical and current Cascades frog range. Historical range is a concave polygon of historical and current sites and does not represent historical suitable habitat.

2.4.1 Survey Data and Methodology

Data were gathered from our partners through a request for information (Table 2). Data was highly variable in age and detail based on its original intended purpose. Data may have been gathered incidentally as part of a broad scale or other survey effort (i.e., surveys for another species or purpose) or through intensive population monitoring associated with focused research. Data is from 1990 to 2020. Observation records were used in a Geographic Information System (GIS) (ArcGIS Pro v2.8.3, Esri Redlands, CA) to map the range and current occupancy of the species, assess current condition (Section 5.1), develop a Habitat Suitability Model (HSM) (Section 6.1), and project future scenarios (Section 6.3). We acknowledge that the data set we have created is not a complete census, therefore it is likely we are missing a percentage of actual locations across the landscape. We did not receive data from every agency and non-agency partner to which we reached out, and data may not have been collected on Cascades frogs in some areas yet.

Table 2. Cascades frog detection point data sources used for our analyses.

Data Source	Agency Jurisdiction	State	Number of Observations
National Park Service	North Cascades NP	WA	35
National Park Service	Olympic NP	WA	1190
National Park Service	Mount Rainier NP	WA	3072
Bureau of Land Management/US Forest Service (Pac NW Region)	Forests and Districts within OR/WA	OR/WA	1258
California Department of Fish and Wildlife	N/A	CA	381
US Geological Survey	N/A	OR	153
Oregon Biodiversity Information Center	N/A	OR	1529
US Forest Service (Pac SW Region)	Shasta-Trinity NF	CA	155
Washington Department of Fish and Wildlife	N/A	WA	1191

Few studies provide population estimates based on egg mass counts or Cascades frogs observed and marked at breeding sites. Following breeding, frogs, particularly females and very young juveniles, move across the landscape and can be difficult to observe and count reliably. Egg mass counts may also be used as an index of adult female abundance (typically a 1:1 ratio) when frogs may have already completed breeding and dispersed. While we are unaware of the optimal level of abundance or densities needed, we do assume, based on general principles of conservation biology, that populations containing larger numbers of breeding sites and greater abundance of Cascades frogs are likely to be more resilient than those containing fewer numbers of breeding sites and lower abundance of frogs.

Additionally, we used citizen science data to fill in gaps in the data from our partners. We obtained iNaturalist “research grade” observations which is required to go through a community vetting process (iNaturalist 2021). Unfortunately, this location data is randomly buffered up to a 30 km (18.64 mi) distance and therefore not suitable for much of our analyses. While it is possible to obtain unbuffered locations from iNaturalist by establishing a research project and reaching out to individual observers, we were unable to do so during the timeframe of this species status assessment.

2.4.2 Washington

There have been a series of monitoring efforts in Washington over the past two decades, but none at the broad scale or design to allow occupancy or trend analysis at a statewide scale. An Olympic National Park amphibian and reptile inventory from 1999 to 2001 found Cascades frog to be the most common lentic breeding amphibian (Galvan et al. 2003, p.33). In a similar amphibian inventory in Mount Rainier National Park from 2001 to 2003, Cascades frog were the most frequently observed lentic breeding amphibian, found in 75% of lentic surveys, and in approximately 40% of lotic (moving water) and riparian surveys (Samora et al. 2013, pp. 12 and 21).

In more recent years, intensive monitoring efforts have occurred as part of long-term monitoring of mountain lakes within Mount Rainier National Park, Olympic National Park, and North Cascades National Park Complex (NPS 2012, entire). Sites were selected for monitoring using stratified random sampling of mountain lakes to allow trend analysis at the park or regionwide scale. Within Olympic and Mount Rainier National Parks, there were positive population growth trends over the surveyed period. However, neither trend was significant due to high annual variation relative to the overall increases (Figure 9). Cascades frogs were not observed within the intensively monitored ponds in North Cascades National Park Complex.

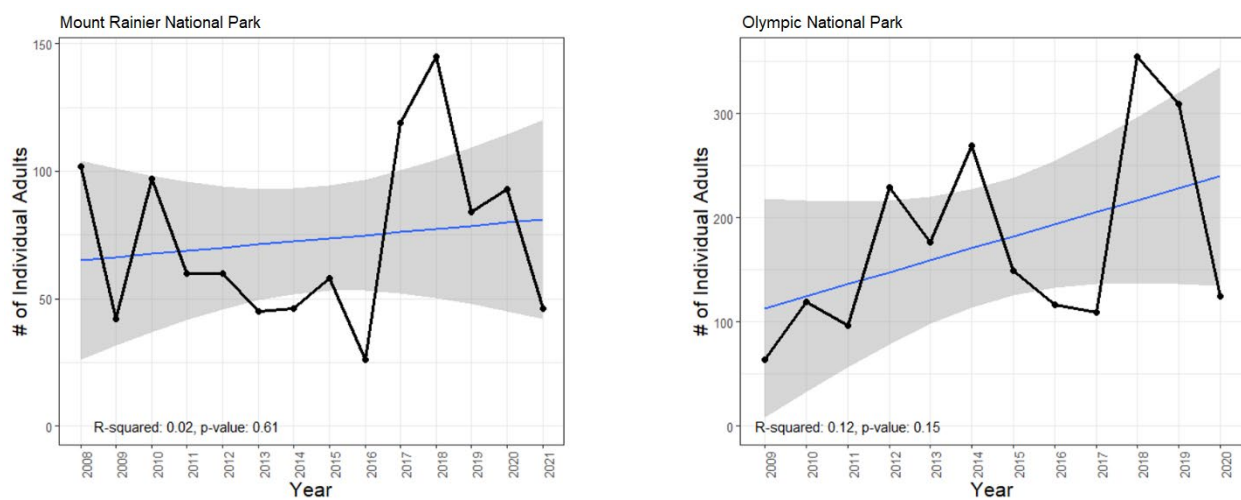


Figure 9. Cascades frog detection trends at representative mountain lakes in Mount Rainier National Park (left) and Olympic National Park (right). Black dots represent annual observations. Blue lines represent trend line based on linear models. Shaded area represents 95% confidence intervals around model prediction (NPS, unpubl. data 2021).

The only long-term study focused specifically on Cascades frogs was conducted in the Seven Lakes Basin of northwestern Olympic National Park. Population growth rate was modeled for the period between 1980 and 2006 and found to be uncertain but centered around a relatively stable population growth rate ($\lambda=0.97$, 95% CI: 0.84–1.13; Kissel et al. 2019, p. 7).

Each of these long-term studies was conducted within the protected boundaries of the National Park system, therefore threats may differ, and are likely reduced compared with other parts of the Cascades

2.4.3 Oregon

In response to reports of amphibian declines in the Cascade Range of the Pacific Northwest and ongoing research into theoretical causes of the suspected declines, two broad scale monitoring efforts have taken place in Oregon since 2001. Historical Cascades frog breeding sites ($n = 67$) were surveyed throughout the state from 2001 to 2004 and the same sites resurveyed from 2018 to 2019 (Pearl et al. 2009, entire; Duarte et al. 2021, entire). In both studies, repeated survey visits facilitated occupancy modeling that accounted for imperfect and variable detection probabilities, which in turn provides a way to estimate the proportion of sites that are occupied (Pearl et al. 2009, p.167). From 2001 to 2004, occupancy adjusted for detectability was 72.4% (SE 6.6%) and from this study the authors concluded "...our relatively high estimates of occupancy are not consistent with the hypothesis that ... *R. cascadae* have experienced broad declines in the Oregon Cascade Range" (Pearl et al. 2009, pp. 173-174 ,178). The second study, which compared the 2018 to 2019 surveys to the previous 2001 to 2004 surveys, found that if there was a decline it was <20% over the 15-year period between survey efforts (Duarte et al. 2021, p. 368). While a decline of site occupancy up to 20% should be considered substantial, the uncertainty in the data did not support that an actual decline had occurred (Duarte et al. 2021, p. 367). Based on these two studies there is not enough evidence to suggest that Cascades frog site occupancy has declined substantially across the Oregon Cascades. However, despite a lack of evidence supporting declines in occupancy, it is important to recognize that occupancy is simply whether the species is present or not and does not provide information on abundance. We are currently unaware of any studies that focused on or included monitoring frog abundance and trends and know of only one ongoing study investigating Cascades frog population abundance in Oregon; however, it is too early in this study to provide abundance and trend information (Pearl, USGS, pers. comm. 2021).

2.4.4 California

Several studies in the Klamath and Cascades mountains of California have documented Cascades frog site occupancy and indicate that abundance has declined significantly, particularly in the southern Cascades in the vicinity of Lassen Volcanic National Park. Cascades frog may have been extirpated from Lassen Volcanic National Park following the rapid decline from the 1970s to 1990s. Of the 16 sites historically known to support Cascades frog in and near Lassen Volcanic Park the last observed frog was from Juniper Lake in 2007 (Fellers and Drost 1993, pp. 178-180; Fellers et al. 2007, p. 32; Pope et al. 2011, p. 5). Between 1993 and 2007, only 6 extant populations were located in the Lassen area (includes Lassen Volcanic National Park and surrounding area primarily to the south of the park), each containing no more than 10 adult Cascades frogs (Fellers et al. 2007, p. 32). From 2008 to 2010, surveys were conducted at the 11 sites (8 populations) known to still support Cascades frog in the southern Cascades area and all continued to have frogs. However, with 7 to 150 adult frogs at a site, approximately half the sites were at risk of extirpation (Pope et al. 2011, pp. 5-10).

In 2014, the U.S. Forest Service (USFS) developed the Cascades Frog Conservation Assessment (Pope et al. 2014, entire). The assessment focuses on the southern populations of the Cascades frog in the southern Cascades Range and Klamath Mountains in California. Below is a summary of information for the two areas.

Southern Cascades Range in California: The report identified 11 known populations remaining as of 2011 in the southern Cascades north and south of Lassen Volcanic National Park (Pope et al. 2014, pp. 13-16). Of the 11 sites in the southern Cascades, 5 are grouped genetically with the Klamath Mountains

(California North) and 6 are grouped together genetically in the California South (Hardy et al. 2021, p. 4). Of the 5 California North sites, at least 4 (Big Bend Flat, Cutter Meadow, Old Cow Creek and Screwdriver Pond and Creek) are likely to still be extant (Figure 11). Big Bear Flat and Screwdriver Pond and Creek were trending down when last surveyed (Pope and Cummings, USFS, unpl. data 2021). The Nelson Creek population (in Shasta County) has an unknown status after the most recent surveys due to not detecting any frogs (Pope and Cummings, USFS, unpl. data 2021). Of the 6 sites monitored in the California South group, 2 are likely extirpated while 3 are known to support frogs. The last site is believed to be extant, however, surveys stopped in 2018 (Figure 11), so the current status is unknown.

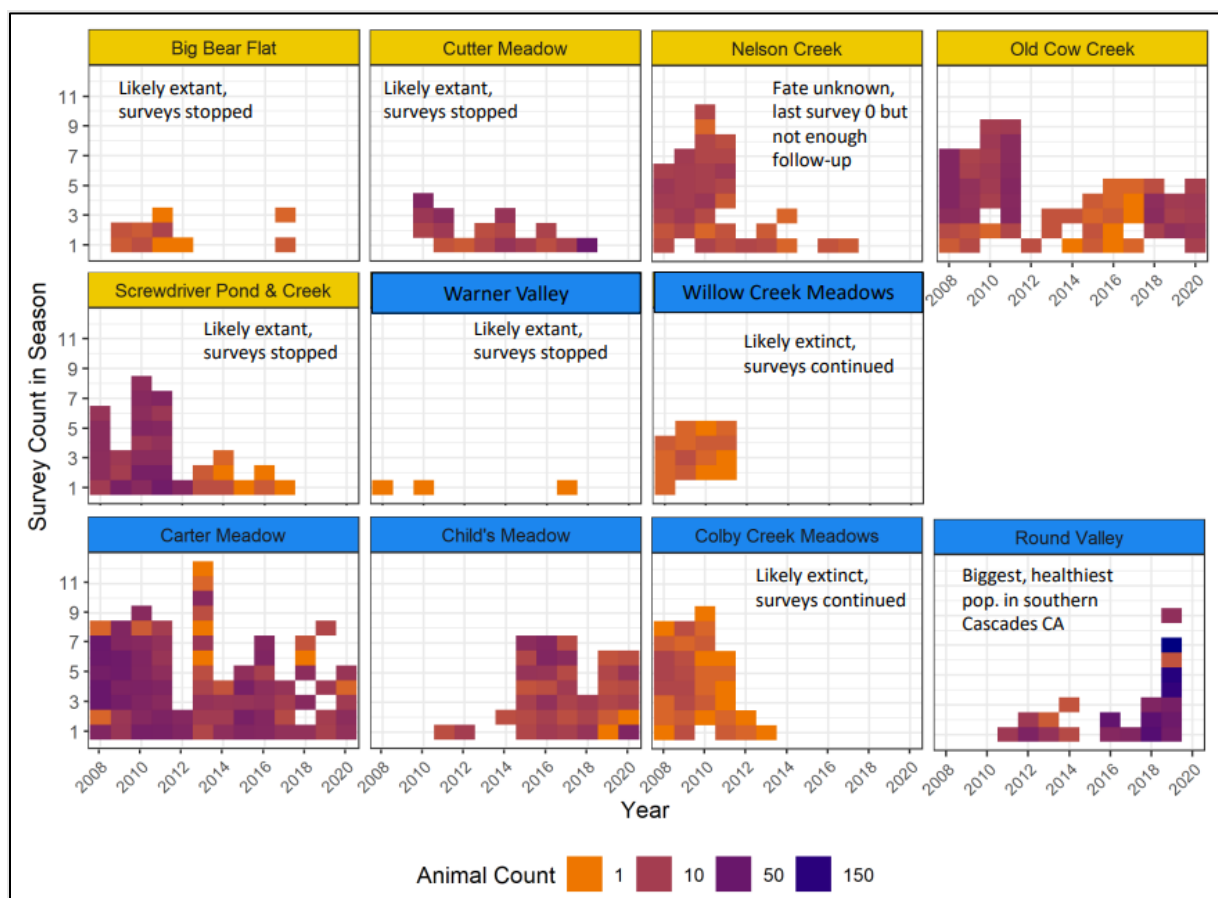


Figure 11. Monitoring data for 11 California Cascades sites. Gold sites are in California North genetic group and blue sites are in California South genetic group. Y-axis is survey visits (effort) and X-axis survey year. Number of adult Cascades frogs are represented by color (Pope and Cummings, USFS, unpl. data 2021; Collins Pine Company and Sierra Pacific Industries 2021, entire).

Klamath Mountains in California: The Klamath Mountains are unusual in that they are often referred to by their submountain ranges such as the Trinity Alps or Marble Mountains; however, we are referring to all mountains west of the Sacramento River and Interstate 5 as part of the Klamath Mountains. In the Klamath Mountains, Cascades frogs remain widespread and relatively abundant when compared to the populations in the California Cascades (Welsh 2006, p. 307; Pope et al. 2014, p. 16). However, this is not an even distribution among the different mountain wilderness areas comprising the larger Klamath

Mountains. One study found Cascades frogs were much less abundant in the Marble Mountains and Russian Wilderness compared to the Trinity Alps and concluded that the species may be in danger of extirpation based on the low numbers of occupied sites (Welsh et al 2006, pp. 307-308). Subsequent surveys of the same occupied sites found that 79% (88 of 112 sites) of occupied Cascades frog sites from 1999 to 2001 remained occupied in 2008 (Piovia-Scott et al. 2011, p. 2917). Additional surveys were begun in 2021; however, conflicts with wildfires ended the survey efforts prematurely. Surveys are planned to continue in 2022 (Garwood, CDFW, pers. comm. 2021).

In addition to ongoing landscape level survey efforts, long-term population monitoring of Cascades frogs in the Deep Creek Basin of the Trinity Alps Wilderness have been ongoing since 2003 (Garwood, CDFW, unpl. data 2021). Egg mass counts from 2003 to 2021 indicate that following an increase in 2007 and 2008, egg mass counts have an overall declining trend with the most recent three breeding seasons showing a greater downward trend (Figure 12) (Garwood, CDFW, unpl. data 2021). Data for the same period tracking breeding patches and waterbodies also follow a similar pattern, particularly showing the downward trend for waterbodies the last three years (Garwood, CDFW, unpl. data 2021). Currently, it is not clear whether the recent decline reflects winter precipitation patterns or is a result of other factors. Drought undoubtedly plays a role in reducing frog abundance by limiting hydroperiod. Over this same period, Cascades frog use of seasonal wetlands for breeding has also declined (Garwood, CDFW, unpl. data 2021). This suggests Cascades frogs are becoming increasingly dependent on perennial water features for breeding. Typically, this would concentrate frogs in fewer breeding sites and potentially increase exposure to non-native trout. However, trout were removed from the basin by 2015 (Garwood, CDFW, pers. comm. 2021). The last two winters (2019/20 and 2020/21) have had low winter precipitation with approximately 50 to 60% of average precipitation (Figure 13). Snowpack information for the same 2019 and 2020 winters also shows the rapid loss of snowpack through the month of April leading up to the frog's breeding season (Figure 14). While reduced winter precipitation in the form of snow may explain some of this decline, similar low water periods did not result in such declines. For example, the period of 2013 to 2015 had similar drought conditions though egg mass counts increased slightly. This slight increase may be due to the net benefit of trout removal; however, the current decline is independent of trout. It is possible another stressor such as *Bd* may be acting synergistically with the current drought conditions (Garwood CDFW pers. comm. 2021). In a 2008 study, *Bd* was found to be widespread in the Klamath Mountains and suspected of potentially causing recruitment failures in Cascades frogs (Pope et al. 2011, p. 11; Piovia-Scott et al. 2011, p. 2919). *Bd* can limit juvenile survival and thus adult recruitment (Pope et al. 2011, p. 11). The effect of limited juvenile survival and recruitment can be masked over the short-term when monitoring a relatively long-lived frog (Pilliod and Peterson 2001, p. 331).

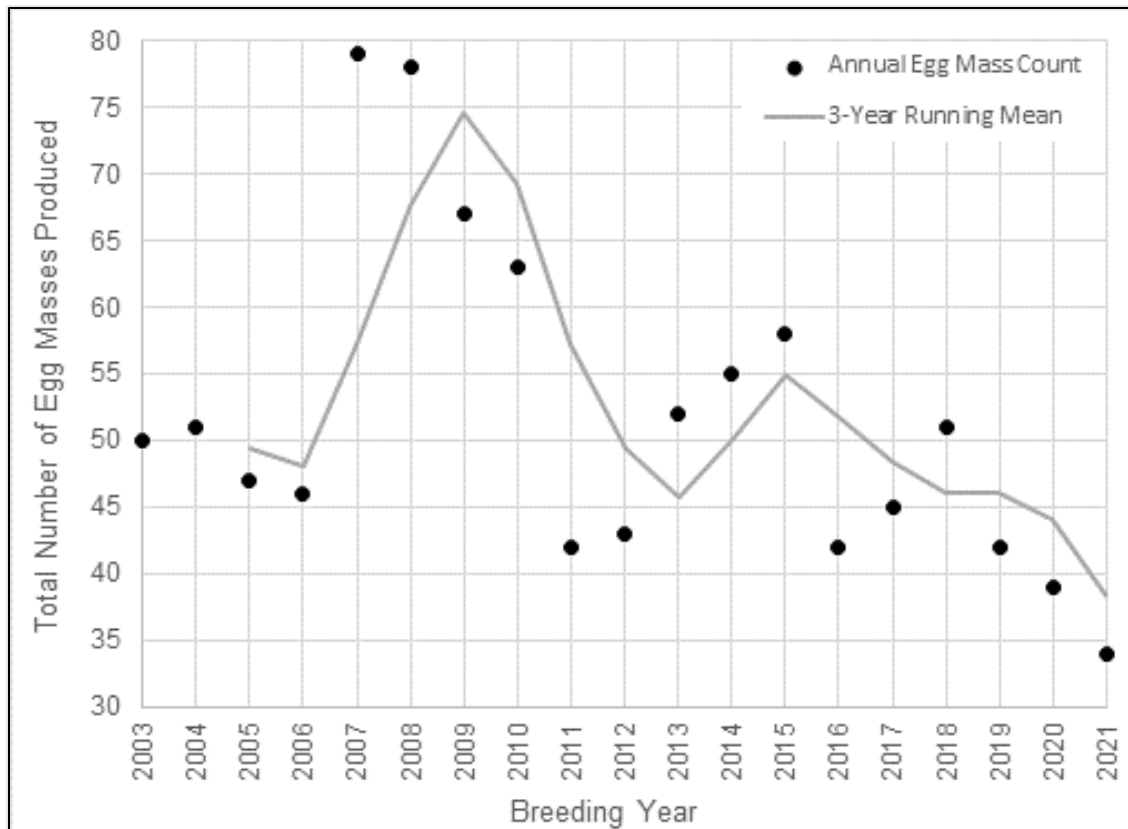


Figure 12. Annual Cascades frog reproductive output in Deep Creek Basin, Trinity Alps Wilderness, California, from 2003 to 2021. Egg mass counts are based on multiple egg mass surveys completed across an entire breeding population containing fifteen isolated breeding patches and fifty-two individual breeding waterbodies (Garwood, CDFW, unpl. data 2021). Gray trend line indicates the 3-year running mean of the egg mass counts.

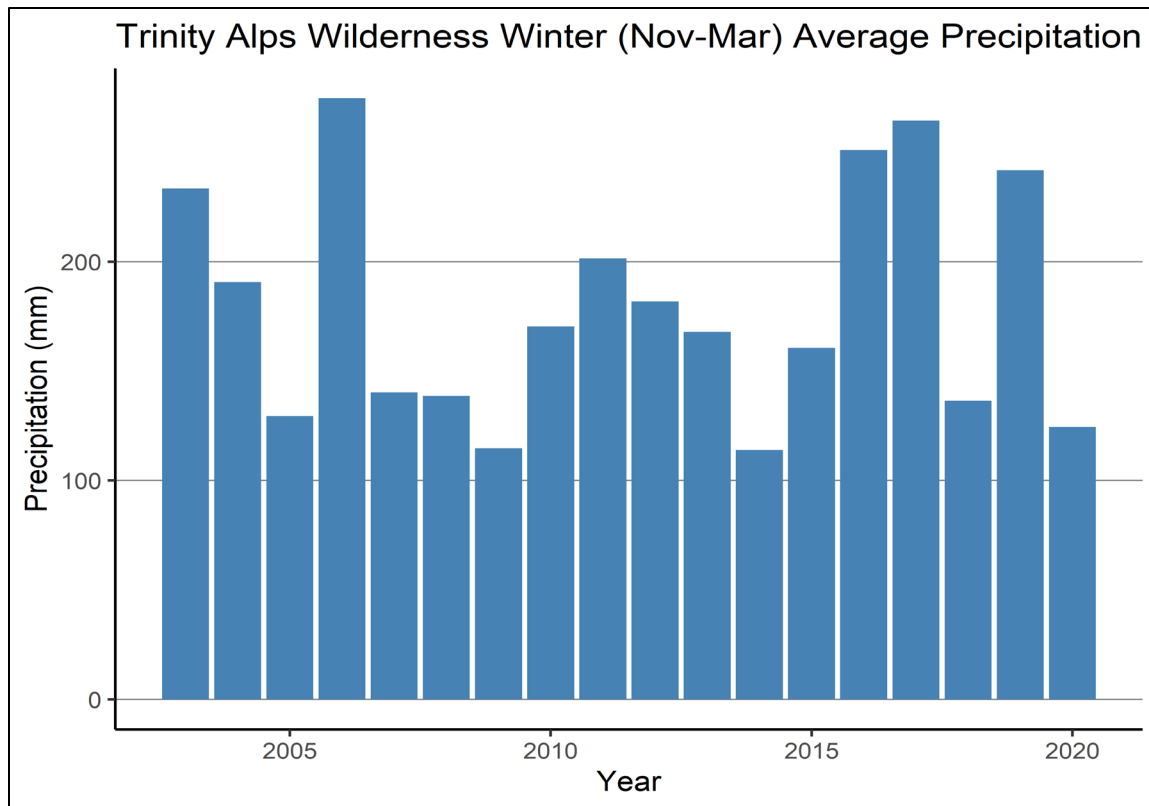


Figure 13. Average winter precipitation for the Trinity Alps Wilderness from 2003 to 2020. 100 mm is 54% and 200mm is 109%, respectively, of the 40-year average (184.94mm) (DayMet data).

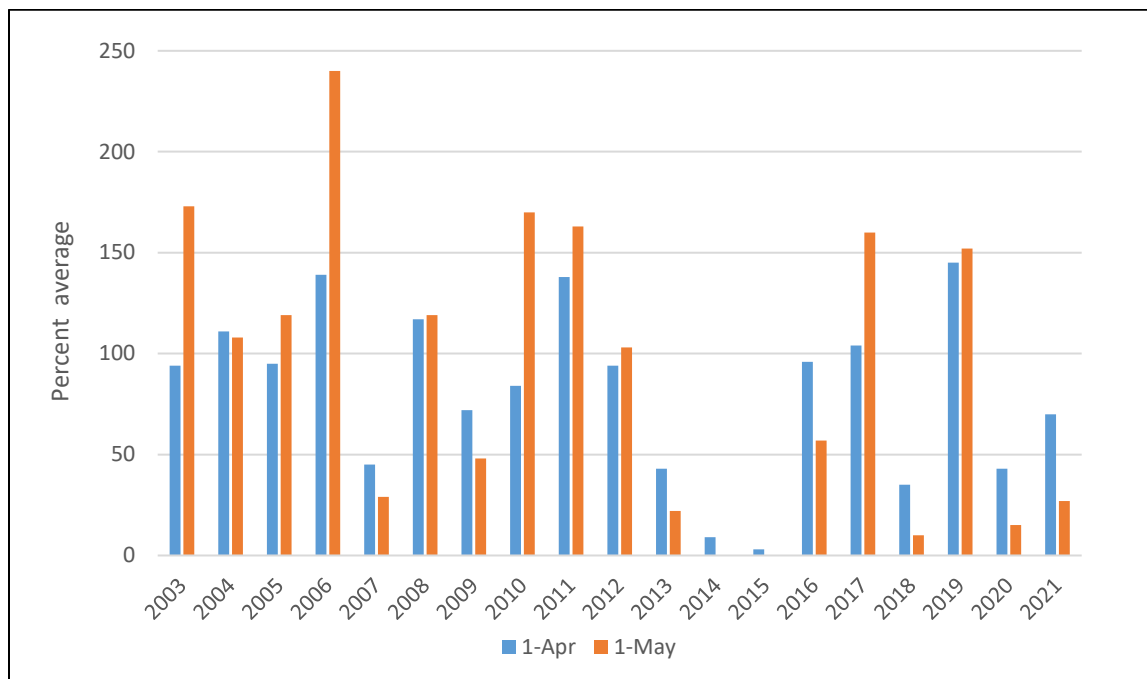


Figure 14. Average snowpack for the North Coast Snow Surveys Summary, California, from 2003 to 2021 illustrating recent drought periods and the difference between 1 April and 1 May snowpack measures for the North Coast (<https://cdec.water.ca.gov/reportapp/javareports?name=COURSES.202104>).

While the Cascades frog continues to be widely distributed and relatively abundant throughout the Klamath Mountains, recent local declines suggest this area may be experiencing accelerated declines due to recent weather patterns potentially compounded by effects of the pathogen *Bd*.

2.4.5 Land Ownership

Cascades frogs are found on a combination of Federal, State, Tribal and private land throughout their range. Approximately 74% of the species' range is on federally owned land, the vast majority of which is managed by the USFS (62%), with the National Park Service (NPS) (11%), and Bureau of Land Management (BLM) (1%) the two other primary federal land managers (Table 3). U.S. Forest Service lands include the Gifford Pinchot, Okanogan-Wenatchee, Mt. Baker-Snoqualmie, Olympic (WA); Fremont-Winema, Rogue River-Siskiyou, Umpqua, Deschutes, Willamette, Mt. Hood (OR); Lassen, Shasta-Trinity, and Klamath (CA), National Forests. The National Parks supporting Cascades frog habitat include Lassen Volcanic, Crater Lake, Mt. Rainier, North Cascades and Olympic National Parks. While Cascades frog also occur on other Federal and non-Federal lands, many of these lands are at the lower elevational edge of the species habitat and it is likely that we have overestimated the amount of habitat in those ownerships. A majority of 17% private land is likely industrial timber producing lands.

Table 3. Land ownership within the Washington, Oregon and California Range of the Cascades frog. Cascades frog habitat occurs on a variety of Federal lands, including those managed by the U.S. Forest Service (USFS), the National Park Service (NPS), the Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (USFWS), and the U.S. Bureau of Reclamation (USBR).

Land Manager	CA (ac)	OR (ac)	WA (ac)	Total (ac)	Percentage
Federal	1,500,245	5,051,432	6,499,737	13,051,414	74%
<i>USFS</i>	1,420,095	4,626,007	4,864,618	10,910,720	62%
<i>NPS</i>	78,837	165,801	1,619,689	1,864,327	11%
<i>BLM</i>	1,313	245,652	1,521	248,486	1%
<i>Other (USFWS, USBR)</i>	-	13,972	13,909	27,881	0.2%
State	15,147	19,654	656,707	691,508	4%
Tribal	-	306,511	583,740	890,251	5%
Private	893,641	731,666	1,345,630	2,970,937	17%
Total	2,409,033	6,109,263	9,085,814	17,604,110	
Wilderness	549,240	1,044,895	3,277,888	4,872,023	28%
<i>BLM</i>	-	553	-	553	0%
<i>NPS</i>	54,305	-	1,558,076	1,612,381	33%
<i>USFS</i>	494,936	1,044,342	1,719,812	3,259,089	67%

2.5 Life History

2.5.1. Life Cycle

The Cascades frog life cycle is well described and can be divided into three phases — the first year, the juvenile (pre-reproductive) phase, and the adult phase. Each new life cycle begins with breeding (Figure 15).

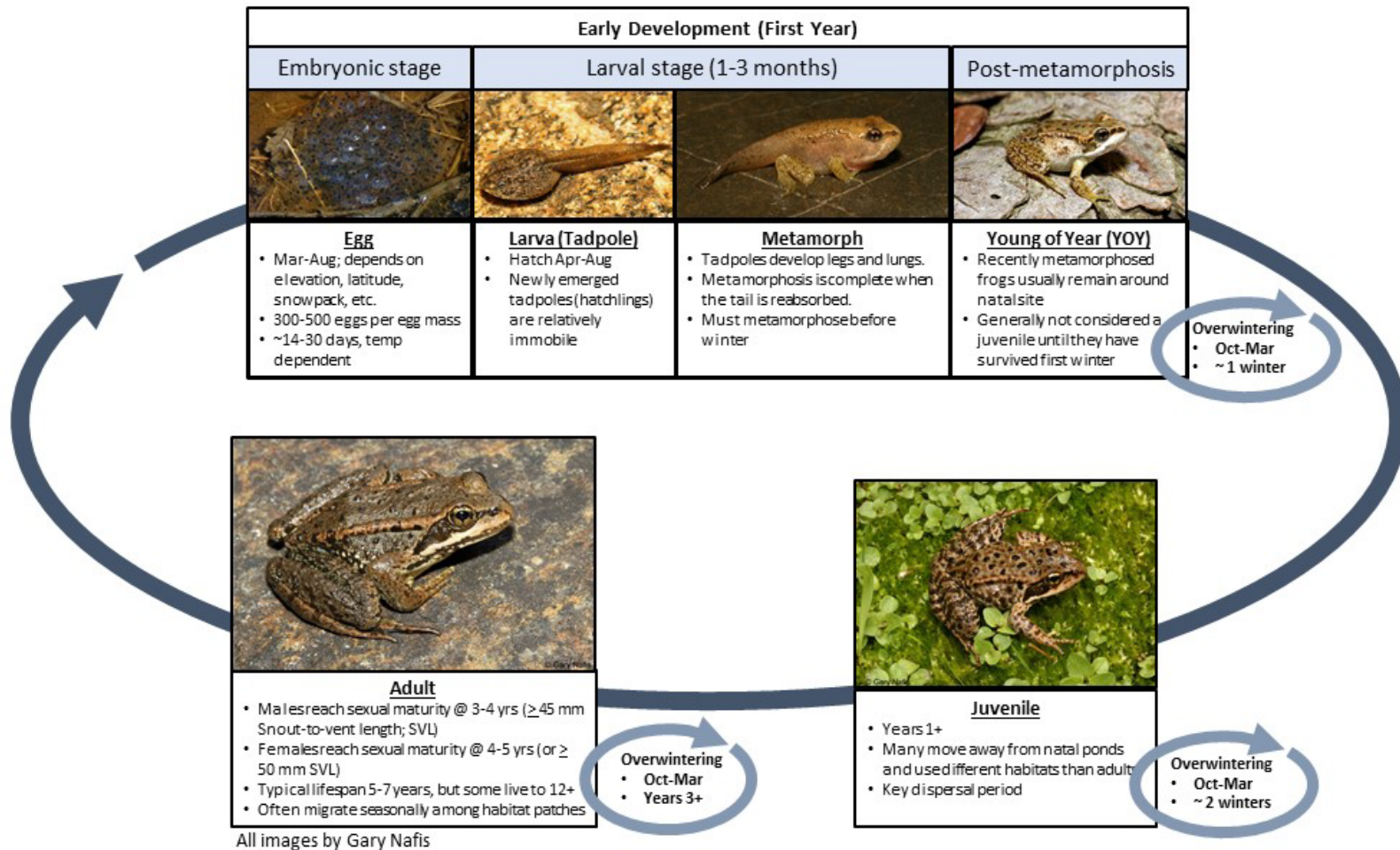


Figure 15. Life stages of the Cascades frog.

2.5.1.1. Breeding

Adult Cascades frogs emerge from overwintering in early spring to breed and lay eggs when spring snowmelt begins. The breeding season typically extends from March to July depending on elevation, annual snowpack and subsequent ice melt (Syte 1974, p. 71; Nussbaum et al. 1983, p. 167; Garwood and Welsh 2007, p. 3, Pope et al. 2014, p. 8). Mating begins simultaneously with emergence, and male advertising occurs with water temperatures lower than 7°C (44.6°F) (Briggs 1987, p. 242; Garwood and Welsh 2007, p. 44). Breeding sites include mountain lakes, ponds, meadow pools, and even small, slow moving, low gradient stream channels (Pope et al. 2014, p. 9). Breeding sites may include human altered and created aquatic habitat such as dammed springs and streams (Briggs and Storm 1970, p. 284) and roadside ditches (Tyson, WDFW, pers. comm. 2022).

Males arrive at breeding sites before females and vocalize in chorusing groups from the shallow waters near shore (Nussbaum et al. 1983, p. 167; Pope et al. 2014, p. 8). Males vocalize above or below water during the day (Syte 1974, p. 71; Briggs 1987, p. 241). Females arrive at the breeding sites a few days later, then males and females pair up in amplexus and eggs are externally fertilized by males, as the females deposit them, during daylight hours (Nussbaum et al. 1983, pp. 167-169). Cascades frogs have been recorded making at least three different calls (Briggs 1987, pp. 241-242). The primary advertisement call has been described as “a series of low, slow, croaks or chuckles” and is comprised of a continuous series of 4 to 39 “cluck” notes at a rate of about 6.7 notes per second (Nussbaum et al. 1983, p. 167; Briggs 1987, pp. 241-242).

In Northern California, egg laying generally occurs between April and July, but varies based on elevation and seasonal conditions (Pope et al. 2014, p. 8). In Olympic National Park in western Washington, frogs typically breed in June and July; however, it may occur as early as late March in low snow years such as 2015 (Tyson, WDFW, pers. comm. 2022) or as late as mid-August (2011) during a heavy snow year (Kissel et al. 2019, p. 3). Annual snow accumulation and subsequent melt influences the timing of breeding initiation as well as breeding duration (Garwood and Welsh 2007, p. 44). Heavy snow years and late snowfalls delay breeding and prolongs the breeding season (Garwood and Welsh 2007, p. 44).

Cascades frogs are “explosive” breeders, meaning their reproduction is rapid and synchronous (Briggs, 1987 p. 243; Garwood and Welsh 2007, p. 44). Within an individual site, egg deposition may be completed in 3 to 10 days although duration may be longer across a basin or complex of breeding sites depending on timing of ice melt and water temperature at individual sites (Syte 1974, p. 72; Garwood and Welsh 2007, p. 44). In a study in the Klamath Mountains of Northern California, basin-wide breeding within a single patchy population lasted an average of 58 days ranging from 49 to 69 days (Garwood and Welsh 2007, p. 44). Males have been detected calling from multiple breeding locations, up to 1 kilometer (km) (0.62 miles (mi)) apart, within a season and may move from lower to higher elevation sites as the snow melts and sites become accessible (Garwood and Welsh 2007, p. 36). Females are highly cryptic during the breeding season and leave the breeding site as soon as oviposition (egg laying) is complete (Briggs 1987, p. 242; Garwood and Welsh 2007, p. 20).

2.5.1.2. First Year

The first year includes egg, larval, metamorph, and young-of-year stages. The first-year life stage starts when females deposit eggs and continues until an individual survives their first winter.

Eggs (embryos)

Females deposit eggs during the day in shallow (from 5 to 18 cm (1.96 to 7.08 in)), slow moving or still water, along the margins of lakes, ponds, and springs with a high percentage of silt substrate (Syte 1974, p. 72; Nussbaum et al. 1983, p. 169; Welsh et al. 2006, p. 303; Pope et al. 2014, pp. 5 and 8). Eggs are often loosely attached to boulders, submerged vegetation, or submerged dead wood, but have also been found free floating and in deep (2 m (6.56 ft.)) water (Garwood et al. 2007, p. 95; Pope et al. 2014, p. 8). Oviposition (egg laying) generally occurs between March and July, depending on local conditions including elevation, latitude, and snowpack. Individual eggs measure approximately 2 mm (0.08 in) wide and are grouped in a jelly-like “mass” of 300 to 500 eggs (Syte 1974, p. 72; Nussbaum et al. 1983, p. 169; Olson *in* Jones et al. (Eds.) 2005, p. 186). Egg masses may be deposited singly or laid communally (Olson *in* Jones et al. (Eds.) 2005, p. 186; Garwood and Welsh 2007, p. 24; Pope et al. 2014, p. 8). Often, several females will deposit their eggs near previously deposited egg masses, resulting in large clusters of 30 to 70 egg masses, though these numbers may represent historic high density populations (Syte 1974, p. 72; Nussbaum et al. 1983, p. 169). In 19 years of monitoring in the Klamath Mountains clusters have only been as high as 9 egg masses (average 2.95, n=174 communal egg groups) (Garwood, CDFW, pers. comm.). In one study in the southern Cascades region of California, egg masses found in pond habitats were laid communally, while egg masses in meadows pools were found singly (Pope et al. 2014, p. 8).

Once deposited, the egg jelly absorbs water and swells, and the upper portion of the egg mass may rise out of the water (Briggs 1987, p. 242). Eggs above the surface of the water may be destroyed due to desiccation and freezing (Syte 1974, pp. 78-79; Nussbaum et al. 1983, p. 169). Symbiotic algae may grow within the gel of egg masses (Nussbaum et al. 1983, p. 169; Ault et al. 2012, pp. 135-136). Eggs hatch after 8-35 days, depending on the water temperature, with warmer water temperatures speeding development and reducing hatching time (Nussbaum et al. 1983, p. 169). In a laboratory study, eggs hatched in as few as 3 days when held at a constant 25°C (77°F) but took approximately 24.5 days at 10°C (50°F) (Syte 1974, pp. 57-61; Nussbaum et al. 1983, p. 169). Optimal developmental temperatures ranged between 8°C (46.4°F) and 25°C (77°F), with critical thermal minimum and maximum temperatures for normal embryo development at 6°C (42.8°F) and 27°C (80.6°F), respectively (Syte 1974, pp. 48-49). In California, eggs generally hatch in approximately three weeks (Pope et al. 2014, p. 8).

Larvae (Tadpoles)

The larval stage begins when individuals hatch from eggs and ends with the beginning of metamorphosis. Larval development is also influenced by water temperature. In the lab, larvae can develop from hatching to metamorphosis in approximately 37.5 days (900 hours) at 23°C (73.4°F) (Nussbaum et al. 1983, p. 169). Larvae appear to exhibit enhanced resistance to temperatures above their optimal thermal range as their development advances (Syte 1974, p. 52). One field study in California noted apparent temperature stress and subsequent behavioral modification of larvae in waters around $\leq 38^{\circ}\text{C}$ (100.4°F) (Pope et al. 2014, p. 9).

One field study in the Klamath Mountains of California from a cold temperature spring pond estimated that Cascades frogs have a maximum four-month larval period *in situ* (Garwood and Welsh 2007, p. 46). In California, larvae generally hatch from eggs in June or July (Pope et al. 2014, pp. 8-9). After hatching, larvae, or tadpoles, are small (around 13 mm (0.08 in) total length) and relatively immobile (Nussbaum et al. 1983, p. 169; Olson *in* Jones et al. (Eds.) 2005, p. 186). As larvae develop and become more mobile, they tend to form loose aggregations of <100 individuals in the warmest areas of the breeding pools during the day (Olson 2005, p. 186; Pope et al. 2014 p. 9). These areas are commonly shallow, gently

sloping near-shore areas that are protected from the wind (Pope et al. 2014 p. 9). Cascades frog larvae and metamorphs exhibit kin recognition and preferentially associate with related individuals in laboratory and field experiments, which may affect growth and predator avoidance (O’Hara and Blaustein 1985, p. 44; Hokit and Blaustein 1997, p. 1730; Pope et al. 2014, p. 9).

In some years at sites with short hydroperiods, water levels drop, and wetlands dry before larvae can metamorphose, resulting in mortality (Garwood and Welsh 2007, p. 46; Pope et al. 2014, p. 9). As wetlands dry, water temperatures increase and allow for accelerated larval growth rates (Syte 1974, pp. 57-61; Kissel et al. 2019, p. 9). However, field studies in Washington documented that wetland drying can occur well before larvae reach metamorphosis at individual sites in some years (Kissel et al. 2019, p. 9). For individuals that survive to metamorphosis, accelerated growth rates may come at the cost of smaller body sizes at metamorphosis, which may negatively impact their survival through their first winter and in the juvenile stage (Kissel et al. 2019, p. 2).

Metamorphs

The metamorph stage (Gosner stages 42 to 46 (Gosner 1960, entire)) begins when larvae grow front legs, and ends when the tail has been fully reabsorbed. As tadpoles develop legs and lungs, they may emerge on land. At metamorphosis, Cascades frogs can measure between 10 and 25 mm (0.39 to 0.98 in) snout-vent length (SVL) (Olson in Jones et al. (Eds.) 2005, p. 186; Nussbaum et al. 1983, p. 169).

Cascades frog larvae generally have a single year development period (with a documented extremely rare instance of overwintering larvae in CA) and metamorphose in late summer or early fall, before overwintering (Garwood and Welsh 2007, p. 3, 46, Garwood, CDFW, pers. comm. 2022). In one 1967 study in Oregon, peak metamorphosis occurred between late July and early August, with few tadpoles observed by September (Briggs and Storm 1970, pp. 293-294). In California, larvae generally metamorphose in late August or September, depending on early spring snowpack and the timing of breeding initiation (Garwood and Welsh 2007, p. 46; Pope et al. 2014, pp. 8-9). In a study in the Klamath Mountains of California, frogs metamorphosed as early as August 2 during a low (38% of normal) snowpack year and were still found in pre-metamorphic larval stages on October 8 during a heavy (251% of normal) snowpack year (Garwood and Welsh 2007, p. 46). Cascades frogs have very rarely been documented surviving between years as tadpoles in California (Pope et al. 2014, p. 9, Garwood and Welsh 2007, p.46, Garwood, CDFW, pers. comm. 2022).

Young-of-year

In a field study in Oregon, the sex ratio of a sample of recently metamorphosed frogs was about 1:1 (Briggs and Storm 1970, p. 295). Recently metamorphosed Cascades frogs usually remain in close proximity to their natal site and many may overwinter in breeding pools (Garwood and Welsh 2007, pp. 26, 37). Post-metamorphic frogs are generally not considered juveniles until they have survived at least one winter. In a field study in the Klamath Mountains of California, 94% of frogs captured after their first winter were within 100m (328 ft.) of their natal site (Garwood and Welsh 2007, p. 37).

2.5.1.3. Juveniles

The juvenile, or pre-reproductive stage lasts from the spring after the frog’s first winter until they are sexually mature. Cascades frogs are believed to overwinter at least three winters before reaching sexual maturity (Briggs and Storm 1970 p. 288). The juvenile stage is a key dispersal period for Cascades frogs (Garwood and Welsh 2007, p. 43). Many juveniles move away from their natal site and often use different habitats than young-of-year and adult frogs, such as streams, however these habitats are not fully known

(Garwood and Welsh 2007, p. 37). A study in the Olympic Mountains of Washington that modeled demographic rates found that juvenile survival was likely lower than adult survival (Kissel et al. 2019, p. 10).

