Species Status Assessment Report for the Foothill Yellow-legged Frog (*Rana boylii*)

Version 2.11, April 2023

Photo credit: Marcia Grefsrud

U.S. Fish and Wildlife Service

Acknowledgements

This document was prepared by the U.S. Fish and Wildlife Service's Sacramento Fish and Wildlife Office (Stephanie C. Prevost and Josh Hull) with assistance from the U.S. Fish and Wildlife Service's foothill yellow-legged frog Core Team comprised of biologists from field and regional offices in the Pacific Southwest Region (Region 8) (Cole Caldwell, Cat Darst, Jenny L. Hutchinson, Nadine Kanim, Robert McMorran, Chad Mellison, John Peters, Katherine Powelson, Arnold Roessler, and Dou-Shuan Yang) and the Pacific Northwest Region (Region 1) (Jeffrey Dillon).

For the rangewide Population Viability Analysis used in this assessment, thank you to Jonathan P. Rose and Brian J. Halstead of the U.S. Geological Survey Western Ecological Research Center, and to Sarah J. Kupferberg. For providing environmental data used in the Population Viability Analysis, thank you to Arthur Cooper, Jason Kreitler, and Benjamin Sleeter. For egg mass count data, thank you to Don Ashton, Jamie Bettaso, Steve Bobzien, Ryan Bourque, Alessandro Catenazzi, Koen Breedveld, Joe Drennan, Earl Gonsolin, Marcia Grefsrud, Andie Herman, Matt House, Sarah J. Kupferberg, Amy Lind, Karla Marlow, Ryan Peek, Alan Striegle, Michael van Hattem, Clara Wheeler, Jeff Wilcox, Kevin Wiseman, California Department of Fish and Wildlife, East Bay Regional Park District, Eel River Recovery Project, Green Diamond Resource Company, Marin Municipal Water District, Marin Open Space District, Pacific Gas & Electric Co., Placer County Water Agency, San Francisco Public Utilities Commission, and U.S. Forest Service.

For providing additional information or insights on foothill yellow-legged frog occurrences, ecology, and/or threats, we thank Andrea Adams, Don Ashton, Ryan Bourque, Andy Fecko, Ted Grantham, Andie Herman, Rob Huff, Patrick Kleeman, Sarah J. Kupferberg, Amy Lind, Deanna H. Olson, Laura Patterson, Christopher Pearl, Ryan Peek, Ben Ransom, Michael van Hattem, Kelli Van Norman, Michael Westphal, Julie Zimmerman, the Bureau of Land Management, the U.S. Forest Service, and the U.S. Geological Survey.

Additionally, valuable peer and partner reviews of a draft of this document were provided by Sarah Bullock, Adam Duarte, Darren Fong, Brian Halstead, Rob Huff, Jade Keehn, Saylor Moss, Deanna H. Olson, Christopher Pearl, Ryan Peek, Brad Shaffer, Michael van Hattem, Kelli Van Norman, and the California Department of Forestry and Fire Protection.

Changes Made Between Version 1.0 and Version 2.0

Following receipt of peer and partner review comments, some changes were made to this Species Status Assessment report. In addition to minor editorial changes throughout the document, one notable change was made to the current condition of resiliency for the North Coast Oregon analysis unit. In Version 1.0 of the report, current resiliency in the North Coast Oregon unit was described as "reduced." Several reviewers commented that there were additional records of detections of foothill yellow-legged frogs in Oregon that, if included in our analyses, may alter our assessment of current condition. Reviewers that are familiar with the species in Oregon, also emphasized the scarcity of survey information for the species in Oregon. Upon obtaining missing data, we reassessed the current condition of the North Coast Oregon unit and determined that current resiliency is "intact." We also removed the four occurrences/stream segments in the northeastern extent of North Coast Oregon unit from consideration in this Species Status Assessment because reviewers commented that they were misidentifications of the species.

Other minor changes between Version 1.0 and Version 2.0 of this report include various clarifications, additions of information and references that further support the report's discussions and conclusions, updated decade of most recent detection for two occurrences and addition of one occurrence along the South Fork Feather River (North Feather analysis unit), addition of nonnative barred owl predation as a potential threat to the species, specific evidence of drying and drought impacts to a population in southern Oregon, and addition of several beneficial influences (conservation efforts and regulatory mechanisms) in Section 7.15. We also incorporated the information from a section of Version 1.0 (entitled "Key Uncertainties") into the text of other chapters, where applicable, instead of presenting the information in a standalone section.

Changes Made Between Version 2.0 and 2.1

Following receipt of public comment on the December 2021 proposed listing rule for the species, some minor changes were made to Version 2.0 of this Species Status Assessment Report. Specifically, we updated Section 4.1 (Oviposition and Rearing Sites) to reflect new information on oviposition sites in the Mokelumne River watershed. Additionally, we updated Section 4.2 (Algal Food (Nutritious Diatoms)) to indicate that poor habitat conditions can facilitate the spread of algal food with low nutrition quality for foothill yellow-legged tadpoles.

Changes made between Version 2.1 and Version 2.11

Following additional review of peer review comments received in response to v1.0 of this Species Status Assessment Report we made some minor revisions to version 2.1 of this report. Specifically, we updated the executive summary to reflect that chytridiomycosis is not necessarily threatening the species primarily in the South Sierra, Central Coast, and South Coast DPSs. Additionally, we removed a discussion in the Metapopulation Structure section (Section 2.9) of using conclusions on genetic differentiation from Dever (2007) to delineate metapopulation boundaries in the species because of information from Peek (*in litt*, 2021b) indicating population connectivity beyond the 10-km distance inferred by Dever (2007). Similarly, we removed a reference to Peek *et al.* (2021) in the Metapopulation Connectivity section (Section 5.5) which was used to support a 10-km boundary to genetic connectivity. Instead Peek *et al.* (2021) suggests that the genetic distance between populations 10-km apart in a regulated watershed is comparable to populations 50-km apart in an unregulated watershed.

Recommended Citation

U.S. Fish and Wildlife Service. 2023. Species status assessment report for the foothill yellow-legged frog (*Rana boylii*), Version 2.11. April 2023. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Sacramento, California.

i) Executive Summary

The U.S. Fish and Wildlife Service (Service) was petitioned to list 53 species of reptiles and amphibians, including the foothill yellow-legged frog (*Rana boylii*), as endangered or threatened under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531-1543), in July 2012 by the Center for Biological Diversity. In July 2015, the Service published a 90-day finding that the petition presented substantial scientific or commercial information indicating that listing may be warranted for the foothill yellow-legged frog (80 FR 37574, July 1, 2015). Based on this status review, the Service will issue a 12-month finding for the foothill yellow-legged frog.

This report summarizes the results of the Species Status Assessment (SSA) for the foothill yellow-legged frog. The SSA begins with a compilation of the best available biological information on the species (taxonomy, life history, and habitat) and the species' needs at the individual, population, and species levels. The SSA then evaluates the current and potential future viability of the species based on the conservation biology principles of resiliency, redundancy, and representation (together, the 3 Rs). The 3 Rs describe the ability of a species to withstand environmental and demographic stochasticity (resiliency), catastrophic events (redundancy), and novel changes in the biological and physical environment (representation). To assess the future viability of the foothill yellow-legged frog, three future scenarios were considered, representing a range of plausible future environmental conditions based on the best available science. Future viability was assessed for a 40-year timeframe (2020–2060).

The historical distribution of the foothill yellow-legged frog extends from the Willamette River drainage in Oregon south to at least the Upper San Gabriel River in Los Angeles County, California. Within this latitudinal distribution, the taxon inhabits foothill and mountain streams between the Pacific coast and the Sierra-Cascade crest, from sea level to approximately 1,524 meters (5,000 feet). The current distribution of the foothill yellow-legged frog has seen range contractions in the southern and, to a lesser extent, northern parts of the species' range. Two rangewide assessments of foothill yellow-legged frog genomics revealed that this taxon is extremely differentiated following biogeographical boundaries (McCartney-Melstad *et al.* 2018, p. 112; Peek 2018, p. 76). These studies delineated six statistically-supported genetic groups (henceforth, clades). The SSA treated each genetic clade as an individual analysis unit, except for the largest clade, which was split into two analysis units (North Coast Oregon and North Coast California units). Population viability was assessed for the species at the rangewide scale and for each individual analysis unit.

Overall population viability depends on the health (resiliency) of foothill yellow-legged frog populations, quantity and distribution of populations (redundancy), and adaptive capacity (representation). The requirements for foothill yellow-legged frog population resiliency include adequate levels of abundance (number of breeding females), reproduction and recruitment, juvenile and adult survival, and population connectivity. The habitat elements that are most important for completion of the foothill yellow-legged frog's life cycle are oviposition and rearing sites (including specific physical, temporal, and hydrological properties), nutritious algal food, invertebrate prey, sufficient hydroperiod, intermittent canopy, geomorphic heterogeneity, interstitial spaces, upland and tributary habitat, and migration and dispersal routes.

Assessment of past, current, and future influences on foothill yellow-legged frog requirements for long-term population viability revealed the following as the most influential threats: altered

hydrology (largely attributable to dams, water diversions, channel modifications), nonnative species, disease and parasites, agriculture (including pesticide drift), mining, urbanization (including roads and recreation), drying and drought, high-severity wildfire, extreme flood events, the disease chytridiomycosis, and the effects of climate change. Some threats (drying and drought, extreme flood events, and the effects of climate change) are more strongly affecting population viability in the three southern analysis units. However, these threats may become more common in the northern part of the range as climate change stressors amplify.

Under current conditions, the range of the foothill yellow-legged frog contains three analysis units with “intact” resiliency, one unit with “reduced” resiliency (much resiliency lost but sufficient resiliency in portions of the unit), two units with “substantially reduced” resiliency (most resiliency lost throughout unit), and one unit with “extensively reduced” resiliency (imminent risk of unit-wide extirpation). In terms of redundancy, long-term viability after a catastrophic event is likely in two units (North Coast Oregon and North Coast California), is potentially plausible in one unit (North Sierra), and is unlikely in four units (North Feather and the three southern analysis units — South Sierra, Central Coast, and South Coast). In terms of representation, the species currently has six genetically divergent clades and occupies a range of ecological conditions. A synthesis of the best available science indicates that the species has likely lost diversity due to large extirpations and exhibits an overall trend of decreasing genetic diversity (McCartney-Melstad *et al.* 2018, pp. 120–121; Peek 2018, p. 74). This SSA indicates that the adaptive capacity of the foothill yellow-legged frog is constrained by declining population resiliency and poor genetic connectivity throughout most of the range.

Environmental conditions for the three future scenarios (lower change, mean change, and higher change) are based on the best available projections for changes in environmental parameters that drive foothill yellow-legged frog population dynamics (i.e., forest and shrub cover, stream temperature, annual streamflow (discharge), and climate variability) (Rose *et al.* 2020, pp. 32–33). The environmental conditions in each future scenario are plausible in that they are not meant to represent the lowest and highest projections of what is possible. The mean change scenario represents the mean projected changes in environmental conditions, while the lower change and higher change scenarios reflect the lower end and upper end (respectively) of confidence intervals from projections (Rose *et al.* 2020, pp. 22–23).

Over the next 40 years, population viability is projected to decrease across the foothill yellow-legged frog’s range under all three future scenarios. The southernmost and most genetically distinct analysis unit (South Coast unit) is at high risk of unit-wide extirpation under all future scenarios. Under the lower change scenario, resiliency would be slightly lower than under current conditions for six of the seven units. Under the mean change and higher change scenarios, resiliency would be significantly lower. Four of the seven units (North Feather and the three southern analysis units) would be at risk of unit-wide extirpation or functional extirpation under the mean change scenario and five of the seven units (North Coast California, North Feather, and the three southern analysis units) would be at risk under the higher change scenario. Future extirpations could result either from natural stochasticity (environmental or demographic) because of poor resiliency, or from a single catastrophic event because of poor redundancy. The species’ adaptive capacity is also projected to be lower under all future scenarios because of declining population resiliency, declining genetic diversity, and poor genetic connectivity. While the species is likely to persist into the future beyond 40 years, declining trends are likely to continue, and extirpation of entire genetic clades are possible within 40 years.

ii) Table of Contents

iii) Symbols, Abbreviations, and Acronyms

Symbol, Abbreviation, or Acronym	**Meaning**
=	Equals
>	Greater than
<	Less than
≥	Greater than or equal to
≤	Less than or equal to
%	Percent
3 Rs	Resiliency, redundancy, and representation
°C	Degrees Celsius
°F	Degrees Fahrenheit
Bd	*Batrachochytrium dendrobatidis*
CAL FIRE	California Department of Forestry and Fire Protection
CDFW	California Department of Fish and Wildlife
cm	Centimeter(s)
cm/s	Centimeter(s) per second
CNDDB	California Natural Diversity Database
DNA	Deoxyribonucleic acid
et al.	Et alia ("and others")
Etc.	Et cetera ("and other similar things" or "and so forth")
FERC	Federal Energy Regulatory Commission
ft	Foot/feet
HCP	Habitat Conservation Plan
HSI	Habitat Suitability Index
HUC	Hydrologic Unit Code
in.	Inch(es)
In litt.	In litteris ("communication in writing")
km	Kilometer(s)

Symbol, Abbreviation, or Acronym	**Meaning**
LUCAS	Land Use and Carbon Scenario Simulator model (Sleeter *et al.* 2019)
m	Meter(s)
MDAT	Maximum 30-day average water temperature
mi	Mile(s)
mm	Millimeter(s)
MPVA	Multiple Population Viability Analysis
n	Number
NCCP	Natural Community Conservation Plan
NHD	National Hydrography Dataset
OCAMP	Oregon Connectivity Assessment and Mapping Project
ODFW	Oregon Department of Fish and Wildlife
ORBIC	Oregon Biodiversity Information Center
pers. comm.	Personal communication
pers. obs.	Personal observation
PG&E	Pacific Gas and Electric Company
PVA	Population Viability Analysis
SD	Standard deviation
Service	U.S. Fish and Wildlife Service
SSA	Species Status Assessment
SUL	Snout-urostyle length
U.S.	United States

CHAPTER 1 Introduction

The U.S. Fish and Wildlife Service (henceforth, Service) uses the Species Status Assessment (SSA) framework (Service 2016, entire) and the SSA Report to support an in-depth review of a species' biology and threats. The SSA Report includes an evaluation of a species' biological status, and an assessment of the resources and conditions needed for the species to maintain long-term viability. The SSA Report is intended to be easily updated as new information becomes available and to support all functions of the Service's Endangered Species Program. As such, the SSA Report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year status reviews, would be based if the species warrants listing under the Act.

1.1 The Species Status Assessment Framework

This Report is a summary of the SSA analysis, which entails three iterative assessment stages (Figure 1):

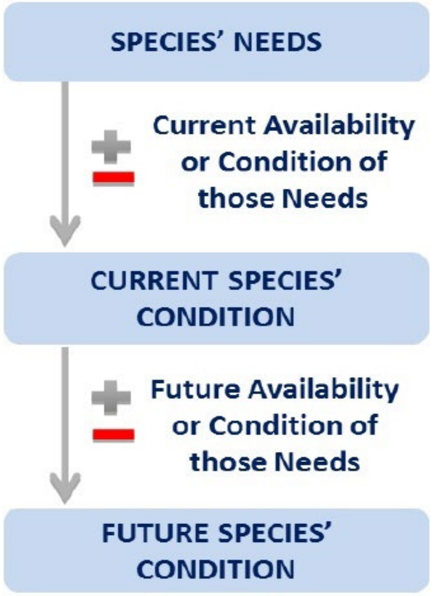


Figure 1. Species Status Assessment Framework (Service 2016, p. 6)

Species Ecology and Needs

An SSA begins with a compilation of the best available biological information on the species (taxonomy, life history, and habitat) and its ecological needs at the individual, population, and species levels. It is based on how environmental factors are understood to act on the species and its habitat.

Current Species Condition

An SSA describes the current condition of the species habitat and demographics and the probable explanations for past and ongoing changes in the abundance and distribution within the species' ecological settings. The ecological settings are the areas representative of the geographic, genetic, or life history variation across the species range.

Future Species Condition

An SSA forecasts the species response to probable future scenarios of environmental conditions and conservation efforts. As a result, the SSA characterizes the ability of the species to sustain populations in the wild over time (i.e., viability). It is based on the best scientific understanding of current and future abundance and distribution within the species ecological settings.

1.2 Resiliency, Redundancy, and Representation

Throughout the assessment, the SSA uses the conservation biology principles of resiliency, redundancy, and representation (3 Rs) (Shaffer and Stein 2000, pp. 306–310; Wolf *et al.* 2015, entire), as a lens to evaluate the current and future condition of the species. Together, the 3 Rs—and their core autecological parameters of abundance, distribution, and diversity—comprise the key characteristics that contribute to a species' ability to sustain populations over time. When combined across populations, they measure the health of the species as a whole.

Resiliency is having sufficiently robust populations for the species to withstand stochastic events (i.e., events arising from random factors). Resiliency can be assessed based on metrics of habitat and population health (e.g., birth versus death rates and population size). Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (i.e., demographic stochasticity), variations in rainfall (i.e., environmental stochasticity), or the effects of anthropogenic activities. For foothill yellow-legged frog, resiliency was measured by assessing (1) spatial and temporal trends in occupancy and reports of population abundance where available, (2) connectivity and isolation among occupied areas, (3) modeled risk of population decline that incorporates demographic and environmental information, and (4) status of threats to the species' viability.

Redundancy describes the ability of a species to withstand catastrophic events. Adequate redundancy spreads risk among multiple populations to minimize the potential loss of the species from catastrophic events. Redundancy is characterized by having multiple, resilient populations distributed within the ecological settings and range of the species. For the foothill yellow-legged frog, we considered the number, spatial distribution, and resiliency of occupied areas and regions.

Representation describes the ability of a species to adapt to changing environmental conditions. It is characterized by the breadth of genetic and environmental diversity within and among populations. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range. For the foothill yellow-legged frog, representation was assessed by considering the diversity of ecological conditions and of genetic material (i.e., ribonucleic acid (RNA) and deoxyribonucleic acid (DNA)) throughout the current range of the species.

1.3 Viability

Viability is the ability of a species to sustain populations in the wild over time. Viability is not a static state, and thus we do not attempt to define the species as viable or not viable. In general, species with higher resiliency, redundancy, and representation, are better protected from stochastic and catastrophic impacts to the environment, can better tolerate threats and adapt to changing conditions, and are thus more viable than those with lower levels of the 3 Rs. We assessed species viability using the best available science to analyze the species' ecology, current condition, and potential future condition under three future scenarios, all in the context of the 3 Rs.

In summary, this SSA is a review of the best scientific and commercial information available, including published scientific literature, gray literature, and discussions with experts, related to the biology and conservation status of the foothill yellow-legged frog.

CHAPTER 2 Species Ecology

2.1 Physical Description

As reviewed in Hayes *et al.* (2016, p. 4), the foothill yellow-legged frog is a small- to medium-sized (37 to 82 millimeters (mm) (1.5 to 3.2 inches (in.)) snout-urostyle length (SUL)) frog with indistinct dorsolateral folds, fully webbed feet, and rough pebbly skin. Dorsal color is highly variable and is usually light and dark mottled gray, olive, or brown, with variable amounts of brick red. The undersurfaces of the posterior abdomen and ventral surfaces of the rear legs are varying shades of yellow. The foothill yellow-legged frog is sexually dimorphic with females attaining larger sizes than males, and mature males having a dark swollen bump on the dorso-medial surface of each thumb, proportionally larger forearm muscles, and narrower waists. Juvenile foothill yellow-legged frogs are similar to adults except for their smaller size (14 to 36 mm (0.5 to 1.4 in.) SUL) more contrasting dorsal coloration, and lack of significant yellow on their undersurfaces (reviewed in Hayes *et al.* 2016, p. 4). Tadpoles can be distinguished from tadpoles of co-occurring species by the greater number (five or more) of rows of teeth in the upper and lower jaw (Storer 1925, p. 256; R. Peek 2019, *in litt.*).

2.2 Taxonomy

The foothill yellow-legged frog retains its classification as *Rana boylii*, ascribed in 1854 by S.F. Baird (Baird 1854, p. 62; Frost 2019, not paginated). In 1955, the *R. boylii* (formerly spelled "*boylei*") group was comprised of six *Rana boylii* subtaxa but were then split into six discrete taxa by Zweifel (1955, pp. 210, 273). The foothill yellow-legged frog is now the only entity classified as *Rana boylii* and the taxon is not subdivided into subtaxa (Zweifel 1968, pp. 71.1–71.2). However, this taxon continues to be the focus of genetic research, which has recently demonstrated that the foothill yellow-legged frog has deeper population structure than that observed in any anuran with similar data (McCartney-Melstad *et al.* 2018, p. 112). The California Department of Fish and Wildlife (CDFW) recently classified this species as having six unique, genetic clades (i.e., lineages) (CDFW 2019b, pp. 4, 13).

For more information about the six biogeographical clades of foothill yellow-legged frog, see CHAPTER 3 Analysis Units.

2.3 Hybridization

Recent genetic research has documented two first-generation hybrids between the foothill yellow-legged frog and the Sierra Nevada yellow-legged frog (*Rana sierra*e) in the Feather River basin of California (Peek *et al.* 2019, p. 4636). However, subsequent genetic admixture studies did not detect any progeny of these hybrids and indicate that first generation hybrids are not reproducing.

2.4 Historical Distribution

The historical distribution of the foothill yellow-legged frog extended from the Willamette River drainage in Oregon south to at least the Upper San Gabriel River in Los Angeles County, California (Figure 2). Within this latitudinal distribution, the taxon occupied foothill and mountain streams between the Pacific coast and the Sierra-Cascade crest, from sea level to approximately 1,524 meters (m) (5,000 feet (ft)) (pers. comm. cited in CDFW 2019b, p. 8). Historical records suggest that individuals of this species may have occasionally used areas that were up to 1,950 m (6,400 ft) in elevation or higher (Hemphill 1952, p. 65; CDFW 2020, dataset). However, there is some uncertainty in the boundaries of this species' distribution because of the difficulty in distinguishing foothill yellow-legged frogs where their range borders or overlaps with ranges of similar species, such as the Sierra Nevada yellow-legged frog. In areas such as the Feather River basin in California, genetic study may be needed to validate historical range boundaries because species misclassification is plausible where yellow-legged frog ranges overlap (Peek *et al.* 2019, p. 4644).

There are also historical records of the foothill yellow-legged frog that are outside of the expected historical range of the species. In 1958, four specimens of foothill yellow-legged frog were collected from the Mokelumne River drainage in the middle of the Central Valley, northern San Joaquin County (CDFW 2020, dataset). These specimens are likely the result of waif dispersal (via flooding) as the area is not considered suitable habitat (CDFW 2019b, p. 34; CDFW 2020, dataset). Also, in 1961, two specimens were collected from an isolated population of yellow-legged frogs in the Sierra de San Pedro Mártir, Baja California Norte, Mexico (Loomis 1965, pp. 78–79; Stebbins 2003, pp. 232, 479). Based on morphological examinations, two ranid experts (R. Stebbins from the University of California at Berkeley and. R. Zweifel from the American Museum of Natural History, New York) identified the specimens as foothill yellow-legged frogs (Loomis 1965, p. 80). However, these specimens were lost in shipment (Loomis 1965, p. 79), and are considered unverified (Thomson *et al.* 2016, p. 88). Based on our knowledge of foothill yellow-legged frog genetic divergence at much smaller spatial scales of isolation (McCartney-Melstad *et al.* 2018, p. 121; Peek 2018, p. 76), the distant Mexico population of yellow-legged frog, now extirpated, might have been considered a different taxon.

Recent observations of the foothill yellow-legged frog (past 20 years), particularly those just outside of the eastern boundary of the species' range in the Sierra Nevada Mountains (Figure 3), suggest that the historical and/or current range boundary may need to be adjusted as more information is acquired. The area just east of the range boundary in the Sierra Nevada Mountains is likely under-surveyed because of difficulty of access due to terrain and/or private property (R. Peek 2021a, *in litt.*).

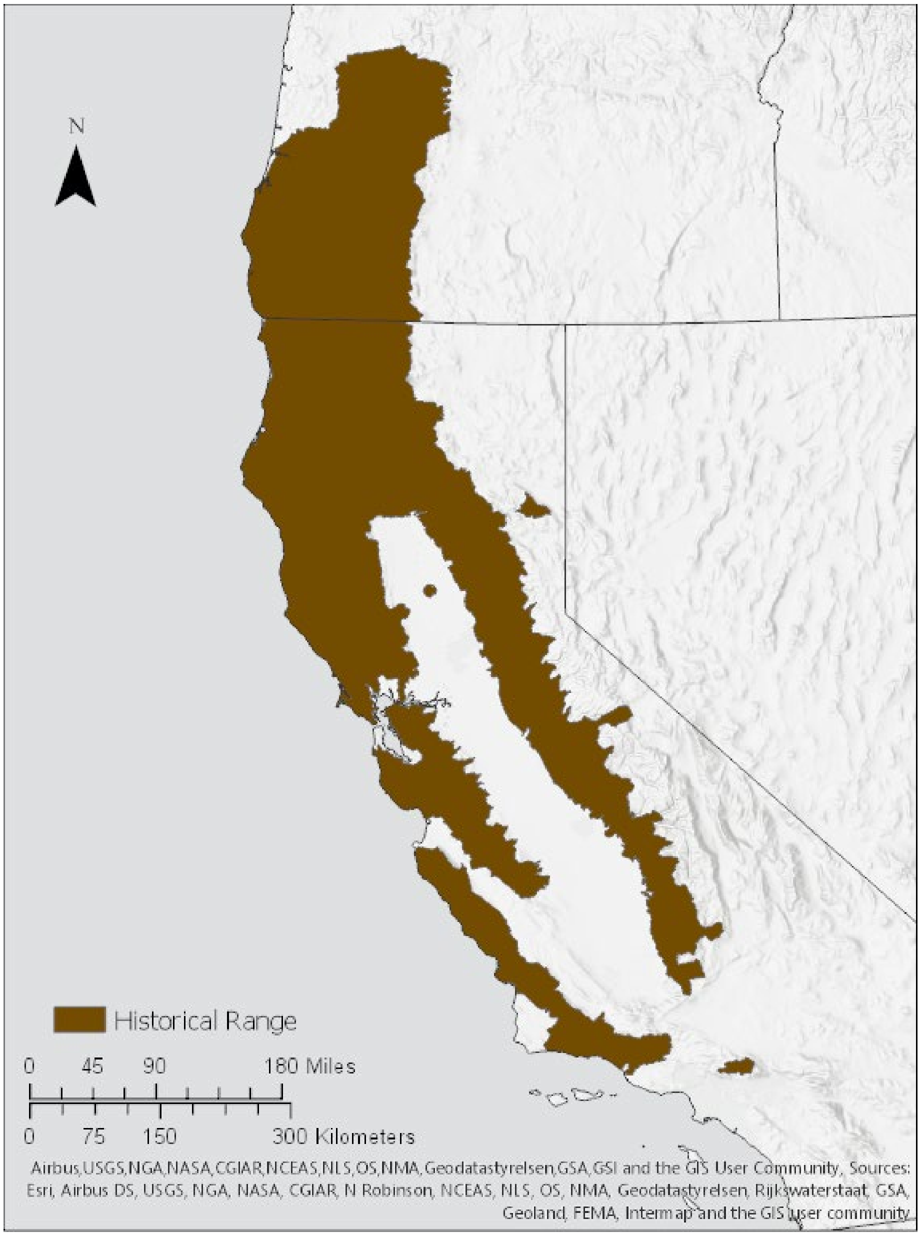


Figure 2. Estimated historical distribution of the foothill yellow-legged frog (adapted from CDFW (2019b, p. 4, figure 1)).

2.5 Current Distribution

The current distribution of the foothill yellow-legged frog generally follows the historical distribution of the species except with range contractions in the southern and, to a lesser extent, northern parts of the species' range (Figure 3). Within areas currently occupied, foothill yellow-legged frog distribution is currently in a declining trend in several parts of the species' range with the species having disappeared from more than half of its historically-occupied locations (Lind 2005, pp. 38, 61, table 2.1). The regions that have been hardest hit by these declines are the

Willamette Valley in Oregon, the southern Sierra Nevada Mountains, and the coast and transverse ranges south of San Francisco Bay (Lind 2005, pp. 65, 68, figures 2.1 and 2.4).

Circa 1970, foothill yellow-legged frog populations in the coast and transverse ranges south of Monterey County, California, abruptly declined. Much of the species' distribution in southern California was extirpated between 1969 and 1980 (Sweet 1983, abstract; CDFW 2020, dataset). By 1981, all California Coast Range and coastal valley occurrences south of northern San Luis Obispo County south to Los Angeles County were extirpated (CDFW 2020, dataset). Combined with natural and anthropogenic factors, the fungus *Batrachochytrium dendrobatidis* (Bd), the causative agent of chytridiomycosis, likely played a role in the rapid extirpation of the foothill yellow-legged frog from southern California (Adams *et al.* 2017b, entire). Increased human use of foothill yellow-legged frog habitat in the 1970s and introduction of bullfrogs as a reservoir host may have played a key role in spreading Bd among foothill yellow-legged frogs in southern California (Adams *et al.* 2017b, pp. 10225–10226). It has also been speculated that record flooding events in January and February of 1969 reduced some populations below their ability to recover (Sweet 1983, abstract).

In Oregon, range contraction has reportedly occurred in the north and east-southeast portions of the historical range (Olson and Davis 2009, p. 10, figure 1). In their conservation assessment, Olson and Davis (2009) estimated that the foothill yellow-legged frog's range in Oregon (based on minimum convex polygon) has contracted by 41 percent and may be entirely extirpated from Benton and Klamath counties (Olson and Davis 2009, p. 10). The researchers also stated that localized extirpations have occurred and continue to occur throughout the species' distribution in Oregon (Olson and Davis 2009, pp. 10–11, figure 1), leading to population fragmentation (i.e., separation of a population into disconnected fragments).

Range contraction has also occurred in the Sierra Nevada Mountains. All foothill yellow-legged frog occurrences south of Johnsondale, California (Tulare County) were extirpated during the 1970s or earlier (CDFW 2020, dataset). The extirpation of all foothill yellow-legged frogs from Caliente Creek (Kern County, east of Bakersfield) during the mid-1970s is attributed to extreme flooding events (CDFW 2020, dataset).

Smaller, localized extirpations have also occurred throughout the range of the species (Figure 3), including extirpation from Sutter Buttes in the northern Central Valley of California. In 1951, a single foothill yellow-legged frog specimen was collected from Sutter Buttes in northern Sutter County, California (Olson *et al.* 2016, p. 362; CDFW 2020, dataset). Herpetological inventories in 2006 and 2007 determined that foothill yellow-legged frogs were extirpated from Sutter Buttes and suitable habitat was no longer available (Olson *et al.* 2016, p. 362).

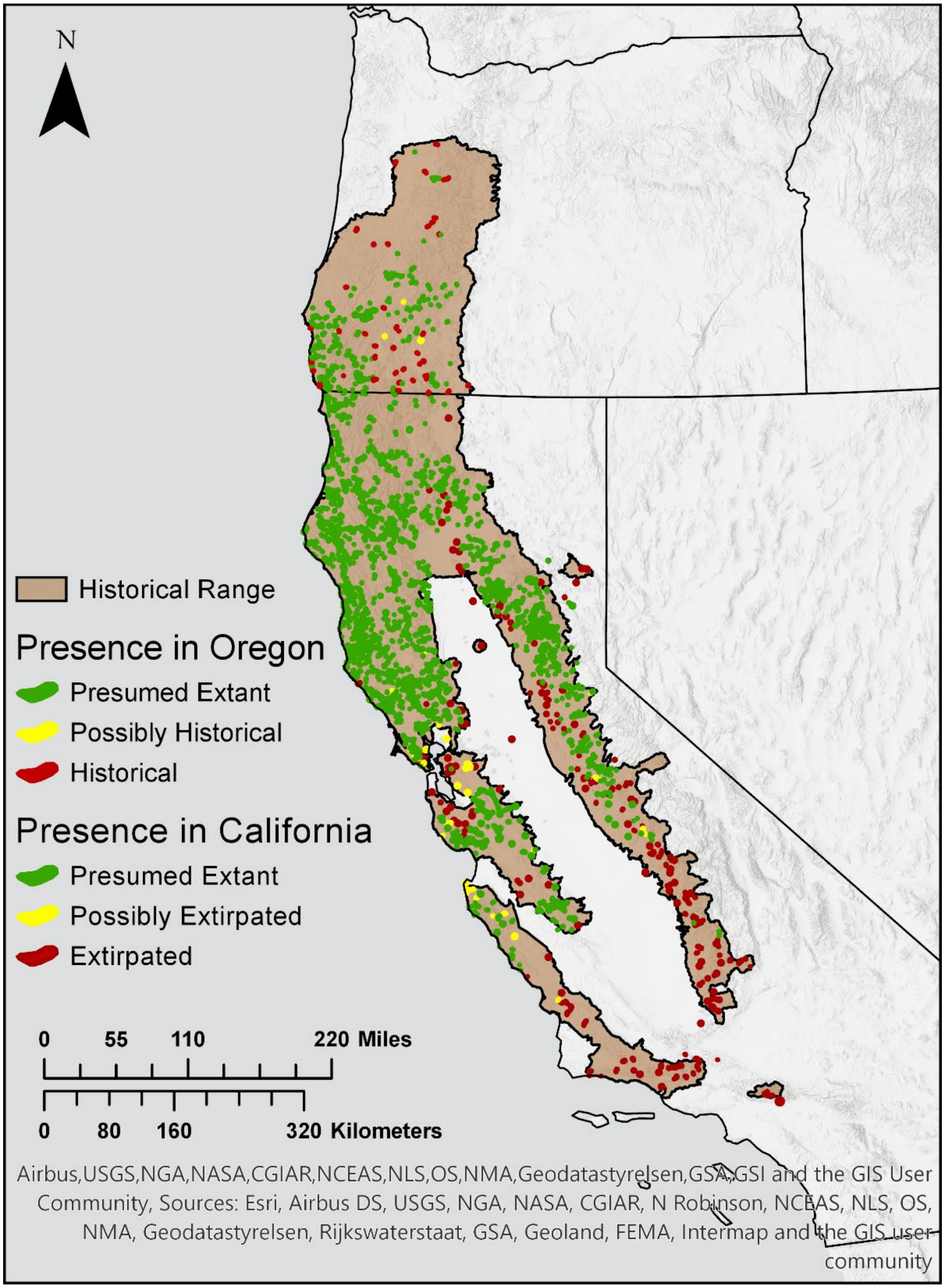


Figure 3. Foothill yellow-legged frog occurrences from the Oregon Biodiversity Information Center (ORBIC 2019, dataset) and California Natural Diversity Database (CNDDB; CDFW 2020, dataset). For presence in Oregon, the green, yellow, and red categories are based on ORBIC designations for element occurrence rank ("EO_rank"). For presence in California, the green, yellow, and red categories are based on CNDDB designations for "presence" in the dataset. See CHAPTER 8 Current Condition for more comprehensive occurrence data and additional information on the current status of foothill yellow-legged frog occurrences.

2.6 Genetic Clades

There is substantial evidence that the foothill yellow-legged frog is biogeographically divided into multiple clades with little or no gene flow between the clades. Earlier studies provided strong evidence that there are deep genetic divisions in this taxon (Lind *et al*. 2011, entire; Peek 2010, pp. 38–47). Subsequent, more in-depth and rangewide genetic studies (McCartney-Melstad *et al.* 2018, entire; Peek 2018, pp. 50–77) confirmed the certainty and depth of the phylogenetic divisions using population genomics (study of genome-wide patterns of DNA sequence variation). The two rangewide genomic studies revealed that there are six discrete genetic clades within the range of the foothill yellow-legged frog (McCartney-Melstad *et al.* 2018, entire; Peek 2018, pp. 50–77) (Table 1; Figure 4).

Table 1. Terminology for the six foothill yellow-legged frog genetic clades.

Clade names (this document)	Clade geography	Clade names used by McCartney-Melstad *et al.* (2018)	Clade names used by Peek (2018)	Clade names used by CDFW (2019b)
North Coast	California and Oregon: Oregon and northwestern California south to San Francisco Bay	Northwestern California/Oregon (NW)	North Coast	Northwest/ North Coast
North Feather	California: southern Cascades to northern Sierra Nevada transition zone (Butte and Plumas counties)	Northeastern California (NE)	Northern Sierra-Feather	Feather River
North Sierra	California: transition between the northern and central Sierra Nevada ecoregions (primarily Yuba, Sierra, Nevada, and Placer counties)	Northeastern California (NE)	Northern Sierra	Northeast/ Northern Sierra
South Sierra	California: Sierra Nevada from the South Fork American River sub-basin (El Dorado County) to the Tehachapi Mountains	Eastern California (E)	Southern Sierra	East/ Southern Sierra
Central Coast	California: southern San Francisco Bay, Diablo Range, and the Coast Range east of Salinas Valley	Western California (W)	Central Coast	West/ Central Coast
South Coast	California: coastal Santa Lucia Range (west of Salinas Valley), Sierra Madre Mountains, and San Gabriel Mountains	Southwestern California (SW)	South Coast	Southwest/ South Coast

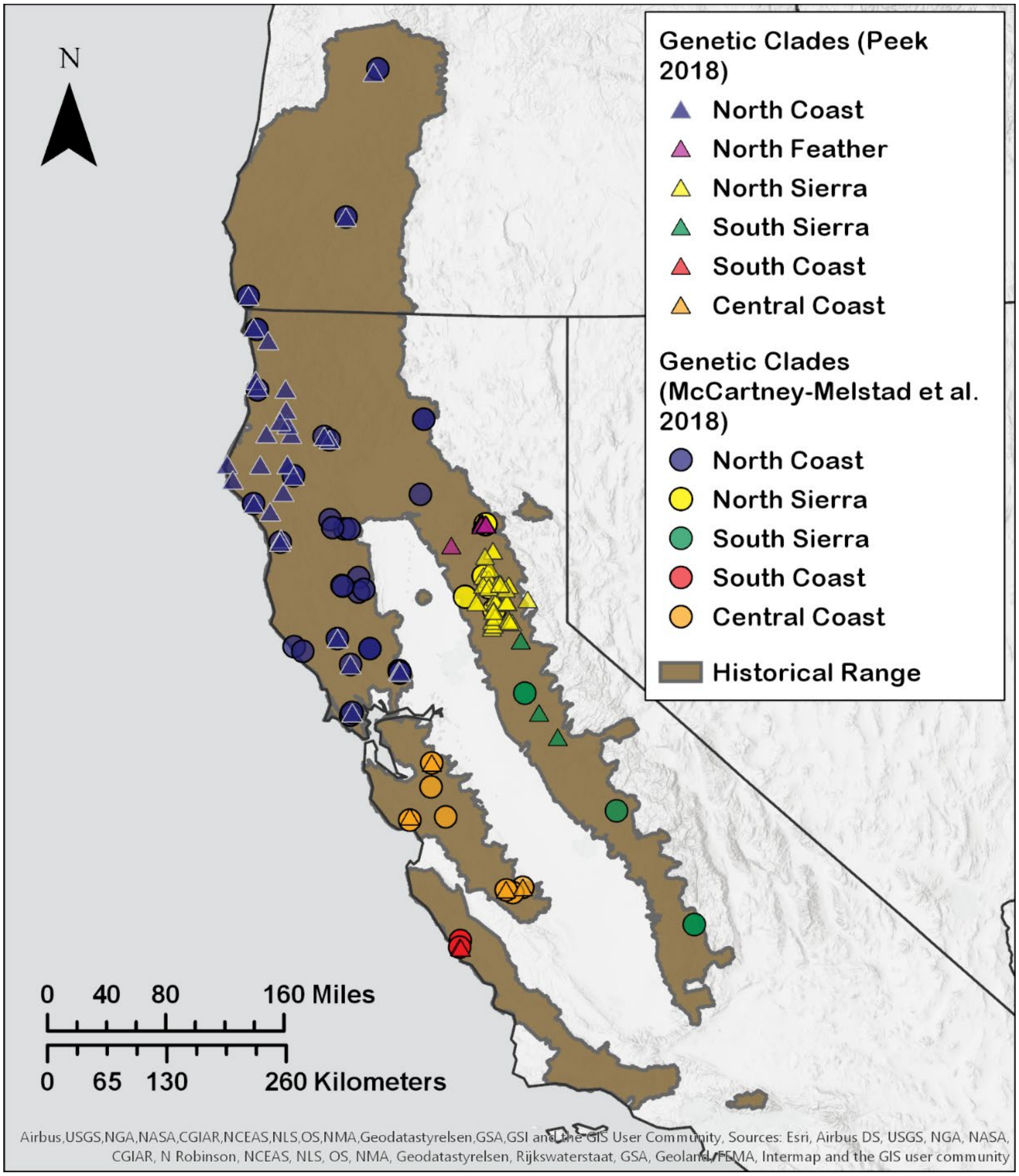


Figure 4. Genetic sample localities from Peek (2018) and McCartney-Melstad *et al.* (2018).

The first study (McCartney-Melstad *et al.* 2018, entire) used genetic samples from 93 foothill yellow-legged frogs and identified five reciprocally monophyletic clades[1] associated with five

---

[1] Reciprocal monophyly indicates that there is no interbreeding among clades and that the clades have been genetically isolated from each other for a long period of time. Each clade of foothill yellow-legged frog is composed only of individuals that descended from a common ancestor to that clade and does not include descendants from any other foothill yellow-legged frog clades. This means that individuals from one clade are all more closely related to each other than to any individuals from other clades.

geographic regions (Figure 4), each with 100 percent bootstrap[2] support. The results from several different analytical approaches (maximum likelihood phylogeny, hierarchical Bayesian clustering, analysis of molecular variance, principal components analysis, and population differentiation with admixture analysis) all supported extremely differentiated clades in a spatially cohesive pattern (McCartney-Melstad *et al.* 2018, p. 112). The deepest phylogenetic division was between the coastal localities that are south of the San Francisco Bay (i.e., Central Coast and South Coast clades) and the rest of the range. Within the rest of the range, the South Sierra clade was found to be most differentiated, followed by the split between the North Sierra clade from the rest of the range, comprising a single clade (North Coast clade) that includes all of northwest California (north of San Francisco Bay) and all of Oregon (McCartney-Melstad *et al.* 2018, pp. 114, 116). Principal components analysis broadly supported the phylogenetic results, separating the Central Coast and South Coast clades from each other and all other samples with the South Coast most isolated from all others. Hierarchical structuring (with fastStructure) split the foothill yellow-legged frog into four groups in its first run; it identified the Central Coast, South Coast, North Coast, and grouped the northern Sierra and southern Sierra clades together (North Sierra + South Sierra), (McCartney-Melstad *et al.* 2018, p. 117). A specific genetic analysis of only the Sierra Nevada group subdivided the Sierra localities into three groups (McCartney-Melstad *et al.* 2018, p. 117). The subdivisions were consistent with the North Sierra and South Sierra clades identified in the phylogenetic analysis except that the cluster analysis also distinguished the Feather River locality as its own group (McCartney-Melstad *et al.* 2018, p. 117). In pairwise comparisons, each of the five monophyletic clades had extremely high levels of differentiation from each of the other clades. The differentiation value (F_{ST} — value between 0 and 1 that measures genetic differentiation due to variance in allele frequencies between different groups or subpopulations) was highest (0.794) between the South Coast and South Sierra clades; and was lowest (0.312) between the North Coast and North Sierra clades, with the South Coast being most differentiated (McCartney-Melstad *et al.* 2018, p. 120).

The second genomic study (Peek 2018, entire) provided additional geographic and genetic resolution to clade divisions by examining an entirely new genetic dataset. Peek (2018, pp. 52–53) analyzed genetic samples from 1,103 individual foothill yellow-legged frogs across the extant range of the species, and with greater coverage of localities in the northern Sierra Nevada range (Figure 4). Like McCartney-Melstad *et al.* (2018, entire), multiple analytical methods were used to quantify genetic structure, including principal components analysis, population differentiation (F_{ST}), and admixture analysis. The principal components analysis identified patterns that largely conformed to the five clades described by McCartney-Melstad *et al.* (2018) but also identified another discrete group (North Sierra-Feather clade) (Peek 2018, pp. 63–64). The North Sierra-Feather (henceforth, North Feather) clade had been included in the North Sierra phylogenetic cluster in the McCartney-Melstad *et al.* (2018, figure 1 on p. 114) study. While remaining genetically distinct, the North Coast and North Sierra groups showed consistent patterns of substructure and limited admixture (Peek 2018, pp. 65–66). Peek (2018, p. 68) also used pairwise comparisons (F_{ST}) to obtain measures of differentiation, but did so by pairing individual localities, instead of clades. Differentiation values (F_{ST}) for paired localities ranged from 0 (no differentiation) to 0.646 (very great genetic differentiation (Wright 1978, p. 85; Hartl

---

[2] Bootstrapping is a statistical method that uses repeated random sampling (with replacement) to measure the confidence of the result of an analysis. To have 100 percent bootstrap support means that all of the analyses of repeated subsamples of the data came to the same conclusion as the analysis of the entire dataset.

and Clark 1997, pp. 118–119, 158)). Congruent with the McCartney-Melstad (2018, p. 120) results, differentiation was greatest between the southern coastal localities (Central Coast and South Coast clades) and those of the other regions (Peek 2018, pp. 68, 73).

2.7 Habitat

The foothill yellow-legged frog is a stream-obligate species that typically occurs from sea level to approximately 1,524 m (5,000 ft) (pers. comm. cited in CDFW 2019b, p. 8). The foothill yellow-legged frog occurs in a wide variety of vegetation types including valley-foothill hardwood, valley-foothill hardwood-conifer, valley-foothill riparian, ponderosa pine, mixed conifer, mixed chaparral, and wet meadow (Hayes *et al.* 2016, p. 5). The extensive range of the foothill yellow-legged frog demonstrates the species' non-specificity in regards to vegetation type and macroclimate of the species' terrestrial habitat component.

Foothill yellow-legged frogs are primarily observed in or along the edges of streams (Zweifel 1955, p. 221; Kupferberg 1996a, p. 1339). Most foothill yellow-legged frogs breed along mainstem water channels and overwinter along smaller tributaries of the mainstem channel (Kupferberg 1996a, p. 1339; GANDA 2008, p. 20). Stream morphology is a strong predictor of breeding habitat because it creates the microhabitat conditions required for successful oviposition (i.e., egg-laying), hatching, growth, and metamorphosis. Foothill yellow-legged frogs that overwinter along tributaries often congregate at the same breeding locations along the mainstem each year (Kupferberg 1996a, p. 1334; Wheeler and Welsh 2008, p. 128).

During the non-breeding season, the smaller tributaries, some of which may only flow during the wet winter season, provide refuge while the larger breeding channels may experience overbank flooding and high flows (Kupferberg 1996a, p. 1339). Habitat elements that provide both refuge from winter peak flows and adequate moisture for foothill yellow-legged frogs include pools, springs, seeps, submerged root wads, undercut banks, and large boulders or debris at high-water lines (van Wagner 1996, pp. 74–75, 111; Rombough 2006b, p. 159).

An in-depth discussion of habitat elements required for the foothill yellow-legged frog to complete its life cycle is in CHAPTER 4 Individual-level Habitat Elements.

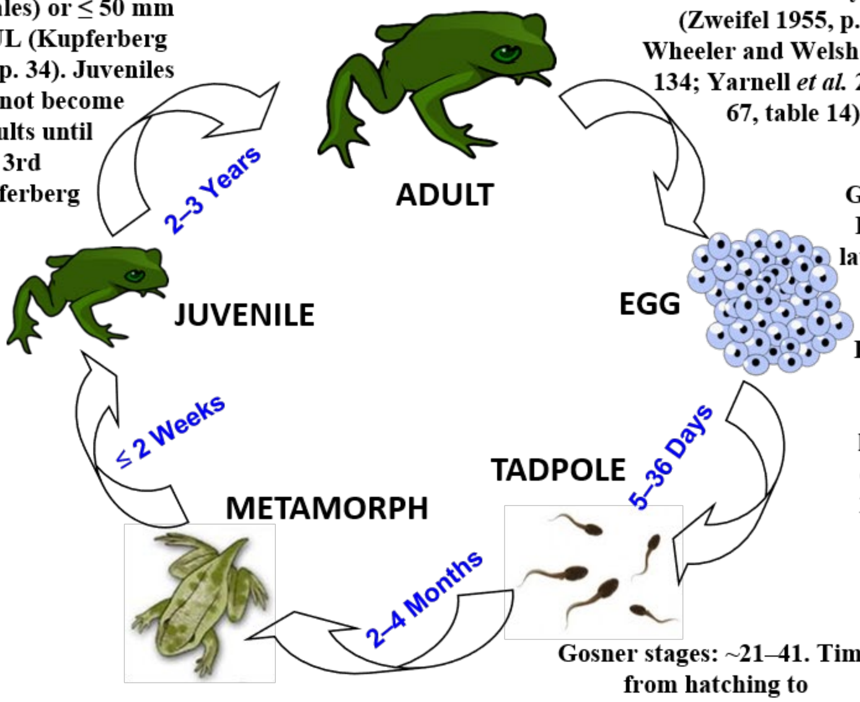
2.8 Life Cycle

There are five primary life stages for the foothill yellow-legged frog — egg, tadpole, metamorph, juvenile, and adult. Each new life cycle begins with breeding (Figure 5). This section summarizes foothill yellow-legged frog ecology related to breeding and each of the five life stages.

Breeding

Throughout the range of the species, breeding takes place between late March and early July (Zweifel 1955, p. 228; Yarnell *et al.* 2013, pp. 64, 67, table 14), during the transition from wet season to dry season. Onset and duration of the foothill yellow-legged frog breeding season is plastic and closely linked to the natural hydrologic cycle (Wheeler and Welsh 2008, p. 128) and water temperature (Kupferberg 1996a, p. 1337; Wheeler *et al.* 2018, p. 294). Male frogs begin breeding vocalizations when water levels and flow rates decrease following rain and snowmelt runoff events (Wheeler *et al.* 2018, p. 293). In general, the initiation of breeding occurs during a gradual decrease in stream flow rate while water temperatures rise above 10 degrees Celsius (°C) (50 degrees Fahrenheit (°F)) (Kupferberg 1996a, p. 1340; GANDA 2008, p. 30; Wheeler and Welsh 2008, p. 137; Yarnell *et al.* 2013, pp. 64–68; Hayes *et al.* 2016, p. 13; Wheeler *et al.* 2018, pp. 293–294).

Initiation of breeding activity and oviposition (i.e., egg-laying) is extremely variable among years and by geography (Wheeler *et al.* 2018, pp. 289, 292–293). Breeding may occur earlier during low base-flow years and later during high base-flow years (Kupferberg 1996a, p. 1337 (Eel River); Wheeler and Welsh 2008, p. 136 (Hurdygurdy Creek); Yarnell *et al.* 2013, p. 66, figure 41 (North Fork American)). However, studies in some locations suggest that initiation of breeding activity is more closely linked to photoperiod (i.e., day of the year) than to interannual variations in streamflow (Gonsolin 2010, p. 49). Temporary cessation of breeding activity has been observed when rain events increase stream flow (Wheeler and Welsh 2008, p. 136; Gonsolin 2010, p. 51). This may occur because higher flows submerge male calling sites and underwater velocities would be too high for oviposition (Wheeler and Welsh 2008, p. 136). In Oregon, larger populations (i.e., those with more than 100 breeding adults) consistently had longer periods of breeding activity than smaller populations and researchers potentially attributed the longer breeding season duration to the influence of population abundance (unpublished data cited in Hayes *et al.* 2016, p. 14).



Breeding activity lasts for 14–52 days between late March and early July (Zweifel 1955, p. 228; Wheeler and Welsh 2008, p. 134; Yarnell *et al.* 2013, p. 67, table 14).

Gosner stages: 1–20. Egg-laying between late March and early July (Yarnell *et al.* 2013, pp. 64–68; Hayes *et al.* 2016, p. 13). Embryonic development is highly temperature dependent (Zweifel 1955, p. 229; Hayes *et al.* 2016, p. 14).

Gosner stages: ~21–41. Time from hatching to metamorphosis varies in relation to both temperature and algal food availability (Catenazzi and Kupferberg 2013, p. 46).

Gosner stages: 42–46. Metamorphosis typically occurs during late summer (CDFW 2019b, p. 21) and lasts for up to 2 weeks (S. Kupferberg 2020b, *in litt.*).

≤40 mm (males) or ≤ 50 mm (females) SUL (Kupferberg *et al.* 2009c, p. 34). Juveniles typically do not become breeding adults until their 2nd or 3rd spring (Kupferberg *et al.* 2009c, pp. ix, 7–8).

Figure 5. Life cycle diagram of the foothill yellow-legged frog. Gosner stages from Gosner (1960, entire).

Eggs (Embryos)

Oviposition is the laying of an egg mass (Figure 6), which contains many individual foothill yellow-legged frog embryos (Gosner stages[3] 1 to approximately 20 (Gosner 1960, entire)). Oviposition typically occurs between late March and June, depending on geography and environmental conditions (Hayes *et al.* 2016, p. 13). Oviposition can occur as late as July in the Sierra Nevada Mountains when the snowmelt recession occurs later in the summer (Yarnell *et al.* 2013, pp. 64, 67, table 14) or where there are cold-water releases from dams (Hayes *et al.* 2016, p. 13). Female-biased sex ratios at breeding locations also appear to affect timing of oviposition (GANDA 2008, pp. 35–36; unpublished data cited in Hayes *et al.* 2016, p. 14). At individual sites, oviposition spans an approximate 50-day period (Wheeler and Welsh 2008, p. 134) but may be as short as approximately 14 days (Zweifel 1955, p. 228).

---

[3] Gosner stages refer to a system of 46 stages that describes the progression of anuran egg and tadpole development through the completion of metamorphosis (Gosner 1960, entire).

Female foothill yellow-legged frogs lay one egg mass per year, containing approximately 1,000 to 2,500 eggs (Storer 1925, p. 254; Kupferberg *et al.* 2009c, p. 24), but may range from approximately 100 (Hayes *et al.* 2016, p. 5) to more than 4,000 eggs (Kupferberg *et al.* 2009c, figure 2.5 on p. 24). Number of eggs laid per clutch (i.e., egg mass) decreases as the season progresses (Kupferberg *et al.* 2009c, p. 25; Gonsolin 2010, p. iv). This relationship between individual fecundity and laying date appears to be related to the earlier arrival of larger females to breeding areas (GANDA 2008, p. 32; Kupferberg *et al.* 2009c, p. 25; Gonsolin 2010, p. iv).

Egg masses require a narrow range of microsite conditions for successful hatching (Kupferberg 1996a, p. 1336; Lind *et al.* 2016, p. 263). Embryonic development is highly temperature dependent (Hayes *et al.* 2016, p. 14). Hatching may take anywhere from approximately 5 days at 20 °C (68 °F) (Zweifel 1955, p. 229) to 36 days (pers. obs. cited in Hayes *et al.* 2016, p. 15). Oviposition microsites have shallow water depths and slow water velocities when compared to ambient conditions (Kupferberg 1996a, p. 1336; Wheeler *et al.* 2006, p. 7; Bondi *et al.* 2013, p. 93). Substrate (i.e., streambed surface material) also plays a critical role in oviposition site selection, with most egg masses being attached to cobblestones and/or the downstream side of rocks (Storer 1925, p. 253; Kupferberg 1996a, p. 1336). Under ideal conditions, hatching success is approximately 83 percent and does not appear to vary across the species' range (Kupferberg *et al.* 2009c, p. 24).


Photo credit: Marcia Grefsrud

Figure 6. Foothill yellow-legged frog egg mass on cobble substrate in Alameda Creek, Alameda County, California.

Tadpoles (Larvae)

The tadpole (larval) stage (Figure 7), from hatching to metamorphosis (Gosner stages approximately 21 to 41 (Gosner 1960, entire)), may last from approximately 7 weeks (Wheeler *et al.* 2015, p. 1280) to four months (Storer 1925, p. 255; Catenazzi and Kupferberg 2013, p. 46). Time from hatching to metamorphosis varies; tadpoles reach metamorphosis more quickly as temperature and algal food availability increase (Kupferberg *et al.* 2011a, entire; Catenazzi and Kupferberg 2013, p. 46). Unless disturbed, newly hatched tadpoles remain with the egg mass for several days (Ashton *et al.* 1997, pp. 7, 9) (Figure 8). After this, young tadpoles disperse short distances and begin using interstitial spaces in the stream substrate for shelter (Ashton *et al.* 1997, p. 9).

Under sub-optimal conditions, tadpoles remain in this vulnerable life stage for longer, which increases risk of mortality. Furthermore, tadpoles may fail to undergo, or complete metamorphosis prior to fall/winter flows, which can cause mortality because foothill yellow-legged frogs do not have morphological adaptations that would allow them to withstand high water-velocity conditions (Kupferberg *et al.* 2009c, p. 6). In temperature-controlled laboratory experiments, tadpoles from Sierra Nevadan populations demonstrated a capacity for faster growth and development than tadpoles from coastal populations (Kupferberg *et al.* 2011a, pp. 63, 65, figure 38).


Photo credit: Marcia Grefsrud

Figure 7. Foothill yellow-legged frog tadpole (left) from Alameda Creek, Alameda County, California.

Figure 8. Foothill yellow-legged frog tadpoles swimming near an egg mass in Alameda Creek, Alameda County, California.

Metamorphs

The metamorph stage (Gosner stages 42 to 46 (Gosner 1960, entire)) begins when a tadpole grows forelimbs (Figure 9) and ends upon full resorption of the tail. Foothill yellow-legged frog larvae begin to develop hind limb buds at approximately 30 mm (1.2 in.) in length (Storer 1925, p. 255), usually during late August or early September (pers. comm. cited in CDFW 2019b, p. 21). Size at metamorphosis is strongly influenced (positively) by water temperature and nutritious algal food availability (Catenazzi and Kupferberg 2013, entire; Catenazzi and Kupferberg 2018, entire). During metamorphosis, tadpoles rapidly undergo physiological changes that allow them to become terrestrial/aquatic carnivores. The duration of metamorphosis is negatively related to water temperature and can last from a few days to two weeks (S. Kupferberg 2020b, *in litt.*; R. Peek 2020, *in litt.*; M. Rousser 2020, *in litt.*). During this time, metamorphs are especially vulnerable because of their inefficiency moving as either a tadpole or a frog (Arnold and Wassersug 1978, p. 1019). Upon completion of metamorphosis, the young frogs can exit the water and begin a diet of macroinvertebrates.

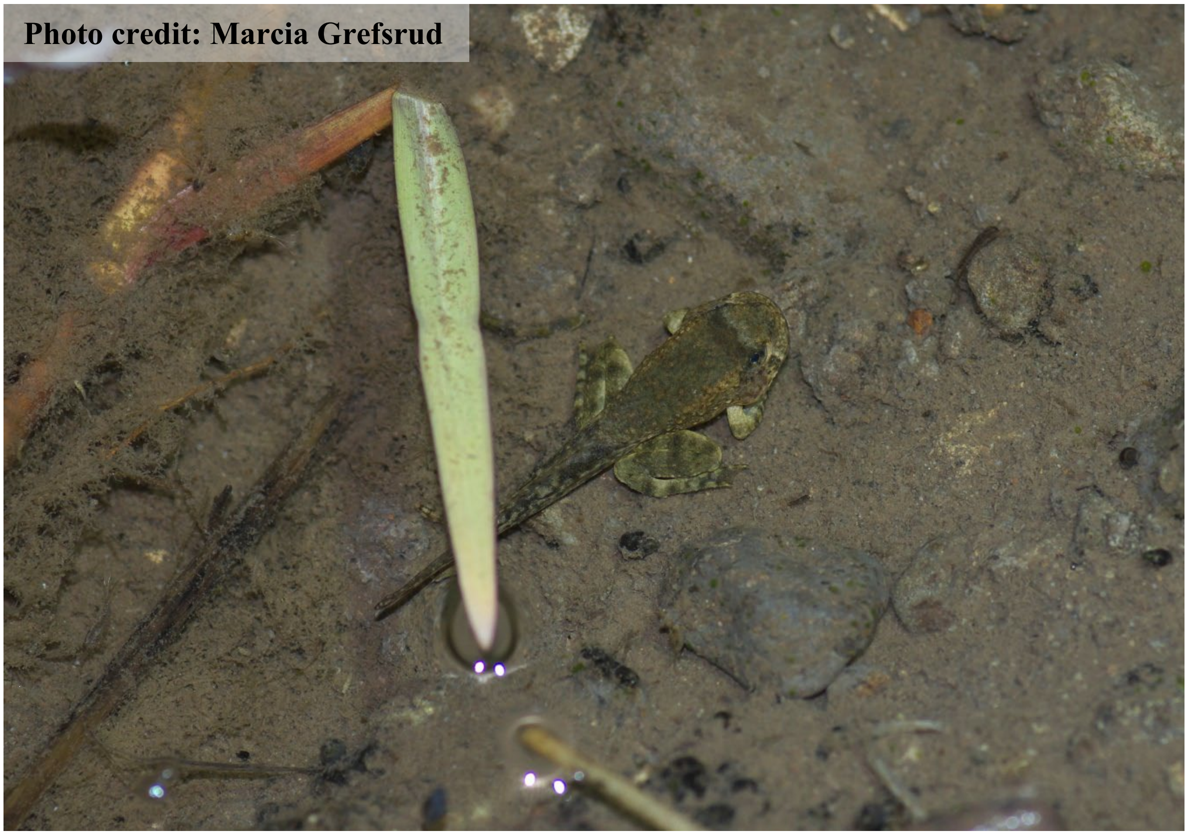


Figure 9. Foothill yellow-legged frog in the metamorph life stage, Sonoma County, California.