2.5.1.4. Adults

Male Cascades frogs become sexually mature and have been documented breeding when they are between 3 to 4 years old and meet or exceed 45 mm SVL (snout-vent length) (Briggs and Storm 1970, p. 298; Pope et al. 2014, p. 9). Females reach sexual maturity between 4 to 5 years old, when they meet or exceed 50 mm (approx. 1.97 in) SVL (Pope et al. 2014, p. 9). Cascades frogs surviving to adulthood may live to between 5 to 7 years (Nussbaum et al. 1983, p. 170; Garwood and Welsh 2007, p. 63). However, a skeletochronology study in California found that Cascades frogs can live in excess of 10 years (Pope et al. 2014, p. 9), and ongoing long-term mark-recapture studies have documented individuals at least 16 years old in Washington and 18 years old in California (Tyson, WDFW, pers. comm. 2021; Garwood, CDFW, pers. comm. 2022). In a mark-recapture study in the Olympic Mountains in Washington, adult survival averaged 7.5% higher for males than females (Kissel et al. 2019, p. 6). Survival also appears to vary by site and habitat conditions.

2.5.2. Foraging

After hatching and until metamorphosing, larvae feed on periphyton (algae and other materials growing on submerged surfaces), suspended particulates, and detritus (O'Hara 1981, p. 6). Post-metamorphic frogs (young-of-year, juveniles, and adults) are generalist predators and feed both aquatically and terrestrially (Pope et al. 2014, p. 11). Adult Cascades frogs feed on a variety of adult aquatic and terrestrial insects, spiders, and mollusk prey and occasionally young conspecifics (Rombough 2003, p. 138; Joseph et al. 2011, entire; Larson 2012, entire).

A study in northern California noted a high level of dietary breadth representing 110 invertebrate taxa but found five categories of prey to be of highest relative importance: grasshoppers (*Acrididae*), spiders (*Araneae*), ants (*Formicidae*), insect larvae, and crane flies (*Tipulidae*) (Larson 2012, p. 46). Diet varied by sex and by life stage in the spring and the fall (Larson 2012, p. 46). Specifically, female Cascades frogs consumed a higher volume of five prey categories (*Araneae*, *Acrididae*, *Carabidae* (ground beetles), *Noctuidae* (owllet moths), and *Scarabaeidae* (beetles)) in a season than either male or juvenile frogs (Larson 2012, p. 46). Another study in the Klamath Mountains of northern California examined the stomach contents of Cascades frogs in lakes with and without introduced trout and found caddisflies (*Trichoptera*), water striders (*Hemiptera*), butterflies/moths (*Lepidoptera*), dragonflies/damselflies (*Odonata*), spiders (*Araneae*), beetles (*Coleoptera*), true bugs (*Hemiptera*), and wasps/bees (*Hymenoptera*) to be the most important prey items numerically depending on presence/absence of trout (Joseph et. al. 2011, pp. 833-834).

2.5.3. Overwintering

Young-of-year, juvenile, and adult Cascades frogs overwinter and may spend up to seven to nine months out of the year in a dormant state (Garwood 2009, p. 4; Kissel et al. 2019, p. 2). Overwintering habitat availability is estimated to be nearly as restrictive as breeding habitat (Garwood 2009, pp. 71-72; Pope et al. 2014, p. 7). Cascades frogs overwinter aquatically in the loose mud and organic material at the bottom of ponds or in aerobic areas covered in water, such as near springs (Briggs 1987, p. 241; Barreca 2010, p. 20). In a field study in the Klamath Mountains of Northern California, over half of all frogs were captured in aquatic habitats associated with groundwater springs (Garwood 2009, p. 75). Frogs were found in both

lentic and lotic aquatic areas (Garwood 2009, p. 75). Around half of the frogs in the study overwintered in or within close proximity (<100 m; 328 ft.) to breeding sites, while the other half migrated between separate overwintering and breeding habitats (Garwood and Welsh 2007, p. 34).

In a radio-telemetry study in Washington State, Cascades frogs overwintered in a spring pond with a silty substrate, moderate levels of dissolved oxygen, and stable water temperatures (Barreca 2010, p. 20). Overwintering frogs were found clustered on a submerged shelf beneath an undercut bank at the edge of the spring or burrowed into the silt-water interface and covered with a light layer of silt (Barreca 2010, pp. 14-15, 21). Researchers also found one Cascades frog overwintering in a creek at a nearby site (Barreca 2010, pp. 20-21). Frogs were active during the winter and moved among microhabitat patches within the spring pond and adjacent wetland (Barreca 2010, pp. 15, 21).

Overwintering mortality is thought to be high, and frogs are sensitive to habitat disturbance during this time (Briggs and Storm 1970, p. 288; Barreca 2010, p. 22; Pope et al. 2014, p. 11). A laboratory study found that Cascades frogs are not freeze tolerant and did not survive freezing down to -1.5°C (29.3°F) (Barreca 2010, p. 22). Cascades frogs rely on their fat reserves during the winter while food resources are limited (Barreca 2010, p. 23). Frogs with inadequate reserves may be more vulnerable to overwintering mortality or to adverse weather conditions such as unusually long winters or late spring storms (Barreca 2010, p. 23; Pope et al. 2014, p. 11). Some evidence suggests that milder winters may increase overwintering survival; however, body condition may decline if winter temperatures are inadequate (too warm) to maintain dormancy throughout the winter (Kissel et al. 2019, p. 2). Frogs emerge from overwintering following ice-out (when surface ice melts and open water becomes available on a water body), which varies by elevation and annual snow and ice accumulation, but typically occurs between late-February and June (Syte 1974, p. 71; Briggs 1987, p. 241; Garwood and Welsh 2007, p. 44).

2.5.4. Seasonal Variability

Variation in hibernation timing and initiation of breeding exists along an elevational and latitudinal gradient (Figure 16). Higher elevations and more northerly populations generally breed later than lower elevation and southern populations. Breeding generally occurs as soon as there is open water, which may vary widely from year to year (Syte 1974, p. 71; Nussbaum et al. 1983, p. 167; Garwood and Welsh 2007, p. 3, Pope et al. 2014, p. 8).

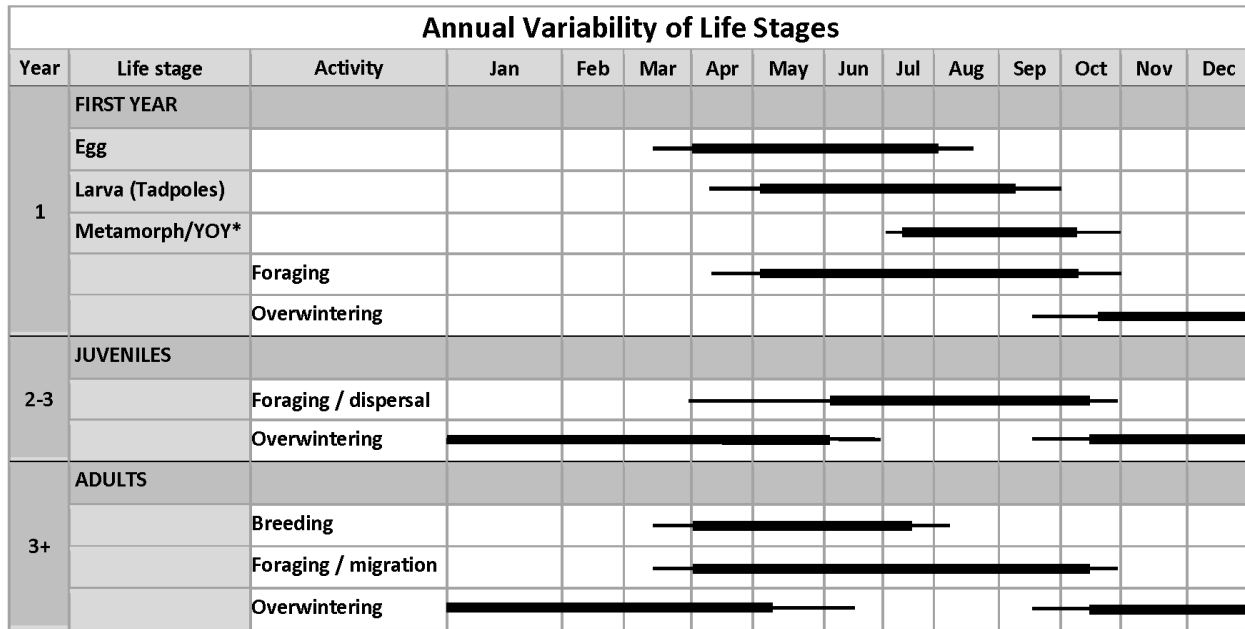


Figure 16. Variability in timing of life stages of the Cascades frog. Young-of-year (YOY) refers to recently metamorphosed individuals from the time after they have reabsorbed their tail until the individual has survived their first winter and reemerged in the spring. Variation in overwintering and active period (breeding and foraging/migration) exists along an elevational and latitudinal gradient. Higher elevations and more northerly populations generally breed later than lower elevation and more southern populations. Breeding generally occurs as soon as water temperatures have reached 7°C (44.6°F), which may vary from year to year.

2.5.5. Spatial and Movement Ecology

Cascades frogs are highly mobile, primarily aquatic, diurnal (active during daytime) amphibians. Cascades frogs move across the landscape between habitat patches for breeding, feeding, sheltering (including overwintering), and to disperse to adjacent habitat patches and to separate basins with accessible suitable habitats (Garwood and Welsh 2007, pp. 30-43). Several studies have described movements between and among breeding and non-breeding aquatic sites; however, the spatial scale at which populations function is still a matter of research (Brown 1997, entire; Monsen and Blouin 2004, entire; Crisafulli *in* Dale et al. 2005, pp. 183-197; Olson *in* Jones et al. (Eds.) 2005, p. 189; Garwood and Welsh 2007, pp. 30-43; Garwood 2009, entire).

Adult Cascades frogs often migrate seasonally among habitat patches to meet their resource needs (Garwood and Welsh 2007, p. 30). Adults migrate between overwintering and breeding sites and may migrate to other habitats after breeding (Garwood and Welsh 2007, p. 34). Females, especially, leave breeding sites after laying eggs (Briggs 1987, p. 242; Garwood and Welsh 2007, p. 20), and males have been documented moving among multiple breeding sites up to 1 km (0.62 mi) apart within a single breeding season (Garwood and Welsh 2007, p. 36). A study in the Klamath Mountains of California found that nearly half the frogs tracked (47% of females and 45% of males) made migrations >100 m (328 ft.) from wintering to breeding sites (Garwood and Welsh 2007, p. 34). The longest round-trip migrations documented were between 1600 to 1980 m, and on average, females migrated farther than males (Garwood and Welsh 2007, p. 34). Newly metamorphosed individuals stick close to their natal pond for the first year (25 to 100 m; 80 to 328 ft.), but older juveniles move seasonally between foraging sites with

less site fidelity (>100 m; 328 ft.) (Garwood and Welsh 2007, p. 38; Garwood 2009, pp. 44-45; Pope et al. 2014, p. 11). The juvenile stage is thought to be a key dispersal period for Cascades frogs with 51% of juveniles dispersing from natal patches while only 7% of adults moved from one breeding site to a new breeding site in subsequent years (Garwood 2009, pp. 44-48).

Cascades frogs utilize streams as movement corridors, but dispersal also occurs overland, primarily after snow melt or summer storms when the landscape is still wet and soil moisture is high (Garwood and Welsh 2007, pp. 30, 40; Garwood 2009, pp. 54, 65-69). Frogs have been observed migrating between overwintering and breeding habitats along a narrow gap between a rock outcrop and a snowfield, where soils were likely moist from melting snow (Garwood 2009, p. 66). Although rare, movement across ridgetops and steep landscape features has been documented (Garwood 2009, p. 65). In one radio-telemetry study in the Klamath Mountains of California, two radio tagged frogs were documented navigating steep (>70° slope), rocky terrain during a rainstorm (Garwood 2009, p. 65). One frog was located 20 m (~66 ft.) up a barren, rocky stream bank, sheltering in a rodent burrow, while the other was able to navigate down a 4 m (13 ft.) nearly vertical cliff (Garwood 2009, p. 65). Landscape features such as downed wood, boulders, seeps, and springs likely provide refuge from desiccation, especially in late summer and early fall before the return of fall rains (Garwood and Welsh 2007, pp. 28-29). In dry summer months, frogs may also move overland at night (Garwood and Welsh 2007, p. 30).

A study in the Klamath Mountains of California used radio telemetry to document Cascades frog movement and found that individual wetland sites contributed to a complex of seasonal resource patches and were unlikely to independently support self-sustaining sub-populations (Garwood 2009, p. iii). Basins containing patches of habitats were connected by dispersing and migrating individuals (Garwood and Welsh 2007, p. 57). Inter-basin dispersal was documented 19 times, and researchers estimated that the minimum distances frogs travelled averaged 1.17 km (0.73 mi) but ranged from 0.736 to 1.886 km (0.46 to 1.17 mi) (Garwood and Welsh 2007, p. 66), so basins may function as sub-populations within a metapopulation (Garwood and Welsh 2007, p. 57). After the 1980 eruption of Mount St. Helens in Washington, two marked Cascades frogs were documented moving 0.75 km (0.47 mi) and 1.2 km (0.75 mi) between waterbodies (Crisafulli *in* Dale et al. 2005, p. 195). Genetic and radio-telemetry studies have both provided evidence for connectivity and genetic exchange between wetland basins in close proximity (≤ 5 km; ≤ 3.10 mi), likely in a stepping-stone fashion (Monsen and Blouin 2004, pp. 832-833; Garwood and Welsh 2007, p. 40), but Cascades frogs exhibit a strong pattern of isolation by distance between sites separated by ≥ 10 km (≥ 6.21 mi) (Monsen and Blouin 2004, p. 832).

3.0 SPECIES ECOLOGICAL NEEDS

3.1 Individual Resource Needs

We evaluate the individual needs of the Cascades frog in terms of the resource needs that are necessary to complete each stage of the life cycle, including eggs, larvae, metamorphs, young-of-year (post metamorphosis), juveniles, and adults. All life stages of the Cascades frog are dependent upon the maintenance of suitable aquatic, thermally appropriate microhabitats supporting abundant small invertebrate prey. In addition, winters must be suitably cold with ample snowpack to support overwintering and the wetlands Cascades frogs depend on for breeding, foraging, and sheltering.

3.1.1. Aquatic Habitats

Due to the frog's dependence on aquatic habitat for all of its life stages, the presence and persistence of aquatic habitat has a substantial influence on Cascades' frog short and long-term presence, abundance and persistence (Garwood and Welsh 2007, entire; Pearl et al. 2009, entire; Pope et al. 2014, pp. 5-8). Cascades frogs require a diversity of aquatic features, particularly those that are perennial, across the landscape for breeding, feeding, sheltering, overwintering, and dispersing.

3.1.1.1. Aquatic Features

Cascades frogs are highly aquatic and require a variety of aquatic resources throughout the year to survive and reproduce. Breeding habitats including shallow margins of lakes, ponds, slow-moving springs with a high percentage of silt substrate (usually <2 m (6.56 ft.) deep) are necessary to support eggs, larvae, and metamorphs (Pope et al. 2014, p. 5, 8; Welsh et al. 2006, p. 303). Low gradient, near shore water margins offer wind protection, and provide suitable water temperatures (Pope et al. 2014 p. 9). To successfully reproduce, Cascades frogs require wetlands with an adequate hydroperiod (the length of time a wetland retains water) to allow larvae to complete metamorphosis before the wetland dries or before the onset of winter (Garwood and Welsh 2007, pp. 3 and 46; Kissel et al. 2019, p. 2). Depending on factors including water temperatures, food availability, and elevation, larvae may require stable hydroperiods for up to five months (Fellers and Drost 1993, p. 180; Garwood et al. 2007, p. 96, Kissel et al. 2019, p. 2). Eggs are sensitive to changes in water level and can freeze or desiccate if the water level drops before they hatch (Syse 1974, pp. 78-79; Kissel et al. 2019, p. 2). Similarly, larvae can become isolated and desiccate if wetlands dry before they can complete metamorphosis (Pope et al. 2014, p. 9).

During the nonbreeding active season, juveniles and adults utilize a diversity of aquatic sheltering, foraging and dispersal habitat across the landscape including ponds, lakes, springs, seeps, wet meadows and streams (Garwood 2009, pp. 38, 65-69; Pope et al. 2014, p. 7). Females in particular use streams for foraging in summer months (Garwood 2009, p. 38).

3.1.1.2. Structural Features

Although many subalpine wetlands feature simplified shorelines and eggs are laid in full sunlight, some structural features, such as vegetation, downed wood, and rocks are required often used to anchor egg masses in breeding pools (Garwood et al. 2007, pp. 24, 95). Additionally, these shoreline structural features shelter larvae and metamorphs from temperature extremes and wind (Garwood and Welsh 2007, p. 47; Pope et al., 2014, p. 9). The more terrestrial life stages, including young-of-year, juveniles, and adults require a diversity of landscape features (e.g., logs and rocks) that provide refuge from desiccation and support basking and foraging (Garwood and Welsh 2007, pp. 28-29).

3.1.1.3. Forage Base

All life stages of Cascades frogs require adequate food resources to support growth and the development of overwintering reserves. For the primarily aquatic larval life stages, including tadpoles and metamorphs, food resources first include egg jelly, then detritus, suspended particulates, periphyton (algae and other materials growing on submerged surfaces), and (opportunistically) dead animal tissue (O'Hara 1981, p. 6). The more terrestrial life stages, including young-of-year, juveniles, and adults, forage from open, sunny shorelines, emergent vegetation, floating logs or emerged rocks (Fellers and Drost 1993, p. 178; Pope et al. 2014, p. 7), and their diet expands to include adult aquatic and terrestrial insects and spiders (Pope et al. 2008, pp. 989-990; Joseph et al. 2011, pp. 832-833; Larson 2012 pp. 36, 46; Pope et al. 2014, p. 11).

Adults forage similarly to juveniles but exhibit more seasonal movement between breeding and foraging sites (Garwood 2009, p. 54). Adults also forage upon adult aquatic and terrestrial insects and spiders (Pope et al. 2014, p. 11; Joseph et al. 2011 p. 833, Larson 2012 p. 20) though adults can feed on larger items likely due to their larger size (Larson 2012, p. 50). Cascades frog diets also vary in lakes with or without non-native trout. In lakes with trout, frogs eat more terrestrial insects, while without trout, frogs eat more adult aquatic (i.e., winged) insects such as caddisflies (Joseph et al. 2011, pp. 832-833).

3.1.1.4. Overwintering Features

Young-of-year, juvenile, and adult Cascades frogs are not freeze tolerant and require perennial aerobic aquatic features that do not freeze completely in winter (Barreca 2010, p. 22; Pope et al. 2014, p. 8). Overwintering habitats include undercut banks of ponds, lakes, low gradient stream sections, and springs (Briggs 1987, p. 241; Garwood 2009, pp. 43-44; Barreca 2010, p. 13). Sufficiently low thermal conditions may be important for sustaining dormancy throughout the winter (Kissel et al. 2019, p. 2). Frogs may become more active during warmer conditions, which may decrease body condition in spring if food resources are scarce (Kissel et al. 2019, pp. 2, 9). Snowpack may be important insulation that maintains stable temperatures within overwintering habitats (Barreca 2010, pp. 16-17).

3.1.1.5. Connectivity

The more terrestrial life stages of Cascades frog life stages (young-of-year, juveniles, and adults) require habitat connectivity for dispersal and migration. Individuals require a diversity of aquatic sheltering, foraging and dispersal habitat across the landscape including ponds, lakes, springs, seeps, meadows and streams (Garwood 2009, pp. 38, 65-69; Pope et al. 2014, p. 7). Streams may often function as movement corridors (Garwood and Welsh 2007, p. 30). Migration and dispersal may also occur overland, primarily after snow melt or summer storms when the terrestrial landscape is still moist (Garwood and Welsh 2007, pp. 30, 40; Garwood 2009, pp. 54, 65-69). Landscape features such as downed wood, boulders, seeps, and springs likely provide refuge from desiccation, especially in late summer and early fall before the return of fall rains (Garwood and Welsh 2007, pp. 28-29). While Cascades frogs are mobile amphibians capable of dispersing or migrating across terrestrial habitats (Garwood and Welsh, 2007, pp. 30-43), genetic studies have found that Cascades frogs are isolated by distance across their range with a pattern of limited gene flow between populations separated by 10 km (6.21 mi) or more (Monsen and Blouin 2004, p. 832). In addition to the naturally low frequency of individual Cascades frogs dispersing between distant populations, human created or influenced partial barriers will likely further reduce the probability of individual dispersal between populations. Partial barriers may include high traffic roads and areas of high fire intensity.

3.1.1.6. Precipitation

Water sources, primarily in the form of winter snowpack and summer and fall rains are critical for supporting breeding, feeding, sheltering, and dispersal/migration of all life stages of Cascades frogs. Precipitation directly supports seasonal and perennial aquatic features and recharges groundwater sources. Sustained snowmelt from snowpack maintains water levels in many wetlands (Kissel et al. 2019, p. 2). Additionally, moist soils from snowmelt facilitate migration between overwintering and breeding sites and maintain temporary dispersal corridors among separate watersheds over mountain passes (Garwood 2009, p. 54 and 69) and summer and fall rains facilitate movement across the landscape after breeding or metamorphosis (Garwood and Welsh 2007, p. 30).

3.1.1.7. Summary of Individual Resource Needs

Individual resource needs are summarized in Table 4.

Table 4. Individual resource needs of the Cascades frog. Cascades frogs require habitat for breeding (B), feeding (F), sheltering (S), dispersing (D) and migration (M). Young-of-year (YOY) refers to recently metamorphosed individuals from the time after they have reabsorbed their tail until the individual has survived their first winter and reemerged in the spring.

Habitat Factors (Resource Needs)	Egg	Larvae, Metamorphs, & YOY	Juvenile	Adult
Aquatic Features - A diversity of aquatic features across the landscape providing open water for at least 5 months (B,F,S)	• Shallow margins of lakes, ponds, slow-moving springs and stream backwaters (depth usually <2 m (6.56 ft.)) with a high percentage of silt substrate. • Water temperatures between 2°C and 27°C (35.6°F and 80.6°F). Larval development is extended at cooler temperatures. • Stable hydrology/water level to limit desiccation.	• Low gradient, near-shore water margins with wind protection. • Adequate hydroperiod to protect from desiccation, becoming stranded, and to complete metamorphosis (2-3 months).	• Diversity of aquatic sheltering, foraging and dispersal habitat across the landscape including ponds, lakes, springs, seeps, meadows and streams.	• Shallow margins of lakes, ponds, slow-moving springs and stream backwaters (depth usually <2 m (6.56 ft.)) to support breeding immediately after ice-out. • Ponds, meadows, lakes and streams to provide sheltering and foraging habitat in the nonbreeding active season (June through October).
Structural Features - Non-aquatic abiotic and biotic components of sheltering and foraging habitat (F, S)	• Vegetation, wood, boulders and shoreline to anchor egg mass. • Full exposure to sunlight.	• Vegetation, rocks, and logs provide shelter from temperature extremes and wind.	• Diversity of landscape features (e.g., logs and rocks) that provide refuge from desiccation and support basking and foraging. • Open, sunny shorelines, floating logs or partially submerged rocks to support foraging.	
Forage Base - Food resources supporting growth and overwintering reserves (F)	• Egg jelly supports initial growth and development	• Detritus, suspended particulates, periphyton and (opportunistically) dead animal tissue.	• Aquatic and terrestrial insects and spiders.	

Table 4 continued. Individual resource needs of the Cascades frog. Cascades frogs require habitat for breeding (B), feeding (F), sheltering (S), dispersing (D) and migration (M). Young-of-year (YOY) refers to recently metamorphosed individuals from the time after they have reabsorbed their tail until the individual has survived their first winter and reemerged in the spring.

Habitat Factors (Resource Needs)	Egg	Larvae, Metamorphs, & YOY	Juvenile	Adult
Connectivity - Aquatic and landscape features to support dispersal and refuge from desiccation (B, F, S, D/M)		Although many newly metamorphosed individuals stay close to natal pond for first year (25-100m (82.02-328.08 ft.)), if wetlands dry, YOY will need to disperse to new habitats for foraging and overwintering	- Older juveniles move with less site fidelity (>100 m (328.08 ft.)) but are the key dispersal stage - Connectivity needs similar to adults	- Diversity of aquatic sheltering, foraging and dispersal habitat across the landscape including ponds, lakes, springs, seeps, meadows and streams to support seasonal migrations between overwintering, breeding, and foraging sites. - Adults generally exhibit breeding site fidelity and may return to the same site for a period of years, while other individuals are more “nomadic.”
Precipitation - Water sources, primarily in the form of winter snowpack and summer and fall rains (B, F, S, D/M)			Damp landscape features (such as after snow melt or summer storms) support overland juvenile dispersal and adult movement	
	Seasonal and perennial aquatic features directly supported by rainfall and snowmelt, recharged groundwater sources.			
Overwintering Features - Perennial aerobic aquatic features that do not freeze completely in winter (S)			- Perennial, often spring fed, aerobic aquatic environments that do not freeze below the surface (e.g., undercut banks of ponds, lakes, low gradient stream sections, springs). - Sufficient snowpack to maintain consistent temperatures and a stable wintering metabolism	

3.2 Population Needs for Resiliency

We evaluate the population needs of the Cascades frog in terms of what is required for populations to be resilient or able to withstand environmental stochasticity. As previously defined in Section 1.2, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. Resiliency is based upon the ability of a population to withstand and recover from environmental or demographic stochastic events such as drought, decreases in abundance, or the impacts of fire. We evaluate resiliency in terms of demographic requirements and habitat resources that are necessary to maintain abundance, distribution, and reproduction. Though we summarized individual habitat resource needs for Cascades frog in Section 3.1, here we look at habitat and demographic requirements at a population scale for the species.

While Cascades frog has been studied throughout its range, no clear definition of population exists. Genetic studies on Cascades frog use the term “population” to define genetic divergence between geographic regions (See Taxonomy and Genetics, Section 2.2). We considered populations as occupied suitable habitat with connectivity to other occupied habitat to facilitate genetic exchange and recolonization of habitat through dispersal. While Cascades frogs are periodically mobile amphibians capable of dispersing or migrating across terrestrial habitats (Garwood and Welsh, 2007, pp. 30-43), genetic studies have found that Cascades frogs are isolated by distance across their range with a pattern of reduced gene flow between populations separated by 10 km (6.21 mi) or more (Monsen and Blouin 2004, p. 832). Gene flow among populations is gradual and likely occurs in a steppingstone fashion (Monsen and Blouin 2004, pp. 827, 832-833) where nearest populations exchange migrants across the range.

Cascades frog distributions and movements loosely exhibit the characteristics of metapopulations (Brown 1997, entire, Pope et al. 2014, p. 10). A metapopulation consists of a collection of partially isolated breeding habitat patches, connected by occasionally dispersing individuals whereby each patch exists with non-zero extinction probability (Smith and Green 2005, p. 111). Cascades frogs often migrate seasonally between breeding, summer foraging, and overwintering sites with some sites providing year-round resources (Garwood 2009, p. 31). Two dispersal patterns have been described for Cascades frog: the more common local dispersal, or migration between patches, within a basin, and inter-basin dispersal that is supportive of metapopulation dynamics (Smith and Green 2005, p. 111; Garwood 2009, pp. 80-81).

While local occupied sites may become extirpated due to stochastic events (drought, fire), sufficient connectivity (less than 5 km (3.10 mi)) may help facilitate the recolonization of sites if suitable habitat is available (Pope et al. 2014, pp. 10-11). There are several examples of recolonization of suitable habitat from neighboring occurrences, but they occurred at different rates; Cascades frogs relatively quickly (2 to 7 years) recolonized lakes after the Mount St. Helens eruption from source lakes up to 3.7 km (2.29 mi) away, however another extirpated site in Oregon took 12 years to be recolonized, despite having another occupied site within 2 km (1.24 mi) (Crisafulli *in* Dale et al. 2005, pp. 193-194; Pope et al. 2014, p. 10). Similar connectivity distances were found for Oregon spotted frog (*R. pretiosa*) in Oregon and varied based on the availability of water across the landscape (Duarte et al. 2020, pp. 1469-1471). Cascades frogs are considered to have strong genetic isolation by distance and high genetic distinction between populations, suggesting that without sufficient connectivity between occupied habitat patches, recolonization is less likely (Monsen and Blouin 2003, pp. 3280-3281).

3.2.1 Habitat

Viable populations of Cascades frog must have access to suitable habitat to support the species across all its life stages. Cascades frog is reliant on aquatic features with sufficient hydrology to support breeding, larval development, foraging, and overwintering (Pope et al. 2014, entire; Garwood 2009, pp. 38, 65-69; J. Garwood, CDFW, pers. comm. 2021; Kissel et al. 2019, p. 2). Precipitation, primarily in the form of winter snowpack and summer and fall rains, recharges aquatic features (Garwood 2009, pp. 38, 65-69; Pope et al. 2014, p. 7). Perennial aerobic aquatic features that do not freeze solid are necessary for overwintering within populations to provide the thermal conditions for frogs to maintain consistent metabolic rates and increase survival (Barreca 2010, entire; Pope et al. 2014, p. 7). Structural features, such as non-aquatic plants, rocks, and logs provide habitat complexity to support sheltering and foraging (Garwood et al. 2007, p. 95; Garwood 2009, pp. 38, 65-69; Pope et al. 2014, p. 7; Fellers and Drost 1993, p. 179; Pope 2008, p. 1577; Joseph et al. 2011, p. 832). Food resources support body condition and promote growth and physiological preparation for overwintering, increasing potential for survival, dispersal, and reproduction within populations (Pope et al. 2008, pp. 989-990; Joseph et al. 2011, pp. 832-833; Larson 2012 p. 36, 46; Pope et al. 2014, p. 11; O'Hara 1981, p. 6). Cascades frogs need moist aquatic and landscape features to facilitate dispersal and to provide refuge within populations during the non-breeding active season (Garwood 2009, entire; Pope et al. 2014, p. 7).

3.2.2 Demography

While we lack data on the precise demographic factors that impact population stability across its range (e.g., rates of breeding or recruitment, survival or mortality rate, sex ratio), we identified several factors that contribute to maintaining resilient populations of Cascades frogs. Resiliency is positively related to adult longevity, population size and growth rate and may be influenced by connectivity among populations. Generally speaking, populations need abundant individuals within habitat patches of adequate area and quality to maintain survival and reproduction in spite of disturbance.

Estimates for effective population size (N_e) in Cascades frog have been cited variably in the literature using different methods. One study comparing various *Rana* spp. in the Pacific Northwest estimated N_e as ranging from 15 to 45 (Phillipsen et al. 2011, pp. 2932-2937). In a study focused on the southern extent of Cascades frog's range, effective population size estimates ranged from 16 to 285 and were higher in southern Oregon (mean 215.5) than in California (mean 75.1), and lower south of Lassen compared to north of Lassen and in the Klamath Mountains (means 62 vs. 80, respectively) (Hardy et al. 2021, p. 6). Effective population size mirrored genetic diversity results in that study, where Oregon populations tended to have higher diversity than those in California (Hardy et al. 2021, p. 8), suggesting that larger populations and greater genetic diversity support more resilient populations.

Adult survival and recruitment are related to population abundance and resiliency. Low survival can limit population growth and limit a population's ability to withstand stochastic events and recolonize other sites. In populations with low survival and isolation from other occupied habitat, genetic diversity may decline. Adult survival ensures continuation of breeding opportunities within the population. Recruitment to adulthood indicates that individuals have survived the earlier life stages and can contribute to the breeding population.

Information on vital rates for Cascades frog is limited across its range, however some studies provide estimates of survival within different areas. Adult Cascades frog have higher survival rates than younger life stages (Pope et al. 2014, p. 10). Estimated adult survival rates in populations in California varied

between 44% to 93% (Pope et al. 2008, entire; Pope et al. 2014, p. 10), and were considerably higher than survival of younger life stages including metamorphs and first-year juveniles (<1 to <20%, respectively). In a study conducted in the Seven Lakes Basin in the Olympic Mountains between 2002 and 2015, the mean annual female survival rate was 74% and male survival was 81% (McCaffery et al. *in* McCaffery and Jenkins (Eds.). 2018, p. 231). In a study looking at removal of non-native fish from Cascades frog habitat in the Klamath Mountains of northern California, the population growth rate was highly correlated with recruitment and not with adult survival (Pope et al. 2008, p. 1578).

Genetic diversity is achieved through dispersal and connectivity, when frogs travel over aquatic and moist landscape features between sites for reproduction, foraging, and overwintering (Garwood 2009, entire). Genetic diversity is essential to provide the capacity to adapt to environmental and demographic changes over time. Populations with more individuals will be more resilient and have a higher likelihood, given density, to disperse at greater distances to participate in genetic exchange and recolonization of unoccupied suitable habitat.

3.2.3 Population Needs Summary

As outlined in Table 5 below, the significant determinants of population-level viability for Cascades frog are healthy demography and sufficient habitat and resources to support individuals through all of their life stages and facilitate connectivity for genetic exchange. Demography is a function of abundance, genetic connectivity (ideally sites within 5 km (3.10 mi) of other occupied sites), adult survival, adult recruitment to maintain the breeding population, and genetic diversity to maintain adaptive capacity in the face of demographic or environmental changes over time.

Table 5. Cascades frog population level needs for resiliency.

	Element	Importance
Habitat	Aquatic features - A diversity of perennial and seasonal aquatic features across the landscape	Supports all active season life stages; breeding, larval development, foraging, and refuge from predators and desiccation.
	Structural features - Non-aquatic abiotic and biotic components of sheltering and foraging habitat	Provides habitat complexity to support sheltering and foraging.
	Forage base - Food resources supporting growth and overwintering reserves	Supports body condition that enhances survival, reproduction, and resilient populations.
	Connectivity - Aquatic and landscape features to support dispersal and refuge from desiccation.	Functions as conduit for dispersal between populations and extirpated sites.
	Precipitation – Water sources, primarily in the form of winter snowpack and summer and fall rains.	Directly supports seasonal and perennial aquatic features and recharges groundwater sources. Facilitates movement across the landscape.
	Overwintering features - Perennial, aerobic aquatic features that do not freeze completely during winter.	Supports overwintering. Stable thermal conditions assist frogs in maintaining a consistent metabolic rate and can improve survival.
Demographic	Abundance - $N_e > 20$ individuals (range 16-285)	Facilitates prolific breeding so population can be self-sustaining and support dispersal.
	Adult recruitment - Recruitment exceeding adult mortality rates	Maintains breeding population by replacing adult mortality.
	Adult survival	Longer lifespans provide multiple breeding opportunities and can mitigate against stochastic events.
	Genetic connectivity - Connectivity (<5 km (3.12 mi)) among occupied sites.	Facilitates genetic exchange and recolonization of extirpated sites.
	Genetic diversity	Provides adaptive capacity.

3.3 Species Needs for Representation & Redundancy

We evaluate the species' needs in terms of the resources and/or the circumstances that support the representation and redundancy of the species.

Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments— termed adaptive capacity— is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al. 2015, p. 1269). For Cascades frogs, representation is evaluated based on both the presence of self-sustaining populations distributed across the breadth of the species' range and in populations that span a diversity of elevation gradients. These populations will maintain the Cascades frog's adaptive

capacity by supporting adequate gene flow and providing a reservoir of behavioral flexibility and ecological variation across the range.

Redundancy is a species' ability to withstand catastrophic events. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely (Mangal and Tier 1993, p. 1083). A species has redundancy when there are a sufficient number and distribution of healthy populations to guard against catastrophic events wiping out portions of the species adaptive diversity. For Cascades frogs, redundancy is evaluated by the presence of multiple, self-sustaining populations distributed throughout its range.

A species with a high degree of resiliency, representation, and redundancy (the 3Rs) is better able to adapt to novel changes and to tolerate environmental stochasticity and catastrophes. The viability of the Cascades frog is supported by having multiple (Redundancy) self-sustaining (Resiliency) populations distributed throughout the geographical extent of its range along varying suitable elevations (Representation).

4.0 FACTORS INFLUENCING THE SPECIES

In this section, we describe the past and present factors influencing the ecological needs of the Cascades frog, and the likely explanations for ongoing changes in abundance and distribution within landscapes representing important geographic and genetic areas. The species' ecological needs, as assessed above, provide the basis to explain changes in abundance and distribution.

Many influence factors were presented in the petition or discussed in the literature regarding potential impacts on higher elevation amphibians including the Cascades frog. We have reviewed the effects of these potential factors including non-native trout, other invasive predators, meadow contraction, chytridiomycosis, other disease, water management, climate change, livestock grazing, roads, contaminants, wildfire, recreation, timber harvest and hybridization (Table 6). Only influence factors found to exert present negative effects at the population level have been carried forward in our viability analysis as primary stressors. Our assessment of influence factors not found to exert negative population-level effects can be found in Appendix II.

Table 6. Influence factors evaluated for Past (Before 2010) and Present (2010 – 2020) negative species-level effects to resiliency. “U” indicates effects are unknown. Influence factors with present negative effects at the population level (shown in bold) are considered primary stressors and are further analyzed in Section 4.2. Our assessment of influence factors without present negative population-level effects can be found in Appendix II.

Influence Factor	Negative Effect to Individuals		Negative Effects to Populations	
	Past	Present	Past	Present
<i>Batrachochytrium dendrobatidis (Bd)</i> or Chytridiomycosis	Yes	Yes	Yes	Yes
Climate change	Yes	Yes	Yes	Yes
Contaminants	Yes	Yes	U	U
<i>Saprolegnia</i> Fungus	Yes	Yes	U	U
Fire Prevention and Suppression	Yes	Yes	No	No
Hybridization	U	Yes	U	U
Livestock grazing	Yes	Yes	Yes	No
Meadow Contraction	Yes	Yes	No	No
Non-native trout	Yes	Yes	Yes	Yes
Recreation	Yes	Yes	No	No
Roads (crushing and barriers)	Yes	Yes	No	No
Timber Harvest	Yes	Yes	No	No
UV-B radiation	Yes	Yes	No	No
Water Management/withdrawal	Yes	Yes	No	No
Wildfire	Yes	Yes	No	No

4.1 Stressors

4.1.1 Non-Native Trout

4.1.1.1. History and Scale

Introduced non-native trout have long been recognized as a direct predator on many amphibians and more recently as a stressor on western ranid frog populations (Bradford 1989, pp. 776-777; Knapp and Mathews 2000, pp. 315-316; Pilliod and Peterson 2001, pp. 326-327; Welsh et al 2006, pp. 302-303). Widespread stocking of non-native trout has occurred throughout the western United States for over 100 years but was most intensively conducted from approximately the 1940's to the 1970's, with the use of aerial stocking (Bahls 1992, pp. 184-185; Pister 2001, pp. 280-281). Greater than 95% of the estimated 16,000 high elevation lakes in the west were originally fishless but now 60% of all lakes and 95% of larger (>2 hectares (4.94 acres)) and deeper (>3 m depth (9.84 ft.)) lakes are estimated to contain fish (Bahls 1992, pp. 183-184). Whether stocking continues or not, non-native trout are now established throughout the Cascade, Klamath, and Olympic mountains, resulting in both naturally reproducing and supplemented populations of trout throughout the Cascades frog's range (Bahls 1992, p. 184; Welsh et al 2006, p. 298).

The primary trout species used in stocking efforts across the Pacific Northwest include brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) and to a lesser degree cutthroat trout (*Oncorhynchus clarkii* ssp.) and golden trout (*Oncorhynchus aguabonita*). Rainbow and cutthroat trout are native species to the Cascades region and likely occurred in streams below natural barriers. Historically, the vast majority of high elevation lakes were isolated from natural fish-bearing streams, though presently many now support non-native trout populations. In the western U.S., brook trout are frequently the focus of impacts on amphibians, likely due to their early adoption into high elevation stocking programs, their ability to reproduce even in the absence of stream spawning habitat (the other species predominantly spawn in streams), and for their tendency to rapidly increase in abundance, often to densities that result in stunted individual growth due to competition for food (Pister 2001, p. 281). All of the introduced trout species will eat amphibians, particularly larvae (Ziller, ODFW, pers. comm. 2021). Higher densities of fish and a greater size distribution associated with naturally reproducing fish populations have been found to have greater impacts on amphibians than lower density, less size diverse populations associated with trout stocking (Liss et al. 1999, p. 108).

4.1.1.2. Habitat Use/Dispersal

Trout predation impacts western ranid frog habitat suitability, particularly deeper, perennial aquatic features (>2m (6.56ft) in depth) by reducing the abundance of frog larvae and their recruitment as adults (Vredenburg 2004, p. 7648; Pilliod and Peterson 2001, pp. 326-327). Trout are primarily present in perennial aquatic features but may be present in seasonal aquatic features when connected by streams or high-water following snow melt. Perennial aquatic features support most of the Cascades frog's life history functions, and individuals frequently move among sites spatially and temporally (Garwood and Welsh 2007, p. 57; Pope et al. 2011, p. 6). The presence of trout in perennial aquatic features is a more significant issue in the summer and fall when seasonal wetlands are dry and shallow margins of ponds and lakes have receded, thus pushing frogs into deeper water and increasing their exposure to trout. The presence of trout in perennial aquatic features may limit suitable overwintering sites, and negatively influence dispersal across the landscape (Pilliod and Peterson 2001, pp. 330-331; Welsh et al. 2006, p. 302).

4.1.1.3. Direct Impacts

Predation

It is well established that trout directly feed on ranid frogs, particularly on the larvae (Pilliod and Peterson 2001, pp. 326-327; Vredenburg 2004, p. 7649; Welsh et al. 2006, p. 302). Unlike some newt and toad species, Cascades frogs are palatable to fish, are highly aquatic and use perennial water features (Welsh et al. 2006, p. 299). Size and life history of fish species affects the size of their prey with smaller, aquatic larvae able to be consumed by more fish size classes (Liss et al. 1999, p. 108; Welsh et al. 2006, pp. 306-307). Adult Cascades frogs may also be able to recognize trout as a predator and thus avoid them by moving to fishless aquatic features or by using shallow or seasonal habitat less suitable to fish (Welsh et al. 2006, p. 306; Garwood and Welsh 2007, p. 54). Studies of site occupancy in the Oregon Cascades found that Cascades frogs were less likely to be detected in aquatic features containing trout, but the studies could not evaluate whether this was due to lower abundance from direct predation, or any other factor, based on the data collected (Pearl et al. 2009, pp. 176-177; Duarte et al. 2021, pp. 368-369).

Low annual survival for ranid frog larvae is not unusual and can be attributed to several factors (e.g., desiccation); however, depredation from trout is demonstrated to reduce overall abundance at breeding sites and adult recruitment on a site and basin scale (Bradford 1989, pp. 414-415; Pilliod and Peterson

2001, pp. 326-327; Vredenburg 2004, p. 7649; Welsh et al. 2006, p. 302; Pope 2008, pp. 1577-1578). Similarly, multiple studies have demonstrated the removal of trout from lakes can allow rapid recovery of frog abundance (Bradford 1989, pp. 416-417; Vredenburg 2004, p. 7648; Knapp et al. 2007, p. 7; Pope 2008, p. 1576; Larson et al. 2017, p. 234).

4.1.1.4. Indirect Impacts

Forage Base

Non-native trout feed on many of the same aquatic insects that adult and juvenile Cascades frogs feed on (Pope et al. 2009, p. 988; Joseph et al. 2011, pp. 832-833). Cascades frogs are generalist predators that feed on adult aquatic insects as well as terrestrial insects, spiders, centipedes, and other small prey in and around the water's edge (Pope et al. 2009, p. 988; Joseph et al. 2011, pp. 832-833; Larson 2012, p. 20). In lakes with trout, Cascades frog diets shifted predominantly to terrestrial prey compared to adult aquatic insects in fishless lakes (Joseph et al. 2011, p. 833). The removal of trout from lakes rapidly increased the abundance of adult aquatic insects such as mayflies, caddisflies, and overall insect biomass (Pope et al. 2009, p. 988). The recovery of insect abundance paralleled the abundance recovery of Cascades frogs in trout removal lakes which appeared to recover to fishless control lake levels in approximately three years (Pope 2008, p. 1576; Pope et al. 2009, p. 988). Though the presence of trout caused the frog's diet to shift to more terrestrial prey, stomach sample biomass remained similar; thus, it has not been shown that competition for aquatic prey has limited the Cascades frog's overall foraging condition (Joseph et al. 2011, p. 833)

Subsidizes Native Predators

Cascades frogs are known to be preyed upon by other native wildlife as well as non-native trout. Many mammals, snakes, birds, insects and other amphibians including adult Cascades frogs will feed on larvae, metamorphs and adult frogs at the water's edge (Rombough 2003, p. 138; Olson in Jones et al. (Eds.) 2005, p. 189; Garwood and Welsh 2007, p. 47). In general, native predators do not appear to be considered a significant stressor on Cascades frog populations, though natural predation is suspected to be a significant individual and local mortality factor (Garwood and Welsh 2007, p. 47; Pope et al. 2008, p. 1327). Adult frogs are physiologically and behaviorally cryptic, likely limiting predation; however, in one study 16% of monitored adult Cascades frogs were eaten by garter snakes (Garwood and Welsh 2007, p. 47). In the same study, within the Klamath Mountains, common garter snakes (*Thamnophis sirtalis*) were found to only eat amphibians, of which 90% were Cascades frogs. The diet of aquatic garter snakes (*T. atratus*) was approximately 44% amphibians, of which 89% were Cascades frogs. Because aquatic garter snakes were found in high densities near water with brook trout, it is likely they have an increased influence on Cascades frogs due to their prey base being supplemented with introduced trout (Garwood & Welsh 2007, p. 58; Pope et al 2008 pp. 1327-1328). This was supported by two other studies in the same area that concluded that aquatic garter snake numbers were elevated due to the non-native trout and that the garter snake was likely invasive at a higher elevation than normal and having an increased impact on Cascades frog due to the presence of trout in historically fishless habitat (Pope et al. 2008, pp. 1327-1329; Demianew 2018, entire).