Juveniles

Juvenile foothill yellow-legged frogs (Figure 10) are post-metamorphic frogs that have not yet developed sexual reproductive characteristics. Juveniles are typically less than 40 mm (1.6 in.) SUL, with females maturing at a larger size than males (Kupferberg *et al.* 2009c, p. 34). Juveniles can remain active and grow during the winter (Rombough 2006b, p. 159), but grow very little (Storer 1925, pp. 255–256). During the breeding season following metamorphosis, wild juvenile frogs (i.e., yearlings) are still smaller than adults and do not breed (Storer 1925, p. 256; Zweifel 1955, p. 229). In most populations, female foothill yellow-legged frogs begin reproductive activity during their third spring post-metamorphosis; however, evidence suggests that in some central coast populations, females breed during their second spring (Kupferberg *et al.* 2009c, pp. ix, 7–8, figure 1.1).

Figure 10. Juvenile foothill yellow-legged frog in Sonoma County, California.

Adults

Foothill yellow-legged frogs are considered adults when the individual's SUL is greater than 40 mm (1.6 in.) (males) or greater than or equal to 50 mm (1.9 in.) (females) (Zweifel 1955, p. 229; Kupferberg *et al.* 2009c, p. 34). Apparent annual survival of adults is higher than the survival of earlier life stages (except eggs) but is still estimated to be less than 50 percent and might be different for males and females in some populations (Rose *et al.* 2021, p. 7, table 1). A variety of life expectancies have been estimated for foothill yellow-legged frogs (reviewed in CDFW 2019b, p. 7). An analysis of length data estimated maximum age to be between 11 and 13 years, depending upon population and sex (Drennan *et al.* 2015, abstract). Using skeletochronology, another study estimated the average age of 63 foothill yellow-legged frogs (9 males and 53 females) in the Red Bank Creek watershed (Tehama County, California) to be 3.9 years old (range: 1.2 to 7.2) (Bourque 2008, p. 54).

2.9 Spatial and Movement Ecology

Metapopulation Structure

At a population level, foothill yellow-legged frog distributions and movements exhibit the characteristics of metapopulations (Lind 2005, p. 49; S. Kupferberg *et al.* 2009b, p. 132). A metapopulation consists of a network of spatially separated population units (subpopulations) that interact at some level. Subpopulations are subject to periodic extirpation from demographic or environmental stochasticity, but then are naturally repopulated via colonization from nearby subpopulations. Connectivity among metapopulations or among subpopulations within a metapopulation is also subject to stochastic environmental conditions which influence population abundance and rates of dispersal among subpopulations (e.g., water availability).

Seasonal Movement (Dispersal and Migration)

Seasonal movement refers to dispersal (one-way travel) and migration (round-trip travel) that occur in relation to the time of year. The terms "movement" or "travel" are used instead of specifying "dispersal" or "migration" because most seasonal movement observations are not confirmed as either one-way or round-trip. In fact, some individual foothill yellow-legged frogs exhibit site fidelity (returning to the same location during two or more years) while others are recaptured in different locations during the same and/or different years (Wheeler *et al.* 2006, p. 12; Bourque 2008, pp. 62, 64–65).

It is widely observed that adult foothill yellow-legged frogs travel to and from breeding areas each year. During late winter or spring, frogs congregate near suitable breeding sites, which are often found interspersed along mainstem channels (Kupferberg 1996a, p. 1339; GANDA 2008, p. 33; Gonsolin 2010, pp. 55–56). Outside of the breeding season, foothill yellow-legged frogs are primarily found in small tributaries (Kupferberg 1996a, p. 1339; GANDA 2008, p. 33; Gonsolin 2010, p. 55). Timing of movement, much like timing of breeding activity, is associated with time of year, increase in water temperature, and decrease in streamflow velocity (Bourque 2008, p. 61; GANDA 2008, p. 25). Male frogs travel to breeding areas earlier than females and leave breeding areas later than females (GANDA 2008, p. 20; Wheeler and Welsh 2008, p. 137). In 2005, at Flea Valley Creek on the North Fork Feather River (Butte County, California), the first males began their movement to breeding areas in February, more than seven weeks before females (GANDA 2008, p. 25). Females generally depart breeding areas after egg laying, but some females reside in breeding habitat outside of the breeding season (Wheeler *et al.* 2006, p. 9; Bourque 2008, pp. 30, 63–64).

On average, female foothill yellow-legged frogs tend to travel farther than males and overwinter in areas farther from breeding habitat (Wheeler *et al.* 2006, p. 17; Gonsolin 2010, p. iv). In the North Fork Feather River system, males moved an average of 26 m (85 ft) per day and females, 51 m (167 ft) per day, while traveling to breeding locations (GANDA 2008, p. 22). The longest movement observed during the study was 1.90 kilometer (km) (1.18 mile (mi)), completed over six days or fewer (GANDA 2008, p. 22). In a study of a Tehama County, California, population during spring, mobile (i.e., moved at least 35 m (115 ft)) males moved 72 to 578 m (median = 149 m) (236 ft to 0.36 mi (median = 489 ft)) while mobile females moved 130 m to 7.04 km (median = 525 m) (427 ft to 4.37 mi (median = 0.33 mi)) (Bourque 2008, p. 30). Distances were measured as maximum travel distance along the stream network between initial and final capture locations (Bourque 2008, p. 11).

One or more factors may be influential for the seasonal movements undertaken by adult foothill yellow-legged frogs. Breeding sites may lack adequate resources throughout the year and/or they may be less favorable than upland and/or tributary habitats because of predators or winter conditions (e.g., flooding) (Kupferberg 1996a, p. 1339; Bourque 2008, p. 63; Gonsolin 2010, pp.

64–65). Breeding habitats, however, are not entirely inadequate or unfavorable during winter because some foothill yellow-legged frogs appear to overwinter in breeding areas (van Wagner 1996, pp. 73–74; Bourque 2008, pp. 64–65).

Intertributary Movement

While most seasonal movements from an overwintering tributary conclude at breeding sites near the confluence of that tributary with the main stem (Kupferberg 1996a, p. 1339; GANDA 2008, p. 33), a few foothill yellow-legged frogs have been found to travel farther than other frogs from the same overwintering tributary. Three male foothill yellow-legged frogs from tributaries in the North Fork Feather River (Butte County, California) traveled to breeding areas near tributaries that were 0.5 to 0.8 km (0.3 to 0.5 mi) upstream or downstream from the tributary of original capture (GANDA 2008, p. 33). Also in the North Fork Feather River system, a mark-recapture study documented three frogs traveling 3.1–3.8 stream km (1.9–2.4 stream mi) from their summer capture locations in Bean Creek, to downstream portions of Spanish Creek to spring breeding sites (Dillingham 2019, not paginated).

Home Range and Territoriality

During the breeding season, foothill yellow-legged frogs exhibit different movement strategies with some individuals moving very little ("sedentary" individuals that appear to establish home ranges or defend territories) and others moving greater distances without appearing to establish home ranges ("mobile" individuals). Many male foothill yellow-legged frogs establish small calling territories at lek sites (see Section 2.10) during the breeding season (Wheeler and Welsh 2008, pp. 137–138). Over a 17-day period in Hurdygurdy Creek (Del Norte County, California), Wheeler and Welsh (2008, p. 135) measured a mean territory size of 0.58 square m (6.24 square ft) for 15 of 22 (68 percent) males tracked during the breeding season. The other seven males (32 percent) did not appear to be attached to a specific area or home range (Wheeler and Welsh 2008, p. 134). Similarly, four of nine (44 percent) male frogs in the Red Bank Creek watershed (Tehama County, California) made only short-distance movements (≤35 m (≤115 ft)) during the breeding season (Bourque 2008, pp. 11–12, 27). However, the size of the home ranges measured for these sedentary males (median distance of 5.5 m (18 ft) of creek length) (Bourque 2008, p. 27) were much larger than the observed territories in Hurdygurdy Creek, potentially because observations were made over a longer time period in the Red Bank Creek watershed. The five mobile males in the Red Bank Creek watershed moved along a median distance of 149 m (489 ft) of creek length over a period of 20 to 31 days (Bourque 2008, p. 27).

Female foothill yellow-legged frogs also appeared to be either mobile (80 percent) or sedentary (20 percent) during the spring breeding season in the Red Bank Creek watershed (Bourque 2008, p. 30). Sedentary females moved only 2 to 14 m (median = 4 m) (7 to 46 ft (median = 13 ft)) along the stream network (Bourque 2008, p. 30). As reported above in Seasonal Movement (Dispersal and Migration), mobile females moved 130 m to 7.04 km (median = 525 m) (427 ft to 4.37 mi (median = 0.33 mi)) (Bourque 2008, p. 30).

Little is known about home range and territoriality during the non-breeding season, but some study results suggest that foothill yellow-legged frogs tend to be sedentary outside of the breeding season. A study in Clear Creek (Nevada County, California) found that foothill yellow-legged frogs moved more during pre-breeding and egg-laying than during June through February when frogs moved a mean maximum distance of 14 m (46 ft) (van Wagner 1996, p. 130). Females also exhibited strong philopatry to specific pools during June through February (van Wagner 1996, p. 110). In the North Fork Feather River system, frogs were often relocated in the same locations (e.g., same pool) during multiple surveys prior to spring movements (GANDA 2008, p. 22).

Juvenile Movement

Little is known about the movement ecology of juvenile foothill yellow-legged frogs, but some researchers have measured distances to nearest potential natal sites when they documented juveniles traveling or sheltering. In Mendocino County, juvenile frogs were found, apparently dispersing from a natal creek, up into a residential neighborhood (Cook *et al.* 2012, p. 325). Young frogs were primarily found on residential roadways, 16 to 331 m (mean = 71.3 m) (52 to 1,086 ft (mean = 233 ft)) from the creek (Cook *et al.* 2012, p. 325). During October through May, juveniles in northwestern California were found inhabiting small unmapped streams, seeps, inboard ditches of roads, a storm water drainage, and crevices in a moist log near a pond (R. Bourque 2019, *in litt.*). Straight-line distances from the frogs to the nearest breeding habitats ranged from 42 m to 2.7 km (mean = 763 m) (46 to 1.7 mi (mean = 0.47 mi)) (Bourque 2018, unpublished data).

In Clear Creek (Nevada County, California), long-distance movements were recorded for two juvenile frogs during the non-breeding season (June through February). One juvenile moved 264 m (948 ft) over 14 days, and another moved 555 m (0.34 mi) over 92 days (van Wagner 1996, pp. 102–103). However, most juveniles (captured two or more times during the five-year study) appeared to move much less than 100 m along Clear Creek[4] and distance did not significantly differ by breeding versus non-breeding season (van Wagner 1996, pp. 60–61, figure 12).

Overwintering

Overwintering is the least understood aspect of foothill yellow-legged frog ecology (Hayes *et al.* 2016, p. 11). Foothill yellow-legged frogs appear to use different overwintering strategies in terms of seasonal movement and habitat type, even within a single population (Bourque 2008, p. 65). Generally, foothill yellow-legged frogs travel up along small tributaries where they become inactive for a period during the winter. However, foothill yellow-legged frogs may remain active during the winter if conditions are favorable (van Wagner 1996, pp. xix, 74). The foothill yellow-legged frog inactive period is variable among years and by geography, climate, and life stage. The inactive period, if it occurs at all, typically extends from mid-fall until late February or early March, with adults remaining inactive for longer periods than juveniles (Zweifel 1955, p. 226). Activity may begin earlier during mild winters and active individuals have been observed throughout the winter in the San Francisco Bay area (Zweifel 1955, p. 226). Compared to higher elevation populations, coastal populations and those in lower-elevations of the Sierra Nevada might be active for an extra month in the fall and extra month in the late winter; in the highest range elevations, the inactive period may be four or five months long (Zweifel 1955, p. 226).

---

[4] Mean distance was not provided for juveniles by Van Wagner (1996).

For attributes of overwintering habitat, see Section 4.8 Upland and Tributary (Nonbreeding) Habitat.

2.10 Behavior

When out of the water, foothill yellow-legged frogs are typically observed in the open, perched on an exposed rock, sand bar, or sandy shore (Zweifel 1955, p. 223). A radio-telemetry study in Dexter Creek (Santa Clara County, California) found that adult foothill yellow-legged frogs spent approximately three-quarters of the time outside of the water and were under substrate approximately one-third of the time (Gonsolin 2010, pp. 40, 87, figure 18, figure 19).

During the breeding season, foothill yellow-legged frogs exhibit a lek-style mating system, where males congregate at breeding sites and often establish small calling territories to attract female mates (Wheeler and Welsh 2008, pp. 137–138). Several types of vocalizations are made by male foothill yellow-legged frogs, primarily underwater (MacTague and Northen 1993, p. 1; Silver 2017, p. 33). The diversity of calls suggests that vocalizations are used for more than just mate attraction (MacTague and Northen 1993, p. 1). An underwater duet between a male and female foothill yellow-legged frog in amplexus (i.e., the mating position) has also been recorded (Silver 2017, p. 33). A study of vocalizations from foothill yellow-legged frog populations in three California counties (Mendocino, Butte, and Alameda counties) showed significant regional variation in dialect (Silver 2017, p. 30).

CHAPTER 3 Analysis Units

In order to compare the habitat conditions, species needs, threats, and the species current and potential future condition across such a wide-ranging species, we separated the foothill yellow-legged frog range into seven analysis units (Figure 11), largely based on the results of two recent genetic studies. As discussed in Section 2.6 Genetic Clades, the extensive genomic data available for this species demonstrate that there are discrete patterns of biogeographical discontinuity across the taxon's range (McCartney-Melstad *et al.* 2018, entire; Peek 2018, pp. 50–77). We considered the available information and determined that the clade boundaries estimated by CDFW (2019b, pp. 26–27, figure 5, figure 6) were congruent with the best available information. Therefore, we delineated six analysis units in California based on the clade boundaries presented in the CDFW's Status Review of the foothill yellow-legged frog in California (CDFW 2019b, pp. 26–27, figure 5, figure 6) (Figure 11).

We treated the species' range in Oregon as a separate analysis unit (Figure 11), even though the genetic samples from Oregon were grouped with those of the North Coast clade in California (McCartney-Melstad *et al.* 2018, pp. 114, 116, figure 1; Peek 2018, p. 67, figure 3.4). We assessed the status of the foothill yellow-legged frog in Oregon separately for a combination of the following reasons:

- The differences in state laws, regulations, land management, wildlife management, and conservation priorities lead to differences in the types and magnitudes of various current and future threats on either side of the state border (e.g., mining).
- Differences between California's and Oregon's priorities and needs may lead to a different range of plausible future scenarios on either side of the state border (e.g., pressure to transport water from northern to southern California).
- The methods of gathering data or estimating parameters in regards to both foothill yellow-legged frog populations (e.g., types of surveys) and habitat covariates (e.g., stream flow estimation) are different between California and Oregon. Some of these differences would necessitate separate analyses regardless of analysis unit.
- Preliminary review of available information and discussions with species experts suggested that population trends may be different between the North Coast clade in California and the North Coast clade in Oregon.
- There is evidence of deep genetic structure between two groups of North Coast clade samples that may approximately be divided a little north of the California-Oregon border (McCartney-Melstad *et al.* 2018, pp. 117, 123, figure 3). Foothill yellow-legged frog workshop participants expressed concern that Oregon genetic samples were grouped with those of northern California because there were too few Oregon samples (Service 2019, *in litt.*, p. 30).
- Assessing the entire North Coast clade (California and Oregon) as a single unit would make the unit disproportionately large in comparison to the other units.

The assumptions and uncertainties associated with the division of the seven analysis units are in Section 3.1. This chapter also contains brief descriptions of the ecological settings of foothill yellow-legged frog habitat in each of the seven analysis units. Henceforth, the term "unit" is used instead of "clade" when referring to the analysis units (Table 2).

Table 2. Names of the seven analysis units as compared to clade names from column 1 of Table 1.

Analysis unit names	**Clade names** (Section 2.6)
North Coast Oregon unit	North Coast clade
North Coast California unit	North Coast clade
North Feather unit	North Feather clade
North Sierra unit	North Sierra clade
South Sierra unit	South Sierra clade
Central Coast unit	Central Coast clade
South Coast unit	South Coast clade

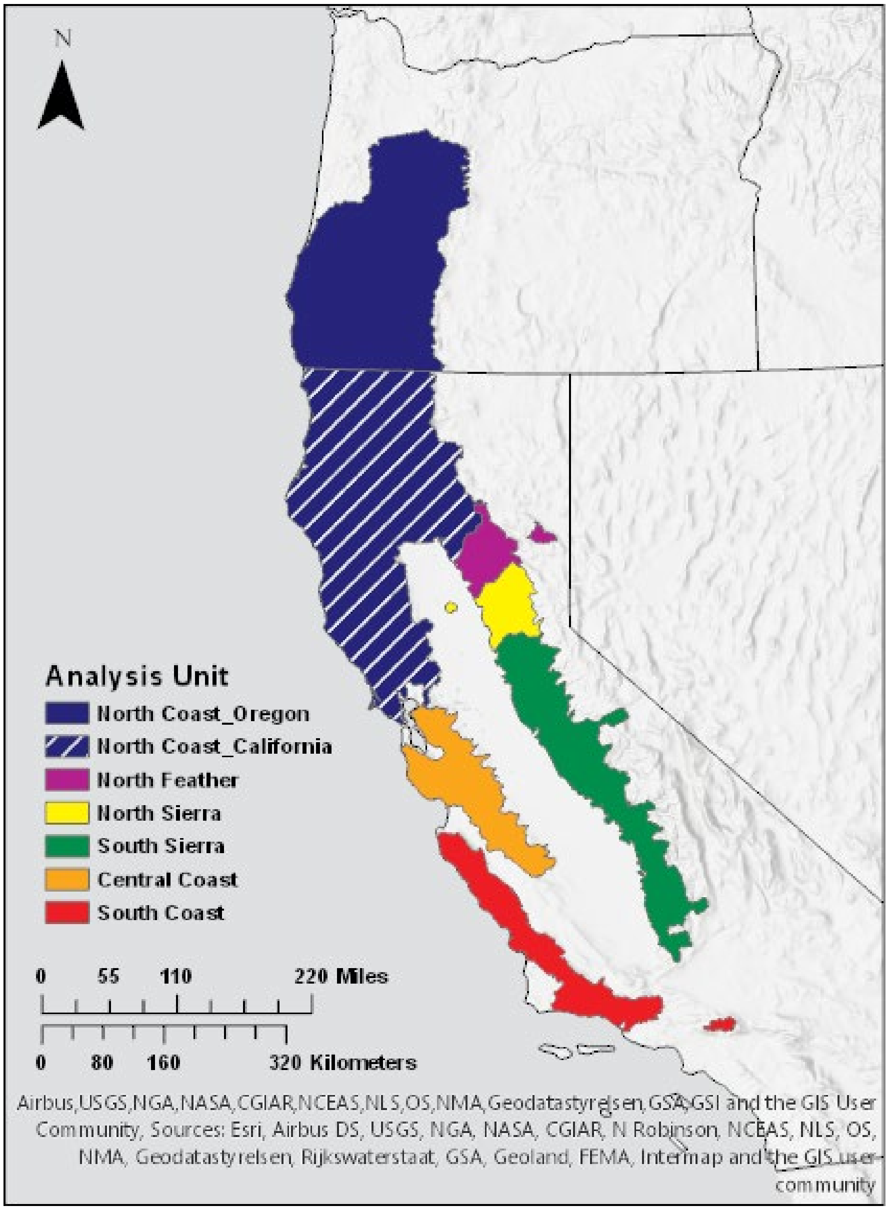


Figure 11. Seven analysis units for the foothill yellow-legged frog SSA.

3.1 Assumptions and Uncertainties

Some of the geographic boundaries that delineate the foothill yellow-legged frog units are fairly certain because of clear physical boundaries, such as the San Francisco Bay, or because of continuous genetic sampling efforts in neighboring watersheds. However, other unit boundaries were estimated or inferred because continuous landscape-level sampling was unavailable. Our best estimation based on the information available of the historical distribution of the South Coast unit includes Los Padres National Forest and Angeles National Forest; however, genetic samples have only been analyzed from the last remnant occurrences along the border between Monterey and San Luis Obispo counties (Figure 4). In addition, the precise boundaries separating the North Feather unit from its neighboring units to the north (North Coast California) and to the south (North Sierra) are also uncertain.

The distinctions between ecological settings occupied by the North Sierra and North Feather units are less clear than they are among the other regions. While the other five units contain ecoregions (Environmental Protection Agency Level IV Ecoregions (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire)) that are unique for the species, the North Sierra and North Feather units occupy transition zones between ecoregions that are also occupied by neighboring units.

Table 3. Mean annual precipitation and mean annual temperature based on 30-yr (1981–2010) normals (PRISM Climate Group 2012). Standard deviations (SD) are in parentheses.

Description	North Coast Oregon	North Coast California	North Feather	North Sierra	South Sierra	Central Coast	South Coast
Mean annual precipitation (SD)	160 cm (63.9) 63 in.	136 cm (55.2) 54 in.	144 cm (50.3) 57 in.	137 cm (39.4) 54 in.	80 cm (31.0) 31 in.	54 cm (22.0) 21 in.	65 cm (19.5) 26 in.
Mean annual temperature (SD)	10.2 °C (2.01) 50.4 °F	12.7 °C (2.37) 54.9 °F	11.6 °C (3.06) 52.9 °F	13.3 °C (2.45) 55.9 °F	13.7 °C (3.40) 56.7 °F	15.2 °C (0.84) 59.4 °F	15.1 °C (1.15) 59.2 °F

3.2 North Coast Oregon Unit

The North Coast Oregon analysis unit includes the foothill yellow-legged frog range north of the California-Oregon border. This unit occupies parts of the Cascade Range, Klamath Mountains, Oregon Coast Range, and the Willamette Valley. The North Coast Oregon unit covers the second largest geographic area of the seven units. When combined with the rest of the North Coast clade (i.e., including the North Coast California unit), this region has the greatest amount of genetic diversity (McCartney-Melstad *et al.* 2018, p. 121; Peek 2018, p. 76). The North Coast Oregon unit has the greatest precipitation and coolest temperatures within the species' range (Table 3; PRISM Climate Group 2012, 30-year climate dataset). The North Coast Oregon unit contains several Level IV Ecoregions that are not found anywhere else in the foothill yellow-legged frog range. Ecoregions unique to this unit include the Coastal Uplands (1b), Mid-Coastal Sedimentary (1g), Southern Oregon Coastal Mountains (1h), Inland and Coastal Siskiyous (78e-78f), Willamette River and Tributaries Gallery Forest (3b), Willamette Valley Foothills (3d), Western

Cascades Montane Highlands (4b), Cascade Crest Montane Forest (4c), Klamath Oak Savanna Foothills (78b), and Umpqua Interior Foothills (78c) (Environmental Protection Agency Level IV Ecoregions (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire)). Photographs of breeding habitats in the North Coast Oregon analysis unit are in Figure 12.

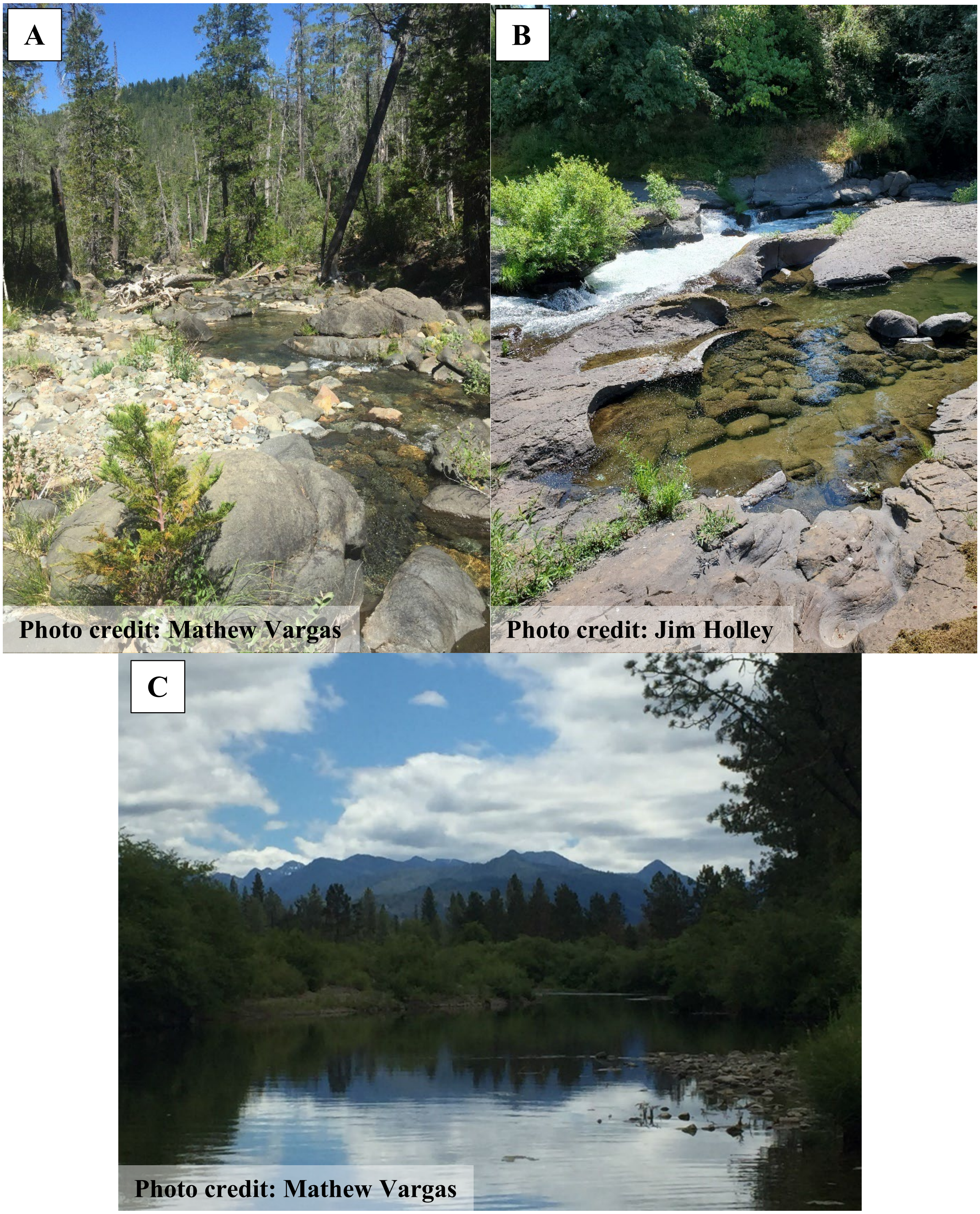


Figure 12. Foothill yellow-legged frog habitat photos from the North Coast Oregon analysis unit, (A) Josephine County, (B) Linn County, and (C) Josephine County, Oregon.

3.3 North Coast California Unit

The North Coast California analysis unit includes all of northwestern California south to the northern border of the San Francisco Bay and east until the approximate borders of Plumas and Butte counties. This unit occupies parts of the Cascade Range, Klamath Mountains, northern California Coast Range, and central California foothills. The North Coast California unit covers the largest geographic area of the seven units. When combined with the rest of the North Coast clade (i.e., including the North Coast Oregon unit), this region has the greatest amount of genetic diversity (McCartney-Melstad *et al.* 2018, p. 121; Peek 2018, p. 76). This unit also has the least amount of genetic structure, suggesting that there may be more connectivity within this unit (McCartney-Melstad *et al.* 2018, pp. 117, 121, 123, figure 3). On average, the North Coast California unit is cooler and wetter than the analysis units to the south but is about equal to that of the North Sierra unit (Table 3; PRISM Climate Group 2012, 30-year climate dataset). Ecoregions unique to this unit include those associated with the Klamath Low Elevation, Montane, and Subalpine Forests (78i–78l, 78o); Marble/Salmon Mountains-Trinity Alps (78m); Scott Mountains (78n); Outer and High North Coast Ranges (78q–78r); Central California Foothills and Coastal Mountains north of San Francisco Bay (6f-6o); Coastal Franciscan Redwood Forest (1k); King Range/Mattole Basin (1j); Fort Bragg/Fort Ross Terraces (1l); and California Cascades Eastside Conifer Forest (4g) (Environmental Protection Agency Level IV Ecoregions (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire)). Photographs of breeding habitats in the North Coast California analysis unit are in Figure 13.

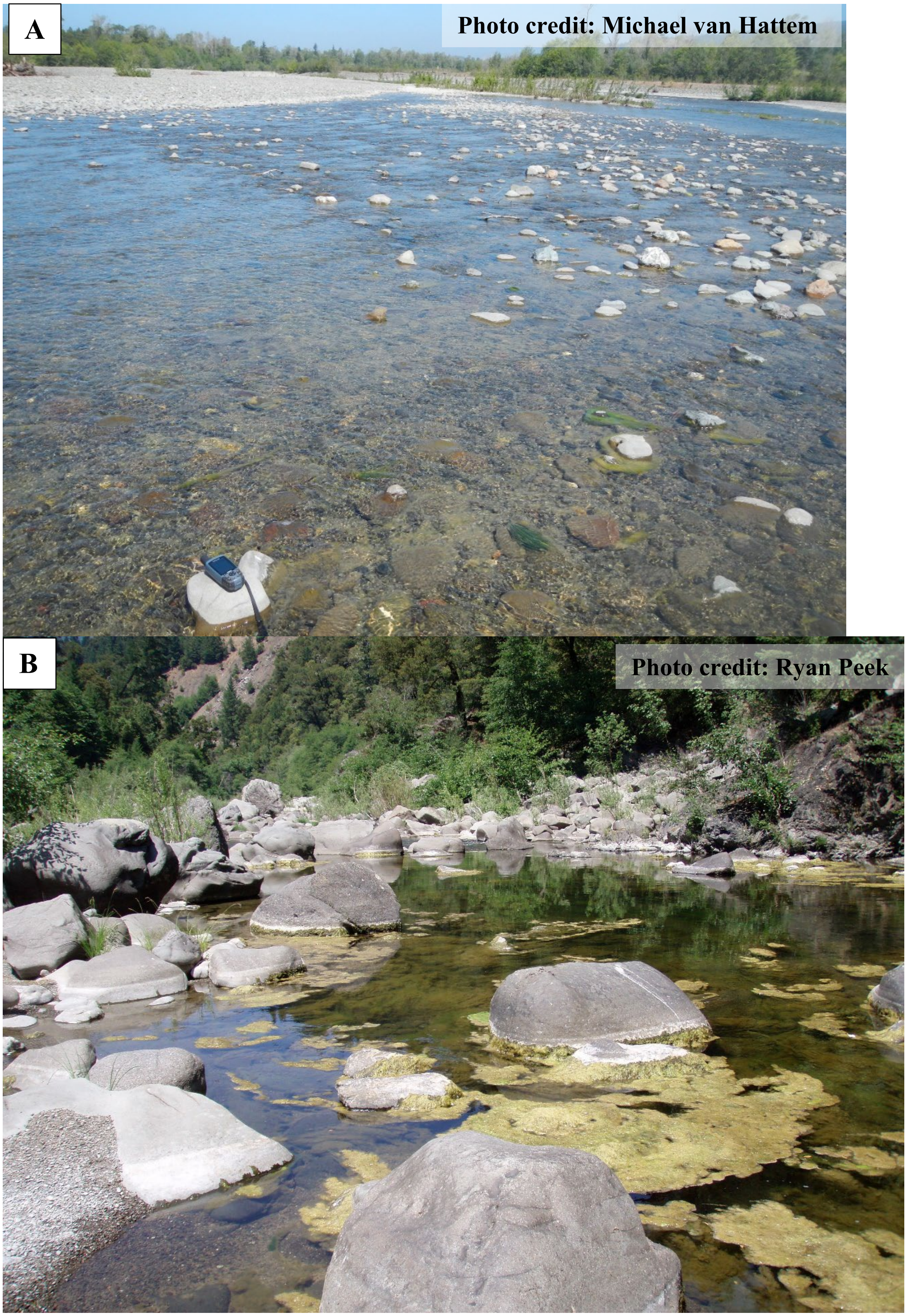

A
Photo credit: Michael van Hattem
B
Photo credit: Ryan Peek

Figure 13. Foothill yellow-legged frog habitat photos from the North Coast California analysis unit, (A) Humboldt County, (B) Mendocino County, and (C) Marin County, California.

3.4 North Feather Unit

The North Feather analysis unit is located primarily in Plumas and Butte counties. This unit occupies the transition zone between the northern Sierra Nevada, Southern Cascades Foothills, and Tuscan Flows ecoregions. The Tuscan Flows is an ecoregion that is geologically related to the Cascades but has similarities to the Sierra Nevada Foothills ecoregion (Environmental Protection Agency Level IV Ecoregions (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire)). The North Feather unit differs from the surrounding watersheds in terms of geology and aspect (Peek *et al.* 2019, p. 4638), and is the only known area where the foothill yellow-legged frog and Sierra Nevada yellow-legged frog currently coexist (Peek *et al.* 2019, p. 4637). As expected by its position at the northern end of the Sierra Nevada Range, the North Feather unit averages cooler and wetter than the analysis units to the south (Table 3; PRISM Climate Group 2012, 30-year climate dataset). Photographs of breeding habitats in the North Feather analysis unit are in Figure 14.

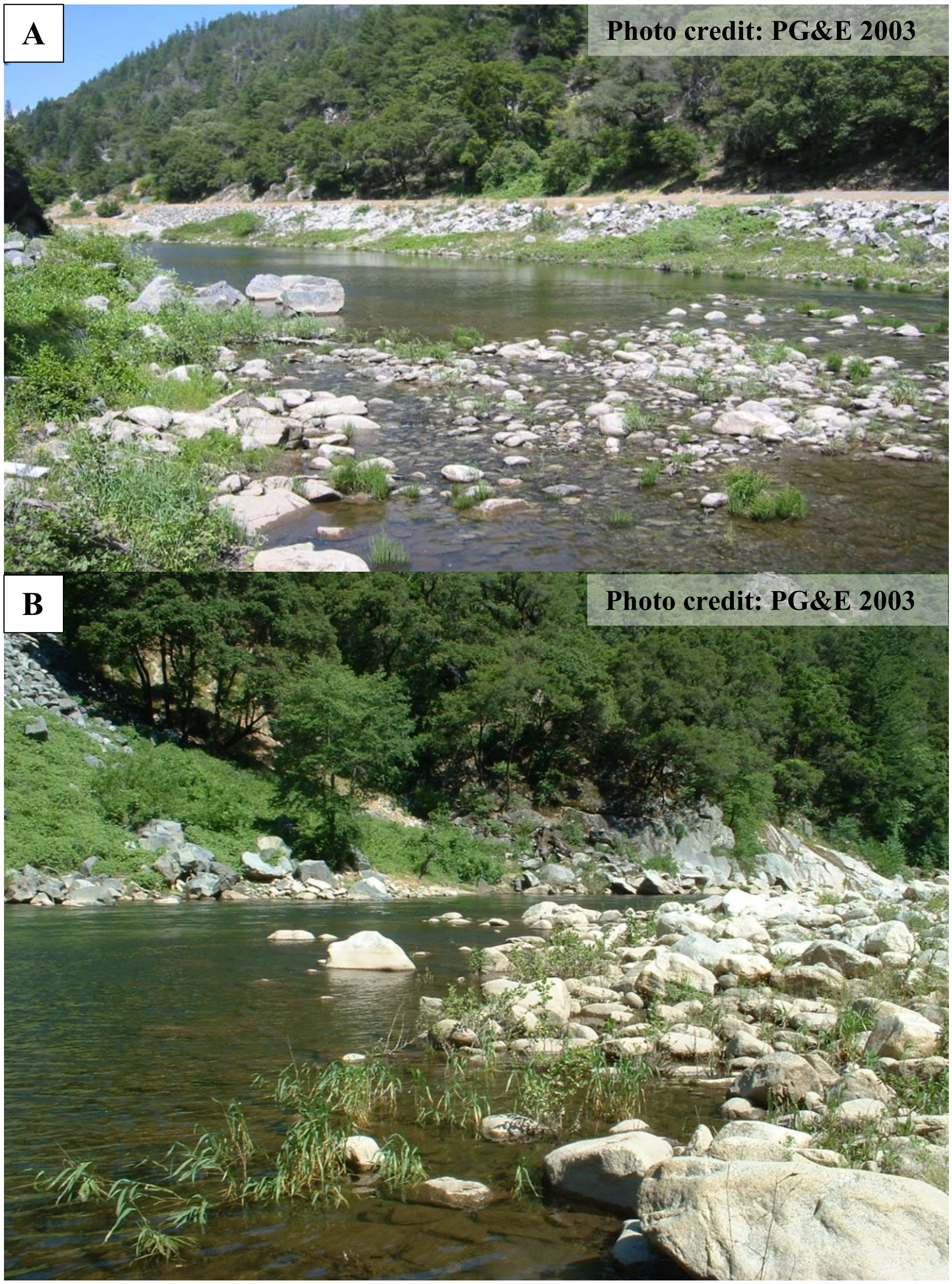


Figure 14. Foothill yellow-legged frog habitat photos (courtesy of PG&E; GANDA 2004, appendix 4) from the North Feather analysis unit, (A–B) North Fork Feather River, Plumas County, California.

3.5 North Sierra Unit

The North Sierra analysis unit is located primarily in Yuba, Sierra, Nevada, and Placer counties, California. This unit occupies the transition zone between the northern and central ecoregions of the Sierra Nevada Range. This transition zone is characterized by a southward decrease in annual precipitation, decrease in Douglas and white firs, increase in ponderosa pine, and geological shift from metamorphic rocks to volcanic and granitic rocks (Environmental Protection Agency Level IV Ecoregions (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire)). Like the North Feather, the North Sierra unit receives notably more precipitation than the South Sierra unit; however, the mean annual temperature in the North Sierra unit is more similar to that of the South Sierra unit than to the North Feather unit (Table 3; PRISM Climate Group 2012, 30-year climate dataset). Photographs of breeding habitats in the North Sierra analysis unit are in Figure 15.

Photo credit: Ryan Peek

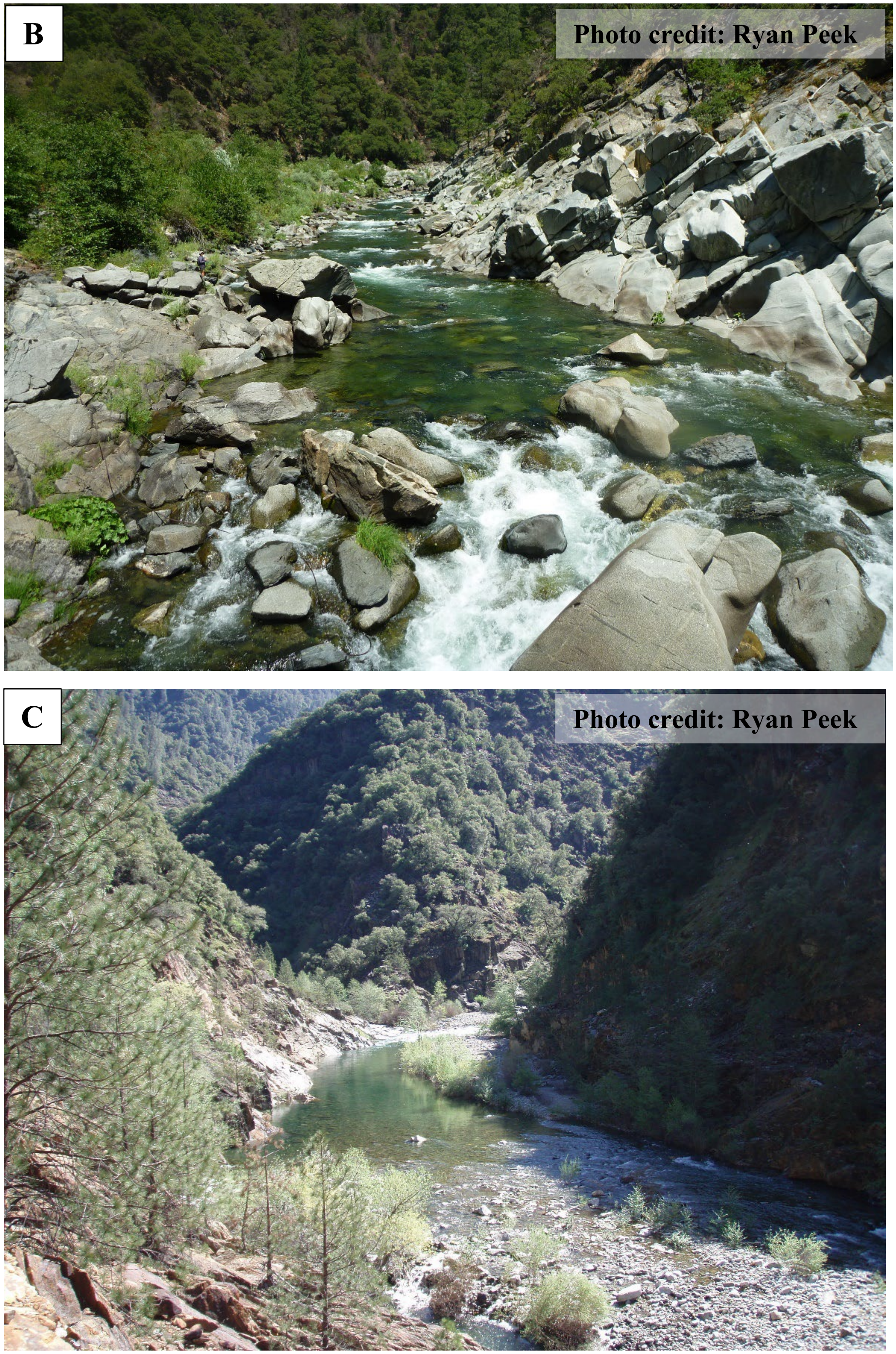


Figure 15. Foothill yellow-legged frog habitat photos from the North Sierra analysis unit, (A) El Dorado County, (B) Butte County, and (C) Placer County, California.

3.6 South Sierra Unit

The South Sierra analysis unit extends from the South Fork American River sub-basin to the transition zone between the Sierra Nevada and the Tehachapi Mountains that border the south end of the California Central Valley. This unit largely includes ecoregions that are unique to the southern and central Sierra Nevada Range including the Southern Sierra Mid-Montane Forests (5m), Southern Sierra Lower Montane Forest and Woodland (5n), Southern Sierran Foothills (6c), Tehachapi Mountains (5o), and Tehachapi Foothills (6ae) (Environmental Protection Agency Level IV Ecoregions (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire)). The South Sierra unit also shares an ecoregion transition zone with the North Sierra unit, as described in Section 3.5 above (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire). In terms of average precipitation and temperature, the South Sierra unit is fairly dry and warm, but it falls intermediately among the northern analysis units and the units south of San Francisco Bay (Table 3; PRISM Climate Group 2012, 30-year climate dataset). Photographs of breeding habitats in the South Sierra analysis unit are in Figure 16.

Figure 16. Foothill yellow-legged frog habitat photos from the South Sierra analysis unit, (A) Amador County and (B) Tuolumne County, California.

3.7 Central Coast Unit

The Central Coast unit extends south from the San Francisco Bay through the Diablo Range and through the Coast Range (Santa Cruz Mountains and Gabilan Mountains) east of the Salinas Valley. It is unknown whether foothill yellow-legged frogs historically occupied San Francisco County (CDFW 2019b, p. 38). On average, the Central Coast unit receives the least amount of annual precipitation of all the analysis units (Table 3; PRISM Climate Group 2012, 30-year climate dataset). Ecoregions that are unique to the Central Coast unit include those associated with the Diablo Range (6r, 6x, and 6z), Santa Cruz Mountains (1n), San Mateo Coastal Hills (1o), Eastern Hills (6aa), Bay Terraces/Lower Santa Clara Valley (6t), Upper Santa Clara Valley (6v), and Livermore Hills and Valleys (6u) (Environmental Protection Agency Level IV Ecoregions (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire)). Although the mountain ranges of the Central Coast unit are geologically unique and separated from those of the South Coast unit by the Salinas Valley, there are several attributes that are similar between the two analysis units. For example, there are similarities in mountain elevation range, elevation grade, and some vegetation types (Griffith *et al.* 2016, entire). The Central Coast and South Coast units are both warm and dry (Table 3; PRISM Climate Group 2012, 30-year climate dataset) and their waterways are similar in terms of hydrological properties (see Section 3.8 below). Photographs of breeding habitats in the Central Coast analysis unit are in Figure 17.

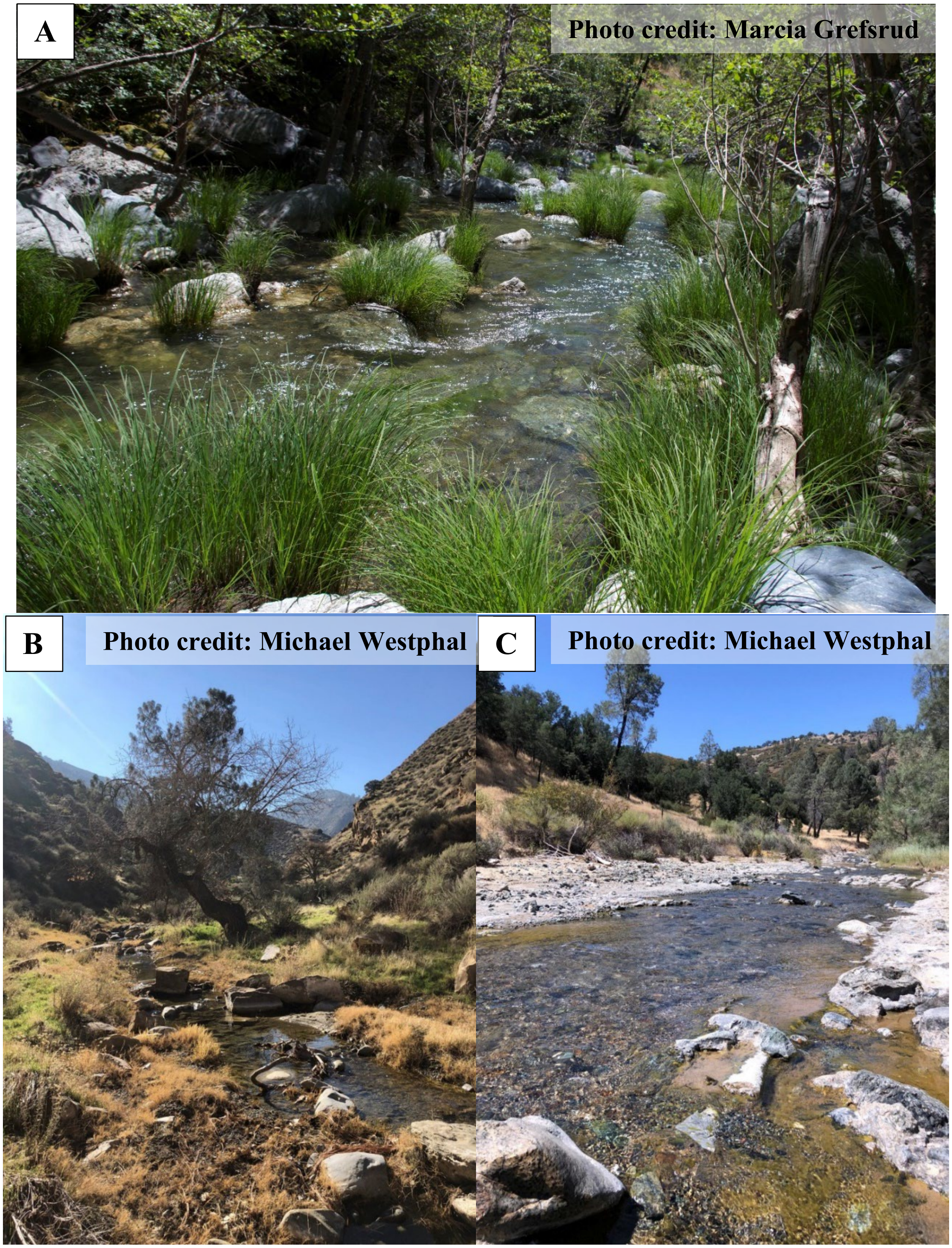


Figure 17. Foothill yellow-legged frog habitat photos from the Central Coast analysis unit, (A) Alameda County, California and (B–C) San Benito County, California.

3.8 South Coast Unit

The South Coast unit extends along the coastal Santa Lucia Range and the Sierra Madre Mountains. This unit is also believed to include an isolated, historical population in the San Gabriel Mountains (Los Angeles County), which is 77 km (48 mi) from the closest foothill yellow-legged frog population in record (Zweifel 1955, p. 239). Ecoregions that are unique to the South Coast unit include those associated with the Santa Lucia Range (6ag–6aj), Western Transverse Range (8a–8b), and Southern California Lower Montane Shrub and Woodland (8e) (Environmental Protection Agency Level IV Ecoregions (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire)).While the streams and rivers in the South Coast unit are different from those in most other parts of the foothill yellow-legged frog range, they share similarities to many waterways in the Central Coast unit. Waterways in the South Coast and Central Coast units tend to have flashier flows, more ephemeral channels, and a higher degree of intermittency because of the region's more variable, and lower amount of, precipitation (Storer 1925, pp. 257–258; Gonsolin 2010, p. 54; Adams *et al.* 2017b, p. 10227). The South Coast and Central Coast units receive the least amount of annual precipitation and average the warmest temperatures within the species' range (Table 3; PRISM Climate Group 2012, 30-year climate dataset). Photographs of breeding habitats in the South Coast analysis unit are in Figure 18.

Photo credit: Sarah Kupferberg

Photo credit: Sarah Kupferberg

Figure 18. (A–D) Foothill yellow-legged frog habitat photos from the South Coast analysis unit, Monterey County, California. Photos were taken in 2020; foothill yellow-legged frogs were present in locations depicted in B, C, and D.

CHAPTER 4 Individual-level Habitat Elements

We assessed the best available information to identify the physical and biological needs to support individual fitness (i.e., survival and ability to produce viable offspring) at all foothill yellow-legged frog life stages. The habitat elements that are considered most important to the species include oviposition and rearing sites (stream velocity, water depth, water temperature, and streambed substrate), algal food (nutritious diatoms), invertebrate prey, sufficient hydroperiod, intermittent canopy, geomorphic heterogeneity, interstitial spaces, upland and tributary habitat, migration and dispersal routes, and diurnal temperature variation. These resource needs are summarized by life stage and resource function in Table 4.

Table 4. Physical and biological needs of foothill yellow-legged frogs summarized by life stage and function (B = Breeding, F = Feeding, S = Sheltering, M = Migration/dispersal, and T = Thermoregulation).

Habitat Elements	Life Stage & Function	Carried forward for analysis?
Oviposition and rearing sites (stream velocity, water depth, water temperature, and streambed substrate)	Eggs — S Tadpoles — F, S, T Metamorphs — S, T Adults — B	Yes
Algal food	Tadpoles — F	Yes
Invertebrate prey	Juveniles — F Adults — F	Yes
Sufficient hydroperiod	Eggs — S Tadpoles — F, S, T Metamorphs — S, T Juveniles — F, S, T Adults — F, S, T	Yes
Intermittent canopy (tree canopy broken with sunny gaps)	Eggs — unknown Tadpoles — F, T Metamorphs — T Juveniles — T Adults — T	Yes
Geomorphic heterogeneity	Eggs — S Tadpoles — S, T Metamorphs — S, T Juveniles — S, T Adults — S, T	Yes

Habitat Elements	Life Stage & Function	Carried forward for analysis?
Interstitial spaces	Tadpoles — S, T Metamorphs — S, T Juveniles — S, T Adults — S, T	Yes
Upland and tributary habitat	Juveniles — F, S, M, T Adults — F, S, M, T	Yes
Migration and dispersal routes	Juveniles — S, M, T Adults — S, M, T	Yes
Diurnal temperature variation	Eggs — unknown Tadpoles — T Juveniles — T Adults — T	No

4.1 Oviposition and Rearing Sites

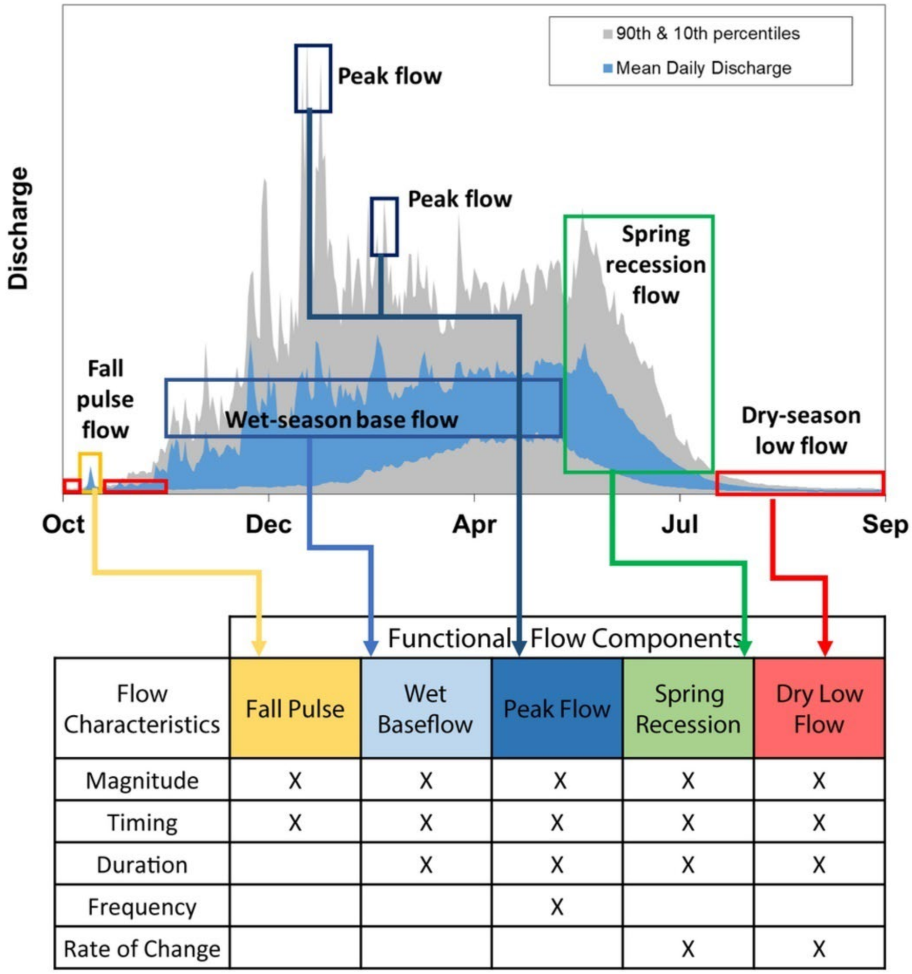
Foothill yellow-legged frogs are obligate stream-breeding frogs (Wheeler and Welsh 2008, p. 128) that have been found in first- through eighth-order streams (Strahler method[5]) (Olson and Davis 2009, p. 12). While habitat conditions can be vastly different among these stream sizes, and across the species' geographic range, only a narrow range of abiotic conditions are tolerated by early life stages (i.e., eggs, tadpoles, and metamorphs) (Kupferberg 1996a, p. 1336; Bondi *et al.* 2013, p. 101; Lind *et al.* 2016, p. 263; Catenazzi and Kupferberg 2018, pp. 1044–1045). The abiotic conditions that directly influence the success of early life stages are those associated with stream velocity, water depth, water temperature, and streambed substrate. Parameters for these conditions are in Table 5 and descriptions of each are provided in the following subsections.

Stream velocity, water depth, water temperature, and streambed substrate are most suitable for foothill yellow-legged frog oviposition and rearing in streams that exemplify the natural hydrological pattern that is associated with freshwater systems in Mediterranean climates (Kupferberg *et al.* 2009b, p. 3; Power *et al.* 2016, pp. 714, 716, figure 33.2) (Figure 19). The Mediterranean hydrological pattern in foothill yellow-legged frog habitat is characterized by strong winter flows in mainstem channels, followed by very dry summers (Power *et al.* 2016, pp. 714, 716, 719, figure 33.2). Winter flows can maintain and/or increase foothill yellow-legged frog breeding habitat by widening and diversifying channel morphology, improving rocky substrate conditions, and increasing sunlight (Lind *et al.* 1996, pp. 64–65; Lind *et al.* 2016, p. 269; Power *et al.* 2016, p. 719). The transition from the wet season to the dry season is characterized by a gradually decreasing discharge called the spring recession flow (Figure 19),

---

[5] The Strahler method is a way of classifying stream type based on number of tributaries. Small streams with no tributaries are first-order and stream order increases by one for each confluence of two streams of the same order. For example, a second-order stream begins at the confluence of two first-order streams, a third-order stream begins at the confluence of two second-order streams, etc. (Strahler 1957, p. 914).

decreasing water velocity, and increasing temperature (Kupferberg *et al.* 2012, p. 520; Power *et al.* 2016, pp. 714, 716, figure 33.2). Guided by these environmental cues, foothill yellow-legged frogs begin oviposition during this transition (graphically represented as a descending line on a hydrograph), ideally after winter and spring precipitation events have ceased (Kupferberg 1996a, pp. 1340; Kupferberg *et al.* 2009b, p. 7; Kupferberg *et al.* 2012, p. 520, figure 3). Foothill yellow-legged frogs rely on these natural, predictable changes during the hydrological cycle to optimize early life-stage growth and survival (Kupferberg 1996a, p. 1332; Bondi *et al.* 2013, p. 100).



	Functional Flow Components				
Flow Characteristics	Fall Pulse	Wet Baseflow	Peak Flow	Spring Recession	Dry Low Flow
Magnitude	X	X	X	X	X
Timing	X	X	X	X	X
Duration		X	X	X	X
Frequency			X		
Rate of Change				X	X

Figure 19. Figure from Yarnell *et al.* (2020, p. 320, figure 2) depicting the components of a natural hydrological cycle within the range of the foothill yellow-legged frog. The most important flow components for foothill yellow-legged frog ecology are the spring recession flow and dry-season low flow. Peak flows during winter are also important for maintaining quality breeding habitat. Source caption: “Functional flow components (boxes) for a mixed rain-snowmelt runoff system (hydrograph) typical to rivers in California, with key flow characteristics for each flow component (table). Other seasonal river systems, such as those in Australia, have similar functional flow components defined by intra-annual high and low flows.”

Certain geomorphic stream features (largely controlled by the natural hydrological cycle) are associated with the optimal abiotic (and biotic (discussed in subsequent sections)) conditions for oviposition and rearing. Across the wide range of stream types occupied by foothill yellow-legged frogs, successful breeding reaches are characterized by having wide and shallow channel morphology, intermittent canopy, and rocky substrate that is cobble-sized (64 to 256 mm (2.5 to 10.1 in.)) or larger (Hayes and Jennings 1988, p. 152; Kupferberg 1996a, pp. 1335–1337; Yarnell 2005, p. 54; Lind *et al.* 2016, p. 269; CDFW 2018, p. 2). Wide and shallow channels are preferred because their water velocities and depths are more resistant to large changes in stream discharge caused by precipitation or altered flow regimes (e.g., dam releases) (Kupferberg 1996a, pp. 1337, 1340, figure 8). Notably, compared to foothill yellow-legged frogs in the Eel River (Kupferberg 1996a, p. 1336), Feather River, and Tuolumne River watersheds (Lind et al. 2016, p. 266) foothill yellow-legged frogs in the Mokelumne River watershed oviposit in deeper locations (up to 155 cm deep) further from shore (up to 21 meters from shore) (PG&E 2015, p.26). Further research is necessary to determine whether this differing oviposition behavior is unique to the Mokelumne River population or is also present in other populations. Intermittent canopy affects stream temperature and is therefore important for early life-stage development and thermoregulation (Hayes *et al.* 2016, p. 5). Loose, rocky substrate that is not embedded in sediment is critical for breeding and survival of early life stages, as detailed later in Section 4.1.

Table 5. Quantitative estimates of abiotic microsite conditions needed for each early life stage. Details and caveats associated with these estimates, and their sources, are in the text of Section 4.1. Cm/s = centimeters per second; cm = centimeter; °C = degrees Celsius; MDAT = maximum 30-day average water temperature.

Early life stage	**Stream velocity**	**Water depth**	**Water temperature**	**Streambed substrate**
Oviposition/ Eggs	▪ <5 cm/s is optimal ▪ 0–15 cm/s is suitable	▪ Approx. 9–155 cm	▪ 10–19 °C	▪ Primarily cobble and boulder
Tadpoles	▪ <5 cm/s is optimal for all tadpoles ▪ 0–16 cm/s is suitable for early-stage tadpoles ▪ 0–12 cm/s is suitable for late-stage tadpoles	▪ <30 cm is optimal for early-stage tadpoles ▪ <10 cm is optimal for late-stage tadpoles	▪ MDAT = 18.8–22.0 °C for North Coast California and Central Coast units ▪ MDAT = 20.3–24.2 °C for North Feather, North Sierra, and South Sierra units	▪ Primarily cobble ▪ Increased use of gravel and sand

Early life stage	Stream velocity	Water depth	Water temperature	Streambed substrate
Metamorphs	▪ <5 cm/s is optimal ▪ <10 cm/s is required	▪ Similar to late-stage tadpole needs	▪ Similar to tadpole needs ▪ MDAT = approx. 20 °C	▪ Primarily cobble ▪ Increased use of gravel and sand

Stream Velocity

Seasonally appropriate stream velocity as described above, is essential for the various life stages of foothill yellow-legged frog. Elevated stream velocity causes scour or displacement of egg masses, tadpoles, and metamorphs. Scour and displacement of these sensitive life stages decreases early life stage survival by direct mortality, injury, or displacement from suitable habitat. Based on the Habitat Suitability Index (HSI) developed for the foothill yellow-legged frog in the Sierra Nevada Mountains[6] (Bondi *et al.* 2013, entire), water velocities of 0 to 15 centimeters per second (cm/s) are considered "suitable" for oviposition sites (Bondi *et al.* 2013, p. 95, fig. 4), However, water velocities of <5 cm/s are optimal[7] for egg masses and tadpole rearing microsites (Bondi *et al.* 2013, p. 95, fig. 4). Mean velocities at oviposition sites between 1 and 5 cm/s are also observed in North Coast California unit populations (Kupferberg 1996a, p. 1336; Lind *et al.* 2016, p. 266, table 1). In the Eel River population of foothill yellow-legged frogs (North Coast California unit), velocities at oviposition sites (typically on the downstream side of rocks) ranged from 1.1 to 13.5 cm/s (mean = 3.2 cm/s) (Kupferberg 1996a, p. 1336). When water velocities were high in the Eel River during oviposition, egg masses were laid underneath overhanging portions of boulders, where microsite velocities were much lower than ambient velocities (Kupferberg 1996a, p. 1340). In another North Coast California unit population, the total number of egg masses laid per year was negatively related to maximum annual streamflow, a proxy for stream velocity (Wheeler and Welsh 2008, p. 137).