Disease

Introductions of trout through stocking may introduce diseases that affect amphibians. The pathogenic fungus *Saprolegnia ferax* has been found to reduce hatching success in Cascades frog and is transferred through infected hatchery fish (Kiesecker and Blaustein 1995, p. 11051; Kiesecker et al. 2001, pp. 1067-1068). However, while it can be transmitted by hatchery trout, it is still unknown whether it was a native

fungus or was introduced. In either case fish stocking may increase the fungus density and infection rates (Kiesecker et al. 2001, p. 1069). It is also unknown whether fish have assisted the spread of *Bd*, though it is possible anglers have inadvertently transported *Bd* via their clothing (e.g., wading boots). There is little known about the extent of human transfer versus animal or other natural means. It is believed that *Bd* is already widespread in the Pacific Northwest, particularly in northern California, though it is unclear how prevalent it is in Cascades frogs in Oregon and Washington (Pearl et al. 2007, pp. 146-147).

4.1.1.5. Summary

Cascades frogs and other western ranid frogs have persisted for decades in the presence of non-native trout; however, predation by trout is a significant stressor that is also synergistically working with other stressors to impact Cascades frog population resiliency range wide. Within Lassen Volcanic National Park, Cascades frog populations began to noticeably decline in the late 1980s, approximately 10 years after stocking had ended, while in the Klamath Mountains where stocking continued (and there was a much higher prevalence of trout) Cascades frog populations remained viable (Fellers et al 2007, pp. 33-34). While it is difficult to determine whether non-native trout have caused the extirpation of local Cascades frog populations, the majority of studies have shown that non-native trout continue to exert negative pressure on frog population resiliency and could lead to loss of local populations when compounded with other stressors (Welsh et al. 2006, p. 308; Fellers et al. 2007, pp. 34-35; Pope et al 2014, pp. 30-31).

4.1.2 Amphibian Chytrid Fungus

4.1.2.1. History and Scale

Chytridiomycosis is an emerging infectious amphibian disease caused by infection with the amphibian chytrid fungus, *Batrachochytrium dendrobatidis* (*Bd*) (Piotrowski et al. 2004, p. 9). Globally, *Bd* has been implicated in the declines of nearly 400 amphibian species (Lips 2016, p. 1). It has now been found on every continent except Antarctica, and has been documented infecting over 700 species (Lips 2016, p. 2). The date of fungus introduction to the Cascades frog range is uncertain but is thought to have occurred in the early to mid-1970s in Northern California (De León et al. 2017, p. 155). *Bd* is now present throughout the Cascades frog range in California, Oregon, and Washington (Pearl et al. 2009 p. 209, Adams et al. 2010 p. 294, Gaulke et al. 2011 p. 210, and Piovia-Scott et al. 2011 p. 2917). Although widely distributed, *Bd* is still thought to be spreading and may not yet occur in every population (Adams et al. 2010 p. 298-299). Occurrence studies from 2010 estimated that *Bd* occurred in approximately half the populations examined, but *Bd* may be more widespread currently, more than a decade later (Adams et al. 2010 p. 299). Several lineages and strains of *Bd* exist, with variable levels of virulence (Berger et al. 2005 p. 47; Piovia-Scott et al. 2015, p. 1570, Lips 2016, p. 2). Recently, global amphibian declines were linked to the global pandemic lineage of *Bd* (Lips 2016, p. 2).

4.1.2.2. Impacts to Individuals and Populations

Bd is transmitted by an aquatic, flagellated (self-propelled) zoospore (Briggs et al. 2010, p. 9695). *Bd* zoospores can survive in and move through the aquatic environment outside of amphibian hosts (Johnson and Speare 2003, p. 922). Infection can be spread by zoospores in the water, and zoospores can survive on moist surfaces including sand and bird feathers in the laboratory (Johnson and Speare 2003, p. 922; Johnson and Speare 2005, p. 181). In other frog species, infection transmission has also been documented between individuals (Rachowicz and Vredenburg 2004, p. 75). *Bd* infection occurs when zoospores present in the environment become enclosed in a cyst in an amphibian's tissues (Vredenburg et al. 2010, p. 9689). Once encysted, they develop into zoosporangium and produce new zoospores, which are further released into the environment (Vredenburg et al. 2010, p. 9689).

Bd is somewhat temperature sensitive and fungal growth declines substantially at temperatures above 28°C (82.4°F) (Piotrowski et al. 2004, p. 14; Richards-Zawacki 2010, p. 520). However, *Bd* growth and pathogenicity increase at higher temperatures (17 to 25°C (62.6 to 77°F); with peak growth and pathogenicity at 23°C (73.4°F) (Piotrowski et al. 2004, p. 9; Richards-Zawacki 2010, p. 520), and *Bd* can survive outside of a host longer at cooler temperatures (4 to 14°C (39.2 to 57.2°F)) (Rollins-Smith et al. 2011, p. 553).

Impacts to Individuals

Bd infects keratinized tissues in amphibians, which occur in the mouthparts of larvae and the skin of post-metamorphic individuals (Marantelli et al. 2004, p. 174, Rachowicz and Vredenburg 2004, p. 76, Piovia-Scott et al. 2011, p. 2913). The impact of *Bd* zoospores on eggs is not well studied but developing frog larvae do not contain keratinized tissues until just before hatching from the eggs (Marantelli et al. 2004, p. 174).

In laboratory studies, *Bd* did not increase larval Cascades frog mortality (Piovia-Scott et al. 2011, p. 2918), but *Bd* exposure may contribute to sub-lethal developmental changes. In many species, *Bd* can infect the tooth rows and jaw sheaths of larvae and lead to developmental changes in mouthparts and feeding strategies (Blaustein et al. 2005, p. 1461). These sub-lethal impacts of *Bd* may impair foraging ability and reduce growth and developmental rates (Blaustein et al. 2005, p. 1466). Reduced developmental rates may delay metamorphosis and exacerbate challenges faced by frogs in ephemeral habitats with short growing seasons, thereby reducing juvenile recruitment.

Infection with *Bd* zoospores in metamorphs, juveniles, subadults, and adult frogs can lead to chytridiomycosis (Vredenburg et al. 2010, p. 9689). Signs of chytridiomycosis include sloughing skin, lethargy, and reduced coordination while jumping (Carver et al. 2010, p. 490). These signs appear to be caused by a disruption of osmoregulatory functions in frog's skin, including the ability of frogs to rehydrate and to uptake sodium and potassium (Voyles et al. 2009 p. 584, Carver et al. 2010, p. 493).

Adult Cascades frogs appear to be minimally impacted by *Bd* infection, but survival of young frogs can be greatly reduced (Garcia et al. 2006, p. 165-166; Pope et al. 2014 p. 25). Recently metamorphosed Cascades frogs appear to be highly susceptible to *Bd* and died in large numbers within one week of exposure in laboratory experiments (Garcia et al. 2006, p. 166). In a field study in the Klamath Mountains of California, juvenile Cascades frogs had a higher prevalence of *Bd* than other life stages, including metamorphs, but researchers were uncertain whether this was because infection takes time to build in individuals or whether it was an artifact of large numbers of metamorphs dying and not being observed by the study (Piovia-Scott et al. 2011 pp. 2913, 2918).

Although mortality can occur in juvenile, subadult, and adult life stages of Cascades frogs, some infected individuals appear to recover (Briggs et al. 2010 p. 9695, Piovia-Scott et al. 2011 p. 2918). Infection outcome appears to be related to a variety of biotic and abiotic environmental factors, as well as host specific factors. Environmental factors can include temperature, moisture, elevation, season, amphibian community, and host density (Piovia-Scott et al. 2011 p. 2914; Lips 2016 p. 2; Adams et al. 2021, p. 296). Internal host factors include immune function, behavior, antimicrobial skin peptides, and protective skin bacteria, in addition to zoospore dose and virulence (Piovia-Scott et al. 2011 p. 2914; Lips 2016 p. 2, Sauer et al. 2020, p. 2).

The effects of temperature and elevation vary by species and are still a topic of study (Sauer et al. 2020, p. 2). In studies in Oregon and Northern California, *Bd* prevalence and probability of infection appeared to show seasonal patterns at higher elevations for some life stages (Adams et al. 2010, p. 296; Piovia-Scott et al. 2011, p. 2917). In one study, *Bd* prevalence increased throughout the season at high elevations, while it decreased throughout the season at lower elevations (Adams et al. 2010, p. 296). Another study found that the probability of infection was highest early in the active season at high elevation and decreased throughout the summer season, but seasonal patterns were less clear at lower elevations (Piovia-Scott et al. 2011, p. 2917). This same study found that the pattern differed between adults and subadults and while infection probability declined throughout the season for adults, it did not decline for subadults (Piovia-Scott et al. 2011, p. 2917).

These seasonal and elevation patterns may be further confounded by temperature and life stage interactions. *Bd* thrives in low temperatures and infected individuals shed more zoospores at cooler (4 to 14°C) (39.2 to 57.2°F) temperatures (Rollins-Smith et al. 2011, p. 557), such as those found early in the season at high elevations. *Bd* zoospores are killed by complete drying and by prolonged (4+ hour) periods above 37°C (98.6°F) (Johnson et al. 2003, p. 255). Individuals of some species appear to be able to reduce or clear *Bd* infections by warming themselves behaviorally (Richards-Zawacki 2010, p. 526; Piovia-Scott et al. 2011 p. 2914).

Later in the active season, as larvae metamorphose, they undergo a substantial immune system restructuring (Rollins-Smith et al. 2011, p. 556) and are likely to be both more vulnerable to infection and living at higher densities than adults. Host-pathogen models based on *Bd* outbreaks in populations of a related frog in the Sierra Nevada Mountains of California estimated that *Bd* loads in individuals can increase more rapidly in denser frog populations, which may increase host mortality (Briggs et al. 2010, pp. 9698-9699; Piovia-Scott et al. 2015, p. 1575). Density impacts may become even more pronounced in drought years when fewer breeding habitats are available.

Stress hormones, such as corticosterone, have also been documented to reduce immune function in amphibians (Rollins-Smith et al. 2011, p. 556) and are naturally elevated in frogs during metamorphosis, explosive breeding events, and during times of decreased food availability (Rollins-Smith et al. 2011, p. 556). There is also evidence that amphibian immune function varies with temperature and decreases at lower temperatures (Rollins-Smith et al. 2011, p. 558; Piovia-Scott et al. 2011, p. 2918). Several studies have also indicated that amphibian immune function is also decreased during times of natural hibernation, such as overwintering (Rollins-Smith et al. 2011, p. 557).

Impacts to Populations

Globally, the effect of *Bd* on amphibian populations ranges widely, from coexistence between the host species and pathogen, to declines, extirpations and even extinction (Piovia-Scott et al. 2015, p. 1570, Sauer et al. 2020, p. 2). Some co-occurring species, including Pacific chorus frogs, can withstand *Bd* infection and may be considered reservoir species capable of spreading or prolonging disease outbreaks (Reeder et al., 2012, p. 1). *Bd* is widespread throughout the Cascades frog range in Washington, Oregon, and California, and is thought to have been spreading in California since the 1970's (Piovia-Scott et al. 2015, p. 1571; De León et al. 2017, p. 155). Despite widespread *Bd* prevalence, it is not clear whether Cascade frog populations in Oregon and Washington have experienced substantial declines in recent decades (Pearl et al. 2009, p. 166; Duarte et al. 2021, pp. 361, 367). *Bd* was found to reduce apparent survival in related anuran species in the Western US, despite a lack of large observable die offs (Russell et

al. 2019, p. 9). *Bd* has been implicated in recent Cascade frog population declines in Northern California (Piovia-Scott et al. 2011, p. 2913; Piovia-Scott et al. 2015, p. 1570); however, extant populations with active population monitoring and *Bd* screening appear to be coping with the disease in the short term (Pope et al. 2014 p. 26).

Several strains of *Bd* exist, with variable levels of virulence, and research into their origins and spatial occurrence is ongoing (Berger et al. 2005 p. 47; Farrer et al. 2011, p. 18732; Piovia-Scott et al. 2015, pp. 1570-1571). An especially virulent strain is thought to have been responsible for a significant juvenile mortality event in the Klamath Mountains of California (Pope et al. 2014, p. 25; Piovia-Scott et al. 2015, p. 1570). During this mortality event, researchers observed a >99% reduction in juvenile abundance over the course of four years (Piovia-Scott et al. 2015, p. 1575). Adult abundance increased steadily for a time but began to decline three years after the juvenile decline began, in a pattern consistent with recruitment failure and a loss of juveniles before they can replenish the breeding population (Piovia-Scott et al. 2015, pp. 1573, 1575). Chytridiomycosis is considered a high threat to population persistence in California (Pope et al. 2014 p. 26, Hardy et al. 2015, p. 244). As more virulent *Bd* strains continue to spread, previously un-impacted populations may be more heavily impacted.

4.1.3 Climate Change

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC 2018, p. 544). Climate change is currently occurring and is projected to continue with global impacts (IPCC 2018, entire). Human activities have caused an increase of approximately 1 °C (1.8 °F) of global warming from pre-industrial levels and are likely to reach an increase of 1.5 °C (2.7 °F) between 2030 and 2052 if warming continues to increase at the current rate (IPCC 2018, p. 4).

4.1.3.1. Climate Change in the Pacific Northwest

Impacts from human-induced climate change are evident and will continue to occur into the future, particularly in montane wetlands of the Pacific Northwest (Ryan et al. 2014, p. 236; Lee et al. 2015, pp. 18-19). Snowpack has started to decline in the last half century with a shift toward earlier snowmelt runoff and water availability in the spring, and a decrease in soil moisture through the summer (Hamlet et al. 2005, p. 4546; Ryan et al. 2014, p. 236). Across the western United States, snow water equivalent (the amount of liquid water contained in snowpack) is projected to decline 25% by 2050. Models suggest that snow disappearance (low-to-no snow) could occur within 35 to 60 years if greenhouse gas emissions continue, with potentially catastrophic impacts on the water system (Siirila-Woodburn et al. 2021, p. 800). Across the range of Cascades frog, snow water equivalent is projected to decline by 5 to 10.5 inches in future condition scenarios (RCP 4.5 and RCP 8.5, 2010 - 2039 and 2040 – 2069).

River basins in the west (Washington, Oregon, and California) depend on snow for water storage and are therefore vulnerable to changes in the timing and magnitude of spring snowpack, altering groundwater and streamflow dynamics (Mote et al. 2005, p. 39; Mote et al. 2017, p. 1; Siirila-Woodburn et al. 2021, p. 800). Effects from a decline in snowpack are difficult to tease apart from other factors such as high evapotranspiration, altered vegetation, and changes in wildfire behavior (Siirila-Woodburn et al. 2021, p. 800). A low-to-no snow climate impacts the spatiotemporal partitioning of water, including precipitation

stores (e.g., surface water, soil moisture, and groundwater) and fluxes (e.g., evapotranspiration, runoff, and streamflow) (Siirila-Woodburn et al. 2021, p. 808).

Climate change projections across the range of Cascades frog predict an increase of winter temperatures from -17 °C to -15 °C (2 to 5 °F) and an increase in summer maximum temperature from -16 °C to -14 °C (3 to 7 °F) leading to higher evapotranspiration rates (Chandler et al. 2016, p. 2). Higher temperatures and more frequent summer droughts result in earlier and faster wetland drawdown, reduced water availability, particularly in spring and summer, increased frequency of drying, and a longer dry period in the summer (O'Regan et al. 2014, p. 845; Ryan et al. 2014, entire; Siirila-Woodburn et al. 2021, p. 808). Increased temperatures alter hydrology, with projections indicating a likely increase in precipitation as rain rather than snow and less precipitation during summer months (Mote et al. 2005, p. 48; Hamlet et al. 2013, p. 404; Ryan et al. 2014, entire; Lee et al. 2015, entire).

Montane wetlands are likely to experience hydrologic changes in response to climate change throughout the range of Cascades frog (Lee et al. 2015, p. 19). Groundwater recharges montane systems, where snowmelt more effectively infiltrates the surface when compared to rainfall (Siirila-Woodburn et al. 2021, p. 808). A study looking at montane wetland hydrology across the range of Cascades frog found consistent projected effects of climate change on all classes of wetlands (ephemeral, intermediate, perennial, and permanent) including earlier drawdown, more rapid recession rate in summer, and reduced minimum water levels leading to longer, drier summers (Lee et al. 2015, entire). Ephemeral and intermediate wetlands (those that dry in most years or in particularly dry years) were most sensitive to climate change, with a higher likelihood of drying and therefore reductions in the availability of wetland habitat for many species (Lee et al. 2015, p. 1). By the 2080s, 58% of intermediate wetlands are projected to become ephemeral, and 22% of perennial wetlands (those that do not dry except in extremely dry years) are projected to become intermediate, with 3% becoming ephemeral. Additionally, 32% of permanent wetlands (those that do not dry) are projected to become perennial (those that do not dry except in the most extreme dry years) (Lee et al. 2015, p. 14).

4.1.3.2. Climate Change Impacts to Cascades Frog

Climate change will impact survival of all life stages of Cascades frog. Survival for Cascades frogs depends on breeding wetlands holding sufficient water to allow the aquatic life stages (eggs, larvae) to survive through metamorphosis (Chandler et al. 2016, p. 2; Kissel et al. 2019, entire). Decreases in snowpack, extended summer drought, and increased evaporation are expected to increase the rate and frequency of wetland drying, particularly in ephemeral and intermediate wetlands (Lee et al. 2015, p. 20). For the aquatic stages of Cascades frogs, shorter wetland hydroperiods will dry ponds earlier in the year, leading to egg desiccation (mortality) and lower survival to metamorphosis. Changes in wetland hydrology are likely to reduce both the number of sites available for breeding, and rearing, overwintering, and connectivity between those sites which could promote more isolation. It may also reduce larval densities and survival, as well as reduce size at metamorphosis (Lee et al. 2015, pp. 19-20; Ryan et al. 2014, entire). A population in the Almanor Forest in California experienced 40% egg mass mortality following a dry winter and summer in 2021, which was noted to reduce lentic habitat and overall standing water during the breeding season (Howell and Reno 2021, pp. 8, 19-20).

Optimal overwintering body condition for Cascades frogs is a function of a low metabolic rate. Increasing winter temperatures will increase Cascades frog metabolic rates, resulting in sub-optimal body condition at emergence from hibernation, and subsequent increased risk of female mortality and population

decline (Reading 2007, pp. 126-130). Increased temperatures can limit foraging by juveniles and adults, impacting overwintering survival, movement, and behavior due to thermoregulation (Sears et al. 2016, p. 10595; Kissel et al. 2019, p. 2). As temperature increases so too does evaporative water loss for amphibian thermal regulation. To accommodate this, frogs will need to use behaviors and environments that help maintain hydration. Given climate change impacts, dehydration leading to desiccation may play an equally or more restrictive role in amphibian movement and survival than temperature. The synergistic effects of these two stressors may also compound the physiological risk to the species posed by climate change (Lertzman-Lepofsky et al. 2020, pp. 4868-4869). As water availability of montane wetlands declines, so does the spatial distribution of suitable habitats, impacting potential connectivity. Declines in water availability on the landscape could contribute to isolation of the species if gene flow is reduced due to reduced connectivity.

Climate change is also thought to present potential opportunities for some amphibians, including faster development rates for the aquatic stages (O'Regan et al. 2014, p. 845), but increased growth rates may not compensate for increased rates of pond drying (O'Regan et al. 2014, p. 853; Lee et al. 2015, entire; Kissel et al. 2019, p. 2). Climate change could positively impact survival as severity of winters decrease (McCaffery and Maxell 2010, p. 1844); however, if temperatures do not remain low enough to sustain dormancy, body condition of post-metamorphic frogs could decline, resulting in increased susceptibility to disease, increased mortality, and eventual population declines (Reading 2007, p. 130; Kissel et al. 2019, p. 2).

A study investigating climate change impacts to Cascades frog in the Olympic Mountains projected that by the 2080's, the 20-year extinction risk will increase from 42% to 62% (Kissel et al. 2019, entire). Initially, increased temperatures are projected to have a greater impact on larval mortality than adult survival. However, a drier climate and shorter winters will increase pond drying over time and disproportionately affect adults, causing negative impacts to multiple life stages and reduced population growth rate overall (Kissel et al. 2019, entire). This study highlights the effects of climate change that combine at multiple life stages to reduce the population growth rate (Kissel et al. 2019, entire).

The effects of climate change on wetland integrity depend on the wetland's water source. A study of wetlands across the range of Cascades frog found the primarily groundwater-fed wetlands in Oregon and California were projected to have earlier drawdown but maintain enough water for larval development, while the primarily surface water-fed wetlands in Washington were projected to be more sensitive (Lee et al. 2015, p. 19). For species like the Cascades frog that are dependent upon a single season to develop to metamorphosis, the timing and frequency of wetland drying can have large impacts. The USFS conducted an assessment of species sensitivity to climate change in Olympic National Forest and Olympic National Park, concluding that due to the occupation of sensitive habitats and reliance on hydrology, Cascades frog will be directly affected by extremes in temperature and precipitation under future climate conditions. Cascades frog was considered the third most sensitive species of those modeled based on expert elicitation (USDA 2011a, pp. 91-108).

A study comparing climate change impacts on adult and larval survival in the Olympic Mountains, Washington, and Trinity Alps, California, found that under projected 2080 conditions both regions will be warmer with shorter winters, have reduced snow water equivalent, and have more frequent drying of breeding ponds. These unpublished projections suggest both regions will experience similar larval mortality in the 2080s, including divergent levels of adult survival with projected decreases in the Olympic

Mountains but increases in the Trinity Alps (Kissel 2017, pp. 44-46). These diverging projections could be due to more snowpack-fed hydrology in the Olympics with greater climate change impacts on water levels, whereas in the Trinity Alps many of the wetlands are more groundwater-fed and could exhibit more stable hydrology even in drier summers (Lee et al. 2015, p. 19; Kissel 2017, pp. 44-46). These predictions did not account for disease dynamics that could interact with climate change to impact populations of Cascades frog, particularly in the southern extent of its range.

4.1.3.3. *Interaction with Other Stressors*

Climate change could have a synergistic effect with other stressors such as the presence of non-native fish, broader impacts to community structure facilitated by non-native fishes, disease, and hybridization (Rodder et al. 2010, entire; Pope et al. 2008, entire; Pope et al. 2014, p. 24; Ryan et al. 2014, entire; Lee et al. 2015, p. 20). As climate eliminates many shallow, fish-free wetlands, Cascades frogs may be forced to breed in ponds that support non-native trout, increasing risk during breeding and decreasing survival (Ryan et al. 2014, p. 232). There is evidence that the parasitic fungus *Bd* may be reduced with increasing temperatures; however, the effects on populations of frogs that are already stressed are unknown (Rodder et al. 2010, p. 205). A study looking at global impacts of climate change on disease found that species adapted to colder environments may experience increasing parasite prevalence and disease risk during abnormally warm periods (Cohen et al. 2020, p. 4). With climate change, there may be an elevational shift of *Rana* spp. ranges, increasing the potential for gene flow and hybridization between species (Peek et al. 2019, p. 9; Tyson, WDFW, pers. comm. 2021).

4.1.3.4. *Summary*

Climate change will impact habitat and survival of Cascades frog across its range. Changes in snowpack (timing, duration, quantity), increased evapotranspiration resulting from increased temperatures (air and water) and more frequent summer drought, precipitation transitioning from snow-dominated to rain-dominated, and changes in seasonal hydrology (earlier pond drying) will decrease water availability in montane wetlands across the range of Cascades frog. High elevation amphibians, living at the extreme ends of their thermal tolerances, are thought to be more sensitive to climate change than those adapted to low elevation (Kissel et al. 2017, p. 28).

Multiple studies looking at climate change impacts on Cascades frogs and other amphibians that rely on montane wetlands, indicate that there will be fewer suitable wetlands with less available water to support the species (O'Regan et al. 2014; Ryan et al. 2014, entire; Lee et al. 2015, entire; Kissel 2017, entire; Kissel et al. 2019, entire; Lertzman-Lepofsky 2020, p. 4868). Survival for Cascades frogs depends on adequate water levels in wetlands to allow aquatic life stages (eggs, larvae) to survive through metamorphosis (Chandler et al. 2016, p. 2; Kissel et al. 2019, entire). Aquatic stages of Cascades frogs will be impacted by shorter wetland hydroperiods and earlier pond drying which can result in egg desiccation (mortality), and lower survival to metamorphosis, and less connectivity between resilient habitat patches.

Changes in wetland hydrology will reduce the number and distribution of sites available for breeding (Ryan et al. 2014, entire; Lee et al. 2015, pp. 19-20). Interactions between temperature and dehydration also pose physiological risk to Cascades frog as they search for areas to maintain moisture and avoid desiccation. This can reduce connectivity and gene flow, particularly in populations with low abundances and geographic isolation (Lertzman-Lepofsky 2020, p. 4868; Garwood CDFW, pers. comm. 2021). Warmer winters could result in reduction of female body size and fewer eggs laid annually, given higher metabolic demands during overwintering (Reading 2007, pp. 125-126). In one population in the Olympic Mountains,

the 20-year extinction risk will increase from 42% to 62% by the 2080s, given decreases in water availability and increased wetland drying impacting both larval and adult survival (Kissel et al. 2019, entire). The interactive effects of climate change with other stressors (non-native trout, disease, hybridization) are not fully understood, but could result in even greater declines (Ryan et al. 2014, pp. 234-236).

4.2 Voluntary and Regulatory Conservation Measures

The Cascades frog was also petitioned for listing in California March 1, 2017, under the California Endangered Species Act (CESA) and on October 17, 2017, the California Fish and Game Commission published its preliminary positive finding to list the Cascades frog as a threatened or endangered species. California Department of Fish and Wildlife (CDFW, formerly California Department of Fish and Game) is in the process of conducting their 12-month species status review. Currently, The Oregon Department of Fish and Wildlife (ODFW) has listed the species as ‘Sensitive’ in the Oregon Conservation Strategy (ODFW 2016, online document accessed: 10/21/21). The Cascades frog is not listed in the State of Washington. Cascades frog is listed as a sensitive species in California by the Forest Service and near threatened by the International Union for Conservation of Nature (Table 7).

Table 7. Listing status of the Cascades frog across its range by agency or organization.

Agency/State	Status	Current Evaluation Process
U.S. Fish and Wildlife Service	Petitioned species	Species Status Assessment; 12-month finding
California Department of Fish and Wildlife	Warranted for listing	12-month Species Status Review
Oregon Department of Fish and Wildlife	Sensitive Species	N/A
Washington Department of Fish and Wildlife	Not listed - Monitor Species	N/A
U.S. Forest Service (CA only)	Sensitive Species	N/A
International Union for Conservation of Nature (IUCN) Red List	Near Threatened	N/A

Because Cascades frog’s habitat occurs at relatively high elevations across most of its range, a significant amount is located in land designated as wilderness. Within the species’ range, approximately 28% of total land and 37% of Federal land is designated as Wilderness within National Park or National Forest lands. Wilderness designation limits many types of activities and retains a more natural condition by limiting access and development.

4.2.1 Management of Non-Native Trout

Natural resource managers began recognizing the ecological impacts of introduced trout to native amphibians and biodiversity starting in the 1970’s (Pister 2001, entire). Consequently, the National Park Service (NPS) began phasing out stocking in the 1970’s and ended it by 1991 in all but a few lakes in North Cascades National Park Complex (Downen 2004, entire; NCNPC 2008, entire; MRNP 2017, entire).

California, Oregon, and Washington fish and wildlife agencies have either been forced by legal action or independently began evaluating their high mountain lakes stocking programs and have made changes, partly to address impacts to native amphibians (Uehara 2005, entire; Ziller, ODFW pers. comm. 2021).

State fish and wildlife agencies are primarily responsible for fish stocking programs on National Forest lands including wilderness areas. The California Department of Fish and Wildlife (CDFW) has stopped stocking fish in any water known to support Cascades frogs following the *Pacific Rivers Council, et al., v. California Department of Fish and Game* (CaseNo. 06 CS 01451) (ICF Jones and Stokes 2010) and is currently directed to conduct basin level management plans to determine the suitability of stocking within the range of several sensitive native fish and amphibian species including the Cascades frog. The Washington Department of Fish and Wildlife (WDFW) has evaluated its fisheries program, and while stocking continues, WDFW biologists estimate an average of 62% of ponds and lakes larger than 0.04 ha (0.1 acre) are managed for a fishless condition (Uehara 2005, p. 9; Spinelli, WDFW, pers. comm. 2021). Fisheries biologists from the Oregon Department of Fish and Wildlife (ODFW) worked with Forest Service district fish biologists to evaluate their program based on recreational demand, cost effectiveness, and ecological impacts such as those to native amphibians. Currently, the ODFW is stocking up to 250 lakes > 3 m (10 ft.) in depth, or less than 1% of all lakes in the Cascade Range (Ziller, ODFW, pers. comm. 2021). State fish and wildlife agencies are using a variety of methods to reduce reproduction rates in stocked fish and control the density of stocked populations. Although stocking has ended or has been greatly reduced from historical levels, many lakes contain self-sustaining trout populations, particularly in deeper lakes that are connected to streams.

In some lakes where stocking has ceased, fish populations are anticipated to gradually decline. In the 10-to-25-year period following the cessation of stocking in lakes within Yosemite and Mount Rainier National Parks, non-native fish populations were reported to have decreased by approximately 15% and 30%, respectively (Knapp et al. 2016, p. 11890; Larson et al. 2017, p. 234). In Yosemite National Park, the recovery of Sierra Nevada yellow-legged frog (*Rana sierrae*) has been partially attributed to the cessation of stocking and subsequent decline of non-native trout populations, combined with an increased tolerance of the chytrid fungus (Knapp et al. 2016, p. 11890).

Non-native trout removal has primarily been experimental and is not yet a widespread management tool for amphibian conservation due to competing agency priorities, costs, and the logistical difficulty in removing fish, particularly where ponds or lakes are connected to stream systems (Ryan et al. 2014, p. 238). However, non-native trout removal has been shown to be an effective method for rapid recovery of local ranid frog populations (Bradford 1989, pp. 416-417; Vredenburg 2004, p. 7648; Knapp et al. 2007, p. 7; Pope 2008, p. 1576; Larson et al. 2017, p. 234) and is beginning to be used as a management option to recover amphibian abundance and assemblages, particularly in national parks (Knapp et al. 2016, p. 11893; Larson et al. 2017, p. 235; NCNPS 2008, entire; MRNP 2017, entire). In addition to the experimental removal, both North Cascades and Mount Rainier National Parks have initiated non-native trout removal in multiple lakes as a part of their overarching Fish Management Plans (NCNPS 2008, entire; MRNP 2017, entire). Manual removal (gill netting) is the primary tool currently used, however, piscicides such as rotenone may be used in specific situations. Rotenone has been found to be highly lethal to gill breathing amphibians such as larvae but does not appear to affect lung-breathing juveniles and adults. In Yellowstone National Park, a fish removal project using rotenone found 100% mortality in larval Columbia spotted frogs (*R. luteiventris*), therefore, timing of use and local amphibian status are important in determining use (Billman et al. 2012, pp. 785-786). Subsequent monitoring found a return of

larval abundance by the next breeding season and no change in juvenile or adult abundance (Billman et al. 2012, pp. 785-786). While it can take at least five years to fully remove trout manually or three years using rotenone, non-native trout removal remains a long-term goal for species conservation and climate change resiliency in the National Parks and might also provide benefits elsewhere within the range of the species (Ryan et al. 2014, p. 238).

Though non-native trout stocking is anticipated to continue into the future in National Forest Wilderness Areas and surrounding non-wilderness lands, lawsuits and current state management evaluations have significantly reduced it in scope (Uehara 2005, p. 9; ICF Jones and Stokes 2010, entire; Ziller, ODFW pers. comm. 2021). Despite these current trends and management actions, we anticipate non-native fish will continue to be a chronic stressor for the foreseeable future, particularly in larger, deeper, perennial aquatic features or those with adjoining stream systems supporting fish populations. However, we anticipate long-term gradually declining landscape-level impacts from non-native trout, particularly at shallower isolated sites as fish populations decline or disappear without stocking or supplementation. This slow decline has been documented in national parks where stocking ended 30 years ago. A similar decline is likely already in progress in other areas where state agencies have ended stocking, and it may be further accelerated in areas as fish removal becomes a more utilized management tool.

4.2.2 Management of Amphibian Chytrid Fungus

Researchers have been piloting intervention and treatment options for small, at-risk populations in Northern California, as larger populations have a higher likelihood of persisting with chytrid (Pope et al. 2014, p. 25). One study found that treatment with the fungicide itraconazole helped reduce *Bd* prevalence in newly metamorphosed frogs and may have contributed to improved overwinter survival (Hardy et al. 2015, pp. 247-248). Research into antimicrobial skin peptides and symbiotic skin bacteria are also ongoing (Rollins-Smith et al. 2011, p. 552; Pope et al. 2014, p. 26; Lips 2016, p. 2). Thus far, treatment efforts have primarily been experimental and are not yet a widespread management tool for amphibian conservation due to competing agency priorities, costs, and logistical difficulty.

4.2.3 Management Response to Climate Change

The majority of Cascades frog populations occur on public lands, managed by the NPS and the USFS. The NPS has committed to meeting the challenge of and building a collaborative response to climate change. The NPS Climate Change Response Strategy features four components: science, adaptation, mitigation, and communication. The NPS will participate in partnerships that increase scientific understanding of climate change, analyze potential climate change impacts and adaptively apply the information to improve planning and resource conservation, set high standards for energy efficiency and greenhouse gas emissions reduction, and to communicate broadly about climate change science and its impacts and the actions that can be taken to mitigate and adapt (NPS 2010, p. 11).

Cascades frog populations span nine national forests extending from northern Washington through northern California, all managed by the Forest Service. In 2011 the USFS published their National Roadmap for Responding to Climate Change which outlines the agency's response to climate change including assessing current risks, vulnerabilities, policies and gaps in knowledge, engaging employees and stakeholders to seek solutions, and managing for resilience in ecosystems through adaptation, mitigation, and sustainable consumption strategies (USDA 2011b, pp. 1-4). The USFS conducted an Olympic Peninsula Climate Change Study which addressed potential climate change impacts to Cascades frog (USDA 2011a, pp. 91-108). The commitment from both of these agencies will ensure that impacts of

climate change on species such as Cascades frog will be evaluated and considered. However, plans for species-specific management or potential mitigation are not clear.

4.3 Summary of Factors Influencing the Species

We identified non-native trout, chytridiomycosis, and climate change as stressors with population-level effects on Cascades frogs. Figure 17 shows the relationships among these stressors with individual resource needs, population demographic needs, species needs, and ultimately species viability.

Non-native trout have been stocked extensively in the West for over 100 years, increasing the percentage of lakes with fish from approximately 5% to 60% (Bahls 1992, pp. 183-184). Since the 1970s, with recognition of the detrimental effects on aquatic ecosystems, stocking has slowly declined (Downen 2004, entire; Uehara 2005, entire; NCNPSC 2008, entire; MRNP 2017, entire; Ziller, ODFW, pers. comm. 2021). Recently, trout removal has occurred in a limited number of locations which were previously stocked. These factors have resulted in a slow decline in trout populations and occupancy in parts of the Cascades frog range (Knapp et al. 2016, p. 11890; Larson et al. 2017, p. 234).

Chytridiomycosis (*Bd*) has likely been spreading within California since the 1970s and is now widespread throughout the Cascades frog's range (Pearl et al. 2009, p. 209; Adams et al. 2010, p. 294; Gaulke et al., 2011 p. 210; Piovia-Scott et al. 2011, p. 2917; Piovia-Scott et al. 2015, p. 1571). However, the disease may not be present in all populations (Adams et al. 2010, pp. 298-299). *Bd* reduces survival of young and recently metamorphosed Cascades frogs but has little impact on adult survival (Pope et al., 2014 p. 25; Garcia et al. 2006, pp. 165-166). Mortality from *Bd* reduces recruitment into the Cascades frog breeding population, therefore reducing population size (Pope et al. 2014, p. 26).

Climate change has resulted in changes across the Cascades frog range (Ryan et al. 2014, p. 236; Lee et al. 2015, pp. 18-19). Altered precipitation patterns, along with increased temperatures, are expected to reduce available aquatic habitat spatially and temporally for all life stages, preventing young-of-year from surviving through metamorphosis (O'Regan et al. 2014; Ryan et al. 2014, entire; Lee et al. 2015, entire; Chandler et al. 2016, p. 2; Kissel 2017, entire; Kissel et al. 2019, entire; Lertzman-Lepofsky 2020, p. 4868). Additionally, increased temperatures and reduced aquatic habitat may lead to higher mortality from desiccation at ephemeral sites and may ultimately restrict gene flow.

The Cascades frog has various legal and management protections across its range (Table 7). The species is listed as a state sensitive species in Oregon, its protection is currently under review in California, and it has no legal status in Washington. Additionally, much of the species' range is protected within the boundaries of the NPS and USFS. Both agencies have committed to evaluating climate change impacts on imperiled species (NPS 2010, p. 11; USDA 2011b, pp. 1-4). Changes in management of trout, including reduced stocking and limited removal, have provided additional benefits to the species (ICF Jones and Stokes 2010; Downen 2004, entire; NCNPSC 2008, entire; MRNP 2017, entire).

Climate change and chytridiomycosis are novel and increasing threats across much of the Cascades frog range, while the threat from non-native trout has gradually decreased in recent years. Despite the reduction in trout stocking and density, their presence in ponds and lakes throughout the Cascades frog range limits available breeding habitat both in quantity and quality. If trout occupancy is not reduced in the future, it may prevent Cascades frogs from having the necessary habitat to adapt to other threats.

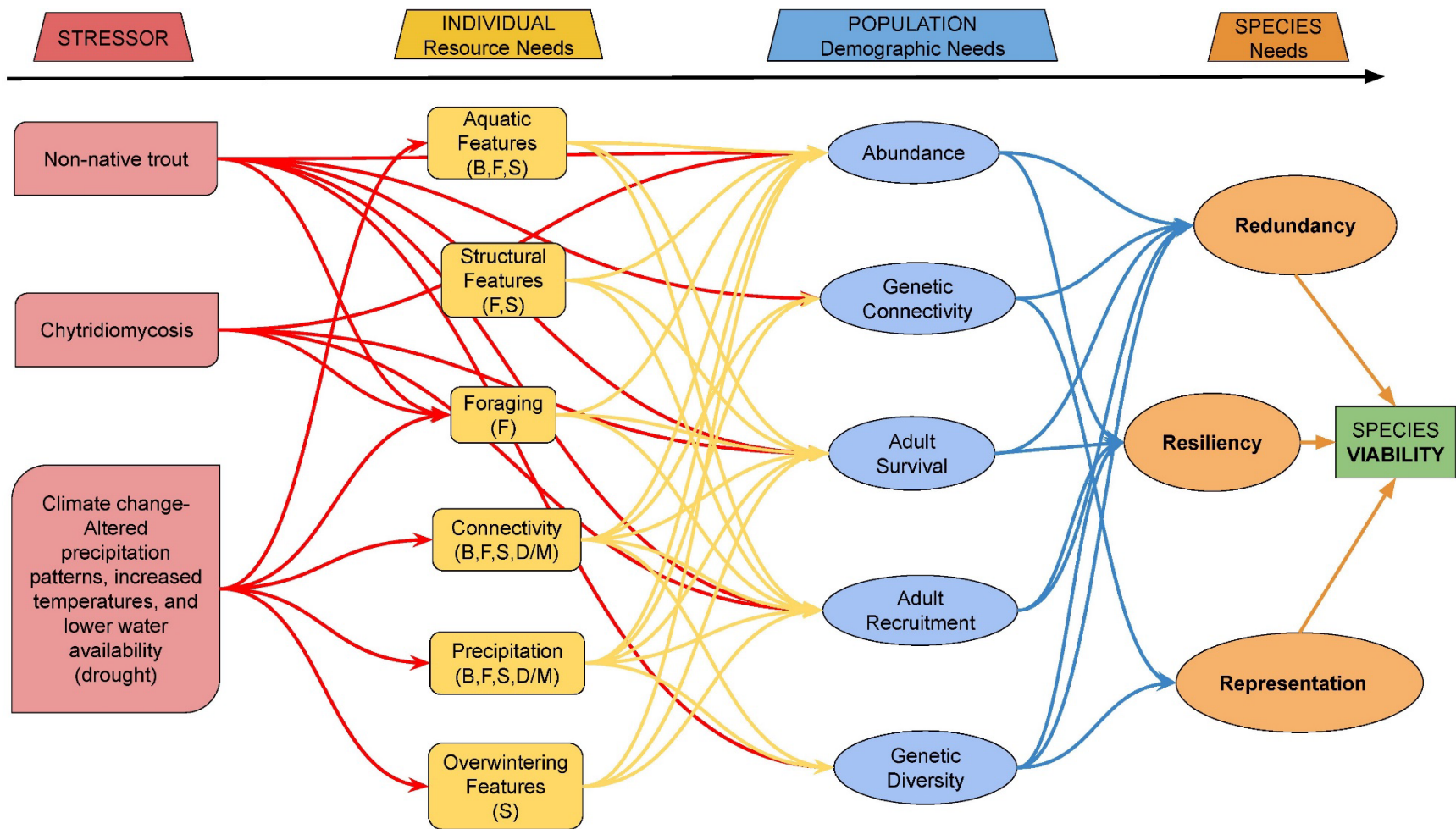


Figure 17. Relationship among Cascades frog stressors, individual resource needs, population demographic needs, and species needs, for viability.

5.0 CURRENT CONDITION

Current condition is our assessment of the past and present factors of the Cascades frog's habitat, demographics, and distribution (Smith et al. 2018, p. 306). We used the best scientific and commercial data available to analyze and describe these conditions at a regional scale. The methods and results of our assessment of current condition are described in the subsequent section.

5.1 Methodology

This section provides a brief overview of our approach to assessing the current condition of the Cascades frog. We assessed the current condition of the species in terms of the conservation biology principles of resiliency, redundancy, and representation (Section 1.2).

Cascades frog's resiliency, or the ability for populations to withstand stochastic events, is a function of metapopulation health and the connectivity among occupied sites making up metapopulations. As discussed in Section 2.5, Cascades frog life history traits such as being relatively mobile, long-lived and able to produce many offspring was historically well suited to respond to natural stochastic environmental events. A healthy Cascades frog population can generally be defined in terms of its abundance, reproductive and recruitment rates, juvenile and adult survival, and site connectivity for individual movement and genetic exchange.

We developed our current condition categories from the habitat and demographic population needs for the species (Section 3.2). We consulted our federal and state Cascades frog species and ecology experts to develop metrics to rank the various factors with the data we had available and their relative importance to Cascades frogs. Because abundance and survival data are unavailable for the majority of Cascades frog sites, we focused on the spatial arrangement of recent (1990 to 2020) Cascades frog detections for our demographic factors. These factors included connectivity and site occupancy. For our habitat factors, we focused on aquatic features and winter precipitation. We combined all four factors using a weighted average, with aquatic features weighted twice as important relative to the other categories (40% vs. 20%; Table 8). We conducted our current condition analysis using Geographic Information Systems (GIS) to reduce subjectivity. For the purposes of our analysis a "site" or "occupied site" is simply one or more Cascades frog observation, typically associated with an aquatic feature. From these locations, we examined their arrangement to estimate individual and genetic connectivity. In many cases, an aquatic feature may have had multiple occurrence records. In these cases, we thinned the occurrence data to 100 m (328 ft.) before performing the spatial analysis to reduce calculation errors due to site duplication. The thinning was performed using the spThin package in R (R Core Team, 2021, version 2.8.3). The 100 m (328 ft.) distance was selected by trial and error as it was close enough to account for variable locations associated with one aquatic feature and was not so great to lump points associated with different aquatic features. In rare instances, observations for one aquatic feature may be greater than 100 m (328 ft.) apart and would overestimate the number of sites.

Cascades frogs will travel between sites up to 1 km (0.62mi) apart seasonally, and up to 5 km (3.10 mi) apart in a stepping-stone manner between distant sites (Garwood and Welsh 2007, pp. 34-41). There is a sharp drop in genetic exchange between sites > 10 km (> 6.21 mi) apart (Monsen and Blouin 2004, p. 832). Occupied sites, 1 km (0.62 mi) buffers, and 5 km (3.10 mi) buffers were plotted via ArcGIS Pro v2.8.3 (Esri Redlands, CA).

Table 8. Condition Metrics to evaluate current condition by analytic unit (AU).