Tadpoles that have just hatched are most vulnerable to elevated water velocities. Velocities as low at 10 cm/s can be directly lethal to recently hatched tadpoles (Kupferberg *et al.* 2009b, p. 84). However, tadpoles just beyond the vulnerable hatchling period, which lasts from approximately a few days to one week (S. Kupferberg 2020b, *in litt.*; R. Peek 2020, *in litt.*), are more tolerant to elevated velocities than tadpoles approaching metamorphosis (Kupferberg *et al.* 2009b, pp. 67–68, table 4.7, figure 4.9). As tadpoles develop and grow larger, their tolerance for higher water velocities decreases because the proportion of tail surface area to body mass decreases (Kupferberg *et al.* 2011b, pp. 147–148, figure 4). While optimal velocities for tadpoles are <5 cm/s, suitable velocities, based on the HSI, are <16 cm/s for early-stage tadpoles[8] and <12

---

[6] The HSI was developed using data from large rivers in the Sierra Nevada (North Feather, North Sierra, and South Sierra units). Therefore, the HSI might not be applicable across river types and/or the species range.

[7] Optimal is defined as an HSI value greater than 0.5.

[8] Early-stage tadpoles were defined as those observed during a July visit when most tadpoles had no rear limbs or only small limb buds (Bondi *et al.* 2013, pp. 90–91).

cm/s for late-stage tadpoles[9] (Bondi *et al.* 2013, p. 95, fig. 4). The optimum of <5 cm/s for tadpoles is congruent with Kupferberg *et al.* (2011b; North Coast California, North Feather, and Central Coast units) (detailed results of the studies were also reported in Kupferberg *et al.* (2009b)). In the absence of flow refugia (e.g., cobbles), tadpoles' average time to being swept away at 5.0 cm/s water velocity was 7.4 ± 2.6 minutes, with a maximum of 25 minutes (Kupferberg *et al.* 2011b, p. 146). The mean critical velocity for tadpoles being swept away or swimming to exhaustion is approximately 20 cm/s (Kupferberg *et al.* 2011b, p. 147).

In addition to the risk of displacement and swimming to exhaustion, elevated water velocities also have stress-related effects on foothill yellow-legged frog tadpoles that lead to lower body condition and increased mortality risk. A study in the South Fork Eel River (North Coast California unit) demonstrated that tadpoles exposed to higher velocities (5 to 10 cm/s) at weekly intervals, had stunted growth and development (Kupferberg *et al.* 2011b, pp. 141, 146). Tadpoles also had greater likelihood of predation when exposed to velocity stress (Kupferberg *et al.* 2011b, pp. 146–147).

Metamorphs are similar to late-stage tadpoles in that they are poor swimmers. Kupferberg *et al.* (2011b, pp. 141, 147) found that 10 cm/s can be a critical velocity for large tadpoles nearing metamorphosis. Therefore, microsites with water velocities <10 cm/s are needed for metamorphs, but <5 cm/s are likely optimal.

Altered hydrological flow regimes, such as those below many dams, appear to affect the composition and availability of algal food for tadpoles (Furey *et al.* 2014, pp. 1, 8–9). Altered hydrological regimes also may rapidly change water depth (Kupferberg *et al.* 2009c, p. 5, table 1.1; Kupferberg *et al.* 2012, p. 521), water temperature (Kupferberg *et al.* 2009c, p. 5, table 1.1; Wheeler *et al.* 2015, p. 1281), and streambed substrate (Lind and Yarnell 2008, pp. 23–24). See CHAPTER 7 Influences on Viability, for additional discussion on altered hydrological flow regimes.

Water Depth

Appropriate water depths are important for egg, tadpole, and metamorph survival. Based on the HSI developed by Bondi *et al.* (2013), "suitable" water depths for oviposition were 14 to 67 cm (Bondi *et al.* 2013, p. 95, fig. 4). However, the range of depths may be shallower in different regions and/or habitat types. Mean water depths reported for oviposition sites ranged from 9 to 21 cm in various North Coast California unit rivers, 12 to 32 cm in various Sierran rivers (Lind *et al.* 2016, pp. 266, 268, table 1), and 13 to 24 cm in Coyote Creek (Santa Clara County, California; Central Coast unit) (Gonsolin 2010, p. 99, table 6). Therefore, an approximate range of suitable water depths for egg masses is 9 to 67 cm.

For tadpoles and metamorphs, optimum water depths are similar to those for egg masses but are slightly shallower. Compared to other life stages, egg masses are more vulnerable to stranding (exposure to desiccation) at shallow depths because they require more vertical space to remain submerged. Tadpoles and metamorphs are only vulnerable to stranding when they are isolated from deeper water as a streambed dries; otherwise they are able to move as the water edge recedes throughout the season. From a life history perspective, shallow water has benefits to

---

[9] Late-stage tadpoles were defined as those observed during an August or September visit when most tadpoles had rear limbs present or fully developed (Bondi *et al.* 2013, pp. 90–91).

early life stages of foothill yellow-legged frogs. Shallow water is likely to be warmer and have better algal food resources than deeper water. In deeper water, pre- and post-metamorphic frogs may also be exposed to more types of predation (Lind *et al.* 2016, p. 269) and stronger water velocities. Optimal water depths, based on the HSI from Bondi *et al.* (2013), are <30 cm (suitable range = 1 to 54 cm) for early-stage tadpoles and <10 cm (suitable range = 1 to 51 cm) for late-stage tadpoles (Bondi *et al.* 2013, p. 95, fig. 4). The optimum water depth for metamorphs is expected to be the same, or similar, to that for late-stage tadpoles.

Water Temperature

Rising water temperature, in addition to decreasing water velocity, is a suspected cue for foothill yellow-legged frogs to begin breeding activity (Kupferberg 1996a, p. 1340; CDFW 2019b, p. 49). Streams that do not warm above critical minimum temperatures during the summer may preclude breeding. Optimal water temperatures are different for each life stage with an increasing trend from oviposition to metamorphosis. A temperature measurement that is broadly reflective of foothill yellow-legged frog breeding and recruitment success is the maximum 30-day average water temperature (MDAT) (Catenazzi and Kupferberg 2017, p. 1260). The realized thermal niche is higher for inland (Sierra Nevada Mountain) populations than for coastal populations. Water temperatures in Sierran streams are lower than coastal streams in the spring because of snowmelt, but they become warmer than coastal breeding sites during the summer (Catenazzi and Kupferberg 2017, p. 1255). Realized thermal niche temperature ranges (MDAT where there were >5 breeding females per river km) were 18.8 to 22.0 °C for coastal units (North Coast California and Central Coast) and 20.3 to 24.2 °C for Sierran units (North Feather, North Sierra, and South Sierra) (Catenazzi and Kupferberg 2017, p. 1260). MDATs below 17 to 18.8 °C on the coast and below 19.3 °C in the Sierras appear to limit relative abundance of foothill yellow-legged frogs (Kupferberg *et al.* 2011a, pp. 13, 82). Reproductive populations in the Sierras were absent where MDAT was below 17.6 °C and were densest when MDAT was between 20.3 and 24.2 °C (Kupferberg *et al.* 2011a, p. 13). In the Eel River watershed (North Coast California unit), maximum population abundance occurred at the MDAT of 19.7 °C (Kupferberg *et al.* 2011a, p. 13). Low-density populations have been observed at MDATs as low as 15.7 °C in the North Coast California unit and 17.5 °C in the North Sierra unit (Catenazzi and Kupferberg 2017, pp. 1259–1260, figure 3).

Foothill yellow-legged frog embryonic development is highly temperature dependent (Hayes *et al.* 2016, p. 14). Hatching may take anywhere between approximately 5 days at 20 °C (Zweifel 1955, p. 229) and up to 36 days at colder temperatures (pers. obs. cited in Hayes *et al.* 2016, p. 15). For normal embryonic development, laboratory experiments showed that critical water temperatures were between 6 and 26 °C (Zweifel 1955, p. 262). Across the species' range, oviposition generally occurs when water temperatures are between approximately 10 and 19 °C (Hayes *et al.* 2016, p. 7, table 1; Wheeler *et al.* 2018, p. 294). Hayes *et al.* (2016, p. 7, table 1) compiled data from several sources (published and unpublished) and reported oviposition water temperatures ranging from 10 to 15 °C in the North Coast California unit and 12 to 19 °C in the Sierras (North Feather, North Sierra, and South Sierra units). Lind (2005, pp. 146–7, table 4.2) reported means of temperatures (point measurements, not daily means) at egg masses in the North Coast California unit ranging from 11.6 to 19.3 °C and in the Sierras (North Feather and South Sierra units) ranging from 15.9 to 19.0 °C. In the South Fork Eel River (North Coast California unit), Kupferberg (1996a, p. 1340) observed that oviposition began once average daily water temperature reached approximately 12 °C. In Upper Coyote Creek (Central Coast unit), most egg masses were laid when daily mean water temperatures were between 13 and 17 °C (mean = 14.6 °C, range = 11.3 to 19.3 °C) (Gonsolin 2010, pp. 35, 99, table 6).

Like embryo development, tadpole growth, metabolic efficiency, and development are temperature dependent. Estimated tadpole survival through metamorphosis was greatest where MDATs were approximately 20 °C in the North Coast California unit (Kupferberg *et al.* 2011a, pp. 14, 60–61, figure 34). In colder water, tadpoles have lower growth rates, lower body condition, and undergo metamorphosis at a smaller size (Catenazzi and Kupferberg 2013, entire; Wheeler *et al.* 2015, pp. 1280–1281, 1283; Catenazzi and Kupferberg 2018, entire). Foothill yellow-legged frog tadpoles and metamorphs are more vulnerable to predation and have lower survival under cold conditions (Wheeler *et al.* 2015, p. 1283; Railsback *et al.* 2016, p. 773; Catenazzi and Kupferberg 2018, pp. 1042–1044).

Tadpole growth and development is also related to the quality and quantity of algal food, which in turn, is affected by temperature (Kupferberg *et al.* 2011a, pp. 83–85; Furey *et al.* 2014, pp. 1, 8–9). Supplemental feeding of high-quality algal food to tadpoles at a cold-rearing site (in-situ (i.e., within habitat) rearing enclosures where average daily water temperature in July was 15.8 °C) improved the likelihood of survival, but tadpoles took longer to reach metamorphosis and only grew to half the size of those raised where the average daily water temperature in July was 21.5 °C (Catenazzi and Kupferberg 2013, pp.42, 46, table 1).

Foothill yellow-legged frog tadpoles have positive linear growth responses to temperature, regardless of unit (Catenazzi and Kupferberg 2017, pp. 1255, 1261, figure 4). However, there may be tradeoffs to having water temperatures exceed a particular threshold. Although successful metamorphosis has been observed in pools where maximum daily temperatures reached 30 °C (Kupferberg *et al.* 2011a, p. 15), tadpole survival is estimated to be greatest at intermediate temperatures (Kupferberg *et al.* 2011a, pp. 14, 72). Results from an in situ rearing experiment (North Coast California unit) suggest that, while tadpoles develop faster at a very warm temperature (running average daily temperature of 22.2 °C), they do not grow as large as tadpoles reared at intermediate temperatures (Kupferberg *et al.* 2011a, p. 72, figure 47). Furthermore, researchers observed an unexpected die-off (unknown cause) of late-stage tadpoles (Gosner Stages 35 to 42) that coincided with maximum daily temperatures exceeding 25 °C (Kupferberg *et al.* 2011a, pp. 14, 58; Catenazzi and Kupferberg 2018, pp. 43–44, figure 2).

Temperatures outside of the preferred thermal range may also have lethal or sublethal effects to tadpoles and metamorphs from pathogens (see Section 7.3 Disease and Parasites for more information on pathogens). Cooler water temperatures may increase the risk of chytridiomycosis from the fungus, *Batrachochytrium dendrobatidis* (Bd). In laboratory experiments with the Cuban treefrog (*Osteopilus septentrionalis*), frogs were more resistant to Bd at higher incubator temperatures (20 or 25 °C compared to 15 °C) (Raffel *et al.* 2013, pp. 148–149). Conversely, high temperatures may promote infection by parasites (Kupferberg *et al.* 2009a, p. 529; Kupferberg *et al.* 2011a, p. 15). When MDAT reached or exceeded 24.0 °C in the Clavey River (South Sierra unit), copepod infection prevalence (proportion of individuals infected) was 42 percent compared to only one infected individual in the cooler Rubicon River (North Sierra unit) (Kupferberg *et al.* 2011a, p. 15).

Laboratory experiments have revealed that foothill yellow-legged frog tadpoles alter their thermoregulatory behavior (i.e., move to warmer or cooler environments) based on prior rearing temperature. In a laboratory thermal gradient (11.9 to 34.7 °C), mean temperature selected by Eel River tadpoles was 19.6 °C (central 50 percent of the temperatures selected between 16.5 and 22.2 °C), which was consistent with MDAT (19.7 °C) where breeding populations were densest in the Eel River watershed (≥ 125 breeding females per km) (Kupferberg *et al.* 2011a, pp. 13, 40–41; Catenazzi and Kupferberg 2013, pp. 40, 44). When eggs collected from North Coast California, North Feather, and North Sierra units were raised under the same conditions (i.e., MDAT = 17.8 °C), mean selected temperature within the thermal gradient was 20.5 °C (central 50 percent of the temperatures selected between 19.1 and 21.5 °C) and preference did not significantly differ by region (Kupferberg *et al.* 2011a, p. 41). Although tadpoles experience different temperature ranges in different regions, thermal preference appears to be dependent upon prior rearing temperature (tadpoles prefer warmer water if reared in cold water and prefer cooler water if reared in warm water), as opposed to the tadpoles' region of origin (Kupferberg *et al.* 2011a, p. 41; Catenazzi and Kupferberg 2013, p. 46; Catenazzi and Kupferberg 2017, p. 1255).

Laboratory experiments also showed that foothill yellow-legged frog tadpoles exhibit different growth rates depending on region of origin. Under the same rearing conditions, Sierran tadpoles (North Feather and North Sierra units) had higher intrinsic growth rates than tadpoles from coastal populations (North Coast California and Central Coast units) (Catenazzi and Kupferberg 2017, pp. 1261–1262, figure 4). The authors suspect that this difference resulted from selective pressure for more rapid growth in the time-constrained environment of the Sierras (Catenazzi and Kupferberg 2017, p. 1262).

The microsite water temperature conditions needed for completion of the metamorph life stage have not been explicitly studied but they are expected to be approximately the same as they are for late-stage tadpoles. Because the metamorph stage is brief (from a few days to two weeks (S. Kupferberg 2020b, *in litt.*; R. Peek 2020, *in litt.*; M. Rousser 2020, *in litt.*)), it is unlikely that foothill yellow-legged frogs would have adapted a significantly different range of optimal water temperatures from that of late-stage tadpoles.

Streambed Substrate

The common factor at breeding sites across the species' range is a rocky substrate that is stable (i.e., does not readily shift during bank-full conditions); has interstitial spaces; and provides shelter from ambient or occasional, high flows. A mix of rocky substrate sizes is beneficial in foothill yellow-legged frog habitat because the resulting height differentials (between larger and smaller rocks) create low-velocity microsites (Lind and Yarnell 2008, p. 23). Streambed substrates provide camouflage and shelter for all life stages of foothill yellow-legged frog, but it is especially critical for the early life stages, which have limited mobility to seek refuge.

For the egg life stage, rocky substrate provides the attachment surface for egg masses, which keeps the egg mass submerged and prevents it from flowing out of suitable habitat. Because most egg masses are oviposited on the downstream side of substrate, the substrate also shelters eggs from scour (Storer 1925, p. 253; Kupferberg 1996a, p. 1336). In most of the species' range, eggs are oviposited on cobble (64−256 mm (2.5−10 in.)) substrate (Storer 1925, p. 253; Kupferberg 1996a, p. 1336; Lind *et al.* 2016, pp. 266, 268, figure 2). In some areas, especially where cobble bars are less common, foothill yellow-legged frog egg masses are regularly found on boulders (> 256 mm (10 in.)) (Kupferberg 1996a, p. 1336; Bondi *et al.* 2013, pp. 93–94; Lind *et al.* 2016, p.

268; Silver 2017, p. 6). In Coyote Creek (Central Coast unit), egg masses were primarily found on very coarse gravel (32 to 64 mm (1.25−2.5 in.)) substrate, followed by cobble substrate (Gonsolin 2010, p. 98, table 5). Very coarse gravel was also used for 13 percent of egg masses observed by Lind *et al.* (2016, p. 266, figure 2) in various North Coast California unit streams. Infrequently, foothill yellow-legged frog egg masses are found on bedrock (Kupferberg 1996a, p. 1336) or plant material (Kupferberg 1996a, p. 1336; van Wagner 1996, p. 119; Gonsolin 2010, p. 98, table 5).

Underwater rocky substrate provides tadpoles with camouflage (Jennings and Hayes 1994, p. 68; Davis and Olson 2008, pp. 6, 8), interstitial spaces for refuge from water flows (Kupferberg *et al.* 2011b, p. 149), opportunities for thermoregulation, and surfaces for algal food growth (Ashton *et al.* 1997, p. 7). The substrate preferred by tadpoles and metamorphs does not substantially differ than that for oviposition. However, cobble substrate may be preferred over boulders, even where boulders are the dominant attachment substrate for oviposition (Bondi *et al.* 2013, p. 93–94, fig. 3). Compared to egg masses, tadpoles and metamorphs are also more likely to be found in areas with smaller-sized substrates, such as gravel or sand (Yarnell 2005, p. 25; Lind and Yarnell 2008, p. 23; Bondi *et al.* 2013, p. 95).

4.2 Algal Food (Nutritious Diatoms)

Algae, of adequate quantity and nutrient content, is required for the tadpole life stage. Foothill yellow-legged frog tadpoles feed on algae, diatoms, and detritus that are scraped from submerged rocks and vegetation (Ashton *et al.* 1997, p. 7; Fellers 2005, p. 535). The period of fastest tadpole growth coincides with the bloom of epiphytic nitrogen-fixing diatoms, their preferred food source (Catenazzi and Kupferberg 2013, p. 41). Algae with greater proportions of epiphytic nitrogen-fixing diatoms are higher in protein, a nutrient positively correlated with the speed of tadpole growth and development (Kupferberg 1997b, p. 146). The availability of this type of nutritious food positively affects tadpole growth rate, size at metamorphosis, and survival (Kupferberg 1997b, p. 146; Catenazzi and Kupferberg 2013, p. 46). A natural climatic and hydrological cycle positively influences the availability of epiphytic nitrogen-fixing diatoms for tadpoles, because diatom abundance and species composition are influenced by temperature, solar radiation, river stage, water velocity, and winter flows (Kupferberg *et al.* 2011a, p. 83–85; Furey *et al.* 2014, pp. 1, 8–9; Power *et al.* 2015, p. 208; Power *et al.* 2016, pp. 719, 722). Poor habitat conditions such as variable flow or cooler temperatures can facilitate the spread of stalk-producing diatom taxa such as rock snot (*Didymosphenia geminata*) which have poor nutritional quality for foothill yellow-legged frog tadpoles (Furey *et al.* 2014, p. 9).

4.3 Invertebrate Prey (Terrestrial and Aquatic Invertebrates)

During metamorphosis, the foothill yellow-legged frog digestive system transforms from a system for consuming small bits of algae to one for consuming comparatively large pieces of animal tissue (Ashton *et al.* 1997, p. 8). Ranid species do not typically have specific food preferences in the adult life stage and feed upon a wide range of arthropods, small fish, and small frogs (Zweifel 1955, p. 223). Cannibalism has also been observed in the foothill yellow-legged frog under laboratory conditions (Zweifel 1955, p. 223). Juvenile and adult foothill yellow-legged frogs prey upon many types of aquatic and terrestrial invertebrates including snails, moths, flies, water striders, beetles, grasshoppers, hornets, and ants (Nussbaum *et al.* 1983, p.

165). The arthropods identified from stomach contents (in the North Sierra unit) were predominantly insects (88 percent), followed by arachnids (12 percent) (van Wagner 1996, p. 89). Similarly, the stomach contents were primarily terrestrial (88 percent), as opposed to aquatic (i.e., captured on or under water) (van Wagner 1996, pp. 88–89, 94, figure 38).

4.4 Sufficient Hydroperiod

Foothill yellow-legged frogs, like other amphibians, require a hydroperiod (i.e., period of time during which an area is saturated with or full of water) that is sufficient for successful breeding and survival through dry periods. The time frame and duration of the hydroperiod required for foothill yellow-legged frogs varies by year because breeding may occur earlier or later than average depending on that year's conditions. The required hydroperiod time frame and duration would also differ by region because of regional differences in timing of hydrological breeding cues (e.g., temperature, spring recession flow), intrinsic tadpole growth rates (Catenazzi and Kupferberg 2017, pp. 1261–1262, figure 4), and ambient conditions (e.g., temperature) that influence early life stage development.

Shifts in the hydroperiod can influence the foothill yellow-legged frog both directly and indirectly. If streams dry or river stage drops too quickly during the rearing season, early life stages become exposed to stranding and desiccation (Railsback *et al.* 2016, p. 774). Frogs in these sensitive life stages are also exposed to increased competition, predation, and pathogen exposure as they become more concentrated in drying pools of water (Storer 1925, p. 261; Adams *et al.* 2017a, pp. 8, 11).

A sufficient hydroperiod is also important for survival of juvenile and adult life stages. Surface water is important for thermoregulation and maintaining prey populations. Moisture in interstitial spaces is critical to prevent desiccation, especially during cold winters when frogs are inactive and would not be capable of dispersing to wetter areas. Flowing water and pools also provide shelter and concealment for all foothill yellow-legged frog life stages (Davis and Olson 2008, pp. 6, 8; Yarnell 2008, p. 20).

4.5 Intermittent Canopy

Intermittent canopy is important because it provides opportunities for thermoregulation of mobile life stages (in and out of sunlight). Solar radiation in rearing habitat is also required for algal food production and it can temporarily increase water temperatures, enhancing growth and development, especially of the early life stages (Kupferberg *et al.* 2011a, p. 83; Catenazzi and Kupferberg 2013, pp. 45, 47; Power *et al.* 2016, pp. 714, 721–722, 726; Catenazzi and Kupferberg 2018, p. 1037). Juvenile and adult foothill yellow-legged frogs frequently bask in the sun on rocks to raise their body temperatures (Zweifel 1955, p. 228). Raising their body temperatures increases the rates of metabolic processes, such as digestion (Zweifel 1955, p. 228). Zweifel (1955, p. 228) suggests that the foothill yellow-legged frog's ability to inhabit cold streams is dependent upon the availability of basking sites. A review of habitat conditions (Hayes *et al.* 2016, p. 5) suggests that foothill yellow-legged frogs rarely use streams with dense canopy cover or no canopy cover. This species appears to favor conditions where there is 20 to 90 percent shade cast by riparian canopy (Hayes *et al.* 2016, p. 5). This preference may be due to the relationship between open canopy and factors such as basking sites, breeding and rearing conditions such as temperature, and/or food abundance (Hayes *et al.* 2016, p. 5).

4.6 Geomorphic Heterogeneity

Geomorphic heterogeneity is defined here as the spatial variation, or patchiness, of geomorphic units such as hydrological features (e.g., pools, riffles, glides, runs, springs, etc.), substrates (e.g., cobble bars, gravel, boulders, etc.), and other structural features (e.g., vegetation, woody debris, etc.). Stream reaches that have high geomorphic heterogeneity are positively associated with foothill yellow-legged frog abundance because fine-scale habitat diversity provides a greater variety of thermoregulatory and sheltering opportunities, especially as river stage fluctuates during the year (Yarnell 2005, pp. 1, 5; Bourque 2008, p. 73; Yarnell 2008, pp. 2, 15, 20, figure 4; Hayes *et al.* 2016, pp. 10, 41; CDFW 2019b, p. 2).

High geomorphic heterogeneity also allows for the ideal conditions for each life stage to be present within a small area. Several foothill yellow-legged frog studies support the observation that geomorphic unit preference varies by life stage, and possibly by region. Glides, runs, and shallow pools are largely favored for oviposition sites because they are most hospitable to early life-stage growth and survival (van Wagner 1996, pp. 81–82, figure 28; Yarnell 2000, p. 97; Bourque 2008, pp. 49, 66; Lind *et al.* 2016, p. 266, figure 2). During spring, frogs in a North Coast California unit population primarily used run or glide habitats for breeding (88 percent of 48 breeding sites), but post-metamorphic frogs at non-breeding sites were found in riffle (87 percent of 15 sites) or pool (13 percent of 15 sites) habitats (Bourque 2008, pp. 49, 66). In a North Sierra unit population, some juvenile frogs moved from natal sites into adjacent riffles after metamorphosis (van Wagner 1996, p. 108). In the Coyote Creek area (Central Coast unit), adults preferred pool features (compared to turbulent or flatwater features) and boulder-dominated substrate during the summer and fall (Gonsolin 2010, p. 105, tables 14 and 15).

Juveniles and adults use both aquatic and terrestrial habitats; therefore, they use a more diverse range of geomorphic units than early life stages and habitat use changes depending upon time of year (Bourque 2008, p. 72; CDFW 2019b, p. 18). A mix of substrate sizes (e.g., boulders, cobbles, gravel, etc.) within and alongside the waterway provides sites for basking, lekking (i.e., courtship displaying), foraging, and cover from predation (van Wagner 1996, p. 109). Various sources of aquatic and terrestrial cover types that are used by foothill yellow-legged frogs include water with surface turbulence (e.g., riffles), deep water, undercut banks, root wads, downed wood, trees, grasses, sedges, mats of algae, leaf litter, and aquatic vegetation (van Wagner 1996, p. 109; Gonsolin 2010, p. 104).

4.7 Interstitial Spaces

Interstitial spaces within substrate or other habitat elements are important for all mobile life stages of foothill yellow-legged frogs. A diversity of types and sizes of interstitial spaces allows for the different sheltering and thermoregulatory needs of different life stages and for environmental fluctuations (e.g., river stage) that may suddenly alter habitat. Interstitial spaces are used as shelter from high water velocities, desiccation, and predation (Kupferberg *et al.* 2011b, p. 149; CDFW 2019b, p. 57). Interstitial spaces are also used by invertebrate prey species (Olson and Davis 2009, p. 25). Foothill yellow-legged frogs have been observed using interstitial spaces around various types of aquatic and terrestrial features including cobbles, boulders, undercut banks, root wads, downed wood, leaf litter, and live vegetation (van Wagner 1996, p. 109; Davis and Olson 2008, p. 8; Lind and Yarnell 2008, p. 22–24; Gonsolin 2010, p. 104; Kupferberg *et al.* 2011b, p. 149).

In aquatic habitat, the presence of interstitial spaces is largely determined by the input of fine sediments into the waterway and the hydrological cycle (Kupferberg *et al.* 2011b, p. 149). Sedimentation that fills in the interstitial spaces may occur as a result of different types of natural processes (e.g., erosion) or human activities (e.g., dam operation, road construction). A natural hydrological cycle can help maintain or restore interstitial spaces in the substrate because high discharge can remove the fine sediment from the streambed (Hogg and Norris 1991, p. 516).

4.8 Upland and Tributary (Nonbreeding) Habitat

For those frogs that remain in or near breeding streams through the winter, upland habitat might be considered the riparian and edgewater habitat adjacent to streams. In Clear Creek (Nevada County, California; North Sierra unit), juveniles that had not moved from their natal area, were observed moving away from the mainstem as the creek swelled during fall and winter rain. These juveniles took refuge in temporary stream edge overflow areas, beneath overhanging sedges, under rocks, or beneath leaf litter (van Wagner 1996, pp. 73–74). During large precipitation events, adults and juveniles have been observed moving upslope, away from the waterway, suggesting that they use upland areas temporarily as a strategy to avoid scouring flows (van Wagner 1996, p. 74; Bourque 2008, p. 70; Hayes *et al.* 2016, p. 21).

For frogs that disperse or migrate out of breeding habitat (most foothill yellow-legged frogs), upland and tributary habitat is used at different rates by adult females, adult males, and juveniles. Adult females probably use upland and tributary habitat more than adult males because they spend less time at breeding sites (GANDA 2008, p. 20; Wheeler and Welsh 2008, p. 137). Most juveniles appear to leave their natal areas during fall or winter (Twitty 1967, p. 353, figure 2; van Wagner 1996, p. 107; Cook *et al.* 2012, p. 325) but little is known about the duration of time spent in breeding habitat between initial dispersal and first breeding. During April in the upper South Fork of the Coquille River (North Coast Oregon unit), juveniles were found sheltering in moist, rocky outcrops at least 50 m (164 ft) from the river (Nussbaum *et al.* 1983, p. 163). Anecdotal observations in several watersheds in the North Coast California unit have documented juveniles using unmapped ephemeral or headwater streams, inboard ditches of roads, a seep, an ephemeral man-made stream, a wet drainage ditch of a graded area, a puddle on a road crossing, a storm water drainage, and crevices in a large log near a pond (R. Bourque 2019, *in litt.*).

Most frogs spend much of the year outside of breeding areas, so it is extremely important that nonbreeding habitat meet their feeding, sheltering, and thermoregulatory needs. Although there are few accounts of habitat use by foothill yellow-legged frogs outside of the breeding season, we can assume that the characteristics of upland and tributary habitat would include sources of invertebrate prey, intermittent canopy (van Wagner 1996, p. 101), thermally stable microsites (Rombough 2006b, p. 159), and moist, interstitial spaces. During winter, it is especially important that moist sheltering sites are not exposed to scouring winter flows. Features that can provide these refugia for overwintering frogs include springs, seeps, pools, woody debris, root wads, undercut banks, clumps of sedges, and large boulders or debris at high-water lines (van Wagner 1996, pp. 74–75, 111; Rombough 2006b, p. 159; CDFW 2018, p. 2).

A study on Oregon's South Santiam River (1999 to 2006) highlights the potential importance of seeps and woody debris in overwintering habitat (Rombough 2006b, p. 159). Overwintering (November to March) juvenile foothill yellow-legged frogs were mostly encountered in seeps along the channel margin, typically hidden under woody debris along the high-water line (Rombough 2006b, p. 159). The highest densities of frogs were found in seeps with a combination of bedrock substrate, continuous laminar flow, and abundant woody debris. Seeps were likely favored by frogs because of their moisture availability, prey availability, and temperature stability (Rombough 2006b, p. 159).

In systems with large rivers and streams, non-breeding habitats are typically found along small tributary streams with adjacent riparian habitat (Kupferberg 1996a, p. 1339; GANDA 2008, p. 33; Gonsolin 2010, p. 55). Nonbreeding tributary habitat used by foothill yellow-legged frogs is generally cooler and darker than the warmer sunlit areas required for breeding and rearing (Kupferberg 1996a, p. 1339; Halstead *et al.* 2020, p. 204). Streamflow in nonbreeding areas may be perennial (Kupferberg 1996a, p. 1339), but many overwintering tributaries are intermittent or ephemeral (Kupferberg 1996a, p. 1339; van Wagner 1996, p. 30; Bourque 2008, pp. 53–54). Because foothill yellow-legged frogs prefer breeding areas that are relatively close to tributary confluences (Kupferberg 1996a, p. 1335; Yarnell 2005, p. 5), proximity to breeding areas may also be a valuable feature for tributary habitat. Notably, tributary habitat can also be used as breeding habitat by the species if environmental conditions allow, such as in small tributaries in the Sierra Nevada mountains (Peek *in litt.* 2021)

4.9 Migration and Dispersal Routes

Adult foothill yellow-legged frogs primarily use waterway corridors to migrate or disperse (Bourque 2008, p. 70) and make their movements over multiple days (GANDA 2008, p. 22). While most foothill yellow-legged frogs are found in, or very close to, water, juveniles and an adult have also been observed moving through upland areas outside of riparian corridors. In Mendocino County (North Coast California unit), juvenile frogs were found dispersing into a residential neighborhood 16 to 331 m (52 to 1,086 ft) from the creek (Cook *et al.* 2012, p. 325). In Tehama County (North Coast California unit), a radio-telemetered female traveled approximately 7 km (4.3 mi), using intermittent tributaries (some of which were dry with only moist substrates) and cresting a ridge (Bourque 2008, p. 30). Bourque (2008, p. 72) noted that adults at the Tehama County study site typically moved during hot and dry conditions but avoided desiccation by restricting travel routes to drainage networks with moist substrates (Bourque 2008, p. 72).

The habitat characteristics needed by foothill yellow-legged frogs for migration and dispersal are largely the same as they are for upland and tributary habitat. However, movement routes do not need to be moist for extended periods. Routes need to connect breeding areas and overwintering habitat without exposing frogs to large physical barriers or high risk of predation. Dams, reservoirs, and hydrologically altered rivers can be barriers to foothill yellow-legged frog connectivity (Peek 2010, p. 44; Peek 2012, p. 15; Peek *et al.* 2021, p. 14). Juveniles have been observed on, and/or crossing, residential roads but 13 percent (7 of 56) were killed by vehicles

(Cook *et al.* 2012, p. 325). It is unknown whether or not foothill yellow-legged frogs cross large roads or highways, but road mortality would be expected to increase with the size of the road.

4.10 Diurnal Temperature Variation

Diurnal temperature variation appears to play an important role in foothill yellow-legged frog ecology. Many parts of the species' life cycle are closely linked to water temperature. Daily shifts in water temperature likely influence foothill yellow-legged frog feeding, metabolism, nutrient absorption, and behavior (S. Kupferberg 2019, pers. comm.). In some of the most productive foothill yellow-legged frog populations, daily temperature swings are particularly large; daily maximums and minimums are separated by 10 to 15 °C (18 to 27 °F) (R. Peek 2019, pers. comm.). Rearing of foothill yellow-legged frog tadpoles in captivity has recently indicated that a static water temperature might be fatal for this taxon. Under otherwise ideal conditions, most tadpoles reared in a static warm temperature believed to be optimal for growth, appeared to succumb to copepod parasitism (S. Kupferberg 2019, pers. comm.; Oakland Zoo 2019, p. 1; M. Rousser 2019, pers. comm.). Tadpoles from the same egg masses, but raised in outdoor tanks that underwent diurnal temperature variation[10], thrived and underwent metamorphosis at faster rates (S. Kupferberg 2019, pers. comm.; Oakland Zoo 2019, p. 1).

In addition to physiological benefits of temperature fluctuation, the temperature variation may also limit the prevalence of anuran pathogens in foothill yellow-legged frog habitat. While the risk of infection by copepod parasites is greater in warmer conditions (Kupferberg *et al.* 2009a, p. 529; Kupferberg *et al.* 2011a, p. 15), the prevalence and effects of other pathogens, such as Bd, increase under colder conditions (Raffel *et al.* 2013, pp. 148–149). Bd cultures grown in diurnally fluctuating temperatures had decreased total growth, growth rate, viability, and zoospore production compared to Bd grown at a constant temperature of 17.5 °C (63.5 °F) (Lindauer *et al.* 2020, p. 5). In laboratory experiments with the Cuban treefrog, Bd prevalence and load were lower for frogs experiencing a diurnal temperature shift of 10 °C (18 °F), compared to frogs with incubators set to constant temperatures of 15 or 20 °C (59 or 68 °F), or incubators with random temperature fluctuations (Raffel *et al.* 2013, p. 149). Therefore, wide diurnal temperature variation may regulate the prevalence of pathogens that might otherwise cause fatal outbreaks under static conditions (S. Kupferberg 2019, pers. comm.; R. Peek 2019, pers. comm.).

Diurnal temperature variation will not be considered further in the SSA analysis because it does not appear to be affecting foothill yellow-legged frogs in the wild. There is no evidence that the natural night/day temperature cycle in foothill yellow-legged frog habitat (and the species' ability to move between warmer and cooler parts of habitat) is inadequate to meet this need in the wild. However, this need should be considered when planning activities that require foothill yellow-legged frogs to be held in captivity.

---

[10] Daytime temperatures in the outdoor tanks with foothill yellow-legged frog larvae were approximately 24 to 27 °C but temperatures decreased by up to 10 °C overnight. Indoor tanks with foothill yellow-legged frog tadpoles were initially maintained at approximately 20 °C but were later increased to 25 °C. Within 48 hours of the temperature increase, approximately half of the indoor tadpoles died (Oakland Zoo 2019, p. 1).

CHAPTER 5 Population-level Demographic and Distribution Parameters

At the population level, we used the best available information to assess the resources, circumstances, and demographics that most influence the resiliency of foothill yellow-legged frog populations. Resiliency determines the ability of a population to withstand stochastic events. Stochastic events that may be experienced by foothill yellow-legged frog populations include, but are not limited to, spring storms or pulse flows, floods, droughts, high-severity wildfires, disease outbreaks, and predation.

In this chapter, we first describe the structure of a healthy foothill yellow-legged frog population (Section 5.2) and then we describe the demographic and distribution parameters necessary for a foothill yellow-legged frog population to have resiliency. The demographic and distribution parameters (population needs) being considered in this SSA are abundance, reproduction and recruitment, juvenile and adult survival, and metapopulation connectivity.

5.1 Population Definition

Foothill yellow-legged frog distributions and movements exhibit the characteristics of metapopulations (Lind 2005, p. 49; Kupferberg *et al.* 2009b, p. 132). A metapopulation consists of a network of spatially separated population units, or subpopulations, that interact at some level. Subpopulations are subject to periodic extirpation from demographic or environmental stochasticity, but then are naturally repopulated via colonization from nearby subpopulations. Therefore, it is more informative to look at species' status at the metapopulation level, which is more stable than the subpopulation level. A metapopulation is distinguished from an adjacent metapopulation by the rate of gene flow, with gene flow and recolonization rates being greater within a single metapopulation than between adjacent metapopulations. Given this definition, we can deduce that each of the six foothill yellow-legged frog genetic clades (2.6 Genetic Clades) contains one or more metapopulations that are unique to that clade. Often, metapopulations are separated by large distances (greater than typical dispersal distances) and/or unsuitable habitat, or by topological features that act as barriers to dispersal. Although there is information about distances moved by marked frogs (up to 1000's of m (Bourque 2008, p. 30; Gonsolin 2010, p. 38)) and the distances at which genetic differentiation can be observed (10 km (6.2 mi) (Dever 2007, p. 171;)), the actual boundaries of foothill yellow-legged frog metapopulations are largely unknown.

5.2 Abundance

Abundance, the number of individuals within a population, is a tenet of population resiliency (Wolf *et al.* 2015, p. 205, table 2) because it is an important predictor of extinction risk (Matthies *et al.* 2004, p. 483; Pearson *et al.* 2014, p. 219, figure 1). Abundance is also related to a population's carrying capacity (i.e., maximum number of individuals that a habitat can support) where populations with higher carrying capacities often have higher abundances. Carrying capacity, like abundance, is negatively related to a species' extinction risk (Gabriel and Burger 1992, p. 66). In general, the larger the population, the more resilient it is to stochastic demographic and environmental influences (Shaffer 1987, p. 71). For foothill yellow-legged frog populations, which are strongly influenced by environmental stochasticity (e.g., wet year versus dry year, precipitation timing, etc.) (Kupferberg 1996a, pp. 1332, 1340–1341), large abundances may be especially important for persistence probability (Goodman 1987, p. 33; Shaffer 1987, p. 73).

Population models demonstrate how foothill yellow-legged frog population abundance can have a sizeable effect on extirpation probability (Kupferberg *et al.* 2009c, p. ix; Rose *et al.* 2021, p. 12, figure 5). However, the minimum abundance required for a foothill yellow-legged frog population to be viable (i.e., minimum viable population) over an extended period is unknown. Multi-year survey data show how the average abundance of breeding females per km varies drastically among populations (Rose *et al.* 2020, pp. 63–64, table 1). The highest abundances (>100 breeding females per km) have only been recorded in the North Coast California unit (Rose *et al.* 2020, pp. 63–64, 76, table 1, figure 4). One of the most abundant foothill yellow-legged frog populations is along the Mad River (Humboldt County, North Coast California unit) where the average breeding female density was 259 per km for 2008–2019 (Green Diamond Resource Company 2020, *in litt.*). Egg mass abundance (i.e., proxy for number of breeding females) peaked in 2017 when 1,469 egg masses were counted within a 2.35 km stretch of the Mad River during a single survey (Green Diamond Resource Company 2020, *in litt.*). There are also populations that have exhibited long-term stability with much lower abundances, such as 18 breeding females per km, in some Central Coast unit streams (Rose *et al.* 2020, pp. 63, 76, table 1, figure 4). Locations where breeding female abundances are much lower (e.g., 5 per km) could be population sinks where female emigrants from nearby populations lay eggs but recruitment typically fails due to poor spawning and rearing conditions (Rose *et al.* 2020, pp. 47–48).

5.3 Reproduction and Recruitment

Reproduction and recruitment are required to maintain and increase population abundance. As such, they are required for population resiliency. For the purpose of this SSA, we define reproduction as the fertilization and oviposition of eggs and define recruitment as the successful completion of the metamorph life stage and entry into the terrestrial environment as a juvenile. We chose this definition of recruitment (as opposed to the completion of the juvenile life stage) because the ecology of, and threats acting upon, juveniles are more similar to those of adult foothill yellow-legged frogs than to those of early life-stages (Kupferberg *et al.* 2009c, p. 6; Rose *et al.* 2021, p. 2).

To persist into the future, metapopulations must have reproduction and successful recruitment into the adult breeding population. The rate of reproduction and recruitment must compensate for the rates of juvenile and adult mortality. For successful reproduction, foothill yellow-legged frogs must be in adult breeding condition, have access to mates, and have adequate oviposition sites. The success of early-season reproducers may be more valuable to foothill yellow-legged frog metapopulations because early-season egg masses tend to contain more eggs (Kupferberg *et al.* 2009c, p. 25; Gonsolin 2010, p. iv) and young have more time to complete metamorphosis. Recruitment is contingent on the survival of eggs, tadpoles, and metamorphs. Successful recruitment requires adequate rearing habitat that is not consistently affected by threats (e.g., irregular flow regimes, predators, pathogens, etc.) that can reduce recruitment rates below those required for population maintenance or growth. The implications of irregular flow regimes, and other threats that affect reproduction and recruitment, are discussed in CHAPTER 7 Influences on Viability.

Another feature of foothill yellow-legged frog population ecology is the species' ability to have high recruitment rates in some years, which may compensate for years that have little or no recruitment because of unfavorable conditions (e.g., late-season precipitation events). This theory is supported by the high fecundity of individual females (egg masses containing approximately 1,000 to 2,500 eggs each (Storer 1925, p. 254; Kupferberg *et al.* 2009c, p. 24)) and the wide variation in population growth rate among years (Kupferberg *et al.* 2009c, p. 45, table 3.2). High fecundity is also consistent with early life stages of foothill yellow-legged frogs being common prey for many species (Zweifel 1955, p. 225; Fellers 2005, pp. 535–536; GANDA 2008, p. 36).

5.4 Juvenile and Adult Survival

Survival, like reproduction and recruitment, is positively related to metapopulation abundance and resiliency. Low survival rates are extremely limiting for population growth and abundance; and they may prevent populations from being able to withstand stochastic events. While foothill yellow-legged frog population persistence is inextricably linked to early life-stage survival (Kupferberg *et al.* 2009c, p. 55), fluctuations in juvenile and adult (i.e., post-metamorphic) survival rates may have a greater influence on metapopulation viability than survival of early life stages (Rose *et al.* 2021, p. 11). Thus, adequate post-metamorphic survival is required for population resiliency.

Juvenile and adult foothill yellow-legged frogs have higher apparent survival rates than early life stages (except eggs); however, annual survival rates are still estimated to be less than 50 percent for adults and juveniles in healthy populations (estimates based on integrated population models that used egg-mass counts and capture–mark–recapture data from two North Coast California populations) (Rose *et al.* 2021, p. 7, table 1). While data are limited on the drivers of post-metamorphic survival, several types of threats are suspected to have had a significant role in foothill yellow-legged frog population declines. Some of the threats attributed to declines (by acting synergistically to decrease juvenile and adult survival, often in addition to decreasing early life stage survival) include disease (Adams *et al.* 2017a, p. 15; Adams *et al.* 2017b, p. 10221), extreme drought (Adams *et al.* 2017a, pp. 2–3), agrochemicals (Davidson *et al.* 2002, pp. 1597–1598), habitat destruction or modification (Davidson *et al.* 2002, p. 1597), and extreme flooding (Sweet 1983, abstract). The implications of these threats are discussed further in CHAPTER 7 Influences on Viability.

5.5 Metapopulation Connectivity

For the purpose of this SSA, we are defining metapopulation connectivity as the ease of mobility (for post-metamorphic frogs) within a metapopulation and between different metapopulations. Connectivity may also be viewed as the probability of a frog moving between patches of habitat (Kindlmann and Burel 2008, p. 882). A resilient metapopulation should have a network of quality breeding/rearing sites (often on or near the mainstem channel) and overwintering sites (often on tributaries of the mainstem) that are connected by habitat suitable for migration and dispersal (Section 4.9 Migration and Dispersal Routes). Both breeding/rearing and overwintering sites need to be distributed across the metapopulation area. Foothill yellow-legged frog occupancy (i.e., presence of breeding adults in a given area) must also be well distributed, such that dispersers are able to repopulate extirpated areas of the metapopulation. Furthermore, a metapopulation that is connected to other metapopulations (via dispersal habitat) is also more resilient because it can receive new individuals that might colonize extirpated sites and/or enhance the genetic diversity of the metapopulation.

CHAPTER 6 Species-level Conservation Parameters

Species-level conservation parameters are attributes that support viability, which is the ability of a species to maintain populations in the wild over time. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf *et al.* 2015, entire) (Figure 20). Resiliency is assessed at the population level and representation and redundancy are typically assessed across the entire range of the species.

6.1 Resiliency

Resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. Foothill yellow-legged frog resiliency is a function of metapopulation health and the distribution of these populations. A healthy metapopulation is defined in terms of its abundance, level of reproduction and recruitment, juvenile and adult survival, and connectivity (CHAPTER 5 Population-level Demographic and Distribution Parameters). The required number and distribution of populations is influenced by the degree and spatial extent of environmental stochasticity. Generally speaking, the greater the number of healthy populations and spatial heterogeneity occupied by the species, 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.

Refer to the conceptual diagram in Figure 20 to review how individual-level habitat elements and population-level parameters relate to resiliency.

6.2 Redundancy

Redundancy describes the ability of a species to withstand catastrophic events. Redundancy gauges the probability that the species has a margin of safety to survive and rebound after catastrophic events. It can be measured through the number and distribution of metapopulations across the range of the species. The greater the number of metapopulations a species has distributed over a landscape, the more probable recovery will be after catastrophic events. Redundancy can also be assessed as the amount of area occupied by a species, where the greater the occupied area, the greater the viability of the species. Occupied area may be the most important predictor of extinction risk due to climate change for amphibians and reptiles (Pearson *et al.* 2014, p. 217). Catastrophic events that could affect the foothill yellow-legged frog include long-term drought, large floods, high-severity wildfires, exotic species invasions, toxic chemical spills, and disease epidemics. Implications of these threats are discussed in more detail in CHAPTER 7.

6.3 Representation

Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (e.g., climate conditions, habitat conditions, habitat structure, etc.) and biological (e.g., pathogens, competitors, predators, etc.) environments. This ability to adapt to change (referred to as adaptive capacity) is essential for viability, as species need to continually adapt to their changing environments (Nicotra *et al.* 2015, p. 1269). Species adapt to novel changes in their environment by either (1) moving to new, suitable environments or (2) by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Nicotra *et al.* 2015, p. 1270; Beever *et al.* 2016, p. 132). Representation is measured by the breadth of genetic and environmental diversity within and among populations.

Physical and biological changes that are occurring, or are expected to occur, in foothill yellow-legged frog habitat include hydrological management, habitat alteration, high-severity wildfire, climate change, disease, parasites, nonnative species, and dynamics of predation and competition. Implications of these changes are discussed in more detail in CHAPTER 7 Influences on Viability.

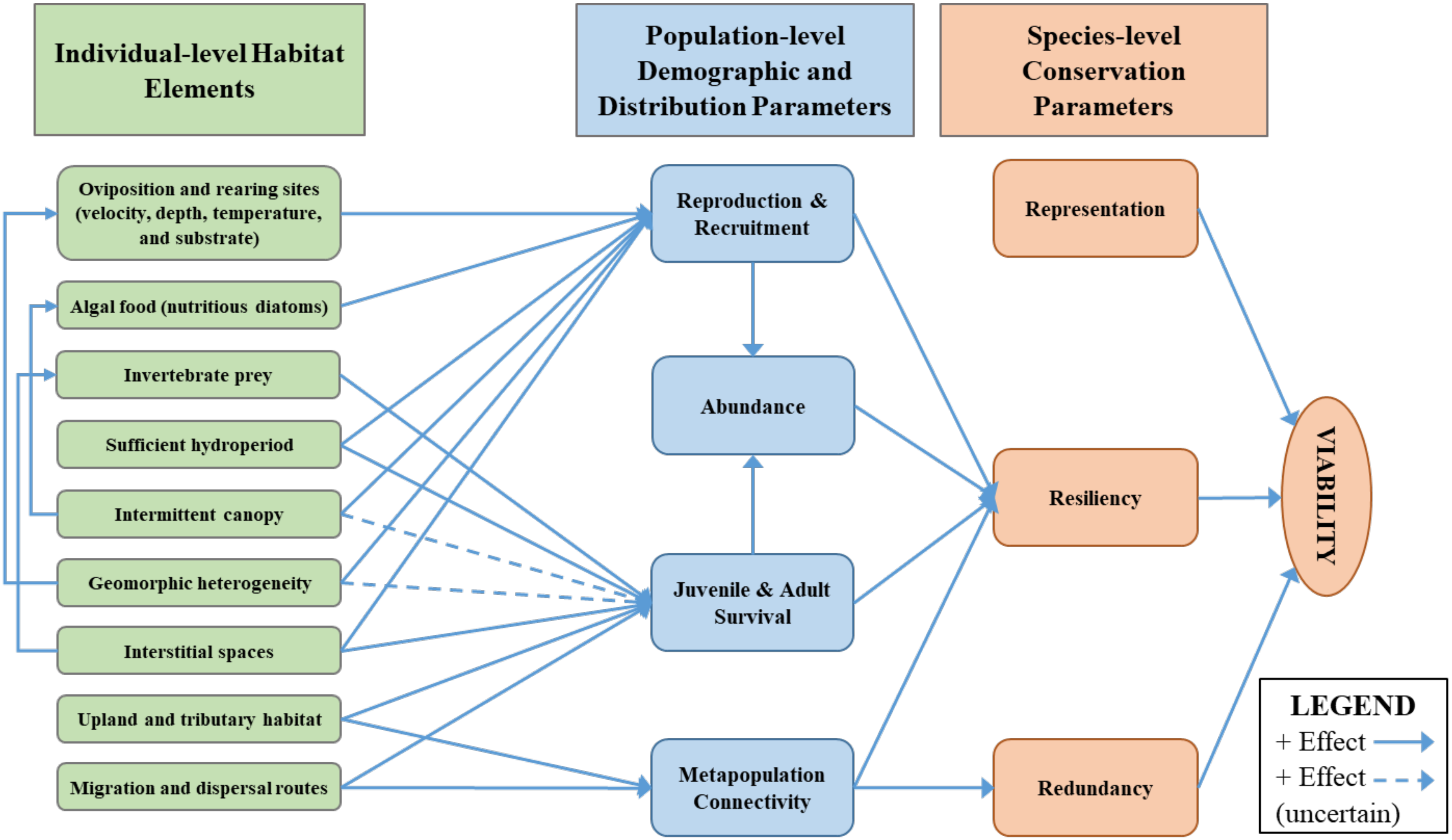


Figure 20. Conceptual diagram of the requirements for foothill yellow-legged frog viability.

CHAPTER 7 Influences on Viability

In this section, we evaluate the significant past, current, and future influences that are affecting foothill yellow-legged frog resiliency, redundancy, and representation. These influences affect individual, population, or species needs, ultimately affecting the viability of the species. The majority of these influences are considered threats to the foothill yellow-legged frog, in that they negatively influence viability. Positive influences on foothill yellow-legged frog viability, such as conservation efforts, are also covered in this chapter.

In our 90-day finding (supporting documents), we identified several threats from the petition that may negatively affect the foothill yellow-legged frog. The potential threats identified included dams (altered hydrology), nonnative species, pollution, mining, urbanization, roads, and recreation. Since the 90-day finding, we have identified additional threats including disease, parasites, increased sedimentation (including debris flows), agriculture, drought, high-severity wildfire, extreme flood events, high rates of predation or competition, competing conservation interests, and the effects of climate change. While some of these threats strongly influence the viability of the species, the majority of threats, when considered individually, affect population resiliency to a small degree. However, many of the threats are interrelated and act concurrently on populations. The influence of synergistic effects from concurrent threats can severely reduce population resiliency or cause population extirpations. We have taken into consideration the cumulative effects of threats impacting the species as part of our overall review of threats facing the species and not as a separate analysis. We also consider the cumulative effects of threats in light of those actions and conditions that will have positive effects on the species, such as any existing regulatory mechanisms or conservation efforts.

Livestock grazing and timber harvest were discussed as potential threats and potential beneficial influences in the recent status assessment for the foothill yellow-legged frog in California (CDFW 2019b, pp. 64–65, 67). These activities were also considered in the conservation assessment for the species in Oregon (Olson and Davis 2009, pp. 18–20). While there is potential for harm to the species (e.g., when grazing and timber practices cause excessive erosion and sedimentation into streams), there are also potential positive benefits to foothill yellow-legged frog habitat from these practices (Olson and Davis 2009, pp. 18–20; CDFW 2019b, pp. 64–65, 67). Considering the potential habitat benefits and scarce evidence that current grazing and timber practices are negatively affecting foothill yellow-legged frog populations, we do not explicitly assess livestock grazing and timber harvest in this Chapter. Instead, the potential negative impacts associated with grazing and timber harvest (e.g., water impoundments for cattle, erosion, logging roads) are captured in our assessment of altered hydrology (Section 7.1), sedimentation (Section 7.4), and roads (Section 7.7).

In the Oregon conservation assessment for the foothill yellow-legged frog, Olson and Davis (2009, p. 14) identified the three major threats in Oregon to be (1) habitat loss or alteration from impoundments and altered flow regimes, (2) competition and predation by nonnative species such as smallmouth bass and American bullfrogs, and (3) habitat loss or alteration from water diversion and water level fluctuations caused by agricultural irrigation.

In the conservation assessment for the foothill yellow-legged frog in California, Hayes *et al.* (2016, p. 32) identified five major risk factors and twelve other risk factors. In order of greatest to least concern, the five primary risk factors identified were (1) water development and diversion (altered hydrology); (2) climate change (increases in precipitation variability, drought, and water temperature); (3) habitat loss, urbanization, and fragmentation; (4) introduced (nonnative) species; and (5) mining (Hayes *et al.* 2016, pp. 32, 45). The twelve other risk factors, which had varying levels of support, included airborne contaminants (including pesticides), acid deposition, disease, fire management, livestock grazing, locally applied pesticides, recreational activities (including pack stock), research activity, restoration, roads, mid-range ultraviolet radiation (290 to 320 nanometers), and vegetation and fuels management (Hayes *et al.* 2016, pp. 32–36).

In the recent status review of the foothill yellow-legged frog in California, CDFW (2019b, p. 3) determined that the most widespread, and potentially most significant, threat is the presence of dams and altered flow regimes, particularly where dams use hydropeaking (i.e., pulse flows that are generally much greater in frequency and intensity compared to other sources of flow fluctuations (Greimel *et al.* 2018, p. 92)) to generate power. Climate change, disease, pollution, and nonnative species were also identified as major contributors to foothill yellow-legged frog declines (CDFW 2019b, pp. 3–4).

Based on our assessment across the entire range of the species, the threats that are, or have been, most influential to viability among the seven analysis units include altered hydrology (largely attributable to dams, water diversions, channel modifications), nonnative species (especially bullfrogs), Bd (pathogen responsible for the disease chytridiomycosis), agriculture, mining, urbanization (including roads and recreation), drought, high-severity wildfire, extreme flood events, and effects of climate change (e.g., increased temperature, greater proportion of precipitation falling as rain instead of snow, increased frequency and severity of extreme events, etc.) (Table 6). These influences to viability, and the other factors discussed in this chapter, do not affect all foothill yellow-legged frog analysis units or metapopulations to the same degree. Nor are the threats evenly distributed throughout the range of the species. Furthermore, the severity of effects may depend on the natural or anthropogenic ecological conditions in each analysis unit, metapopulation, or subpopulation.

Table 6. Past (before 2010) and present (2010 to 2020) threats to foothill yellow-legged frogs, organized by analysis unit. Pres = present. “Yes” indicates that the threat appears to have population-level effects in the analysis unit while “No” indicates that the threat is absent or does not appear to have population-level effects in the analysis unit. “U” indicates unknown. Bold indicates moderate-to-high certainty (greater than 50 percent) of influence on viability; italics indicate moderate-to-low certainty (less than or equal to 50 percent) of influence on viability. *Extreme flood events are a current threat in many, if not all, of the analysis units; however, extreme flood events have not been implicated in population declines during 2010–2020, therefore, “No” is attributed to present status of the threat for all analysis units.

	North Coast Oregon		**North Coast California**		**North Feather**		**North Sierra**		**South Sierra**		**Central Coast**		**South Coast**	
Threat	Past	Pres	Past	Pres	Past	Pres	Past	Pres	Past	Pres	Past	Pres	Past	Pres
Altered Hydrology	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Nonnative Species	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

	North Coast Oregon		**North Coast California**		**North Feather**		**North Sierra**		**South Sierra**		**Central Coast**		**South Coast**	
Threat	Past	Pres	Past	Pres	Past	Pres	Past	Pres	Past	Pres	Past	Pres	Past	Pres
Bd	U	U	U	U	U	U	U	U	U	U	*Yes*	**Yes**	*Yes*	U
Agriculture	**Yes**	**Yes**	**Yes**	**Yes**	*Yes*	*Yes*	*Yes*	*Yes*	**Yes**	**Yes**	*Yes*	*Yes*	*Yes*	*Yes*
Mining	**Yes**	U	**Yes**	U	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	U	**Yes**	U	**Yes**	U
Urbanization, Roads, and Recreation	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Drought	*No*	*No*	*No*	*No*	U	U	U	U	U	*Yes*	**Yes**	**Yes**	**Yes**	**Yes**
High-severity Wildfire	U	U	U	U	U	*Yes*	U	U	U	U	U	U	U	U
Extreme Flood Events*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*	**Yes**	*No*	*Yes*	*No*	**Yes**	*No*
Climate Change	*No*	*Yes*	*No*	*Yes*	*Yes*	**Yes**	*Yes*	**Yes**	*Yes*	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

7.1 Altered Hydrology (Dams, Surface-water Diversions, and Channel Modifications)

Dams and other waterway modifications alter the hydrology, temperature, and morphology of foothill yellow-legged frog stream habitat (Figure 21). As discussed in preceding chapters, foothill yellow-legged frog ecology and habitat needs are closely tied to the natural hydrological cycle. Successful foothill yellow-legged frog breeding and recruitment are dependent upon specific stream morphologies and upon predictable hydrological patterns that are concordant with climatic cues (Kupferberg 1996a, p. 1337). Therefore, alterations of stream hydrology can have a large influence on foothill yellow-legged frog distribution and metapopulation dynamics (Hayes *et al.* 2016, pp. 24–25; Figure 21).

Many population declines across the foothill yellow-legged frog's range have been attributed to the altered flow regimes and habitat fragmentation associated with water storage and hydropower dams (Kupferberg *et al.* 2009c, p. ix). Where populations of foothill yellow-legged frogs persist, breeding population densities were more than five times smaller below dams than in free-flowing rivers (based on populations in the North Coast California, North Feather, and Central Coast analysis units) (Kupferberg *et al.* 2012, p. 520). Dams and impoundments for the purpose of transporting logs in the North Coast Oregon unit have also presumedly caused extirpations of the species in some locations (Linnell and Davis 2021, not paginated, figure 6, figure 7).