Condition Category	Demographic Factors		Habitat Factors		Scoring	
	Connectivity - Connectivity for individual frogs (< 1 km; 0.62 mi) and genetically among occupied sites (< 10 km; 6.21 mi)	Site Occupancy- number of occupied sites in the AU (from 1990 to present)	Aquatic features - A diversity of perennial and seasonal aquatic features across the landscape	Precipitation - Winter snow and rain from November through March	Composite condition score - weighted average of all scores	AU score
Null (1 pt.) - not generally supportive of a population	50% or more sites occur more than 10 km (6.21 mi) from other occupied sites	0 sites	Neither perennial nor seasonal wetlands are available within 1 km (0.62 mi) of 50% or more of sites	AU has received less than 50% of 40 year 'average' winter precipitation for the last five years.	1.00-1.50	Null
Poor (2 pts.) - significant negative departure from expected condition for a healthy population	50% or more sites occur more than 5 km (3.10 mi), but less than 10 km (6.21 mi) from other occupied sites	1 site	Perennial wetlands are NOT available but seasonal wetlands or streams are available within 1 km (0.62 mi) of 50% or more of sites	AU has received 50 to 75% of 40 year 'average' winter precipitation for the last five years.	1.51-2.50	Poor
Fair (3 pts.) - minor to moderate negative departure from expected baseline condition for a healthy population	50% or more sites occur within 5 km (3.10 mi) of other occupied sites	Between 2 and 5 sites	Perennial wetlands are available but seasonal wetlands are NOT available within 1 km (0.62 mi) of 50% or more of sites	AU has received 75 to 99% of 40 year 'average' winter precipitation in the last five years.	2.51-3.50	Fair
Good (4 pts.) - expected condition to support a healthy or self-sustaining population	50% or more sites occur within 1 km (0.62 mi) of other occupied sites	6 or more sites	Both perennial and seasonal wetlands are present within 1 km (0.62 mi) of 50% or more of sites	AU has received ≥100% of 40 year 'average' winter precipitation in the last five years.	3.51-4.00	Good
Percentage of Total Score	20%	20%	40%	20%	100%	

Overlapping 5 km (3.10 mi) buffers were merged into single analytic units (AUs). An occupied site with no connecting 5 km (3.10 mi) buffer (i.e., a distance >10 km (> 6.21 mi) to the nearest occupied site) would be a single 5 km (3.10 mi) radius circle and our smallest possible AU.

For our condition model, we assumed that small, isolated sites are less likely to be ‘rescued’ by dispersing animals from a nearby site and are less resilient to stochastic events, whereas areas with more occupied sites, more closely spaced together on the landscape are more likely to function as a metapopulation and provide dispersing animals to recolonize sites temporarily extirpated due to stochastic events. Thus, we considered AUs containing more historical detection sites to be in better current condition. The breaks between the number of sites per AU in the condition model were informed both by the frequency distribution of the data and the biology of the species.

The literature and our species experts emphasized that a diversity of aquatic features, especially perennial aquatic features, on the landscape are critical to supporting Cascades frog’s life history functions (Section 2.3 and 2.4). We used the National Hydrography Dataset Plus HR (NHD) to identify and assess the number and type of aquatic features within 1 km (0.62 mi) of occupied sites for each AU. For the purposes of this exercise, we used two wetland types, seasonal and perennial, to represent annual variation in hydrologic duration (USGS 2018, entire). Seasonal wetlands are anticipated to dry each year. More ephemeral seasonal wetlands will dry within a few weeks while others are anticipated to dry in most years by late summer. Perennial wetlands represent those that generally remain on the landscape year-round but may lose a percentage of their volume seasonally, particularly during dry years. The AUs with more perennial and seasonal aquatic features were ranked higher than those with only seasonal wetlands or streams because perennial aquatic features provide more resiliency at the landscape level. However, this does not take into consideration the presence of non-native trout.

Winter precipitation, primarily in the form of snow, supports seasonal wetlands, ground water and perennial wetland recharge, and stream runoff in montane areas (Mote et al. 2005, entire; Lee et al. 2015, p. 2). While hydroperiod and winter precipitation are intuitively linked, the relationship from a quantitative perspective is less clear (Adams USGS pers. comm. 2021). However, we’re using winter precipitation as an index to assess the snow and rain supporting the hydroperiod in higher elevation montane habitats. We used the DayMet: Monthly Climate Summaries on a 1 km (0.62 mi) Grid for North America, Version 4 data for precipitation from November through March to represent winter precipitation (Thornton et al. 2020, entire). We compared the average winter precipitation for the last five years (2016 to 2020) to the 40-year average (1980 to 2020) to get a relative measure of current precipitation. Raster values ranged from 50% to 150% of the 40-year average and were averaged within AUs. The greater the percentage of average winter precipitation the more resiliency an individual AU currently has.

Our final current condition score across the four demographic and habitat factors provided a relative measure of the species resiliency by AU (n=73). The AUs are the base unit by which we assess resiliency of a given connected metapopulation, which can then be scaled up to our larger regional level representative units (representative units; n=5) (Figure 18). We divided the current range of the species into five representative units based on natural geological and elevational gaps in the range of the species, such as the Puget Trough separating the Cascades and the Olympic Mountains, distance, and accepted genetic information (Monsen and Blouin 2004, p. 832; Hardy et al. 2021, p. 4; Brown et al., WDFW,

unpublished data 2021). The five representative units are the Washington Olympics, Washington Cascades, Oregon Cascades, California North and California South (Figure 18).

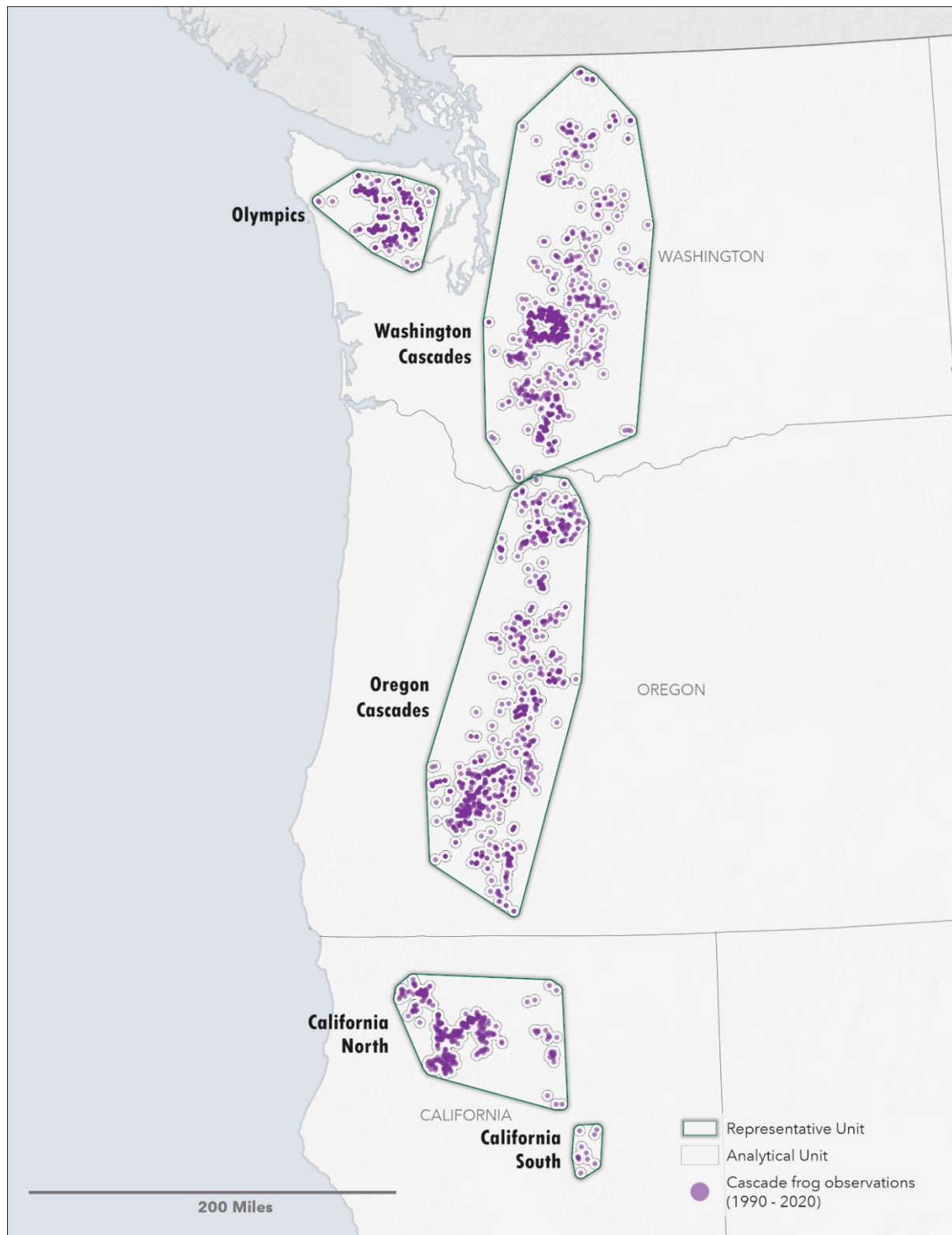


Figure 18. Representative units with analytic units (AUs) and observations from 1990-2020.

5.1.1 Representative Unit Descriptions

Washington Olympics

This representative unit boundary primarily encircles the Olympic Mountains on the Olympic Peninsula but does extend down in elevation on the west side of the Olympic Mountains to encompass some of the lowest elevation known occupied sites for Cascades frog (O'Donnell and MacCracken 2006, p. 102). This representative unit is separated from the Washington Cascades geologically by the north-south Puget Trough, a low elevation area including many sloughs and other saltwater bodies such as Hood Canal and Puget Sound. Genetic information [Section 2.2] suggests the distinctness of the Cascades frogs in the Olympic Mountains (Monsen and Blouin 2003, pp. 3282-3283; Brown et al., WDFW, unpublished data 2021). However, low elevation habitat surrounding this area also supports the northern red-legged frog (*R. aurora*) though no known hybrids have been found in the area.

Washington Cascades

The representative unit extends from the area just south of the U.S. and Canada border through the Cascades south to the Columbia River Gorge. The Skagit River roughly corresponds to the northern edge of the Cascades frog range (Buller pers. comm. 2020). However, while the Cascades frog has not been recorded in Canada, recent environmental DNA (eDNA) sampling in the Skagit Valley and Manning Provincial Park have detected Cascades frog eDNA, though these data should be viewed with caution until they are confirmed (Ovaska et al. 2019, p. 36). Though observations on either side of the east-west Columbia River Gorge are relatively close in proximity, it is extremely steep and rocky terrain and approximately a 900 m drop from the rim to the Columbia River. Two genetic studies suggest the Columbia River Gorge as a more recent natural break between the Washington and Oregon Cascades populations (Monsen and Blouin 2003, pp. 3282-3283; Brown et al., WDFW, unpublished data 2021). In addition to the Columbia River Gorge being a likely natural barrier, the river now has east-west traversing major high traffic volume highways (Highway 14 (WA) and I-84 (OR)) on the north and south sides and native and non-native predatory fish in the river, making it an even greater functional barrier to connectivity. Additionally, preliminary results from genetic work suggests further division up to as many as five genetic groups in the Washington Cascades (Brown et al., WDFW, unpublished data 2021).

Oregon Cascades

The single Oregon representative unit extends from the Columbia River Gorge in the north, south through the Cascades to the natural break northeast of the Cascades-Siskiyou National Monument and west-northwest of the Klamath Basin and north of the Klamath River. The area between there and the closest Cascades frogs to the south in the California Cascades is a recognized biogeographical break likely created during the last glacial period (approximately 2 million years ago) (Bury and Pearl 1999, p. 346; Monsen and Blouin 2003, p. 3283). We are unaware of historical observations from this area, and it is currently a distance of approximately 50 km (31.06 mi) between the nearest known occupied sites. Similar to Washington, preliminary results from genetic work suggests further division into two genetic groups in the Oregon Cascades may be warranted (Brown et al., WDFW, unpublished data 2021).

California North

This representative unit encompasses the California Cascades from just northeast of Mount Shasta south to Redding, CA and west encompassing the Trinity Alps and Marbled Mountains of the Klamath Mountains. Genetic analysis found these two subgroups to be more closely related than those further to the south in the Cascades (Hardy et al. 2021, p. 4). Though the populations in the Cascades north of Lassen Volcanic National Park and Klamath Mountains populations are genetically similar, they may now

be functionally separated by distance and human-made barriers such as I-5, which runs north south between these mountain ranges.

California South

This representative unit encompasses the historical and current locations of Cascades frog in and to the south of Lassen Volcanic National Park from approximately an east west line through the middle of the park south to approximately Butte Creek at Butte Meadows, Butte County, California. This area is northwest of the North Fork Feather River. The representative unit is currently separated by over 20 km (12.42 mi) from the nearest sites in the California North representative unit and genetic analysis found the Cascades frogs in this group to be distinct from those to the north (Hardy et al. 2021, p. 4). In addition, this area is different geologically from the Klamath Mountains due to more recent volcanic activity and glaciation with hydroperiod being driven more by snow melt runoff rather than groundwater (Garwood, CDFW, pers. comm. 2022; Hardy et al. 2021, p. 7). Frogs in this representative unit have also been existing, albeit with difficulty, with climate extremes in the form of heat and frequent droughts and may also have been experiencing *Bd* longer or exposure to a more virulent strain which may provide adaptive capacity (Knapp et al. 2016, p. 11891).

5.2 Uncertainty

As with most similar efforts, there is uncertainty in different aspects of the available data and our analysis. As described in Section 2.4.1, initial occurrence data came with temporal and information uncertainty. While older data are still valuable, they inherently have less certainty depending on the amount of time since collection and whether they still accurately represent the current condition. We received approximately 8,000 data points across the range of the species from our partners. The information associated with a given location varied considerably from simple incidental observations to long-term monitoring projects looking at multiple aspects of Cascades frog life stages. We reviewed the temporal and informational aspects of the observation data and when ranking the resiliency of each AU we also provide a qualitative assessment of our confidence in the data behind the ranking as a high, moderate, or low level of confidence as scaled in Figure 19. For example, if an AU ranked out as poor and

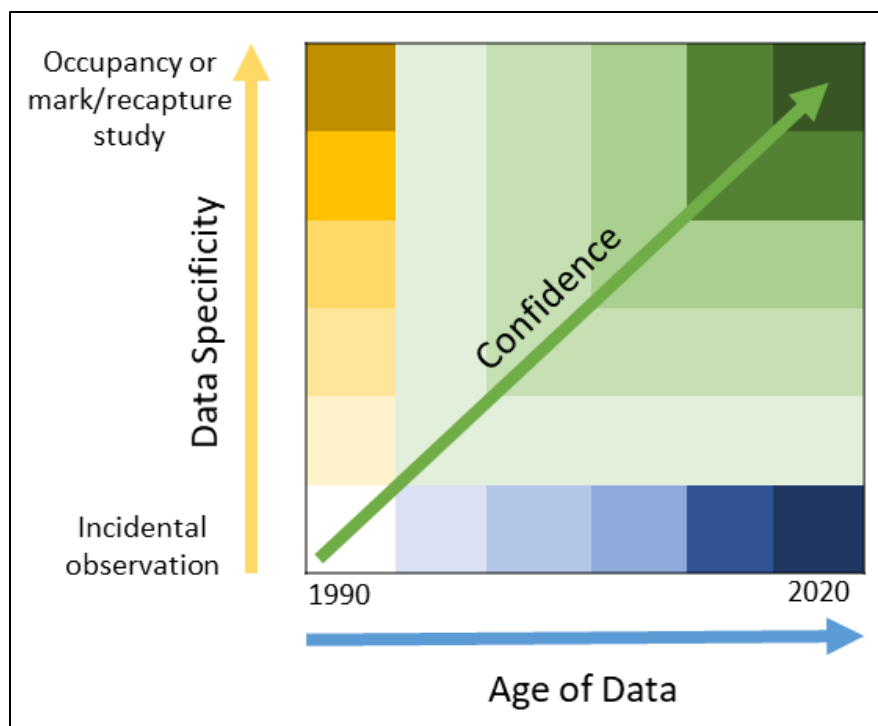


Figure 19. Conceptual diagram of our confidence, or certainty, in the Cascades frog observation data.

our data confidence rating was high then we are more confident in the overall score. Our AU scores are only as good as the data underlying them, but this will help managers understand where there is uncertainty.

In addition to uncertainties associated with individual datasets, several potential landscape-scale uncertainties in the intensely monitored southern portion of the range were identified by our experts. Our grouping of occupied sites based on a 5 km (3.10 mi) radius could overestimate connections where topographic features (i.e., high alpine ridges or steep elevational drops) may act as natural breaks (Garwood CDFW, pers. comm. 2021). Two such situations were identified in the Klamath Mountains, and we are addressing these in our spatial analysis. Also, we identified a situation where our method of thinning by 100 m (328 ft.) distance resulted in multiple occupied sites being identified at a single known breeding location (Pope USFS, pers. comm. 2021). This result occurred in the California South representative unit where there are few extant populations, so it was important to correct. As this is meant to be a living document, our hope is that biologists with greater local knowledge further define topographic or other barriers to movement that can be incorporated into future status updates for the Cascades frog. Conversely, we may have underestimated connections in some locations, such as within the lower elevation range of the species, where surveys and observations are sparse. More of our single site AUs are in lower elevations and it is unknown if this reflects actual sparse occurrence of the species or lack of survey data.

However, in general we do not think this is a significant uncertainty in Oregon and Washington as there are many more occupied sites, and the representative units are generally much larger, especially compared to the California South representative unit. Our assessments, combined with local on the ground landscape expertise, as well as the ongoing genetic work by WDFW suggests that there are more

genetic breaks within our Oregon and Washington representative units that could benefit long-term management.

We believe we have minimized several sources of our own uncertainty and bias and increased objectivity by using GIS spatial analysis to calculate the AU scores. This analysis could continue to be refined over time now that more attention has been brought to the status of the Cascades frog through this process, and it may help some partners to re-evaluate how their monitoring could be changed to provide better information.

Lastly, we know there is uncertainty behind our assessment of the current population status and trends because the objectives for data collection differed across the range. No state has both occupancy modeling data and population abundance/trend information. Data sources are discussed specifically in Section 2.4.1 by state to highlight the monitoring needs in the various jurisdictions.

5.3 Current Resiliency, Redundancy, and Representation

5.3.1 Resiliency

Resiliency is the ability to maintain population viability through the natural range of favorable and unfavorable environmental conditions. As discussed in detail in Section 3.2, Cascades frog resiliency is a function of demographic requirements and habitat resources that are necessary to maintain abundance, distribution, and reproduction. Demographic factors supporting a healthy population are defined in terms of its abundance, level of reproduction and recruitment, juvenile and adult survival, and connectivity. The number and distribution of occupied sites is influenced by the availability of habitat and the degree and spatial extent of environmental stochasticity. Typically, the closer in proximity and greater the number of occupied sites, the greater likelihood of sustaining populations through time. Healthy populations are better able to recover from stochastic events and withstand variation in the environment. Thus, the greater the number of healthy populations, the more resiliency the species possesses.

Based on this definition of resiliency, we scored the current condition of each AU by assessing, (1) connectivity among occupied sites, (2) the number of occupied sites connected spatially, (3) the availability and proximity of aquatic habitat features spatially, and (4) the average relative precipitation over the last five years. Appendix I presents the AU scores in terms of the four elements (above) grouped by representative unit and includes a confidence rank for each AU based on the certainty of the data, as discussed in Section 5.2. Figures 20 to 22 summarize appendix I current condition scores by AU and grouped by representative units.

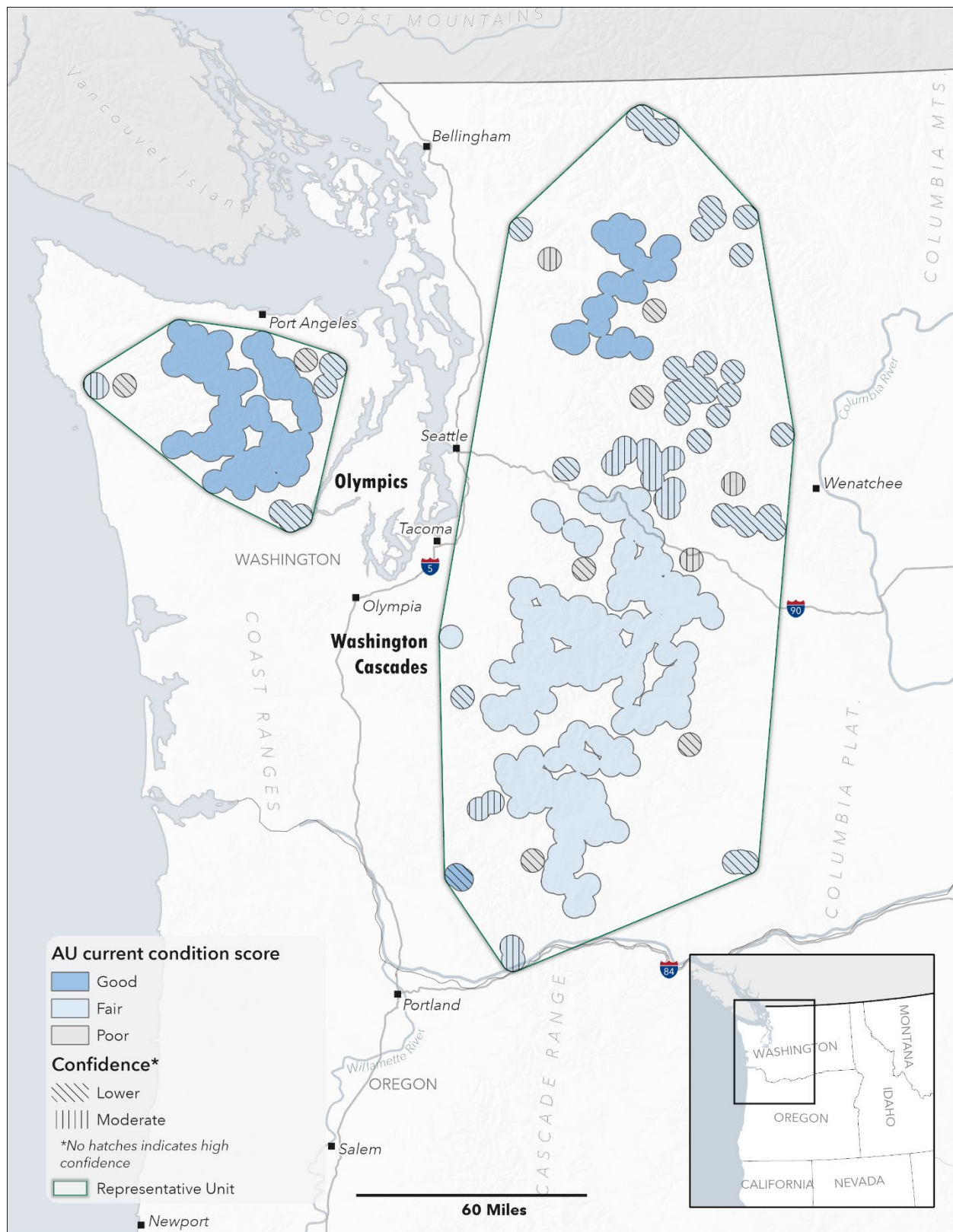


Figure 20. Current condition by analytic unit (AU) in Washington.

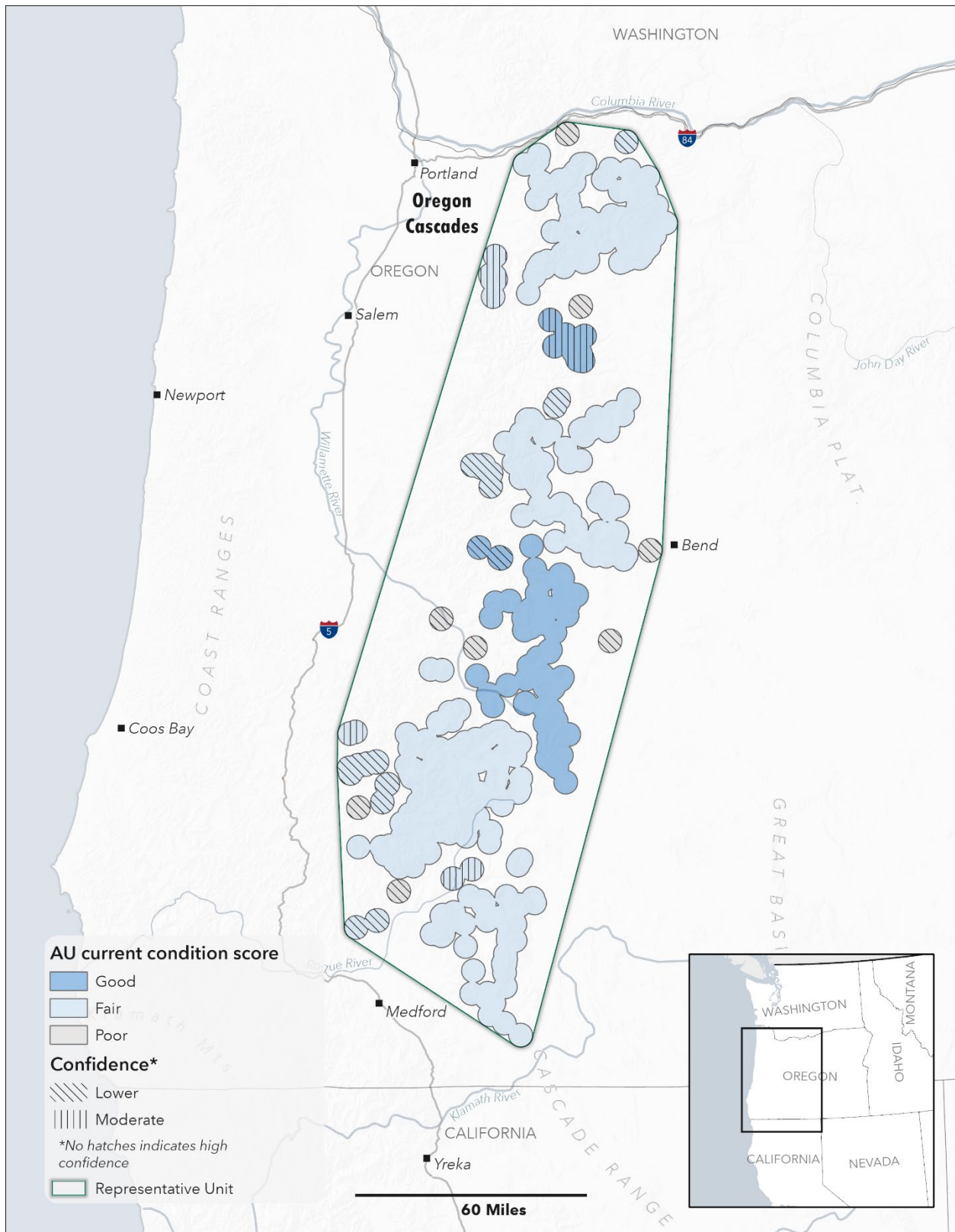


Figure 21. Current condition by analytic unit (AU) in Oregon.

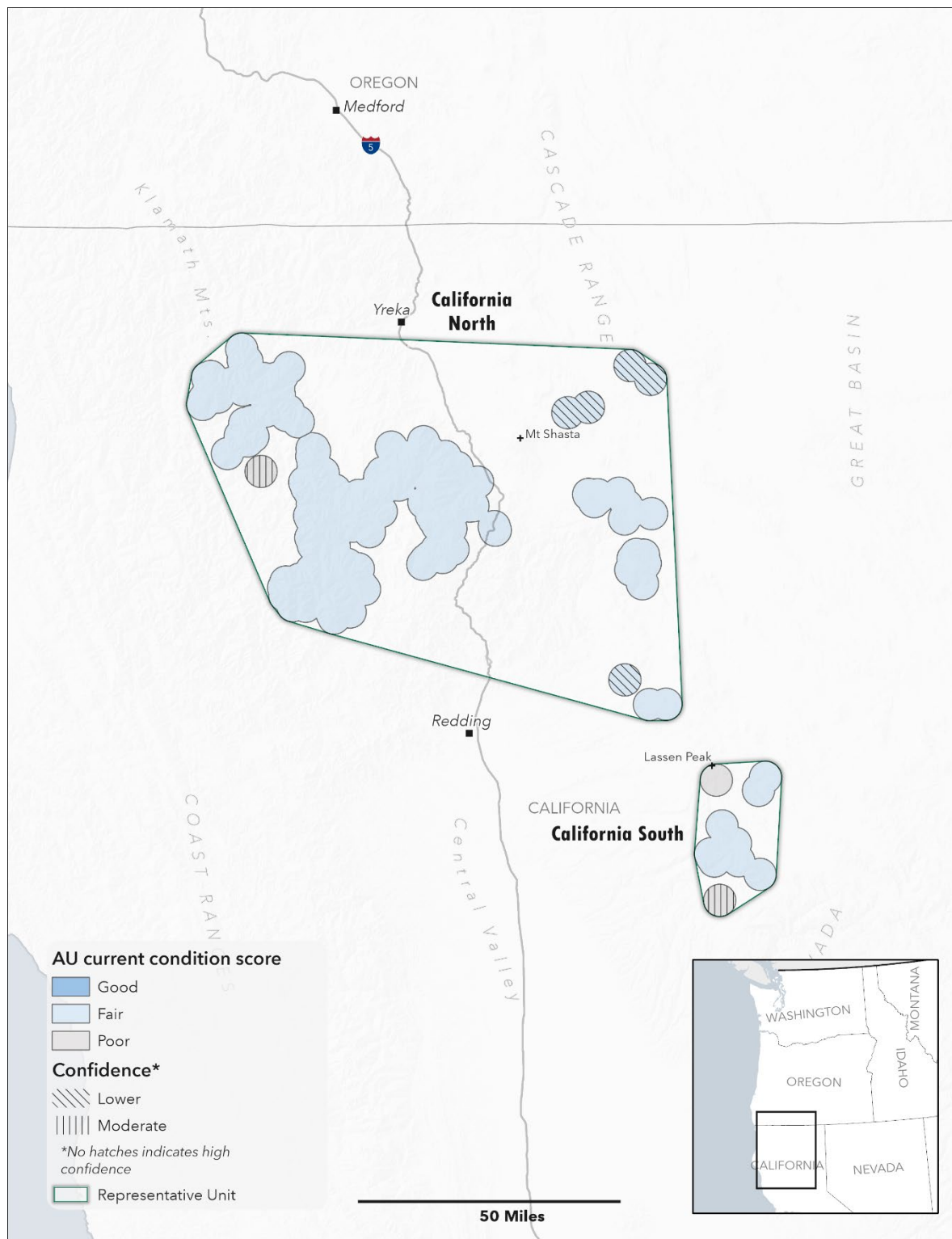


Figure 22. Current condition by analytic unit (AU) in California.

For current condition, we identified 73 unique AUs across the species range (see section 5.1 for more detail). Across our five representative units (described in section 5.1.1), resiliency varied (Figure 23). Both Oregon and Washington support some of the largest AUs that were ranked as good condition (total of six). In the Washington Cascades two AUs were ranked as good condition, with 19 ranked as fair condition, and eight ranked as poor condition. In the Olympic Mountains, one AU was ranked as good condition, three were fair condition, and two were ranked as poor condition. In the Oregon Cascades, three AUs were ranked as good condition, 15 were ranked as fair condition, and eight were ranked as poor condition. California had no AUs ranked as good condition. California North had seven units ranked as fair condition and one unit ranked as poor condition, whereas California South had two units ranked as fair condition and two ranked as poor condition. In general, resiliency of Cascades frog was variable across the range, however the California AUs were less resilient than those in Oregon and Washington.

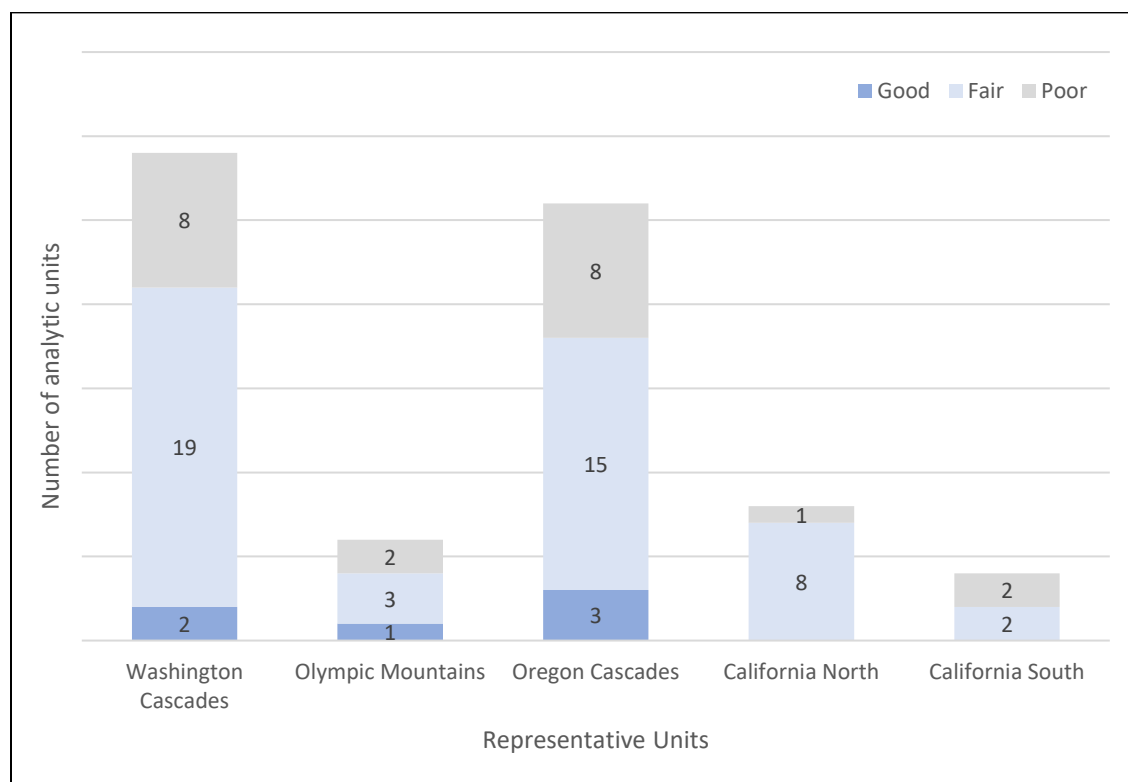


Figure 23. Summary of current condition scores for Cascades frog by representative units in Washington, Oregon, and California.

5.3.2 Redundancy

Redundancy is the ability of a species to withstand catastrophic events and is best achieved by having multiple populations widely distributed across the species' range. Given sufficient redundancy, single or multiple catastrophic events are unlikely to cause the extinction of a species, and the greater redundancy a species has, the more viable it will be. We can measure redundancy by analyzing the number and distribution of populations relative to the scale of anticipated catastrophic events. The analysis assesses cumulative risk of catastrophes occurring over time.

The Cascades Mountain Range is composed of mountains that are volcanic (Mount Rainier, Mount Hood, Mount Lassen) and non-volcanic (North Cascades) in origin; in recent history (1980) the region

experienced a large-scale eruption at Mount Saint Helens, and Mount Lassen erupted from 1914 to 1921. Much of the high elevation montane habitat that supports Cascades frog populations in all three states is in close proximity to volcanic mountains, of which an eruption would be considered a catastrophic event. The Klamath Mountains, though not volcanic in origin, are in close enough proximity to volcanos (e.g., Mount Shasta), that impacts could occur if an eruption took place. The distribution of populations of the species across a broad geographic range (redundancy) ensures that if an eruption were to happen within some portion of the range, the entire species would not be at risk. The Olympic Mountains, which are not volcanic in origin, support populations that are geographically isolated enough from the Cascades that impacts from a volcanic eruption are less likely.

Amphibian disease, including *Bd* has potential to impact the species across its range, although impacts are local. However, the California South representative unit has few known extant populations and has experienced large losses in Cascades frogs associated with this disease (see section 4.1.2).

Wildfire and prolonged drought are becoming more common occurrences in the Pacific Northwest, which will likely impact the species locally and across representative units. Given the broad distribution of the species, it is unlikely that wildfire would greatly impact redundancy of the whole species, but it could have impacts on populations in smaller representative units, including those in California South that are already experiencing impacts from disease.

Catastrophic events are unlikely to cause the species to become extinct since this species' range is extensive (approximately 966 km (600.24 mi) in length) and populations are distributed throughout. In the Washington and Oregon Cascades, populations are larger, and the analytic

units are well distributed along the Cascades crest. Therefore, there is suitable habitat to support the species and its connectivity, and thus higher redundancy. The more disjunct representative units, including the Washington Olympics, California North, or California South, could experience more impacts from catastrophic events given smaller number of AUs, isolation, and lack of connectivity to other populations across the range of the species. The lack of connectivity in both of California's representative units, and declines seen from *Bd*, have led to less redundancy in representative units in California than those in Oregon and Washington.

5.3.3 Representation

Representation is the ability of a species to adapt to near-term and long-term changes in its physical (e.g., climate conditions, habitat conditions, habitat structure) and biological (pathogens, competitors, predators, etc.) environments. The ability of a species to adapt to these changes is often referred to as adaptive capacity. Representation can be measured by examining the breadth of genetic and ecological diversity found within a species and its ability to disperse and colonize new areas.

There are 73 AUs for Cascades frog that are encompassed within five representative units, which were determined based on factors that contribute to the species adaptive capacity including habitat, distribution of occurrences, connectivity, natural geological and elevational gaps in the range of the species, and management considerations. (Appendix I; Figures 20-22). These representative units encompass montane wetlands, with habitat described in detail in Section 2.3. The range of Cascades frog extends across approximately 966 km (600.24 mi), extending from northern Washington to northern California, with disjunct populations in the Washington Olympics and Klamath Mountains.

Cascades frogs vary genetically across their range. Genetic data supports differences between the Washington Olympics, Washington Cascades, Oregon Cascades, California North, and California South representative units (see Section 2.2; Monsen and Blouin 2003, entire; Hardy et al. 2021, entire; Brown et al., WDFW, unpl. data 2021). The Washington Cascades and Oregon Cascades representative units encompass very large latitudes and a wide diversity of habitats along the entirety of the Cascades crest. These units contain the majority of the AUs with good resiliency (two in Washington Cascades and 3 in the Oregon Cascades (Figure 20 and 21).

The Washington Olympics populations are considered genetically distinct from those in the Washington Cascades and other representative units and have no potential for connectivity to other geographic regions (Brown et al., WDFW, unpl. data 2021). Within the Washington Olympics, one AU ranked as good, with three as fair, and two ranked as poor. Overall, the number of AUs in the Washington Olympics are much fewer (six) than the 29 in the Washington Cascades (Figure 20). The Washington Olympics have more snow-fed aquatic systems, indicating that they could be more sensitive to climate change impacts than habitat in other parts of Cascades frogs' range (Lee et al. 2015, p. 19). While there has been no *Bd* testing in the Washington Olympics, based on the regular population and breeding surveys in the region there have been no occurrences of widespread adult mortality consistent with *Bd* (Palen, Simon Frasier Univ. pers. comm. 2022). Non-native trout are pervasive in wetlands of the Washington Olympics, reducing the number of safe habitats available to the species to complete its life cycle (Ryan et al. 2014, p. 232).

Cascades frog populations in California are geographically isolated from populations in Oregon and have likely been separated from them for two million years, since the beginning of the last glacial maximum, (Monsen and Blouin 2003, p. 3283). Neither California North (eight AUs) nor California South (four AUs) have any AUs that ranked as good. These populations possess lower genetic diversity and are genetically distinct from those in Oregon, but California North and California South representative units possess comparable genetic diversity to one another (Hardy et al. 2021, p. 8).

Populations within the California South representative unit have experienced declines, local extirpations, and low population viability due in part to *Bd*, droughts and non-native trout stocking (Fellers and Drost 1993, pp. 180-181; Fellers et al. 2007, entire; Pope et al. 2014, p. 16), and lack of connectivity to other habitat. These factors will perpetuate low genetic diversity and population declines. Cascades frogs have disappeared from an estimated 95% of their historical habitats in the Lassen region within California South (Fellers and Drost 1993, pp. 178-179; Pope et al. 2014, p. 1). Populations in the Klamath Mountains of California North are considered more stable; however, extirpations have been documented (Pope et al. 2014, p. 16) and the lack of good resiliency in AUs indicates that these areas could be more vulnerable to threats including climate change, *Bd*, and non-native trout.

6.0 SPECIES' FUTURE CONDITION AND STATUS

6.1 Methodology

To project an estimate of future condition and associated potential extinction risk of the Cascades frog, we modeled habitat suitability under four future scenarios. We first created a baseline Habitat Suitability Model (HSM) for comparison using the Cascades frog occurrence data supplied from state, federal, and non-agency partners.

To build the baseline HSM, environmental data layers were used primarily from Climate Toolbox (<https://climatetoolbox.org>) and represented modeled historic mean values for 1971-2000. We chose climate variables based on their effects on suitable habitat, and the existence of adequate data. The specific climate variable data we used was obtained from the Climate Toolbox (climatetoolbox.org) and includes:

1. **Maximum Temperature (°F):** The average daily highest temperature, computed over the time period. Projection models are available for spring (March, April, May), summer (June, July, August), fall (September, October, November), winter (December, January, February), and annual time periods.
2. **Minimum Temperature (°F):** The average daily lowest temperature, computed over the time period. Projection models are available for seasonal and annual time periods.
3. **Precipitation (in):** Accumulated (total) amount of precipitation, including all forms of precipitation (rain/snow), computed over the time period. Projection models are available for seasonal and annual time periods.
4. **Snow Water Equivalent (in):** The amount of water (total) contained in the snow cover on the ground. Projection models used were based on data from April 1, representative of spring snow water equivalent.
5. **Soil Moisture (in):** The amount of water contained in the upper few meters of soil. Projection models are available for seasonal and annual time periods.
6. **Potential Evapotranspiration (Grass):** Represents the maximum water demand for a reference grass crop calculated using the FAO Penman-Monteith method. Looking at percentiles in potential evapotranspiration is similar to the Evaporative Demand Drought Index (EDDI). Projection models are available for seasonal and annual time periods.

Additionally, two terrain-based layers were used, a digital elevation model (DEM) from USGS National Elevation Dataset (USGS 2019) and a Topographic Wetness Index (TWI) derived from the DEM. Appendix III provides a detailed description of the HSM and future climate modeling process.

Along with the baseline condition, we developed four climate scenarios to project future condition under a range of plausible future scenarios. Future climate data was gathered from the Historical and Future Climate Mapper (climatetoolbox.org). Each future climate scenario is based on variation in the representative concentration pathways (RCP) model which predicts future climate of temperature and precipitation based on changes in the greenhouse gas emissions in the atmosphere. Scenario RCP 4.5 is a low emissions scenario where atmospheric concentrations of greenhouse gases are expected to equal approximately 650 parts per million (ppm) after the year 2100 and scenario RCP 8.5 represents a high emission, “business as usual”, scenario in which greenhouse gases continue to rise unchecked through the end of the century (Ternado et al. 2020, p. 10). RCPs 4.5 and 8.5 represent upper and lower boundaries of what can be expected for the future effects of climate change (Ternado et al. 2020, p. 17).

Because there is a lag time between present emissions and their effects on climate, current emissions will not have a substantial effect until mid-century. The minor deviations we see in climate projections from now to mid-century are driven primarily by unresolved science about how the climate system works. In the latter half of this century, climate change projections begin to greatly diverge, driven primarily by

future greenhouse gas emissions (Ternado et al. 2020, p. 15). Because the future global response to climate change is unknown, we limited our predictions to the 21st century. We assessed the future condition of the Cascades frog for two different time periods, 2010 to 2039 and 2040 to 2069 (Table 9).

Each of the raster cells in the five model outputs (one baseline, four future) were classified into four habitat classes:

- Null: This unsuitable habitat has conditions below average for sites not expected to have cascades frogs.
- Poor: This marginal habitat has a lower probability of Cascades frog presence less than expected by random chance, and above average for sites not expected to have cascades frogs.
- Fair: This suitable habitat has a higher probability of having Cascades frogs than expected by random chance, and below average for sites expected to have cascades frogs.
- Good: This highly suitable habitat has conditions above average for sites expected to have cascades frogs.

These outputs were then averaged across each AU. A detailed description of these methods can be found in Appendix III.

Table 9. Future scenarios. We developed our future scenarios based on RCP 4.5 and RCP 8.5 for two different time periods, 2010-2039 and 2040-2069. This resulted in four future scenarios, two near-term and two long-term.

*Evapotranspiration units are inches and are calculated using the FOA Penman-Monteith equation. Detailed descriptions of this method can be found online at sites such as <https://www.fao.org/3/x0490e/x0490e06.htm>.

	Near-term 1 Reduced Emissions	Near-term 2 Status Quo Emissions	Long-term 1 Reduced Emissions	Long-term 2 Status Quo Emissions
<i>Projections Data</i>	<i>RCP 4.5 Years 2010-2039</i>	<i>RCP 8.5 Years 2010-2039</i>	<i>RCP 4.5 Years 2040- 2069</i>	<i>RCP 8.5 Years 2040-2069</i>
Temperature (degrees Fahrenheit)	Winter Min Temp – increase by 2.0 Summer Max Temp – increase by 3.0 Fall Max Temp – increase by 2.0	Winter Min Temp – increase by 2.2 Summer Max Temp – increase by 3.5 Fall Max Temp – increase by 2.3	Winter Min Temp – increase by 4.0 Summer Max Temp – increase by 5.0 Fall Max Temp – increase by 4.0	Winter Min Temp – increase by 5.0 Summer Max Temp – increase by 7.0 Fall Max Temp – increase by 6.0
Precipitation (inches)	Spring – increase by 0.10 Summer – decrease by 0.30 Fall – increase by 0.60 Winter – increase by 1.0	Spring – increase by 0.20 Summer – decrease by 0.40 Fall – increase by 0.10 Winter – increase by 2.0	Spring – increase by 0.30 Summer – decrease by 0.15 Fall – increase by 0.10 Winter – increase by 1.10	Spring – increase by 0.20 Summer – decrease by 0.25 Fall – increase by 0.13 Winter – increase by 1.20
Snow Water Equivalent (inches)	April – decrease by 5.0	April – decrease by 5.5	April – decrease by 8.5	April – decrease by 10.5
Soil Moisture (inches)	Annual – decrease by 0.30 Spring – increase by 0.50 Summer – decrease by 3.0 Fall – decrease by 1.0 Winter – increase by 0.40	Annual – decrease by 0.20 Spring – increase by 0.70 Summer – decrease by 2.0 Fall – decrease by 1.0 Winter – increase by 0.80	Annual – decrease by 0.50 Spring – increase by 0.80 Summer – decrease by 3.0 Fall – decrease by 1.6 Winter – increase by 0.90	Annual – decrease by 0.50 Spring – increase by 1.0 Summer – decrease by 2.6 Fall – decrease by 1.4 Winter – increase by 1.3
Potential Evapotranspiration (inches*)	Annual – increase by 2.0	Annual – increase by 2.6	Annual – increase by 4.0	Annual – increase by 5.5

6.2 Future Resiliency, Redundancy, and Representation

6.2.1 *Future Resiliency*

The future resiliency of many of the 73 AUs shifts under near-term and long-term climate projections (Tables 10-12; Figure 24). While broad trends in these shifts appear to vary by representative unit, across the range there is a projected general decline of good habitat suitability with an increase in fair habitat suitability (Figure 24).