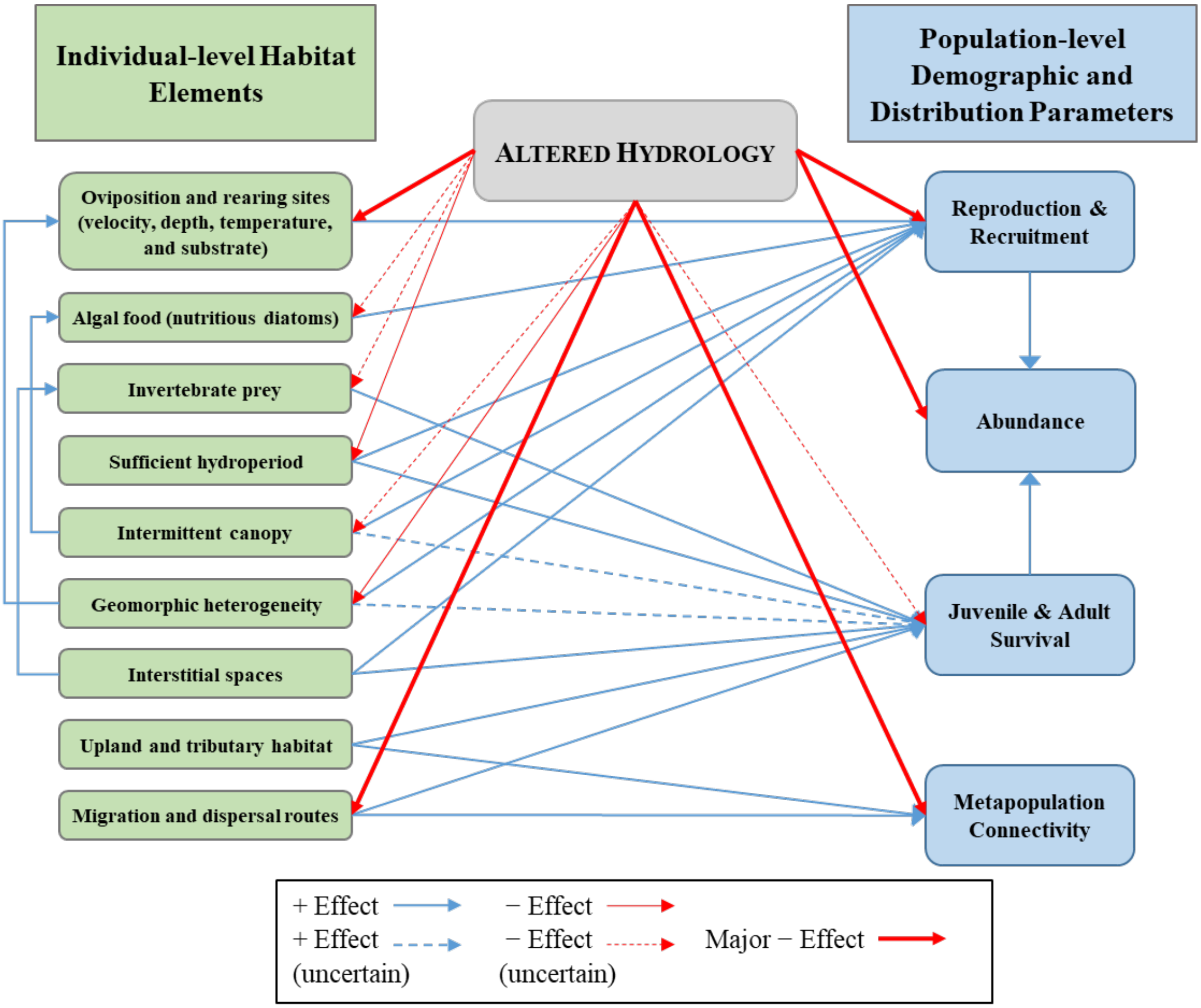


Figure 21. Conceptual diagram depicting the direct influences of altered hydrology on habitat elements and the demographic and distribution parameters for the foothill yellow-legged frog.

The artificial flow regimes associated with many hydrological projects include extreme fluctuations in water discharge over short intervals. These periods of high flows as water is discharged from a dam are called “pulses,” or “pulse flows” (Figure 22). When pulse flows are used for hydropower energy production, the term “hydropeaking” is used to describe the stream or river reach below the hydropower dam. Hydropeaking induces pulse flows that are generally much greater in frequency and intensity compared to other sources of flow fluctuations (Greimel *et al.* 2018, p. 92). Several studies have demonstrated how early life stages of foothill yellow-legged frogs are negatively affected by pulse flows during the breeding and rearing season because pulses alter the water velocities and depths in oviposition and rearing habitat (Kupferberg *et al.* 2009c, p. ix; Kupferberg *et al.* 2011b, p. 141). Variability in stream flow (i.e., the volume of water that moves over a designated point over a fixed period) during the spring and summer is strongly correlated with early life-stage mortality and subsequent declines in population abundance (Kupferberg *et al.* 2012, pp. 513, 520). A high flow event after oviposition risks scouring egg masses and washing tadpoles downstream (Kupferberg *et al.* 2009b, p. 1). In addition, the cessation of a pulse flow, characterized by a rapid decline in stream flow, can cause egg mass desiccation and/or tadpole stranding (Kupferberg 1996a, p. 1336; Ashton *et al.* 1997, p. 11; Kupferberg *et al.* 2009b, p. 1). In a study on the Trinity River (early 1990's), the timing of pulse flows from dams resulted in the loss of all cohorts in two years of the four-year study (Lind *et al.* 1996, p. 65). According to a population viability model, even a single pulse flow each summer can result in a three-fold to five-fold increase in 30-year extirpation risk for the species (Kupferberg *et al.* 2009c, p. 55).

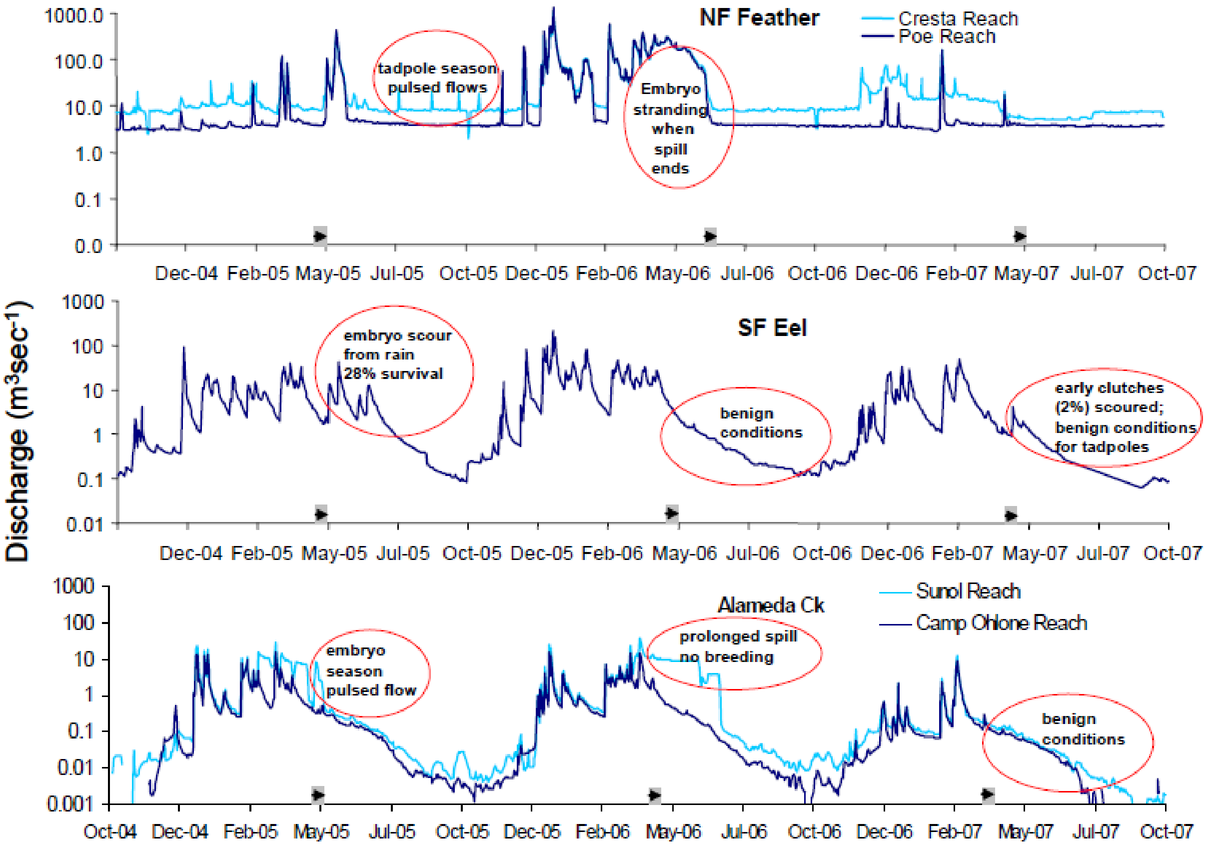


Figure 22. From Kupferberg *et al.* (2009c, p. 10, figure 1.2), "Mean daily discharge (m^3sec^{-1}) for water years 2005–2007 in one regulated [Sunol] and one unregulated reach of Alameda Creek (bottom), the unregulated SF [South Fork] Eel (middle) and two regulated reaches of the NF [North Fork] Feather (top). Circled regions of hydrographs indicate periods and events important to the survival of early life stages of *Rana boylii* [foothill yellow-legged frog]. Small arrows along the x-axes indicate dates when the oviposition and tadpole rearing seasons began in each river system."

Exacerbating the effects of unnatural flow regimes, water releases from dams are typically colder than natural water temperatures during spring and summer (Service and Hoopa Valley Tribe 1999, p. 34). Cold-water releases from impoundments (i.e., reservoirs) negatively affect foothill yellow-legged frog fitness by lowering stream water temperature below the optimal range for breeding, growth, and development. For example, late-spring and summer water temperatures on the mainstem Trinity River below Lewiston Dam (North Coast California unit) have become as much as 11 °C (20 °F) cooler than pre-dam temperatures (Service and Hoopa Valley Tribe 1999, p. 87). As discussed in CHAPTER 4, water temperature is a cue for foothill yellow-legged frogs to begin breeding activity (Kupferberg 1996a, p. 1340; CDFW 2019b, p. 49). Colder water temperatures also negatively affect egg and tadpole survival by limiting growth and development (Wheeler *et al.* 2015, pp. 1280–1281; Hayes *et al.* 2016, p. 14).

Pulse flows and cold-water releases negatively affect algal food and invertebrate prey via the same mechanisms that they affect the frog life cycle. Changes in flow velocity and water temperature associated with pulse flows affect the quantity and quality of periphyton, invertebrate biomass, and invertebrate community structure (Steel *et al.* 2018, pp. 855–856; reviewed in Greimel *et al.* 2018, pp. 96, 100). Like frog eggs, aquatic-insect eggs are subject to desiccation mortality when river levels drop unexpectedly (Kennedy *et al.* 2016, p. 564). In hydropeaking rivers of the western U.S., aquatic insect diversity is strongly negatively related to the degree of hydropeaking (i.e., a hydropeaking index measured by the daily coefficient of variation in discharge) (Kennedy *et al.* 2016, p. 569).

Another consequence of altered hydrology is a decrease in the quality and quantity of foothill yellow-legged frog breeding habitat (Lind *et al.* 1996, p. 65). Dams and water diversions can decrease the intensity and frequency of downstream winter flow events, which can lead to extensive changes to foothill yellow-legged frog breeding habitat (GANDA 2018, pp. 37–38; CDFW 2019b, p. 51). Strong winter flow events that are typical in breeding areas during winter help maintain and/or create foothill yellow-legged frog breeding habitat by widening and diversifying channel morphology, improving rocky substrate conditions, removing sediment, and increasing sunlight by limiting vegetation encroachment (Lind *et al.* 1996, pp. 64–65; Lind *et al.* 2016, p. 269; Power *et al.* 2016, p. 719; GANDA 2018, pp. 37–38). The nonnative algae (*Didymosphenia geminata*) which causes impacts to food resources and alters habitat conditions for the foothill yellow-legged frog by forming thick algal mats on rocky substrate, has been associated with areas below dams where winter flows are regulated (Spaulding and Elwell 2007, entire; Furey et al. 2014, pp. 8–10).

Dam construction also causes habitat loss and fragmentation by creating impoundments. Impoundments lead to direct habitat loss and local extirpations by inundating areas that were formerly occupied by foothill yellow-legged frogs (Hayes *et al.* 2016, pp. 36, 40, table 8). They also aid in the establishment and spread of nonnative species, such as American bullfrogs (Kupferberg 1996b, p. 16; Lind *et al.* 1996, p. 65; Cooper *et al.* 2013, p. 383). Altered flow management below dams can create the conditions for establishment of stable pools and aquatic vegetation that benefit nonnative species downstream of impoundments (Lind *et al.* 1996, p. 65; Cooper *et al.* 2013, p. 383).

Dams, impoundments, and hydrologically altered rivers also appear to impede foothill yellow-legged frog dispersal and metapopulation connectivity, which can prevent recolonization of extirpated areas and cause genetic bottlenecks (Peek 2010, p. 44; Peek 2012, p. 15). Genetic comparisons among subpopulations demonstrated that gene flow is decreased in regulated systems, even when regulation intensity is low (i.e., bypass reaches) (Peek 2012, p. 15; Peek *et al.* 2021, p. 14).

A number of anthropogenic and environmental factors influence hydrological functioning of streams with the greatest factor being water demand. Hydrological developments for water consumption (agricultural and municipal), hydropower energy, and flood control have a long history in California (California Natural Resources Agency (CNRA) *et al.* 2020, pp. 50–51). Amidst climate change, human population growth, and land use trends, water demand for renewable hydropower energy, agriculture, and municipal use are expected to continue to increase in California (Wilson *et al.* 2017, p. 16). Hydropower dams are relied upon for a considerable portion of the state's energy, currently supplying approximately 15 percent of California's electricity (Escriva-Bou *et al.* 2019, not paginated). In California, there is also an ongoing trend toward conversion of annual croplands to higher-value perennial croplands (i.e., orchards and vineyards) (CNRA *et al.* 2020, p. 11). This trend of increasing perennial cropland is projected to continue into the future (2062) under a diverse range of future land use scenarios (Wilson *et al.* 2017, pp. 8, 10, figure 4). Increases in perennial cropland are expected to intensify demand for annual water supplies because growers are unable to forgo irrigation of perennial crops during drought (CNRA *et al.* 2020, p. 11). The effects of climate change (Section 7.13) will likely intensify the need for hydrological management due to projected increases in frequency of floods and water shortages from extreme dry-to-wet precipitation events (Swain *et al.* 2018, p. 427). With the projected changes, there will likely be growing demand for hydrological infrastructure expansion or improvements that increase water storage capacity, increase water diversion and transport capabilities, and protect communities and property from flooding.

Hydrological alteration is expected to continue being a major threat for the foothill yellow-legged frog in the future (CDFW 2019b, pp. 90–91). However, it is also worth noting that flow regulation can be managed to reduce effects to riparian ecosystems and wildlife (Yarnell *et al.* 2020, entire). While flow regulation can be managed to reduce negative effects, this typically requires a determination by the Federal Energy Regulatory Commission to include such measures in a new hydropower license. For some hydropower licenses in California, terms and conditions have been added during relicensing that require modified flow regimes and/or standard best management practices that limit the negative effects of operations on fish and wildlife (CDFW 2019b, pp. 87–88; Table 9).

7.2 Nonnative Species

Foothill yellow-legged frog viability can be negatively influenced by several nonnative animal species. The American bullfrog (*Lithobates catesbeianus*, also known as *Rana catesbeiana*), nonnative crayfish (*Pacifastacus spp.*), and nonnative fish (e.g., smallmouth bass (*Micropterus dolomieu*)) have all been linked to decreases in foothill yellow-legged frogs (Olson and Davis 2009, pp. 17–18; Hayes *et al.* 2016, pp. 49–51). The following subsections provide details on how these nonnative species influence the foothill yellow-legged frog at various life stages by increasing predation, competition, and/or disease transmission.

Other nonnative species, such as the barred owl (*Strix varia*), might also negatively influence foothill yellow-legged frog viability but are not discussed in detail because of limited information. Barred owls are suspected to be an emerging threat to foothill yellow-legged frogs in the North Coast analysis units (D. Olson 2021, *in litt.*) because of their predation of ranid frogs (Wiens *et al.* 2014, p. 25, table 12).

Bullfrogs

American bullfrogs, in particular, are a severe threat in all seven analysis units. Bullfrogs affect foothill yellow-legged frog populations in several ways because they are simultaneously competitors, predators, and disease vectors; they also impact life stages from tadpoles to adults (Figure 23). The earliest known transport of bullfrogs to California was in 1896, when they were beginning to be raised on California ranches for human consumption (Heard 1904, p. 24). Bullfrogs have since become widespread throughout much of the foothill yellow-legged frog range (Yap *et al.* 2018, pp. 1, 6, figure 2). The spread of bullfrogs is facilitated by altered hydrology, land-use change, drought, and increasing water temperatures (Moyle 1973, p. 21; Fuller *et al.* 2011, pp. 210–211; Adams *et al.* 2017a, p. 13). Moyle (1973, p. 21) advised that bullfrogs might replace foothill yellow-legged frogs throughout the Sierra Nevada foothills if anthropogenic habitat alterations (i.e., change in channel or water condition as a result of direct or indirect human activities) of foothill streams continued (Moyle 1973, pp. 19, 21).

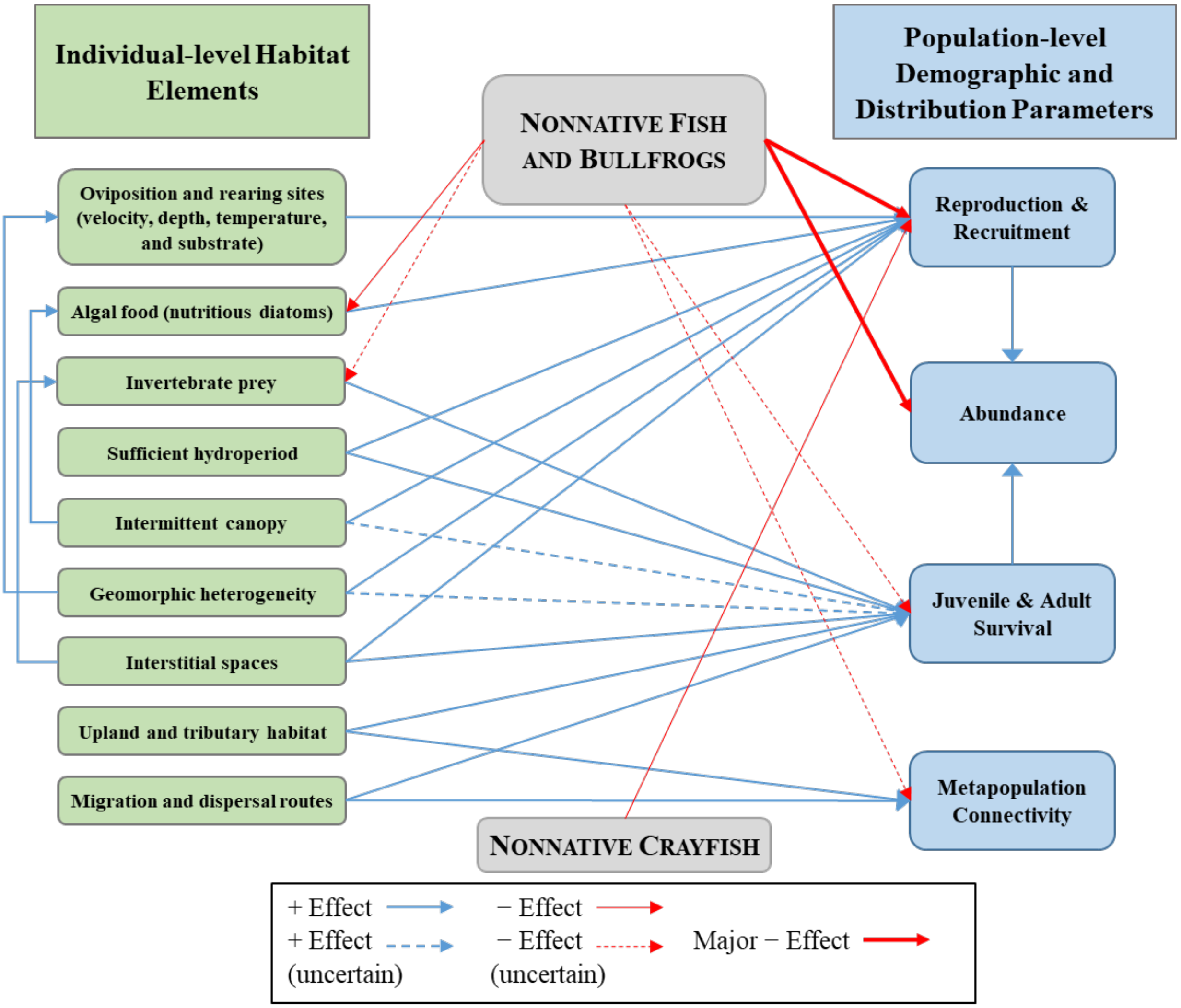


Figure 23. Conceptual diagram depicting the direct influences of nonnative species on habitat elements and the demographic and distribution parameters for the foothill yellow-legged frog.

Although the effects of bullfrogs on foothill yellow-legged frogs are difficult to distinguish from the co-occurring threats that accompany bullfrog invasion, research indicates that bullfrogs have had an instrumental role in foothill yellow-legged frog population declines through competition, depredation, and disease transmission (Moyle 1973, p. 21; Kupferberg 1997a, p. 1749; Adams *et al.* 2017a, p. 13; Yap *et al.* 2018, p. 2). Bullfrogs impact foothill yellow-legged frogs by direct predation (Crayon 1998, p. 232; Hothem *et al.* 2009, pp. 279–281, table 1) and indirectly by reducing survival. For example, an experiment on the South Fork Eel River (North Coast California unit) determined that the presence of competing bullfrog tadpoles reduced foothill yellow-legged frog tadpole survivorship by 48 percent, and mass at metamorphosis by 24 percent (Kupferberg 1997a, p. 1736). The study also found that the algal and macroinvertebrate assemblages were significantly altered by bullfrog tadpoles (Kupferberg 1996b, p. 2; Kupferberg 1997a, p. 1736), which would affect food sources for foothill yellow-legged frog tadpoles, juveniles, and adults.

Bullfrogs are implicated in the spread of the pathogen that causes chytridiomycosis (i.e., Bd), both locally and globally (Huss *et al.* 2013, p. 341; Adams *et al.* 2017b, p. 10226; Yap *et al.*

2018, pp. 1–2; Byrne *et al.* 2019, p. 20386). A study of a Central Coast unit population found that bullfrog presence was a positive predictor of Bd prevalence (proportion of individuals infected) and Bd load in foothill yellow-legged frogs (Adams *et al.* 2017a, p, 1).

Crayfish

Several nonnative crayfish species can prey upon early life stages of foothill yellow-legged frog. While the signal crayfish (*Pacifastacus leniusculus*) is native to part of the North Coast units (i.e., Oregon and northwestern corner of California), it has been introduced into several areas within the coast ranges of northern California and the Sierra Nevada (Wiseman *et al.* 2005, p. 162; Pintor *et al.* 2009, p. 582; CDFW 2019b, p. 56). In both the native and introduced range of the signal crayfish, the species preys upon foothill yellow-legged frog egg masses, and likely contributes to dislodging egg masses from substrate (Rombough and Hayes 2005, p. 163; Wiseman *et al.* 2005, p. 162). Signal crayfish are also known to prey upon foothill yellow-legged frog tadpoles in a laboratory setting (Kerby and Sih 2015, p. 266) and observations of tail injuries in wild tadpoles suggest crayfish predation also occurs in the wild (Rombough and Hayes 2005, p. 163; Wiseman *et al.* 2005, p. 162). Recently, researchers suggested that signal crayfish might be creating holes in the in-situ rearing enclosures and consuming tadpoles in the North Feather unit (Dillingham 2019, p. 10).

Other nonnative crayfish species also occur within the range of the foothill yellow-legged frog. Although evidence of direct impacts to foothill yellow-legged frogs is lacking for these species, the evidence of predation on other native amphibians suggests that the presence of at least one of these crayfish species would also limit foothill yellow-legged frog recruitment. Native to the southern United States, the red swamp crayfish (*Procambarus clarkii*) has been recorded throughout the range of the foothill yellow-legged frog, except for the northern Sierra Nevada (Nagy *et al.* 2020, not paginated). Presence of the red swamp crayfish in southern California streams is negatively correlated with Pacific treefrog (*Pseudacris regilla*) egg mass and tadpole density (Riley *et al.* 2005, pp. 1899–1900). Red swamp crayfish predation of eggs and tadpoles is also implicated in localized declines of the California newt (Gamradt and Kats 1996, pp. 1155, 1161). In addition to the red swamp crayfish, the ringed crayfish (*Faxonius neglectus*, formerly *Orconectes neglectus*; native to the central United States) has also invaded foothill yellow-legged frog habitat in Oregon (U.S. Geological Survey 2020, not paginated). However, impacts of ringed crayfish introductions to amphibians have not been documented.

Fish

Nonnative fish are predators, and potentially competitors, of foothill yellow-legged frogs. The severity of effect of nonnative fish on frog populations is difficult to distinguish from that of bullfrogs because bullfrogs typically co-occur with nonnative fish (Moyle 1973, p. 19; Hayes and Jennings 1986, pp. 499–500). Smallmouth bass (*Micropterus dolomieu*), green sunfish (*Lepomis cyanellus*), mosquitofish (*Gambusia affinis*), and trout (*Oncorhynchus*, *Salmo*, and *Salvelinus spp.*) may compete with foothill yellow-legged frogs for invertebrate food resources (Hayes *et al.* 2016, p. 51). The fish species that is most often referred to as a threat to foothill yellow-legged frogs is the nonnative smallmouth bass. Adult smallmouth bass have been documented consuming foothill yellow-legged frog tadpoles and adults (Rombough 2006a, not paginated; Paoletti *et al.* 2011, p. 166), as well as consuming tadpoles of other related frog species (Kiesecker and Blaustein 1998, pp. 784–785). Behavior experiments suggest that foothill yellow-legged frog tadpoles have not yet evolved a response to smallmouth bass as a threat, which would make the frogs more vulnerable to predation (Paoletti *et al.* 2011, pp. 161, 166). While the smallmouth bass is not native to Oregon, it is now also considered a game fish and regulated by the Oregon Department of Fish and Wildlife (ODFW) (ODFW no year, entire; ODFW 2009, entire). This bass species has also been identified as a potential cause of foothill yellow-legged frog declines and extirpations in Oregon (Rombough 2006a, not paginated; Olson and Davis 2009, pp. 13, 17). Native freshwater fish also prey upon foothill yellow-legged frog eggs and hatchlings (Rombough and Hayes 2005, p. 164), but population declines of foothill yellow-legged frogs have not been attributed to predation by native fish.

The distribution of smallmouth bass in California includes the entire South Coast analysis unit and lower elevation areas of the South Sierra, North Sierra, and North Feather analysis units. Areas in the foothill yellow-legged frog's range in the Salinas, Santa Clara, Central, and Sacramento valleys are also within the range of the smallmouth bass. In the North Coast California unit, smallmouth bass occupy the Russian River, Trinity River, and Eel River drainages (Conservation Biology Institute 2011, entire). In Oregon, smallmouth bass can be found in the entire range of the North Coast Oregon unit except the extreme southeastern portion near the Klamath basin (Carey *et al.* 2011, p. 306).

7.3 Disease and Parasites

Foothill yellow-legged frog viability can be negatively influenced by the presence of *Batrachochytrium dendrobatidis* (Bd; causative agent of chytridiomycosis), parasitic copepods, and water molds (Saprolegniaceae family) (Figure 24). The following subsections provide details on how these three pathogens influence the foothill yellow-legged frog at various life stages.

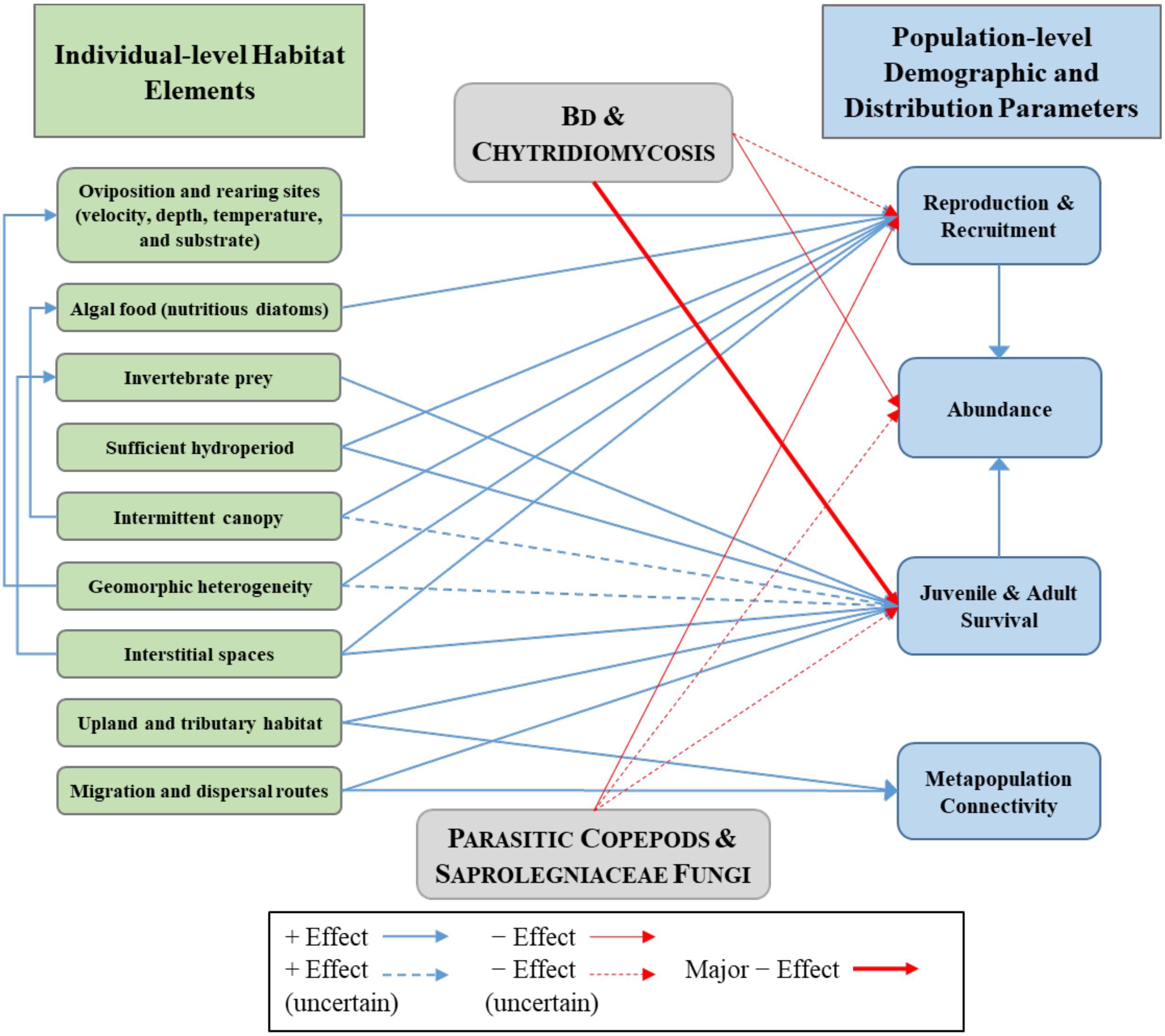


Figure 24. Conceptual diagram depicting the direct influences of Bd, parasitic copepods, and Saprolegniaceae fungi on demographic parameters for the foothill yellow-legged frog.

Batrachochytrium dendrobatidis (Bd)

The amphibian chytrid fungus, *Batrachochytrium dendrobatidis* (Bd), causes the disease, chytridiomycosis. Bd is implicated in the declines or presumed extinctions of hundreds of amphibian species (Scheele *et al.* 2019, p. 1). Spatial and temporal evidence of Bd prevalence suggests that Bd played a role in the precipitous decline of the foothill yellow-legged frog in southern California (Adams *et al.* 2017b, p. 10224). The spread of Bd in the range of the foothill yellow-legged frog is presumably linked to increased human use of habitat and the introduction of nonnative bullfrogs, which are considered Bd reservoir hosts (Huss *et al.* 2013, p. 341; Adams *et al.* 2017b, pp. 10225–10226; Yap *et al.* 2018, pp. 1–2; Byrne *et al.* 2019, p. 20386). In addition to bullfrogs, other probable reservoir species include the exotic African clawed frog (*Xenopus laevis*) and the native Pacific treefrog (Padgett-Flohr and Hopkins 2009, pp. 1, 7).

Until recently, it was not well known that foothill yellow-legged frogs are susceptible to the effects of Bd (J. Alvarez 2018, *in litt.*). Foothill yellow-legged frogs appear to be less susceptible to mortality from chytridiomycosis than some other anurans because of their secretion of robust antimicrobial skin peptides (Davidson *et al.* 2007, p. 1774). Records of foothill yellow-legged frog mortality events caused by chytridiomycosis were not published in scientific literature until 2017 even though the earliest observations of such events were from the 1980s (Adams *et al.* 2017a, p. 9; Adams *et al.* 2017b, p. 10221). The documented mortality events related to Bd-caused chytridiomycosis in foothill yellow-legged frogs have all occurred in the Central Coast unit (Table 7). However, Bd is implicated in the decline of the foothill yellow-legged frog in both the Central Coast and South Coast units (Adams *et al.* 2017b, p. 10224). It was suggested that the southern California precipitation regime (i.e., alternation of extreme droughts and floods) may increase the likelihood of disease outbreaks (Adams *et al.* 2017b, p. 10228).

Based on the recent mortality events in Central Coast unit populations, Bd prevalence and loads appear to peak in the fall when foothill yellow-legged frogs are most concentrated at drying pools (S. Kupferberg 2020a, *in litt.*). Juvenile foothill yellow-legged frogs appear to be the most susceptible life stage to Bd and chytridiomycosis (Lowe 2009, pp. 180–181, figure 2; Adams *et al.* 2017a, p. 2; S. Kupferberg 2020a, *in litt.*).

Table 7. Documented mortality events related to Bd-caused chytridiomycosis in foothill yellow-legged frogs.

Year	Location	Analysis Unit	Source
1986	Stream in Stanislaus County (85 died over 2 weeks)	Central Coast	Adams *et al.* 2017b, p. 10221
1989	Clear Creek, San Benito County (6 died in laboratory 6 weeks after collection)	Central Coast	Adams *et al.* 2017b, p. 10221
2013	Arroyo Hondo, Alameda County	Central Coast	Adams *et al.* 2017a, pp. 2–3
2013	Alameda Creek, Alameda County	Central Coast	Adams *et al.* 2017a, pp. 2–3
2018	Coyote Creek, Santa Clara County	Central Coast	M. Grefsrud 2018, *in litt.*
2019	Coyote Creek, Santa Clara County	Central Coast	B. Blinn 2019, *in litt.*

The Bd pathogen has been documented within all the analysis units (Yap *et al.* 2018, p. 5, figure 1). Study of museum amphibian specimens suggests that Bd has been in California for more than 100 years (Adams *et al.* 2017b, pp. 10221–10222, table 3). However, the presence of Bd may not necessarily lead to chytridiomycosis because factors such as environmental context and Bd genetic lineage likely play a role in the pathogen's virulence (Voyles *et al.* 2012, pp. 2246–2247; Adams *et al.* 2017b, p. 10227; Byrne *et al.* 2019, pp. 20382–20383). The earliest evidence of chytridiomycosis in southern California is from histological examination of two western toad (*Anaxyrus boreas*) specimens collected in 1915 from Los Angeles County (South Coast unit)

(Adams *et al.* 2017b, pp. 10221–10222, table 3). Bd DNA has been detected on foothill yellow-legged frog specimens collected as early as 1940 in Ventura County (South Coast unit) (Adams *et al.* 2017b, p. 10222, table 3). DNA analysis of amphibian museum specimens collected from Ventura, Santa Barbara, Los Angeles, and San Luis Obispo counties (South Coast unit) showed that Bd prevalence steadily increased starting in the early 1970s and continued through the 1990s, after which, Bd prevalence declined (Adams *et al.* 2017b, p. 10221).

The earliest evidence of Bd in the Central Coast unit is from DNA analysis of bullfrog museum specimens collected in 1929 in Santa Clara County (Huss *et al.* 2013, supplemental material). The earliest evidence of Bd-positive foothill yellow-legged frogs from the Central Coast unit is from specimens collected during 1966 from Santa Cruz and Alameda counties (Padgett-Flohr and Hopkins 2009, p. 4).

Sublethal effects of Bd exposure are also a serious concern for foothill yellow-legged frogs. In a laboratory study, wild-caught foothill yellow-legged frogs from Mendocino County (North Coast California unit) that were exposed to Bd grew 40 percent less than those that were not exposed (Davidson *et al.* 2007, 1773). In the wild, foothill yellow-legged frogs that tested positive for Bd in the Central Coast unit had lower body mass to length ratios although the frogs showed no other signs of infection (Lowe 2009, pp. 180–181). Tadpole susceptibility experiments with other western anurans documented species-specific effects of Bd exposure such as tadpole lethargy (motionless at bottom of tank), disorientation, weak response to prodding, and increased incidence of tadpole mouthpart deformities (Blaustein *et al.* 2005, pp. 1464–1466).

It is unknown whether certain foothill yellow-legged frog populations are inherently more susceptible to chytridiomycosis. Different species of anurans have different levels of susceptibility to mortality and/or sublethal effects of Bd exposure (Blaustein *et al.* 2005, pp. 1464–1465). Alternatively, temporal and/or environmental contexts may have contributed to more extirpations in certain regions over others (Adams *et al.* 2017b, p. 10227). Lower daily streamflow is related to higher Bd loads (Adams *et al.* 2017a, p. 11). Bd is also responsive to temperature, but the temperature regime that is most conducive to Bd outbreaks appears to depend on host-pathogen interactions and/or other unknown factors (Raffel *et al.* 2013, pp. 148–149; Adams *et al.* 2017a, pp. 11–12; Adams *et al.* 2017b, p. 10228; Lindauer *et al.* 2020, p. 6). That is, warmer temperatures lead to higher Bd growth rates in laboratory cultures, but cooler temperatures are associated with greater Bd prevalence and load on some host organisms (Raffel *et al.* 2013, p. 148), including foothill yellow-legged frogs (Lowe 2009, p. 181). The "thermal mismatch hypothesis" has been used to describe the wide intra- and inter-species variation in susceptibility to Bd based on a species' thermal niche (and its temperature-dependent susceptibility to Bd) and environmental conditions (Nowakowski *et al.* 2017, entire; Cohen *et al.* 2017, entire). There are also different genetic lineages of Bd that vary in geographic extent, virulence, and response to temperature (Stevenson *et al.* 2013, pp. 8, 10; Voyles *et al.* 2017, pp. 369–370; Byrne *et al.* 2019, pp. 20382–20383). Bd can grow well in culture at a wide range of temperatures from 2 to 27 °C (36 to 81 °F) and exhibits greatest growth between 13 and 25 °C (55 and 77 °F), depending on the origin or genetic lineage of the Bd (Stevenson *et al.* 2013, p. 8; Voyles *et al.* 2017, pp. 368–369).

In summary, Bd has likely played a role in declines and extirpations of the foothill yellow-legged frog in southern California. Chytridiomycosis outbreaks are currently causing mortality events in some Central Coast unit populations but Bd could be having detrimental sublethal effects to populations throughout the species' range. With an incomplete understanding of the complex nature of Bd and its interactions with its hosts and environments, it is uncertain whether Bd is likely to have a major influence on foothill yellow-legged frog viability into the future. However, the impact of Bd on foothill yellow-legged frog populations will likely increase if co-occurring threats also increase because of the synergistic effects of multiple stressors on this species.

Parasitic Copepods

Parasitism of foothill yellow-legged frogs by the Eurasian copepod, *Lernaea cyprinacea*, is linked to malformations in tadpole and juvenile foothill yellow-legged frogs (Kupferberg *et al.* 2009a, p. 529). In addition to malformations, there are likely other sublethal effects of this parasite on foothill yellow-legged frogs, such as stunted growth (Kupferberg *et al.* 2009a, p. 529). Although direct foothill yellow-legged frog mortality from this parasite has not been documented in the wild, copepod parasitism may be responsible for mortality of tadpoles in captivity (S. Kupferberg 2019, pers. comm.; Oakland Zoo 2019, p. 1; M. Rousser 2019, pers. comm.).

In contrast to Bd, outbreaks of *Lernaea cyprinace* is associated with unusually warm summer water temperatures (Kupferberg *et al.* 2009a, p. 529). Based on a multiyear study of foothill yellow-legged frogs in the South Fork Eel River (North Coast California unit), Kupferberg *et al.* (2009a) suggest that the changes predicted by climate change models (i.e., increased summer water temperatures and decreased daily discharge) may promote outbreaks of this parasite that could threaten the long-term conservation of the foothill yellow-legged frog throughout its range (Kupferberg *et al.* 2009a, p. 529).

Saprolegniaceae Fungi

Water molds (Saprolegniaceae family) are known to cause egg mortality in amphibians of the Pacific Northwest (Blaustein *et al.* 1994, p. 251). Fungal infections of foothill yellow-legged frog egg masses, potentially from the *Saprolegnia* genus, have been observed in the mainstem Trinity River (Ashton *et al.* 1997, pp. 13–14), in approximately 25 percent of egg masses during a study in the South Fork Eel River (Kupferberg 1996a, p. 1337), and in 14 percent of egg masses during 2002 and nearly 50 percent of egg masses during 2003 in the Cresta reach of the North Fork Feather River (GANDA 2004, p. 55). While fungal infections are not a major source of mortality for foothill yellow-legged frogs, this threat can have a strong effect in other amphibian populations (Blaustein *et al.* 1994, pp. 251–253) and might influence foothill yellow-legged frog resiliency when combined with other threats (CDFW 2019b, pp. 54–55).

7.4 Sedimentation

Sedimentation is the deposition or accumulation of small particles in the bottom of a water body. Sedimentation is a threat for foothill yellow-legged frogs because it reduces the availability of important habitat features including coarse rocky substrates, geomorphic heterogeneity, and interstitial spaces. Increased sedimentation can increase turbidity, impact food resources, or impede foothill yellow-legged frog egg mass attachment to substrate (Cordone and Kelley 1961, pp. 191–192; Ashton *et al.* 1997, p. 13). Fine sediments can also fill interstitial spaces between rocks, which provide shelter from high velocity flows, cover from predators, and sources of aquatic invertebrate prey (Harvey and Lisle 1998, pp. 12–14; Olson and Davis 2009, p. 11; Kupferberg *et al*. 2011b, pp. 147–149). Additional adverse effects that have been proposed (but not proven) include impediment of gas exchange as fine sediments are deposited on egg masses, encroachment of vegetation that reduces basking or foraging habitat, decrease in algal food availability for tadpoles, and decrease in prey availability for post-metamorphic stages (Cordone and Kelley 1961, p. 213; Borisenko and Hayes 1999, p. 25; Olson and Davis 2009, p. 25; CDFW 2019b, p. 57).

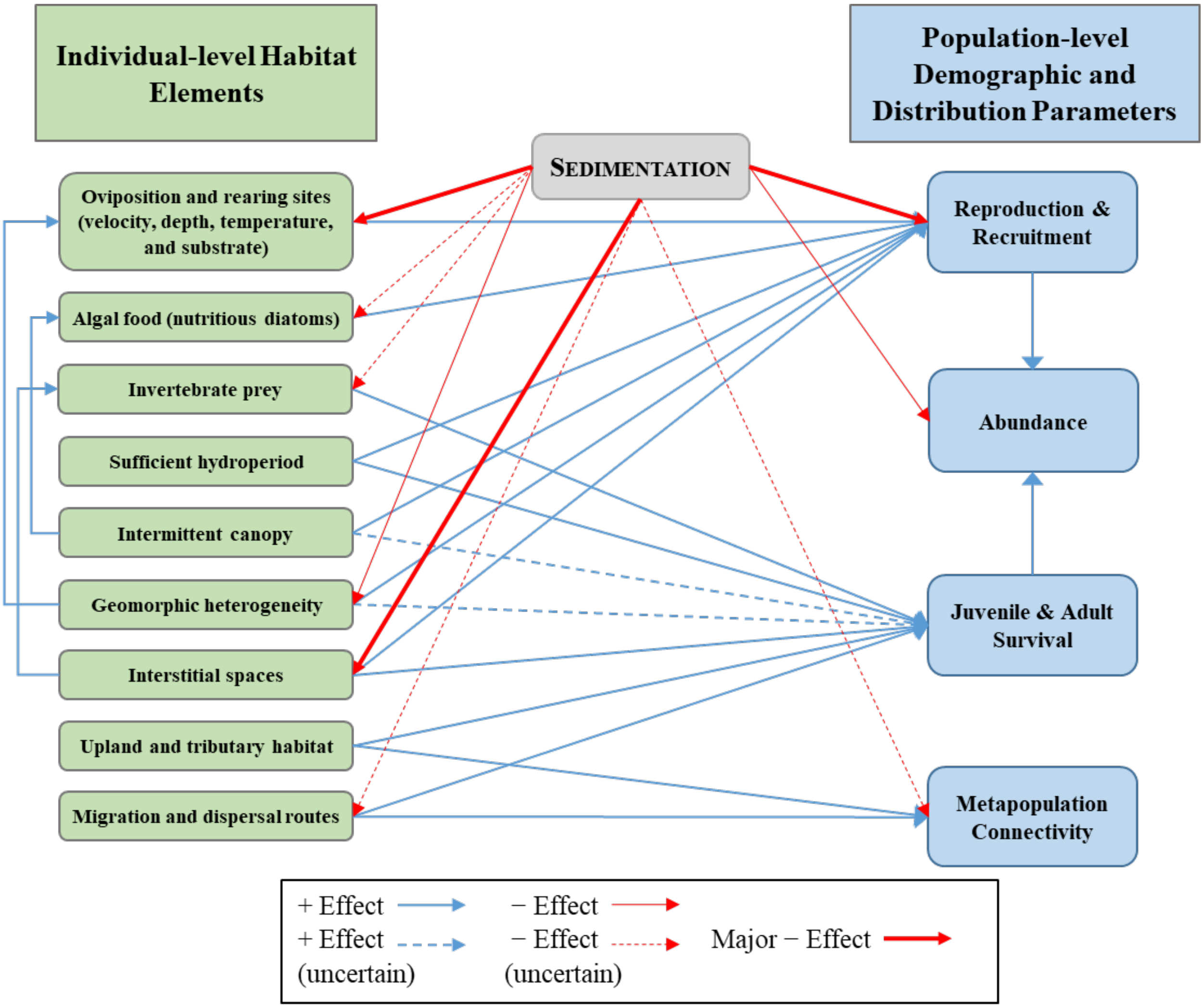


Figure 25. Conceptual diagram depicting the direct influences of sedimentation on habitat elements and the demographic and distribution parameters for the foothill yellow-legged frog.

Sedimentation can result from a wide range of natural and anthropogenic processes. High sediment loads can result from run-off due to heavy precipitation, precipitation events after wildfire or long-term drought, landslides, debris flows, erosion, or other natural disturbances. Human activities including agriculture, mining, livestock grazing, poorly constructed roads, and timber operations all have the potential to degrade habitat through increased sedimentation (Moyle and Randall 1998, p. 1324–1325; CDFW 2019b, p. 57).

7.5 Agriculture

Agriculture is a source of threats to the foothill yellow-legged frog because of agriculture's role in habitat degradation, contribution of pesticides and pollutants to the environment, and role as a driver of other threats such as altered hydrology and nonnative species (Figure 26). Agricultural land uses have been linked to declines in foothill yellow-legged frog populations (Davidson *et al.* 2002, p. 1597; Lind 2005, pp. 19, 51, 62, table 2.2). Foothill yellow-legged frog presence is negatively associated with agriculture within 5 km (3.1 mi) (Olson and Davis 2009, pp. 15, 22; Linnell and Davis 2021, not paginated, figure 6, figure 7).

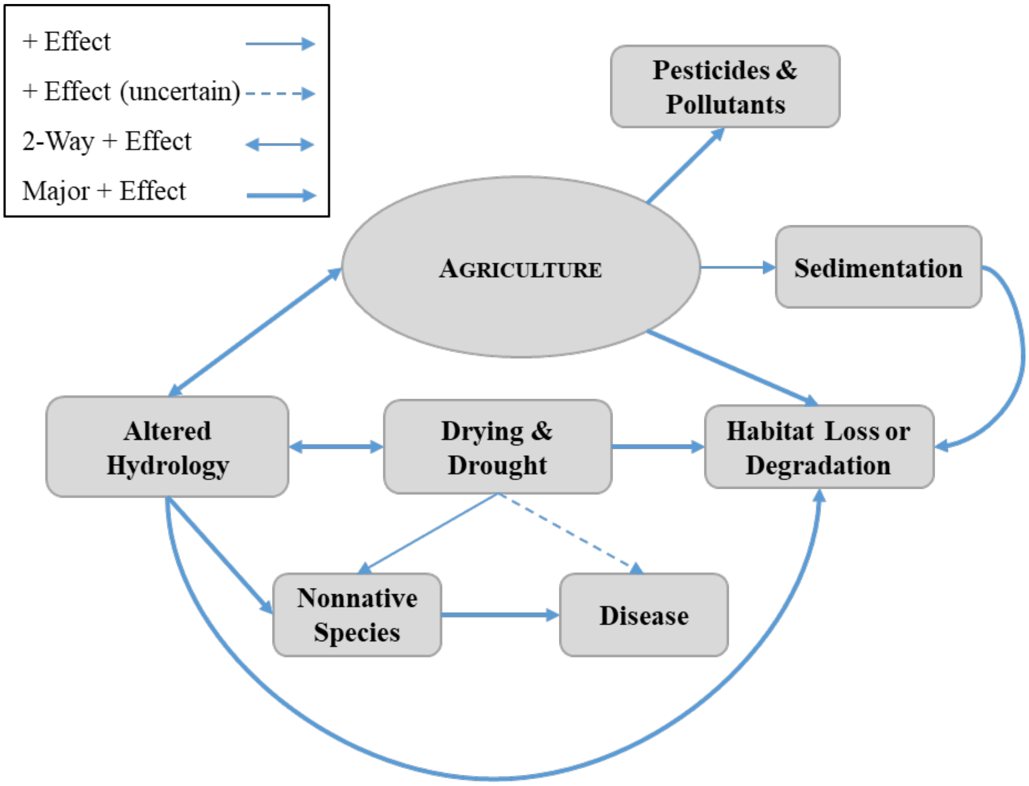


Figure 26. Conceptual diagram depicting the role of agriculture as a source and driver of threats to foothill yellow-legged frog viability.

Localized effects of agricultural land-uses can include habitat destruction and/or degradation (Figure 27), altered hydrology, and impoundments that can be problematic source populations of bullfrogs (CDFW 2019b, p. 58). Large-scale agriculture also has far-reaching effects that act on populations much farther away from the source of the threat. Far-reaching effects may result from large-scale hydrological alterations and water diversions, sedimentation, runoff or airborne drift of pesticides and pollutants (Figure 28), and facilitation of the spread of nonnative species and pathogens (CDFW 2019b, pp. 56, 58).

The proximity of foothill yellow-legged frog habitat downwind of the San Joaquin Valley (greatest use of airborne pesticides) suggests that foothill yellow-legged frog declines in the South Sierra unit are linked to agricultural pesticide-use (Davidson *et al.* 2002, p. 1594; Davidson 2004, pp. 1900–1901; Bradford *et al.* 2011, p. 690). Numerous studies have described direct and indirect impacts of agricultural pesticides, and other pollutants, to amphibians and to amphibian algal and invertebrate food sources (U.S. Environmental Protection Agency 2020, database). In particular, considerable attention has been paid to the heavy pesticide use in California's Central Valley and its potential role in the declines of Sierra Nevada amphibian populations that are downwind (Sparling *et al.* 2001, entire; Davidson *et al.* 2002, entire; Davidson 2004, entire; Fellers *et al.* 2004, entire; Smalling *et al.* 2013, entire; Sparling *et al.* 2015, entire). Water samples from low elevations in the Sierra Nevada have had concentrations of pesticides that were within the lethal range for foothill yellow-legged frogs (Bradford *et al.* 2011, p. 690).

Studies linking specific pesticide chemicals to foothill yellow-legged frog health and survival are limited (Davidson *et al.* 2007, entire; Sparling and Fellers 2007, entire; Sparling and Fellers 2009, entire; Kerby and Sih 2015, entire). However, the studies that have occurred suggest that foothill yellow-legged frog tadpoles are especially vulnerable to pesticides, especially if pesticide exposure occurs in the presence of other threats, such as competition or predation. The foothill yellow-legged frog has been shown to be more sensitive than the co-occurring Pacific treefrog (*Pseudacris regilla*) to three common insecticides, carbaryl (Kerby and Sih 2015, p. 255), chlorpyrifos[11], and endosulfan[12] (Sparling and Fellers 2009, p. 1696). Foothill yellow-legged frogs are especially sensitive to endosulfan with it being 121-fold more toxic to foothill yellow-legged frogs than to Pacific treefrogs (Sparling and Fellers 2009, p. 1700). Not only were these chemicals fatal to foothill yellow-legged frog tadpoles at much lower concentrations than they were for the Pacific treefrog, foothill yellow-legged frogs also exhibited reactions to sublethal concentrations that reduced their chances of survival. Exposure to sublethal concentrations of either chlorpyrifos or endosulfan negatively affected body size, development rate, and time to metamorphosis in foothill yellow-legged frog tadpoles (Sparling and Fellers 2009, p. 1701). Chlorpyrifos also decreased cholinesterase activity (Sparling and Fellers 2009, p. 1701) while endosulfan caused a right-angle bend abnormality in the bodies of tadpoles (Sparling and Fellers 2009, p. 1698). Sublethal exposure to carbaryl reduced foothill yellow-legged frog tadpoles' development rate and their ability to compete with the conspecific Pacific treefrog (Kerby and Sih 2015, pp. 255, 260). Sublethal carbaryl exposure also reduced anti-microbial skin peptides (presumedly a defense against the disease, chytridiomycosis) for at least three days in young foothill yellow-legged frogs (Davidson *et al.* 2007, p. 1774). A strong synergistic effect was also found between concurrent exposure to carbaryl and a nonnative crayfish predator, which increased foothill yellow-legged frog tadpole mortality from approximately 10 percent (when

---

[11] As of the end of the 2020 calendar year, the use of the pesticide, chlorpyrifos, is banned within the state of California (CDPR 2019a, entire).

[12] Pesticides containing endosulfan were banned by the U.S. Environmental Protection Agency in 2010 with use of the products being phased out by the end of July 2016 (U.S. Environmental Protection Agency 2010b, entire). However, endosulfan and its toxic degradant, endosulfan sulfate, may continue to threaten the foothill yellow-legged frog due to their potential for long-term persistence in the environment (U.S. Environmental Protection Agency 2010a, p. 37).

exposed to only carbaryl or only predation) to approximately 50 percent (Kerby and Sih 2015, pp. 261–263, 266, figure 5).

The effects of two specific types of agriculture, trespass grows (illegal cannabis grows on public lands) and viticulture (grape growing), may be particularly harmful to foothill yellow-legged frog populations. Trespass grows are of high concern because they occur within foothill yellow-legged frog habitat (direct habitat loss); illegally divert substantial proportions of stream surface water for the crop's intensive water needs (Bauer *et al.* 2015, pp. 1–2); and apply lethal, controlled, or banned pesticides (CROP Project 2019, not paginated). Even in the water-rich region of northwestern California, estimates of water demand for cannabis cultivation could exceed available surface water during the dry season (Bauer *et al.* 2015, p. 17). Illegal water diversions and pesticides for trespass grows in the North Coast California unit are reportedly linked to local declines of foothill yellow-legged frogs in the Eel and South Fork Trinity rivers (Service 2019, *in litt.*, p. 33). Trespass grows occur in all of the seven analysis units but the North Coast California, Central Coast, and South Coast units may be most at risk from this threat (CDFW 2019b, pp. 97–98).

Viticulture is also a current concern because of its occurrence in foothill yellow-legged frog habitat (direct habitat loss), substantial water requirements (although less than cannabis), use of impoundments that support bullfrog populations, and use of pesticides (Kupferberg 1996b, pp. 9–10; CDFW 2019b, pp. 62, 64). In California during 2018, wine grapes were the second crop to only almonds by area (4,282,576 ha (10,582,475 ac)) and received pesticides (total of all pesticides by weight) at a rate 1.9 times that of almonds (CDPR 2019b, dataset). Viticulture is also placing increased demands on water availability in southern Oregon (J. Keehn 2021, *in litt.*).

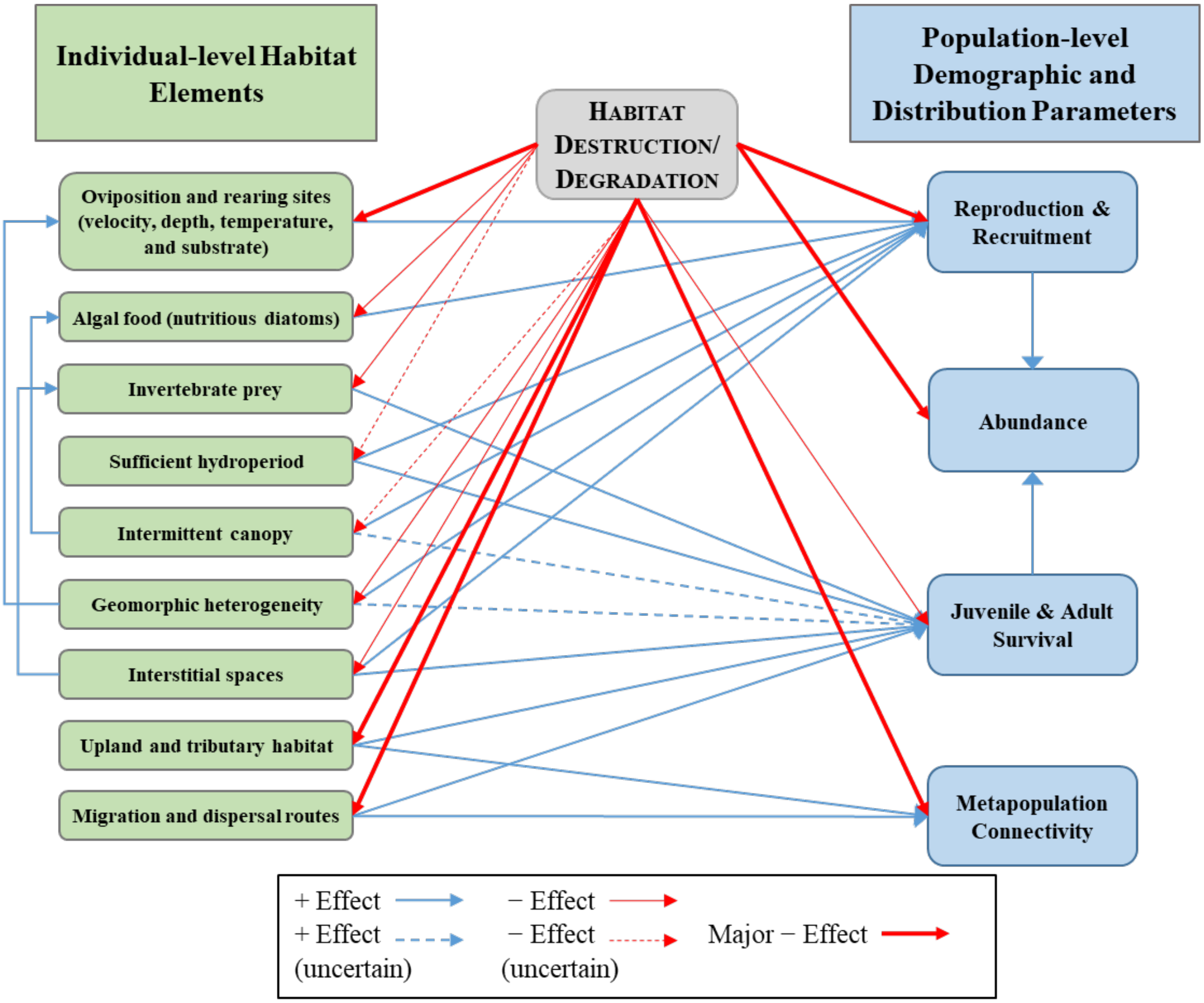


Figure 27. Conceptual diagram depicting the direct influences of habitat destruction and/or degradation (related to agriculture (mostly historical), mining, and urbanization) on habitat elements and the demographic and distribution parameters for the foothill yellow-legged frog.

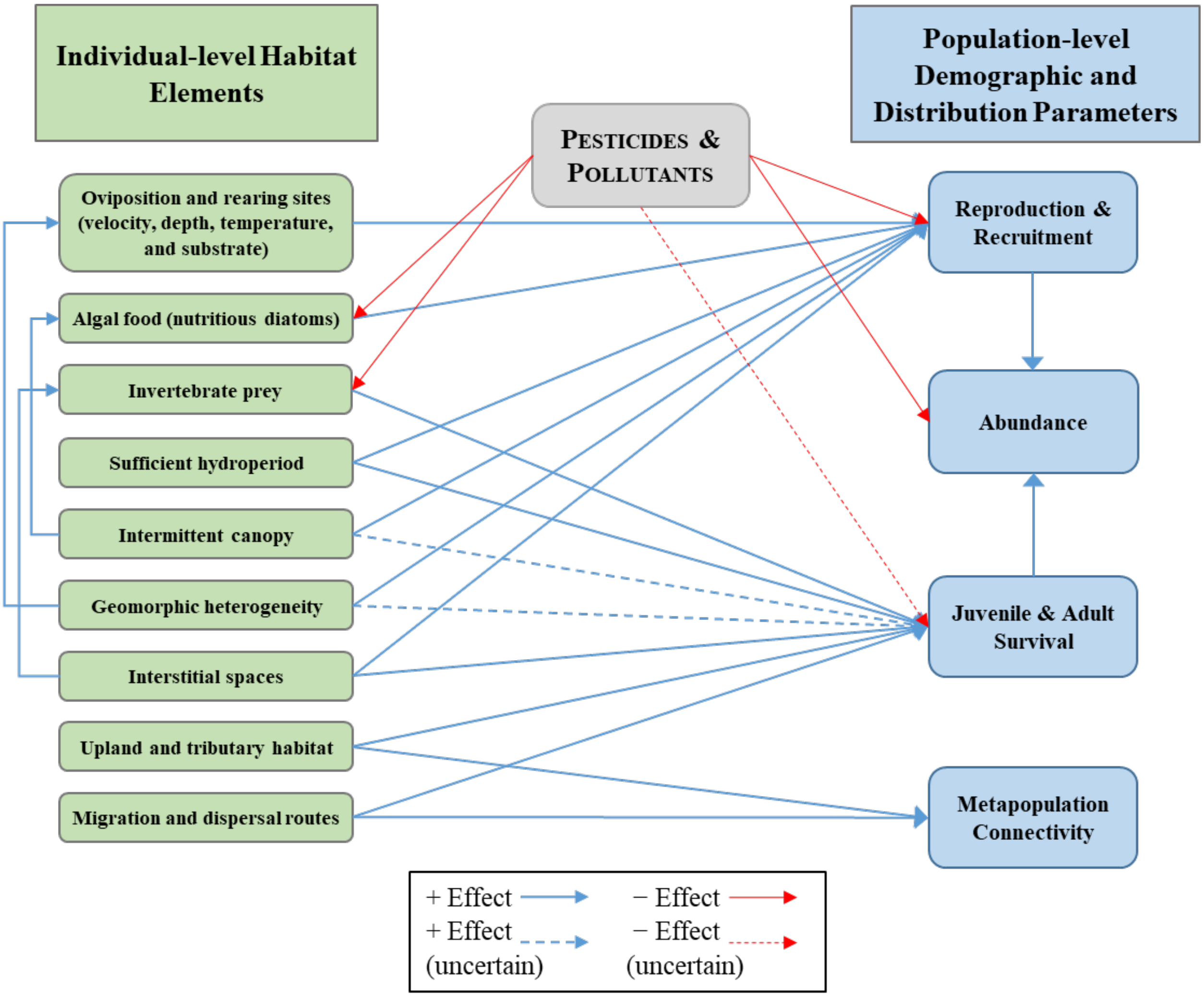


Figure 28. Conceptual diagram depicting the direct influences of pesticides and pollutants (related to agriculture, mining, and urbanization) on habitat elements and demographic parameters for the foothill yellow-legged frog.

7.6 Mining

Mining is a source of threats to the foothill yellow-legged frog because of its role in habitat destruction and degradation, pollution, and expansion of nonnative species (Figure 29). Several types of mining practices have negatively affected foothill yellow-legged frog habitat; these include aggregate, hard-rock, hydraulic, and suction-dredge mining (Hayes *et al.* 2016, pp. 52–54). Although the most environmentally damaging practices have been outlawed (e.g., hydraulic mining), the long-lasting legacy effects of historical mining practices are still affecting aquatic ecosystems (Hayes *et al.* 2016, pp. 52–54; CDFW 2019b, pp. 57–58). The northern Sierra Nevada (North Feather and North Sierra units) are suspected to be the most impacted from historical mining (Hayes *et al.* 2016, pp. 53–54). The immediate effects, legacy effects, and current status of each of the four mining practices in the foothill yellow-legged frog range are outlined in Table 8. To see how the habitat elements and the demographic and distribution parameters for the foothill yellow-legged frog are affected by mining-caused sedimentation, habitat destruction, and pollution, refer to Figure 25, Figure 27, and Figure 28, respectively.

Table 8. Immediate effects (occur during mining or shortly thereafter), legacy effects (continuing or permanent impacts that affect the foothill yellow-legged frog or its habitat long after mining ceases), and current status of four mining practices that have affected foothill yellow-legged frogs in California and Oregon (Olson and Davis 2009, p. 22; Hayes *et al.* 2016, pp. 52–54; CDFW 2019b, pp. 57–58; J. Dillon 2020, *in litt.*). Levels of effects to foothill yellow-legged frog populations from historical and current mining are unknown.

Type of mining	**Immediate effects**	**Legacy effects**	**Current status in species' range**
Aggregate (in-stream)	Breeding habitat destruction and degradation; direct mortality; stream morphology change; decreased geomorphic heterogeneity; nonbreeding habitat alteration; erosion; sedimentation; decreased water quality	Change in sediment transport regime (sedimentation); change in stream morphology; decreased geomorphic heterogeneity	In the Sierra Nevada, major in-stream and/or terrace operations exist in every river system throughout the historical range of foothill yellow-legged frogs. Extent of affected habitat in Oregon is unknown.
Aggregate (terrace; occurs outside of wetted stream perimeter)	Nonbreeding habitat destruction and fragmentation	Sedimentation into streams; may create perennial ponds that can become nonnative fish and bullfrog habitat	In the Sierra Nevada, major in-stream and/or terrace operations exist in every river system throughout the historical range of foothill yellow-legged frogs. While in-stream mining is preferred by industry, mining above the wetted stream perimeter is typically required when listed salmonids are present. Extent of affected habitat in Oregon is unknown.
Hard-rock (shafts)	Disturbances associated with digging mine shafts	Source of waterway acidification and toxic metal pollution	Extent of overlap with frog range is uncertain but highest potential for effect is in the northern Sierra Nevada Mountains. Extent of affected habitat in Oregon is unknown.

Type of mining	Immediate effects	Legacy effects	Current status in species' range
Hydraulic	Historical: Drastically altered water quality and stream morphology; large increases in sedimentation; breeding and nonbreeding habitat destruction; direct mortality	Widespread mercury contamination; bioaccumulation of mercury in anurans, including foothill yellow-legged frogs; continued hillside erosion and sedimentation with inputs of acid, cadmium, mercury, and asbestos into waterways; creation of water developments to trap polluting sediments	Outlawed in 1884 but the effects on water pollution may still be apparent in the northern Sierra Nevada and parts of the Trinity and Sacramento River drainages. Mercury (used for gold extraction) used for hydraulic mining in California was primarily extracted from mines in the Coast Ranges (North, Central, and South Coast analysis units) (Wiener *et al.* 2003, p. 5, figure 2). Extent of affected habitat in Oregon is unknown.
Suction-dredge	Breeding habitat destruction; direct mortality (entrainment); nonbreeding habitat alteration; erosion; sedimentation; stream morphology change; decreased geomorphic heterogeneity; decreased water quality; may affect invertebrate prey	Creates relict tailing ponds that can become nonnative fish and bullfrog habitat, but ponds may also benefit foothill yellow-legged frog habitat	Moratorium in California since 2009 but permitting processes are in development (State Water Resources Control Board 2020, entire). Extremely restricted in the foothill yellow-legged frog's range in Oregon since 2013.

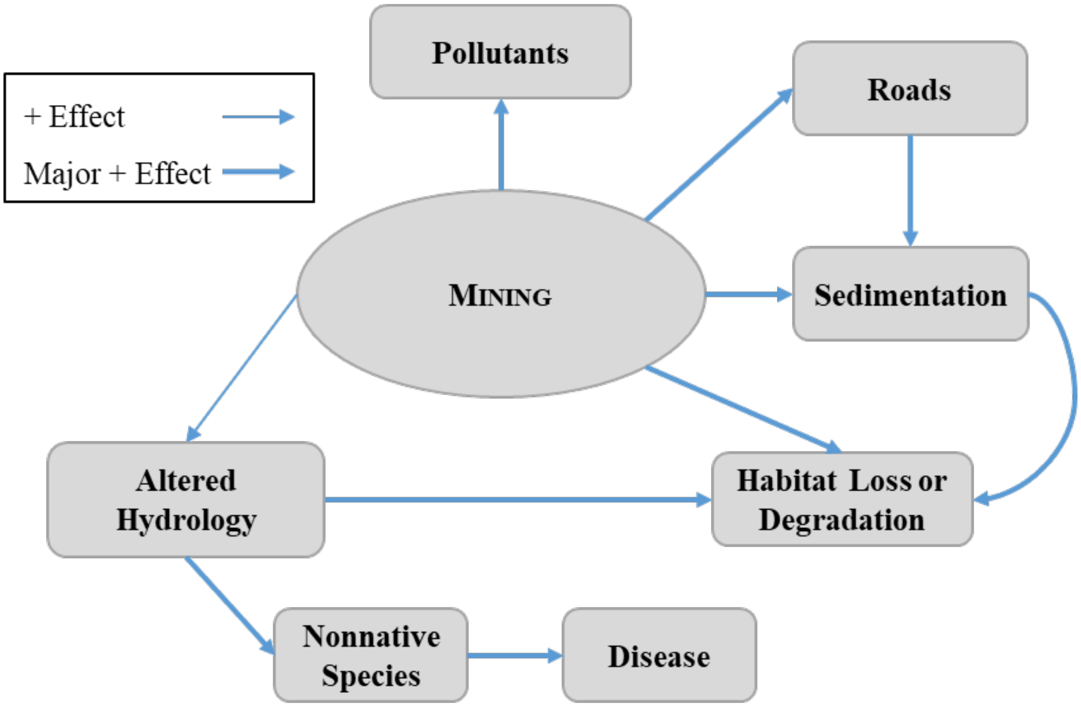


Figure 29. Conceptual diagram depicting the role of mining as a source of threats to foothill yellow-legged frog viability.

7.7 Urbanization, Roads, and Recreation

Urbanization, roads, and recreation can affect foothill yellow-legged frog viability directly through mortality, but they are also major sources of threats to the foothill yellow-legged frog because of their role in habitat destruction, degradation, and fragmentation; contribution of pesticides and pollutants to the environment; and their role as drivers of other threats such as altered hydrology, nonnative species, and disease transmission (Figure 30). Conversion or alteration of natural habitats for urban land uses has been linked to declines in foothill yellow-legged frog populations (Davidson *et al.* 2002, p. 1597; Lind 2005, pp. 19, 51, 62, table 2.2). Foothill yellow-legged frog presence is negatively associated with cities and road density (Davidson *et al.* 2002, p. 1594; Olson and Davis 2009, p. 22). Increases in urbanization and roads have been reportedly associated with foothill yellow-legged frog extirpations in the South Coast unit, possibly by facilitating the spread of Bd and nonnative species (Adams *et al.* 2017b, p. 10227). To see how the habitat elements and the demographic and distribution parameters for the foothill yellow-legged frog are affected by urbanization-caused habitat destruction, pesticides and pollutants, and roads and recreation, refer to Figure 27, Figure 28, and Figure 31, respectively.

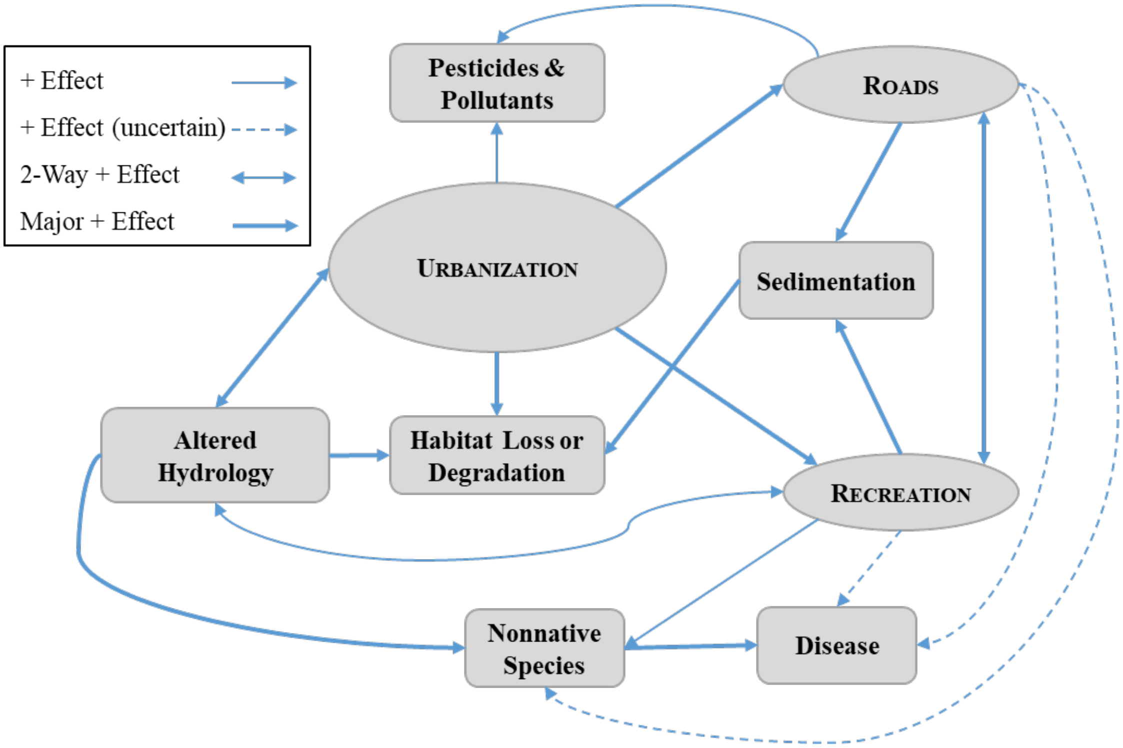


Figure 30. Conceptual diagram depicting the roles of urbanization, roads, and recreation as sources and drivers of threats to foothill yellow-legged frog viability.

Urban environments and roads can fragment habitat (Brehme *et al.* 2018, p. 912) and cause mortalities to dispersing foothill yellow-legged frogs (Cook *et al.* 2012, p. 325). Culverts generally provide safe transit corridors for frogs to travel underneath human-made infrastructure, such as roads or railroads. However, poor culvert design can lead to foothill yellow-legged frog mortalities by inadvertently trapping frogs (GANDA 2008, p.34) or creating artificial pools that become habitat for nonnative fish and bullfrogs (van Wagner 1996, p. 105). Poorly constructed roadways near waterways can cause erosion and sedimentation that degrades amphibian habitat (Welsh and Ollivier 1998, pp. 1119, 1125). Major transit corridors and road density can also increase the risk of toxic spills into waterways (Bury 1972, p. 295; Ashton *et al.* 1997, p. 14). In 1970, a diesel spill in Trinity County, California (North Coast California unit) resulted in habitat degradation and mass mortalities of invertebrates, fish, and foothill yellow-legged frog tadpoles and metamorphs (Bury 1972, pp. 291, 293–294, table 1). Diesel spills from trains have also affected foothill yellow-legged frogs in Oregon (Olson and Davis 2009, p. 22).

Recreation can affect foothill yellow-legged frogs in a variety of ways, depending on the region and type of recreation. Some forms of recreation can also cause mortality through trampling or dislodging of egg masses while others degrade habitat, disturb frog behavior, and/or contribute to other threats. Jet boats (like those used in the Rogue River in Oregon) can cause substantial wakes along river edges that could dislodge egg masses, strand tadpoles, disrupt behavior, and erode shoreline (Borisenko and Hayes 1999, pp. 18, 28; Clayton and Miller 2005, p. 9; Olson and Davis 2009, p. 23). Off-highway vehicle recreation on stream gravel bars, a popular activity in some areas (e.g., southwestern Oregon) (K. Van Norman 2021, *in litt.*), can be a serious disturbance and source of mortality during the breeding and rearing season. Off-highway vehicle recreation in or near waterways can also cause sedimentation that degrades stream and breeding habitat quality (Figure 32). Like urbanization and roads, increased recreational use of streams can increase the likelihood of disease transmission (Adams *et al.* 2017b, pp. 10220–10221). Recreational fishing contributes to nonnative species by supporting the management for and stocking of nonnative fish species in California and Oregon (ODFW 2009, pp. 8, 11; CDFW 2019a, entire). And even moderate use of hiking trails can cause disturbances that alter wildlife behavior. Another stream-dwelling ranid (the Iberian frog (*Rana iberica*)) reduced its use of stream bank habitat by 80 percent when pedestrians passed the study area at a rate of 5 hikers per hour, and by 100 percent when the rate increased to 12 hikers per hour (Rodriguez-Prieto and Fernandez-Juricic 2005, pp. 5–7).

Whitewater boating is a recreation interest that has the potential to indirectly affect the persistence of foothill yellow-legged frog populations below dams. Some dam operations include planned, short pulse flows during the spring and summer to provide recreation opportunities for whitewater boaters (Kupferberg *et al.* 2012, p. 518). The timing of these strong flows has coincided with the foothill yellow-legged frog breeding and rearing season, leading to population-level impacts in the North Feather unit (Kupferberg *et al.* 2012, pp. 518, 520–521, figure 3b), and probably elsewhere in the Sierra Nevada.

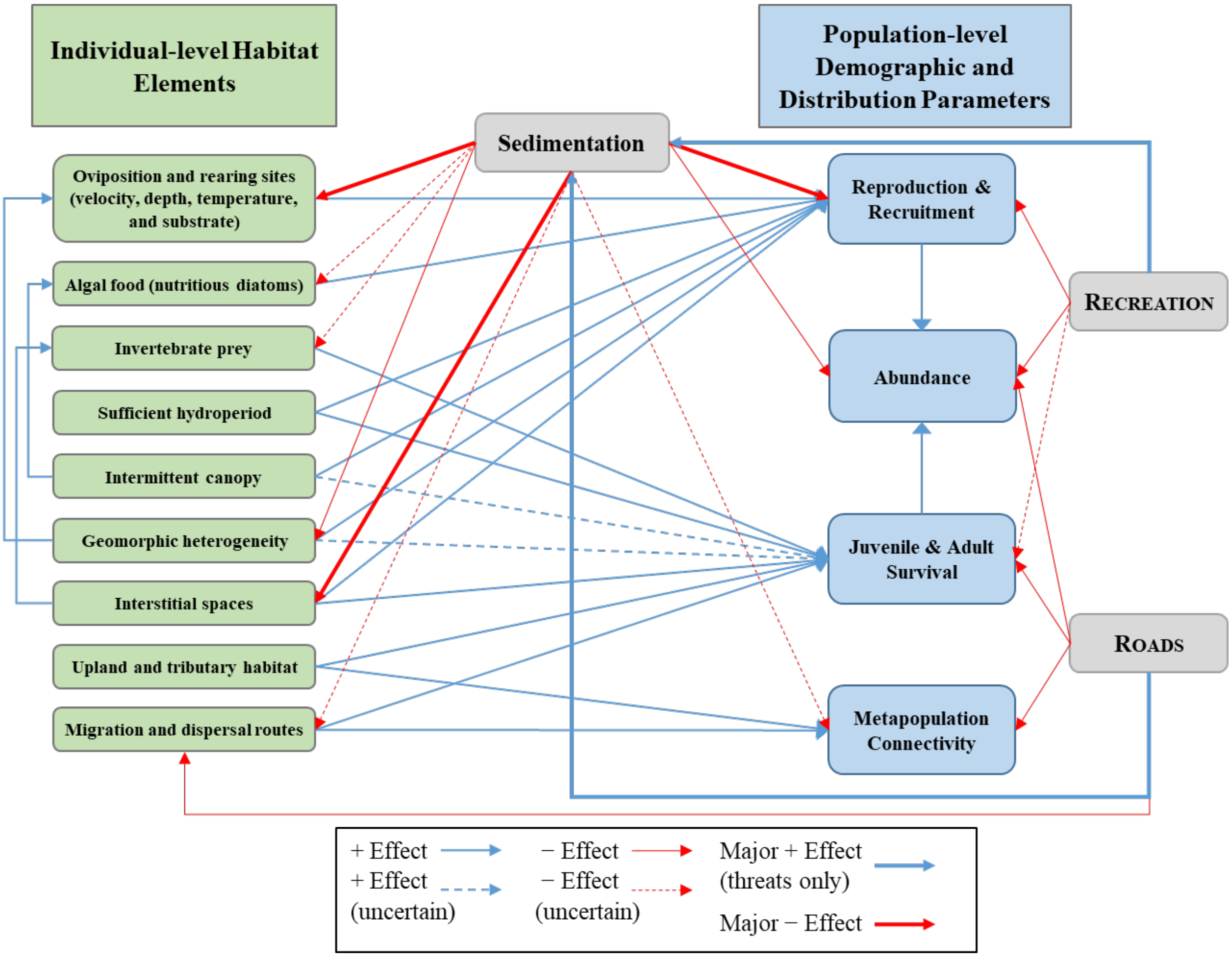


Figure 31. Conceptual diagram depicting the direct influences of roads and recreation on demographic and distribution parameters for the foothill yellow-legged frog. The direct influences of sedimentation are also depicted to highlight the important indirect effects of roads and recreation.

Figure 32. Unauthorized road created by recreationists that caused breeding habitat degradation downslope. Photo taken on Bureau of Land Management land in the southern Central Coast unit (credit: Michael Westphal, Bureau of Land Management).

7.8 Drying and Drought

Temporary drying of waterways (from anthropogenic water allocation and/or drought) is implicated in declines and extirpations of foothill yellow-legged frogs because it shortens the hydroperiod; negatively affects habitat elements that are hydrology-dependent; limits recruitment, survival, and connectivity; and exacerbates the effects of other threats (Figure 33, Figure 34). Periodic drying of waterways and/or drought occurs naturally in foothill yellow-legged frog habitat, particularly in the southern analysis units (South Sierra, Central Coast, and South Coast units) (Adams *et al.* 2017b, p. 10227), but frequency of drying and drought is increasing because of anthropogenic water use and the effects of climate change (Section 7.13). Breeding sites that completely dried during consecutive severe drought years had zero reproductive success (S. Kupferberg, pers. comm. cited in Wheeler *et al.* 2018, p. 296; M. Parker 2021, *in litt.*). As drying occurs, frogs become more concentrated in the remaining pools and thus, become more susceptible to competition (Moyle 1973, p. 21), predation (Storer 1925, p. 261; Moyle 1973, p. 21), and exposure to diseases and parasites (Kupferberg *et al.* 2009a, p. 529; Adams *et al.* 2017a, p. 11). Reduced flow volume is associated with increased Bd load in foothill yellow-legged frog habitat (Adams *et al.* 2017a, pp. 8, 11). Absence of strong winter flows enables bullfrogs to expand their spatial distributions, which also contributes to disease transmission (Adams *et al.* 2017a, pp. 1–2). Multi-year droughts can also lead to tree mortality, which in turn, increases wildfire risk (OEHHA 2018, pp. 179–180) (discussed further in Section 7.9 below).

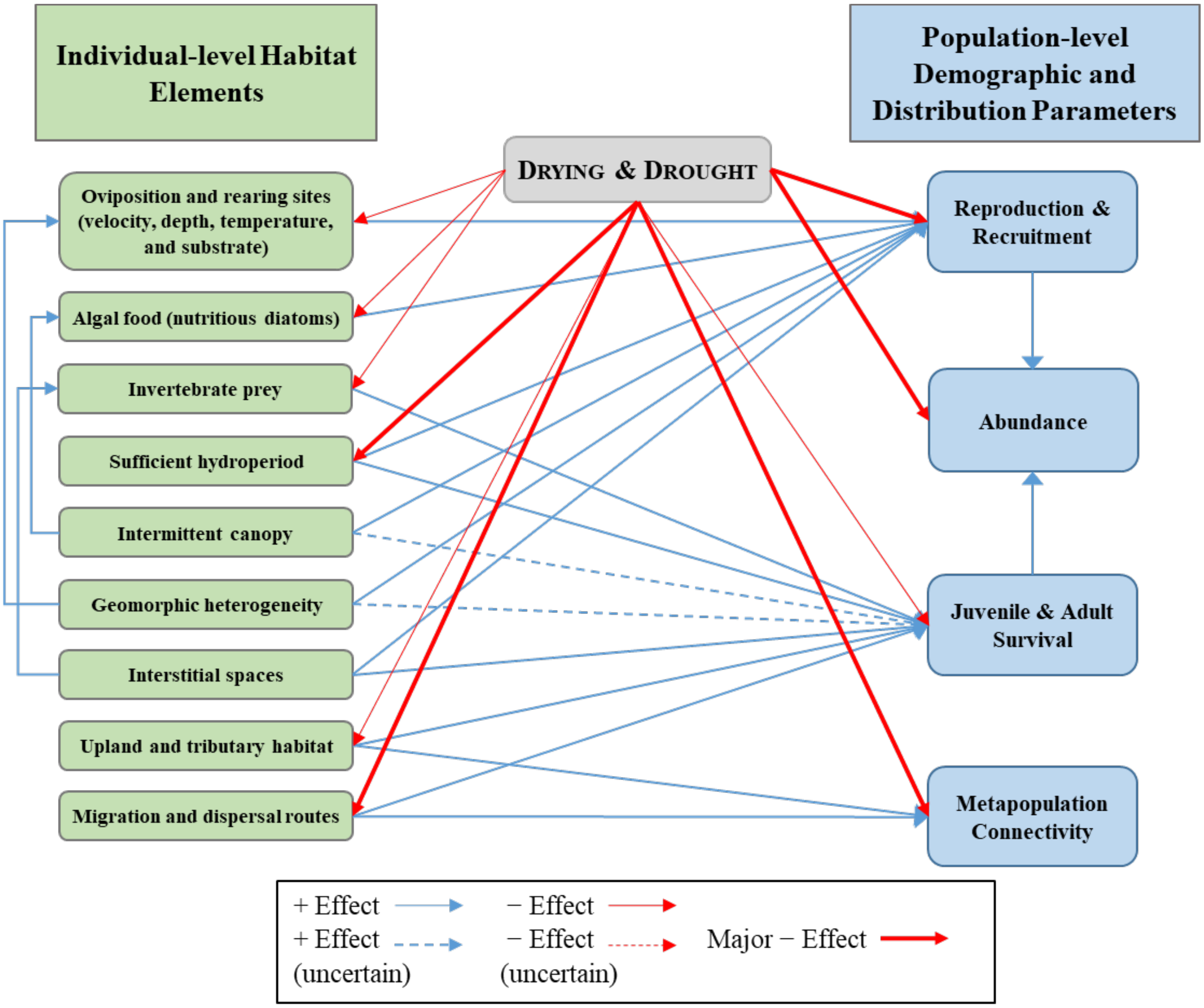


Figure 33. Conceptual diagram depicting the direct influences of drying and drought on the habitat elements and the demographic and distribution parameters for the foothill yellow-legged frog.

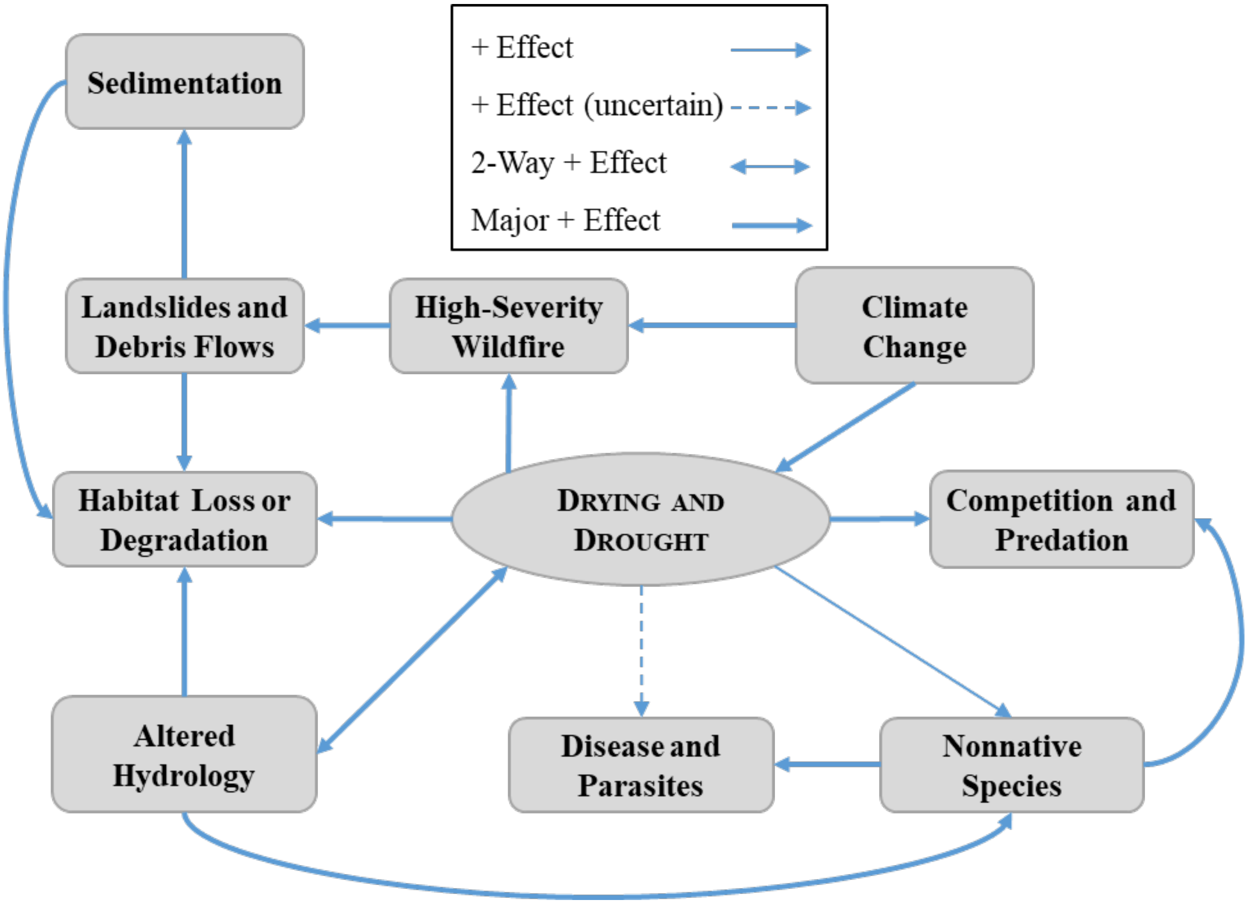


Figure 34. Conceptual diagram depicting the relationships among drying and drought and related threats to foothill yellow-legged frog viability.

The Central Coast and South Coast units are the most susceptible to the effects of drying and drought. These units have lower annual precipitation and higher mean annual temperatures than elsewhere in the range of the species (PRISM Climate Group 2012, 30-year climate dataset). Many of the foothill yellow-legged frog localities in these units are subject to drying completely or to just a few pools (Adams *et al.* 2017a, pp. 2–3, 14; M. Westphal 2019, *in litt.*).

In the Central Coast unit, a severe drought (2012–2015) coincided with the invasion of bullfrogs and chytridiomycosis outbreaks in two populations of foothill yellow-legged frog near Calaveras Reservoir (Adams *et al.* 2017a, pp. 2–3). Long-term monitoring also noted that the Alameda Creek foothill yellow-legged frog distribution shifted during the drought (Adams *et al.* 2017a, pp. 2–3). Unregulated reaches that formerly supported abundant populations of foothill yellow-legged frogs had lost all surface flow by mid-summer leading frogs to shift their distribution into the regulated reach below Calaveras Dam (Adams *et al.* 2017a, pp. 3–4, figure 2). Adams *et al.* (2017a, p. 3) suggested that the drought played a synergistic role in the Bd outbreaks that began in 2013.

The South Sierra unit is also highly susceptible to intermittent drying of streams during drought. There is anecdotal evidence that drought has caused extirpations in the southern Sierra foothills (Service 2019, *in litt.*, p. 39). In the Upper Stanislaus sub-basin, Eagle Creek went dry during a recent drought (2014–2016), potentially leading to the extirpation of the Eagle Creek subpopulation (Service 2019, *in litt.*, p. 41). The North Fork Tuolumne (Upper Tuolumne sub-basin) also went dry during 2015–2016, which reduced the number of both nonnatives (positive effect) and foothill yellow-legged frogs (negative effect) (Service 2019, *in litt.*, p. 42).

While drying is more severe in the southern part of the foothill yellow-legged frog's range, some areas in northern analysis units are also susceptible to drying. For example, in Jackson County, Oregon (North Coast Oregon unit), foothill yellow-legged frog metamorphs and juveniles become concentrated in isolated pools along Tyler and Emigrant creeks as streamflow diminishes over the summer (M. Parker 2021, *in litt.*). During 2020 and 2021, both creeks dried to a single pool at their confluence much earlier than usual and no tadpoles appeared to survive to metamorphosis (M. Parker 2021, *in litt.*). It is predicted that some of these southern Oregon occurrences will be lost if drought conditions persist and temperatures increase (M. Parker 2021, *in litt.*).

7.9 Wildfire

The effects of wildfire on foothill yellow-legged frogs are not well understood and have not been directly studied (CDFW 2019b, p. 71). Anecdotally, foothill yellow-legged frog populations have shown signs of resiliency after low- to moderate-severity wildfires (Lind *et al.* 2003, p. 27; CDFW 2019b, p. 71). It is suspected that low-severity fires do not have any adverse effects on the foothill yellow-legged frog (Olson and Davis 2009, p. 24). In fact, wildfires may be beneficial to habitat quality by decreasing canopy cover and increasing habitat heterogeneity (Pilliod *et al.* 2003, pp. 171, 173; Olson and Davis 2009, p. 24). Direct mortality from scorching is unlikely given the species' aquatic nature and the sightings of foothill yellow-legged frogs immediately after wildfires (CDFW 2019b, p. 71).

High-severity wildfires, however, have the potential to greatly alter water and habitat quality (Figure 35). High-severity wildfires can remove all vegetative canopy and reduce habitat heterogeneity by burning vegetative and woody debris that foothill yellow-legged frogs use for shelter. Short- and long-term effects of severe fires include potentially harmful changes in water chemistry, increased erosion, and increased sedimentation (CDFW 2019b, pp. 71–72), which can destroy or degrade breeding habitat and interstitial spaces. In the years following high-severity wildfires in 2008 (Concow Fire) and 2018 (Camp Fire), spring rains caused debris and sediment flows that buried foothill yellow-legged frog egg masses in the Flea Valley Creek area (North Feather unit) (GANDA 2020, p. 40). High-severity fire might also cause conversion of forest to other ecotypes because increased distance to live trees decreases the likelihood of postfire seedling establishment (Parks and Abatzoglou 2020, p. 7).

While wildfire is a natural phenomenon throughout the range of the foothill yellow-legged frog, wildfire occurrence and/or severity are positively influenced by urbanization, roads, recreation, climate change, and drying and drought (Figure 36). Landslides and debris flows, which can occur when heavy precipitation falls in sloped terrain that has been affected by high-severity wildfire, can be another consequence of wildfire (Figure 36). Small landslides or debris flows could potentially be beneficial for geomorphic heterogeneity, but larger events can cause extensive habitat destruction or degradation (Olson and Davis 2009, pp. 24–25; CDFW 2019b, p. 73).

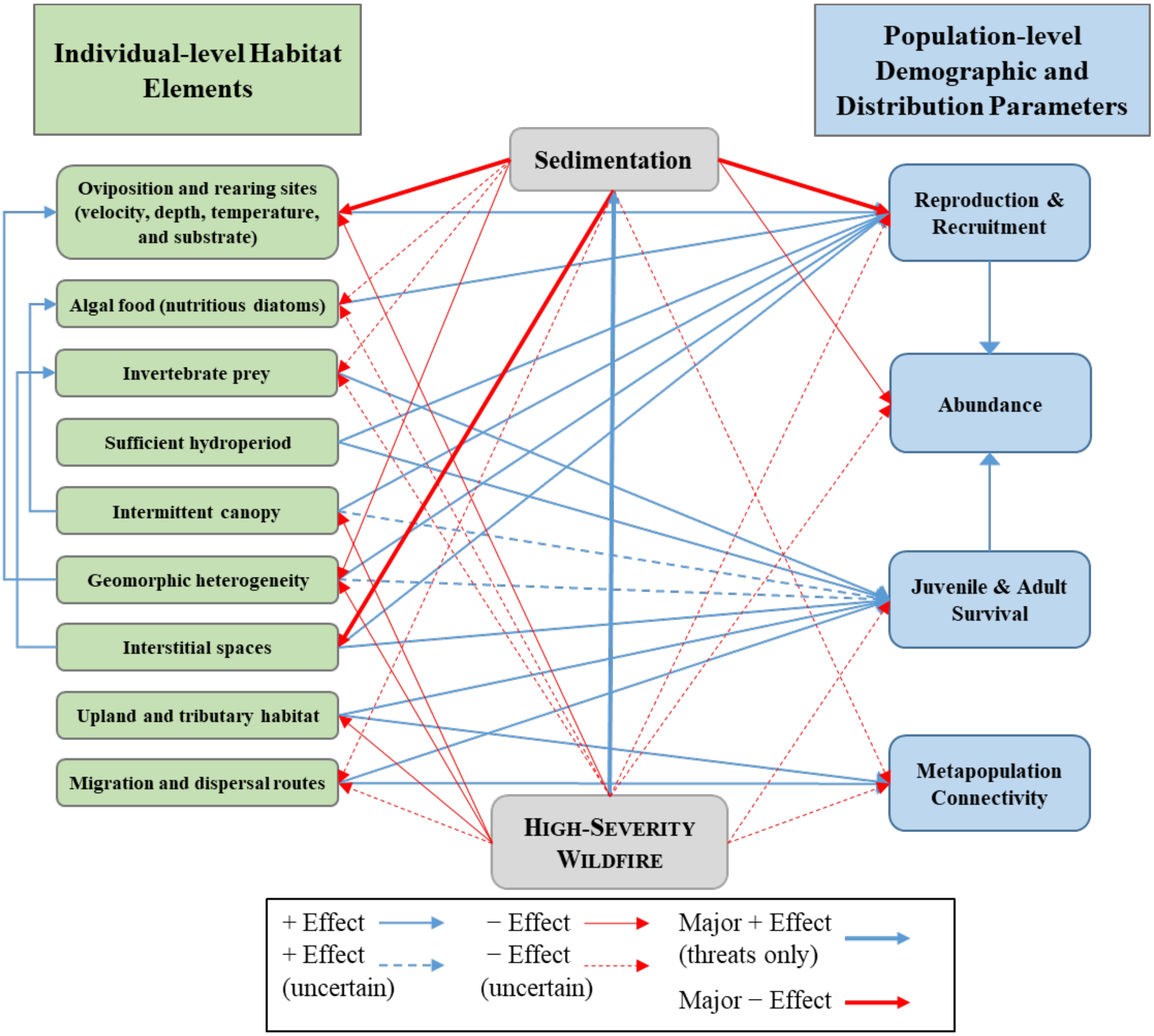


Figure 35. Conceptual diagram depicting the direct influences of high-severity wildfire on habitat elements and the demographic and distribution parameters for the foothill yellow-legged frog. The direct influences of sedimentation are also depicted to highlight some of the indirect effects of high-severity wildfire.

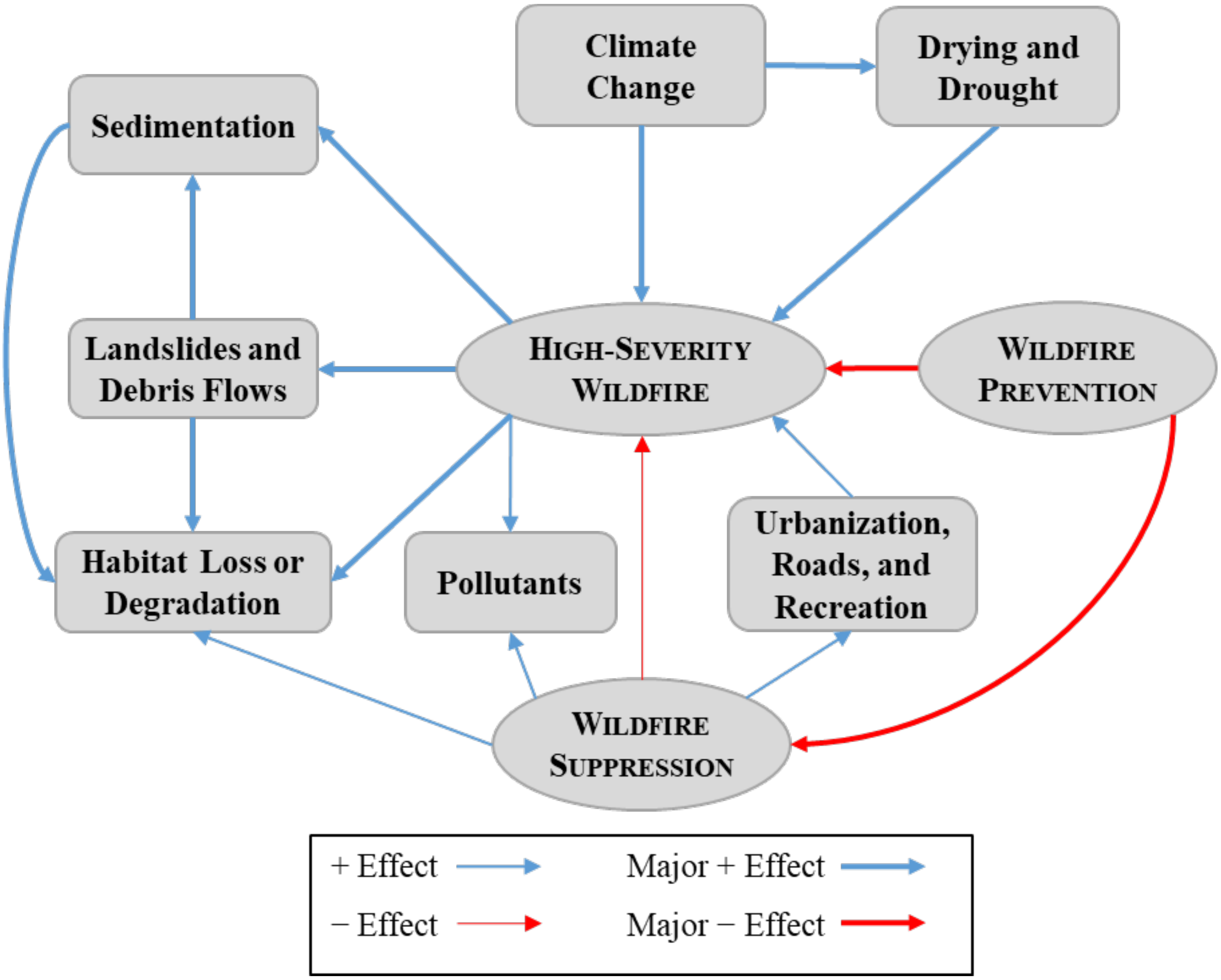


Figure 36. Conceptual diagram depicting the relationships among high-severity wildfire and related threats to foothill yellow-legged frog viability.

The effects of wildfire suppression and wildfire prevention on foothill yellow-legged frogs are also unstudied (Hayes *et al.* 2016, p. 35, table 6). Activities associated with the suppression of wildfire (e.g., emergency fire break construction, emergency road construction, fire retardant application) are likely to have negative effects on the species and its habitat (Figure 37) because emergency firefighting situations cannot typically accommodate careful avoidance and impact minimization measures. The creation of fire roads and firebreaks can cause direct road mortalities and can contribute to habitat degradation through erosion and sedimentation (Pilliod *et al.* 2003, p. 174).

The use of fire retardants and suppressants during wildland fire fighting can affect amphibians by harming water quality and by direct toxicity to amphibians and their food sources (Pilliod *et al.* 2003, pp. 174–175; Service 2018, pp. 42–44). In a control study where fire retardant was applied to dry, Mediterranean temporary wetlands, the retardant clearly affected nutrients and indirectly affected other water quality parameters (e.g., chlorophyll a, pH, dissolved oxygen, temperature, and steady-state turbidity) for at least two subsequent hydrologic cycles (Angeler and Moreno

2006, pp. 1617, 1620–1622). In field settings, toxicity of retardants containing sodium ferrocyanide (yellow prussiate of soda) can be lethal to amphibians by increasing free cyanide concentrations upon exposure to ambient solar radiation (Calfee and Little 2003, pp. 1525, 1529–1530). Exposure of water bodies to fire retardant chemicals can also disrupt trophic systems by impacting algae and invertebrates (McDonald *et al.* 1996, pp. 62, 69, 71; Finger *et al.* 1997, pp. 136–137), which are also important food sources for the foothill yellow-legged frog. Bioaccumulation of retardant chemicals from affected food resources might also impact amphibians (Hale *et al.* 2002, p. 732; Pilliod *et al.* 2003, p. 175).

Activities associated with wildfire prevention (e.g., fire break construction, forest thinning, control burning) might have some minor negative effects on the foothill yellow-legged frog but these activities may be equally likely to benefit habitat by decreasing dense canopy cover, increasing geomorphic heterogeneity, and reducing the risk of high-severity or catastrophic wildfire (Figure 37). Because wildfire prevention activities are not taken during emergency situations, more care can be taken to avoid habitat degradation and mortality to sensitive species.

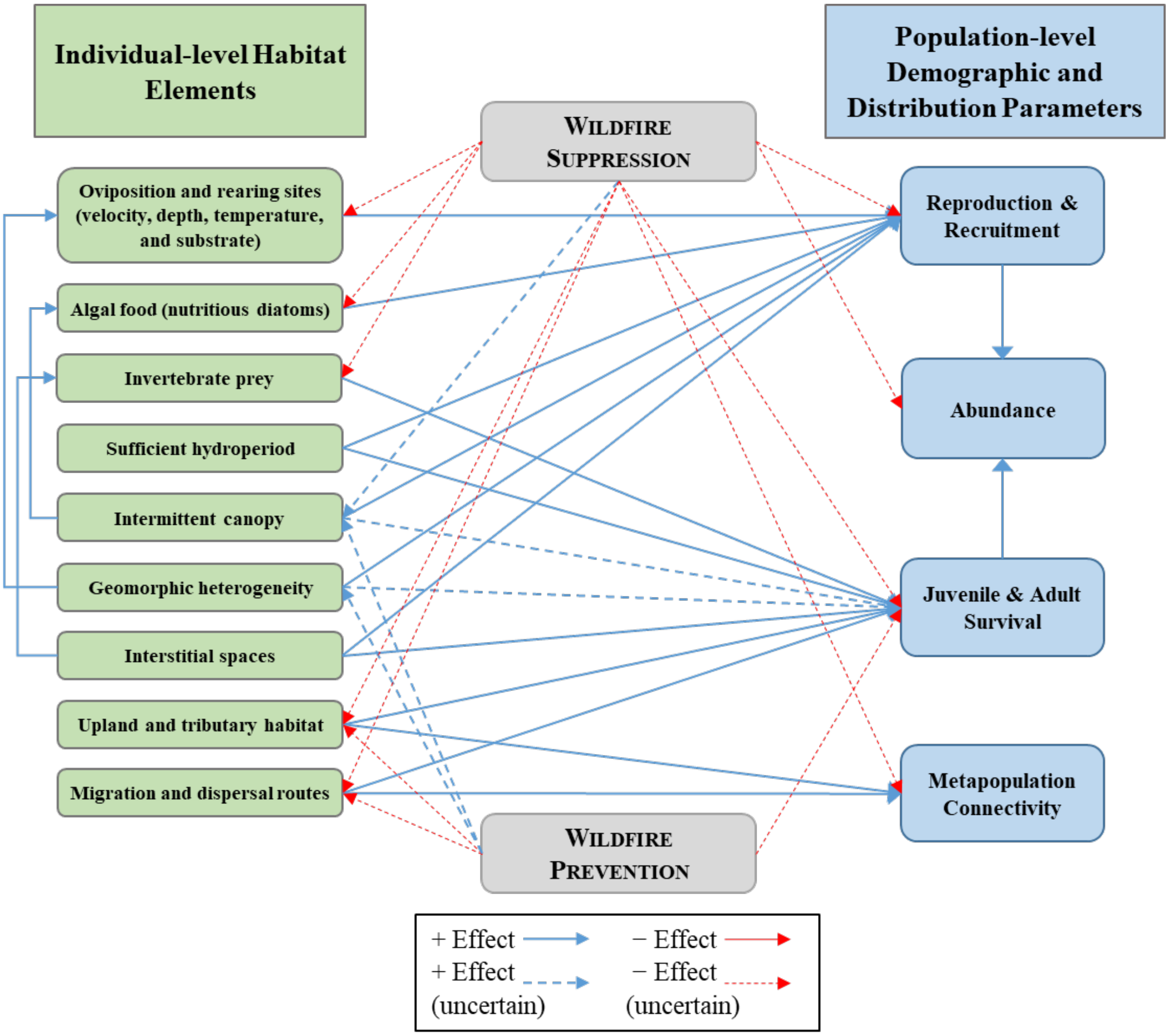


Figure 37. Conceptual diagram depicting the potential direct influences of wildfire suppression and prevention on habitat elements and the demographic and distribution parameters for the foothill yellow-legged frog. Activities associated with wildfire suppression include emergency fire break construction, emergency road construction, and fire retardant application. Activities associated with wildfire prevention include fire break construction, forest thinning, and control burning.

Both a warming climate trend and increased woody fuel connectivity are influencing upward trends in fire size and severity (Moritz *et al.* 2018, pp. 2, 5). In dry mixed-conifer forests of the Inland Northwest and Pacific Southwest, there has been an increase in high-severity fires and an increase in the potential for fires of higher severity (Moritz *et al.* 2018, p. 3). Observed and projected trends in warmer and drier fire seasons in the western U.S. are likely to continue the trend toward higher-severity wildfires and larger burn areas (Parks and Abatzoglou 2020, pp. 1, 5–6). There is broad agreement among fire scientists that dry forests are becoming less resilient to fire under current and projected climate (Moritz *et al.* 2018, p. 3). In some regions, large high-severity wildfires, combined with emergent warmer-drier conditions, are leading to conversion of large areas of forest to persistent grasslands or shrublands (Moritz *et al.* 2018, p. 5).

Since 1950, proportion of analysis unit area burned annually by wildfires (National Interagency Fire Center 2020, dataset) has been growing most sharply in the South Coast unit, followed by the North Feather, North Coast California, South Sierra, and North Coast Oregon units (Figure 38, Figure 39). In the North Sierra and Central Coast analysis units, annual area burned has not changed much since 1950 (Figure 38, Figure 39).

Burn severity has also been increasing in the foothill yellow-legged frog range in California. Between 1984 and 2017, total areas burned at low, moderate, and high severities (U.S. Forest Service 2018, dataset) have all increased but high severity burn areas increased more than the other severity categories (Figure 40). This shift toward higher severity burns (i.e., greater proportions of burn areas that have high to complete mortality of the dominant vegetation) appears to be driven by fires in the South Sierra (Figure 41) and South Coast units (Figure 42). Among South Sierra and South Coast unit wildfires, the proportion of burned area that is high severity has been increasing while the proportions that burn at low or moderate severity have been decreasing (Figure 41 and Figure 42).

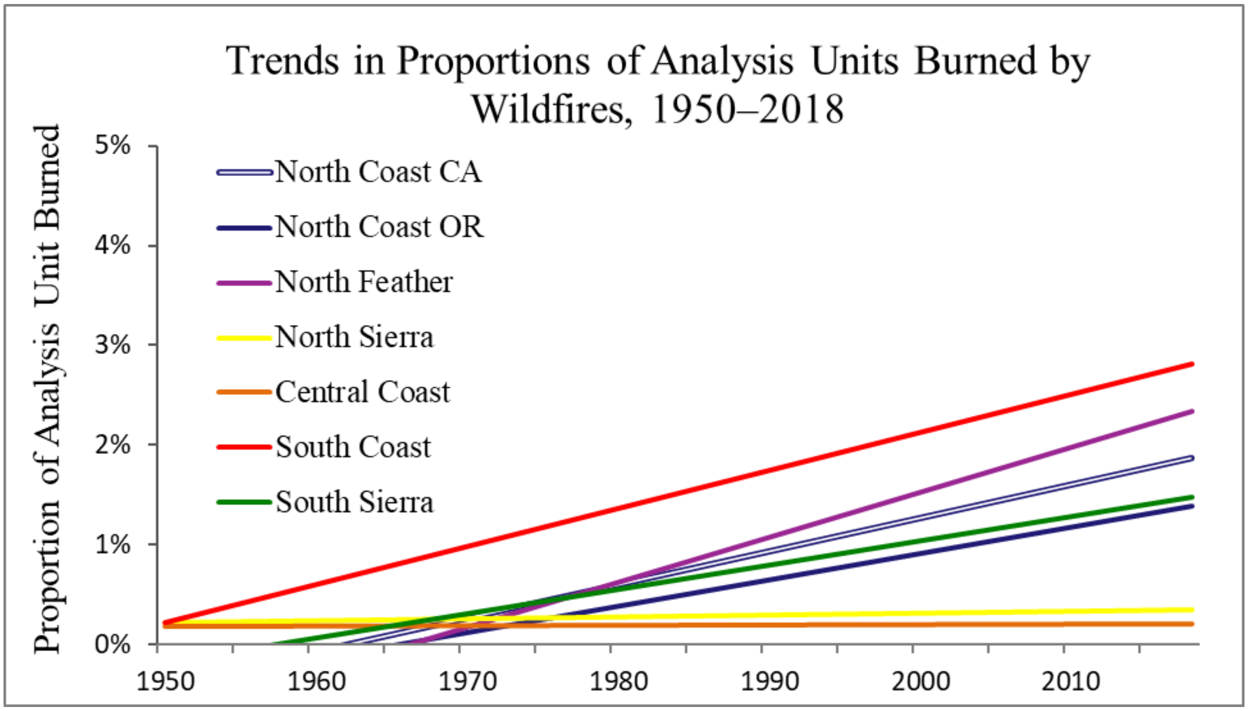


Figure 38. Linear trendlines for annual burn area (i.e., number of hectares burned each year) during 1950–2018, measured as the proportion of total analysis unit area within wildfire perimeters for each year (National Interagency Fire Center 2020, dataset). This plot is a summary of the trends from the data presented in Figure 39, with the exception that the y-axis is the proportion of analysis unit area burned per year instead of total hectares burned per year. CA = California. OR = Oregon.

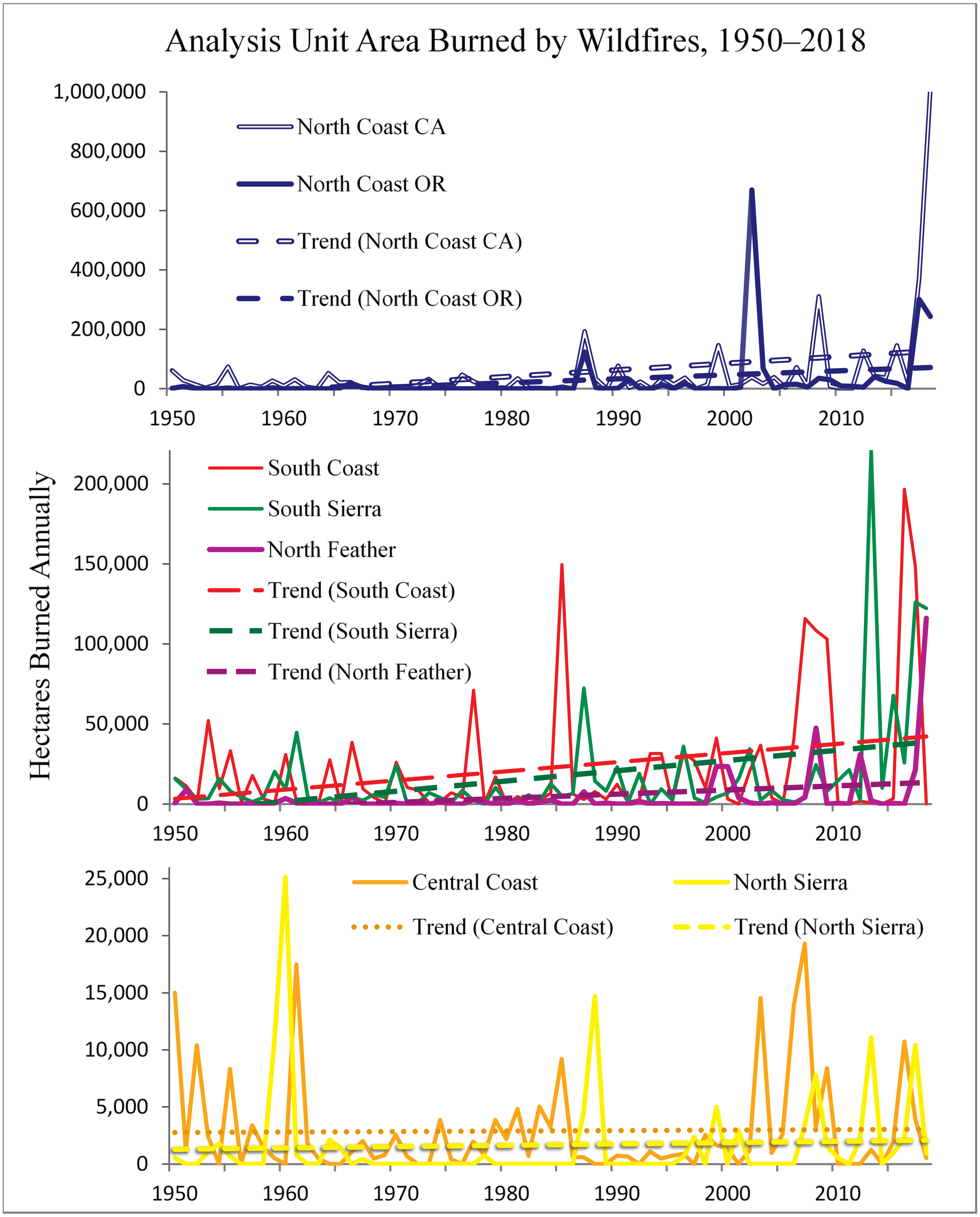


Figure 39. Annual burn area for 1950–2018 measured as total hectares within analysis units that were within wildfire perimeters for each year (National Interagency Fire Center 2020, dataset). Linear trendlines are displayed for each analysis unit through time. Note scale differences of y axes; analysis units are grouped based on scale of annual area burned. CA = California. OR = Oregon.

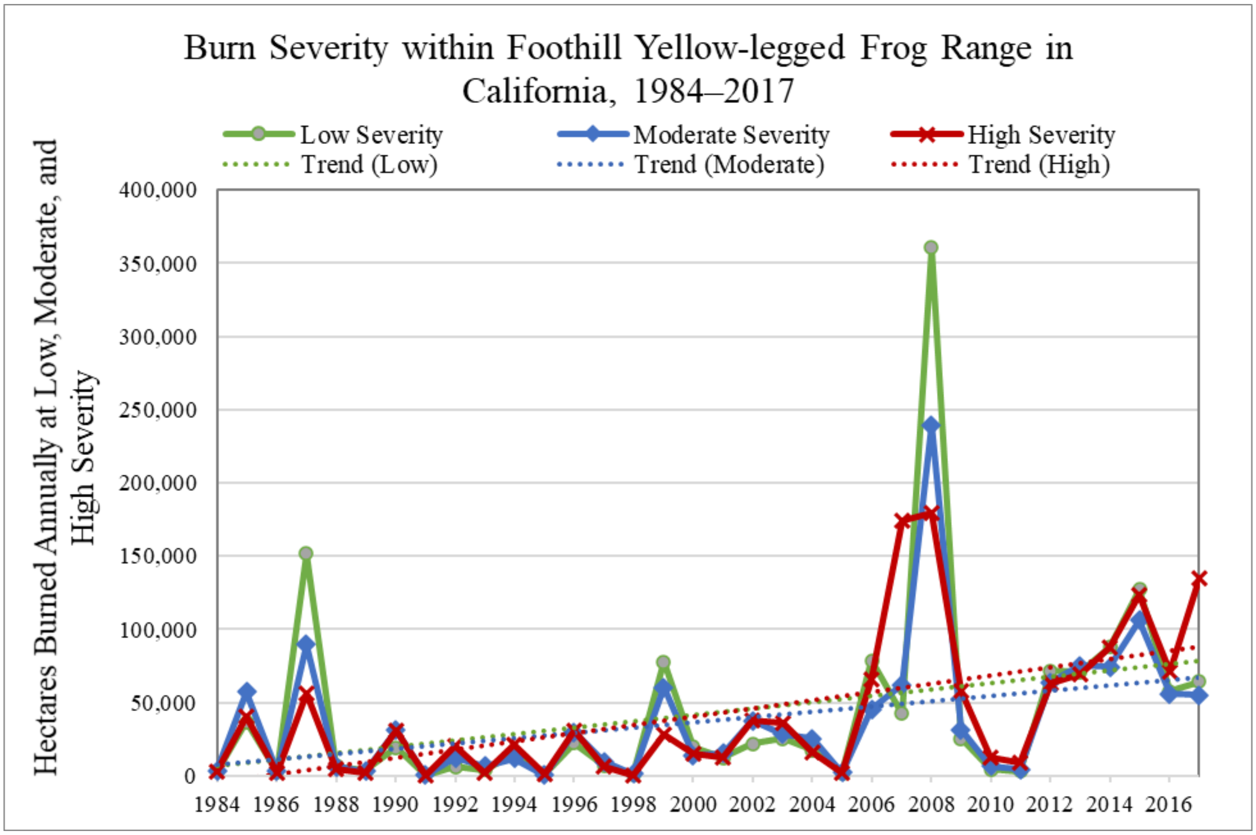


Figure 40. Trends in burn severity for 1984–2017, measured as the total hectares burned at low, moderate, and high severities for each year within the range of the foothill yellow-legged frog in California (note: dataset does not include Oregon range). The wildfire severity data are from the U.S. Forest Service Pacific Southwest Region database for selected wildfires since 1984 and are calibrated to the Composite Burn Index (U.S. Forest Service 2018, dataset). Low-severity fire is defined as areas of surface fire with little change in cover and little mortality of the structurally dominant vegetation. Moderate severity is defined as a mixture of effects on the structurally dominant vegetation. High severity is defined as areas where the dominant vegetation has high to complete mortality. Linear trendlines are displayed for low, moderate, and high severity through time.

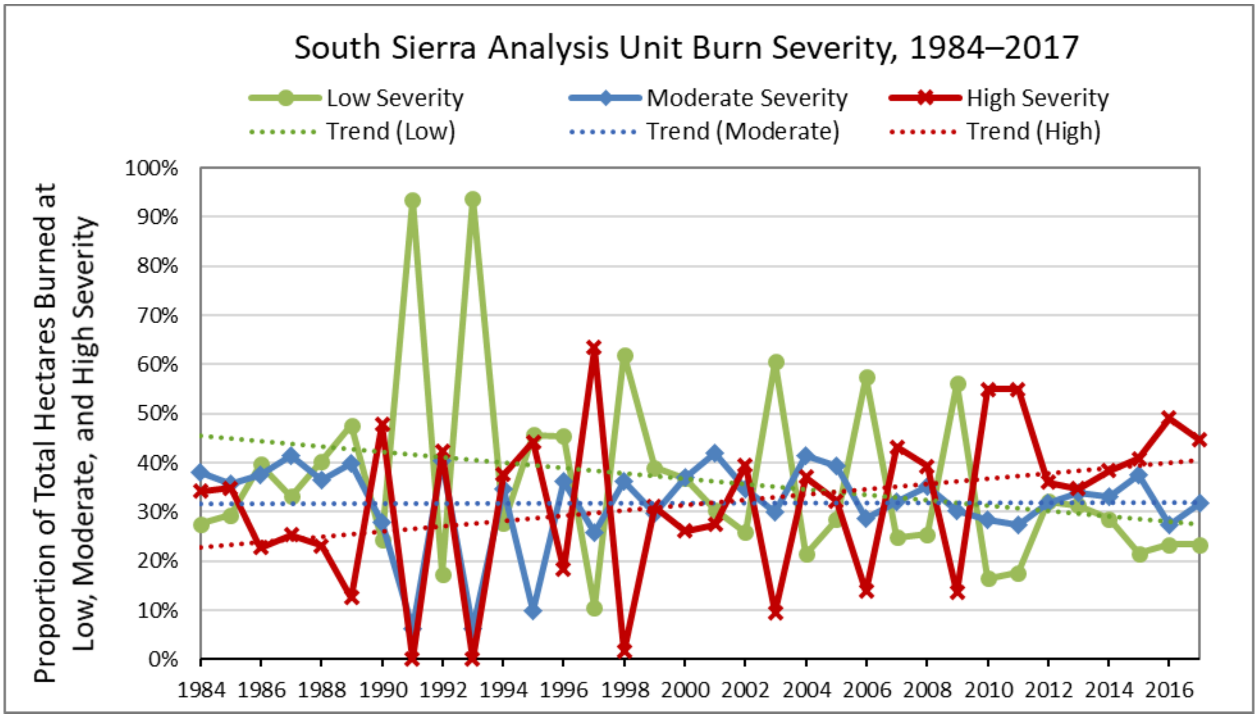


Figure 41. South Sierra analysis unit trends in burn severity for 1984–2017, measured as the percent of total burn area that burned at low, moderate, and high severities for each year. The wildfire severity data are from the U.S. Forest Service Pacific Southwest Region database for selected wildfires since 1984 and are calibrated to the Composite Burn Index (U.S. Forest Service 2018, dataset). Low severity fire is defined as areas of surface fire with little change in cover and little mortality of the structurally dominant vegetation. Moderate severity is defined as a mixture of effects on the structurally dominant vegetation. High severity is defined as areas where the dominant vegetation has high to complete mortality. Linear trendlines are displayed for low, moderate, and high severity through time.