Table 10. Baseline and future analytic unit (AU) habitat suitability in Washington. Arrows indicate departure from baseline habitat suitability assessment.

WA Olympics	AU	Baseline	Near-term 1		Near-term 2		Long-term 1		Long-term 2	
	9	Fair		Fair	↓	Poor	↓	Poor	↓	Poor
	10	Fair		Fair	↓	Poor	↓	Poor	↓	Poor
	11	Null		Null		Null		Null		Null
	12	Null		Null		Null		Null		Null
	15	Fair		Fair		Fair		Fair		Fair
	21	Null		Null		Null		Null		Null

WA Cascades	AU	Baseline	Near-term 1		Near-term 2		Long-term 1		Long-term 2	
	1	Fair		Fair		Fair		Fair		Fair
	2	Poor		Poor	↑	Fair	↑	Fair	↑	Fair
	3	Poor	↑	Fair	↑	Fair	↑	Fair	↑	Fair
	4	Fair		Fair	↓	Poor	↓	Poor	↓	Poor
	5	Poor	↑	Fair	↑	Fair	↑	Fair	↑	Fair
	6	Poor		Poor		Poor		Poor		Poor
	7	Fair		Fair		Fair		Fair		Fair
	8	Poor	↑	Fair	↑	Fair	↑	Fair	↑	Fair
	13	Fair		Fair		Fair		Fair		Fair
	14	Fair		Fair		Fair		Fair		Fair
	16	Poor		Poor	↑	Fair	↑	Fair	↑	Fair
	17	Fair		Fair		Fair		Fair		Fair
	18	Null		Null		Null		Null		Null
	19	Fair		Fair		Fair		Fair		Fair
	20	Null	↑	Poor	↑	Fair	↑	Fair	↑	Fair
	22	Poor	↑	Fair	↑	Fair	↑	Fair	↑	Fair
	23	Poor		Poor		Poor		Poor	↓	Null
	24	Poor		Poor		Poor		Poor	↑	Fair
	25	Fair		Fair		Fair		Fair	↓	Poor
	26	Fair		Fair		Fair		Fair		Fair
	27	Null		Null		Null		Null		Null
	28	Poor		Poor	↓	Null	↓	Null	↓	Null
	29	Poor	↑	Fair	↑	Fair	↑	Fair	↑	Fair
	30	Good	↓	Fair	↓	Fair	↓	Fair	↓	Fair
	31	Good	↓	Fair	↓	Fair	↓	Fair	↓	Fair
	32	Fair		Fair		Fair		Fair		Fair
	33	Null	↑	Poor	↑	Poor	↑	Poor	↑	Fair
	34	Null		Null		Null		Null		Null
	35	Null		Null		Null		Null		Null

Table 11. Baseline and future analytic unit (AU) habitat suitability in Oregon. Arrows indicate departure from baseline habitat suitability assessment.

OR Cascades	AU	Baseline	Near-term 1		Near-term 2		Long-term 1		Long-term 2	
	36	Poor		Poor		Poor		Poor		Poor
	37	Null		Null		Null		Null		Null
	38	Fair	↓	Poor	↓	Poor	↑	Poor	↑	Poor
	39	Fair	↓	Poor	↓	Poor	↓	Poor	↓	Poor
	40	Good		Good		Good	↓	Fair	↓	Fair
	41	Good		Good		Good	↓	Fair	↓	Fair
	42	Good		Good	↓	Fair	↓	Fair	↓	Fair
	43	Poor		Poor		Poor		Poor		Poor
	44	Fair		Fair		Fair		Fair		Fair
	45	Null		Null		Null		Null		Null
	46	Poor		Poor		Poor		Poor		Poor
	47	Null		Null		Null	↑	Poor	↑	Poor
	48	Null		Null		Null		Null		Null
	49	Poor		Poor		Poor	↑	Fair	↑	Fair
	50	Fair		Fair		Fair		Fair		Fair
	51	Fair		Fair		Fair		Fair		Fair
	52	Null		Null		Null	↑	Poor	↑	Poor
	53	Poor		Poor		Poor		Poor		Poor
	54	Fair		Fair		Fair		Fair		Fair
	55	Fair		Fair	↓	Poor		Fair		Fair
	56	Poor		Poor		Poor		Poor		Poor
	57	Fair	↑	Good	↑	Good	↑	Good	↑	Good
	58	Fair		Fair		Fair		Fair		Fair
	59	Null		Null		Null		Null		Null
	60	Null		Null		Null		Null		Null
	61	Fair		Fair		Fair		Fair		Fair

Table 12. Baseline and future analytic unit (AU) habitat suitability in California. Arrows indicate departure from baseline habitat suitability assessment.

CA North	AU	Baseline	Near-term 1		Near-term 2		Long-term 1		Long-term 2	
	62	Poor		Poor		Poor		Poor		Poor
	63	Good	↓	Fair	↓	Fair	↓	Fair	↓	Fair
	64	Null		Null		Null		Null		Null
	65a	Fair	↓	Poor	↓	Poor	↓	Poor	↓	Poor
	65b	Fair		Fair		Fair		Fair	↓	Poor
	66	Poor		Poor		Poor		Poor		Poor
	67	Poor		Poor		Poor		Poor		Poor
	68	Fair		Fair	↓	Poor	↓	Poor	↓	Poor
	69	Fair		Fair		Fair		Fair		Fair

CA South	AU	Baseline	Near-term 1		Near-term 2		Long-term 1		Long-term 2	
	70	Fair		Fair	↑	Good	↑	Good	↑	Good
	71	Poor	↑	Fair	↑	Fair	↑	Fair	↑	Fair
	72	Fair		Fair		Fair		Fair		Fair
	73	Fair		Fair		Fair		Fair		Fair

The number of AUs with good habitat is projected to decrease in the near-term and continue to decline in the long-term (Tables 10-12; Figure 24). Fair habitat is projected to increase over both the near and long-term scenarios, with the majority of AUs in fair condition under both long-term scenarios. The number of AUs with poor habitat is projected to remain relatively stable across all scenarios. Null habitat condition decreases slightly over the near-term and long-term scenarios, with the fewest number of AUs under the long-term 1 scenario. Across all scenarios, there is a net increase in the number of AUs with fair and good habitat quality, with a net decrease in the number of AUs with null and poor habitat quality.

Lastly, it is important to recognize that these projected changes in habitat suitability are the product of our habitat suitability model based on several climate and topographic variables (Appendix III) that are highly correlated with current sites (i.e., habitat) supporting Cascades frogs. We are not saying that Cascades frogs will colonize the new habitat, we are simply saying it is plausible based on the projected future climate variables becoming more favorable. It is not clear whether Cascades frogs will eventually colonize new suitable habitat, which is generally at higher elevations. Much of this will depend on healthy contributing populations, connectivity to existing populations and will also require forage species, vegetation, and a diversity of aquatic features with sufficient hydroperiod to support Cascades frogs.

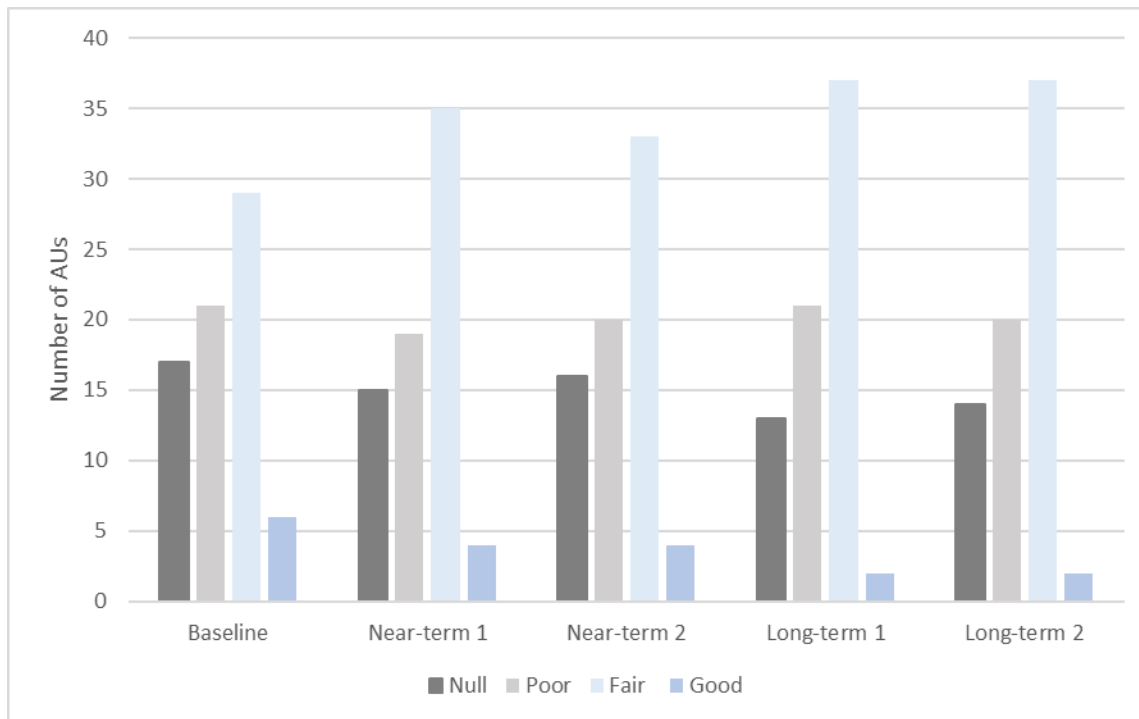


Figure 24. Summary of baseline and future habitat suitability under two climate scenarios (1-reduced emissions, 2-status quo emissions) and two time periods (near-term: 2010 - 2039, long-term: 2040 – 2069).

6.2.2 Future Redundancy

Given our analysis for future redundancy, the species is capable of withstanding most catastrophic events under the low and high emissions scenarios both in the near-term and the long-term. Given the species' extensive range and distribution, a catastrophic event is unlikely to impact viability, however the more isolated representative units (Washington Olympics and California North and South) could be more at risk given lack of connectivity to suitable habitat.

Under future condition scenarios, habitat suitability is projected to decline in the Washington Olympics and California North representative units, which could decrease potential connectivity for local populations and result in extirpations of populations in these areas. Suitable habitat is projected to increase in the Washington Cascades representative unit whereas the Oregon Cascades will see a net decline in habitat suitability under near-term scenarios but approximately equivalent proportions of habitat improvement and decline under long-term scenarios. Given the extensive geographic distribution and potential for connectivity in these two representative units, redundancy is considered higher than other representative units. In California South, the habitat suitability is projected to increase in two of the four AUs, which could add to species redundancy within that representative unit but could be hindered by declines in population density already experienced due to *Bd*. While the habitat suitability model projects increases in suitable habitat in some representative units, the potential for Cascades frog to colonize suitable habitat will be dependent on the health of existing source populations, connectivity, and habitat features to support the species across all life stages.

Impacts from *Bd*, localized wildfire, or prolonged drought could have large scale impacts at the representative unit scale, given the decline in available suitable habitat and inability of some populations

to recolonize new sites due to increased isolation and decreased connectivity. In summary, projected future decline in suitable habitat for AUs in the Washington Olympics and California North representative units is more likely than in the Washington Cascades, Oregon Cascades, and California South representative units, putting populations in those two representative units at greater risk from catastrophic events.

6.2.3 Future Representation

The change in habitat suitability under the future scenarios is summarized by Representative Unit in Table 13 and graphically in Figures 25 and 26 and displayed spatially across the range in Figures 27 and 28.

Table 13. Change in Habitat Suitability within Representative Units under two climate scenarios (1-reduced emissions, 2-status quo emissions) and two time periods (near-term: 2010 - 2039, long-term: 2040 – 2069).

Representative Unit	Near-Term 1	Near-Term 2	Long-Term 1	Long-Term 2
Washington Olympics (6 AUs)				
# of AUs improve (%)	0	0	0	0
# of AUs no change (%)	6 (100%)	4 (67%)	4 (67%)	4 (67%)
# of AUs decline (%)	0	2 (33%)	2 (33%)	2 (33%)
# of AUs decline to null	0	0	0	0
Washington Cascades (29 AUs)				
# of AUs improve (%)	7 (24%)	9 (31%)	9 (31%)	10 (34%)
# of AUs no change (%)	20 (69%)	16 (55%)	16 (55%)	13 (45%)
# of AUs decline (%)	2 (7%)	4 (14%)	4 (14%)	6 (21%)
# of AUs decline to null	0	1	1	2
Oregon Cascades (26 AUs)				
# of AUs improve (%)	1 (4%)	1 (4%)	5 (19%)	5 (19%)
# of AUs no change (%)	23 (88%)	21 (81%)	16 (62%)	16 (62%)
# of AUs decline (%)	2 (8%)	4 (15%)	5 (19%)	5 (19%)
# of AUs decline to null	0	0	0	0
California North (9 AUs)				
# of AUs improve (%)	0	0	0	0
# of AUs no change (%)	7 (88%)	6 (75%)	6 (75%)	5 (63%)
# of AUs decline (%)	1 (13%)	2 (25%)	2 (25%)	3 (38%)
# of AUs decline to null	0	0	0	0
California South (4 AUs)				
# of AUs improve (%)	1 (25%)	2 (50%)	2 (50%)	2 (50%)
# of AUs no change (%)	3 (75%)	2 (50%)	2 (50%)	2 (50%)
# of AUs decline (%)	0	0	0	0
# of AUs decline to null	0	0	0	0

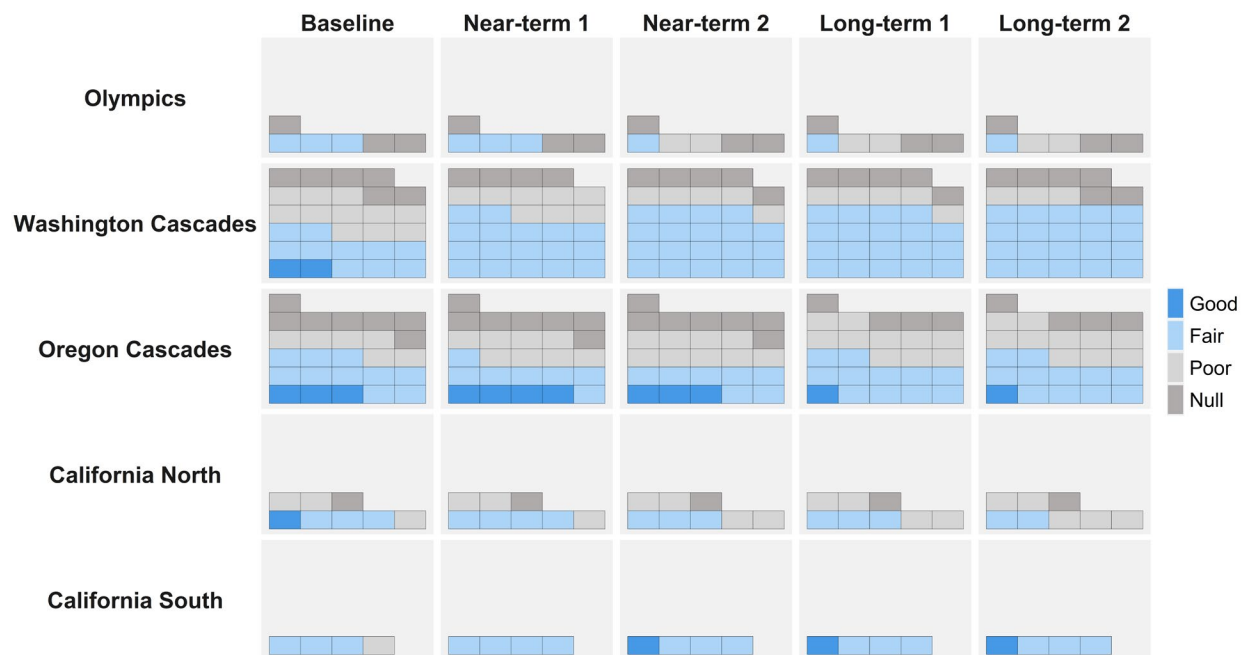


Figure 25. Number of analytic units by representative unit in the baseline and each future scenario.

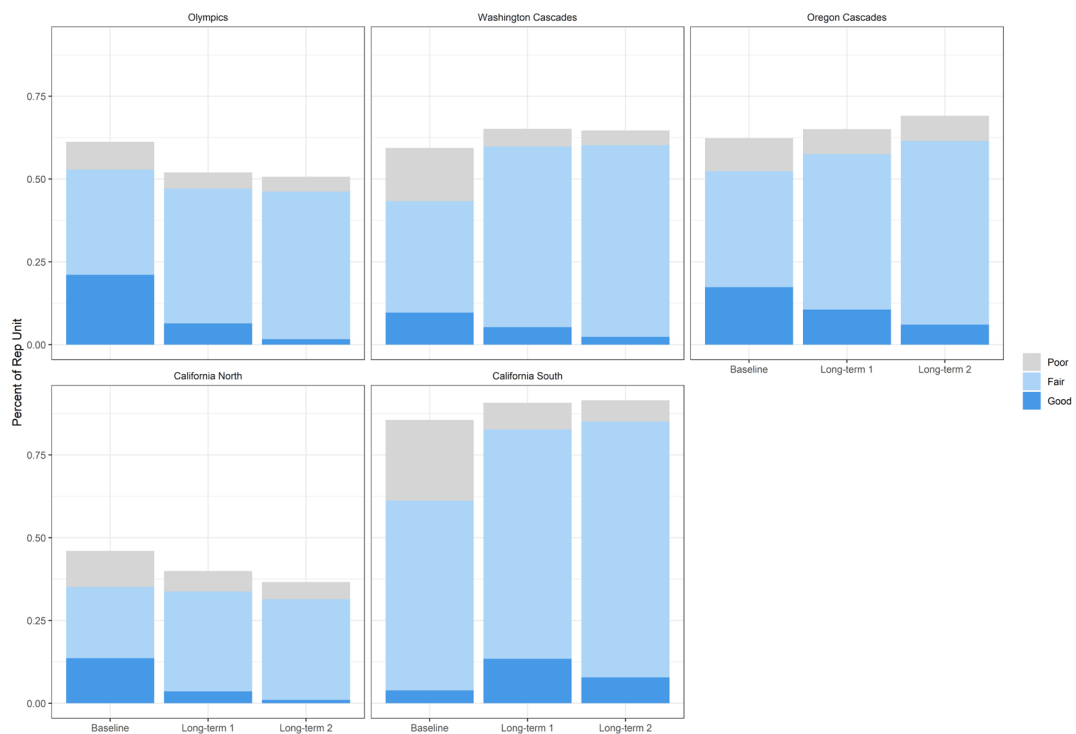


Figure 26. Modeled future habitat suitability by representative unit. Along the x-axis are the current baseline and the 2 long-term emission scenarios. The y-axis represents the percent of the total areas within the representative unit that falls in each habitat class. This figure does not include modeled near-term habitat suitability.

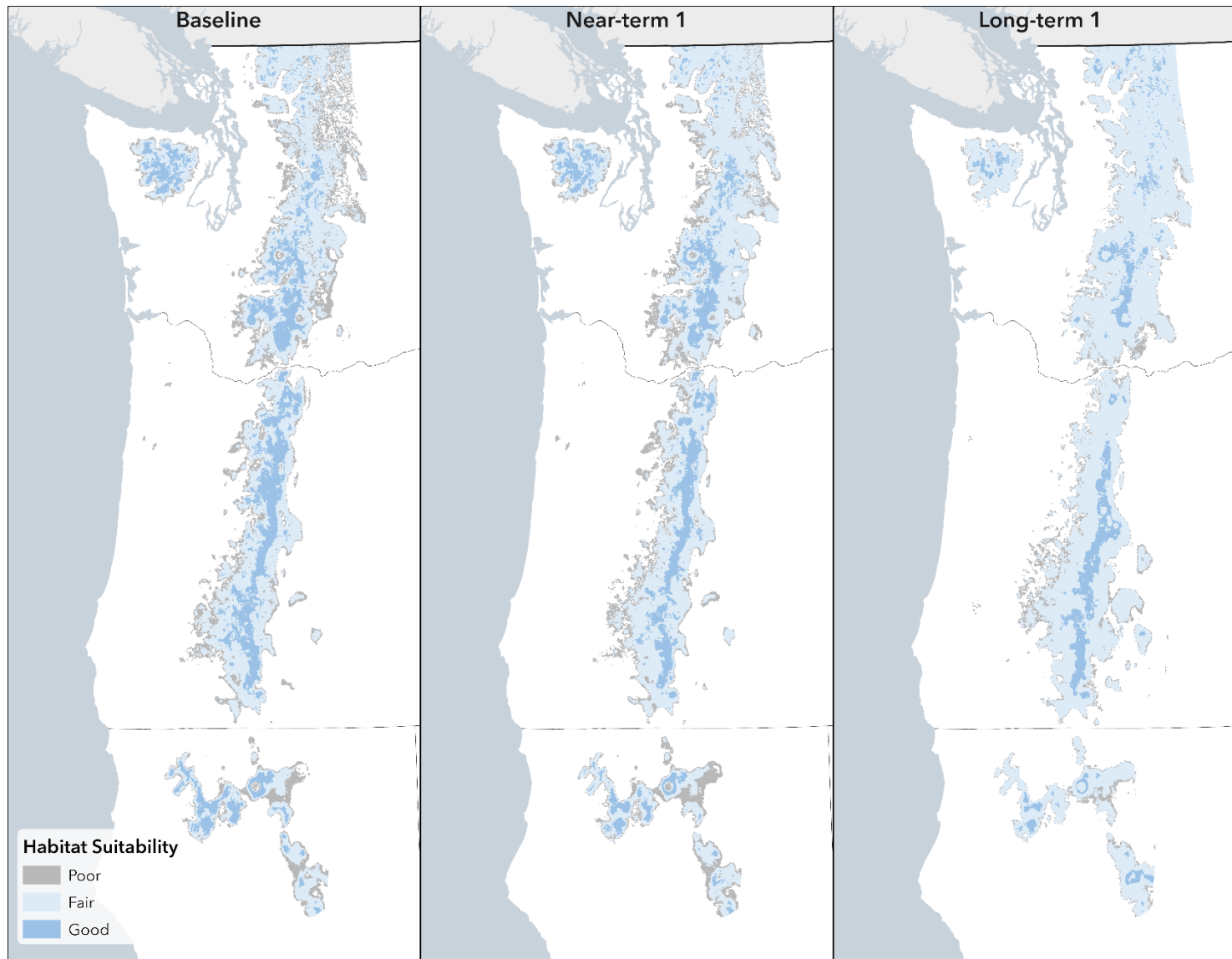


Figure 27. Projected habitat suitability for the reduced emissions scenario over two time periods (near-term: 2010 - 2039, long-term: 2040 – 2069).

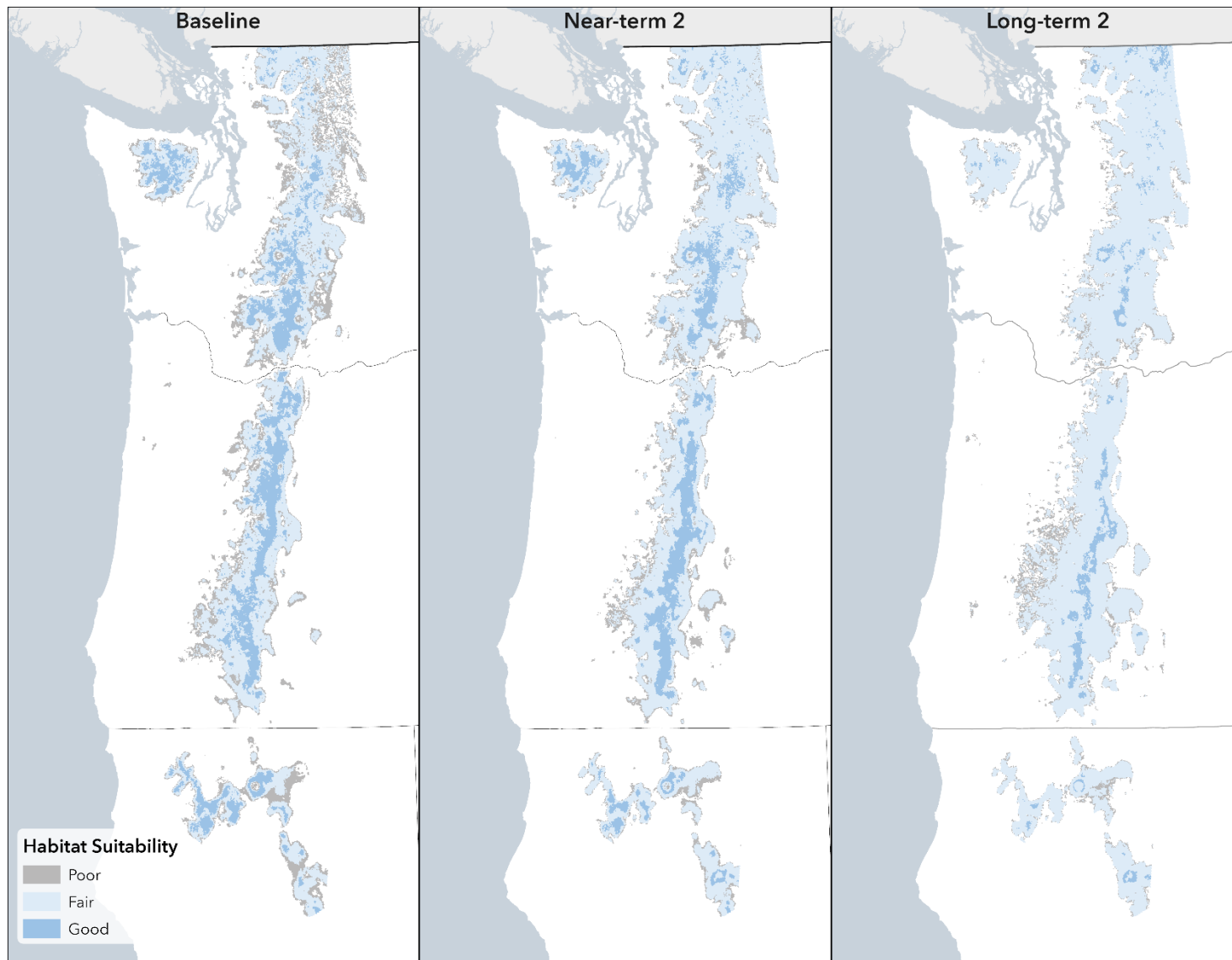


Figure 28. Projected habitat suitability for the status quo emissions scenario over two time periods (near-term: 2010 - 2039, long-term: 2040 – 2069).

In the Washington Olympics representative unit, habitat suitability is projected to remain stable or decline across both the near-term and long-term climate projections. Based on our HSM, three AUs are considered to not be within suitable habitat for Cascades frog (or “null”) under baseline and future scenarios. This is because the low elevation of these AUs relative to most other sites used to create the model. When compared to baseline condition, two AUs are projected to decline under the near-term 2 scenario and both long-term scenarios. The remaining four AUs remain stable under all scenarios. Under both long-term scenarios, the majority of the AUs in the Washington Olympics representative unit (five out of six) are projected to either be in poor condition or not supportive of a population due to lack of suitable habitat. The Washington Olympics representative unit is considered genetically distinct from other representative units and has no potential connectivity to other occupied areas. Genetic and environmental representation is likely to decline in this region because of the projected declines in suitable habitat and the resulting lack of connectivity. A study investigating climate change impacts to Cascades frog in the Olympic Mountains based on long-term population data projected that by the 2080's, the 20-year extinction risk will increase from 42% to 62% (Kissel et al. 2019, entire).

In the Washington Cascades representative unit, future habitat suitability varies across all climate scenarios. Habitat condition improves over all future scenarios, represented predominantly by changes from poor to fair condition, with the most improvement occurring in the long-term 2 scenario (34% of all AUs). The two AUs that had good baseline habitat quality decline to fair in all future scenarios. One AU declines to null condition under the near-term 2 and long-term 1 scenarios, and two decline under the long-term 2 scenario. Overall, habitat quality in this representative unit increases from baseline condition across all four climate scenarios, indicating that future conditions could result in the creation of more fair habitat quality in an area with high connectivity, though none of the increases resulted in good habitat quality. The Washington Cascades representative unit is the largest, with 28 AUs, and high potential connectivity along the Cascade Crest. Given projected increases in potential suitable habitat, future representation within the Washington Cascades is higher than other representative units.

Within the Oregon Cascades representative unit, future habitat suitability varies across the climate change scenarios. In the near-term 1 scenario, two AUs are projected to decline with four declining in the near-term 2 scenario. There is an increase in good habitat under the near-term 1 scenario, and the near-term 2 scenario has the same number of AUs with good habitat as the baseline. Under long-term scenarios, there is one AU with good habitat suitability. Habitat suitability declines in two AUs in the near-term 1 scenario (from fair to poor) and in four AUs under the near-term 2 scenario. Long-term climate projections indicate equivalent number of AUs increasing and declining in habitat quality. One AU (Number 57) is projected to increase across the near-term 2 scenario and both long-term scenarios. The Oregon Cascades representative unit is composed of 26 AUs which are widely distributed across the Cascades crest in Oregon. Projected increases and declines in suitable habitat could impact Cascades frog variably depending on location and connectivity to other populations. Upward shifts in elevation may diminish connectivity between many of these AUs, decreasing the potential gene flow and the ability for new suitable habitat to be colonized.

The California North representative unit contains nine AUs (AU 65 was split based on local expertise and topography) that are distributed in the Klamath Mountains and northern end of the Cascade Range of California. This representative unit supports AUs that are already functionally isolated from one another due to roads and other natural barriers. Despite these differences, genetic evidence suggests that populations within this representative unit are closely related and should be considered genetically

distinct from other populations (Hardy et al. 2021, entire). Future climate projections suggest that habitat suitability of this representative unit will decline across all projections. In the near-term 1 scenario, habitat suitability declines in two AUs (from good to fair or fair to poor) and in the near-term 2 and long-term 1 scenarios, three AUs decline. In the long-term 2 scenario, suitable habitat declines in four of the AUs. One AU remains in null habitat suitability across the baseline and all future climate scenarios. Populations in California have lower genetic diversity than those in Oregon (Hardy et al. 2021, entire), and potential habitat declines are likely to result in further decreases in genetic diversity due to reduced potential for connectivity.

The California South representative unit has a baseline of three fair AUs and one poor AU based on our HSM. In all future climate scenarios, AUs are projected to remain stable or improve. Under the near-term 1 scenario, one AU increases from poor to fair condition while the rest remain in fair suitability. Under the near-term 2 and both long-term scenarios, one AU increases to good habitat suitability and the rest are in fair habitat suitability. The California South representative unit possesses lower genetic diversity and is genetically distinct from those in Oregon and California North (Hardy et al. 2021, p. 8). Populations within the California South representative unit have experienced declines, local extirpations, and low population viability due to *Bd*, non-native trout stocking (Fellers and Drost 1993, pp. 180-181; Fellers et al. 2008, entire; Pearl et al. 2009, entire, Pope et al. 2014, p. 16), and a lack of connectivity to other habitat. These impacts may continue to perpetuate further declines in genetic diversity and population density. While future climate projections indicate there could be an increase in suitable habitat for two of the AUs, it is unknown if the populations in this area will have enough density to colonize new suitable habitat. Given the low number of AUs and low current resiliency, the potential benefits of new suitable habitat are unlikely to outweigh the low genetic diversity and impacts from stressors that these populations are already experiencing.

7.0 SYNTHESIS

The following subsections summarize AU and representative unit current and potential future condition in terms of resiliency, redundancy, and representation. These summaries synthesize information from previous sections for each representative unit to characterize the viability of the species as a whole.

7.1 Washington Olympics

There are six AUs within the Washington Olympics representative unit (Table 13). Population information summarized in Section 2.3 suggests that Cascades frogs are currently widespread within the Olympic Mountains of Olympic National Park and were reported as the most common lentic breeding amphibian (Galvan et al. 2003, p. 33). Local research within the park suggests a relatively stable population with high annual variability (Kissel et al. 2019, p. 7). One large AU (Number 15) covers the majority of Olympic National Park and most of the higher elevation suitable habitat. Much of the population information came from this AU, therefore our confidence in the current condition score is high (Figure 20). The rest of the AUs are outside of the Olympic National Park and are some of the lowest elevation populations known for the species. These AUs (Numbers 9-12, 21) are smaller and appear to be isolated. They are comprised of one to three known occupied sites and little abundance information is available. In addition, because three AUs are very low in elevation (Numbers 11, 12, 21) compared to the vast majority of the points used to build our HSM, they are not considered by our model to be in suitable habitat. Though these sites do not conform to typical suitable habitat based on our model, they are obviously “suitable” as frogs persist there. These Cascades frogs may be relics of historical conditions, different genetically, or

may have been displaced in similar habitat by northern red-legged frogs. Nevertheless, two AUs are projected to decline in habitat suitability while four are projected to remain the same under future climate scenarios. Though AU 15 is projected to remain fair in habitat suitability in our future climate scenarios, recent research on impacts of climate change on wetland hydrology found that decreases in larval and adult survival resulting from drier summers and shorter winters will lead to an increased extinction risk of 62% by the 2080s (Kissel et al. 2019, pp. 8-9). In addition, the Washington Olympics representative unit is isolated and relatively limited in terms of new suitable habitat becoming available outside of the AUs as a result of climate change (Table 13).

7.2 Washington Cascades

There are 29 AUs in the Washington Cascades representative unit. Currently, the Cascades frog is widespread and abundant within this representative unit with over 72% of the AU's classified as fair to good (Appendix I). All eight of the AUs classified as poor are single occupied sites (Figure 20). Cascades frogs are particularly common in Mount Rainier National Park and were found to be the most frequently observed lentic breeding amphibian (Samora et al. 2013, pp. 12 and 21). Based on the observation data we received, frogs appear to be less common in the northern portion of the Washington Cascades representative unit. This may be a result of fewer surveys or reduced availability of suitable habitat. Our future scenario projections indicate a net increase in habitat quality under all climate change scenarios, with most AUs in fair condition. Though suitable habitat was projected to increase overall, no AUs were considered in good condition under future scenarios. This is likely due to more high elevation "alpine" habitat potentially becoming suitable with climate change. High elevation suitable habitat is also predicted to increase in the northern portion of the representative unit outside of the AUs. It is unknown if Cascades frogs will colonize this new habitat; however, populations appear to be most resilient in the Washington Cascades representative unit currently and in the future, though climate change is likely to narrow and shift the availability of suitable habitat to higher elevations and eastward (Figure 27 and 28).

7.3 Oregon Cascades

There are 26 AUs in the Oregon Cascades representative unit. Recent and repeated occupancy modeling have not supported a substantial decline in Cascades frog occupancy of historical breeding sites (Pearl et al. 2009, pp. 173-174, 178; Duarte et al. 2021, p. 368). Currently, the Cascades frog is widespread, but abundance is not well understood. Previous accounts of declines in abundance did not provide data supporting the claims (Blaustein and Wake 1990, p. 203). However, this may be expected as Cascades frog abundance can have high annual variation based on precipitation patterns and available hydroperiod. In addition, ranid frog breeding sites are known to become extirpated and recolonized over time at the landscape scale (Duarte et al. 2020, entire). As with the Washington Cascades, the Oregon Cascades has a similar number and proportion of AUs with approximately 69% scored fair to good and 30% poor (Appendix I). All eight of the AUs in the Oregon Cascades representative unit that scored poor are also single occupied sites (Figure 21). Based on the observation data we received, frogs appear to be well distributed across the representative unit, however, there are some breaks between AUs that may need additional local expertise to discern if they are true topographic breaks (i.e., elevation or potentially lava fields) or represent gaps in our observation data. Our future climate scenario projections predict a net stability in suitable habitat within the Oregon Cascades. Under the near-term climate scenario there is likely to be a slight decline in habitat suitability with a balancing out of declining and improving AUs by the long-term climate scenarios. Unlike the Washington Cascades there was not a net improvement in new

suitable habitat becoming available. This is likely due to less high elevation habitat becoming suitable within the Oregon Cascades as a result of climate change. Cascades frog populations appear to currently be relatively resilient in the Oregon Cascades representative unit; however, we project in the future, climate change is likely to reduce the availability of highly suitable habitat (Table 13; Figure 25, 26, 27, and 28).

7.4 California North

Because of the Cascades frog population concerns first raised in the California South representative unit, surveys and monitoring have also increased significantly in this representative unit. Of the eight AUs in the California North representative unit, seven were scored as fair (Appendix I). The two largest AUs (65a and 65b, formerly one AU split based on local expertise and topography) are both within the Klamath Mountains while six smaller AUs are within the Cascades. As noted in our Cause and Effects Analysis on roads, these two areas of the California North representative unit are very likely functionally isolated due to distance, non-native trout in streams and potentially the high traffic volume I-5. Populations in the Cascades portion of this representative unit are relatively isolated and made up of few occupied sites (Figure 22). In addition, recent large fires are an emerging issue that needs to be studied to understand the effects of these catastrophic fires on the frog's aquatic habitat. Cascades frogs continue to be widespread and relatively abundant within the Klamath Mountains portion of the representative unit; however, recent declines have occurred, and it is unclear whether these declines are simply a result of recent low water years, or whether it's potentially compounded by the effects of *Bd* (Piovia-Scott et al. 2011, p. 2919; Garwood CDFW unpl. data 2021).

Our future climate scenarios predict a net decline in habitat suitability for the AUs in the California North representative unit compounded by the effects of non-native trout and *Bd* (Table 13; Figure 25). Cascades frog populations appear to be resilient in this representative unit currently; however, we project future climate change is likely to reduce the suitability of existing Cascades frog habitat and is less likely to provide new habitat. Genetic diversity in this representative unit is lower than the Oregon Cascades representative unit and given the lack of connectivity within the representative unit, we consider redundancy and representation to be low.

7.5 California South

The California South representative unit is the smallest of the five units and is comprised of only four AUs. Genetic work has identified Cascades frogs within this representative unit as distinct from the frogs to the north in California and elsewhere in the species' range (Hardy et al. 2021, pp. 4-6). In addition, the distance that now exists between the California North and South representative units likely eliminates genetic exchange (Monsen and Blouin 2004, p. 832). This representative unit is where severe population declines of Cascades frog were first documented (Fellers and Drost 1993, pp. 178-180). Declines in both site occupancy and abundance were reported in the early 1990s and the remaining sites have continued to be monitored since then with additional sites now extirpated and only a few (≤ 5) occupied sites supporting the existing AUs (Fellers et al. 2007, p. 32; Pope et al. 2014, pp. 13-16; Pope and Cummings USFS unpl. data 2021). Cascades frogs may be extirpated from Lassen Volcanic National Park (Fellers and Drost 1993, pp. 178-180; Fellers et al. 2007, p. 32; Pope et al. 2011, p. 5). Research starting in the 1990s suggested that a combination of influence factors acting synergistically were likely leading to the severe declines in AUs in the California South representative unit (Fellers and Drost 1993, p. 179; Fellers et al. 2007, pp. 33-34). Influence factors that we do not believe to be affecting the species across the range

may be having local effects on frog populations in individual AUs. However, the life history of the Cascades frog and the research on threats reviewed for this assessment still support the early assessments that frequent and prolonged drought influencing hydroperiod and non-native trout likely reduces frog abundance and recruitment. Trout may continue to limit abundance and dispersal where they occur. In addition, the fungal pathogen *Bd* is reducing juvenile survival (Pope et al. 2011, p. 11).

Contrary to the current population information (Appendix I; Figure 22), our HSM predicts stable habitat suitability in the future for two AUs and increases for two AUs (Table 12 and 13). This may be due to higher elevation habitat becoming more favorable but more likely is historical suitable habitat in Lassen Volcanic National Park that is currently extirpated and outside of our AUs. Cascades frog were present historically in the highest elevation lakes, and without features such as glaciers there may not realistically be new habitat to become available with climate change (Grinnell et al. 1930, p. 144; Fellers and Drost, p. 197). Unfortunately, because there are so few occupied sites and AUs remaining in the California South representative unit, and because the abundance of frogs is relatively low at all but two sites, the resilience, redundancy and representation of this representative unit is low and without management measures could be extirpated prior to historical sites becoming recolonized and new habitat becoming available. While the California South representative unit is currently in danger of being extirpated, the AUs are projected to roughly maintain a similar balance of suitable habitat based on our future climate scenarios, though the configuration may change. With only four AUs currently, it is imperative to maintain the existing populations in the California South AU so that Cascades frogs are present to expand into new suitable habitat in the future.

7.6 Species Viability Summary

We assessed the resiliency, redundancy and representation for the current and future Cascades frog populations across its range in Washington, Oregon and northern California. The Cascades frog continues to be widespread throughout most of its historical range except for the southern end in and around Lassen Volcanic National Park and the Lassen National Forest and sites in the Cascades associated with the California North representative unit which are also small and isolated. In three of the five representative units, where occupancy has been investigated and abundance information are available (Section 2.4), the frog continues to occupy historical sites, and abundance appears to be relatively stable (based on limited local studies). However, while the frog is currently widespread in the California North representative unit, population declines have recently been noted and it is unclear if this is simply a result of recent drought conditions or compounded by other factors. Finally, because there are so few occupied sites and AUs remaining in the California South representative unit, and the abundance of Cascades frogs is relatively low at all but two sites, the risk of future extirpation of populations in the representative unit is high.

Our climate change projections suggest an overall reduction of Cascades frog habitat suitability across the range, primarily due to a range wide decline of highly suitable to suitable habitat (Figure 24, 27, and 28). General declines in habitat suitability were predicted for the Washington Olympics and California North, a net stability of suitable habitat for the Oregon Cascades and a net increase in suitable habitat for the Washington Cascades and California South representative units. However, it is unclear whether frog populations will persist in the California South unit long enough to benefit from the potential increase in habitat. While climate change is likely to become the dominant stressor for Cascades frog range wide, the fungal pathogen *Bd* is of increased concern particularly in the southern end of the range. Non-native trout

will also continue to limit resiliency range wide but changes in management are likely reducing this stressor. Climate change will also continue to exacerbate the synergistic effects of the primary stressors as well as other influence factors.

LITERATURE CITED

- Abatzoglou, J.T. and T.J. Brown. 2012. A comparison of statistical downscaling methods suited for wildfire applications. *International Journal of Climatology* 32:772-780.
- Adams, M.J., N.D. Chelgren, D. Reinitz, R.A. Cole, L.J. Rachowicz, et al. 2010. Using occupancy models to understand the distribution of an amphibian pathogen, *Batrachochytrium dendrobatidis*. *Ecological Applications* 20:289-302.
- Aubry, K.B., R.B. Bury, and P.S. Corn. 1991. Regional patterns of terrestrial amphibian communities in Oregon and Washington. Pages 329-344 in L.F. Ruggiero, K.B. Aubry, and M.H. Huff, editors. *Wildlife and Vegetation of Unmanaged Douglas-Fir Forests*. U.S. Department of Agriculture, Forest Service, Portland, Oregon. 533 pp.
- Ault, K.K., J.E. Johnson, H.C. Pinkart, and R.S. Wagner. 2012. Genetic comparison of water molds from embryos of amphibians *Rana cascadae*, *Bufo boreas*, and *Pseudacris regilla*. *Diseases of Aquatic Organisms* 99:127-137.
- Bahls, P. 1992. The status of fish populations and management of high mountain lakes in the western United States. *Biological Conservation* 66:183-193.
- Barreca, A.B. 2010. Overwintering of cascades frogs (*Rana cascadae*) in Washington. Thesis, Central Washington University, Ellensburg, Washington. 29 pp.
- Berger, L., G. Marantelli, L. F. Skerratt, and R. Speare. 2005. Virulence of the amphibian chytrid fungus, *Batrachochytrium dendrobatidis* varies with the strain. *Diseases of Aquatic Organisms* 68:47-50.
- Billman, H.G., C.G. Kruse, S. St-Hilaire, T.M. Koel, J.L. Arnold, and C.R. Peterson. 2012. Effects of rotenone on Columbia spotted frogs *Rana luteiventris* during field applications in lentic habitats of southwestern Montana. *North American Journal of Fisheries Management* 32:781-789.
- Blaustein, A.R., P.D. Hoffman, D.G. Hokit, J.M. Kiesecker, S.C. Walls, and J.B. Hays. 1994. UV repair and resistance to solar UV-B in amphibian eggs: A link to population declines? *Proceedings of the National Academy of Sciences of the United States of America* 91:1791-1795.
- Blaustein, A.R. and D.B. Wake. 1990. Declining amphibian populations: a global phenomenon. *Trends in Ecology & Evolution* 5:203-204.
- Blaustein, A.R., J.M. Romansic, E.A. Scheessele, B.A. Han, A.P. Pessier, and J.E. Longcore. 2005. Interspecific variation in susceptibility of frog tadpoles to the pathogenic fungus *Batrachochytrium dendrobatidis*. *Conservation Biology* 19:1460-1468.
- Bosakowski, T. 1999. Amphibian macrohabitat associations on a private industrial forest in western Washington. *Northwestern Naturalist* 80:61-69.
- Bradford, D.F. 1989. Allotopic distribution of native frogs and introduced fishes in High Sierra Nevada lakes of California: Implication of the negative effect of fish introductions. *Copeia* 1989:775-778.
- Briggs Sr., J.L. 1987. Breeding biology of the Cascade frog, *Rana cascadae*, with comparisons to *R. aurora* and *R. pretiosa*. *Copeia* 1987:241-245.

- Briggs, C.J., R.A. Knapp, and V.T. Vredenburg. 2010. Enzootic and epizootic dynamics of the chytrid fungal pathogen of amphibians. *Proceedings of the National Academy of Sciences of the United States of America* 107:9695-9700.
- Briggs, J.L. and R.M. Storm. 1970. Growth and population structure of the Cascade frog, *Rana cascadae*. *Herpetologica* 26:283-300.
- Brown, C. 1997. Habitat structure and occupancy patterns of the montane frog, *Rana cascadae*, in the Cascade Range, Oregon, at multiple scales: Implication for population dynamics in patchy landscapes. Thesis, Oregon State University, Corvallis, Oregon. 173 pp.
- Bury, R.B. and C.A. Pearl. 1999. Klamath-Siskiyou herpetofauna: Biogeographic patterns and conservation strategies. *Natural Areas Journal* 19:341-350.
- Carver, S., B.D. Bell, and B. Waldman. 2010. Does chytridiomycosis disrupt amphibian skin function? *Copeia* 2010:487-495.
- Case, S.M. 1978. Biochemical systematics of members of the genus *Rana* native to western North America. *Systematic Zoology* 27:299-311.
- Center for Biological Diversity. 2012. Petition to list 53 amphibians and reptiles in the United States as threatened or endangered species under the Endangered Species Act. Report prepared for the U.S. Fish and Wildlife Service, Washington, D.C. Center for Biological Diversity, Portland, Oregon. 454 pp.
- Chandler, H.C., A.L. Rypel, Y. Jiao, C.A. Haas, and T.A. Gorman. 2016. Hindcasting historical breeding conditions for an endangered salamander in ephemeral wetlands of the southeastern USA: Implications of climate change. *PLoS One* 11:1-17.
- Cohen, J.M., E.L. Sauer, O. Santiago, S. Spencer, and J.R. Rohr. 2020. Divergent impacts of warming weather on wildlife disease risk across climates. *Science* 370:11.
- Dale, V.H., F.J. Swanson, and C.M. Crisafulli. 2005. Ecological responses to the 1980 eruption of Mount St. Helens. Springer, New York, NY. 342 pp.
- De León, M.E., V.T. Vredenburg, and J. Piovra-Scott. 2017. Recent emergence of a chytrid fungal pathogen in California Cascades frogs (*Rana cascadae*). *EcoHealth* 14:155-161.
- Downen, M.R. 2004. North Cascades National Park high lakes fishery management historic, current, and proposed future management of sport fish in high-elevation Park Lakes. Report prepared for the Washington Department of Fish and Wildlife, Olympia, Washington. Washington Department of Fish and Wildlife, La Conner, Washington. 75 pp.
- Duarte, A., C.A. Pearl, B. McCreary, J.C. Rowe, and M.J. Adams. 2021. An updated assessment of status and trend in the distribution of the cascades frog (*Rana cascadae*) in Oregon, USA. *Herpetological Conservation and Biology* 16:361-373.
- Duarte, A., J.T. Peterson, C.A. Pearl, J.C. Rowe, B. McCreary, S.K. Galvan, and M.J. Adams. 2020. Estimation of metademographic rates and landscape connectivity for a conservation-reliant anuran. *Landscape Ecology* 35:1459-1479.
- Dumas, P.C. 1966. Studies of the *Rana* species complex in the Pacific Northwest. *Copeia* 1966:60-74.

- Dunlap, D.G. 1955. Inter- and intraspecific variation in Oregon frogs of the genus *Rana*. American Midland Naturalist 54:314-331.
- Farrer, R.A., L.A. Weinert, J. Bielby, T.W.J. Garner, F. Balloux, et al. 2011. Multiple emergences of genetically diverse amphibian-infecting chytrids include a globalized hypervirulent recombinant lineage. Proceedings of the National Academy of Sciences of the United States of America 108:18732-18736.
- Fellers, G.M. and C.A. Drost. 1993. Disappearance of the cascades frog *Rana cascadae* at the southern end of its range, California, USA. Biological Conservation 65:177-181.
- Fellers, G.M., K.L. Pope, J.E. Stead, M.S. Koo, and H.H. Welsh Jr. 2007. Turning population trend monitoring into active conservation: can we save the Cascades frog (*Rana cascadae*) in the Lassen region of California? Herpetological Conservation and Biology 3:28-39.
- Galvan, S.K., M.J. Adams, P.J. Happe, and S.M. Claeson. 2003. Olympic National Park amphibian and reptile inventory, with emphasis upon terrestrial herpetofauna (1999-2001). Report prepared for the Olympic National Park, Olympia, Washington. U.S. Geological Survey, Olympia, Washington. 95 pp.
- Garcia, T.S., J.M. Romansic, and A.R. Blaustein. 2006. Survival of three species of anuran metamorphs exposed to UV-B radiation and the pathogenic fungus *Batrachochytrium dendrobatidis*. Diseases of Aquatic Organisms 72:163-163.
- Garwood, J. 2009. Spatial ecology of the Cascades frog: identifying dispersal, migration, and resource uses at multiple spatial scales. Thesis, Humboldt State University, Arcata, California. 110 pp.
- Garwood, J.M. and H.H. Welsh Jr. 2007. Ecology of the Cascades frog (*Rana cascadae*) and interactions with garter snakes and nonnative trout in the Trinity Alps Wilderness, California. Report prepared for the California Fish and Game, Sacramento, California. Pacific Southwest Research Station, Forest Service, Arcata, California. 87 pp.
- Garwood, J.M., C.A. Wheeler, R.M. Bourque, M.D. Larson, and H.H. Welsh Jr. 2007. Egg mass drift increases vulnerability during early development of Cascades frogs (*Rana cascadae*). Northwestern Naturalist 88:95-97.
- Gaulke, C.A., J.T. Irwin, and S.R. Wagner. 2011. Prevalence and distribution of *Batrachochytrium dendrobatidis* at Montane sites in Central Washington State, USA. Herpetological Review 42:209-211.
- Gosner, K.L. 1960. A simplified table for staging anuran embryos and larvae with notes on identification. Herpetologica 16:183-190.
- Green, D.M. 1986. Systematics and evolution of western North American frogs allied to *Rana aurora* and *Rana boylei*: Karyological evidence. Systematic Biology 35:273-282.
- Grinnell, J., J. Dixon, and J.M. Linsdale. 1930. *Triturus torosus* (Eschscholtz). Pages 136-144 in Grinnell, Dixon, and Linsdale, editors. Vertebrate natural history of a section of northern California through the Lassen Peak Region. University of California Press, Simi Valley, California. 394 pp.
- Haertel, J.D., A. Owczarzak, and R.M. Storm. 1974. A comparative study of the chromosomes from five species of the genus *Rana* (Amphibia: Salientia). Copeia 1974:109-114.

- Hamlet, A.F., P.W. Mote, M.P. Clark, and D.P. Lettermaier. 2005. Effects of temperature and precipitation variability on snowpack trends in the western United States. *Journal of Climate* 18:4545-4561.
- Hardy, B.M., K.L. Pope, and E.K. Latch. 2021. Genomic signatures of demographic declines in an imperiled amphibian inform conservation action. *Animal Conservation* 24:1-13.
- Hardy, B.M., K.L. Pope, J. Piovio-Scott, R.N. Brown, and J.E. Foley. 2015. Itraconazole treatment reduces *Batrachochytrium dendrobatidis* prevalence and increases overwinter field survival in juvenile Cascades frogs. *Diseases of Aquatic Organisms* 112:243-250.
- Hillis, D.M. and T.P. Wilcox. 2005. Phylogeny of the New World true frogs (*Rana*). *Molecular Phylogenetics and Evolution* 34:299-314.
- Hokit, D.G. and A.R. Blaustein. 1997. The effects of kinship on interactions between tadpoles of *Rana cascadae*. *Ecology* 78:1722-1735.
- ICF Jones & Stokes. 2010. Final hatchery and stocking program environmental impact report/environmental impact statement. Accessed October 10, 2021.
- iNaturalist. 2021. iNaturalist research-grade observations. iNaturalist.org. Occurrence dataset. Accessed via GBIF.org on October 03, 2021.
- Intergovernmental Panel on Climate Change (IPCC). 2018. Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Report prepared for the Policy Makers. SAGE Publications, London, England. 1-24 pp.
- Johnson, M.L. and R. Speare. 2003. Survival of *Batrachochytrium dendrobatidis* in water: Quarantine and disease control implications. *Emerging Infectious Diseases* 9:922-925.
- Johnson, M.L. and R. Speare. 2005. Possible modes of dissemination of the amphibian chytrid *Batrachochytrium dendrobatidis* in the environment. *Diseases of Aquatic Organisms* 65:181-186.
- Johnson, M.L., L. Berger, L. Philips, and R. Speare. 2003. Fungicidal effects of chemical disinfectants, UV light, desiccation, and heat on the amphibian chytrid *Batrachochytrium dendrobatidis*. *Diseases of Aquatic Organisms* 57:255-260.
- Jones, L.L.C., W.P. Leonard, and D.H. Olson. 2005. Amphibians of the Pacific Northwest. Seattle Audubon Society, Seattle, Washington. 1-6 pp.
- Joseph, M.B., J. Piovio-Scott, S.P. Lawler, and K.L. Pope. 2011. Indirect effects of introduced trout on Cascades frogs (*Rana cascadae*) via shared aquatic prey. *Freshwater Biology* 56:828-838.
- Kiesecker, J.M. and A.R. Blaustein. 1995. Synergism Between UV-B radiation and a pathogen magnifies amphibian embryo mortality in nature. *Proceedings of the National Academy of Sciences of the United States of America* 92:11049-11052.
- Kiesecker, J.M., A.R. Blaustein, and C.L. Miller. 2001. Transfer of a pathogen from fish to amphibians. *Conservation Biology* 15:1064-1070.

- Kissel, A.M., W.J. Palen, M.E. Ryan, and M.J. Adams. 2019. Compounding effects of climate change reduce population viability of a montane amphibian. *Ecological Applications* 29:1-12.
- Kissel, A.M. 2017. From forecasting vulnerabilities to assessing recovery: The utility of demographic models in addressing population declines. Thesis, Colorado State University, Ft. Collins, Colorado. 162 pp.
- Knapp, R.A. and K.R. Matthews. 2000. Effects of nonnative fishes on wilderness lake ecosystems in the Sierra Nevada and recommendations for reducing impacts. *Journal of Forestry* 6:312-317.
- Knapp, R.A., D.M. Boiano, and V.T. Vredenburg. 2007. Removal of nonnative fish results in population expansion of a declining amphibian (mountain yellow-legged frog, *Rana muscosa*). *Biological Conservation* 135:1-18.
- Knapp, R.A., G.M. Fellers, P.M. Kleeman, D.A.W. Miller, V.T. Vredenburg, E.B. Rosenblum, and C.J. Briggs. 2016. Large-scale recovery of an endangered amphibian despite ongoing exposure to multiple stressors. *Proceedings of the National Academy of Sciences of the United States of America* 113:11889-11894.
- Larson, G.L., R.L. Hoffman, R. Lofgren, B. Samora, and S. Anderson. 2017. Increased amphibian presence in a montane lake after fish removal, Mount Rainier National Park, Washington. *Northwestern Naturalist* 98:228-236.
- Larson, M.D. 2012. Diet of the Cascades frog (*Rana cascadae*) as it relates to prey availability in the Klamath Mountains of northwest California. Thesis, Humboldt State University, Arcata, California. 81 pp.
- Lee, S., M.E. Ryan, A.F. Hamlet, W.J. Palen, J.J. Lawler, and M. Halabisky. 2015. Projecting the hydrologic impacts of climate change on montane wetlands. *PLoS One* 10:1-24.
- Lertzman-Lepofsky, G.F., A.M. Kissel, B. Sinervo, and W.J. Palen. 2020. Water loss and temperature interact to compound amphibian vulnerability to climate change. *Global Change Biology* 26:4868-4879.
- Lips, K.R. 2016. Overview of chytrid emergence and impacts on amphibians. *Philosophical Transactions of the Royal Society B. Biological Sciences* 371:9.
- Liss, W.J., G.L. Larson, and R.L. Hoffman. 2002. Ecological impact of introduced trout on native aquatic communities in mountain lakes phase III final report. Report prepared for the National Park Service North Cascades National Park Service Complex, Sedro-Woolley, Washington. U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, Oregon. 1-115 pp.
- Mangel, M. and C. Tier. 1993. A simple direct method for finding persistence times of populations and application to conservation problems. *Proceedings of the National Academy of Sciences of the United States of America* 90:1083-1086.
- Marantelli, G., L. Berger, R. Speare, and L. Keegan. 2004. Distribution of the amphibian chytrid *Batrachochytrium dendrobatidis* and keratin during tadpole development. *Pacific Conservation Biology* 10:173.

- McCaffery, R.M. and B.A. Maxell. 2010. Decreased winter severity increases viability of a montane frog population. *Proceedings of the National Academy of Sciences of the United States of America* 107:8644-8649.
- McCaffery, R. and K. Jenkins. 2018. Natural resource condition assessment: Olympic National Park. Report prepared for the National Park Service, Fort Collins, Colorado. U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Port Angeles, Washington. 510 pp.
- Monsen, K.J. and M.S. Blouin. 2003. Genetic structure in a montane ranid frog: Restricted gene flow and nuclear-mitochondrial discordance. *Molecular Ecology* 12:3275-3286.
- Monsen, K. and M. Blouin. 2004. Extreme isolation by distance in a montane frog *Rana cascadae*. *Conservation Genetics* 5:827-835.
- Mote, P.W., A.F. Hamlet, M.P. Clark, and D.P. Lettenmaier. 2005. Declining mountain snowpack in western North America. *Bulletin of the American Meteorological Society* 86:39-49.
- Mote, P.W., J.T. Abatzoglou, D.P. Lettenmaier, D.P. Turner, D.E. Rupp, D. Bachelet, and D.R. Conklin. 2014. Integrated scenarios of climate, hydrology, and vegetation for the northwest, final report. Corvallis, Oregon: Pacific Northwest Climate Impacts Research Consortium, Oregon State University.
- Mote, P.W., S. Li, D.P. Lettenmaier, M. Xiao, and R. Engel. 2018. Dramatic declines in snowpack in the western US. *NPJ Climate and Atmospheric Science* 1:1-6.
- Mount Rainier National Park (MRNP). 2017. Fish management plan environmental assessment. Report prepared for the environmental assessment. Mount Rainier National Park Service U.S. Department of the Interior, Ashford, Washington. 1-91 pp.
- National Park Service (NPS). 2010. Climate change response strategy. Report prepared for the National Park Service. National Park Service Climate Change Response Program, Fort Collins, Colorado. 1-36 pp.
- Nicotra, A.B., E.A. Beever, A.L. Robertson, G.E. Hofmann, and J. O'Leary. 2015. Assessing the components of adaptive capacity to improve conservation and management efforts under global change. *Conservation Biology* 29:1268-1278.
- North Cascades National Park Service Complex (NCNPSC). 2008. Environmental impact statement final mountain lakes fishery management plan: Volume one. Report prepared for the National Park Service North Cascades National Park Service Complex and Washington Department of Fish and Wildlife. National Park Service, 501 pp.
- Nussbaum, R.A., J.E.D. Brodie, and R.M. Storm. 1983. *Amphibians and reptiles of the Pacific Northwest*. University of Idaho Press, Moscow, Idaho. 164-170 pp.
- O'Donnell, R.P. and J.G. MacCracken. 2006. Geographic distribution. *Rana cascadae* (Cascades frog). *Herpetological Review* 37:102.
- O'Hara, R.K. 1981. Habitat selection behavior in three species of anuran larvae: Environmental cues, ontogeny, and adaptive significance. Thesis, Oregon State University, Corvallis, Oregon. 157 pp.
- O'Hara, R.K. and A.R. Blaustein. 1985. *Rana cascadae* tadpoles aggregate with siblings: An experimental field study. *Oecologia* 67:44-51.

- Olson, D.H. 1988. The ecological and behavioral dynamics of breeding in three sympatric anuran amphibians. PhD, Oregon State University, Corvallis, OR. 1-271 pp.
- O'Regan, S.M., W.J. Palen, and S.C. Anderson. 2014. Climate warming mediates negative impacts of rapid pond drying for three amphibian species. *Ecology* 95:845-855.
- Ovaska, K., L. Sopuck, and C. Engelstoft. 2019. Clarifying distributions of four species of *Rana* in southwestern British Columbia using eDNA methods forest enhancement final report, 2016 – 2018. Report prepared for the Habitat Conservation Trust Fund, Victoria, British Columbia. Biolinx Environmental Research Ltd., Victoria, British Columbia. 55 pp.
- Pearl, C.A. and M.J. Adams. 2005. *Rana cascadae* Cascades frog. Pages 538-540 in M. Lannoo, editor. *Amphibian Declines: The Conservation Status of the United States Species*. University of California Press, Berkeley, California.
- Pearl, C.A., M.J. Adams, R.B. Bury, W.H. Wente, and B. McCreary. 2009. Evaluating amphibian declines with site revisits and occupancy models: Status of montane anurans in the Pacific Northwest USA. *Diversity* 1:166-181.
- Peek, R.A., M. Bedwell, S.M. O'Rourke, C. Goldberg, G.M. Wengert, and M.R. Miller. 2019. Hybridization between two parapatric ranid frog species in the northern Sierra Nevada, California, USA. *Molecular Ecology* 28:1-12.
- Phillipsen, I.C., W.C. Funk, E.A. Hoffman, K.J. Monsen, and M.S. Blouin. 2011. Comparative analyses of effective population size within and among species: *Ranid* frogs as a case study. *Evolution* 65:2927-2945.
- Pilliod, D.S. and C.R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. *Ecosystems* 4:322-333.
- Piotrowski, J.S., S.L. Annis, and J.E. Longcore. 2004. Physiology of *Batrachochytrium dendrobatidis*, a chytrid pathogen of amphibians. *Mycologia* 96:9.
- Piovia-Scott, J., K.L. Pope, S.P. Lawler, E.M. Cole, and J.E. Foley. 2011. Factors related to the distribution and prevalence of the fungal pathogen *Batrachochytrium dendrobatidis* in *Rana cascadae* and other amphibians in the Klamath Mountains. *Biological Conservation* 144:2913-2921.
- Piovia-Scott, J., K. Pope, S.J. Worth, E.B. Rosenblum, T. Poorten, et al. 2015. Correlates of virulence in a frog-killing fungal pathogen: evidence from a California amphibian decline. *International Society for Microbial Ecology* 2014:1-9.
- Pister, E.P. 2001. Wilderness fish stocking: History and perspective. *Ecosystems* 4:279-286.
- Pope, K.L. 2008. Assessing changes in amphibian population dynamics following experimental manipulations of introduced fish. *Conservation Biology* 22:1572-1581.
- Pope, K.L., J.M. Garwood, H.H. Welsh Jr, and S.P. Lawler. 2008. Evidence of indirect impacts of introduced trout on native amphibians via facilitation of a shared predator. *Biological Conservation* 141:1321-1331.
- Pope, K.L., J. Piovia-Scott, and S.P. Lawler. 2009. Changes in aquatic insect emergence in response to whole-lake experimental manipulations of introduced trout. *Freshwater Biology* 54:982-993.

- Pope, K.L., M.D. Larson, and J. Piovio-Scott. 2011. Status of remnant populations of Cascades frogs (*Rana cascadae*) in the Lassen Area of California. Report prepared for the U.S. Forest Service, Vallejo, California. USDA Forest Service, Pacific Southwest Research Station, Arcata, California. 39 pp.
- Pope, K., C. Brown, M. Hayes, G. Green, and D. Macfarlane. 2014. Cascades frog conservation assessment. Report prepared for the U.S. Department of Agriculture, Forest Service, PSW-GTR-244, Albany, California. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California. 126 pp.
- Rachowicz, L.J. and V.T. Vredenburg. 2004. Transmission of *Batrachochytrium dendrobatidis* within and between amphibian life stages. *Diseases of Aquatic Organisms* 61:75-83.
- Reading, C.J. 2007. Linking global warming to amphibian declines through its effects on female body condition and survivorship. *Oecologia* 151:125-131.
- Redford, K.H., G. Amato, J. Baillie, P. Beldomenico, E.L. Bennett, et al. 2011. What does it mean to successfully conserve a (vertebrate) species? *Bioscience* 61:39-48.
- Reeder, N.M.M., A.P. Pessier, and V.T. Vredenburg. 2012. A Reservoir Species for the Emerging Amphibian Pathogen *Batrachochytrium dendrobatidis* Thrives in a Landscape Decimated by Disease. *PloS One* 7:e33567.
- Richards-Zawacki, C.L. 2010. Thermoregulatory behaviour affects prevalence of chytrid fungal infection in a wild population of Panamanian golden frogs. *Proceedings of the Royal Society B, Biological Sciences* 277:519-528.
- Rödger, D., J. Kielgast, and S. Lötters. 2010. Future potential distribution of the emerging amphibian chytrid fungus under anthropogenic climate change. *Diseases of Aquatic Organisms* 92:201-207.
- Rollins-Smith, L.A., J.P. Ramsey, J.D. Pask, L.K. Reinert, and D.C. Woodhams. 2011. Amphibian immune defenses against chytridiomycosis: Impacts of changing environments. *Integrative and Comparative Biology* 51:552-562.
- Rombough, C.J., D.J. Jordan, and C.A. Pearl. 2003. *Rana cascadae* (Cascade frog) Cannibalism. *Herpetological Review* 34:138.
- Russell, R.E., B.J. Halstead, B.A. Mosher, E. Muths, M.J. Adams, E.H.C. Grant, R.N. Fisher, P.M. Kleeman, A.R. Backlin, C.A. Pearl, R.K. Honeycutt, and B.R. Hossack. 2019. Effect of amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) on apparent survival of frogs and toads in the western USA. *Biological Conservation* 236:296-304.
- Ryan, M.E., W.J. Palen, M.J. Adams, and R.M. Rochefort. 2014. Amphibians in the climate vise: loss and restoration of resilience of montane wetland ecosystems in the western US. *Frontiers in Ecology and the Environment* 12:232-240.
- Samora, B., M. Layers, and R. Lofgren. 2013. Mount Rainier National Park Amphibian Inventory 2001-2003. Report prepared for the U.S. Department of the Interior National Park Service, Fort Collins, Colorado. U.S. Department of the Interior National Park Service, Fort Collins, Colorado. 120 pp.
- Sauer, E.L., J.M. Cohen, M.J. Lajeunesse, T.A. McMahon, D.J. Civitello, et al. 2020. A meta-analysis reveals temperature, dose, life stage, and taxonomy influence host susceptibility to a fungal parasite. *Ecology* 101:9.

- Sears, M.W., M.J.J. Angilletta, M.S. Schuler, J. Borchert, K.F. Dilliplane, et al. 2016. Configuration of the thermal landscape determines thermoregulatory performance of ectotherms. *Proceedings of the National Academy of Sciences of the United States of America* 113:10595-10600.
- Siirila-Woodburn, E.R., A.M. Rhoades, B.J. Hatchett, L.S. Huning, J. Szinai, et al. 2021. A low-to-no snow future and its impacts on water resources in the western United States. *Nature* 2:800-819.
- Slater, J.R. 1939. Description and life-history of a new *Rana* from Washington. *Herpetologica* 1:145-149.
- Smith, A.M. and D.M. Green. 2005. Dispersal and the metapopulation paradigm in amphibian ecology and conservation: are all amphibian populations metapopulations? *Ecography* 28:110-128.
- Smith, D.R., N.L. Allan, C.P. McGowan, J.A. Szymanski, S.R. Oetker, and H.M. Bell. 2018. Development of a species status assessment process for decisions under the U.S. Endangered Species Act. *Journal of Fish and Wildlife Management* 9:302-320.
- Sype, W.E. 1974. Breeding habits, embryonic thermal requirements and embryonic and larval development of the Cascade frog, *Rana cascadae*. Dissertation, University of Oregon, Corvallis, Oregon. 123 pp.
- Terando, A., D. Reidmiller, S.W. Hostetler, J.S. Littell, T.D. Beard, et al. 2020. Using information from global climate models to inform policymaking—The role of the U.S. Geological Survey. Report prepared for the U.S. Geological Survey. US Geological Survey, Reston, Virginia. 25 pp.
- Uehara, J. 2005. Management of Washington's High Lakes. Report prepared for the Washington Department of Fish and Wildlife, Olympia, Washington. Washington Department of Fish and Wildlife Fish Program, Olympia, Washington. 44 pp.
- U.S. Department of Agriculture (USDA). 2011a. Adapting to Climate Change at Olympic National Forest and Olympic National Park. USDA, Forest Service, Pacific Northwest Research Station, Portland. 130 pp.
- United States Department of Agriculture (USDA). 2011b. National Roadmap for Responding to Climate Change. Report prepared for the USDA, Forest Service. United States Department of Agriculture, Washington, D.C. 1-32 pp.
- United States Fish and Wildlife Service (USFWS). 2016. USFWS Species Status Assessment Framework: an integrated analytic framework for conservation. Version 3.4 dated August 2016. Report prepared for the U.S. Fish and Wildlife Service. U.S. Fish and Wildlife Service. 21 pp.
- U.S. Geological Survey (USGS). 2019. National Elevation Dataset. Accessed September 5, 2019 at URL <https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map>
- Voyles, J., S. Young, L. Berger, C. Campbell, W.F. Voyles, et al. 2009. Pathogenesis of chytridiomycosis, a cause of catastrophic amphibian declines. *Science* 326:582-585.
- Vredenburg, V.T. 2004. Reversing introduced species effects: Experimental removal of introduced fish leads to rapid recovery of a declining frog. *Proceedings of the National Academy of Sciences of the United States of America* 101:7646-7650.

- Vredenburg, V.T., R.A. Knapp, T.S. Tunstall, C.J. Briggs, and D.B. Wake. 2010. Dynamics of an emerging disease drive large-scale amphibian population extinctions. *Proceedings of the National Academy of Sciences of the United States of America* 107:9689-9694.
- Welsh, H.H., K.L. Pope, and D. Boiano. 2006. Sub-alpine amphibian distributions related to species palatability to non-native salmonids in the Klamath Mountains of northern California. *Diversity and Distributions* 12:298-309.
- Wolf, S., B. Hartl, C. Carroll, M.C. Neel, and D.N. Greenwald. 2015. Beyond PVA: Why recovery under the Endangered Species Act is more than population viability. *Bioscience* 65:200-207.
- Xie, G.Y., D.H. Olson, and A.R. Blaustein. 2016. Projecting the global distribution of the emerging amphibian fungal pathogen, *Batrachochytrium dendrobatidis*, Based on IPCC Climate Futures. *PLoS One* 11:1-21.

PERSONAL COMMUNICATIONS AND UNPUBLISHED DATA

- Brown, S., J. Tyson, M. Hayes, and M. Lambert. 2021. WDFW, unpublished data: preliminary results: Cascades frog (*Rana cascadae*) population genetic structure. Email
- Buller, P. 2020. NCNPSC, Seasonal biologist. Personal communication emailed to David Leal, USFWS, Portland, OR, Hugh Anthony, NCNPSC, dated December 9, 2020 (Subject: Cascades frog observations in NCNPSC).
- Garwood, J. 2021. CDFW, unpublished data: updated population data for *Rana cascadae* populations in the Klamath Mountains: Memorandum. Memo. November 3, 2021.
- Garwood, J. 2022. CDFW, Personal communication from phone conversation regarding comments on the draft SSA January 20, 2022. (Subject: Discussion of various draft SSA comments to make sure we were interpreting things correctly).
- Hayes, M. 2021. WDFW retired. Personal communication emailed to Erin Gray, USFWS, Lacey, WA, Notes from call, dated January 7, 2021 (Subject: Discussion of Marc's Cascades frog observations).
- Lofgren, R. 2021. MRNP, Aquatic Ecologist. Personal communication emailed to Notes from call, David Leal, USFWS, Portland, OR, dated October 14, 2021 (Subject: MORA fish control efforts to date).
- Palen, W. 2022. Professor, Dept. of Biological Sciences, Simon Fraser University, Burnaby, B.C., Canada. Personal communication emailed to Erin Gray, USFWS, Lacey, WA, dated Jan 18, 2022 (Subject: *Bd* in Olympics).
- Pope, K. L., and A. Cummings. 2021. USFS, unpublished data: updated population information for the California Cascades *Rana cascadae* sites. November 1, 2021.
- Spinelli, J. 2021. WDFW, Fishery biologist. Personal communication emailed to Notes from call, David Leal, USFWS, Portland, OR, dated August 24, 2021 (Subject: WDFW high lakes fish stocking program).

- Tyson, J. 2021. WDFW, Fish and Wildlife Biologist 3. Personal communication emailed to Erin Gray, USFWS, Lacey, WA, dated February 11, 2021 (Subject: Discussion of Julie's work on Cascades frog in Washington).
- Ziller, J. and Kelley, E. 2021. ODFW, District fisheries biologists. Personal communication emailed to Notes from call, David Leal USFWS, Portland, OR, dated June 9, 2021 (Subject: ODFW high lakes fish stocking program).

Appendix I. Current Condition scores by Analytic Units.

Table A1. Cascades frog current condition by analytic unit (AU) and representative unit for Washington.

AU	Connectivity	Site Occupancy	Aquatic Features	Precipitation	AU score	Confidence
9 WA Olympics	Null	Poor	Poor	Fair	Poor	Low
10 WA Olympics	Fair	Fair	Fair	Fair	Fair	Low
11 WA Olympics	Null	Poor	Poor	Good	Poor	Low
12 WA Olympics	Fair	Fair	Poor	Good	Fair	Moderate
15 WA Olympics	Good	Good	Fair	Good	Good	High
21 WA Olympics	Fair	Fair	Fair	Good	Fair	Low
1 WA Cascades	Fair	Fair	Fair	Good	Fair	Low
2 WA Cascades	Good	Fair	Fair	Fair	Fair	Low
3 WA Cascades	Fair	Fair	Poor	Fair	Fair	Low
4 WA Cascades	Null	Poor	Fair	Good	Fair	Low
5 WA Cascades	Null	Poor	Fair	Good	Fair	Low
6 WA Cascades	Null	Poor	Poor	Good	Poor	Moderate
7 WA Cascades	Good	Good	Fair	Good	Good	High
8 WA Cascades	Null	Poor	Poor	Fair	Poor	Low
13 WA Cascades	Fair	Good	Fair	Good	Fair	Low
14 WA Cascades	Null	Poor	Poor	Good	Poor	Low
16 WA Cascades	Null	Poor	Good	Good	Fair	Low
17 WA Cascades	Good	Fair	Poor	Fair	Fair	Low
18 WA Cascades	Fair	Fair	Fair	Good	Fair	Low
19 WA Cascades	Fair	Good	Fair	Good	Fair	Moderate
20 WA Cascades	Null	Poor	Poor	Fair	Poor	Moderate
22 WA Cascades	Fair	Good	Fair	Fair	Fair	Low
23 WA Cascades	Fair	Good	Poor	Good	Fair	High
24 WA Cascades	Null	Poor	Fair	Fair	Poor	Moderate
25 WA Cascades	Null	Poor	Poor	Good	Poor	Low
26 WA Cascades	Good	Good	Fair	Fair	Fair	High
27 WA Cascades	Null	Poor	Fair	Good	Fair	High
28 WA Cascades	Null	Poor	Good	Good	Fair	Low
29 WA Cascades	Null	Poor	Poor	Fair	Poor	Low
30 WA Cascades	Poor	Fair	Fair	Fair	Fair	Moderate
31 WA Cascades	Good	Good	Fair	Fair	Fair	High
32 WA Cascades	Null	Poor	Poor	Fair	Poor	Low

AU	Connectivity	Site Occupancy	Aquatic Features	Precipitation	AU score	Confidence
33 WA Cascades	Fair	Fair	Poor	Good	Fair	Low
34 WA Cascades	Fair	Fair	Good	Good	Good	Low
35 WA Cascades	Poor	Fair	Fair	Fair	Fair	Moderate

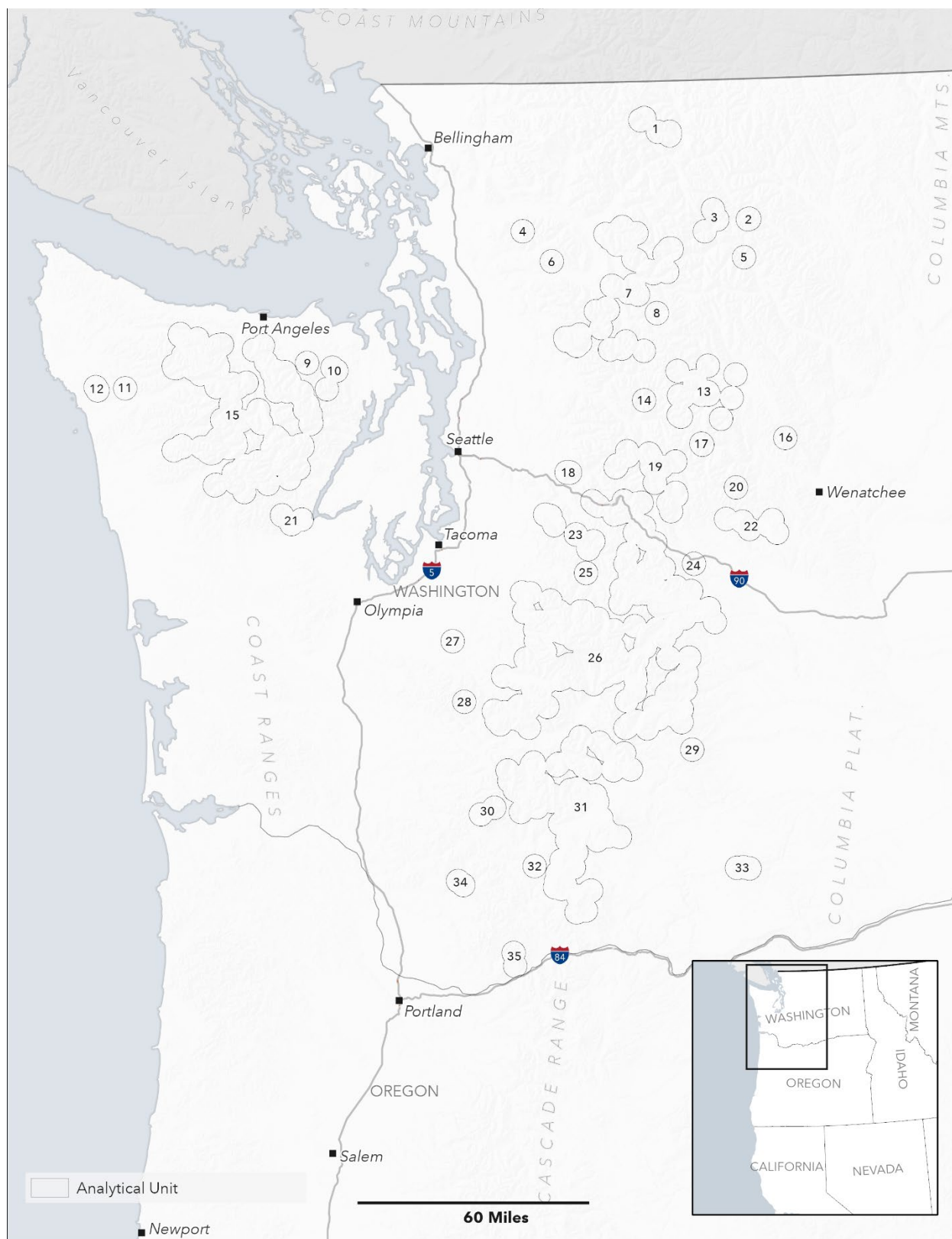


Figure A1. Analytical Unit (AU) numbers in Washington

Table A2. Cascades frog current condition by analytic unit (AU) and representative unit for Oregon.

AU	Connectivity	Site Occupancy	Aquatic Features	Precipitation	AU score	Confidence
36 OR Cascades	Null	Poor	Poor	Fair	Poor	Low
37 OR Cascades	Null	Poor	Good	Fair	Fair	Low
38 OR Cascades	Good	Good	Poor	Fair	Fair	High
39 OR Cascades	Good	Good	Fair	Fair	Fair	Moderate
40 OR Cascades	Null	Poor	Poor	Fair	Poor	Low
41 OR Cascades	Good	Good	Good	Fair	Good	Moderate
42 OR Cascades	Good	Fair	Poor	Fair	Fair	Low
43 OR Cascades	Fair	Good	Poor	Fair	Fair	Low
44 OR Cascades	Good	Good	Fair	Fair	Fair	High
45 OR Cascades	Null	Poor	Poor	Fair	Poor	Low
46 OR Cascades	Good	Fair	Good	Fair	Good	Low
47 OR Cascades	Null	Poor	Fair	Fair	Poor	Low
48 OR Cascades	Null	Poor	Fair	Fair	Poor	Low
49 OR Cascades	Null	Poor	Poor	Fair	Poor	Low
50 OR Cascades	Good	Good	Good	Fair	Good	High
51 OR Cascades	Fair	Fair	Fair	Fair	Fair	High
52 OR Cascades	Fair	Fair	Good	Fair	Fair	Moderate
53 OR Cascades	Good	Good	Poor	Fair	Fair	Low
54 OR Cascades	Good	Good	Poor	Fair	Fair	High
55 OR Cascades	Good	Fair	Poor	Good	Fair	Low
56 OR Cascades	Null	Poor	Fair	Fair	Poor	Low
57 OR Cascades	Fair	Fair	Fair	Fair	Fair	High
58 OR Cascades	Poor	Fair	Poor	Good	Fair	Moderate
59 OR Cascades	Null	Poor	Poor	Good	Poor	Low
60 OR Cascades	Good	Fair	Poor	Good	Fair	Low
61 OR Cascades	Good	Good	Fair	Fair	Fair	High

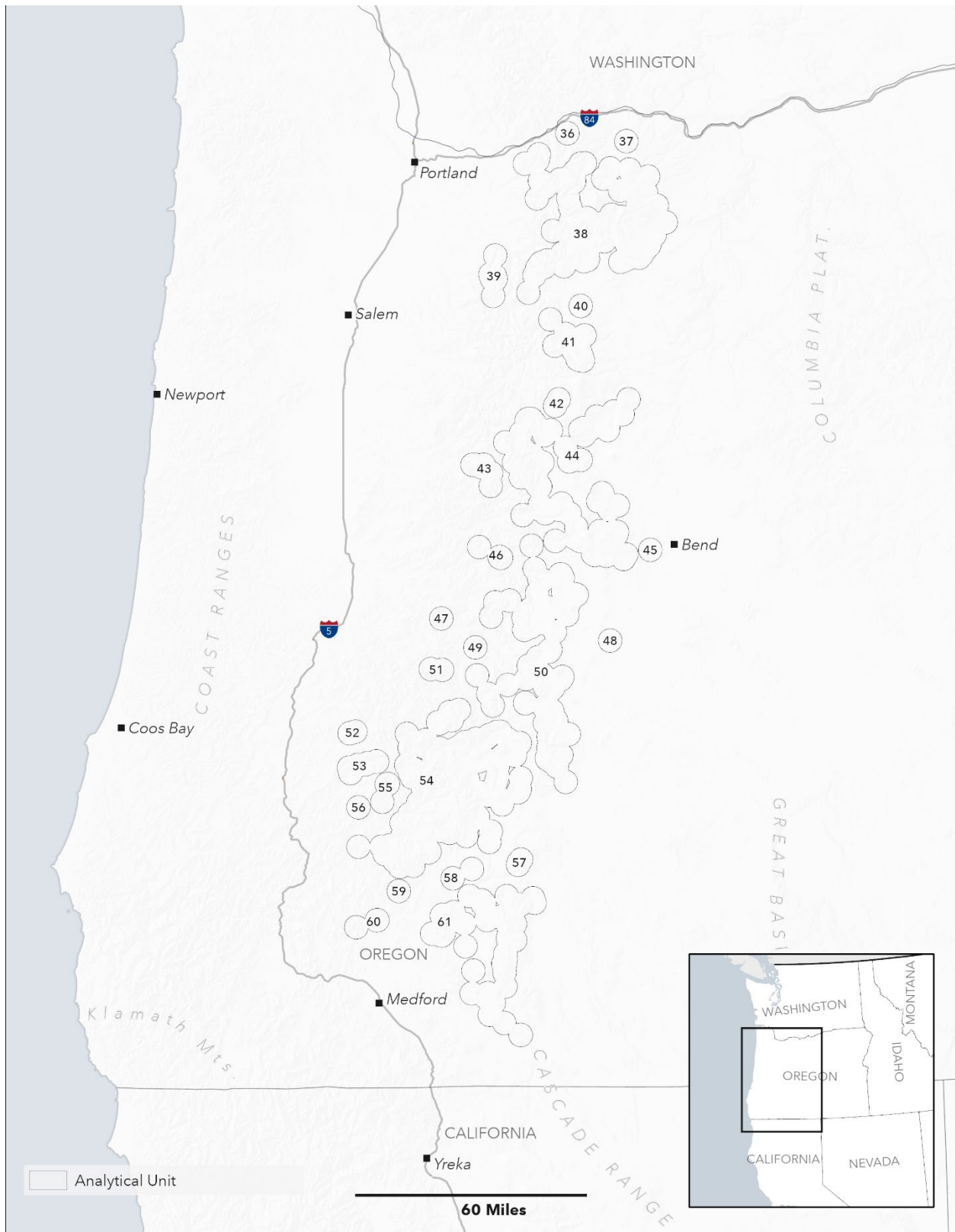


Figure A2. Analytic Unit (AU) numbers in Oregon

Table A3. Cascades frog current condition by analytic unit (AU) and representative unit for California.

AU	Connectivity	Site Occupancy	Aquatic Features	Precipitation	AU score	Confidence
62 CA North	Poor	Fair	Poor	Good	Fair	Low
63 CA North	Poor	Fair	Good	Fair	Fair	Low
64 CA North	Null	Poor	Poor	Fair	Poor	Moderate
65a CA North	Good	Good	Fair	Fair	Fair	High
65b CA North	Good	Good	Fair	Fair	Fair	High
66 CA North	Fair	Good	Fair	Fair	Fair	High
67 CA North	Fair	Good	Poor	Good	Fair	High
68 CA North	Null	Poor	Fair	Good	Fair	Low
69 CA North	Poor	Fair	Fair	Good	Fair	High
70 CA South	Null	Poor	Fair	Fair	Poor	High
71 CA South	Fair	Fair	Fair	Good	Fair	High
72 CA South	Fair	Good	Poor	Good	Fair	High
73 CA South	Null	Poor	Poor	Good	Poor	Moderate

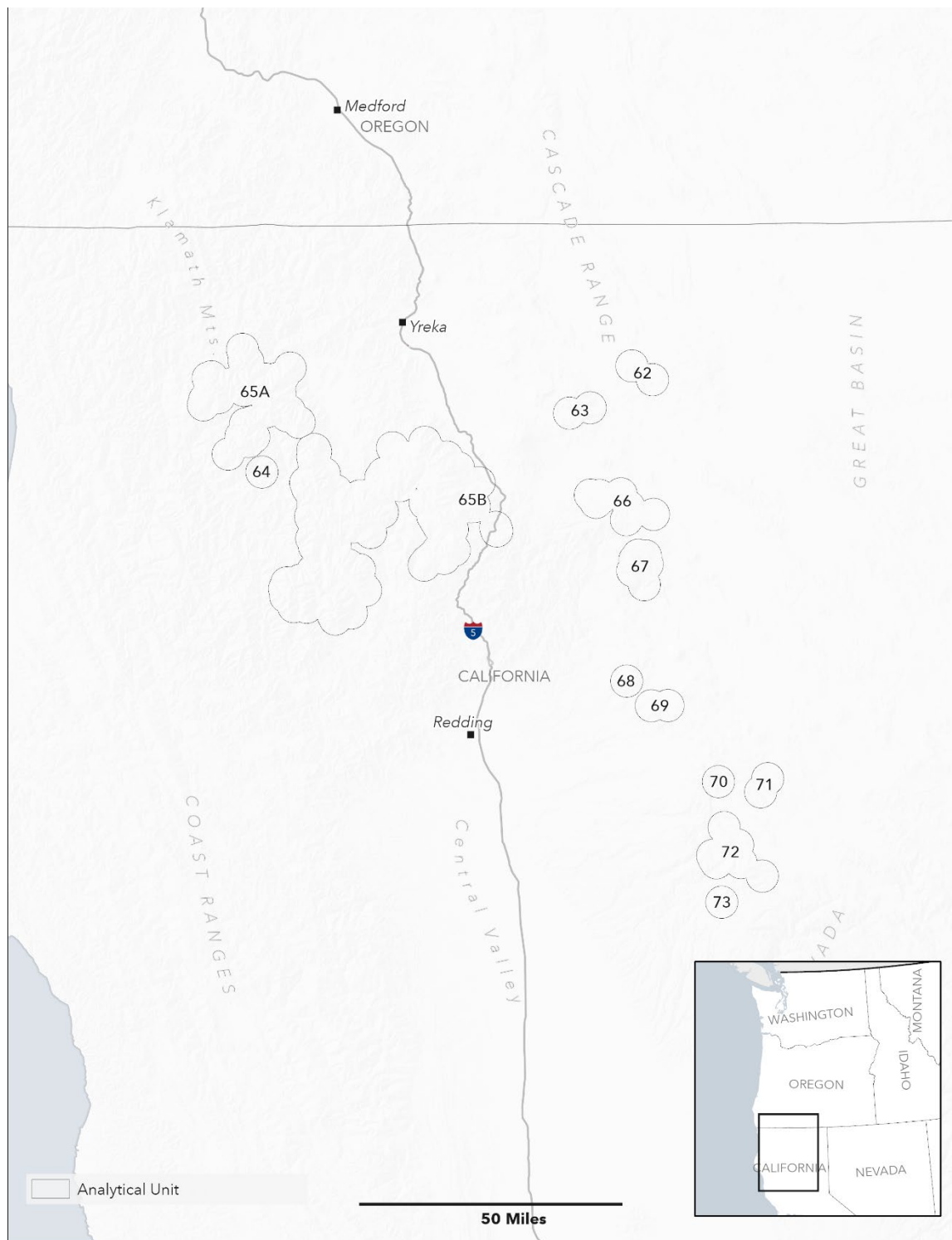


Figure A3. Analytic Unit numbers in California.