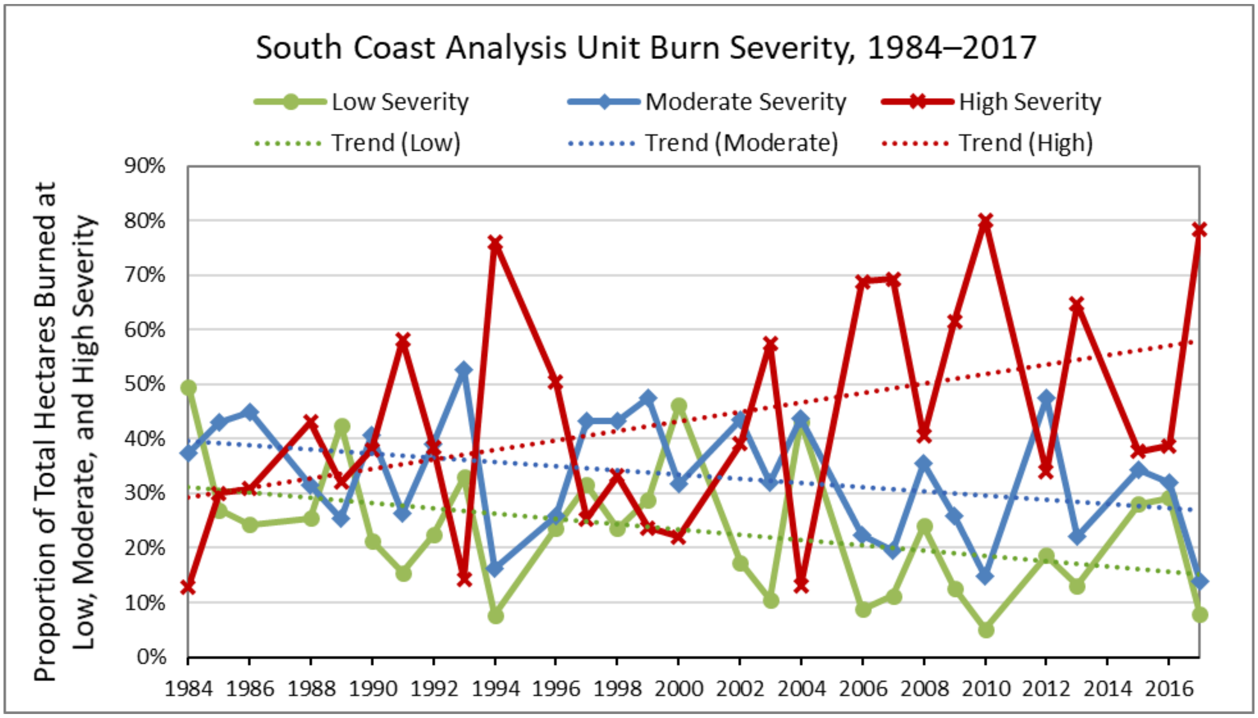


Figure 42. South Coast analysis unit trends in burn severity for 1984–2017, measured as the percent of total burn area that burned at low, moderate, and high severities for each year. The wildfire severity data are from the U.S. Forest Service Pacific Southwest Region database for selected wildfires since 1984 and are calibrated to the Composite Burn Index (U.S. Forest Service 2018, dataset). Low severity fire is defined as areas of surface fire with little change in cover and little mortality of the structurally dominant vegetation. Moderate severity is defined as a mixture of effects on the structurally dominant vegetation. High severity is defined as areas where the dominant vegetation has high to complete mortality. Linear trendlines are displayed for low, moderate, and high severity through time.

7.10 Extreme Flood Events

Strong winter flows from heavy precipitation are typical in Mediterranean climates and small floods can maintain and improve foothill yellow-legged frog breeding habitat (Lind *et al.* 1996, pp. 64–65; Lind *et al.* 2016, p. 269; Power *et al.* 2016, p. 719). However, extreme flood events that only occur every few decades have the potential to cause severe habitat destruction and extirpations (Figure 43), especially when combined with other threats.

Flood events during the latter half of the 20th century in southern California have been linked to severe declines in foothill yellow-legged frog populations in the South Sierra and South Coast units. Population crashes of foothill yellow-legged frogs in the South Sierra unit have been attributed to extreme flood events during the 1960s (Tulare County) and 1970s (Kern County) (Adams *et al.* 2017b, p. 10220; CDFW 2020, dataset). Sweet (1983, abstract) speculated that record flooding in January and February of 1969 reduced populations in the southern Coast Ranges and western Transverse Ranges below their ability to recover. Sweet (1983, abstract) also suggested that the foothill yellow-legged frog's overwintering ecology and habitat requirements might have made this species more vulnerable to the effects of these floods, compared to sympatric species. In the San Gabriel Mountains (South Coast unit), a once abundant foothill yellow-legged frog population was permanently extirpated within a year of the 1969 floods (Adams *et al.* 2017b, p. 10220). It is hypothesized that extreme flood events during 1969 acted in concert with increased prevalence of the Bd pathogen in southern California to extirpate foothill yellow-legged frogs from most of the South Coast unit distribution (Adams *et al.* 2017b, p. 10227).

Periodic extreme flood events occur naturally in foothill yellow-legged frog habitat, particularly in the southern analysis units (South Sierra, Central Coast, and South Coast units) (Adams *et al.* 2017b, p. 10227). However, the frequency of these events is expected to increase across the species' range because of the effects of climate change (Section 7.13).

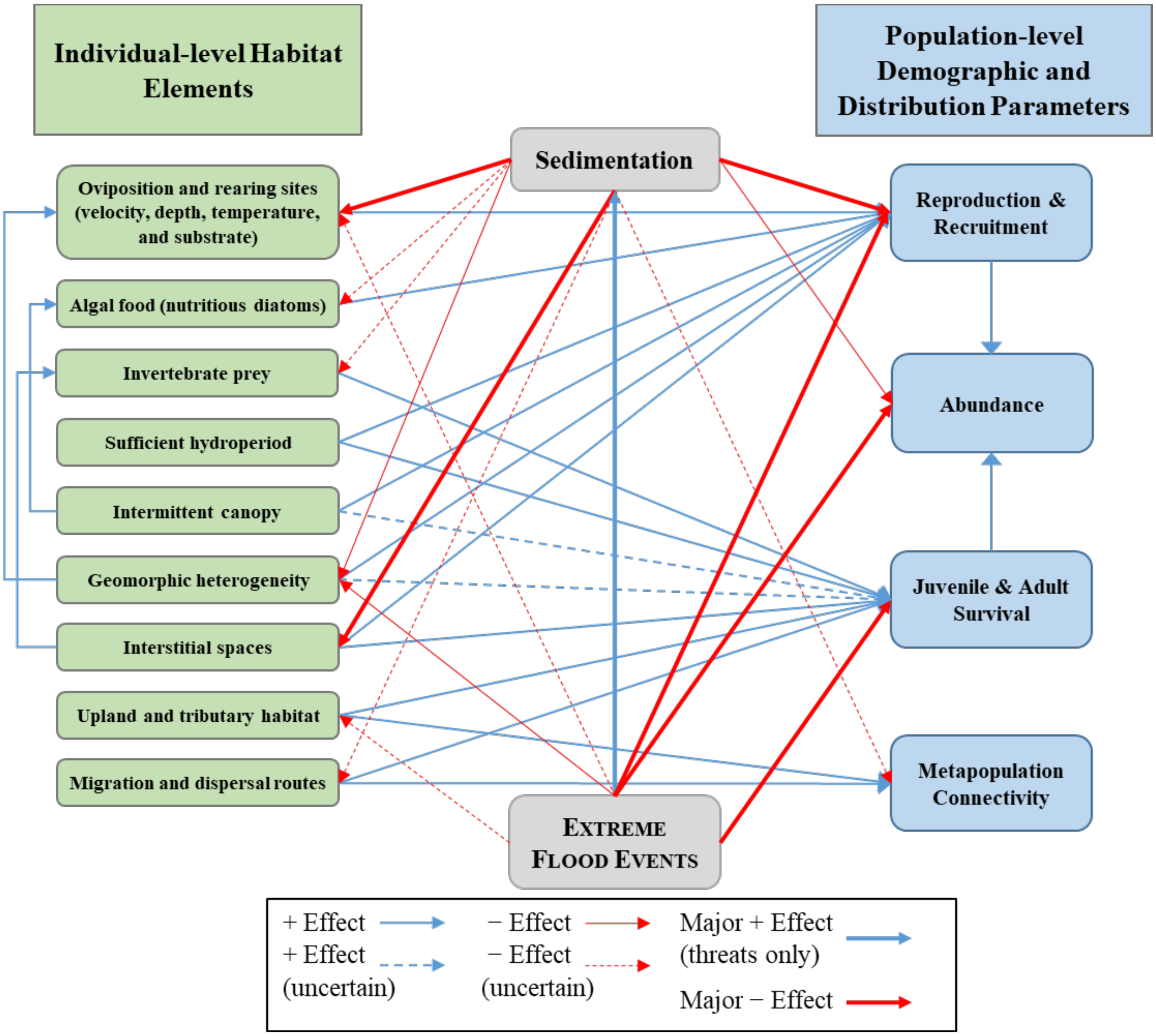


Figure 43. Conceptual diagram depicting the direct influences of extreme flood events on habitat elements and demographic parameters for the foothill yellow-legged frog. The direct influences of sedimentation are also depicted to highlight some of the indirect effects of extreme flood events.

7.11 Predators and Competition

A variety of native and nonnative species prey upon foothill yellow-legged frogs. Predators include amphibians, birds, crustaceans, fish, aquatic insects, mammals, and reptiles (CDFW 2019b, p. 23, table 1). During the juvenile and adult life stages, garter snakes (*Thamnophis* spp.) probably account for most of the predation of foothill yellow-legged frogs (Zweifel 1955, p. 225; GANDA 2008, p. 36) (Figure 44). Although nonnative predation (especially by bullfrogs, crayfish, and fish) is given more attention than native predation (Hayes *et al.* 2016, pp. 56–57), native predation is also a serious concern, particularly when tadpoles and frogs are concentrated in shrinking, disconnected pools (Fitch 1936, p. 641; CDFW 2019b, p. 92; S. Kupferberg 2020a, *in litt.*).


Photo credit: Marcia Grefsrud

Figure 44. A foothill yellow-legged frog being consumed by a garter snake in Alameda Creek, Alameda County, California.

The presence of predators can also have sublethal effects on tadpoles because predators alter prey behavior. The presence of garter snakes reduced the activity of Pacific tree frog (*Pseudacris regilla*) tadpoles by 56 percent (Kupferberg 1997b, p. 154). Decreased activity meant decreased feeding time, which typically results in slower growth, increased time to metamorphosis, and decreased size at metamorphosis (Kupferberg 1997b, p. 154).

Competition, both intraspecific (within species) and interspecific (with other species), can be a threat for foothill yellow-legged frogs, particularly when competitors are nonnative invasive species or when resources are otherwise limited. Tadpoles may be most at risk from competition because of limited mobility. The presence of competing bullfrog tadpoles has an adverse effect on foothill yellow-legged frog tadpole growth, development, and survival (Kupferberg 1997a, p. 1736). Competition intensifies when water and food resources are limited in drying waterways (Moyle 1973, p. 21). Thus, competition is a greater threat in the drier climates that characterize many populations in the Central Coast and South Coast units. Drought and other threats that affect food resources (algal or invertebrate) would also exacerbate the effects of competition.

7.12 Competing Conservation Interests

Many of the conservation activities that support native salmonid fishes (e.g., natural flow management, prevention of sedimentation) have positive influences on foothill yellow-legged frog habitat, connectivity, and juvenile and adult survival (Figure 45). However, some measures that are taken to improve habitat for cold-water salmonid fishes reduce habitat quality for the foothill yellow-legged frog by decreasing stream temperature and increasing tree canopy cover over streams (Figure 45). One of the management techniques used to support salmonid recruitment is to release high volumes of cold water from dams in the spring (to trigger spawning runs or to flush smolts out to the ocean) (Kupferberg 1996a, p. 1342; Kiernan *et al.* 2012, p. 1474). The timing of such flow events can negatively affect foothill yellow-legged frog breeding and recruitment (Kupferberg 1996a, pp. 1336–1337, 1342). Recommendations for salmonid conservation also include increasing canopy cover to lower stream temperature (Swales 2010, p. 30; 14 CA Code of Regs 916.9 [936.9; 956.9] Protection and Restoration of the Beneficial Functions of the Riparian Zone in Watersheds with Listed Anadromous Salmonids). Lowering stream temperature and decreasing solar input have negative implications for foothill yellow-legged frog growth, recruitment, and algal food assemblages (Sections 4.1 and 4.2). Under natural hydrological flow regimes, interannual variations support assemblages of species that flourish under contrasting conditions, with some years favoring certain species over others and vice versa. Therefore, if management actions for the conservation of salmonid fishes are taken without consideration of other species, foothill yellow-legged frog populations may suffer in those areas.

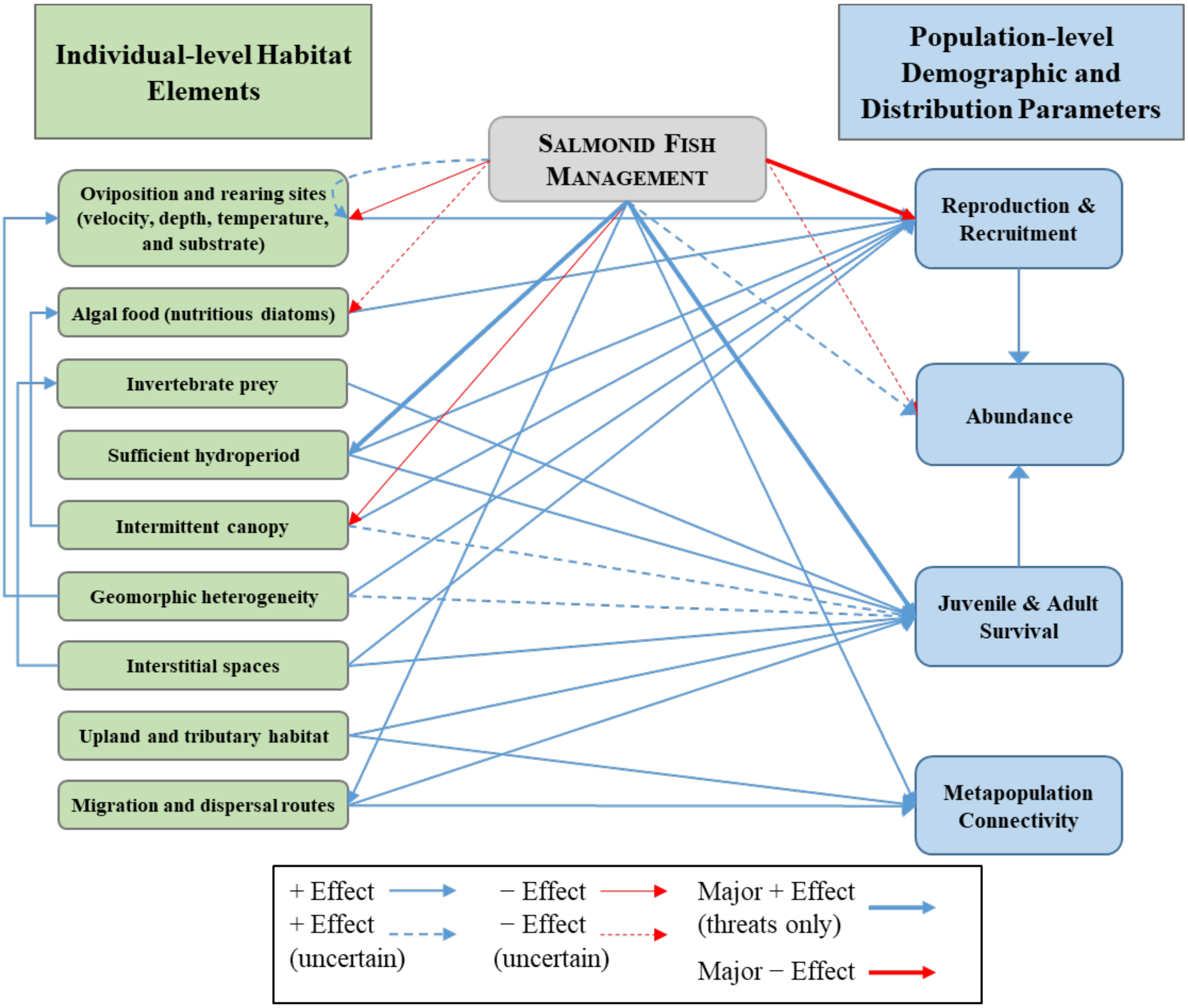


Figure 45. Conceptual diagram depicting the direct influences of salmonid fish management on habitat elements and demographic parameters for the foothill yellow-legged frog.

7.13 Climate Change

Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as the change in the mean or variability of one or more measures of climate that persist for an extended period, whether the change is due to natural variability or human activity (IPCC 2015, p. 120). Climate change is already having statewide impacts in California and Oregon (Bedsworth *et al.* 2018, p. 13; Mote *et al.* 2019, p. ii, summary). Overall trends in climate across the foothill yellow-legged frog's range include increasing temperature, greater proportion of precipitation falling as rain instead of snow, earlier snowmelt, and increased frequency and severity of extreme events such as droughts, heat waves, wildfires, and floods (OCCRI 2019, pp. 5–7, tables 2 and 3; Public Policy Institute of California 2020, not paginated). A rangewide study of occupancy found that foothill yellow-legged frog presence is negatively related to percentage of dry years and to precipitation variability, suggesting that the species may already be declining from climate change (Lind 2005, p. 20). The increased frequency and severity of extreme events also increase extinction risk from catastrophic events.

A climate change vulnerability assessment rated the vulnerability of the foothill yellow-legged frog in California as moderate-high due to a low adaptive capacity and the species' sensitivity to projected changes in conditions such as altered stream flow, water temperature, drought, storms, amount and timing of precipitation, amount of snowpack, and timing of snowmelt/runoff (Central Valley Landscape Conservation Project 2017, pp. 1, 6). The foothill yellow-legged frog was considered to have a low adaptive capacity in California based on low landscape permeability (due to hydrological barriers to connectivity), low intraspecific species diversity (based on diversity of life history strategies, genetic diversity, behavioral plasticity, and phenotypic plasticity), and low resistance to climate impacts and human land uses (Central Valley Landscape Conservation Project 2017, pp. 14–15).

Projected increases in temperature are likely to affect foothill yellow-legged frogs differently in different parts of the range. Warming temperatures are likely to have some positive effects where stream temperatures are relatively cold and negative effects where stream temperatures are already at or above the species' preferred thermal range. Warmer stream temperatures, up to approximately 22 °C (72 °F) (running 30-day average), are related to greater foothill yellow-legged frog population growth rates and early life stage survival (Kupferberg *et al.* 2011a, p. 72; Rose *et al.* 2020, p. 41). However, there may be tradeoffs to having water temperatures exceed a particular threshold. Researchers observed an unexpected die-off (unknown cause) of late-stage tadpoles (Gosner Stages 35 to 42) that coincided with maximum daily temperatures exceeding 25 °C (77 °F) (Kupferberg *et al.* 2011a, pp. 14, 58; Catenazzi and Kupferberg 2018, pp. 43–44, figure 2). Temperatures greater than the preferred thermal range may also have lethal or sublethal effects to tadpoles and metamorphs from parasites (Kupferberg *et al.* 2009a, p. 529; Kupferberg *et al.* 2011a, p. 15). There may be additional negative consequences to rising stream temperatures, even where temperatures are currently cold. Increasing temperatures may facilitate colonization by non-native species (Fuller *et al.* 2011, pp. 210–211; Kiernan *et al.* 2012, pp. 1480–1481). Bd prevalence in bullfrogs was also found to be greater when water temperature was warmer than 17 °C (63 °F) (Adams *et al.* 2017a, pp. 12–13).

Although trends in average total annual precipitation are uncertain within the foothill yellow-legged frog's range (Bedsworth *et al.* 2018, p. 22, table 3; Mote *et al.* 2019, p. ii, summary), changes in hydrology and increasing climate variability are expected (Pierce *et al.* 2018, pp. 20, 27–28; Swain *et al.* 2018, pp. 427–431; OCCRI 2019, p. 5, table 2). Climate models generally suggest increases in winter precipitation and decreases in summer precipitation for 2041–2070 in the foothill yellow-legged frog's range (AdaptWest Project 2015, dataset; Pierce *et al.* 2018, p. 26, figure 16; Mote *et al.* 2019, p. ii, summary). In California, a 25–100 percent increase in the frequency of extreme dry-to-wet precipitation events (such as that of the 2012–2016 drought followed by the extremely wet winter of 2016–2017) is projected during the 21st century (Swain *et al.* 2018, p. 427). This indicates that the threats of drought and extreme flood events may increase by 25–100 percent in California. Increased frequency of extreme heat events, drought, and extreme precipitation and floods events are also projected to increase in Oregon (OCCRI 2019, pp. 5, 6, 13–14, table 2, table 3). Furthermore, drying and surface-flow reductions are projected to increase and occur earlier in many intermittent headwater streams during warm and dry years under future climate change projections (Olson and Burton 2019, pp. 20–21, 23).

Increased and/or earlier drying will reduce the amount or quality of non-breeding and dispersal habitat, and potentially increase population isolation and fragmentation.

The projected changes in temperature, precipitation, and climate variability may exacerbate the effects of other threats on the foothill yellow-legged frog (Figure 46). The following bullets highlight some of the potential interactions (between climate change effects and other threats) that can negatively influence the viability of the foothill yellow-legged frog:

- Increased streamflow during the wet season and decreased streamflow during the dry season will further challenge California's water storage, flood control, and conveyance systems (Grantham *et al.* 2018, p. 439). The increased risk to human safety from flooding and increased risk of water shortages may necessitate more hydrological alterations (e.g., dams, surface-water diversions, and channel modifications). Risk of extreme precipitation events that exceed those of the past century is expected to substantially increase, especially in southern California (Swain *et al.* 2018, pp. 430–431). By mid-century, climate-induced surface water stress (i.e., where human demand outpaces natural supply) is projected to increase from 1900–1970 levels across all watersheds in the range of the foothill yellow-legged frog (Averyt *et al.* 2013, p. 7, figure 7). While climate change is only projected to increase surface water stress by up to 5 percent in the North Coast Oregon analysis unit by mid-century, projected increases range from 5 to 30 percent in California watersheds (Averyt *et al.* 2013, p. 7, figure 7). In the species' California range, climate-induced surface water stress is projected to increase the most in the South Sierra unit and the least in the North Coast California unit (Averyt *et al.* 2013, p. 7, figure 7).
- Increased frequency of drought, decreased spring/summer streamflow, and warmer water temperature may benefit nonnative predators and competitors. American bullfrog density and distribution tend to increase during dry years because bullfrogs prefer pool habitat with little or no flow (Adams *et al.* 2017a, p. 13). And, like the foothill yellow-legged frog, bullfrogs favor warmer and sunnier habitat (Fuller *et al.* 2011, pp. 210–211). Nonnative fish assemblages in the Tuolumne River also appear to benefit from drought, warmer water, and lower April-May streamflow (Brown and Ford 2002, pp. 332, 338–340, figure 3).
- Increased summer water temperatures and/or decreased daily stream discharge are expected to increase copepod parasitism in foothill yellow-legged frogs (Kupferberg *et al.* 2009a, p. 529).
- Increased climate variability may increase the likelihood or exacerbate the effects of disease outbreaks (Raffel *et al.* 2013, p. 147; Adams *et al.* 2017b, p. 10228).
- Observed and projected trends toward warmer and drier fire seasons in the western U.S. are likely to continue the trend toward higher-severity wildfires and larger burn areas (Parks and Abatzoglou 2020, pp. 1, 5–6).

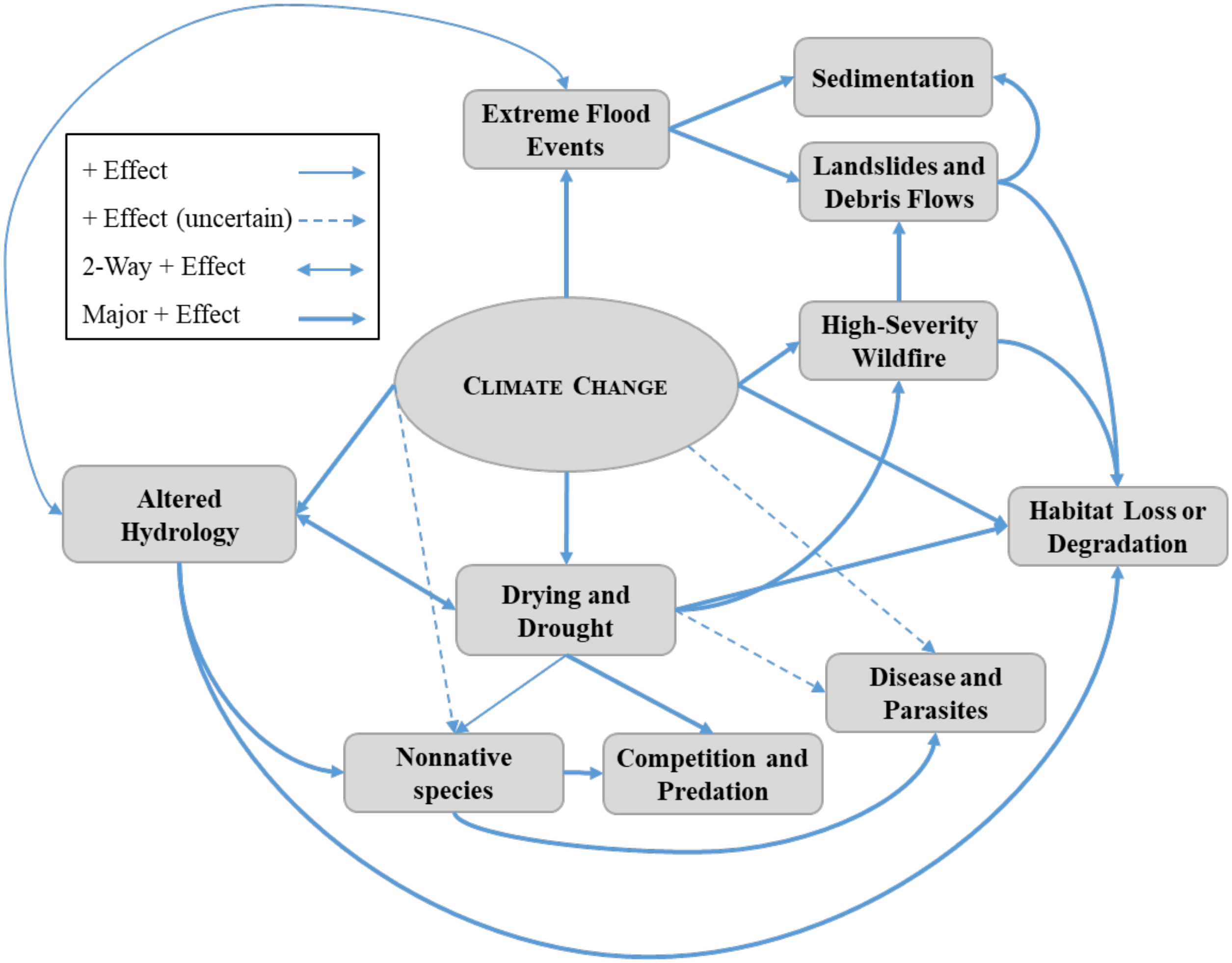


Figure 46. Conceptual diagram depicting the relationships among climate change and related threats to foothill yellow-legged frog viability.

7.14 Synergisms

Synergisms occur when the combined effect of two or more threats is greater than the sum of their separate effects. Many of the threats described above act in synergy with one another. For example, the negative effects of dams can be exacerbated by droughts (Lind 2005, p. 20). Poor habitat conditions, competition, and/or predation pressure can stress individuals, making them more susceptible to disease (Adams *et al.* 2017a, p. 13). Studies have also demonstrated that predation risk typically increases as a result of other threats. In mesocosm experiments, high water velocities altered foothill yellow-legged frog tadpole behavior such that predation by native invertebrates increased (Kupferberg *et al.* 2011b, pp. 145, 148–149, table 5). In field enclosure experiments, the survival of early life stages of a related ranid species (red-legged frog (*Rana aurora*)) was significantly affected only when competitor-predator treatments were combined to include both bullfrog tadpoles and bullfrog adults or both bullfrog tadpoles and smallmouth bass (Kiesecker and Blaustein 1998, entire). In another example, exposure to carbaryl, an insecticide, reduced the ability of foothill yellow-legged frogs to compete and increased mortality from crayfish predation by 50 percent (Kerby and Sih 2015, p. 255).

7.15 Beneficial Influences (Conservation Efforts and Regulatory Mechanisms)

Several initiatives and conservation projects are benefitting, or are expected to benefit, the foothill yellow-legged frog (Table 9). Regulatory mechanisms also provide some protection to the species or reduce or eliminate impacts to habitat from threats. Foremost is the decision by the California Fish and Game Commission to list five foothill yellow-legged frog genetic clades (referred to as analysis units in this document) under the California Endangered Species Act. In February 2020, the California Fish and Game Commission adopted the findings of the CDFW to list the South Coast, Central Coast, and South Sierra clades as endangered and list the North Feather and North Sierra clades as threatened under the California Endangered Species Act (California Fish and Game Commission 2020, p. 1). The U.S. Forest Service and the Bureau of Land Management also provide some protection and conservation for the species through designation of the foothill yellow-legged frog as a sensitive/special-status species (Bureau of Land Management 2009, p. 2; U.S. Forest Service 2005a, p. 80). These agencies consider sensitive/special-status species as those species that require special management consideration to promote their conservation and reduce the need for future listing under the Endangered Species Act (U.S. Forest Service 2005b, pp. 4–5; Bureau of Land Management 2008, section .01).

Other regulations or management/conservation plans that prevent, minimize, or mitigate negative impacts to wildlife or wildlife habitat within the range of the foothill yellow-legged frog include the following:

- Several California regulations (14 CCR 916 [936; 956], 923 [943; 963]; Technical Rule Addendum No. 2; Technical Rule Addendum No. 5) and the California Forest Practice Rules (CAL FIRE 2021b, entire) reduce the negative effects of timber harvest operations on aquatic wildlife (focus on listed salmonids) and aquatic habitat through best management practices (CAL FIRE 2021, *in litt.*).
- California's Wildfire and Forest Resilience Action Plan (California Wildfire and Forest Resilience Task Force 2021, entire) is expected to prevent or minimize the negative impacts of catastrophic wildfire on the foothill yellow-legged frog by increasing the pace and scale of forest health treatment projects through restoration and fuels management (CAL FIRE 2021, *in litt.*). Control-burn treatments may also benefit foothill yellow-legged frog habitat, as described in Section 7.9 Wildfire.
- California's 2009 moratorium on suction-dredge mining prevents new impacts from this type of mining in California. However, permitting processes are in development so that the moratorium may be lifted (State Water Resources Control Board 2020, entire).
- The Northwest Forest Plan (https://www.fs.fed.us/r6/reo/) covers U.S. Forest Service and Bureau of Land Management lands within the range of the northern spotted owl (including the North Coast Oregon unit and the northern part of the North Coast California unit). Among the Plan's benefits are the protection of riparian areas and waters and the Aquatic Conservation Strategy, which aims to restore and maintain the ecological health of watersheds and aquatic ecosystems (U.S. Forest Service and Bureau of Land Management 1994, pp. A-1, B-9–B-12).

- In 2008, Biological Opinions regarding the continued operations and maintenance of the Willamette Project dams were issued by the Service and the National Marine Fisheries Service. The terms and conditions and the conservation recommendations of the Biological Opinions include measures to support conservation of listed fish species (National Marine Fisheries Service 2008, pp. 11-40–11-58, 12-3–12-5; Service 2008, pp. 175–184). Some of these measures, especially those for flow management below dams, also benefit foothill yellow-legged frog habitat in the North Coast Oregon unit.
- Habitat Conservation Plans (HCPs) that include the foothill yellow-legged frog as a covered species are currently being implemented in the Central Coast unit and North Coast California unit. HCPs describe how the anticipated effects of actions (permitted under section 10(a)(1)(B) of the Endangered Species Act) will be minimized or mitigated. Two joint federal and state HCPs and Natural Community Conservation Plans (NCCPs) (i.e., East Contra Costa HCP/NCCP and Santa Clara Valley HCP/NCCP) assist in habitat conservation for foothill yellow-legged frog populations in the northern portion of the Central Coast unit (Jones and Stokes 2006, entire; ICF International 2012, entire). Another federal HCP has been issued to the Humboldt Redwood Company (formerly Pacific Lumber Company). The Humboldt Redwood Company HCP covers specific areas within the North Coast California unit and includes adaptive management strategies designed to monitor and sustain viable populations of the foothill yellow-legged frog and other covered species (Pacific Lumber Company 1999, p. P-76; Mendocino and Humboldt Redwood Companies 2021, pp. 22, 34–35).
- The Clear Creek Management Area Resource Management Plan provides protection, monitoring, and minimization of impacts to foothill yellow-legged frog populations in the Clear Creek Management Area (San Benito and Fresno counties, California; southern Central Coast unit) (Bureau of Land Management 2014, pp. 28, 77, 99–100).

Table 9. Ongoing and planned efforts that are intended to benefit the foothill yellow-legged frog directly or indirectly.

Project Type and analysis unit(s) affected	Timeline	Description	Source(s) and/or project lead(s)
Frog-friendly hydrological management and research (North Feather, North Sierra, and South Sierra units)	Ongoing; 50-year permits	Federal Energy Regulatory Commission relicensing for hydropower facilities in the Sierra Nevada. In some cases, terms and conditions are added to hydropower licenses that require data collection, modified flow regimes, and standard best management practices that limit the negative effects of hydropower operations on fish and wildlife.	Amy Lind, U.S. Forest Service, Pacific Southwest Region; CDFW (2019b, pp. 87–88)

Project Type and analysis unit(s) affected	Timeline	Description	Source(s) and/or project lead(s)
Bullfrog removal (South Sierra unit)	2005–2019	Eradication of the American bullfrog in Yosemite Valley (Kamoroff *et al.* 2020, entire).	Colleen Kamoroff, California-Great Basin Region of the U.S. Fish and Wildlife Service (formerly National Park Service, Yosemite National Park)
Population headstarting (in-situ rearing) (North Feather unit)	2017–2019	Eggs (portions of masses or stranded masses) from the North Fork Feather River system were reared in flow-through cages immediately adjacent to the salvage locations. Tadpoles and juveniles were then released to augment populations in the North Feather unit. The in-situ rearing has been successful, but long-term (population-level) effects are yet to be determined.	Colin Dillingham, U.S. Forest Service, Plumas National Forest
Conservation planning (rangewide)	2018–present	The Service (California-Great Basin and Columbia-Pacific Northwest regions) is developing and implementing Conservation Strategies (i.e., assessment and planning documents) that address the conservation needs of foothill yellow-legged frogs.	Kat Powelson and Claudia Mengelt (California-Great Basin Region) and Jeffrey Dillon (Columbia-Pacific Northwest Region), U.S. Fish and Wildlife Service
Population headstarting (ex-situ (i.e., outside of habitat) rearing) (North Feather unit)	2019–2021	The Service funded a pilot captive-rearing program at the Oakland Zoo. Eggs and tadpoles from the North Fork Feather River system are being reared to adulthood for release in the North Feather unit. More than 100 frogs were released in 2020.	Darren Minier, Conservation Society of California, Oakland Zoo; Kat Powelson, Claudia Mengelt, and Mary Grim, U.S. Fish and Wildlife Service, California-Great Basin Region
Reintroduction feasibility research (Central Coast unit)	2019–2022	The Natural Resources Preservation Program awarded funds to evaluate the feasibility of reintroducing foothill yellow-legged frogs to Pinnacles National Park (Central Coast unit) and identify strategies to improve the likelihood of successful population establishment.	Brian Halstead, U.S. Geological Survey, Western Ecological Research Center

Project Type and analysis unit(s) affected	Timeline	Description	Source(s) and/or project lead(s)
Oregon Wildlife Conservation Project (North Coast Oregon unit)	2020–present	The ODFW is collecting species observations (including for the foothill yellow-legged frog) through citizen science to incorporate species' needs into riparian habitat conservation and prioritization efforts statewide. The project aims to improve compatibility among various riparian species and habitat conservation efforts.	Emily Van Wyk, ODFW Strategy Species Coordinator, ODFW
Oregon Connectivity Assessment and Mapping Project (OCAMP) (North Coast Oregon unit)	2020–present	Related to the Oregon Wildlife Conservation Project described above, OCAMP is a collaborative effort to analyze and map wildlife habitat connectivity at fine resolutions for up to 60 species in Oregon, including the foothill yellow-legged frog. Maps and models produced for OCAMP will aid in statewide planning and prioritization efforts to maintain functional habitat connectivity.	<https://oregonconservationstrategy.org/success-story/the-oregon-connectivity-assessment-and-mapping-project-ocamp/> Accessed August 18, 2020
Restoration and reintroduction feasibility research (South Sierra unit)	2020–present	The Service is funding a feasibility study to identify suitable sites for restoration (including bullfrog removal) in preparation for in-situ rearing or potential reintroductions in the South Sierra unit (Merced and Tuolumne watersheds). This work is being undertaken in collaboration with the bullfrog removal and population headstarting project described below.	Kat Powelson, Claudia Mengelt, and Mary Grim, U.S. Fish and Wildlife Service, California-Great Basin Region; Caren Goldberg and Andrea Adams, Washington State University; Brian Halstead, U.S. Geological Survey, Western Ecological Research Center
Bullfrog removal and population headstarting (in-situ rearing) (South Sierra unit)	2020–2022	California Proposition 68 funds were awarded for site assessment, bullfrog removal, habitat modification, and in-situ rearing in the Tuolumne River watershed.	Rob Grasso, National Park Service, Yosemite National Park

Project Type and analysis unit(s) affected	Timeline	Description	Source(s) and/or project lead(s)
Sensitive species surveys (North Coast Oregon unit)	2019–2022	The Interagency Special Status/Sensitive Species Program (Oregon/Washington Bureau of Land Management and Region 6 U.S. Forest Service) and USGS are conducting survey inventories, including for the foothill yellow-legged frog.	Kelli Van Norman, Inventory and Monitoring Coordinator for the Interagency Special Status/Sensitive Species Program (source: J. Keehn 2021, *in litt.*)
Reintroduction feasibility research (South Coast unit)	2020–2025	The Service is funding a feasibility study to identify potential source populations and reintroduction sites to inform reintroduction planning in the South Coast unit.	Claudia Mengelt, Cat Darst, and Robert McMorran, U.S. Fish and Wildlife Service, California-Great Basin Region
Collaborative climate-informed conservation (South Sierra unit)	2021–2025	The Southwest Climate Adaptation Science Center awarded funds to the Service to work with partners to develop and implement climate-informed conservation actions to benefit a suite of focal species, including the foothill yellow-legged frog. This effort is expected to provide ongoing support for the actions identified in the "Restoration and reintroduction feasibility research" and "Bullfrog removal and population headstarting" projects described above.	Claudia Mengelt and Kat Powelson, U.S. Fish and Wildlife Service, California-Great Basin Region; Carolyn Enquist (Southwest Climate Adaptation Science Center) and Toni Lynn-Morelli (Northeast Climate Adaptation Science Center), U.S. Geological Survey; Nicole Athearn, National Park Service, Yosemite National Park

Although many foothill yellow-legged frog efforts target areas that are small relative to the size of analysis units, some influences could potentially have widespread positive impacts for the species. Specifically, regulatory pressure for "natural" flow management below dams (i.e., "frog-friendly" and/or "fish-friendly" hydrological management in Table 9) could have broad, significant benefits for the species. While potential benefit is high, the effects of natural flow management alone is uncertain and could vary among streams. For example, a change in flow management below a dam could restore the natural flow cycle that is required for successful oviposition and rearing, but the change might not benefit the species if other threats are not also managed (e.g., bullfrogs, sedimentation, etc.). Frog-friendly flow management and research efforts should continue so the effectiveness of such measures for foothill yellow-legged frog conservation can be determined.

The long-term influence of the conservation efforts assessed in this SSA have not yet been determined. Several ongoing and planned efforts are preliminary steps to on-the-ground conservation (e.g., feasibility research (Table 9)). Other efforts have not had enough time to verify long-term success (e.g., population headstarting (Table 9)) or determine if and how the condition of a foothill yellow-legged frog population has improved (e.g., bullfrog removal in Yosemite Valley (Table 9)). Therefore, current conservation efforts are not known to be currently outweighing any of the threats assessed in this chapter. In kind, future benefits of conservation efforts cannot be projected into the future in our assessment of future condition.

CHAPTER 8 Current Condition

Current condition may be described in terms of past and ongoing changes in a species' habitat, demographics, and distribution (Smith *et al.* 2018, p. 306). To assess the current condition of the foothill yellow-legged frog, 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. The methods and results of our assessment of current condition are described in the subsequent sections.

8.1 Summary of Methods

This section provides a brief overview of our approach to assessing the current condition of the foothill yellow-legged frog. We assessed current condition of the species in terms of the conservation biology principles of resiliency, redundancy, and representation (Section 1.2). Where relevant, more methodological details are provided in subsequent sections.

Foothill yellow-legged frog resiliency (having sufficiently robust populations for the species to withstand stochastic events) is a function of metapopulation health and the distribution and connectivity among metapopulations and subpopulations. As discussed in CHAPTER 5, a healthy foothill yellow-legged frog population can be defined in terms of its abundance, reproductive and recruitment rates, juvenile and adult survival, and connectivity. Abundance data for most foothill yellow-legged frog populations are unavailable. Therefore, we estimated resiliency of each analysis unit by assessing (1) spatial and temporal trends in occupancy and reports of population abundance where available (Section 8.2), (2) connectivity and isolation among occupied areas (Section 8.3), (3) modeled risk of population decline that incorporates demographic and environmental information (Section 8.4), and (4) status of threats and their effects, including cumulative effects, to the species' viability (CHAPTER 7). In Section 8.5, we summarize foothill yellow-legged frog resiliency for each analysis unit in terms of the four elements stated above.

The final two sections of this chapter describe foothill yellow-legged frog redundancy and representation. Foothill yellow-legged frog redundancy (ability of the species to withstand catastrophic events) was determined by the number and distribution of resilient metapopulations across the species' range. Foothill yellow-legged frog representation (ability of the species to adapt to change) was determined by the current diversity of ecological conditions and genetic diversity across the species' range.

Current condition results are described for the species rangewide, and by analysis unit. As discussed in CHAPTER 3, we divided the current range of the species into seven analysis units (Figure 11). The seven analysis units reflect discrete patterns of genetic discontinuity across the foothill yellow-legged frog's range (McCartney-Melstad *et al.* 2018, entire; Peek 2018, pp. 50–77), the clade boundaries presented in the CDFW's Status Review of the foothill yellow-legged frog in California (CDFW 2019b, pp. 26–27, figure 5, figure 6), and practical considerations for assessing the status of the species in California versus Oregon.

8.2 Occupancy and Abundance

Geographically disproportionate declines in foothill yellow-legged frog occupancy have been recognized for approximately 50 years (CDFW 2019b, p. 25). During the 1990s, Jennings (1996, pp. 934–935) reported that foothill yellow-legged frogs had disappeared from approximately 45 percent of their historical range in California, including approximately 66 percent of their historical range in the Sierra Nevada. According to extensive surveys of 804 sites (in 40 California counties) between 1993 and 2004, foothill yellow-legged frogs were absent from 60 percent of their historical range in the coastal northwest, 70 percent in the Cascades, 70 percent in the coast range south of San Francisco, and 88 percent in the Sierra Nevada foothills (Fellers 2005, p. 534). Fellers (2005, p. 534) estimated that total stream occupancy in California was 26.5 percent, with occupants in 28 of the 40 surveyed counties. Fellers (2005, p. 534) also revealed that the vast majority of occupied streams had relatively low abundance with only 30 (14 percent) of the 213 occupied sites having population estimates of 20 adults or greater. Range-wide, it is estimated that the species has disappeared from more than half of its historically-occupied locations (Lind 2005, pp. 38, 61, table 2.1).

In this section, we describe the patterns and trends in foothill yellow-legged frog occupancy (using presence data only) across the seven analysis units and summarize reports of abundances where abundance information is available. Sites are presumed to be occupied by foothill yellow-legged frogs if there was a reliable detection of the species between 2000 and 2020, inclusive. This time period was selected to accommodate inclusion of sites that are surveyed infrequently. Without extensive repeated survey data, it is not feasible to accurately estimate the true proportion of the historic range that is occupied. It is possible that foothill yellow-legged frogs are no longer present in some of the locations that were classified as occupied or that some locations are based on detections of individuals that were dispersing or migrating. In these cases, the data might overestimate occupancy. Alternatively, the data might underestimate occupancy if foothill yellow-legged frogs are present in streams where the species has not been detected during 2000–2020. To account for uncertainty in the available data, we relate our results to occupancy and abundance information in the scientific literature and from species experts.

Methods

We assessed occupancy in two primary ways. We first totaled the numbers of locations where foothill yellow-legged frogs are likely present in each analysis unit. A location was presumed to be occupied if there is a record of a foothill yellow-legged frog observation between 2000 and 2020, inclusive. Records of observations (including positive environmental DNA detections) were sourced from the California Natural Diversity Database (CNDDB), U.S. Geological Survey stream amphibian surveys, the Oregon Biodiversity Information Center (ORBIC), the Bureau of Land Management, the U.S. Forest Service, observations shared by collaborating biologists, and other sources such as unpublished reports. For each analysis unit, numbers of presumed occupied locations are reported both as the number of stream segments[13] from Rose *et al.* (2020, p. 21,

---

[13] A "stream segment" is defined as an uninterrupted reach of stream bookended either by the stream's beginning and a confluence, or between two confluences. Stream segments are hydrographical features from the U.S. Geological Survey's National Hydrography Dataset (NHD), which is the standard national dataset for hydrographical features (e.g., rivers, streams, canals, etc.). "Occupied stream segments" refer to the NHD stream segments that are presumed to be occupied by the foothill yellow-legged frog in Rose *et al.* (2020, pp. 21–22).

supplementary data) and as the number of "Element Occurrences" as defined by CNDDB (CDFW 2020, dataset). For context, we compared the number of presumed occupied stream segments to the total number of "potential stream segments" (i.e., stream segments within the range of the foothill yellow-legged frog that may or may not have been historically occupied by the species and that may or may not be habitat for the species) in each analysis unit. This provided information about relative occupancy, accounting for differences in analysis unit size and hydrological system. We also compared the number of Element Occurrences (based on CDFW (2020, dataset) and other sources listed above) that are presumed occupied to the total number of Element Occurrences (currently or historically occupied by the foothill yellow-legged frog) in the California analysis units.

The second way we assessed occupancy was by identifying spatial and temporal patterns of foothill yellow-legged frog occurrences based on date of most recent detection. To do this, we mapped foothill yellow-legged frog occurrences (sourced from the ORBIC (2019), the CNDDB (CDFW 2020), U.S. Geological Survey stream amphibian surveys, the Bureau of Land Management, the U.S. Forest Service, observations shared by collaborating biologists, and other sources such as unpublished reports) as points[14] against the backdrop of historical detections by distinguishing point locations by year of their most recent positive detection of the species. Occurrences were grouped into the following four categories based on the most recent year of detection: prior to 1990, 1990–1999, 2000–2009, and 2010–2020. Records of detections (or specimen collections) that did not include a year for the detection or collection were excluded but records with low spatial accuracy were included in this assessment. While foothill yellow-legged frogs are not necessarily absent from locations that do not have recent detections (locations might not have been surveyed recently or the species might have not been detected even if present), clusters of historical observations in areas where the species has not been observed for several years could suggest spatial patterns where declines and/or extirpations might have occurred. Likewise, high numbers of occurrences in clusters could result from high survey effort within an occupied stream or watershed. Given the uncertainties with inconsistent survey efforts, occupancy patterns observed in the occurrence maps were also cross-referenced with information from the scientific literature and other sources.

Rangewide Summary of Occupancy

Foothill yellow-legged frog occupancy[15] varies widely among analysis units with generally greater occupancy in the northern half of the range. The North Sierra unit has the greatest proportion of presumed occupied stream segments (relative to the number of potential stream segments), followed by the North Coast California and North Feather units (Table 10). Proportions of presumed occupied stream segments were much lower in the rest of the units with the South Coast unit having the lowest proportion of presumed occupied segments, followed by the South Sierra unit (Table 10). Based on historical and current "Element Occurrence" data for

---

Occupied stream segment data for the North Coast Oregon unit data differ slightly from those in Rose *et al.* (2020) because we incorporated information obtained during peer and partner review of the SSA report.

[14] If observations were attributed to polygon features, the centroids of the polygons were used for points.

[15] Foothill yellow-legged frog occupancy is defined here as the number of locations (either number of stream segments or number of Element Occurrences) where a positive detection of the species was reported for 2000–2020. Thus, we presume that locations where the foothill yellow-legged frog was observed during 2000–2020 are likely to be currently occupied.

California (CDFW 2020), 67–70 percent of all known Element Occurrences are presumed to be occupied by the foothill yellow-legged frog in the northern analysis units (i.e., North Coast California, North Feather, and North Sierra) (Table 10). Whereas less than 45 percent of known Element Occurrences are presumed occupied in the South Sierra, Central Coast, and South Coast units (Table 10). Some of these occupancy results might be affected by bias in the extent and intensity of survey effort, which differs among analysis units. Therefore, it is also valuable to look at the spatial patterns of occupancy by decade of most recent detection (Figure 47 through Figure 53).

Based on patterns of historical and current occupancy by decade of most recent detection (Figure 47 through Figure 53), occupied area appears to be declining in parts of each of the analysis units but less so in the northern part of the species' range (Figure 47 through Figure 50). This is mostly congruent with the greater proportions of presumed occupied stream segments (relative to the number of potential stream segments) in the northern half of the species' range (Table 10). There are large regions in the southern half of the species' range (South Sierra (Figure 51), Central Coast (Figure 52), and South Coast (Figure 53) units) that have not had any reported observations of foothill yellow-legged frogs for two or more decades.

Table 10. Numbers of presumed occupied locations reported as numbers of stream segments and CNDDB Element Occurrences. A location was presumed occupied if the most recent observation of foothill yellow-legged frog was during 2000–2020. For reference, we also provide the total number of potential stream segments (i.e., stream segments within the range of the foothill yellow-legged frog that may or may not have been historically occupied by the species and that may or may not be habitat for the species) and the total number of Element Occurrences (currently or historically known to be occupied by the species) within each analysis unit. Presumed occupied stream segments and numbers of Element Occurrences are affected by levels of survey effort (and reporting), which differs across the range of the species. Comparable Element Occurrence data are not available for the North Coast Oregon analysis unit.

Analysis unit	**Number of presumed occupied stream segments** (Rose *et al.* 2020, p. 70, table 6)	**Number of potential stream segments** (Rose *et al.* 2020, p. 72, table 8)	**Number of presumed occupied Element Occurrences** (CDFW 2020)	**Number of total Element Occurrences**
North Coast Oregon	227	10,536	No data	No data
North Coast California	1,443	24,732	1,075	1,599
North Feather	118	2,350	92	131
North Sierra	302	2,812	162	231
South Sierra	153	11,889	111	256
Central Coast	175	7,075	71	170
South Coast	7	7,592	6	77

Analysis Unit Occupancy and Abundance

Below are summaries describing occupancy and abundance in each of the seven analysis units. The summaries provide an overview of presumed occupancy based on the available presence data (from CNDDB (CDFW 2020), ORBIC (2019), and other sources) and relate these results to foothill yellow-legged frog occupancy and abundance information in the scientific literature and from species experts.

North Coast Oregon

Observation data for the North Coast Oregon unit must be interpreted in light of the knowledge that survey efforts and reporting in Oregon have been inconsistent over the years. According to the available records used in Rose *et al.* (2020, entire), the North Coast Oregon unit contains a low proportion of presumed occupied stream segments (relative to the number of potential stream segments) (Table 10), which could suggest low occupancy, low survey effort, and/or low reporting. Additional survey data that became available since Rose *et al.* (2020) suggest that the North Coast Oregon unit may have greater occupancy than previously thought. For example, recent environmental DNA survey results (National Genomics Center for Wildlife and Fish Conservation 2021, unpublished data) demonstrated that the foothill yellow-legged frog currently occupies the Coastal Range northeast of Coos Bay (Figure 47), an area where there had only been historical (pre-1990) records. These new data might suggest that records are sparse in parts of Oregon due to low survey effort or reporting, not necessarily to low occupancy. Given the complicating factors associated with the available data for this unit, our assessment of current occupancy in the North Coast Oregon unit also considers information reported by researchers in publications and reports (described below).

Declines in foothill yellow-legged frog occupancy and/or abundance in parts of Oregon have been reported by Borisenko and Hayes (1999, p. 10, figure 1), Fellers (2005, p. 534), Lind (2005, p. 65, figure 2.1), and Olson and Davis (2009, p. 9). Range contraction was estimated at 41 percent of the estimated historical distribution in the 2009 Conservation Assessment for the foothill yellow-legged frog in Oregon, developed by the U.S. Forest Service and Bureau of Land Management as part of their Sensitive Species Program requirements (Olson and Davis 2009, p. 10). The estimated range contraction took place in the north-northwest and east-southeast portions of the species' historical range in Oregon (Olson and Davis 2009, p. 10, figure 1), which is consistent with concentrations of anthropogenic disturbances (Linnell and Davis 2021, not paginated, figure 6). Sites where the species was surveyed for but not detected have been associated with historical (splash dams used for log transport) and current (water impoundments and agriculture) disturbances (Linnell and Davis 2021, not paginated, figure 6). While the species' range in Oregon has likely contracted to some extent, foothill yellow-legged frogs have recently been detected (Figure 47) in areas where they were assumed to be extirpated by Olson and Davis (2009, pp. 10–11, figure 1). Therefore, the estimated 41 percent range contraction in Oregon (Olson and Davis 2009, p. 10) is an overestimate of the unit's range contraction. Lack of survey and/or insufficient survey effort (Olson and Davis 2007, p. 7) are the likely causes of the overestimation.

Data are extremely limited in regard to foothill yellow-legged frog abundance in the North Coast Oregon unit. During the 1930s, foothill yellow-legged frogs were reported as "probably the most abundant amphibian" in the Rogue River basin, Oregon (Fitch 1936, p. 640). In contrast, surveys leading up to the 2009 Conservation Assessment rarely detected numerous individuals, even with considerable survey effort (Olson and Davis 2009, p. 26). Visual encounter surveys by Borisenko and Hayes (1999, p. 10, figure 3) rarely detected more than ten individuals (counts included metamorphs, juveniles, and/or adults) at occupied sites and only five or fewer individuals were detected at 49 percent of occupied sites. Anecdotal evidence suggests that these relative abundances are lower than those during the first half of the 20th century (Fitch 1936, p. 640; Borisenko and Hayes 1999, pp. 20–21).

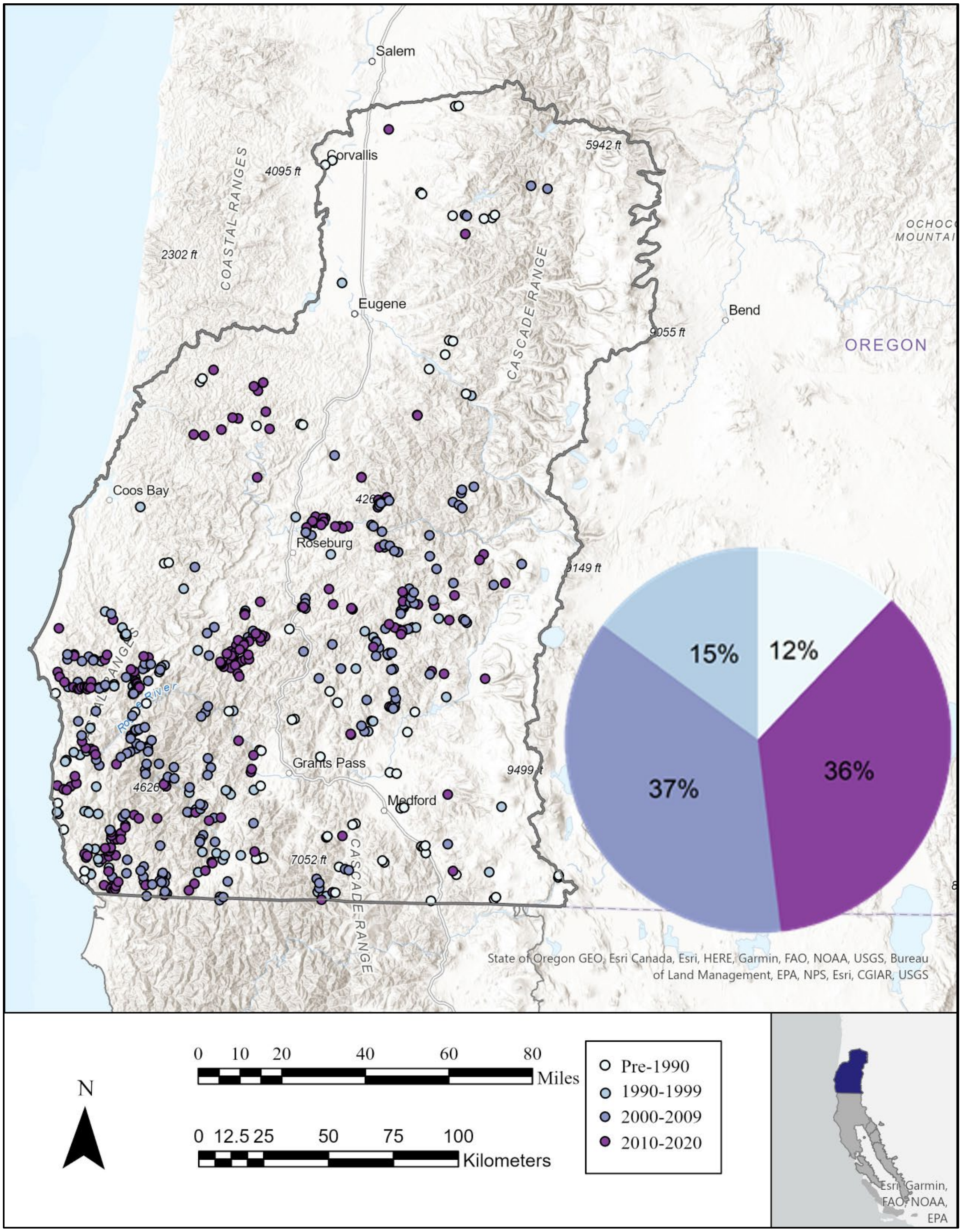


Figure 47. Distribution of foothill yellow-legged frog occurrences in the North Coast Oregon analysis unit by decade of most recent detection. Observations are from U.S. Geological Survey stream amphibian surveys, the Oregon Biodiversity Information Center (ORBIC 2019), the Bureau of Land Management, U.S. Forest Service, recent observations shared by collaborating biologists, and other sources such as unpublished reports. Occurrences are color coded by most recent date of detection. Pie chart percentages refer to proportions of total occurrences (in the analysis unit) in each color-coded time period.

North Coast California

The North Coast California unit is the largest analysis unit and, compared to the rest of the range, it contains the majority (60 percent) of presumed occupied stream segments (Rose *et al.* 2020, p. 70, table 6) and the majority (63 percent including Oregon occurrences) of recent foothill yellow-legged frog occurrences (2000–2020) (Table 10). This unit has a relatively high proportion of presumed occupied stream segments (relative to the number of potential stream segments) and more than half of all known occurrences are presumed to be occupied (Table 10; Figure 48). The North Coast California unit also has several documented extirpations, particularly in areas just north of the San Francisco Bay and in the foothills along the northeast corner of the Central Valley (Jennings and Hayes 1994, p. 67, figure 18; GANDA 2010, p. 6, figure 1; CDFW 2020, dataset). Also, two of the five occurrences in the northeastern corner of the unit are documented as extirpated and the other three have not had foothill yellow-legged frog observations since 1972 or earlier (Jennings and Hayes 1994, p. 67, figure 18; CDFW 2020, dataset). The dearth of recent observations of foothill yellow-legged frogs in the larger northeastern part of the unit can be seen in Figure 48.