Appendix II. Cause and Effect Tables

Influence factors that were not carried forward as primary stressors.

Confidence Terminology	Explanation
Highly Confident	We are more than 90% sure that this relationship or assumption accurately reflects the reality in the wild as supported by documented accounts or research and/or strongly consistent with accepted conservation biology principles.
Moderately Confident	We are 70 to 90% sure that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Somewhat Confident	We are 50 to 70% sure that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Low Confidence	We are less than 50% sure that this relationship or assumption accurately reflects the reality in the wild, as there is little or no supporting available information and/or uncertainty consistency with accepted conservation biology principles. Indicates areas of high uncertainty.

THEME: Hybridization		
ESA Factor(s):	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Hybridization	
- Activity(ies)	Crossbreeding between related taxa	
STRESSOR(S)	Landscape changes can influence crossbreeding or hybridization between related species. Changes to genetic structure and speciation.	Low confidence
- Affected Resource(s) or individuals	All life stages	Low confidence
- Exposure of Stressor(s)	Hybridization can occur between Rana species when their ranges overlap. In Washington, Cascades frog and Oregon Spotted Frog typically occur within different elevational ranges, with the exception of Trout Lake where the occurrences are limited (Hallock 2013, p. 6). Cascades frogs occupy the higher reaches at this site while Oregon spotted frogs occupy the lower reaches. Hybridization between Oregon spotted frogs and Cascades frogs was confirmed from Gold Lake in the Oregon Cascades near Willamette Pass (Green 1985, p. 263; Hallock 2013, p. 7). The hybrids (two males) were considered to be infertile (Green 1985, pp. 263-265) due to lack of chromosome pairing in meiosis in the hybrids. No evidence of backcrossing was observed. In a reciprocal experiment crosses of Cascades frog and Oregon spotted frogs found that tadpoles did not progress beyond the heartbeat state (Dumas 1966, from Green 1985, p. 262). WDFW	Moderately confident

	biologists confirmed hybrids between Cascades frog and northern red-legged frogs near Mt. Rainier (WA) and Timothy Lakes (OR)An ongoing genetic study has confirmed that they do hybridize and can reach adulthood, and will investigate whether they can potentially reproduce (Tyson, WDFW, pers. comm. 2021)	
- Immediacy of Stressor(s)	Hybridization has been noted between Cascades frogs, Oregon spotted frogs, and red legged frogs.	Moderately confident
Changes in Resource(s)	Potential for hybridization could increase as suitable habitat is altered by climate change and if ranges of Rana sp. overlap.	Moderately confident
Response to Stressors: - INDIVIDUALS	Hybridization between species can result in gene flow between species, adaptation, or speciation (Peek et al. 2019, p. 1). Results from a study looking into hybridization between <i>R. boylei</i> and <i>R. sierrae</i> suggest that in areas where range overlaps, limited hybridization and introgression between the species occurred (Peek et al. 2019, p. 8). Given the low level of gene flow between conspecific populations in other Rana species, linked to limited dispersal and gene flow across habitats, hybridization was determined to be limited. The long-term impacts of hybridization to Cascades frog are not well understood.	Low confidence
POPULATION & SPECIES RESPONSES		
Effects of Stressors: -POPULATIONS [RESILIENCY]	In rare species, hybridization that produces sterile offspring could have a cost to the species with low numbers of effective breeders (Peek et al. 2019, p. 9).	Low confidence
- GEOGRAPHIC SCOPE	Hybridization could occur between Rana sp. across the range, in areas where congeners overlap. In Washington, hybridization has been noted between Oregon spotted frog and Cascades frog at Trout Lake and in Oregon at Gold Lake near Willamette Pass. Potential hybrids between Cascades frog and northern red legged frogs have also been noted in Washington near Mt. Rainier and Timothy Lakes.	Moderately confident
- MAGNITUDE	Climate change could impact the future ranges of Rana sp., with some species shifting in elevation, increasing the potential for range overlap and hybridization (Peek et al. 2019, p. 9; Tyson, WDFW, pers. comm. 2021).	Low confidence
SUMMARY	Hybridization has been described between Cascades frog and other species of Rana, when ranges overlap. Current evidence suggests that F1 offspring are infertile. A new study from WDFW is underway to explore hybridization between Cascades frog and northern red legged frog in Washington and Oregon, results anticipated in 2022. Hybridization appears to be relatively uncommon, most likely due to the lack of overlap between range of Cascades frog and other closely related Rana sp. Given potential changes in habitat with climate change, ranges of these species could shift and more overlap could occur, which could increase hybridization between the species. This could result in a cost to the species due to the infertility of the offspring produced and a loss of breeders in the population, and could lead to more gene flow if hybrids are able to reproduce which	Low confidence

	could negatively impact both parental species. These potential impacts are not well understood currently, thus this threat does not rise to the level of a primary stressor.	
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THEME: Ultraviolet Radiation		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	UV-B Radiation	
- Activity(ies)	The human induced loss of the stratospheric ozone layer in the polar regions and extending into the northern hemisphere which has resulted in a subsequent increase in ultraviolet-B radiation (UV-B) intensity (Stolarski et al. 1992, pp. 346-347; Neale et al. 2021, entire).	Highly Confident
STRESSOR(S)	An increase in UV-B radiation (280 to 320 nm wavelength) (Blumthaler and Ambach 1990, p. 248) has been hypothesized as a possible factor in global amphibian population declines (Blaustein et al. 1994, pp 1791). It has also been described as potentially having synergistic affects with other stressors. Kiesecker and Blaustein (1995, p. 11051) found that UV-B in combination with the fungus pathogen <i>Saprolegnia ferax</i> had a greater impact on embryos than UV-B alone. Kiesecker et al. (2001, p. 682) also found reduced survival in <i>Bufo boreas</i> embryo in combination with <i>Saprolegnia ferax</i> in lower water years.	Moderately Confident
- Affected Resource(s) or individuals	May reduce survival and delay development of embryos (Blaustein et al 1994, p.1794; Kiesecker and Blaustein 1995, p. 11050) and result in increased deformities in larvae (Romansic et al. 2009, pp. 226, 228) in laboratory and field experiments.	Highly Confident
- Exposure of Stressor(s)	Embryos/eggs, larvae, juveniles and adults may all be exposed to UV-B radiation, though Cascades frog embryos, in particular, are exposed due to generally being deposited in, and unable to avoid, direct sunlight (Blaustein et al. 1994, p. 1791). However, in nature UV-B exposure is mitigated by several factors including water depth, dissolved organic matter (DOM) (Palen et al. 2002, p. 2954), phenology of breeding (Corn and Muths 2002, p. 2961), and the ability for larvae, juveniles and adults to move to regulate sun/heat exposure (see Blaustein and Belden 2003, entire; Licht 2003, pp. 552-555, for overviews of defensive measures).	Low Confidence
- Immediacy of Stressor(s)	Historic, current, and future. Stratospheric ozone depletion potentially increasing outside of polar regions in the northern hemisphere (Stolarski et al. 1992, pp. 346-347), though change has been small, generally less than 4% per decade, and potentially decreasing following the Montreal Protocol's regulation of ozone	Moderately confident

	depleting substances (Neale et al. 2021, pp. 1, 7). Though annual variation in UV-B radiation still occur and was higher than normal in the Arctic in 2020 (Neale et al. 2021, pp. 1, 7) “for most locations outside the polar regions, long-term changes in UV-B radiation are mainly governed by variations in clouds, aerosols, and surface reflectivity.”	
Changes in Resource(s)	Increase in UV-B intensity likely due to stratospheric ozone depletion from historic levels (Blumthaler and Ambach 1990, p. 248; Stolarski et al. 1992, pp. 346-347). However, the amount of UV-B that amphibians are exposed to is debated. Palen et al. (2002, pp.2953-2954) found that 70-90% of breeding sites sampled across the Pacific Northwest are well protected from UV-B exposure due to attenuation by DOM at 10cm depth.	Moderately Confident
Response to Stressors: - INDIVIDUALS	In Cascades frog, Blaustein et al. (1994, p. 1794) found reduced survival of embryos and increased photolyase (a key enzymatic activity of repair to UV-damage DNA) while Romansic et al. (2009, p. 226) did not find reduced survival of larvae but did have increased deformities. Fite et al. (1998, pp. 908-910) reported abnormalities to the inferior retina in Cascades frog similar to those of light damaged <i>Rana pipiens</i> and attributed it to potential ultraviolet radiation damage. However, there appear to be conflicting results on reduced survival of embryos when you look at various studies across multiple amphibian species. Licht (2003, pp. 557-558) summarized 50 total studies on UV-B effects to embryos in various amphibian species and found nine of those showed a significant effect to embryos and 42 studies found no significant effect (one study found both).	Low Confidence
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	Few studies have been conducted to connect individual UV-B affects to population level trends. Adams et al. (Adams et al. 2005, pp. 493-496) looked at the distributions of eight western amphibian species, including the Cascades frog, in relation to UV-B exposure at three Olympic, Sequoia-Kings Canyon and Glacier National Parks. Of the eight species, only “ <i>Pseudacris regilla</i> showed marginal support for a negative association with UV-B in one of the two parks it occurred in.” The simplest model suggested the odds of detecting Cascades frog in Olympic National Park increased as UV-B increased (Adams et al. 2005, p. 495).	Low Confidence
- GEOGRAPHIC SCOPE	Range-wide stressor. UV-B radiation is increasing at the poles and in the northern hemisphere (Blumthaler and Ambach 1990, p. 248), however, studies such as those by Palen et al (2004, p. 2954) found that many lentic aquatic features in the PNW have high enough DOM to minimize UV-B reaching amphibian embryos and it would be presumptive to assume they’re affecting populations.	Low Confidence

- MAGNITUDE	UV-B dose/exposure are debated; however, dose was a poor predictor of Cascades frog distribution in Olympic NP (Adams et al. 2005, p. 498). There are many factors that mitigate the embryo and larval exposure to UV-B (see Licht 2003, pp. 552-555, for an overview), particularly when viewed at a landscape scale. Palen et al. (2002, pp. 2953-2956) did not find UV-B levels at a landscape scale high enough to reduce survival of embryos and Adams et al. (2005, p. 497) was unable to detect negative Cascades frog distribution patterns in response to higher UV-B levels. Because amphibians frequently have high embryonic and larval mortality, the individual effect of UV-B becomes an even more problematic predictor of population trends (Vonesh and De la Cruz 2002, pp. 331-332; Licht 2003, pp. 559-560).	Low Confidence
SUMMARY	There appears to be considerable debate over the effect and magnitude of UV-B radiation on amphibian populations, including the Cascades frog (Blaustein et al. 2004, entire; Palen et al. 2004 entire; Corn and Muths 2004, entire). Some laboratory and field studies have found reduced survival and increased deformities in Cascades frog embryos and larvae may result from UV-B exposure (Blaustein et al 1994, p.1794; Romansic et al. 2009, pp. 226, 228) while other studies on a variety of species have found no significant effect (Licht 2003, pp. 552-555). While most researchers do not dispute that high UV-B exposure can cause mortality in embryos and larvae, amphibians like the Cascades frog often have high mortality in these life stages independent of the effects of UV-B (Vonesh and De la Cruz 2002, p. 332; Licht 2003, p. 559), therefore, it is difficult to demonstrate a negative effect of UV-B radiation on embryos influencing population declines to date (Palen et al. 2002, p. 2956; Adams et al. 2005, p. 498; Licht 2003, P. 560). In their conclusions, both Licht (2003, p. 560) and Palen et al. (2002, p. 2956) stated that the current information on the effects of UV-B radiation do not currently support the hypothesis of this stressor contributing to amphibian population declines.	Low Confidence

THEME: Recreation		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Recreational activities	
- Activity(ies)	Non-motorized recreational activities such as camping, backpacking, hiking and fishing in National Parks and Forest Service Wilderness and non-wilderness primarily public lands. Outside of NP's and wilderness areas there is an increased likelihood of mountain bike, equestrian and OHV recreational activities (in Pope et al. 2014, pp. 33-34).	Highly Confident

STRESSOR(S)	We are unaware of any studies looking directly at the effects of recreational activities on Cascades frog, though anecdotal observations are reported (USDA, Forest Service, 2020, unpublished data). Negative effects to meadow and aquatic habitat have been demonstrated from studies on other species such as <i>R. muscosa</i> and <i>B. boreas</i> (in Pope et al. 2014, pp. 33-34).	Somewhat Confident
- Affected Resource(s) or individuals	Due to their high elevation range and primarily aquatic life history, there is a low likelihood of crushing all life stages, but eggs and larvae are most vulnerable because of their occurrence in shallow edge habitats and less mobility. Recreationists may trample riparian and emergent vegetation, increasing soil exposure and compaction (Cole et al. 2004, pp. 158-159; Vinson 1998, p. 50), and potentially increase the risk of introducing pathogens (Robinson et al. 2018, p. 375). Increased stress from human activity may work synergistically with other stressors (i.e., drought, trout, chytrid) (in Pope et al. 2014, pp. 33-34).	Somewhat Confident
- Exposure of Stressor(s)	National Parks and wilderness areas within the range of the Cascades frog have high seasonal levels of hiking, backpacking camping and fishing, and it often occurs around lakes, springs and streams. Eggs and larvae could be crushed by people walking in aquatic habitat, but relatively low likelihood. Impacts more likely to emergent vegetation providing cover in aquatic features via crushing by campers and fisherman accessing the water (in Pope et al. 2014, pp. 33-34; Cole and Landres 1995, p. 191). Concentrated use adjacent to aquatic features can also increase local soil exposure and compaction, and potentially impact water quality. Vinson (1998, p. 50) found increased emergent vegetation at <i>R. muscosa</i> sites and a negative correlation to frog occurrence with increased mineral soil at recreation sites, though it was not statistically significant. Pathogens such as the fungus <i>Batrachochytrium dendrobatidis</i> (<i>Bd</i>) could be transported by contaminated footwear/equipment. Pack animal and off-highway vehicle use in meadow and wetland areas may lead to reduced vegetation cover and increased soil exposure (Cole et al. 2004, pp. 158-159) poor water quality and sedimentation (Cole and Landres, 1995, p. 188).	Somewhat Confident
- Immediacy of Stressor(s)	Historic, current, and future. Recreational visitation to National Parks and Forest Service wilderness areas has increased since the early 1900's but has remained high since about the mid 1990's. White et al. (2016, p. 3) reported continued increases in non-consumptive recreation in all categories mentioned here.	Highly Confident
Changes in Resource(s)	Resource impacts will likely increase with increased recreation. From 1999 to 2009, the number of participants visiting wilderness increased 18% while backcountry activities like day hiking and backpacking increased 15% and 8%, respectively, and primitive camping increased 3% (White et al. 2016, p. 3). During the same period activities that are primarily outside of wilderness such as OHV use increased 35% in participants and almost 48% in total days	Moderately Confident

	while equestrian activities increased 2% in participants and declined almost 10% in days. Individuals participating in wildlife viewing and photography increased approximately 25% (White et al. 2016, p. 3).	
Response to Stressors: - INDIVIDUALS	Eggs and larvae could be crushed by trampling particularly by fisherman and others recreating in aquatic habitat; larvae, juveniles and adults may move to avoid people recreating and thus be exposed to predation from trout. Emergent and riparian vegetation trampling will reduce cover. Vinson (1998, p. 51) found that recreation resulted in reduced vegetation and increased soil exposure correlating to lower occurrence of anurans. Survival, abundance, and recruitment are unlikely to be negatively affected beyond local effects.	Somewhat Confident
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	While outdoor recreation is anticipated to increase, trampling impacts to Cascades frog and aquatic vegetation are primarily at a local scale and unlikely to impact populations. However, introduction of pathogens such as <i>Bd</i> could potentially impact populations that have not yet been affected (see chytrid (<i>Bd</i>) section for detailed discussion). Chytrid (<i>Bd</i>) may be spread by the transfer of zoospores from one site to another, potentially by recreation footwear and clothing. Robinson et al. (2018, p. 375) investigated the presence and load of <i>Bd</i> infection in amphibians in Adirondack State Park, New York, and did not find a relationship with recreational intensity and <i>Bd</i> prevalence. There is little known about the extent of human transfer versus animal or other natural means, and it is believed that <i>Bd</i> is already widespread in the Pacific northwest, though it is unclear how prevalent it is in Cascades frogs in Oregon and Washington (Pearl et al. 2007, p. 146-147). It is known to be impacting juvenile Cascades frog survival and adult recruitment at sites in California (Pope et al. 2011, p.11)). Despite a high level of wilderness recreation and widespread prevalence of <i>Bd</i> , a recent publication on <i>R. sierra</i> in Yosemite National Park, found the frog population was recovering in abundance potentially due to a combination of decline in non-native trout (i.e., cessation of stocking and waning populations and limited removal) and increased tolerance of <i>Bd</i> (Knapp et al. 2016, pp. 11890-11893).	Somewhat Confident
- GEOGRAPHIC SCOPE	Range-wide stressor. Locally concentrated in popular hiking, backpacking, fishing and camping areas.	Highly Confident
- MAGNITUDE	Direct effects to individuals, breeding populations and vegetation are most likely localized. <i>Bd</i> and other pathogens may spread by recreating humans, but extent is unknown. The Cascades frog's higher elevation habitat likely restricts direct and indirect impacts from recreation to the warmer summer months. Based on recent trends, it's reasonable to assume a continued increase in outdoor recreational activities in the foreseeable future, though many NP's, wilderness areas, and campsites are now	Low Confidence

	capping visitor use through permits and reservation systems. For example, in 2021, the Deschutes NF in Oregon is initiating a new reservation system for several popular hiking trails into the Three Sisters Wilderness off the Cascades Lakes Highway, Deschutes County.	
SUMMARY	Recreational activities are anticipated to continue having localized impacts on Cascades frogs and aquatic habitat through trampling/crushing of individuals (primarily eggs and larvae) and emergent vegetation (Vinson 1998, p. 50). At lower elevations, and outside wilderness areas, OHV recreation, mountain biking and pack animal use may have more severe local habitat impacts (Cole et al. 2004, pp. 158-159). Recreational activities may also increase stress due to disturbance that can act synergistically with other stressors. While the majority of physical impacts to Cascades frogs are anticipated to be individual and localized, pathogens such as <i>Bd</i> may be spread by recreation equipment and clothing that could have effects at the population scale, however, the extent of human transfer versus animal or other natural means is unknown.	Moderately Confident

THEME: Livestock Grazing		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Livestock Grazing	
- Activity(ies)	Removal of vegetation (Belsky et al. 1999, p. 4; Flenniken et al. 2001, P. 570), trampling (Belsky et al. 1999 p. 1, Flenniken et al. 2001, P. 570), increased sedimentation (Belsky et al. 1999, p. 10), and physical habitat alteration (Belsky et al. 1999, p. 1).	Highly Confident
STRESSOR(S)	Livestock are attracted to riparian areas, where they spend a disproportionate amount of their time (Roath and Krueger 1982, P. 335). Trampling can cause direct effects to Cascades frogs through injury and mortality (Belsky et al. 1999, p. 1; Flenniken et al. 2001, P. 570). Trampling can cause indirect effects by altering riparian habitat; this includes removal of vegetation (Belsky et al. 1999, p. 4; Flenniken et al. 2001, P. 570), increased sedimentation (Belsky et al. 1999, p. 10), decreased water quality (Belsky et al. 1999, p.10; Flenniken et al. 2001, pp. 571-2; Fleischner 1994, p.635; Kauffman and Krueger 1984, p.434), and altered hydrology (Belsky et al. 1999, p. 2). These effects can result in decreased breeding habitat, increased susceptibility to disease, diminishes health, and reduced breeding success (Pilliod et al. 2003, pp. 174–175).	Moderately Confident
- Affected Resource(s) or individuals	All life stages are susceptible to disease because of poor water quality. All life stages are directly susceptible to livestock trampling. There is a potential reduction in habitat for breeding, foraging, overwintering.	Moderately Confident
- Exposure of Stressor(s)	Eggs and larva are susceptible to disease in summer during development because of poor water quality. All life stages are	Moderately Confident

	susceptible to livestock trampling in summer. Livestock could spread of chytrid to new locations.	
- Immediacy of Stressor(s)	Livestock grazing has occurred in the CA mountains since the early 1800s, is still occurring, and is expected to continue to occur in the future. Legacy damage that has not been remediated has remained for decades even without additional grazing.	Highly Confident
Changes in Resource(s)	Water quality may be decreased (Belsky et al. 1999, p10). Vegetation around breeding ponds can be removed by grazing and to promote grasses (Fleischner 1994, pp. 631–632). Wetland area reduction may have occurred from legacy erosion because of grazing. Wetland hydroperiod may be reduced from legacy erosion because of grazing.	Moderately Confident
Response to Stressors: - INDIVIDUALS	Mortality by livestock trampling, dehydration due to lack of shade and water, diminished health due to reduced water quality.	Highly Confident
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	Mortality by livestock trampling may reduce recruitment and population. Increased contaminants may reduce breeding success, reducing recruitment and population. Livestock trampling may reduce population.	Moderately Confident
- GEOGRAPHIC SCOPE	Livestock grazing has occurred in parts of the Cascades frog range since the early 1800s. Grazing is currently occurring throughout much of the species' range, but at a reduced intensity over the past two decades (Pope et al. 2014, p.32). Additional conservation measures such as cattle exclusion fencing have been incorporated to protect some particularly sensitive populations.	Highly Confident
- MAGNITUDE	Livestock grazing is widespread, and its legacy effects may have reduced some local populations. Current risk in parts of their range is low because grazing is not permitted in some sensitive areas (Pope et al. 2014, p.32). Past effects of many years of grazing may have reduced habitat quality and quantity substantially (Pope et al. 2014, P. 33). Trampling has the potential to have significant effects on small populations in the southern Cascades (Pope et al 2014, p.33). The magnitude of the effect of current grazing on Cascades frogs, Yosemite toads, and Oregon spotted frogs has been shown to be low (Allen-Diaz et al. 2010, p. 7; Roche et al. 2012, p. 60; Adams et al. 2009, p. 137; Bull and Hayes 2000, pp. 292-294).	Moderately Confident
SUMMARY	While livestock grazing has likely had cumulative effects on habitat over the past two centuries, it currently does not appear to be contributing additional effects at the population level. If grazing intensity remains the same in the future, we do not expect additional significant effects to the population. Furthermore, limited grazing benefits some life stages of Cascades frogs (Cole et al. 2016) and by preventing encroachment of vegetation and maintaining wet meadow habitat (Bonham 2019, p.64). Based on these factors, livestock grazing does not need to be evaluated further in our analysis.	Moderately Confident

THEME: Fire Prevention and Suppression		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Fire Prevention & Suppression	
- Activity(ies)	Mechanical fuel removal, fire retardant application, water drafting, construction of fire roads and fuel breaks, firefighting.	Highly Confident
STRESSOR(S)	Reduction of open meadows due to succession (Fellers & Drost 1993, p. 180); contaminated water due to fire retardant (Buhl and Hamilton 2000, pp. 410-413); reduced water table due to water drafting; and reduced water input due to reduced snowpack in dense forests.	Highly Confident
- Affected Resource(s) or individuals	Lack of fire allows plant succession and loss of open meadow habitat needed by Cascades frog (Fellers & Drost 1993, p. 180). Clean water is a necessary habitat component, which may be lost by contamination. Reduced water table may decrease breeding habitat and ability to thermoregulate.	Highly Confident
- Exposure of Stressor(s)	Cascades frog needs open water ponds, streams, and marsh habitat during breeding. Contaminated water effects all life stages of Cascades frog (Belsky et al. 1999, p.10; Flenniken et al. 2001, pp. 571-2; Fleischner 1994, p.635; Kauffman and Krueger 1984, p.434).	Highly Confident
- Immediacy of Stressor(s)	Fire suppression has been ongoing for decades and continues to potentially impact the species and habitat today. Climate change will likely increase drought, leading to more fire suppression in the future. However, current and future mitigation measures are possible, such as the USFS avoiding aerial application of retardant on waterways (USFS 2011, p. 2).	Moderately Confident
Changes in Resource(s)	In the southern part of the Cascades frog range where fire is naturally more frequent, fire suppression has reduced habitat in the past and continues to reduce it by tipping the balance in favor of plant succession (Fellers and Drost 1993, p. 180).	Moderately Confident
Response to Stressors: - INDIVIDUALS	Altered hydrology can reduce habitat quality and quantity, increasing competition among individuals in reduced and degraded habitat. Decreased water quality can reduce individual larva chance of breeding or survival through direct toxicity and food contamination (Pilliod et al. 2003, pp. 174–175).	Highly Confident
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	Reduced water levels cause reduced breeding success and reduced recruitment of juveniles (Pope et al. 2011, p. 11). Increased contaminants from fire retardants can reduce breeding success (Pilliod et al. 2003, p. 175).	Highly Confident
- GEOGRAPHIC SCOPE	The impacts of fire suppression have been and continue to be much greater in the southern part of the Cascades frog range. The southern Cascades has both more fire, and more fire suppression due to having less wilderness and more wildland-urban interface. In the northern part of their range, the frog occurs primarily in areas with infrequent fire, and wilderness where fire suppression is less intensive.	Moderately Confident

- MAGNITUDE	Some southern populations (Lassen area) of Cascades frog may be impacted severely by fire suppression (Fellers and Drost 1993, p. 179). However, most populations occur in areas where fire suppression will not be heavily implemented due to regulation (wilderness status), or ecosystem type, and the species as a whole is not expected to be largely impacted (Pope et al. 2014, pp. 27-29).	Moderately Confident
SUMMARY	Much of the Cascades frog range is not threatened by fire prevention and suppression because it is in high-elevation areas with limited vegetation or within wilderness areas, where suppression does not often occur. Fire prevention and suppression may have affected local populations in the Lassen area in the past and remain a concern their due to recent declines and low abundance. Therefore, the effects do not warrant carrying it forward in our analysis.	Moderately Confident

THEME: Wildfire		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Wildfire	
- Activity(ies)	Burning wildland habitat.	Highly Confident
STRESSOR(S)	Acute increase in air temperature from fire; acute increase in water temperature from fire (Pilliod et al. 2003, p.168); Long-term increase in upland and water temperature due to loss of canopy (Johnson and Jones 2000, p. 32; Minshall et al. 1997, p. 2512); and change in water chemical composition (Spencer and Hauer 1991, p. 27; Semlitsch 2000, p. 618).	Highly Confident
- Affected Resource(s) or individuals	Direct effects to individuals from heat and fire; indirect effects to aquatic habitat from changed water chemical composition, acute and long-term increases in water temperatures in ponds and wetlands.	Highly Confident
- Exposure of Stressor(s)	Direct mortality happens in uplands during dispersal and in ponds and wetlands during all life stages when there is an acute increase in water temperature due to fire. Indirect effects from decreased water quality occur in all aquatic habitats where RACA are found.	Highly Confident
- Immediacy of Stressor(s)	Wildfire has been common within the Cascades frog range in the past but was greatly reduced through fire suppression efforts beginning in the early 1900s. Currently, a buildup of fuel loads, and drier conditions due to climate change have increased frequency and severity of wildfires (Moritz et al. 2018, pp. 5-6). Fire regimes in the future are likely to continue to increase in frequency and severity (Parks and Abatzoglou 2020, pp. 5–6; Westerling et al. 2006, pp. 940-941).	Moderately Confident
Changes in Resource(s)	A lack of wildfires due to suppression has reduced open meadow habitat (Taylor 1990, as cited in Fellers & Drost 1993) and possibly reduced habitat quality (Pilliod et al. 2003, pp. 171, 173). There is	Somewhat Confident

	currently no indication that wildfire is currently reducing quality or quantity of RACA habitat on a significant scale.	
Response to Stressors: - INDIVIDUALS	Injury and mortality from acute exposure to increased air temperature and fire can affect dispersing adults. Injury and mortality from increased water temperature can affect all life stages. Increased chemicals in the aquatic environment can cause injury and mortality to all life stages, but amphibian eggs and larvae are particularly sensitive to water quality.	Highly Confident
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	Recruitment may be reduced because of effects to eggs and larvae. Population growth may be reduced because of mortality of all ages.	Low Confidence
- GEOGRAPHIC SCOPE	While this stressor can occur throughout the species range, it is more likely significant in the south where wildfire intervals are shorter.	Highly Confident
- MAGNITUDE	Direct mortality and injury from fire are unlikely because of the aquatic nature of RACA (Pilliod et al. 2003, p.167). In other amphibian species, low intensity wildfires likely don't have adverse effects (Olson and Davis 2009, p. 24), and rebounds occur after severe fires (Hossack & Honeycut 2017, p.8). We expect the stressors associated with wildfires to have a minimal cumulative negative effect on the populations and species as a whole.	Moderately Confident
SUMMARY	There have been limited documented negative effects of wildfire on the species. Additionally, wildfire is likely a key mechanism maintaining open meadow habitat that the species relies on. Wildfire is likely to only have localized negative effects on the Cascades frog. Therefore, the effects do not warrant further analysis.	Moderately Confident

THEME: Contaminants		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Contaminants	
- Activity(ies)	Windborne deposition of agricultural pesticides (Davidson et al. 2002, p.1594; Bradford et al. 2011, p.688; Davidson et al. 2012, p.1898). Roadway pollution from deicer (magnesium chloride) application and other road-related vehicle pollutants and chemical spills. Herbicides used for weed control. Atmospheric deposition of mercury (Eagle-Smith et al. 2020, p. 8782)	Highly Confident
STRESSOR(S)	Chemical contaminants have been proposed as a possible factor in global amphibian population declines (Blaustein et al. 1994, pp 1791). Agricultural pesticides have been detected in high elevation, protected habitat in the Sierra Nevada and Cascades Mountains of California (Bradford et al. 2011, p.688; Davidson et al. 2012, pp. 1898-1899). Windborne drift of agricultural pesticides into the	Somewhat Confident

	Klamath Mountains and southern Cascades Lassen area in California has been documented (Davidson et al. 2012, pp. 1898-1899). In addition, atmospheric deposition and bioaccumulation of mercury in dragonfly larvae in National Parks including Olympic, Mount Rainier and North Cascades has been observed (Eagle-Smith et al. 2020, p. 8782). We are unaware of any documented chemical spills or applications causing die-offs, therefore, roadside spills, deicer and herbicide applications along forest roads are anticipated to be localized impacts and are more likely to have limited mortality or sublethal effects (Carey and Bryant 1995, entire).	
- Affected Resource(s) or individuals	Primary effect to water quality impacting eggs and developing larva. Potential effects from reduced water quality to aquatic invertebrate prey base. Severe exposure such as from a spill could be lethal, however, effects to larvae, juveniles and adults from sources other than a spill are more likely to be sublethal. Sublethal effects such as inhibiting cholinesterase activity (from insecticide exposure) may influence growth and development, immune functions, and predator avoidance (Carey and Bryant 1995, entire; Sparling and Fellers 2009, p. 1701).	Moderately Confident
- Exposure of Stressor(s)	Exposure at aquatic breeding sites to eggs and larvae; prey base impacts in any aquatic foraging habitat (Bradford et al. 2011, p.688; Davidson et al. 2012, pp. 1898-1899; Eagle-Smith et al. 2020, p. 8782).	Somewhat Confident
- Immediacy of Stressor(s)	Historic, current, and future.	Highly Confident
Changes in Resource(s)	Generally, sublethal effects to eggs, larvae and frogs that theoretically may lead to decline in hatching success, development and potentially occupancy (Carey and Bryant 1995, entire; Davidson et al. 2002, p.1594; Sparling and Fellers 2009, p. 1701). Anticipated increase in pollutants in water with continued windborne drift and atmospheric deposition. Potential increase in probability of spills with increased vehicle traffic and pesticide use along roads and rights-of-ways. Unknown resource response with chemicals that may persist in the aquatic environment or bioaccumulate.	Low Confidence
Response to Stressors: - INDIVIDUALS	Laboratory experiments have documented that exposure to common agricultural pesticides can have lethal and sublethal effects on amphibians (Sparling and Fellers 2009, pp. 1697-1698). Concentrations of some of these same chemicals have been detected in protected mountain areas. We are unaware of reported die-offs or acute interactions of Cascades frogs from exposure to contaminants, so we consider any impacts to be more likely sublethal. One study found a correlation with upwind agricultural pesticides and declines of Cascades frog in the Lassen area (Davidson et al. 2002, p.1594), however, two subsequent studies disputed the initial results and were unable to find a correlation between the presence of agricultural pesticides and the absence of	Moderately Confident

	Cascades or mountain and Sierra yellow-legged frogs (Bradford et al. 2011, p.689; Davidson et al. 2012, p. 1899).	
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	Currently, there is limited information on the impacts of contaminants. Two studies by the same author found different results but the most recent paper "...found no pattern of higher chemical residue concentrations at sites where Cascades frogs had disappeared than at sites where Cascades frogs were still present" in the Lassen and Klamath regions of California (Davidson et al. (2012, p. 1899). Research in the Sierra Nevada of California on the southern mountain and Sierra Nevada yellow-legged frogs (<i>Rana muscosa</i> and <i>R. sierrae</i>) showed similar results for those species (Bradford et al. 2011, p.688).	Somewhat Confident
- GEOGRAPHIC SCOPE	Agricultural pesticide drift may be most prevalent in the Lassen region of CA and potentially the central Cascades of OR due to their upwind proximity to more diverse agricultural areas. Neither agricultural area is likely as intensive and as diverse as the San Joaquin Valley where much of the research is based (Sparling and Fellers 2009, p. 1696). Atmospheric deposition of mercury is known to occur in these areas though sources are generally less obvious. Industrial activities are considered the most likely source of atmospheric mercury and it can travel and be deposited over great distances. Deicers, herbicide treatments and spills will primarily occur along roadways throughout the range, though exposure is most likely localized and immediately downstream of roadways or in adjacent wetlands.	Somewhat Confident
- MAGNITUDE	Little is currently known about the effects of contaminants on Cascades frog populations. Studies have conflicted on correlations of windborne contaminants and Cascades frog absence with the more recent and intensive study showing no correlation (Davidson et al. 2002, p.1597-1598; Davidson et al. 2012, p.1899). Cascades frog direct exposure to agricultural chemicals and mercury at higher elevations is likely very limited and localized, as are chemical spills, herbicide applications and deicer use.	Low Confidence
SUMMARY	The evidence is clear that direct exposure to certain chemicals, particularly when tested in the laboratory, can have a variety of lethal and sublethal effects on amphibians (Carey and Bryant 1995, entire; Sparling and Fellers 2009, p. 1701). Much research has been conducted in the Sierra Nevada investigating this issue due to its proximity to the intensive agriculture of the San Joaquin Valley. However, correlations with contaminants and presence/absence for similar high elevation lentic breeding frogs are not conclusive (Bradford et al. 2009, p. 688). A valid point made in some papers unable to find correlations of effects at the population level was that testing for only a few contaminants in each study barely addresses the hundreds of chemicals used in the agricultural industry and new ones are being introduced regularly. Currently, the evidence for	Low Confidence

	effects at the population level is uncertain and continued study and monitoring is prudent given the extent to which pesticides are used.	
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THEME: Timber Harvest		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Timber Harvest	
- Activity(ies)	Tree and vegetation clearing, access road building, heavy equipment operation.	Highly Confident
STRESSOR(S)	Direct mortality by heavy equipment (Pilliod et al. 2003, p. 174); change in forest age and structure (Aubry & Hall 1991, p. 332; Lehmkuhl & Ruggiero 1991, p.45; Pope et al. 2014, p. 103); reduced hydroperiod (Pope et al. 2014, p. 35); increased water temperatures (Johnson and Jones 2000, p. 32); and Habitat fragmentation (Blaustein et al. 1995, p. 53; Lehmkuhl & Ruggiero 1991, p. 45).	Moderately Confident
- Affected Resource(s) or individuals	Timber harvest has direct effects on individuals. Aquatic areas and uplands used by Cascades frogs are both affected by these stressors. Timber stand age is reduced by timber harvest and old growth forests are lost.	Moderately Confident
- Exposure of Stressor(s)	Once logging is complete, decreased canopy cover combined with summer sun and temperatures will subject Cascades frogs to water temperatures higher than they can withstand (Pope et al. 2014, p. 9). Reduced hydroperiod may affect Cascades frogs at any time of year. During spring, summer, and fall, Cascades frogs are present in upland areas (Lehmkuhl & Ruggiero 1991, p. 45; Garwood 2009, p. 76), they will be exposed to direct mortality by heavy equipment, a change in forest age and structure, and habitat fragmentation.	Moderately Confident
- Immediacy of Stressor(s)	Stressors associated with timber harvest were likely more important in the past. Currently, most of the Cascades frogs' range is protected and/or managed for the Cascades frog (Pope et al. 2014, p. 103). Current management will likely persist into the future.	Highly Confident
Changes in Resource(s)	Stand age in surrounding forest is younger. Habitat has structural changes including decreased shade, vegetation, and woody debris (Pope et al. 2014, p. 103). Breeding pools likely have reduced hydroperiods (Pope et al. 2014, p. 35).	Highly Confident
Response to Stressors: - INDIVIDUALS	Larvae are susceptible to high water temperatures in the summer, which are caused by removal of tree canopy (Pope et al. 2014). Juveniles move among habitat patches frequently (Garwood 2009, p. 76). Adults migrate between patches seasonally (Garwood 2009, p. 76). These life stages have exposure to upland timber harvest activities such as direct mortality, dehydration from reduced shading, and habitat fragmentation (Garwood 2009, p. 76). Cascades frogs overwinter at the bottom of springs and lakes. Therefore, heavy equipment operating during this period would have no direct impact.	Moderately Confident
POPULATION & SPECIES RESPONSES		

Effects of Stressors: - POPULATIONS [RESILIENCY]	Shorter hydroperiods in breeding ponds have caused reduced reproductive rates (Pope et al. 2014, p. 35). Cascades frog abundance is positively correlated with stand age, with the highest abundances found in old growth forests (Aubry & Hall 1991, pp. 332, 337). Habitat fragmentation increases risk of extinction by further limiting dispersal (Lehmkuhl & Ruggiero 1991, p. 45; Blaustein et al. 1995, p. 53).	Somewhat Confident
- GEOGRAPHIC SCOPE	Much of the Cascades frogs' range is protected and/or managed for the Cascades frogs (Pope et al. 2014, p. 103). In the southern Cascades, the effects of reduced canopy cover and increased water temperatures are more likely to affect the species because water temperatures there already may be above their tolerable limit.	Moderately Confident
- MAGNITUDE	Much of the range of the cascades frog is protected in National Parks and FS Wilderness designation (Pope et al. 2014, p. 103). Therefore, we expect these stressors to only act on a local level and have a low magnitude.	Highly Confident
SUMMARY	While local Cascades frog populations could face a variety of stressors from timber harvest, much of its range is protected as National Park or FS Wilderness and not for timber production. Therefore, the effects are not population-wide, and do not warrant carrying it forward in our analysis.	Moderately Confident

THEME: Roads and Driving		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Roadways and driving	
- Activity(ies)	The use of roadways for vehicles.	High Confidence
STRESSOR(S)	Direct mortality by crushing frogs on road surfaces, potentially reducing connectivity and altering hydrology (Pope et al. 2014, pp. 98-99).	Low Confidence
- Affected Resource(s) or individuals	Primarily impacting dispersing juveniles and potentially adults moving between breeding, foraging, and overwintering sites.	Low Confidence
- Exposure of Stressor(s)	We are not aware of reports of Cascades frogs being significantly impacted by crushing on roads. This is likely due to them being at higher elevations and in wilderness areas with fewer roads and usually in aquatic habitats, even during dispersal (Pope et al. 2014, pp. 98-99). However, under wet conditions they may disperse across terrestrial habitat (Garwood and Welsh 2007, pp. 40-41). Roadways can vary in permeability to wildlife depending on vehicle traffic volume and other roadway features such as "Jersey" barriers, curbs, bridges and culverts. Roads were partial barriers to red-backed salamanders (<i>Plethodon cinereus</i>) irrelevant of surface type or crushing (Marsh et al. 2005, p. 2007). Northern red-legged frogs (<i>R. aurora</i>) are known to have roadkill events, but they are much more	Low Confidence

	terrestrial frogs as adults and freely cross forested habitat and roads.	
- Immediacy of Stressor(s)	Historic, current, and future. Likely to continue and potentially increase into the future as human population and traffic volumes increase.	Somewhat Confident
Changes in Resource(s)	Roadways may limit amphibian dispersal and movement through crushing individuals or act as barriers (Marsh et al. 2005, p.2007). Increases in traffic volume during the summer when frogs are active may result in increased likelihood of being crushed and dispersal less likely. Road construction, particularly those bisecting meadows on fill material, may alter hydrology patterns based on placement, fill material and surface. Construction of new large highways, especially in Cascades frog range, are rare, however forest roads below wilderness designation are often constructed for timber sales. Increases in forest road density can increase public access and sediment runoff but affects will mostly depend on proximity to aquatic features.	Low Confidence
Response to Stressors: - INDIVIDUALS	Direct mortality and reduced likelihood of successful dispersal. Cascades frogs are unlikely to avoid crossing roads with high traffic volumes. However, due to their primarily aquatic life history they are more likely to follow streams as movement corridors. Old narrow bridges and perched culverts may present barriers (Pope et al. 2014, p. 99). However, state departments of transportation and the FS are gradually replacing these with wider bridges and larger bottomless arch culverts to better accommodate streamflow and wildlife passage.	Somewhat Confident
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	May reduce juvenile dispersal over time, thus potentially limiting recruitment and genetic exchange. However, due to stream passage under most roadways they are unlikely to be a complete barrier.	Low Confidence
- GEOGRAPHIC SCOPE	High traffic volume roadways occur across the frog's range in CA, OR and WA and generally transect the Cascades in an east-west direction. The disjunct populations in the Klamath and Olympic mountains have fewer highways transecting them, though there are roadways through sections and along the edges of the populations. Interstate- 5 is a very high traffic volume highway that runs north-south between the Cascades and the Trinity Alps sites and likely is impervious to frogs crossing its surface due to both traffic volume and barriers.	High Confidence
- MAGNITUDE	Over time, reduced dispersal may slow immigration, recolonization, and genetic exchange. However, most roads have stream crossings in the form of bridges and culverts that provide some level of permeability for Cascades frogs.	Low Confidence
SUMMARY	Though we found no evidence of it in the literature for Cascades frogs, roads may affect dispersing individuals through crushing and could potentially cause isolation of some breeding sites or	Low Confidence

	populations depending on proximity to aquatic habitat. The variable permeability of roadways due to bridges and culverts likely influences how much of a barrier a roadway is. Localized impacts of roads are anticipated to continue and increase along with human population and traffic volume. Specific problem areas may be addressed as highway projects occur by incorporating wildlife crossing such as bottomless arch culverts and wider bridges.	
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THEME: Water Management		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Water withdrawal	
- Activity(ies)	Larger water impoundments to support agricultural irrigation and urban drinking water. Smaller, local impoundments often for recreation that may occasionally be used for activities such as fire suppression and dust abatement (Briggs and Storm 1970, p. 288).	Highly Confident
STRESSOR(S)	The managed seasonal fluctuation of water (retention or withdrawal) from sites can flood shallow wetland areas or expose eggs and larvae to stranding and desiccation when dropped too rapidly (Briggs and Storm 1970, p. 288).	Moderately Confident
- Affected Resource(s) or individuals	Stable water levels that provide breeding conditions particularly for eggs and larvae. Larvae, juveniles and adults can move with gradual water fluctuations, but this may also put them more in contact with trout (Pope 2008, p. 1579).	Somewhat Confident
- Exposure of Stressor(s)	Primarily breeding since eggs and larvae are most susceptible to desiccation. Gradual fluctuations in water depth may simulate natural changes but rapid changes, particularly withdrawals may expose eggs to desiccation and larvae to stranding and desiccation.	Somewhat Confidence
- Immediacy of Stressor(s)	Historic, current, and future. Potentially increase with human water demand.	Moderately Confident
Changes in Resource(s)	Dams and water control structures can create larger waterbodies as well as cause water levels to rise above natural levels, potentially flooding breeding sites. Water can be released from reservoirs for agricultural and urban use, potentially dewatering shallow edge habitat too rapidly. Small local dams may increase the size of existing sites (Briggs and Storm 1970, p. 284).	Somewhat Confident
Response to Stressors: - INDIVIDUALS	Impounding and expanding springs and smaller streams can both eliminate (Pope et al. 2014, pp. 104-105) and expand breeding and overwintering habitat (Briggs and Storm 1970, p. 284), however, this often comes with recreation such as camping and introduced trout for fishing that may be locally significant. If trout are not introduced, small impoundments may expand Cascades frog breeding and overwintering habitat locally, thus benefitting frogs. Larger reservoirs generally have trout and other non-native predatory fish. Rapid withdrawal can result in eggs exposed to air desiccating and	Somewhat Confident

	larvae may also be stranded and desiccate (Briggs and Storm 1970, p. 288).	
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	There is at least one example in the literature of impacts from water withdrawal from a small spring impoundment for dust abatement that led to the loss of annual breeding effort locally (Briggs 1970, p. 288). Otherwise, there is very little reported on human water management in the literature for Cascades frog. This is likely due to the majority of the Cascades frog habitat range-wide being at higher elevations than most of the larger reservoirs used for water storage and supply (Pope et al. 2014, pp. 104-105). Hydroperiod at elevation is much more linked to annual winter precipitation and summer temperatures (Kissel et al. 2019, p. 9). Sustained annual loss of eggs and/or larvae may impact adult recruitment and abundance over time. A lack of reported historically occupied breeding areas lost to water manipulation reduced our confidence in the extent of the effects beyond local impacts.	Somewhat Confident
- GEOGRAPHIC SCOPE	Much of the Cascades frog range is above the large agricultural and urban water impoundments, though there are some throughout the range (e.g., Bull Run Reservoir #1 in Oregon is the municipal water supply for Portland, OR), primarily along the lower elevation of the species range.	Low Confidence
- MAGNITUDE	The geographic scope likely encompasses most of the Cascades frog range, however, natural aquatic features provide the majority of habitat at higher elevations, it is likely that the magnitude of effects of this stressor are low to moderate.	Low Confidence
SUMMARY	Water management from impounding rivers, streams and springs can expand aquatic features increasing available habitat, however, management of water can flood or strand and desiccate Cascades frog eggs and larvae if withdrawn rapidly. In addition, water withdrawal may put larvae more in contact with trout as they are forced to move from shallows to deeper water. We have found few examples in the literature of this occurring for Cascades frog and currently water management has not been considered a significant stressor. Impounding springs and streams for recreation occurs locally throughout the frog's range though the magnitude of water management for irrigation and urban drinking water is limited within the Cascades frog range due primarily to their occurrence at higher elevations than most reservoirs.	Low Confidence