The North Coast California unit is known for having the largest abundances of foothill yellow-legged frogs. There are at least three North Coast California locations with annual egg mass densities that average over 240 per km (386 per mi) (Rose *et al.* 2020, pp. 63–64 , table 1). Fellers (2005, p. 534) noted that the largest foothill yellow-legged frog populations (>100 adults at 6 sites and >50 adults at another 9 sites) were in this unit. Fellers (2005, p. 534) described northwestern California as the stronghold of the foothill yellow-legged frog in California because it had healthy populations scattered throughout the region. However, there are also a number of low-density (<10 egg masses per km (<16 per mi))[16] populations in the North Coast California unit, especially in streams where the upstream degree of regulation[17] is >10 percent (Rose *et al.* 2020, pp. 63–64 , table 1).

---

[16] Egg mass counts are used as a proxy for female foothill yellow-legged frog abundance because, like many other ranid frogs, female foothill yellow-legged frogs lay one egg mass per year (Kupferberg *et al.* 2009c, p. 23; Kupferberg *et al.* 2012, p. 515; Rose *et al.* 2021, p. 13).

[17] Degree of regulation is the percentage of a stream's estimated annual discharge that is stored upstream in reservoirs (Cooper *et al.* 2017, pp. 3–4).

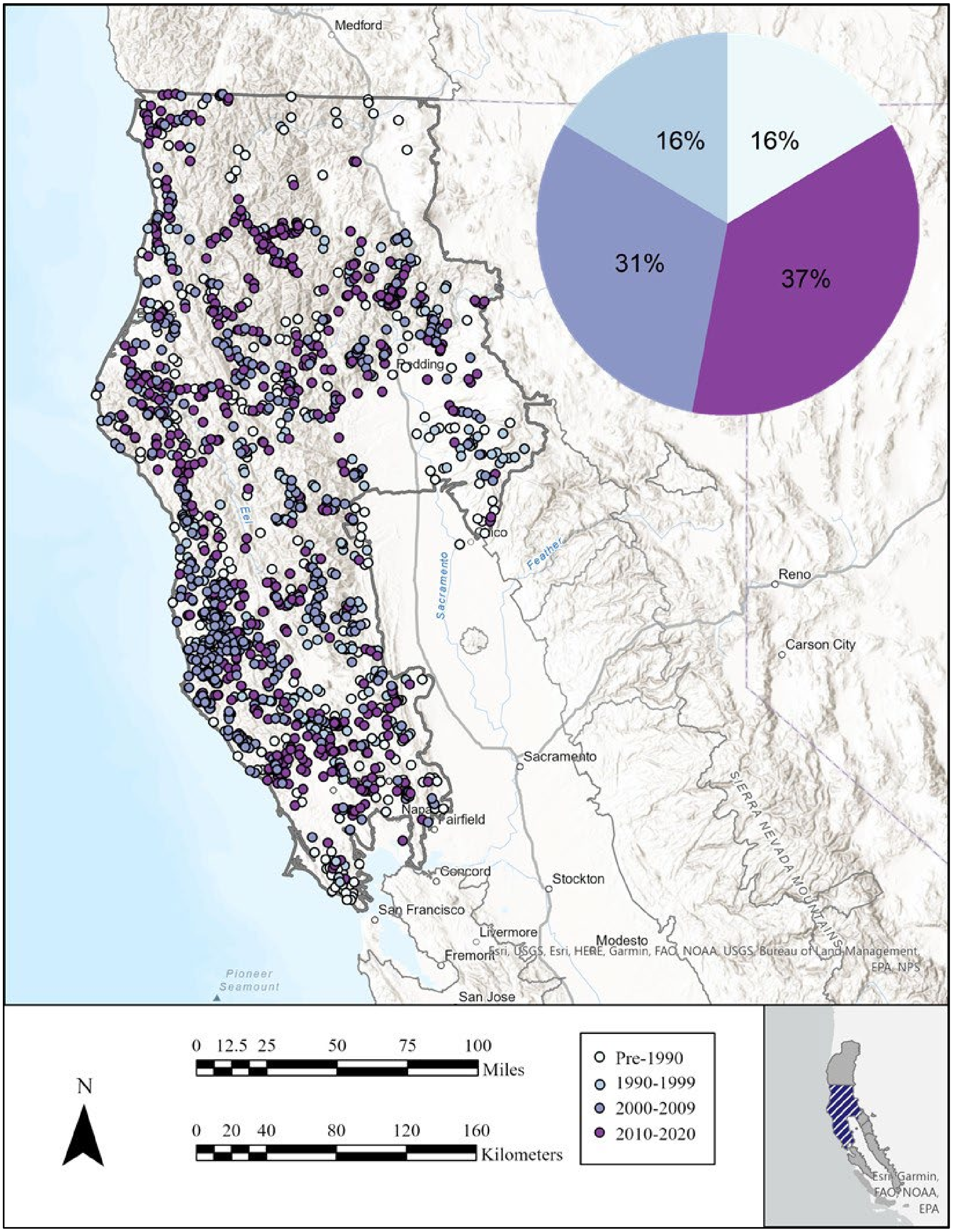


Figure 48. Distribution of foothill yellow-legged frog occurrences in the North Coast California analysis unit by decade of most recent detection. Observations are from the California Natural Diversity Database (CDFW 2019), U.S. Geological Survey stream amphibian surveys, the Bureau of Land Management, U.S. Forest Service, recent observations shared by collaborating biologists, and other sources such as unpublished reports. Occurrences are color coded by most recent date of detection. Pie chart percentages refer to proportions of total occurrences (in the analysis unit) in each color-coded time period.

North Feather

The North Feather analysis unit has a relatively high proportion of presumed occupied stream segments (relative to the number of potential stream segments) and more than half of all known occurrences are presumed to be occupied (Table 10; Figure 49). However, there are parts of the North Feather unit that appear to be either declining in occupancy or extirpated in the extreme eastern portion of the range and in the southwest near Lake Oroville (Figure 49). There are some areas of the North Feather unit that have documented extirpations (Jennings and Hayes 1994, p. 67, figure 18; Lind 2005, p. 65, figure 2.1; CDFW 2020, dataset). The species has not been detected in the far eastern portion of this unit since the 1970s (CDFW 2020, dataset). There are also several historical localities around Lake Oroville (Figure 49) where there have not been foothill yellow-legged frog detections for decades, apart from an observation of a single adult during 2001 in Canyon Creek, just northeast of Lake Oroville (CDFW 2020, dataset). Several other localities in northern Butte County are likely extirpated because there have not been detections of the species for decades (CDFW 2020, dataset).

Abundances of foothill yellow-legged frogs in the North Feather unit are largely unknown but they are very low in the two regulated stream reaches that have long-term monitoring (Rose *et al.* 2020, pp. 63–64, table 1). There have only been long-term surveys in the North Feather unit along the Cresta and Poe reaches of the regulated North Fork Feather River, where surveys are associated with relicensing of hydropower dams by the Federal Energy Regulatory Commission (GANDA 2018, p. 1; CDFW 2019b, p. 31). Over the past several years, declines in abundance and the distribution of egg masses have been severe in the Cresta reach of the North Fork Feather River as a result of four years of recreational pulse flows for whitewater boating (Hayes *et al.* 2016, p. 120; GANDA 2018, pp. 1–3, 13, table 2). Sections of the Cresta reach that historically had relatively high numbers of foothill yellow-legged frog egg masses did not have egg masses for several years (Dillingham 2019, p. 7). The regulated flow regime has been modified since the Cresta reach subpopulation crashed in 2006 but the subpopulation has only recently begun to recover in response to the 2017–2020 in-situ and ex-situ rearing efforts (GANDA 2018, pp. 1–3, 13, table 2; Dillingham 2019, pp. 7–9; Rose *et al.* 2020, pp. 63–64, 76, table 1, figure 4). The U.S. Forest Service has noted improvements in breeding habitat in the Cresta Reach and expects abundances and breeding activity to continue to increase in response to conservation rearing efforts (Dillingham 2019, pp. 7–9). However, density of egg masses in the Poe reach of the North Fork Feather River (regulated but was not affected by the recreational pulse flows), now acting as a source population for the Cresta reach, has had an average of only 7.0 egg masses per km (11.3 per mi) for 2001–2020 (Rose *et al.* 2020, pp. 63–64, table 1). Abundance information is not available for the unregulated Middle Fork Feather River, but recent surveys on the South Fork Feather River (which is highly regulated like the North Fork Feather River) have reportedly found the species to be absent or detected very low numbers (R. Peek 2021b, *in litt.*).

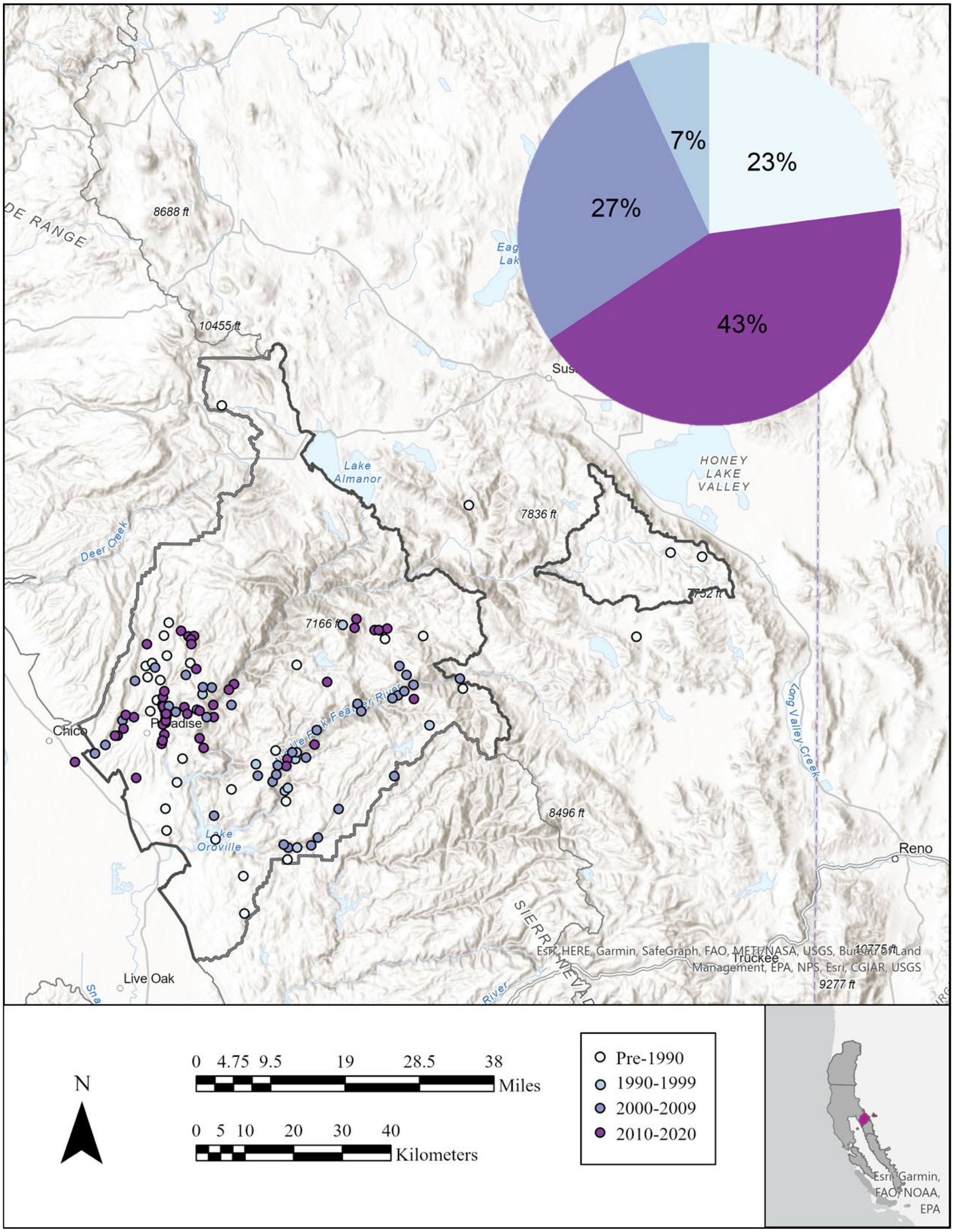


Figure 49. Distribution of foothill yellow-legged frog occurrences in the North Feather analysis unit by decade of most recent detection. Observations are from the California Natural Diversity Database (CDFW 2019), U.S. Geological Survey stream amphibian surveys, the Bureau of Land Management, U.S. Forest Service, recent observations shared by collaborating biologists, and other sources such as unpublished reports. Occurrences are color coded by most recent date of detection. Pie chart percentages refer to proportions of total occurrences (in the analysis unit) in each color-coded time period.

North Sierra

Among the seven analysis units, the North Sierra analysis unit has the greatest proportion of presumed occupied stream segments (relative to the number of potential stream segments) and more than half of all known occurrences are presumed to be occupied (Table 10; Figure 50). The North Sierra unit contains only two confirmed extirpated occurrences (excluding Sutter Buttes in the Central Valley), one near Nevada City, California, and another that was inundated by the creation of New Bullards Bar Reservoir (CDFW 2020, dataset).

There are several robust, stable populations of foothill yellow-legged frog in the North Sierra unit, especially compared to those in the South Sierra unit (CDFW 2019b, p. 34; Rose *et al.* 2020, pp. 63–64, table 1). However, CDFW (2019b, p. 34) reported that the remaining occurrences (i.e., occurrences besides those listed as being “relatively robust” or “sufficiently large and relatively stable”) have only small abundances and limited connectivity.

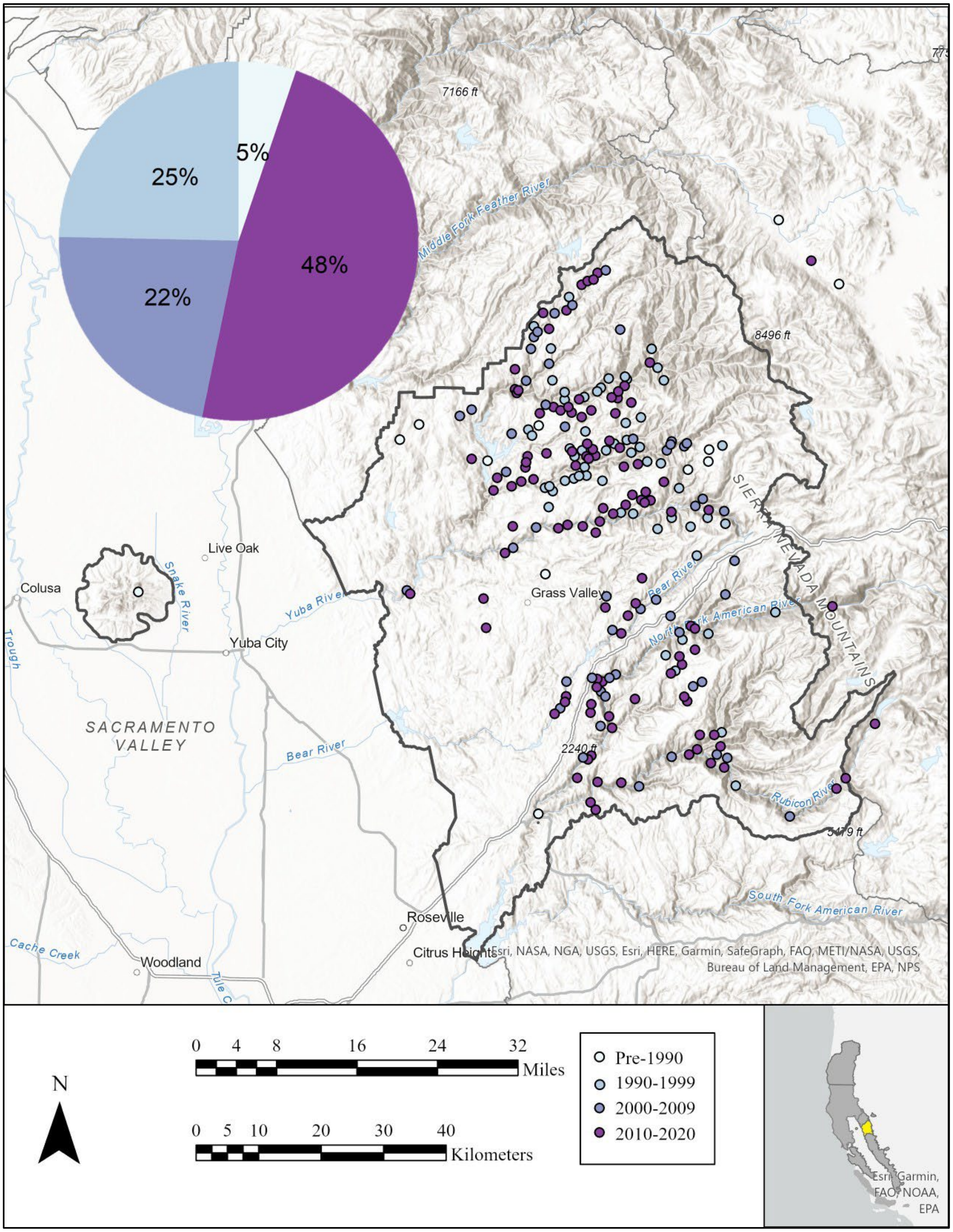


Figure 50. Distribution of foothill yellow-legged frog occurrences in the North Sierra analysis unit by decade of most recent detection. Observations are from the California Natural Diversity Database (CDFW 2019), U.S. Geological Survey stream amphibian surveys, the Bureau of Land Management, U.S. Forest Service, recent observations shared by collaborating biologists, and other sources such as unpublished reports. Occurrences are color coded by most recent date of detection. Pie chart percentages refer to proportions of total occurrences (in the analysis unit) in each color-coded time period.

South Sierra

The South Sierra unit has experienced large declines in occupancy (second only to the South Coast unit), especially within the southern two-thirds of the unit (CDFW 2019b, p. 38; Figure 51). This unit has a low proportion of presumed occupied stream segments (relative to the number of potential stream segments) and fewer than half of all known occurrences are presumed to be occupied (Table 10; Figure 49). Extirpations of the foothill yellow-legged frog within this unit have been documented in numerous publications and reports (Jennings and Hayes 1994, pp. 67, 69, figure 18; Jennings 1995, pp. 132–133, figure 2; Lind *et al.* 2003, p. 4, figure 1; Fellers 2005, p. 534; Lind 2005, pp. 37–38, 65, figure 2.1; Hayes *et al.* 2016, p. 30; CDFW 2019b, pp. 37–38). All foothill yellow-legged frog occurrences south of Johnsondale, California (Tulare County) were extirpated during the 1970s or earlier (CDFW 2020, dataset).

While data are extremely limited in regards to foothill yellow-legged frog abundance in the South Sierra unit, abundances appear to be small relative to more northern populations (Lind *et al.* 2003, p. 26; Rose *et al.* 2020, pp. 63–64, table 1). These low abundances may be recent, however. Prior to extreme flood events in the 1960s (Tulare County) and 1970s (Kern County), foothill yellow-legged frogs were reportedly abundant in the southern Sierra Nevada Mountains (Jennings 1996, pp. 934, 938; Adams *et al.* 2017b, p. 10220).

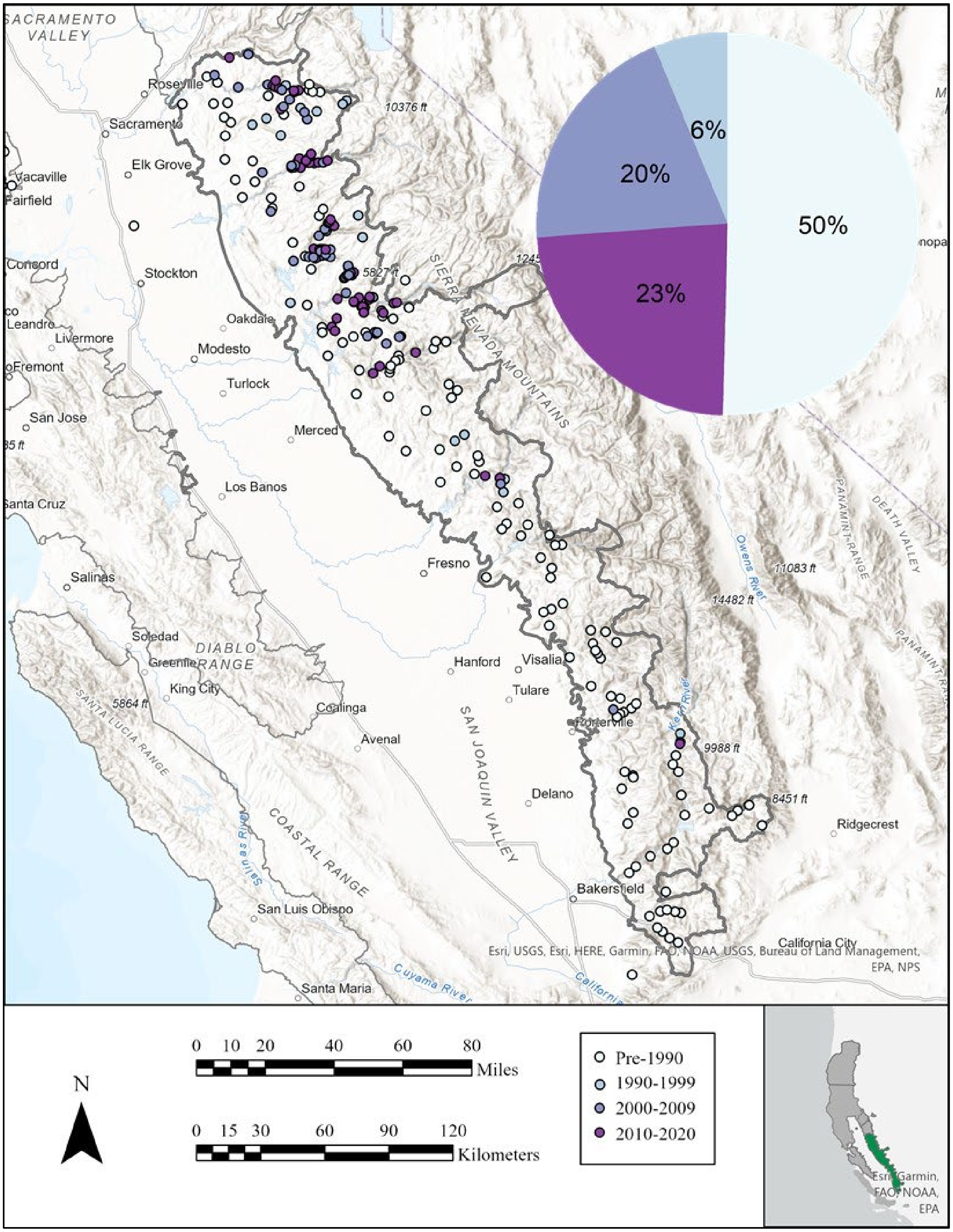


Figure 51. Distribution of foothill yellow-legged frog occurrences in the South Sierra analysis unit by decade of most recent detection. Observations are from the California Natural Diversity Database (CDFW 2019), U.S. Geological Survey stream amphibian surveys, the Bureau of Land Management, U.S. Forest Service, recent observations shared by collaborating biologists, and other sources such as unpublished reports. Occurrences are color coded by most recent date of detection. Pie chart percentages refer to proportions of total occurrences (in the analysis unit) in each color-coded time period.

Central Coast

Foothill yellow-legged frogs have disappeared from much of their range within the Central Coast unit. This unit has a low proportion of presumed occupied stream segments (relative to the number of potential stream segments) and fewer than half of all known occurrences are presumed to be occupied (Table 10; Figure 52). Extirpations of the foothill yellow-legged frog within this unit have been documented in the San Francisco Bay area, San Benito County, and Fresno County (Jennings and Hayes 1994, p. 67, figure 18; Lind 2005, p. 65, figure 2.1; CDFW 2020, dataset). Foothill yellow-legged frogs may be entirely extirpated from Contra Costa County, where frogs have not been observed for many decades at eight of nine occurrences and only two adults were observed in 1997 at the ninth occurrence (CDFW 2020, dataset). The accuracy of the 1997 observation is in doubt by species experts (pers. comm. cited in CDFW 2019b, p. 38).

Abundances of foothill yellow-legged frogs in the Central Coast unit are not near those that are observed in the North Coast California unit but populations in this unit might not have ever been similarly high. However, 800 egg masses were reported at an occurrence in Stanislaus County during 1993 but amount of survey effort (e.g., length of stream searched) was not provided (CDFW 2020, dataset). Of the 4 Central Coast unit populations that have multiple years of egg mass count data[18], there are 3 populations occupying streams that are unregulated or have very little upstream regulation (degree of regulation less than 5 percent), and all have an average of approximately 18 egg masses per km (29 per mi) (Rose *et al.* 2020, pp. 63–64, table 1). The fourth population occupies a highly-regulated stream (upstream degree of regulation of 540 percent) and averages approximately 5 egg masses per km (8 per mi), rarely exceeding 10 per km (16 per mi) in any given year (Rose *et al.* 2020, pp. 63–64, 76, table 1, figure 4). Although abundance data are not available for occupied streams in the southern part of the unit, populations in the Clear Creek Management Area (parts of San Benito and Fresno counties in the southern Central Coast unit) were described as self-sustaining in the area's Resource Management Plan (Bureau of Land Management 2014, pp. 99–100).

---

[18] Egg mass counts are used as a proxy for female foothill yellow-legged frog abundance because, like many other ranid frogs, female foothill yellow-legged frogs lay one egg mass per year (Kupferberg *et al.* 2009c, p. 23; Kupferberg *et al.* 2012, p. 515; Rose *et al.* 2021, p. 13).

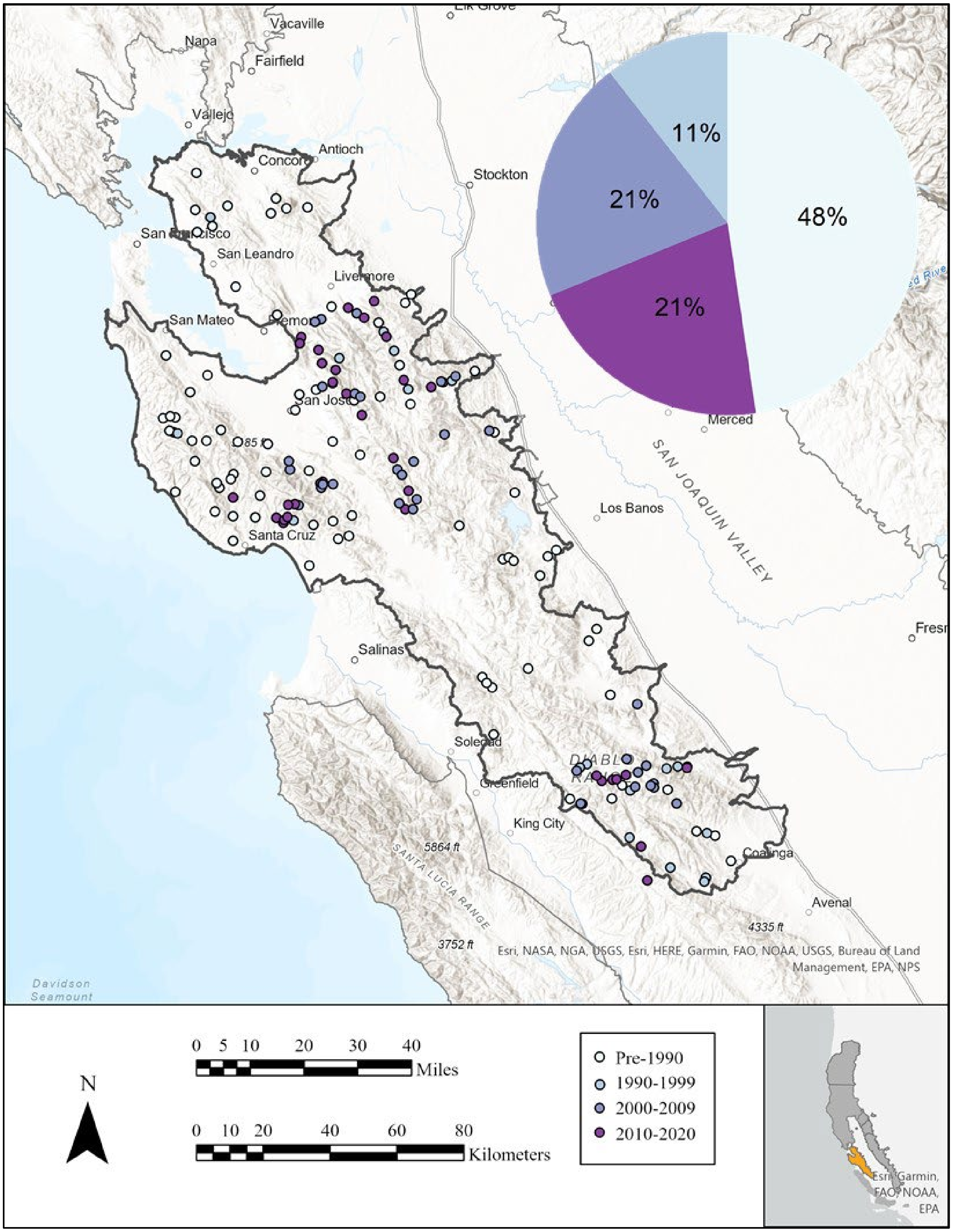


Figure 52. Distribution of foothill yellow-legged frog occurrences in the Central Coast analysis unit by decade of most recent detection. Observations are from the California Natural Diversity Database (CDFW 2019), U.S. Geological Survey stream amphibian surveys, the Bureau of Land Management, U.S. Forest Service, recent observations shared by collaborating biologists, and other sources such as unpublished reports. Occurrences are color coded by most recent date of detection. Pie chart percentages refer to proportions of total occurrences (in the analysis unit) in each color-coded time period.

South Coast

Foothill yellow-legged frogs have disappeared from most of their range within the South Coast unit. This unit has an extremely low proportion of presumed occupied stream segments (relative to the number of potential stream segments) and only eight percent of all known occurrences are presumed to be occupied (Table 10; Figure 53). Only seven stream segments and six occurrences have had foothill yellow-legged frog detections since 2000 (Table 10). The distribution of occurrences in the South Coast unit (Figure 53) demonstrates that the foothill yellow-legged frog has not been reported in any, except a very small part, of this analysis unit for more than three decades.

It is widely reported that the foothill yellow-legged frog is mostly extirpated from the South Coast unit. The disappearance of foothill yellow-legged frogs through much of the South Coast unit is documented in the scientific literature (Sweet 1983, abstract; Jennings 1995, p. 132; Adams *et al.* 2017b, pp. 10217–10218) and in previous status assessments (Jennings and Hayes 1994, pp. 68–69; Hayes *et al.* 2016, p. 28; CDFW 2019b, pp. 43–44). Circa 1970, foothill yellow-legged frog populations abruptly declined in the coast and transverse ranges south of Monterey County, California (Sweet 1983, abstract; CDFW 2020, dataset). By 1981, all California Coast Range and coastal valley occurrences south of northern San Luis Obispo County were extirpated (CDFW 2020, dataset). Particular attention was paid to the species' rapid extirpation from the San Gabriel Mountains of Los Angeles County, where foothill yellow-legged frogs were reportedly abundant (Zweifel 1955, p. 239) until catastrophic floods during 1968–1969 (Adams *et al.* 2017b, p. 10220; CDFW 2020, dataset). Sweet (1983, abstract) speculated that record flooding in January and February of 1969 reduced populations in the southern Coast Ranges and western Transverse Ranges below their ability to recover. However, it is more likely that the 1969 floods acted in concert with increased prevalence of the Bd pathogen in southern California to extirpate foothill yellow-legged frogs from most of the South Coast unit's distribution (Adams *et al.* 2017b, p. 10227).

Recent observations of foothill yellow-legged frogs in the South Coast unit are limited to only two creeks (and a tributary to one of the creeks), suggesting that there are likely two populations that are not connected by stream network. Foothill yellow-legged frog presence in each of the creeks was confirmed during the summer of 2020. Three tadpoles were observed in one of the streams during early July and 52 tadpoles plus 1 juvenile were observed in the other stream during August (Kupferberg and Adams 2020, *in litt.*). Abundances at extant occurrences are unknown but the total abundance of foothill yellow-legged frogs in the South Coast unit can be assumed to be very low because there are so few occurrences.

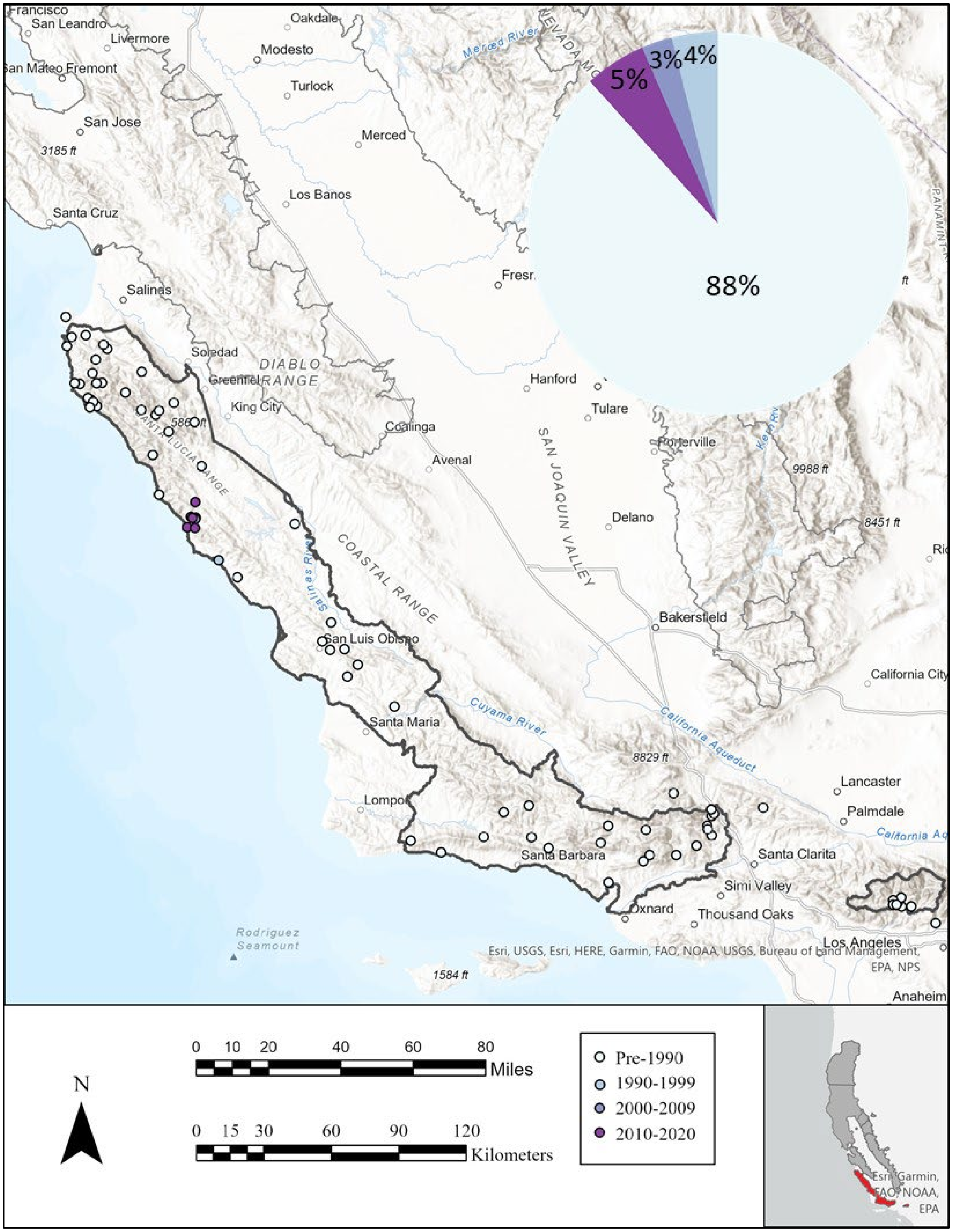


Figure 53. Distribution of foothill yellow-legged frog occurrences in the South Coast analysis unit by decade of most recent detection. Observations are from the California Natural Diversity Database (CDFW 2019), U.S. Geological Survey stream amphibian surveys, the Bureau of Land Management, U.S. Forest Service, recent observations shared by collaborating biologists, and other sources such as unpublished reports. Occurrences are color coded by most recent date of detection. Pie chart percentages refer to proportions of total occurrences (in the analysis unit) in each color-coded time period.

8.3 Connectivity

Foothill yellow-legged frog population connectivity is associated with the ease of mobility (for post-metamorphic frogs) among habitat types and among metapopulations (Section 5.5). Resilient metapopulations have connected networks of quality breeding/rearing sites and overwintering sites and are connected to other metapopulations via dispersal habitat. This connectivity contributes to resiliency because it allows for dispersal and migration, recolonization of extirpated areas, and maintenance or enhancement of the genetic diversity in the metapopulation. Connectivity between metapopulations also contributes to species redundancy (ability of a species to withstand catastrophic events) because it increases the likelihood of recolonization after catastrophic events.

Connectivity can be evaluated in terms of the structural connectivity of the landscape (i.e., habitat contiguity or distance between habitat patches) and/or in terms of functional (or actual) connectivity, which encompasses landscape structure and the behavioral response of individuals to landscape features (e.g., barriers) (Tischendorf and Fahrig 2000, p. 8; Brooks 2003, p. 433). Functional connectivity is more meaningful than structural connectivity because it reflects the actual movement of individuals and their genes among populations (Brooks 2003, p. 435). However, information that reflects functional connectivity, such as measures of gene flow (Brooks 2003, p. 433), are often limited.

In the case of the foothill yellow-legged frog, there is considerable genomic information that indicates that there are breaks in functional connectivity throughout the species' range (McCartney-Melstad *et al.* 2018, p. 112; Peek 2018, p. 76). However, genomic information is sparse for some of the analysis units because few localities were sampled or sampled localities were not evenly distributed throughout the current range of the species. Therefore, we assessed foothill yellow-legged frog connectivity by considering indicators of both structural and functional connectivity. We assessed the (1) structural connectivity as determined by the spatial distribution and isolation of occupied stream segments and (2) functional connectivity as determined by the amount of genetic differentiation among sampled localities within each analysis unit.

This section summarizes the best available information on indicators of foothill yellow-legged frog structural and functional connectivity. In the following subsections, we describe the methods used to assess foothill yellow-legged frog connectivity, summarize the broad patterns in connectivity across the species' range, and synthesize connectivity information for each analysis unit.

Methods

To assess structural connectivity, we considered the spatial distribution of occupied stream segments (based on Rose *et al.* (2020, p. 21, supplementary data) and additional Oregon detection data received in 2021) and the isolation of population fragments (i.e., single or small groups (fewer than 10) of occupied stream segments that are isolated from other occupied stream segments by straight-line distances of at least 20 km (12.4 mi)). Large breaks in structural connectivity (assumed by lack of detections during 2000–2020) are best illustrated in Figure 54 and in the figures showing the distribution of foothill yellow-legged frog occurrences by decade of most recent detection (Figure 47 through Figure 53) in Section 8.2. Isolation of occupied stream segments (Figure 54) was determined using ArcGIS Pro 2.3.3 (Esri Inc. 2018) by buffering each stream segment by 10 km and then joining all buffers that intersected each other. Twenty km was used as a conservative threshold of isolation because it is twice the distance at which genetic differentiation has been observed in foothill yellow-legged frogs in the absence of anthropogenic barriers (Dever 2007, p. 171). Justification for using such a conservative threshold distance includes the uncertainty in the assumption of absence where there are no known occupied segments and the potential for recolonization of unoccupied areas, which could reestablish connectivity between clusters if distances are not too great.

When genetic information is available, functional population connectivity can be realized in the amount of genetic differentiation among individuals from different locations. Although distances may be short between localities on either side of a dam, reservoir, or hydrologically altered river, these hydrographical features can be barriers to foothill yellow-legged frog connectivity (Peek 2010, p. 44; Peek 2012, p. 15; Peek *et al.* 2021, p. 14). A study in the North Sierra unit concluded that hydrologic alteration (regulated rivers) was a better predictor of genetic differentiation among breeding populations than distance or topography (Peek *et al.* 2021, pp. 12, 14). Therefore, we consider the amount of genetic differentiation (also referred to as population structure) among localities within each analysis unit. The amount of genetic differentiation in each analysis unit, as reported in Table 11, is equal to the number of genetically differentiated groups in each analysis unit according to the hierarchical fastStructure results from McCartney-Melstad *et al.* (2018, p. 117, figure 3). However, only a single locality in the North Feather unit was sampled by McCartney-Melstad *et al.* (2018, p. 117, figure 3). Therefore, the number of groups showing genetic differentiation in the North Feather unit was based on a separate study (principal component analysis) by Peek (2018, pp. 63–64, figure 3.2). The number of genetically differentiated groups within each analysis unit is limited by the number of localities sampled; therefore, we also report the total number of localities sampled in each analysis unit.

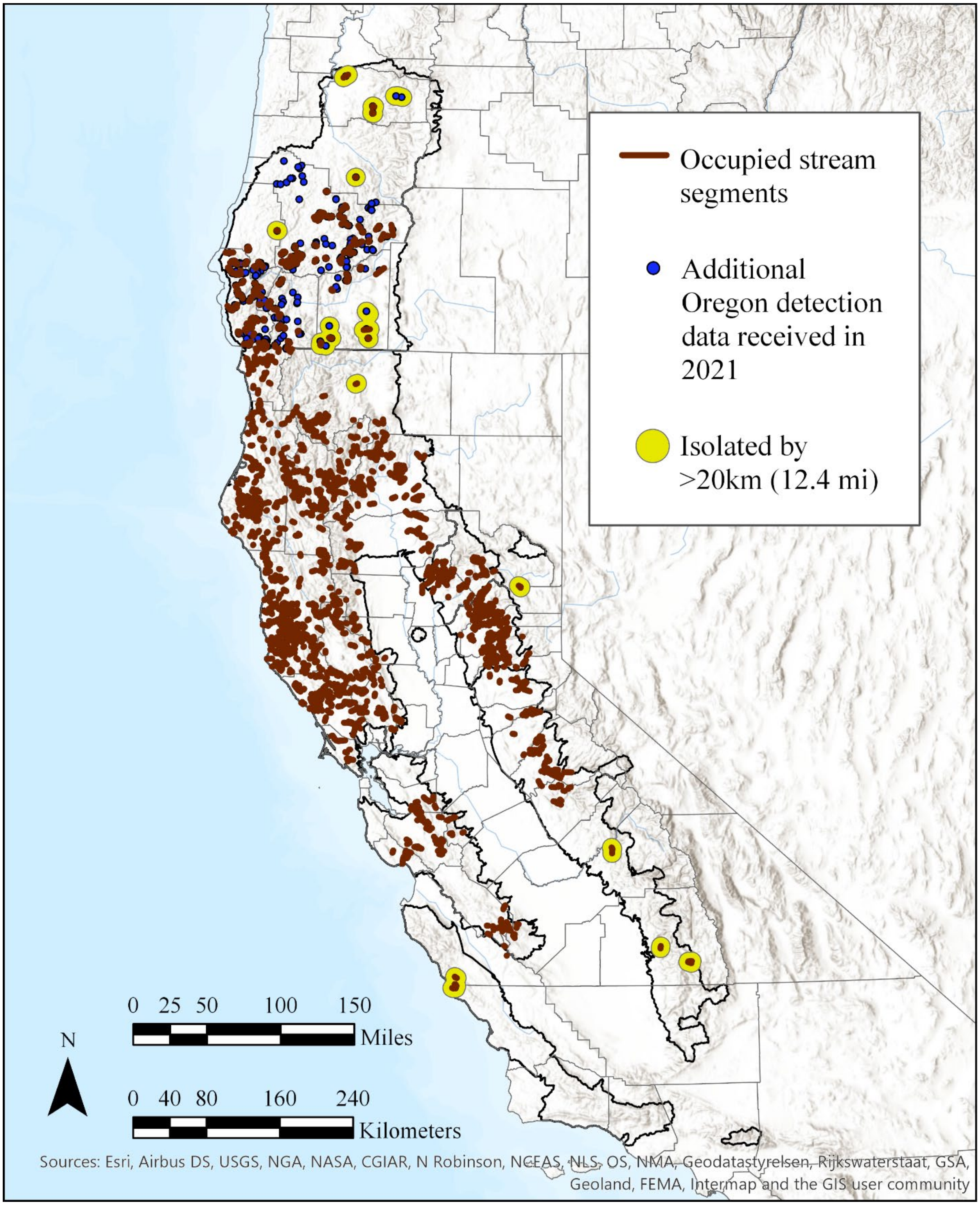


Figure 54. Distribution of presumed occupied stream segments (Rose *et al.* 2020, supplementary data; additional detection data received by the Service in 2021) across the foothill yellow-legged frog range. Stream segments are considered occupied if there were foothill yellow-legged frog observations made from 2000 to 2020 with a medium-high degree of location accuracy. Isolated population fragments are ringed in yellow.

Rangewide Summary of Connectivity

Foothill yellow-legged frog connectivity varies widely among analysis units with greatest connectivity in the northern Coast Range (North Coast California unit and southwest portion of the North Coast Oregon unit) (Figure 54; Table 11). A summary of the spatial and functional connectivity measures discussed in this section are provided in Table 11. Greater values indicate poorer connectivity, especially when the number of occupied stream segments is relatively low. The minimum number of genetically differentiated groups (Table 11, column 4) refers to the number of geographical subdivisions among the genomic data sampled in each analysis unit (McCartney-Melstad *et al.* 2018, p. 117, figure 3; Peek 2018, pp. 63–64, figure 3.2). The number of genetically differentiated groups is a minimum because it cannot exceed the number of locations sampled (parentheses in column 4 of Table 11).

Table 11. Summary of connectivity measured by population isolation (fragmentation) and population genetic structure. Higher numbers (columns 3–4) indicate poorer connectivity, especially when the number of stream segments (column 2) is relatively low. The number of isolated population fragments is the number of small areas containing 1–7 occupied stream segments that are separated from all other occupied segments by more than 20 km (12.4 mi). Genetically differentiated groups are the minimum number of geographical subdivisions among genomic data sampled within each analysis unit (McCartney-Melstad *et al.* 2018, p. 117, figure 3; Peek 2018, pp. 63–64, figure 3.2). An asterisk (*) indicates that one of the isolated fragments in the analysis unit is adjacent to, but outside of, the estimated historical distribution of the species (Figure 54).

Analysis Unit	**Number of occupied stream segments** (Rose *et al.* 2020)	**Number of isolated population fragments** (Figure 54)	**Minimum number of genetically differentiated groups (n=total number of localities sampled)** (McCartney-Melstad *et al.* 2018; Peek 2018)
North Coast Oregon	227	7	3 (n=3)
North Coast California	1,443	1	1 (n=30)
North Feather	118	0	2 (n=7)
North Sierra	302	1*	4 (n=4)
South Sierra	153	3	3 (n=3)
Central Coast	175	0	5 (n=7)
South Coast	7	1	2 (n=2)

There are large regions in Oregon and in the southern half of the species' California range that appear to have gaps in connectivity because foothill yellow-legged frogs have not been reported in these gap areas for two or more decades. Occupied stream segments in northern California are relatively widespread, whereas the distributions of occupied stream segments tend to be patchy in Oregon and the three southern California units (Figure 54)[19]. Large gaps between patches or isolated population fragments suggest a lack of connectivity between metapopulations.

---

[19] While most of the large gaps in the California analysis units are from verified extirpations (CDFW 2020, dataset), the gaps in the North Coast Oregon unit might be because of insufficient survey effort (J. Keehn 2021, *in litt.*) in the gap areas during 2000–2020.

Metapopulation connectivity is required for recolonization after catastrophic events and for maintaining healthy genetic diversity. Small, isolated population fragments (ringed in yellow in Figure 54) are also at risk of genetic drift, inbreeding, and extirpation as a result of normal demographic and/or environmental fluctuations. Therefore, a greater number of isolated population fragments in an analysis unit (Table 11) is associated with increased risk of localized extirpations.

The genetic information available indicates that connectivity is likely poor in all analysis units except for the North Coast California unit where samples from all 30 locations were grouped together (Table 11). These functional connectivity results, and earlier work (Peek 2010, p. 44; Peek 2012, p. 15; Peek *et al.* 2021, entire), emphasize the importance of considering barriers to foothill yellow-legged frog connectivity (e.g., altered hydrology), in addition to isolation by distance.

Analysis Unit Connectivity

Below are summaries describing connectivity in each of the seven analysis units. The summaries are based on the spatial distribution of presence data (from CNDDB (CDFW 2020), ORBIC (2019), U.S. Geological Survey, Bureau of Land Management, U.S. Forest Service, recent observations shared by collaborating biologists, and other sources such as unpublished reports) and the genetic structure of populations (McCartney-Melstad *et al.* 2018, p. 117, figure 3; Peek 2018, pp. 63–64, figure 3.2).

North Coast Oregon

Connectivity in the North Coast Oregon unit appears to be poor, but status of structural connectivity is generally unknown because there is low confidence that surveys for foothill yellow-legged frogs have occurred in many parts of the species' Oregon range during 2000–2020 (J. Keehn 2021, *in litt.*). According to the available presence data, occurrences with recent observations are distributed over a large area, but there are large gaps among occupied areas in the northern, southeastern, and west-central portions of the analysis unit (Figure 47; Figure 54). These gaps appear to isolate seven population fragments (Figure 54). While these large gaps among occupied areas might be explained by patchy declines in occupancy, they might also be explained by insufficient survey effort during 2000–2020. Therefore, structural connectivity in the North Coast Oregon unit is uncertain.

Although foothill yellow-legged frogs from Oregon are in the same genetic clade as those in the North Coast California unit, there is evidence of genetic differentiation across Oregon sample localities while all 30 North Coast California sample localities appear to have good genetic connectivity among them (McCartney-Melstad *et al.* 2018, pp. 114, 116–117, figure 3). The three Oregon localities analyzed by McCartney-Melstad *et al.* (2018, p. 117, figure 3; Figure 4) were subdivided into three different genetic groups, suggesting that there is less interbreeding among localities in Oregon than there is among localities across the North Coast California unit.

North Coast California

Connectivity, both structural and functional, appear to be healthy in the North Coast California unit (Table 11). Occupied stream segments are well-distributed in the North Coast California unit except in the northeastern part where there is a lack of recent detections and an isolated population fragment (Figure 54). The North Coast California unit did not exhibit evidence of genetic differentiation among the 30 localities that were genetically sampled (McCartney-Melstad *et al.* 2018, p. 117, figure 3).

North Feather

Occupied stream segments in the North Feather unit are well-distributed in the northwestern and southeastern portions of the unit but there are relatively large sections of the unit that do not have recent observations (Figure 49). There are not any known isolated population fragments in the North Feather unit (Figure 54). However, this unit likely had small isolated populations in far eastern Plumas County (Figure 49) before the area was extirpated (CDFW 2020, dataset).

The amount of functional connectivity in the North Feather unit is uncertain but it could be similarly poor to that of the neighboring North Sierra unit where altered hydrological conditions (stream regulation) have led to genetic differentiation among neighboring populations (Peek *et al.* 2021, p. 14). The seven localities that were genetically sampled in the North Feather unit were subdivided into two genetic groups (Peek 2018, pp. 63–64, figure 3.2), indicating that connectivity is poor or absent between the two groups. Six of the seven localities were near to one another and connected by the same stream network (Figure 4), suggesting that there may have only been two genetic groups because the sampled locations were not well-distributed across the unit. Genetic sampling in other parts of the unit would be necessary to get a more complete understanding of functional connectivity.

Although certainty would require more genetic sampling, there are reasons to suspect that functional connectivity in the North Feather and North Sierra units are similarly poor. The two neighboring units share similar ecology and threats, and both units have comparable amounts of stream regulation. Among the seven analysis units, the greatest proportions of regulated stream segments (occupied and unoccupied segments) are in the North Sierra (10.8 percent) and North Feather (8.3 percent) units (Supplementary Table 1; Rose *et al.* 2020, p. 72, table 8). Although the North Sierra unit has the greater proportion of regulated stream segments (occupied and unoccupied), the mean upstream degree of regulation in the North Feather unit is 11.0 percent, versus only 5.8 percent in the North Sierra unit (Supplementary Table 1; Rose *et al.* 2020, p. 72, table 8).

North Sierra

In spite of occupied stream segments being well-distributed across the North Sierra unit (Figure 54), functional connectivity is poor. All four localities analyzed by McCartney-Melstad *et al.* (2018, p. 117, figure 3; Figure 4) were subdivided into different genetic groups (Table 11) indicating that, even nearby populations, are genetically isolated from one another. The genetic differentiation is likely due to barriers caused by altered hydrological conditions (stream regulation) (Peek *et al.* 2021, p. 14). As mentioned above, the North Sierra unit has the greatest proportion (10.8 percent) of regulated stream segments (occupied and unoccupied) among the seven analysis units (Supplementary Table 1; Rose *et al.* 2020, p. 72, table 8).

South Sierra

Connectivity is also poor in the South Sierra unit. Occupied stream segments are clustered mostly in the northern third of the unit (Figure 54). This unit has very patchy distribution including three small, isolated population fragments in the southern two-thirds of the unit, and declining occupancy in the northern third (Figure 51). All three localities analyzed by

McCartney-Melstad *et al.* (2018, p. 117, figure 3; Figure 4) were subdivided into different genetic groups (Table 11) indicating a lack genetic connectivity across the unit. The isolated population fragments that represent approximately two-thirds of the extent of the South Sierra unit are especially vulnerable to extirpation, genetic drift, and/or inbreeding depression because of their extreme isolation.

Central Coast

Structural and functional connectivity in the Central Coast unit is intermediate compared to other analysis units. Occupied stream segments in the Central Coast unit can be divided into two clusters, a large northern cluster and a small southern cluster, that are separated by approximately 100 km (62 mi) (Figure 54). Genetic analysis subdivided the Central Coast unit's seven sampled localities into five groups (Table 11), which indicates that there are barriers to connectivity within the larger northern cluster of occupied stream segments (McCartney-Melstad *et al.* 2018, p. 117, figure 3). In contrast to the northern cluster, there may be small-scale connectivity in the southern cluster of occupied stream segments. The three occupied localities that were sampled here (Figure 4) did not show evidence of genetic differentiation (McCartney-Melstad *et al.* 2018, p. 117, figure 3). However, the southern cluster still lacks connectivity to other metapopulations because of its isolation.

South Coast

In the South Coast unit, foothill yellow-legged frogs have only been reported in a very small part of this analysis unit for more than three decades (Figure 53). While all of the occupied stream segments in the South Coast unit are close together, there are only two small populations occupying a total of only seven stream segments. Such low occupancy cannot fulfill the connectivity needs of a resilient metapopulation. Furthermore, differences in genetics between the two occupied creeks in the South Coast unit (McCartney-Melstad *et al.* 2018, pp. 117, 119, 121, figure 3; Figure 4) suggest that little or no dispersal is occurring between the creeks. This means that if the population in one of the creeks crashes, it is unlikely to be recolonized by individuals from the other population and that both populations are at risk of genetic drift and/or inbreeding depression. These populations also appear to be rapidly losing genetic diversity, compared to populations in other analysis units (McCartney-Melstad *et al.* 2018, p. 122).

8.4 Population Viability Analysis

In addition to our assessments of occupancy, abundance, and connectivity, we present the findings of a rangewide Population Viability Analysis (PVA) by Rose *et al.* (2020, entire). This PVA is used to inform both the current condition (CHAPTER 8) and future condition (CHAPTER 9) of the foothill yellow-legged frog. It estimates the relative risk of ≥50 percent population decline by the year 2060, across the range of the species. In the following subsections, we briefly describe the PVA methods, results, and environmental covariate relationships from Rose *et al.* (2020, entire). We also relate the PVA results and discussion from Rose *et al.* (2020) to other aspects of current condition presented earlier in this SSA chapter.

Methods

Risk of decline among foothill yellow-legged frog populations was assessed by fitting Multiple Population Viability Analysis (MPVA) models to time series of egg mass counts in 32 focal streams (Rose *et al.* 2020, pp. 1–2). Egg mass counts were used as a proxy for female foothill yellow-legged frog abundance because, like many other ranid frogs, female foothill yellow-legged frogs lay one egg mass per year (Kupferberg *et al.* 2009c, p. 23; Kupferberg *et al.* 2012, p. 515; Rose *et al.* 2021, p. 13). The models quantified how annual streamflow, stream temperature, upstream degree of regulation, and surrounding forest and shrub land cover affect population growth and density-dependence across the species' range (Table 12). Any remaining annual variation in population growth that was not accounted for by the environmental covariates in the model was attributed to residual environmental stochasticity (Rose *et al.* 2020, p. 23). The residual environmental stochasticity reflects the unmodeled, exogenous environmental factors that are locally influencing egg-mass density in focal populations (Rose *et al.* 2020, p. 45). We briefly describe the methods here; for additional detail see Rose *et al.* (2020, pp. 7–30).

Table 12. Environmental covariates used to fit Multiple Population Viability Analysis models to time series egg mass counts in 32 focal streams (Rose *et al.* 2020, pp. 15–19, 65, table 2).

Environmental Covariate	**Description**	**Predictor Variable**	**Data Source**
Total annual streamflow (discharge)	Total discharge during previous water year (October 1 to September 30); total annual discharge was standardized on a per-stream basis (by subtracting the mean and dividing by the standard deviation for that stream) such that each year had a value indicating the deviation from average total streamflow for that stream in standard deviations.	intrinsic population growth rate	Stream gage data (National Water Information System, https://waterdata.usgs.gov/nwis) and Zimmerman *et al.* (2018)
Stream temperature	Mean August stream temperature, 1993–2015.	intrinsic population growth rate	NorWeST dataset (Isaak *et al.* 2017)
Degree of regulation	Percentage of estimated annual stream discharge that is stored upstream in reservoirs.	density-dependence	Cooper *et al.* (2017)
Land cover	Combined percent of forest cover and shrub cover in the surrounding hydrologic unit subbasin (HUC8); mean for 2001–2019.	density-dependence	Sleeter *et al.* (2019); Sleeter and Kreitler (2020, unpublished data)

The risk of ≥50 percent population decline over a 40-year period was simulated for 2,280 occupied stream segments based on the relationships between population growth parameters and environmental covariates in the 32 focal streams (Rose *et al.* 2020, p. 2). Stream segments were considered occupied if a foothill yellow-legged frog was detected in the stream segment during 2000–2020. To determine the current risk of decline for occupied stream segments, environmental conditions for the simulated 40 years were drawn from the same distribution as environmental conditions during the previous 20 years (Rose *et al.* 2020, p. 22). Residual environmental stochasticity (i.e., annual variation in population growth that was not accounted for by the environmental covariates in the model) for an occupied stream segment was drawn from a distribution centered on the expected value for regulated or unregulated focal streams in the respective analysis unit (Rose *et al.* 2020, p. 23).[20]

Abundance data were not available for most occupied streams. Therefore, all occupied stream segments were set to have the same initial density of 37.8 egg masses per km (60.9 per mi) (proxy for abundance of breeding females), which was the average density in the 32 focal streams (Rose *et al.* 2020, p. 29). This density is likely an overestimate for many streams because the focal streams included several robust populations in the North Coast California analysis unit, which comprise the highest densities of foothill yellow-legged frog egg masses ever recorded (CDFW 2019b, p. 28; Rose *et al*. 2020, pp. 29, 63–64, table 1). In the MPVA (model for the 32 focal streams), initial population density (number of egg masses per km) was negatively related to the risk of decline (Pearson correlation coefficient = -0.48) indicating that denser populations were less likely to exhibit large declines in abundance (Rose *et al.* 2020, p. 34). If the relationship between initial population abundance and risk of decline is causal (as opposed to being correlated only), then actual probabilities of decline might be greater than predicted probabilities for most streams analyzed in the PVA.

A stream segment's risk of decline was measured as the probability (or risk) of ≥50 percent decline from the starting abundance over a 40-year period. The probability of decline is the average probability, across 100 individual simulations, that population density decreased by at least 50 percent of the initial population density (i.e., 37.8 egg masses per km) during a 40-year period (Rose *et al.* 2020, pp. 27–28). The results of the PVA focus on the relative risk of decline (by ≥50 percent of the population) among stream segments, or average relative risk of decline among analysis units (see Box 1 for explanation of relative risk of decline).

---

[20] For analysis units that were not represented in the 32 focal streams, distributions of residual environmental stochasticity from the most similar analysis unit were used. That is, distributions based on streams in the North Coast California unit were used for the North Coast Oregon unit and distributions based on streams in the Central Coast unit were used for the South Coast unit.

Box 1 Relative Risk of Decline

The relative risk of decline was calculated by dividing a stream segment's probability of ≥50 percent decline in abundance after 40 years by the lowest (minimum) probability of ≥50 percent decline across all occupied stream segments. Relative risk of decline is presented instead of absolute probabilities to emphasize comparison of risk of decline among streams and analysis units, avoid focus on absolute probability values when projecting viability into the future based on a small number of variables from each stream segment, and to reduce reliance on model assumptions (see Rose *et al.* (2020, pp. 28–29) for details).

$$\text{Relative Risk}_{\text{stream } x} = \frac{\text{Probability of } \geq 50\ \%\text{ decline for stream } x}{\text{Lowest probability of } \geq 50\ \%\text{ decline across all streams}}$$

A relative risk of 1.0 indicates a probability of ≥50 percent decline that is equal to the lowest probability of decline, a relative risk of 2.0 is twice the lowest probability, a relative risk of 3.0 is three times the lowest probability, etc. The lowest probability of ≥50 percent decline across all streams is 0.219.

Relative risk was binned into three categories, low, medium, and high risk (Table 13).

Table 13. Relative risk category names and definitions from Rose *et al.* (2020). See Box 1 for explanation of relative risk.

Relative risk bin	**Probability of at least 50 percent population decline**	**Relative risk category name**
1–2	22–44 percent	Low risk
>2 and ≤3	44–66 percent	Medium risk
>3 and <4.4	66–96 percent	High risk

Risk of Decline Results

In this subsection, we interpret and summarize the risk of decline results (Rose *et al.* 2020, entire) rangewide and across the seven analysis units. In Section 8.5 Population Resiliency, we focus on each analysis unit separately and interpret the results in the context of patterns in occupancy, current threats, and the scientific literature and/or reports by species experts.