THEME: Meadow Contraction		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	Meadow Contraction	
- Activity(ies)	Fire suppression, reduced cattle and sheep grazing, and wetter summers (Fellers & Drost 1993, p. 180; Thompson 2007, p.1).	Highly Confident

STRESSOR(S)	Reduction of open meadow habitat due to ecological succession (Fellers & Drost 1993, p. 180). Reduced solar exposure (Pope et al. 2014, p.97).	Highly Confident
- Affected Resource(s) or individuals	Open meadow habitat needed by Cascades frog (Fellers & Drost 1993, p. 180).	Highly Confident
- Exposure of Stressor(s)	Cascades frogs need open water ponds, streams, and marsh habitat during breeding. Developing embryos have reduced beneficial solar exposure when shaded by trees (Pope et al. 2014, p.97).	Moderately Confident
- Immediacy of Stressor(s)	This stressor has been occurring for the past century and continues to occur today. It is expected to continue in the future (Fellers & Drost 1993, p. 180; Thompson 2007, p.1).	Moderately Confident
Changes in Resource(s)	With reduced disturbance, open meadow habitat goes through ecological succession, and is replaced by shrubs and trees; breeding habitat is reduced in quality and quantity (Fellers & Drost 1993, p. 180; Thompson 2007, p.1).	Highly Confident
Response to Stressors: - INDIVIDUALS	Individual Cascades frogs must find alternate suitable habitat where they can breed.	Highly Confident
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	Entire sites may be lost due to plant succession preventing Cascades frogs from finding suitable habitat. It is unlikely that this would occur at the population level simultaneously.	Moderately Confident
- GEOGRAPHIC SCOPE	Fire suppression is most common in the southern part of the Cascades frog range, and meadow encroachment may be most important in California. However, meadow contraction is also occurring in Oregon and Washington. Existing meadows in Washington have begun to contract where climate change has caused either wetter or drier conditions (Woodward et al. 1995, p.222). Additionally, meadow contraction throughout the Cascades is being caused by reduce livestock grazing (Fellers & Drost 1993, p. 180; Thompson 2007, p.1).	Somewhat Confident
- MAGNITUDE	Meadow contraction may be reducing available habitat locally but does not appear to have a population-level effect.	Low Confidence
SUMMARY	The effects of meadow contraction on Cascades frogs are important at the site level and may be a component in the drastic declines in the southern end of the range. However, these effects are not population-wide, and therefore we do not need to evaluate them further.	Low Confidence

THEME: <i>Saprolegnia</i> Fungus		
ESA Factor(s): E	Analysis and Supporting Information	Confidence /Uncertainty
SOURCE(S)	<i>Saprolegnia</i> sp. Fungus	
- Activity(ies)	Fish stocking may increase <i>Saprolegnia</i> sp. Fungus (Kiesecker and Blaustein 1995, p. 11051).	
STRESSOR(S)	<i>Saprolegnia ferax</i> growth on embryos.	
- Affected Resource(s) or individuals	<i>Saprolegnia</i> sp. is a water mold that grows on developing eggs (Blaustein et al. 1994, p.252). It has been found on Cascades frog embryos (Kiesecker & Blaustein 1997, p.218).	Highly Confident
- Exposure of Stressor(s)	Soon after amphibian eggs (including Cascades frog) are laid, <i>Saprolegnia</i> sp. spreads throughout egg masses and causing egg mortality (Blaustein et al. 1994, p.252).	Highly Confident
- Immediacy of Stressor(s)	This stressor has occurred in the past, is occurring presently, and likely will occur in the future. Reduced fish stocking may reduce future exposure.	Moderately Confident
Changes in Resource(s)	Aquatic habitat free from <i>Saprolegnia</i> sp. becomes infected with it.	Highly Confident
Response to Stressors: - INDIVIDUALS	One study found that 95% of <i>Bufo boreas</i> embryos died in <i>Saprolegnia</i> sp. infected egg masses (Blaustein et al. 1994, p.252). There are also synergistic effects of <i>Saprolegnia</i> sp. on Cascades frog with UV-B radiation (Kiesecker & Blaustein 1995, pp. 11050-11051), and possibly cooler temperatures (Kiesecker & Blaustein 1997, p.218). Newly metamorphosed Cascades frogs are susceptible to <i>Saprolegnia</i> sp. (Romansic et al 2007, in Romansic et al. 2009, p.188).	Somewhat Confident
POPULATION & SPECIES RESPONSES		
Effects of Stressors: - POPULATIONS [RESILIENCY]	<i>Saprolegnia ferax</i> may be contributing to Cascades frog population declines in the Pacific Northwest (Kiesecker & Blaustein 1997, p.218).	Low Confidence
- GEOGRAPHIC SCOPE	<i>Saprolegnia</i> sp. is found worldwide, and throughout the Cascades frog range (Blaustein et al. 1994, p.252).	Moderately Confident
- MAGNITUDE	<i>Saprolegnia ferax</i> may have population-level effects, but this has not yet been documented.	Low Confidence
SUMMARY	Species like Cascades frog that are communal egg-layers have a higher risk of losing embryos to <i>Saprolegnia ferax</i> (Kiesecker & Blaustein 1997, pp.217-218). While this fungus is widespread and has been shown to have effects on individual egg masses and sites, population level effects to Cascades frog have not yet been documented. Therefore, we did not evaluate this stressor further.	Low Confidence

LITERATURE CITED

- Adams, M.J., C.A. Pearl, B. McCreary, S.K. Galvan, S.J. Wessell, W.H. Wente, C.W. Anderson, and A.B. Kuehl. 2009. Short-Term Effect of Cattle Exclosures on Columbia Spotted Frog (*Rana luteiventris*) Populations and Habitat in Northeastern Oregon. *Journal of Herpetology* 43:132-138.
- Adams, M.J., B.R. Hossack, R.A. Knapp, P.S. Corn, S.A. Diamond, P.C. Trenham, and D.B. Fagre. 2005. Distribution Patterns of Lentic-Breeding Amphibians in Relation to Ultraviolet Radiation Exposure in Western North America. *Ecosystems* 8:488-500.
- Allen-Diaz, B., S. Mcilroy, K. Tate, L. Roche, and A. Lind. 2010. Determining the Effects of Livestock Grazing on Yosemite Toads (*Bufo canorus*) and Their Habitat: An Adaptive Management Study. Report prepared for the US Forest Service, Region 5. University of California Press, none. 68 pp.
- Belsky, E.S., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the Western United States. *Journal of Soil and Water Conservation* 54:419-431.
- Blaustein, A.R. and L.K. Belden. 2003. Amphibian defenses against ultraviolet-B radiation. *Evolution and Development* 5:89-97.
- Blaustein, A.R., J.J. Beatty, D.H. Olson, and R.M. Storm. 1995. The Biology of Amphibians and Reptiles in Old-Growth Forests in the Pacific Northwest. Report prepared for the U.S. Forest Service, Portland, Oregon. USDA, Forest Service, Pacific Northwest Research Station, Corvallis, Oregon. 98 pp.
- Blaustein, A.R., D. Grant Hokit, R.K. O'Hara, and R.A. Holt. 1994. Pathogenic fungus contributes to amphibian losses in the Pacific Northwest. *Biological Conservation* 67:251-254.
- Blaustein, A.R., D.B. Wake, and W.P. Sousa. 1994. Amphibian Declines: Judging Stability, Persistence, and Susceptibility of Populations to Local and Global Extinctions. *Conservation Biology* 8:60-71.
- Blumthaler, M. and W. Ambach. 1990. Indication of increasing solar ultraviolet-B radiation flux in alpine regions. *Science* 248:206-208.
- Bradford, D.F., R.A. Knapp, D.W. Sparling, M.S. Nash, K.A. Stanley, N.G. Tallent-Halsell, L.L. McConnell, and S.M. Simonich. 2011. Pesticide distributions and population declines of California, USA, alpine frogs, *Rana muscosa* and *Rana sierrae*. *Environmental Toxicology and Chemistry* 30:682-691.
- Briggs, J.L. and R.M. Storm. 1970. Growth and Population Structure of the Cascade Frog, *Rana cascadae* Slater. *Herpetologica* 26:283-300.
- Buhl, K.J. and S.J. Hamilton. 2000. Acute Toxicity of Fire-Control Chemicals, Nitrogenous Chemicals, and Surfactants to Rainbow Trout. *Transactions of the American Fisheries Society* 129:408-418.
- Bull, E.L. and M.P. Hayes. 2000. Livestock Effects on Reproduction of the Columbia Spotted Frog. *Journal of Range Management* 53:291-294.
- Carey, C. and C.J. Bryant. 1995. Possible Interrelations among Environmental Toxicants, Amphibian Development, and Decline of Amphibian Populations. *Environmental Health Perspectives* 103:13-17.
- Cole, D.N. and P.B. Landres. 1995. Indirect Effects of Recreation on Wildlife. Pages 183-202 in R.L. Knight and K.J. Gutzwiller, editors. *Wildlife and Recreationists--Coexistence through Management and Research*. Island Press, Washington, DC. 369 pp.

- Cole, D.N., J.W. Van Wagtendonk, M.P. McClaran, P.E. Moore, and N.K. McDougald. 2004. Response of mountain meadows to grazing by recreational pack stock. *Rangeland Ecology and Management* 57:153-160.
- Corn, P.S. and E. Muths. 2004. Variable Breeding Phenology Affects the Exposure of Amphibian Embryos to Ultraviolet Radiation: Reply. *Ecology* 85:1759-1763.
- Davidson, C., B.H. Shaffer, and M.R. Jennings. 2002. Spatial Tests of the Pesticide Drift, Habitat Destruction, UV-B, and Climate-Change Hypotheses for California Amphibian Declines. *Conservation Biology* 16:1588-1601.
- Davidson, C., K. Stanley, and S.M. Simonich. 2012. Contaminant residues and declines of the Cascades frog (*Rana cascadae*) in the California Cascades, USA. *Environmental Toxicology and Chemistry* 31:1895-1902.
- Dumas, P.C. 1966. Studies of the *Rana* Species Complex in the Pacific Northwest. *Copeia* 1966:60-74.
- Eagles-Smith, C.A., J.J. Willacker, S.J. Nelson, C.M. Flanagan Pritz, D.P. Krabbenhoft, C.Y. Chen, J.T. Ackerman, E.H.C. Grant, and D.S. Pilliod. 2020. A National-Scale Assessment of Mercury Bioaccumulation in United States National Parks Using Dragonfly Larvae as Biosentinels through a Citizen-Science Framework. *Environmental Science and Technology* 54:1-12.
- Fellers, G.M. and C.A. Drost. 1993. Disappearance of the cascades frog *Rana cascadae* at the southern end of its range, California, USA. *Biological Conservation* 65:177-181.
- Fellers, G.M., K.L. Pope, J.E. Stead, M.S. Koo, and H.H. Welsh Jr. 2007. Turning population trend monitoring into active conservation: can we save the Cascades frog (*Rana cascadae*) in the Lassen region of California? *Herpetological Conservation and Biology* 3:28-39.
- Fite, K.V., A. Blaustein, L. Bengston, and H.E. Hewitt. 1998. Evidence of Retinal Light Damage in *Rana cascadae*: A Declining Amphibian Species. *Copeia* 1998:906-914.
- Fleischner, T.L. 1994. Ecological costs of livestock grazing in western North America. *Conservation Biology* 8:629-644.
- Flenniken, M., R.R. McEldowney, W.C. Leininger, G.W. Frasier, and M.J. Trlica. 2001. Hydrologic responses of a montane riparian ecosystem following cattle use. *Journal of Range Management* 54:567-574.
- Garwood, J. 2009. Spatial ecology of the Cascades frog: identifying dispersal, migration, and resource uses at multiple spatial scales. Thesis, Humboldt State University, Arcata, California. 110 pp.
- Garwood, J.M. and H.H. Welsh Jr. 2007. Ecology of the Cascades Frog (*Rana cascadae*) and Interactions with Garter Snakes and Nonnative Trout in the Trinity Alps Wilderness, California. Report prepared for the California Fish and Game, Sacramento, California. Pacific Southwest Research Station, Forest Service, Arcata, California. 87 pp.
- Green, D.M. 1985. Natural Hybrids between the Frogs *Rana cascadae* and *Rana pretiosa* (Anura: Ranidae). *Herpetologica* 41:262-267.
- Hallock, L.A. 2013. DRAFT State of Washington Oregon Spotted Frog Recovery Plan. Report prepared for the Washington Department of Fish and Wildlife. Washington Department of Fish and Wildlife, Olympia, WA. 106 pp.

- Hardy, B.M., K.L. Pope, and E.K. Latch. 2021. Genomic signatures of demographic declines in an imperiled amphibian inform conservation action. *Animal Conservation* 24:1-13.
- Hossack, B.R. and R.K. Honeycutt. 2017. Declines revisited: Long-term recovery and spatial population dynamics of tailed frog larvae after wildfire. *Biological Conservation* 212:274-278.
- Johnson, S.L. and J.A. Jones. 2000. Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon. *Canadian Journal of Fisheries and Aquatic Sciences* 57:30-39.
- Kauffman, J.B. and W.C. Krueger. 1984. Livestock Impacts on Riparian Ecosystems and Streamside Management Implications... A Review. *Journal of Range Management* 37:430-438.
- Kiesecker, J.M. and A.R. Blaustein. 1995. Synergism Between UV-B Radiation and a Pathogen Magnifies Amphibian Embryo Mortality in Nature. *Proceedings of the National Academy of Sciences of the United States of America* 92:11049-11052.
- Kiesecker, J.M. and A.R. Blaustein. 1997. Influences of Egg Laying Behavior on Pathogenic Infection of Amphibian Eggs. *Conservation Biology* 11:214-220.
- Kiesecker, J.M., A.R. Blaustein, and C.L. Miller. 2001. Transfer of a Pathogen from Fish to Amphibians. *Conservation Biology* 15:1064-1070.
- Knapp, R.A., G.M. Fellers, P.M. Kleeman, D.A.W. Miller, V.T. Vredenburg, E.B. Rosenblum, and C.J. Briggs. 2016. Large-scale recovery of an endangered amphibian despite ongoing exposure to multiple stressors. *Proceedings of the National Academy of Sciences - PNAS* 113:11889-11894.
- Lee, S., M.E. Ryan, A.F. Hamlet, W.J. Palen, J.J. Lawler, and M. Halabisky. 2015. Projecting the Hydrologic Impacts of Climate Change on Montane Wetlands. *PloS One* 10:e0136385.
- Lehmkuhl, J.F. and L.F. Ruggiero. 1991. Forest fragmentation in the Pacific Northwest and its potential effects on wildlife. USDA Forest Service General Technical Report PNW-GTR - Pacific Northwest Research Station (USA):35-46.
- Licht, L.E. 2003. Shedding Light on Ultraviolet Radiation and Amphibian Embryos. *BioScience* 53:551-561.
- Marsh, D.M., G.S. Milam, N.P. Gorham, and N.G. Beckman. 2005. Forest Roads as Partial Barriers to Terrestrial Salamander Movement. *Conservation Biology* 19:2004-2008.
- Minshall, G.W., C.T. Robinson, and D.E. Lawrence. 1997. Postfire responses of lotic ecosystems in Yellowstone National Park, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2509-2525.
- Moritz, M.A., C. Topik, C.D. Allen, P.F. Hessburg, P. Morgan, D.C. Odion, T.T. Veblen, and I.M. McCullough. 2018. A Statement of Common Ground Regarding the Role of Wildfire in Forested Landscapes of the Western United States. Report prepared for the University of California, Santa Barbara. Fire Research Consensus Working Group, none. 55 pp.
- Monsen, K.J. and M.S. Blouin. 2003. Genetic structure in a montane ranid frog: restricted gene flow and nuclear-mitochondrial discordance. *Molecular Ecology* 12:3275-3286.
- Neale, R.E., P.W. Barnes, T.M. Robson, P.J. Neale, C.E. Williamson, R.G. Zepp, S.R. Wilson, S. Madronich, A.L. Andrady, A.M. Heikkilä, G.H. Bernhard, A.F. Bais, P.J. Aucamp, A.T. Banaszak, J.F. Bornman, L.S. Bruckman, S.N. Byrne, B. Foereid, D. Häder, L.M. Hollestein, W. Hou, S. Hylander, M.A.K. Jansen, A.R. Klekociuk, J.B. Liley, J. Longstreth, R.M. Lucas, J. Martinez-Abaigar, K. McNeill, C.M. Olsen, K.K.

- Pandey, L.E. Rhodes, S.A. Robinson, K.C. Rose, T. Schikowski, K.R. Solomon, B. Sulzberger, J.E. Ukpebor, Q. Wang, S. Wängberg, C.C. White, S. Yazar, A.R. Young, P.J. Young, L. Zhu, and M. Zhu. 2021. Environmental effects of stratospheric ozone depletion, UV radiation, and interactions with climate change: UNEP Environmental Effects Assessment Panel, Update 2020. *Photochemical and Photobiological Sciences* 20:1-67.
- National Park Service, Mount Rainier National Park (NPS MORA). 2021. Mount Rainier National Park Fish Management Plan 2021 Annual Report. Report prepared for the USDOT, National Park Service. USDOT, National Park Service, Ashford, WA. 26 pp.
- Olson, D.H. and R.J. Davis. 2009. Conservation Assessment for the Foothill Yellow-legged Frog (*Rana boylei*) in Oregon. Report prepared for the USDA Forest Service Region 6 and USDI Bureau of Land Management. Interagency Special Status Species Program, Portland, OR. 62 pp.
- Palen, W.J., D.E. Schindler, M.J. Adams, C.A. Pearl, R.B. Bury, and S.A. Diamond. 2002. Optical Characteristics of Natural Waters Protect Amphibians from UV-B in the U.S. Pacific Northwest. *Ecology* 83:2951-2957.
- Parks, S.A. and J.T. Abatzoglou. 2020. Warmer and Drier Fire Seasons Contribute to Increases in Area Burned at High Severity in Western US Forests From 1985 to 2017. *Geophysical Research Letters* 47:10 pp.
- Pearl, C.A., E.L. Bull, D.E. Green, J. Bowerman, M.J. Adams, A. Hyatt, and W.H. Wentz. 2007. Occurrence of the Amphibian Pathogen *Batrachochytrium dendrobatidis* in the Pacific Northwest. *Journal of Herpetology* 41:145-149.
- Peck, R.A., M. Bedwell, S.M. O'Rourke, C. Goldberg, G.M. Wengert, and M.R. Miller. 2019. Hybridization between two parapatric ranid frog species in the northern Sierra Nevada, California, USA. *Molecular Ecology* 28:1-12.
- Pilliod, D.S., R.B. Bury, E.J. Hyde, C.A. Pearl, and P.S. Corn. 2003. Fire and amphibians in North America. *Forest Ecology and Management* 178:163-181.
- Pope, K.L. 2008. Assessing Changes in Amphibian Population Dynamics following Experimental Manipulations of Introduced Fish. *Conservation Biology* 22:1572-1581.
- Pope, K., C. Brown, M. Hayes, G. Green, and D. Macfarlane. 2014. Cascades frog conservation assessment. Report prepared for the U.S. Department of Agriculture, Forest Service, PSW-GTR-244, Albany, California. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California. 126 pp.
- Roath, L.R. and W.C. Krueger. 1982. Cattle Grazing and Behavior on a Forested Range. *Journal of Range Management* 35:332-338.
- Robinson, C.W., S.A. McNulty, and V.R. Titus. 2017. No Safe Space: prevalence and distribution of *Batrachochytrium dendrobatidis* in amphibians in a highly protected landscape. *Herpetological Conservation and Biology* 13:373-382.
- Roche, L.M., B. Allen-Diaz, D.J. Eastburn, and K.W. Tate. 2012. Cattle Grazing and Yosemite Toad (*Bufo canorus* Camp) Breeding Habitat in Sierra Nevada Meadows. *Rangeland Ecology & Management* 65:56-65.

- Romansic, J.M., E.M. Higashi, K.A. Diez, and A.R. Blaustein. 2007. Susceptibility of newly metamorphosed frogs to a pathogenic water mould (*Saprolegnia* sp.). *Herpetological Journal* 17:161-166.
- Romansic, J., A. Waggener, B. Bancroft, and A. Blaustein. 2009. Influence of ultraviolet-B radiation on growth, prevalence of deformities, and susceptibility to predation in Cascades frog (*Rana cascadae*) larvae. *Hydrobiologia* 624:219-233.
- Romansic, J.M., K.A. Diez, E.M. Higashi, J.E. Johnson, and A.R. Blaustein. 2009. Effects of the pathogenic water mold *Saprolegnia ferax* on survival of amphibian larvae. *Diseases of Aquatic Organisms* 83:187-193.
- Ruggeiro, L.F., K.B. Aubry, A.B. Carey, and M.H. Huff. 1991. Wildlife and Vegetation of Unmanaged Douglas-Fir Forests. Report prepared for the General Technical Report PNW-GTR-285. United States Department of Agriculture, Forest Service, Portland, OR. 474 pp.
- Semlitsch, R.D. 2000. Principles for Management of Aquatic-Breeding Amphibians. *The Journal of Wildlife Management* 64:615-631.
- Sparling, D.W. and G.M. Fellers. 2009. Toxicity of two insecticides to California, USA, anurans and its relevance to declining amphibian populations. *Environmental Toxicology and Chemistry* 28:1696-1703.
- Spencer, C.N. and F.R. Hauer. 1991. Phosphorus and Nitrogen Dynamics in Streams during a Wildfire. *Journal of the North American Benthological Society* 10:24-30.
- Stolarski, R., R. Bojkov, L. Bishop, C. Zerefos, J. Staehelin, and J. Zawodny. 1992. Measured Trends in Stratospheric Ozone. *Science* 256:342-349.
- Thompson, J. 2007. PNW Mountain Meadows - Here Today, Gone Tomorrow? Meadow Science and Restoration. *Science Findings* 94:5. <<http://www.fs.fed.us/pnw/>>. Accessed Aug 2021.
- United States Department of Agriculture (USDA). 2011. Nationwide Aerial Application of Fire Retardant on National Forest System Land; Record of Decision. Report prepared for the USDA Forest Service, National Aviation Management. United States Department of Agriculture, Forest Service, Washington D.C. 74 pp.
- United States Department of Agriculture (USDA). 2011. National Roadmap for Responding to Climate Change. Report prepared for the USDA, Forest Service. United States Department of Agriculture, Washington, D.C. 1-32 pp.
- Vinson, M. 1998. Effects of recreational activities on declining Anuran species in the John Muir Wilderness CA. Thesis, University of Montana, Missoula. 94 pp.
- Vonesh, J.R. and O. De la Cruz. 2002. Complex Life Cycles and Density Dependence: Assessing the Contribution of Egg Mortality to Amphibian Declines. *Oecologia* 133:325-333.
- Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and Earlier Spring Increase Western U.S. Forest Fire Activity. *Science* 313:936-940.
- White, E.M., J.M. Bowker, A.E. Askew, L.L. Langner, J.R. Arnold, and D.B.K. English. 2016. Federal Outdoor Recreation Trends: Effects on Economic Opportunities. Report prepared for the U.S. Forest Service,

Portland, Oregon. United States Department of Agriculture Forest Service Pacific Northwest Research Station General Technical Report, Olympia, Washington. 56 pp.

Woodward, A., E.G. Schreiner, and D.G. Silsbee. 1995. Climate, Geography and Tree Establishment in Subalpine Meadows of the Olympic Mountains, Washington, U.S.A. *Arctic and Alpine Research* 27:217-225.

Appendix III. Habitat Suitability Model

Methods for the development of the Habitat Suitability Model used in the future condition projections.

Environmental data layers used in building models were obtained primarily from Climate Toolbox (<https://climatetoolbox.org>) and fell within three major categories: climate, hydrology, and agriculture. Climate variables include: minimum winter (Jan-Feb) temperature, maximum summer (Jun-Aug) and fall (Sep-Nov) temperature, winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug), and fall (Sep-Nov) precipitation. Hydrology layers included April 1st snow water equivalent, mean annual (Jan-Dec) soil moisture as well as mean seasonal (winter, spring, summer, and fall) soil moisture. Lastly, we used annual (Jan-Dec) potential evapotranspiration from the agricultural category, which represents the maximum water demand for a reference grass crop calculated using the FAO Penman-Monteith method. These layers are the mean value of baseline conditions from 1971-2000. Additionally, two terrain-based layers were used, a 1km digital elevation model (DEM) from USGS National Elevation Dataset (USGS 2019) and Topographic Wetness Index (TWI) derived from the DEM. Finally, for future condition projections, we used the same layers from Climate Toolbox listed above for two time periods (2010-2039 and 2040-2069) under two different emissions scenarios (RCP 4.5 and RCP 8.5). The future climate and agricultural layers are projections from 20 climate models and 2 scenarios (RCP 4.5 and 8.5) that were downscaled to a ~4-km (~2.49-mi) resolution across the US (Abatzoglou and Brown 2012). Hydrology layers are projections from 10 global climate models and 2 scenarios simulated using the Variable Infiltration Capacity (VIC v 4.1.1.2) hydrology model, forced with the downscaled MACAv2-Livneh data 1950-2005 (historic) and 2006-2100 (future) to 1/16th degree (Mote et al. 2014).

All Climate Toolbox environmental data layers were resampled to ~1-km (~0.62-mi) spatial resolution rasters with the same extent and cell alignment. Cubic spline interpolation was used for resampling continuous variables.

We digitized presence survey data supplied from state and federal partners to generate the occurrence data used in modeling. Only point location data was used and this resulted in 8,129 occurrence points. Occurrence data was thinned so that only one occurrence point per raster cell was used to prevent pseudo-replication. This reduced the total number of occurrence points to 1,709 for model building.

All predictor variables were checked for correlation using Pearson's correlation coefficient. Variables with a correlation coefficient ($r \leq -0.7$ or ≥ 0.7) were removed. The variable within a correlated pair that had more ecological relevance was retained. Variables that had multiple high intercorrelations with other variables of ecological meaning were also removed. The resulting variable set applied to each model included annual potential evapotranspiration, snow water equivalent, spring (Mar-May) soil moisture, summer (Jun-Aug) precipitation, winter (Dec-Feb) precipitation and minimum temperature, DEM, and TWI.

The habitat suitability model (HSM) (a.k.a., species distribution model) was conducted using the BIOMOD 2 (Thuiller et al. 2017) package for R v4.1.0 (R Core Team, 2021). Formatted presence only locations of *Rana cascadae* were imported into BIOMOD 2. Raster files were stacked and then data were formatted according to the species dataset. Then, five different HSM algorithms were run; the algorithms included were: Generalized Linear models (GLM), Generalized Boosted models (GBM), Generalized Additive models (GAM), Maximum Entropy (MAXENT) and Random Forests (RF). Prior to building the models, pseudo-absence (PA) and background points were generated depending on the model algorithm. We set

the number of pseudo-absences to equal the number of presences from the dataset for the GBM and RF algorithms and used 10,000 background points for GAM, GLM, and MAXENT (Barbet-Massin et al. 2012). PA points were created using the 'sre' algorithm which places PA points in areas outside of the conditions of a selection of 10 percent of the presence points.

Cross-validation accuracy levels were based on 5-fold cross-validation and spatial blocks assuming an ~86 km (~53.44-mi) autocorrelation range as estimated on the 8 quantitative environmental layers using the blockCV R package (Valavi et al., 2019).

For model evaluation, we calculated AUC, True Skill Statistic (TSS), and sensitivity and specificity (Allouche et al. 2006). Implemented variables were evaluated by variable importance (Figure 1) and response curves (Figure 2), which were calculated and created with the associated functions embedded in Biomod 2. The variable importance is given as a value between 0 and 1 with 1 as the highest possible value. The higher the value of a specific variable, the higher is its influence on the model. However, the calculation technique for variable importance (Pearson's correlation) does not account for interactions between implemented variables and hence does not sum up to 1. Response curves demonstrate the quantitative relationship between environmental variables and the logistic probability of the presence of the species (habitat suitability).

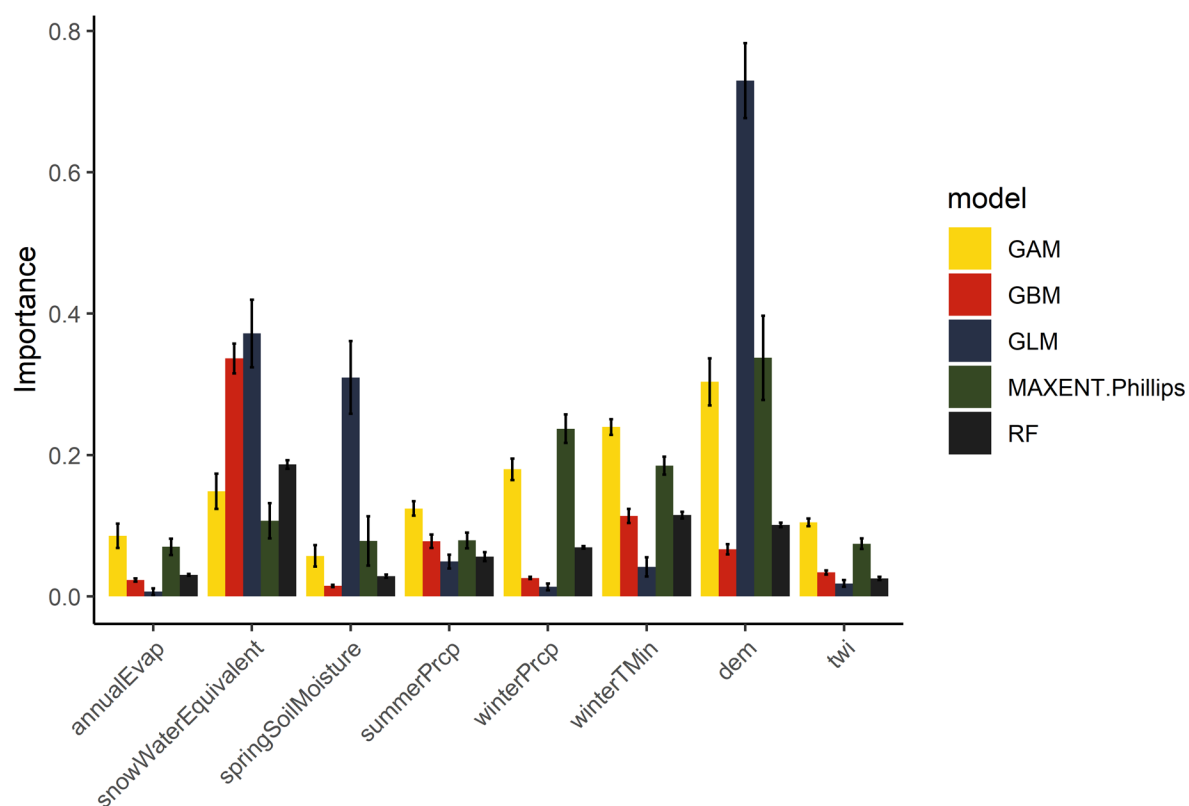


Figure 1. Relative importance of each covariate by model algorithm.

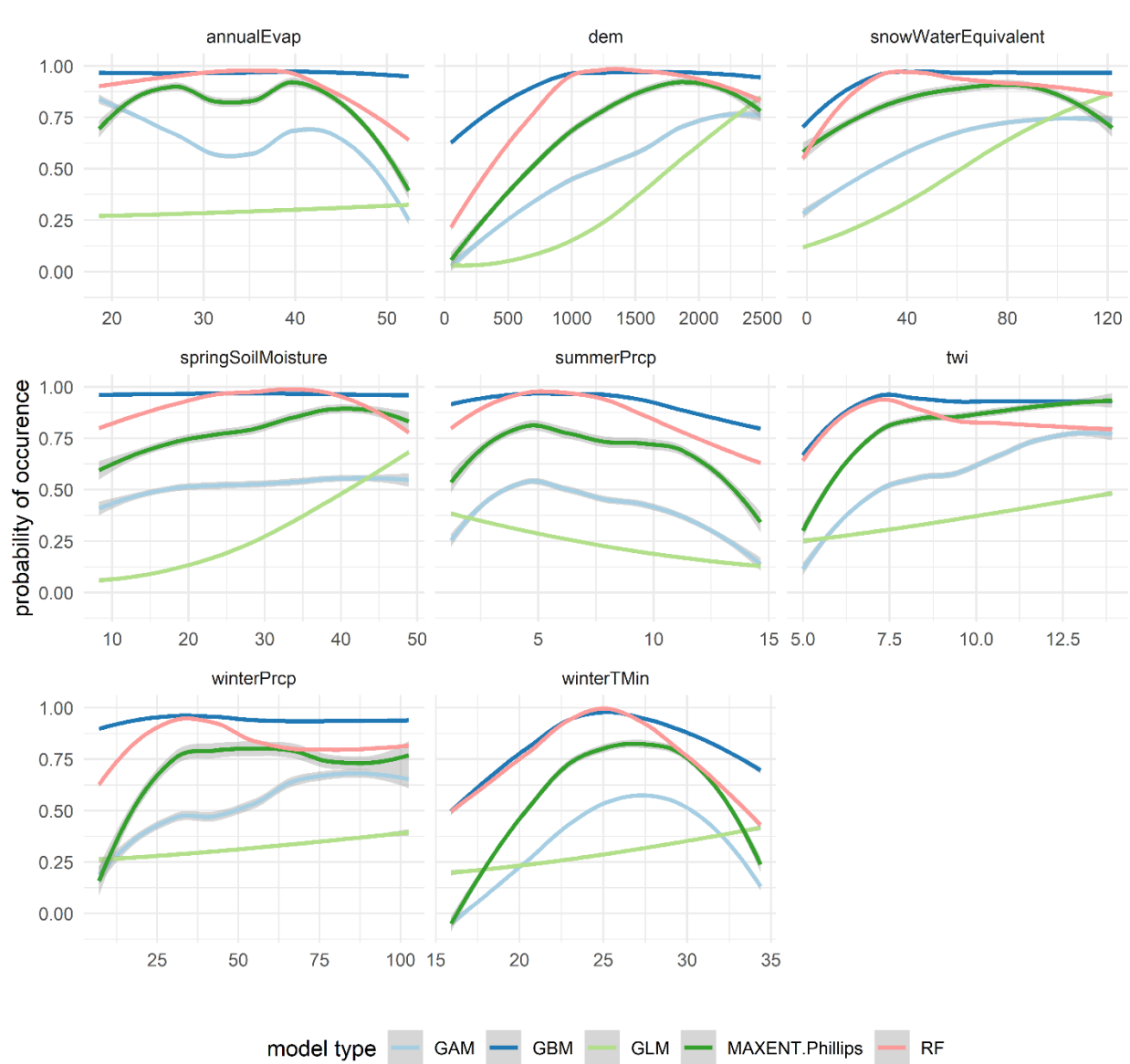


Figure 2. Response curves for each covariate by model algorithm.

Ensemble models were used as they are generally thought to decrease the predictive uncertainty of single models by combining their predictions (Araújo et al. 2005). To accurately compare performance of ensemble models with individual model outputs we used a ‘two-step’ internal validation approach (Hao et al. 2019, Marmion et al. 2008). We first divided all presence and pseudoabsence/background data into ‘outer’ training and testing sets and then further divided outer training sets into ‘inner’ training and testing sets, in both cases using a 70/30 split. The inner data was used to train the final individual and ensemble models. These outputs were then validated on the outer testing set which represents an ‘independent’ dataset (Figure 3).

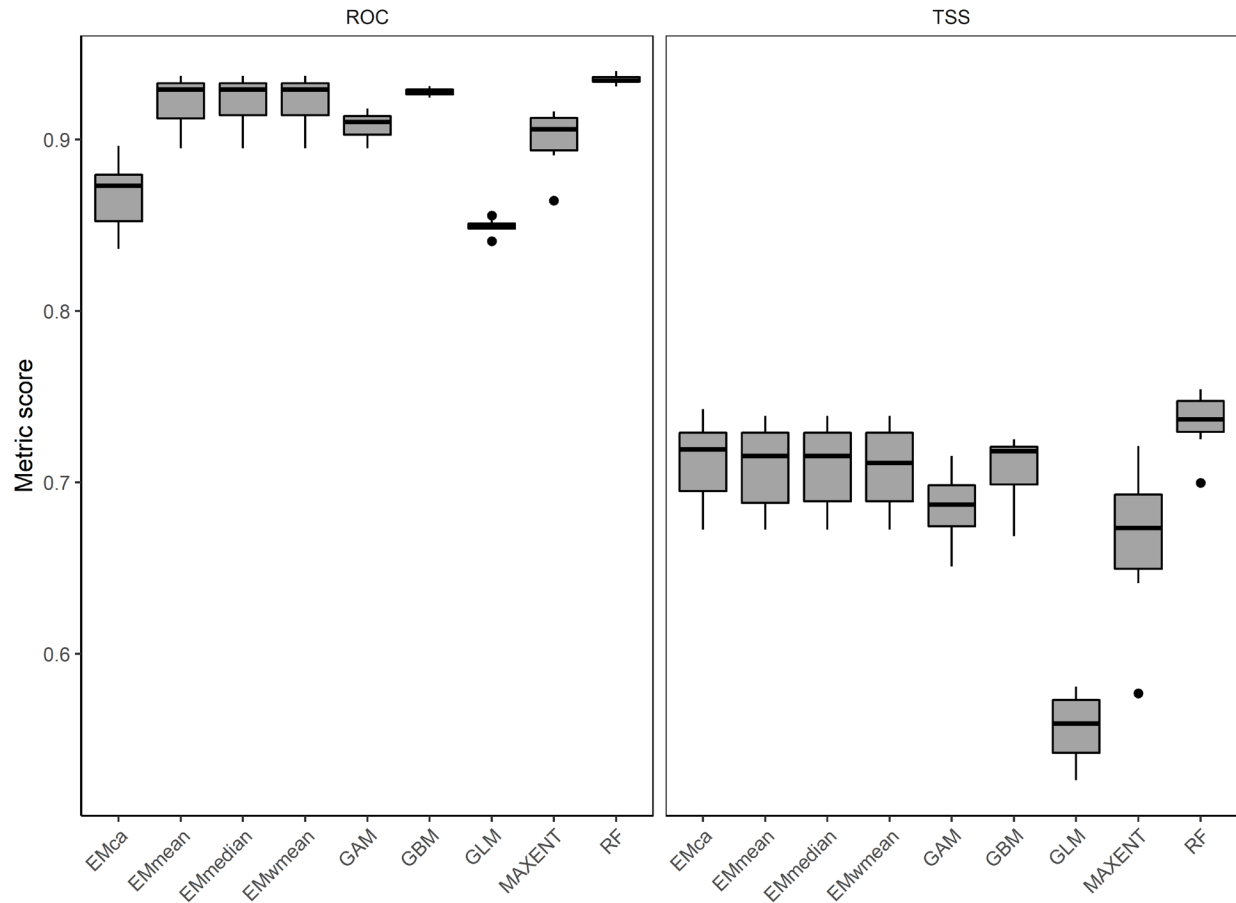


Figure 3. Area under the curve (ROC) and True skill statistic (TSS) values for each ensemble method and algorithm.

Ensemble models were generated from individual modeling outputs using $TSS > 0.6$ as a threshold. We used four common ensemble methods: committee averaging, mean, median, and weighted mean. Committee averaging is calculated by first transforming individual models into binary (0 and 1) data based on thresholds from the model outputs. Then the score is calculated as the average of binary predictions such that scores close to 0 or 1 indicate that all models agree to predict 0 or 1 respectively. Mean is the mean probabilities of all models. Median is the median probability of all models. Lastly, weighted mean is the mean weighted based on TSS score of the individual model.

Habitat probabilities per ensemble output were projected in Biomod 2. Then projections from each ensemble output were stacked and averaged and according raster files were exported as tif format. In addition, habitat suitability was calculated using the Boyce index, which only requires presences and measures how much model predictions differ from random distribution of the observed presences across the prediction gradients (Boyce et al. 2002). Positive values indicate a model which present predictions are consistent with the distribution of presences in the evaluation dataset, values close to zero mean that the model is not different from a random model, negative values indicate counter predictions, i.e., predicting poor quality areas where presences are more frequent (Hirzel et al. 2006). Using this output, we generated a predicted-to-expected (P/E) ratio curve and reclassified the continuous output from the averaged ensemble models into four habitat classes following methods outlined in Davis et al. (2016).

Literature Cited

- Abatzoglou, J.T. and T.J. Brown. 2012. A comparison of statistical downscaling methods suited for wildfire applications, *International Journal of Climatology*, 32:772-780. <https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/joc.2312>
- Allouche, O., A. Tsoar, R. Kadmon. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology*, 43:1223-1232.
- Araújo, M.B., R.J. Whittaker, R.J. Ladle, and M. Erhard. 2005. Reducing uncertainty in projections of extinction risk from climate change. *Global Ecology and Biogeography*, 14:529–538.
- Barbet-Massin, M., F. Jiguet, C.H. Albert and W. Thuiller. 2012. Selecting pseudo-absences for species distribution models: how, where and how many? *Methods in Ecology and Evolution*, 3:327-338.
- Boyce, M.S., P.R. Vernier, S.E. Nielsen and F.K.A. Schmiegelow. 2002. Evaluating resource selection functions. *Ecological Modelling*, 157:281-300.
- Davis, R.J., B. Hollen, J. Hobson, J.E. Gower, D. Keenum. 2016. Northwest Forest Plan—the first 20 years (1994–2013): status and trends of northern spotted owl habitats. General Technical Report PNW-GTR-929. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 54 p.
- Hao, T., J. Elith, G. Guillera-Aroita, and J.J. Lahoz-Monfort. 2019. A review of evidence about use and performance of species distribution modelling ensembles like BIOMOD. *Diversity and Distributions*, 25:839-852.
- Hirzel, A.H., G. Le Lay, V. Helfer, C. Randin and A. Guisan. 2006. Evaluating the ability of habitat suitability models to predict species presences. *Ecological Modelling*, 199:142-152.
- Marmion, M., M. Parviainen, M. Luoto, R.K. Heikkinen, and W. Thuiller. 2009. Evaluation of consensus methods in predictive species distribution modelling. *Diversity and Distributions*, 15:59-69.
- Mote, P.W., J.T. Abatzoglou, D.P. Lettenmaier, D.P. Turner, D.E. Rupp, D. Bachelet, and D.R. Conklin. 2014. Integrated scenarios of climate, hydrology, and vegetation for the Northwest, final report. Corvallis, Oregon: Pacific Northwest Climate Impacts Research Consortium, Oregon State University.
- R Core Team 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Thuiller, W., D. Georges, R. Engler, and F. Breiner. 2017. biomod2: Ensemble platform for species distribution modeling. R package version 3.3-7. Retrieved from <https://CRAN.R-project.org/package=biomod2>.
- U.S. Geological Survey. 2019. National Elevation Dataset. Accessed September 5, 2019 at URL <https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map>
- Valavi, R. et al. 2019. blockCV: an r package for generating spatially or environmentally separated folds for k-fold cross-validation of species distribution models. *Methods Ecol. Evol.* 10: 225–232.