The PVA results demonstrate geographical patterns in risk of ≥50 percent decline among analysis units. The risk of decline was greater for analysis units in the southern half of the species' range (Central Coast, South Coast, and South Sierra units) where all stream segments have medium or high relative risks of population decline (Figure 55) (see Box 1 and Table 13 for explanation of relative risk of decline). Relative risk of decline is also medium to high in the North Feather unit where only 16 occupied stream segments (15 percent) are in the low risk category. Relative risk of decline is lowest in the North Sierra and North Coast Oregon units where the majority of stream segments are in the low risk category (Figure 55). Most stream segments in the North Coast California unit (56 percent) are in the medium risk category.

The risk of decline results among and within analysis units reflect many of the geographical patterns in occupancy (Section 8.2). The North Sierra unit has both the lowest average relative risk of decline (1.87) and the greatest proportion of presumed occupied stream segments (relative to the number of potential stream segments) (Table 10). The North Feather unit has a medium-high average relative risk of decline (2.68; Figure 55) and an intermediate proportion of occupied stream segments (relative to the number of potential stream segments) (Table 10), relative to the other analysis units. Within the North Coast Oregon and North Coast California units, stream segments in northern California and southwestern Oregon have lower risks of decline, compared to streams near the San Francisco Bay area and the northern and eastern extents of the species' range in Oregon (Figure 55). This corresponds to observed patterns of decline in occupancy in the San Francisco Bay area and patterns in the foothill yellow-legged frog's range in Oregon, where extant populations with recent occurrence data are largely found in southwest Oregon (Figure 47) and declines have been reported in the northern and southeastern extents of the species' Oregon range (Olson and Davis 2009, p. 10, figure 1).

The southern analysis units (Central Coast, South Coast, and South Sierra units) exhibit the strongest patterns of declining occupancy and none of the occupied stream segments are in the low relative risk of decline category. In the Central Coast unit, stream segments in the high relative risk category are also near the San Francisco Bay area (Figure 55). This corresponds to an observed pattern of decline in Central Coast unit occupancy, where few recent (i.e., 2000–2020) records exist directly south or directly east of the San Francisco Bay (Figure 52). In the South Sierra unit, the greatest risks of decline are in the northern third of the unit (Figure 55), where occupancy is actually highest (Figure 51). However, there also appears to be an ongoing decline in occupancy in the northern part of the South Sierra unit (Figure 51).

South of the San Francisco Bay area (i.e., southern South Sierra unit, southern Central Coast unit, and the entire South Coast unit), there are only approximately five small metapopulations or population fragments that are currently presumed to be occupied (Figure 55). This southern extent of the species' range has experienced the greatest declines in occupancy. Therefore, it is unsurprising that these remnant occurrences are not in the low relative risk category (Figure 55). However, almost all of these stream segments are in the medium risk category. These occupied stream segments may not fall in the high risk category because they tend to be in unregulated (or low degree of regulation) streams that are surrounded by more undeveloped land (greater forest and shrub cover). For example, the foothill yellow-legged frog metapopulation in the southern part of the Central Coast unit is largely on Bureau of Land Management land that is much less developed and more "natural" than farther north in the San Francisco Bay area.

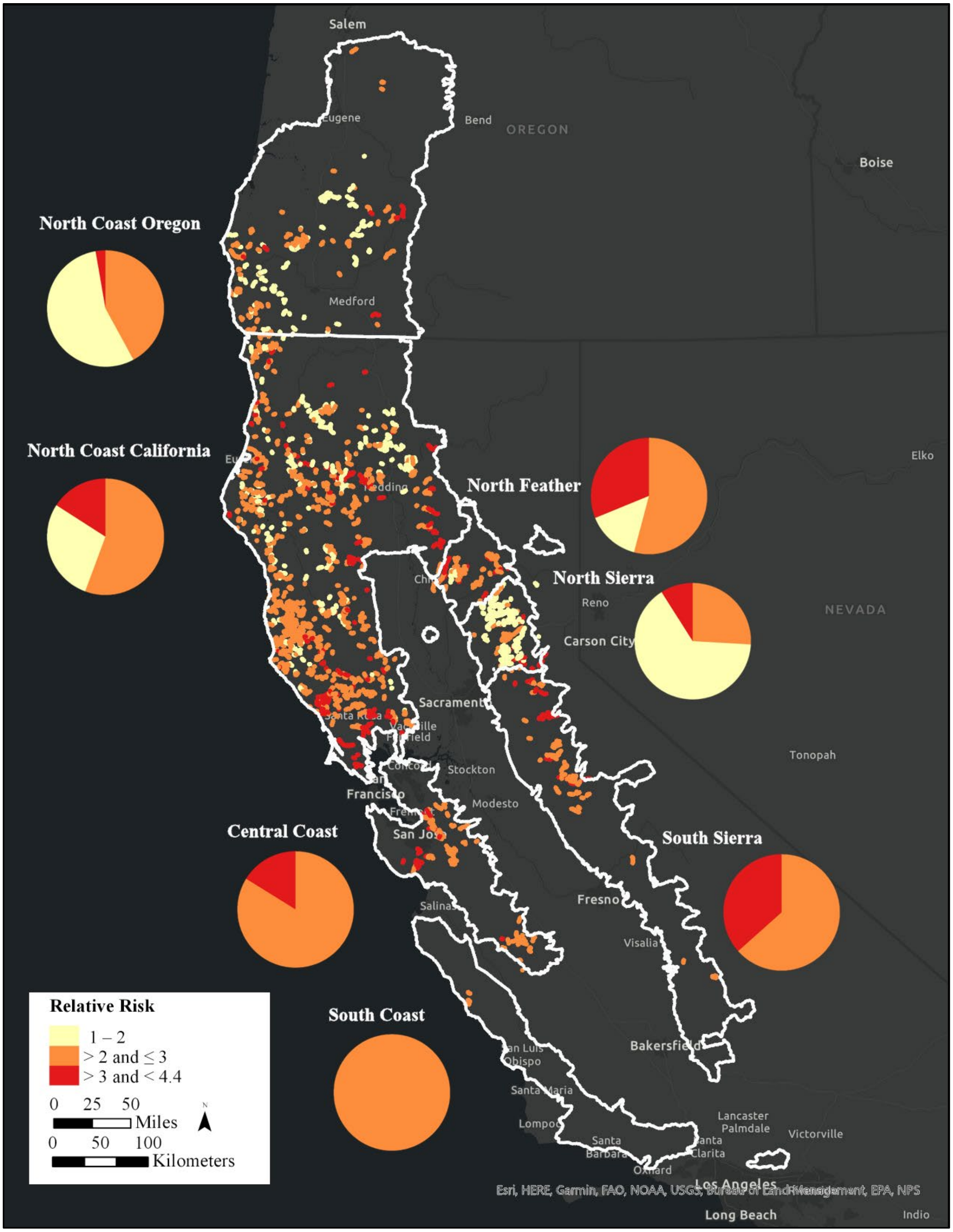


Figure 55. Current risk of ≥50 percent decline over 40 years in stream segments occupied by the foothill yellow-legged frog (Rose *et al.* 2020, p. 88, figure 16, supplementary data). Relative risk (see Box 1) is binned into three categories (Table 13). Risk 1–2 = low (light yellow). Risk >2 and ≤3 = medium (orange). Risk >3 and <4.4 = high (red).

Environmental Covariate Relationships

In this subsection, we highlight the relationships between the environmental covariates in the PVA models and the risk of foothill yellow-legged frog population decline (Rose *et al.* 2020, entire). These relationships exhibit how altered hydrology (stream regulation), annual streamflow (discharge), stream temperature, forest and shrub cover, and residual environmental stochasticity influence foothill yellow-legged frog population viability. The direction and strength (represented as Pearson's correlation coefficients) of the relationships between risk of decline and four environmental covariates are provided in Table 14.

- The average egg mass density over all sites and years is more than ten times higher in unregulated (free-flowing) streams (55.2 egg masses per km (standard deviation = 78.7)) than in regulated streams (5.2 egg masses per km (standard deviation = 6.6)) (Rose *et al.* 2020, p. 30).
- The regulation of streams (through dams, surface-water diversions, and channel modifications) influences foothill yellow-legged frog populations both by lowering carrying capacity (stronger density-dependence) and by increasing residual environmental stochasticity (Rose *et al.* 2020, pp. 32–33). Of the 32 focal streams, the streams where upstream degree of regulation was greater than 10 percent (9 streams) had greater mean residual environmental stochasticity than streams with less than 10 percent of upstream degree of regulation (23 streams) (Rose *et al.* 2020, p. 33).
- Residual environmental stochasticity has the highest absolute correlation to risk of decline for both the 32 focal streams and the 2,280 occupied stream segments (Table 14). Thus, streams with greater interannual fluctuations in population growth (beyond those accounted for by the environmental covariates) tend to have greater risks of decline.
- Greater annual streamflow is linked to greater population growth during the following year (Rose *et al.* 2020, p. 32).
- Colder August stream temperatures are linked to lower population growth rates, which increases the risk of decline for populations in colder streams (Rose *et al.* 2020, p. 32).
- Greater amounts of forest and shrub cover are linked to larger carrying capacities (weaker density-dependence), which decreases the risk of decline for populations with more forest and shrub cover (Rose *et al.* 2020, pp. 33–34).

Table 14. Pearson correlation coefficients for 4 environmental covariates and the risk of ≥50% decline after 40 years for the 32 focal streams used to fit the PVA and the 2,280 stream segments where foothill yellow-legged frog have been observed during 2000–2020 (Rose *et al.* 2020, pp. 83, 86, figure 11, figure 14).

	Risk of Decline for the 32 Focal Streams	Risk of Decline for 2,280 Occupied Stream Segments
Mean August stream temperature	−0.51	−0.31
Upstream degree of regulation	0.41	0.42
Forest and shrub cover	−0.23	−0.50

	Risk of Decline for the 32 Focal Streams	Risk of Decline for 2,280 Occupied Stream Segments
Residual environmental stochasticity	0.58	0.57

8.5 Population Resiliency

Resiliency gauges the ability of a population to remain viable through a natural range of favorable and unfavorable conditions. Resilient populations are better able to recover from stochastic events and withstand variation in the environment. Foothill yellow-legged frog resiliency is a function of metapopulation health and the distribution and connectivity among metapopulations and subpopulations. As described in Section 5.1, a metapopulation consists of a network of subpopulations and is distinguished from other metapopulations by the rate of gene flow.

In this chapter, we described foothill yellow-legged frog population health characteristics at a rangewide level and by analysis unit. We first assessed spatial and temporal trends in occupancy and abundance. We then assessed structural and functional connectivity among occupied areas. We also presented results from a study that modeled the risk of ≥50 percent decline in occupied stream segments using demographic and environmental information. Finally, we related our results to information from scientific literature, reports, and species experts. In this section, we summarize foothill yellow-legged frog resiliency in each analysis unit in terms of occupancy, abundance (where available), connectivity, relative risk of decline, and the distribution of threats across the species' range. Based on these resiliency indicators, current resiliency for each analysis unit was qualitatively categorized as intact, reduced, substantially reduced, or extensively reduced (Table 15).

Table 15. Qualitative resiliency category descriptions for current condition. The term, functional extirpation, is defined as such extensive reduction in analysis unit condition that extirpation of the entire unit is likely to eventually occur as remnant populations experience normal environmental and demographic fluctuations.

Qualitative Resiliency Category	Definition
Intact	Analysis unit may have lost some if its historical resiliency but contains numerous, well-distributed populations that are in the low risk of decline category. Most of the unit is currently occupied. Abundance information, connectivity, and status of threats are also taken into consideration.
Reduced	Analysis unit has lost a lot of its resiliency. Range contraction and/or numerous extirpations have been documented in the literature or state databases. However, there are one or more groups of occupied stream segments that are in the low risk of decline category. Abundance information, connectivity, and status of threats are also taken into consideration.

Qualitative Resiliency Category	Definition
Substantially Reduced	Analysis unit has lost most of its resiliency. Range contraction and/or extirpations have been documented in approximately half or more of the unit. There are no groups of occupied stream segments that are in the low risk of decline category. Abundance information, connectivity, and status of threats are also taken into consideration.
Extensively Reduced	Analysis unit has lost a large majority of its resiliency. The best available information suggests that the unit is at imminent risk of unit-wide extirpation or functional extirpation.

North Coast Oregon

The North Coast Oregon unit is the second largest analysis unit and contains 227 (9 percent) of the 2,425 stream segments with recent (i.e., 2000–2020) observations (Rose *et al.* 2020, p. 70, table 6)[21]. Occupancy appears to be good in the southwestern and central parts of this unit (Figure 47) but the species' status in other areas (e.g., northern and southeastern parts of the unit) is uncertain because of limited survey data. Recent detections of the species in the northwestern part of the unit (Figure 54) (previously thought to be extirpated (Olson and Davis 2009, pp. 10–11, figure 1)) and limited survey effort in Oregon (J. Keehn 2021, *in litt.*) suggests that true occupancy may be better than depicted in Figure 47.

Along with uncertain occupancy, data are extremely limited in regard to foothill yellow-legged frog abundance in the North Coast Oregon unit. Reports from surveys in the 1990s and early 2000s suggested that abundances at occupied sites in Oregon declined since the first half of the 20th century (Borisenko and Hayes 1999, pp. 20–21; Olson and Davis 2009, p. 26). However, current abundances are unknown either because no surveys have been conducted or because surveys only determined species presence and did not provide data that could be used to estimate population size.

Connectivity in the North Coast Oregon unit appears to be good in some areas but poor in others. There is a good distribution of occupied occurrences in the southwestern and central parts of the unit but occurrences in the northern and southeastern parts of the unit are patchy and isolated (Table 11; Figure 54). However, the isolation of these patchy occurrences (Figure 54) is highly uncertain because of limited survey data. There is evidence of genetic isolation among the three Oregon localities sampled by McCartney-Melstad *et al.* (2018, p. 117, figure 3). However, the southernmost of the three localities was grouped with localities in the North Coast California unit, suggesting that connectivity may be present across the Oregon-California state border (McCartney-Melstad *et al.* 2018, p. 117, figure 3).

---

[21] Rose *et al.* (2020) reported 231 occupied stream segments, but we removed four stream segments from the data presented in this report, based on expert reviewer comments that the species in these stream segments were likely misidentified as foothill yellow-legged frogs. Also note the 227 occupied stream segments do not include new detection data that became available during 2021. However, the new data are depicted in Figure 47 and Figure 55.

The North Coast Oregon unit has the second-lowest average relative risk of population decline (1.95) among the seven analysis units (see Box 1 for explanation of relative risk). The majority of stream segments in this unit (55 percent) are in the low relative risk category while only 6 stream segments (3 percent) are in the high relative risk category (Figure 55; see Table 13 for definitions of risk categories).

The major threats that likely have contributed, or are contributing, to the decline of the foothill yellow-legged frog in the North Coast Oregon unit include altered hydrology, nonnative species (particularly bullfrogs and smallmouth bass), agriculture, mining, and urbanization (including roads and recreation) (Olson and Davis 2009, p. 26; Linnell and Davis 2021, not paginated). In the 2009 Conservation Assessment of foothill yellow-legged frogs in Oregon, the threats that were considered most impactful to the species in this part of the range were habitat loss or alteration from impoundments and altered flow regimes, competition and predation by nonnative species such as smallmouth bass and bullfrogs, and habitat loss or alteration from water diversion and water level fluctuations caused by agricultural irrigation (Olson and Davis 2009, p. 14). Like in other parts of the species' range, the co-occurrence of certain threats (e.g., altered hydrology, nonnative species, agriculture) makes it difficult to determine which threats have a larger responsibility for declines and extirpations (Borisenko and Hayes 1999, p. 1).

The legacy effects of splash dams (commonly used to transport logs in western Oregon) may explain some of the reported declines in the North Coast Oregon unit. From the 1880s into the 1950s, sustained pulse flows from splash dams fundamentally changed stream characteristics and habitat features that this species relies upon (e.g., streambed substrate, channel geomorphology) (Miller 2010, pp. 14, 61–63, 70–71, table 2.9). Legacy effects to stream habitat are still apparent (Miller 2010, p. 63). In 1938, Fitch noted that a lack of streams with "open, gravelly margins" in the northern part of the species' range in Oregon is probably a limiting factor in the northern distribution of the foothill yellow-legged frog (Fitch 1938, p. 148). With Fitch's observation, and the association between historical splash dams and foothill yellow-legged frog absences (Linnell and Davis 2021, not paginated, figure 6, figure 7), early habitat loss from splash dam operation may explain the sparsity of historical records and fragmentation of occurrences in parts of the North Coast Oregon unit.

There are both positives and negatives to the unique conditions in the Oregon part of the foothill yellow-legged frog's range. In spite of the strong influence of altered hydrology in Oregon (Olson and Davis 2009, p. 14), the North Coast Oregon unit currently has the lowest proportion of stream segments that are regulated and the lowest average degree of regulation among regulated streams in the seven analysis units (Supplementary Table 1). This means that conditions for the species could improve through restoration of streams that were altered by historical splash dam operation.[22] Restoration of previously splash-dammed streams, such as the Smith River north of the Umpqua River in Oregon, may already be exhibiting improved habitat conditions (K. van Norman 2021, *in litt.*). The North Coast Oregon unit also has the greatest average precipitation within the species' range (Table 3; PRISM Climate Group 2012, 30-year climate dataset). While drying and drought are emerging threats in the drier, southern part of the species' distribution in Oregon (M. Parker 2021, *in litt.*), drying and drought are less significant

---

[22] Restoration of streams affected by splash dams would likely need to be large-scale, whole-watershed efforts, but the intense efforts would likely benefit multiple species including salmonids and Pacific lamprey (*Entosphenus tridentatus*) (Miller 2010, pp. 71–74).

threats to the species in Oregon, relative to other analysis units. In contrast to these more favorable conditions, foothill yellow-legged frog population growth rate might be limited by this unit's relatively cold stream temperatures (Supplementary Table 1) or by jet boat recreation (Borisenko and Hayes 1999, pp. 18, 28; Olson and Davis 2009, p. 23). Nonnative smallmouth bass, in addition to bullfrogs, are of additional concern in Oregon, where these fish are more frequently cited as a threat to foothill yellow-legged frogs (Borisenko and Hayes 1999, p. 26; Rombough 2006a, not paginated; Olson and Davis 2009, p. 14). The benefit of wetter conditions in the North Coast Oregon unit might be partially counteracted by jet boat recreation and increased presence and/or abundance of nonnative predators and competitors.

In summary, resiliency of the foothill yellow-legged frog in the North Coast Oregon unit is intact (see Table 15 for definition of resiliency category). While occupancy, abundance, and connectivity are uncertain in large parts of the analysis unit, there are numerous occupied stream segments in the central and southwestern portions of the unit that are both well-distributed and at a relatively low risk of decline. Average risk of population decline is the second-lowest among the seven analysis units. While threats to the foothill yellow-legged frog in Oregon also occur in the species' California range, the levels of various threats appear to differ in this part of the range. For example, the threat of altered hydrology is least severe in this unit (Supplementary Table 1) and Oregon's wetter climate reduces the likelihood of large-scale extirpations from drying and drought. However, wetter conditions might allow for increased occurrence of other threats such as nonnative fish, bullfrogs, and jet boat recreation. Additional surveys and research of foothill yellow-legged frog population demographics and responses to threats in this unit would improve our understanding of the foothill yellow-legged frog population in the North Coast Oregon unit.

North Coast California

The North Coast California unit is the largest analysis unit and it contains the majority (60 percent) of stream segments with recent (i.e., 2000–2020) observations in the foothill yellow-legged frog's range. The North Coast California unit is also known for having the largest abundances of foothill yellow-legged frogs. While this unit has relatively high occupancy (Table 10), it also has several documented extirpations, particularly in areas just north of San Francisco Bay and in the foothills along the northeast corner of the Central Valley (Jennings and Hayes 1994, p. 67, figure 18; GANDA 2010, p. 6, figure 1; CDFW 2020, dataset).

Connectivity, both structural and functional, appear to be good in the North Coast California unit. In contrast to other units, the North Coast California unit did not exhibit evidence of genetic differentiation among the 30 localities that were genetically sampled (McCartney-Melstad *et al.* 2018, p. 117, figure 3). Occupied stream segments are also well-distributed in the North Coast California unit except in the northeastern part (Figure 48, Figure 55).

While occupancy and connectivity are good in this analysis unit, 72 percent of occupied stream segments have relative risks of decline in the medium or high risk categories (see Table 13 for definitions of risk categories and Box 1 for explanation of relative risk of decline). Streams in the high risk category are largely in the San Francisco Bay area, but are also found in other parts of the unit, including in Humboldt and Trinity counties (Figure 55). The juxtaposition of stream segments with high and low relative risks of decline in northwestern California may indicate that foothill yellow-legged frog populations that are persisting in highly-regulated mainstem channels are acting as population sinks because they are being subsidized by emigrants from healthy tributary populations (Rose *et al.* 2020, pp. 47–48).

Like in the rest of the range, altered hydrology is among the most impactful threats to the foothill yellow-legged frog in the North Coast California unit. Other major threats that likely have or are contributing to the decline in the North Coast California unit include nonnative species, agriculture, mining, and urbanization (including roads and recreation). Illegal cannabis cultivation is also a major issue in the North Coast California unit (CDFW 2019b, pp. 97–98). Illegal water diversions and pesticides for illegal cannabis are reportedly linked to local declines of foothill yellow-legged frogs in the Eel River and South Fork Trinity River (Service 2019, *in litt.*, p. 33).

In summary, resiliency of the foothill yellow-legged frog in the North Coast California unit remains intact (see Table 15 for definition of resiliency category). This unit contains the majority of occupied stream segments, the largest populations, and occupancy is distributed over a large area. Functional connectivity is better in this unit than in any other. Although average relative risk of decline (2.40) is much higher than in the two units with the lowest average risks (North Coast Oregon and North Sierra units), the North Coast California unit still contains 382 occupied stream segments in the low risk category. As a whole, this unit may be the most resilient unit in the species' range and does not currently appear to be at risk of regional extirpation. However, occupancy and population density vary greatly among populations in this unit (Rose *et al.* 2020, pp. 63–64, table 1). Populations are also being affected by altered hydrology, nonnative species, and illegal cannabis operations. Therefore, foothill yellow-legged frog populations in the North Coast California unit should continue to be closely monitored for further declines.

North Feather

The North Feather unit is the smallest analysis unit and contains 118 stream segments with recent (i.e., 2000–2020) foothill yellow-legged frog observations. This unit occupies a transition zone where ecoregions of the Sierra Nevada, Cascades, and Tuscan Flows meet (Environmental Protection Agency Level IV Ecoregions (Omerick and Griffith 2014, entire; Griffith *et al.* 2016, entire)). Occupancy in the North Feather unit is intermediate compared to that of other analysis units. The eastern and southwestern (near Lake Oroville) portions of the unit appear to be either declining in occupancy or extirpated. Several other occurrences (northern Butte County) are also likely extirpated because there have not been detections of the species for decades (CDFW 2020, dataset; Figure 49).

Abundances of foothill yellow-legged frogs in the North Feather unit are largely unknown but egg mass densities are very low in the two regulated stream reaches that have long-term monitoring (Rose *et al.* 2020, pp. 63–64, table 1). Over the past several years, local declines in abundance and the distribution of egg masses occurred as a result of four years of recreational pulse flows for whitewater boating during the early 2000s (Hayes *et al.* 2016, p. 120; GANDA 2018, pp. 1–3, 13, table 2). The regulated flow regime has since been modified but the struggling population has only now begun to recover in response to the successful 2017–2020 in-situ and ex-situ rearing efforts (GANDA 2018, pp. 1–3, 13, table 2; Dillingham 2019, pp. 7–9; Rose *et al.* 2020, pp. 63–64, 76, table 1, figure 4). While the rearing efforts have been successful thus far, long-term success is yet to be determined.

There are not any isolated population fragments that are known to be extant in the North Feather unit but there are at least two genetically differentiated groups in this unit. Additional genetic sampling could reveal that functional connectivity in the North Feather unit is similarly poor to that of the North Sierra unit where highly-regulated rivers act as barriers to connectivity (Peek *et al.* 2021, p. 14).

The North Feather unit has the highest average relative risk of population decline (2.68) among the four northern analysis units (see Box 1 for explanation of relative risk of decline). Only 16 (15 percent) of the 109 analyzed stream segments are in the low risk category and 34 stream segments (31 percent) are in the high risk category (see Table 13 for definitions of risk categories). There does not appear to be a spatial pattern associated with the highest risks of decline in this unit but the lowest risks are in stream segments along the West Branch Feather River in Butte County (Figure 55).

The major threats that likely have or are contributing to the decline of the foothill yellow-legged frog in the North Feather unit include altered hydrology, nonnative species (bullfrogs and crayfish), agriculture, mining, urbanization (including roads and recreation), and climate change. The North Feather unit (along with the North Sierra unit) is in the most hydrologically altered part of the foothill yellow-legged frog's range (Supplementary Table 1) and contains a high density of hydropower dams (CDFW 2019b, p. 97) where pulse flows from hydropeaking are generally much greater in frequency and intensity compared to other sources of flow fluctuations (Greimel *et al.* 2018, p. 92). Some breeding populations in regulated reaches are so small that they may even be at risk of collapse from signal crayfish dislodging egg masses and/or consuming early-stage tadpoles (Rombough and Hayes 2005, p. 163; Wiseman *et al.* 2005, p. 162; Dillingham 2019, p. 10), in addition to other threats. While the North Feather unit has the greatest percent of forest and shrub cover among the analysis units, it may be affected by some of the agriculture in the neighboring Central Valley (Supplementary Figure 1) and it is suspected to be among the units that are most impacted from historical mining (Hayes *et al.* 2016, pp. 53–54).

Foothill yellow-legged frog population growth rate in the North Feather unit may be limited by cold stream temperatures. On average, streams in this unit are colder than anywhere else in the species' range (Supplementary Table 1; Rose *et al.* 2020, pp. 71–72, table 7, table 8). However, North Feather foothill yellow-legged frogs still breed in parts of streams that have similar temperatures to breeding sites in the North and South Sierra units (Rose *et al.* 2020, p. 71, table 7). Therefore, breeding habitat with appropriate thermal conditions may be rarer in the North Feather unit because streams have colder average temperatures.

In summary, resiliency of the foothill yellow-legged frog in the North Feather unit is reduced (see Table 15 for definition of resiliency category). Occupancy in the North Feather unit is intermediate compared to that of other analysis units, but abundance is low where there has been population monitoring. While structural connectivity appears to be fairly good in the North Feather unit, it is likely that functional connectivity is poor because highly-regulated rivers, like those in this unit, are barriers to successful breeding and recruitment. Only 16 (15 percent) occupied stream segments are in the low risk of decline category. The threats in the North Feather unit are severe because of the degree of hydrological alteration and number of hydropower dams. While threats in the North Feather unit are similar to those in the neighboring

North Sierra unit, streams are considerably colder in the North Feather unit, which may limit the quantity of breeding habitat and population growth rate.

North Sierra

The North Sierra unit is the second smallest analysis unit and contains 302 stream segments with recent (i.e., 2000–2020) foothill yellow-legged frog observations. This unit has the greatest occupancy among the seven analysis units (Table 10) and there are only two confirmed extirpated occurrences (CDFW 2020, dataset). There are also several robust, stable populations of foothill yellow-legged frog in the North Sierra unit, but other populations are reportedly small (CDFW 2019b, p. 34; Rose *et al.* 2020, pp. 63–64, table 1).

Functional connectivity in the North Sierra unit is poor, in spite of there being a good distribution of occupied areas across the unit. All four localities that were genetically sampled in this unit were genetically different from each other (McCartney-Melstad *et al.* 2018, p. 117, figure 3). The genetic isolation is likely due to connectivity barriers caused by altered hydrological conditions (stream regulation) (Peek *et al.* 2021, p. 14).

Populations in the North Sierra unit have the lowest average relative risk of population decline (1.87) among the seven analysis units (see Box 1 for explanation of relative risk of decline). The majority (65 percent) of the unit’s 278 analyzed stream segments are in the low relative risk category (see Table 13 for definitions of risk categories). However, relative risks for 25 stream segments (9 percent) are in the high risk category. The stream segments with the highest risks of decline are primarily located along the upper Rubicon River at the southeastern edge of the analysis unit (Figure 55).

The major threats that likely have or are contributing to declines of the foothill yellow-legged frog in the North Sierra unit include altered hydrology, nonnative species, agriculture, mining, urbanization (including roads and recreation), and climate change. The North Sierra unit (along with the North Feather unit) is in the most hydrologically altered part of the foothill yellow-legged frog’s range (Supplementary Table 1) and contains a high density of hydropower dams (CDFW 2019b, p. 97) where pulse flows from hydropeaking are generally much greater in frequency and intensity compared to other sources of flow fluctuations (Greimel *et al.* 2018, p. 92). While the North Sierra unit has a high proportion of forest and shrub cover (86 percent), it may be affected by agriculture in the northern Central Valley (Supplementary Figure 1). The northern Sierra Nevada (North Feather and North Sierra units) is also suspected to be the most impacted from historical mining (Hayes *et al.* 2016, pp. 53–54).

In summary, resiliency of the foothill yellow-legged frog in the North Sierra unit remains intact (see Table 15 for definition of resiliency category). The North Sierra unit has a dense network of occupied stream segments across the unit and has few documented extirpations. While the North Sierra unit lacks functional connectivity, it has the lowest average risk of population decline among the seven analysis units. Based on the relatively low risk of decline and low residual environmental stochasticity in the unit’s focal streams (Rose *et al.* 2020, p. 66, table 3), hydrological alteration may be having a smaller impact on North Sierra unit populations than on populations in other units, for unknown reasons. While North Sierra unit resiliency remains intact, the unit’s lack of functional connectivity, severity of hydrological alteration, and number of hydropower dams continue to threaten the persistence of the unit's foothill yellow-legged frog populations.

South Sierra

The South Sierra analysis unit contains the majority of the foothill yellow-legged frog's range in the Sierra Nevada but only 27 percent of Sierra Nevada stream segments with recent (i.e., 2000–2020) foothill yellow-legged frog observations. This unit has experienced large declines in occupancy (second only to the South Coast unit) (CDFW 2019b, p. 38; Figure 51) and abundances appear to be small relative to more northern populations (Lind *et al.* 2003, p. 26; Rose *et al.* 2020, pp. 63–64, table 1). Local extirpations of foothill yellow-legged frogs in the South Sierra unit have been reported widely (Jennings and Hayes 1994, pp. 67, 69, figure 18; Jennings 1995, pp. 132–133, figure 2; Lind *et al.* 2003, p. 4, figure 1; Fellers 2005, p. 534; Lind 2005, pp. 37–38, 65, figure 2.1; Hayes *et al.* 2016, p. 30; CDFW 2019b, pp. 37–38).

Structural and functional connectivity are particularly poor in the South Sierra unit. Occupied stream segments are clustered mostly in the northern third of the unit and there are three small, isolated population fragments in the southern two-thirds of the unit (Figure 54). These population fragments are especially vulnerable to extirpation, genetic drift, and inbreeding. Based on the three localities that were genetically sampled, there are at least three genetically differentiated groups in the unit (McCartney-Melstad *et al.* 2018, p. 117, figure 3).

In addition to poor occupancy and poor connectivity, streams in the South Sierra unit have the highest average relative risk of population decline (2.94) among the seven analysis units (see Box 1 for explanation of relative risk of decline). None of the 153 occupied stream segments that were analyzed in this unit have relative risks of decline in the low risk category (see Table 13 for definitions of risk categories). Thirty-seven percent of stream segments are in the high risk category. The highest risks of decline are in the northern third of the unit (Figure 55), where occupancy is actually greatest (Figure 51). However, this result mirrors the ongoing decline in occupancy in the northern part of the South Sierra unit (Figure 51).

The major threats that likely have or are contributing to the decline of the foothill yellow-legged frog in the South Sierra unit include altered hydrology, agriculture, nonnative species, disease and parasites, mining, urbanization (including roads and recreation), drought, extreme flooding, and climate change. Although the proportion of total stream segments that are hydrologically altered is lower in the South Sierra unit than in the northern Sierra Nevada (Supplementary Table 1), there are a greater number of serious threats in the South Sierra unit. The proximity of foothill yellow-legged frog habitat downwind of the San Joaquin Valley (greatest use of airborne pesticides) suggests that foothill yellow-legged frog declines in the South Sierra unit could be linked to agricultural pesticide-use in the Central Valley (Davidson *et al.* 2002, p. 1594; Davidson 2004, pp. 1900–1901; Bradford *et al.* 2011, p. 690). The South Sierra unit also receives notably less precipitation than the other units in the Sierra Nevada (Table 3; PRISM Climate Group 2012, 30-year climate dataset) but agricultural water demand in the neighboring Central Valley is high. Extirpations of foothill yellow-legged frogs in this unit have been attributed both to extreme flooding (Adams *et al.* 2017b, p. 10220; CDFW 2020, dataset) and to drought (Service 2019, *in litt.*, pp. 39–42). Like the other southern analysis units, streams in the South Sierra unit are subject to drying, which shortens the hydroperiod; negatively affects habitat elements that are hydrology-dependent; limits recruitment, survival, and connectivity; and exacerbates the effects of other threats.

In summary, resiliency of the foothill yellow-legged frog in the South Sierra unit is substantially reduced (see Table 15 for definition of resiliency category). Foothill yellow-legged frogs in the South Sierra unit appear to be either extirpated or declining in approximately two-thirds of the unit and the limited information regarding abundance suggests that extant populations are relatively small. Connectivity in the South Sierra unit is poor because of the spatial distribution of occupied streams and the evidence of genetically differentiated groups within the unit. Furthermore, occupied stream segments in the South Sierra unit have the highest average risk of population decline among the seven analysis units. While threats in the South Sierra unit are similar to threats in the North Feather and North Sierra units, there are a greater number of serious threats in the South Sierra unit, due to a drier climate and proximity downwind of an agricultural area with high use of airborne pesticides.

Central Coast

Foothill yellow-legged frogs have disappeared from much of their range within the Central Coast unit. Extirpations of the species within this unit have been documented in the San Francisco Bay area, as well as in San Benito and Fresno counties (Jennings and Hayes 1994, p. 67, figure 18; Lind 2005, p. 65, figure 2.1; CDFW 2020, dataset). Structural and functional connectivity is mostly poor with occupied stream segments falling into either a relatively large northern cluster or a relatively small southern cluster (Figure 54). While small-scale connectivity in the smaller cluster appears adequate, functional connectivity within the larger cluster is poor with at least four genetically differentiated groups within the cluster (McCartney-Melstad *et al.* 2018, p. 117, figure 3).

Among the analysis units, average relative risk of population decline (2.76) is second-highest in the Central Coast unit (see Box 1 for explanation of relative risk of decline). Of the 167 occupied stream segments that were analyzed in this unit, 84 percent are in the medium risk category and the remaining 16 percent are in the high risk category (see Table 13 for definitions of risk categories). The highest risks of decline are in the northern cluster of occupied stream segments, which are closer to the San Francisco Bay (Figure 55). This pattern of elevated risk suggests that extirpations of the foothill yellow-legged frog in the northern Central Coast unit may continue to occur. Evidence of genetic differentiation in this northern cluster (McCartney-Melstad *et al.* 2018, p. 117, figure 3) also suggests there is a greater degree of isolation and population fragmentation, which increases risk of extirpation, genetic drift, and inbreeding.

There are many threats affecting foothill yellow-legged frogs in the Central Coast unit. The major threats that likely have or are contributing to the decline in this unit include altered hydrology, drought, nonnative bullfrogs, Bd (disease), agriculture (especially illegal cannabis cultivation), mining, urbanization (including roads and recreation), extreme flood events, and climate change. Relative to the other analysis units, the proportion of all stream segments (i.e., segments both with and without observations) that are regulated in the Central Coast unit is intermediate, but the average degree of regulation among those streams is relatively high (Supplementary Table 1).

On average, the Central Coast unit receives the least amount of annual precipitation of all the analysis units (Table 3; PRISM Climate Group 2012, 30-year climate dataset). Like the other southern analysis units, streams in the Central Coast unit are subject to drying, which shortens the hydroperiod; negatively affects habitat elements that are hydrology-dependent; limits recruitment, survival, and connectivity; and exacerbates the effects of other threats. Among the threats that are likely exacerbated by drying and drought in the Central Coast unit are disease and predation by, and competition with, bullfrogs. Bd is implicated in the decline of the foothill yellow-legged frog in the Central Coast unit (Adams *et al.* 2017b, p. 10224). Chytridiomycosis mortality events in this unit were documented during the 1980s and in recent years (Adams *et al.* 2017a, pp. 2–3; Adams *et al.* 2017b, p. 10221; M. Grefsrud 2018, *in litt.*; B. Blinn 2019, *in litt.*). In addition to bullfrogs being predators and competitors, a study of a Central Coast unit population found that bullfrog presence was a positive predictor of Bd prevalence (i.e., proportion of individuals infected) and Bd load (i.e., quantity) in foothill yellow-legged frogs (Adams *et al.* 2017a, p, 1).

Human land use of the area within and around the Central Coast unit is particularly high. Not only does the Central Coast unit have the lowest proportion of forest and shrub cover (49 percent), it contains the greatest proportion of urban land cover (14 percent) among the seven analysis units (Supplementary Figure 1; Sleeter and Kreitler 2020, unpublished data). There is also a notable amount of agriculture within the analysis unit (4 percent of land cover) and 11 percent of the unit plus its surrounding area is agriculture (Supplementary Figure 1; Sleeter and Kreitler 2020, unpublished data). Central Coast unit populations are also threatened by off-highway vehicle recreation and illegal cannabis cultivation (CDFW 2019b, pp. 97–98; Westphal and Nix 2020, presentation).

In summary, resiliency of the foothill yellow-legged frog in the Central Coast unit is substantially reduced (see Table 15 for definition of resiliency category). Foothill yellow-legged frogs have disappeared from much of their range within this unit and connectivity is mostly poor. While there are some populations that have persisted at approximately 18 breeding females per km (Rose *et al.* 2020, p. 63, table 1), the average risk of population decline in the Central Coast unit is second-highest among the seven analysis units. There are also numerous threats acting upon foothill yellow-legged frogs in the Central Coast unit (e.g., altered hydrology, drought, nonnative species, disease, urbanization, etc.).

South Coast

The South Coast unit has experienced the greatest declines in foothill yellow-legged frog occupancy. The extirpation of the species from nearly the entire extent of the South Coast unit has been widely reported (Sweet 1983, abstract; Jennings and Hayes 1994, pp. 68–69; Jennings 1995, p. 132; Hayes *et al.* 2016, p. 28; Adams *et al.* 2017b, pp. 10217–10218; CDFW 2019b, pp. 43–44). Recent observations (i.e., during 2000–2020) are limited to only two creeks (and a tributary to one of the creeks) (CDFW 2020, dataset). Abundances at extant locations are unknown but overall abundance of the analysis unit can be assumed to be very low with so few occurrences.

Connectivity in South Coast unit is insufficient because it does not meet the needs of a resilient metapopulation. While all of the occupied stream segments in the South Coast unit are close together (Table 11), there are only two small populations occupying a total of seven stream segments. Furthermore, differences in genetics between the two subpopulations in the South Coast unit (McCartney-Melstad *et al.* 2018, pp. 117, 119, 121, figure 3) suggest that little or no dispersal is occurring between the two populations.

Average relative risk of population decline in the seven occupied stream segments (2.54) is greater than in most of the northern analysis units, but is lower than in the other southern units (Central Coast and South Sierra units) (Figure 55) (see Box 1 for explanation of relative risk of decline). All occupied stream segments in the South Coast unit are in the medium risk category for relative risk of decline (see Table 13 for definitions of risk categories).

There are many threats affecting the foothill yellow-legged frogs in the South Coast unit. The major threats that likely have or are contributing to the decline in this unit include altered hydrology, drought, Bd (disease), nonnative species, agriculture (especially illegal cannabis cultivation), mining, urbanization (including roads and recreation), extreme flood events, and climate change. Compared to other units, the proportion of stream segments that are classified as regulated in the entire South Coast unit is fairly low (3.9 percent) (Supplementary Table 1; Rose *et al.* 2020, p. 72, table 8). However, the average upstream degree of regulation in regulated segments is highest in this unit (18.3 percent) and none of the regulated streams in this unit are known to be occupied (Supplementary Table 1; Rose *et al.* 2020, pp. 71–72, table 7, table 8).

Like the Central Coast unit, the South Coast unit is warm and dry (Table 3; PRISM Climate Group 2012, 30-year climate dataset) and waterways in both of these units are similar in terms of hydrological properties. Waterways in the South Coast unit (and Central Coast unit) tend to have flashier flows, more ephemeral channels, and a higher degree of intermittency because of the region's more variable, and lower amount of, precipitation (Storer 1925, pp. 257–258; Gonsolin 2010, p. 54; Adams *et al.* 2017b, p. 10227). Early drying of streams in the South Coast unit negatively affects habitat elements that are hydrology-dependent; limits recruitment, survival, and connectivity; and exacerbates the effects of other threats. Preliminary environmental data collected during 2020 from one of the occupied South Coast unit locations suggest that the hydroperiod at this rearing location is just long enough to allow tadpoles to achieve metamorphosis and disperse before the channel section dries completely (Kupferberg and Adams 2020, *in litt.*); however, hydroperiod is likely to vary from year to year. The stream temperature at this location is also at the upper end of the thermal preference for foothill yellow-legged frog tadpoles (Kupferberg *et al.* 2011a, p. 41; Catenazzi and Kupferberg 2017, p. 1260; Kupferberg and Adams 2020, *in litt.*). The southern California precipitation regime (i.e., alternation of extreme droughts and floods) may also increase the likelihood of disease outbreaks in the South Coast unit (and Central Coast unit) (Adams *et al.* 2017b, p. 10228). Bd has been implicated in the decline of the foothill yellow-legged frog in the South Coast unit (Adams *et al.* 2017b, p. 10224). Increased human use of foothill yellow-legged frog habitat in the 1970s and introduction of bullfrogs as a reservoir host may have played a key role in spreading Bd in this analysis unit (Adams *et al.* 2017b, p. 10225–10226).

Also like the Central Coast unit, human land use of the area within and around the South Coast unit is particularly high. The proportion of land cover classified as agriculture or urban in this unit (approximately seven percent combined) is high relative to all but the Central Coast unit (Supplementary Figure 1; Sleeter and Kreitler 2020, unpublished data). Furthermore, the large amount of urban land cover in the area around the South Coast unit likely has a negative influence on foothill yellow-legged frog resiliency (Supplementary Figure 1; Sleeter and Kreitler

2020, unpublished data). The South Coast unit is also among those most at risk from illegal cannabis cultivation (CDFW 2019b, pp. 97–98).

In summary, resiliency of the foothill yellow-legged frog in the South Coast unit is extensively reduced (see Table 15 for definition of resiliency category). After rapid extirpation from most of the unit, foothill yellow-legged frogs are currently known to occupy only two creeks (and a tributary to one of the creeks) with no evidence of functional connectivity between them. All seven stream segments are in the medium risk category for population decline. There are also numerous threats to foothill yellow-legged frogs in the South Coast unit (e.g., altered hydrology, drought, nonnative species, disease). It is unknown if foothill yellow-legged frogs can persist elsewhere in this unit without threat mitigation.

8.6 Species Redundancy

Redundancy enables a species to withstand catastrophic events. It describes the long-term viability of a species in the face of one or more catastrophic events. Catastrophic events that could affect the foothill yellow-legged frog include long-term drought, extreme flood events, high-severity wildfires, exotic species invasions, toxic chemical spills, and disease outbreaks. While these threats are not necessarily catastrophic, they have the potential to be catastrophic depending on scale and severity.

Redundancy can be measured by the quantity and spatial distribution of resilient metapopulations across the species' range. Generally speaking, the greater the number of healthy subpopulations and metapopulations that are distributed (and connected) across the landscape, the greater the species' ability to withstand catastrophic events and, thus, the greater the species' viability. At the coarsest scale of redundancy, there are seven regions (analysis units) where foothill yellow-legged frogs are extant but only two of them appear to have intact resiliency (Section 8.5). Among the seven analysis units, there are six, substantially-divergent genetic clades, each representing a distinguishable portion of the species' genetic diversity (Section 2.6). Each analysis unit accounts for one genetic clade except for the North Coast Oregon and North Coast California units, which comprise a single genetic clade (i.e., the North Coast clade). The genetic divergence among the clades indicates that there is a lack of functional connectivity among the clades. Therefore, it is also appropriate to consider redundancy within each of the six genetic clades.

To assess the condition of redundancy for each genetic clade, we considered the (1) quantity of occupied stream segments (proxy for subpopulations) (Table 10), (2) spatial distribution of occupied stream segments (Figure 55), and (3) level of population resiliency (Section 8.5), including connectivity, relative risk of decline, and level of threats. These factors were assessed in terms of their potential influence on the ability of foothill yellow-legged frog metapopulations to survive and recover after a plausible catastrophic event. For example, isolation of occupied stream segments or lack of functional connectivity in a genetic clade, could prevent recolonization of extirpated areas after a massive die-off or temporary habitat destruction.

At the clade scale of redundancy, long-term viability after a catastrophic event would likely be possible in the North Coast clade (North Coast California and North Coast Oregon units) and might be possible in the North Sierra clade. In the North Coast clade, there are large numbers of occupied streams and there are numerous occupied stream segments that both are in the low risk of decline category and are distributed widely across the geographical area (Figure 55). Furthermore, resiliency is intact in both of the two analysis units that comprise this clade. Resiliency is also intact in the North Sierra clade because there are numerous occupied stream segments that both are in the low risk of decline category and are distributed widely across the geographical area (Figure 55). However, the North Sierra clade has less redundancy than the North Coast clade because the North Sierra clade is small in size and has poor functional connectivity, which could prevent recolonization after catastrophic events.

Redundancy is limited in the North Feather clade. The North Feather clade is not only the smallest clade, but its occupied stream segments are not well-distributed over the geographical area (Figure 55). The extant North Feather populations occupy an area small enough that a large catastrophic event, such as a high-severity wildfire or drought, could result in functional extirpation[23]. Furthermore, this clade/unit has reduced resiliency because of poor occupancy and relatively high risk of population decline.

Redundancy is poor in the South Sierra and Central Coast clades. Both the South Sierra and Central Coast clades have substantially reduced resiliency because of poor occupancy, poor connectivity, relatively high risk of decline, and substantial threats. A single catastrophic event would be unlikely to extirpate the entirety of either unit but the patchy distribution of occurrences (Figure 55) and limited connectivity would make it extremely unlikely that extirpated areas would be recolonized naturally.

Redundancy within the South Coast clade is nearly zero. Not only is the resiliency in this clade extensively reduced, but there are only two known populations (Section 8.2) in the South Coast clade. These two populations (comprised of seven stream segments) are also very close in proximity (Figure 55). Thus, the entire South Coast clade would be at risk of extirpation from a single catastrophic event.

8.7 Species Representation

Representation describes the ability of a species to adapt to both near-term and long-term changes in its physical (e.g., climate conditions, habitat conditions, habitat structure, etc.) and biological (e.g., pathogens, competitors, predators, etc.) environments. This ability of a species to adapt to these changes is often referred to as “adaptive capacity.” To assess the current condition of representation for the foothill yellow-legged frog, we considered the current diversity of ecological conditions and of genetic material throughout the range of the species.

There are considerable ranges of ecological conditions under which foothill yellow-legged frogs occur. As discussed in Section 2.7 and in CHAPTER 3, there are substantial differences in latitude, elevation, precipitation, average temperature, and vegetative community across the species’ range. Parts of the foothill yellow-legged frog range also differ in terms of co-occurring species composition and in hydrology (rain-fed versus snow-fed systems). Exemplary of these different ecological conditions, foothill yellow-legged frog tadpoles from snow-fed Sierra Nevada populations have higher intrinsic growth rates than tadpoles from rain-fed coastal

---

[23] Functional extirpation is defined as such extensive reduction in condition that extirpation of the entire analysis unit is likely to eventually occur as remnant populations experience normal environmental and demographic fluctuations.

populations, likely due to their constraint to a shorter rearing season in the Sierra Nevada (Catenazzi and Kupferberg 2017, pp. 1255, 1260–1261).

There are six statistically supported genetic clades within the range of the foothill yellow-legged frog. As described in Section 2.6, two rangewide assessments of foothill yellow-legged frog genomic datasets revealed that this taxon is extremely differentiated following biogeographical boundaries (McCartney-Melstad *et al.* 2018, p. 112; Peek 2018, p. 76). The clades that are most genetically divergent (i.e., South Sierra, Central Coast, and South Coast clades), and thus could contribute most to the overall adaptive capacity of this taxon (McCartney-Melstad *et al.* 2018, p. 120; Peek 2018, p. 77), are also the clades with the lowest levels of population resiliency. The South Sierra and Central Coast clades have substantially reduced resiliency and the South Coast clade has extensively reduced resiliency (Section 8.5). The reduced resiliency in these clades, means that the foothill yellow-legged frog is especially vulnerable to loss of this genetic diversity. The Central Coast and South Coast clades are the most genetically divergent, indicating that a significant amount of the taxon's overall genetic diversity would be lost if either clade were extirpated. The Central Coast and South Coast clades are also ecologically unique because they have lower annual precipitation and higher mean annual temperatures than elsewhere in the range of the species (PRISM Climate Group 2012, 30-year climate dataset; Table 3) and the region hosts the highest freshwater endemism of anywhere in the species' California range (Howard *et al.* 2013, p. 5).

While not as at risk of extirpation, the northern Sierra clades (i.e., North Feather and North Sierra clades) might also have unique adaptive potential in the face of climate change because of their admixture history and intermediacy to the South Sierra and North Coast clades (McCartney-Melstad *et al.* 2018, p. 121). The genetic clade that is comprised of the two North Coast units is also genetically valuable to the foothill yellow-legged frog because it contains the greatest genetic diversity and is the only part of the range that shows a trajectory of increasing genetic diversity (McCartney-Melstad *et al.* 2018, pp. 120–121; Peek 2018, p. 74). The North Coast clade also potentially provides connectivity and a large latitudinal gradient for responding to the effects of climate change.

While the foothill yellow-legged frog clearly has a range of genetically divergent populations, it has likely already lost a lot of diversity due to large extirpations in the southern clades. The species is also at risk of further losses amidst trends toward decreasing occupancy and decreasing connectivity. The foothill yellow-legged frog is exhibiting an overall trend of decreasing genetic diversity in spite of the trend of increasing genetic diversity in the North Coast clade (McCartney-Melstad *et al.* 2018, pp. 120–121; Peek 2018, p. 74).

The trend of decreasing genetic diversity in the foothill yellow-legged frog may be leading to losses in adaptive capacity (i.e., ability to adapt to change). Loss of adaptive capacity lowers the species' viability because the decrease in ability to adapt to change increases extinction risk in the face of future changes. For foothill yellow-legged frog conservation, McCartney-Melstad *et al.* (2018, p. 122) strongly recommended that each of the major genetic groups be managed as independent recovery units. Peek (2018, p. 77) also recommended that conservation actions should prioritize protecting foothill yellow-legged frogs in the Central Coast, South Coast, and South Sierra clades because they are simultaneously the most distinct, divergent, and at-risk populations.

CHAPTER 9 Future Condition

This chapter of the SSA forecasts the species' response to a range of plausible future scenarios of environmental conditions. The future scenarios incorporate the range of plausible projections for threats that are likely to change in the future. The assessment of future condition interprets the effects that these changes would potentially have on foothill yellow-legged frog resiliency, representation, and redundancy.

For this SSA, the future was assessed at approximately 40 years. This period represents our best understanding of the projected future environmental conditions related to threats associated with climate change that would impact the species (increasing temperatures; greater proportion of precipitation falling as rain instead of snow; earlier snowmelt (influencing streamflow); and increased frequency, duration, and severity of extreme events such as droughts, heat waves, wildfires, and floods). The 40-year timeframe was also used in the PVA for determining risk of decline for the species into the future.

9.1 Summary of Methods

As for current condition, we assessed future condition of the species in terms of the conservation biology principles of resiliency, redundancy, and representation (Section 1.2). Three plausible future scenarios were considered, and the future resiliency, redundancy, and representation were assessed under each scenario. Descriptions are given for each scenario (Section 9.2) and the anticipated effects of each scenario on resiliency for each foothill yellow-legged frog analysis unit (Section 9.3). The effects of each scenario on overall redundancy (Section 9.4) and representation (Section 9.5) are also summarized.

To assess future resiliency, we examined the same considerations as we did for current resiliency. Under each future scenario, we assessed how the following resiliency measures would change from current condition: (1) occupancy and abundance, (2) connectivity, (3) modeled risk of population decline, and (4) status of threats. Because changes to environmental conditions under the future scenarios were reflected by environmental covariates in the PVA (see Section 9.2 Scenarios; Table 17), we were able to forecast the magnitudes of changes in resiliency by comparing the modeled risk of decline from Rose *et al.* (2020, entire) under current conditions to modeled risk under the three future scenarios. For each analysis unit and scenario, change in resiliency between current condition and future condition was described as "about the same," "slightly reduced," "markedly reduced," or "greatly reduced," based on the magnitude of projected change in the average relative risk of population decline from Rose *et al.* (2020, entire) (Table 16).

We also made inferences about how increases in risk of decline would influence abundance, occupancy, and connectivity for each analysis unit. While the PVA estimated the probability of ≥50 percent decline in abundance over a 40-year period, decline in abundance has implications for occupancy and connectivity. Where foothill yellow-legged frog abundance is high, a 50 percent decline in abundance would not have much influence on occupancy or connectivity. However, where initial abundance is low, a 50 percent decline in abundance may lead to extirpation of the population (i.e., decreased occupancy) and thus, to losses in structural connectivity. The conceptual diagram depicted in Figure 56 shows how we related increases in risk of decline to resiliency and redundancy.

Table 16. Terms used to describe changes in resiliency between current and future conditions based on changes in average relative risk of decline. Maximum relative risk possible = 4.55 = 100 percent probability of ≥50 percent population decline.

Terms used to describe change in resiliency under future scenarios	Change in average relative risk of decline between current condition and future scenario
About the same	Increase of less than 0.05 in average relative risk (less than 1 percent of the maximum relative risk possible).
Slightly reduced	Increase of 0.05–0.32 in average relative risk (increase of 1–7 percent of the maximum relative risk possible).
Markedly reduced	Increase of 0.32–0.64 in average relative risk (increase of 7–14 percent of the maximum relative risk possible).
Greatly reduced	Increase of 0.64–0.95 in average relative risk (increase of 14–21 percent of the maximum relative risk possible).

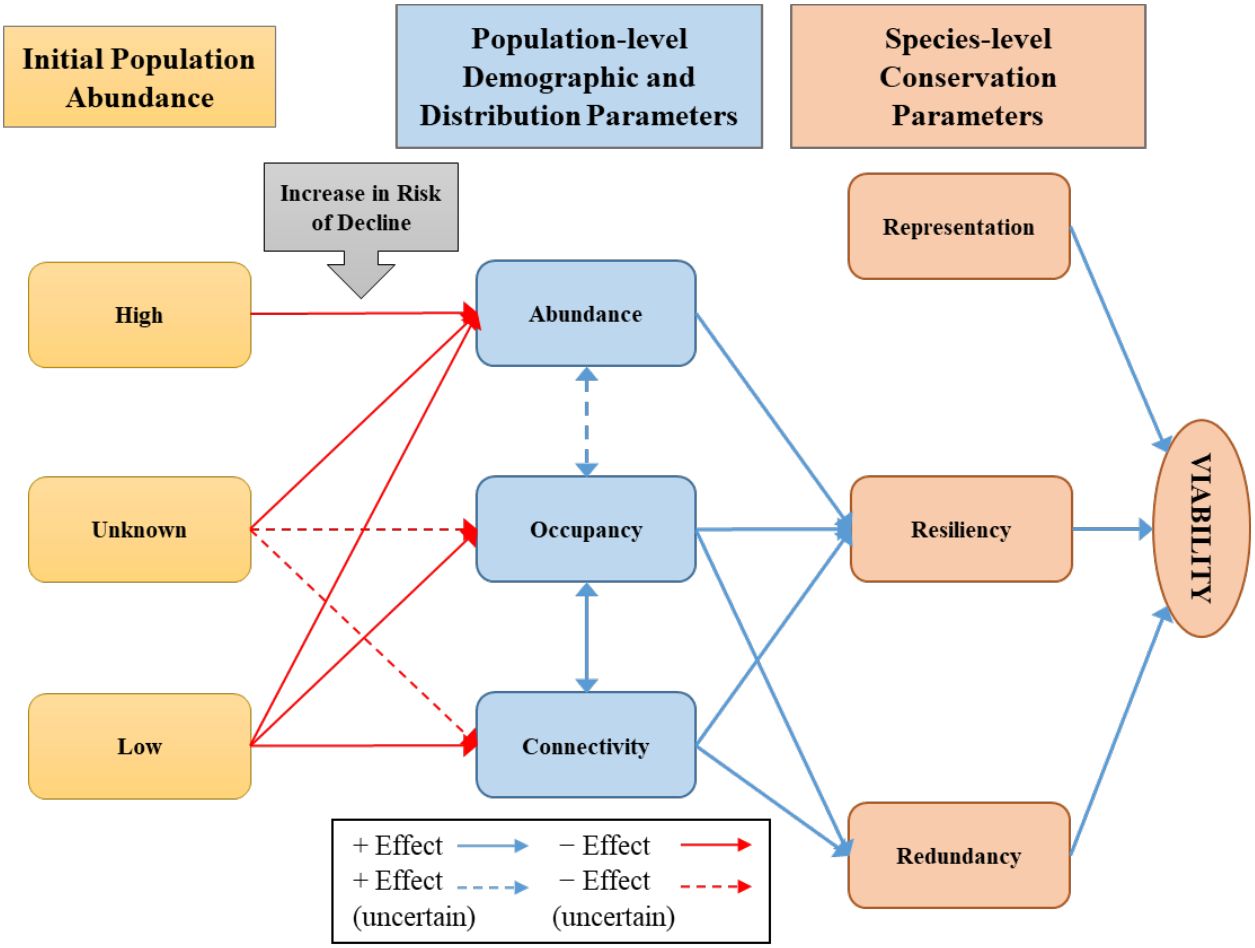


Figure 56. Conceptual diagram depicting how a modest increase in risk of decline would influence foothill yellow-legged frog abundance, occupancy, and/or connectivity (and thus, species viability) depending upon initial population abundance.

The future influences of several threats are reflected in the modeled risk of decline (PVA) for the future scenarios (see Section 9.2 below). However, the PVA did not incorporate the complete influence of certain threats (e.g., high-severity wildfire, changes in degree of regulation, etc.), nor the potential synergistic effects of threat interactions. The uncertainty of where and how threats will influence the foothill yellow-legged frog in the future, preclude our ability to accurately project changes to future condition as a result of such threats. While the potential effects of some of these threats could be incorporated into future scenarios, the plausibility of such scenarios would decrease due to uncertainty. Therefore, we focus on the projected changes in the modeled risk of decline under three future scenarios, giving weight to the threats of land cover change, climate change, and local influences that are currently causing demographic fluctuations in focal populations (reflected in residual environmental stochasticity). In Section 9.3 Future Population Resiliency, we summarize information on some of the trends associated with unmodeled threats in each analysis unit and note unmodeled threats that may be of particular concern in the future. While these unmodeled threats qualitatively affect our interpretation of risk in each analysis unit, they do not alter our projections of future condition.

9.2 Scenarios

The three future scenarios considered in this chapter (Table 17) were developed by Rose *et al.* (2020, pp. 22–27), in consultation with the Service, to inform this foothill yellow-legged frog SSA. Although there are an infinite number of possible scenarios, the chosen scenarios reflect a range of reasonable scenarios based on the current understanding of climate change models, threats, and foothill yellow-legged frog ecology. The environmental conditions in each future scenario are plausible in that they are not meant to represent the lowest and highest projections of what is possible. Rather, the lower change and higher change scenarios are at the lower and upper ends of confidence intervals from climate change projections (Rose *et al.* 2020, pp. 22–23). Environmental conditions for the three future scenarios are based on published studies that used ensembles of global climate models (Isaak *et al.* 2017, p. 9188; Swain *et al.* 2018, p. 427; Sleeter *et al.* 2019, p. 3336). For the projections of spatially explicit covariates (i.e., land cover and stream temperature), downscaled regional climate model data were used (Isaak *et al.* 2017, p. 9186; Sleeter *et al.* 2019, p. 3339). The information from these studies reflects the best scientific and commercial information available (at the time of the analysis) for projections of land cover (Sleeter *et al.* 2019; Sleeter and Kreitler 2020, unpublished data), stream temperature (Isaak *et al.* 2017), and climate variability (Swain *et al.* 2018) within the range of the foothill yellow-legged frog.

Table 17. Descriptions of three plausible future scenarios used to forecast foothill yellow-legged frog condition into the future for 40 years. This table was adapted from Rose *et al.* (2020, p. 65, table 2). Forest and shrub cover change (Sleeter and Kreitler 2020, unpublished data) is based on 100 Monte Carlo runs of the business-as-usual scenario modeled by Sleeter *et al.* (2019, pp. 3336, 3339). Magnitudes of stream temperature increase were scaled by each stream segment's historical stream temperature, such that warmer streams are projected to increase in temperature more than colder streams (NorWeST dataset (Isaak *et al.* 2017, p. 9188)). Future annual streamflow was modeled to exhibit increases in annual variation around the mean (i.e., future streamflow was drawn from distributions with the same historical mean as in current condition, but with increased standard deviations (Swain *et al.* 2018, p. 430; Rose *et al.* 2020, p. 26). The projected increases in residual environmental stochasticity represent the projections for increased inter- and intra-annual variability in climate (Rose *et al.* 2020, p. 23). Residual environmental stochasticity is also intended to reflect other unpredictable factors that influence foothill yellow-legged frog abundance such as nonnative species, disease outbreak, pulsed flows during breeding/rearing, or pulses of recruitment (Rose *et al.* 2020, p. 23).

Environmental Covariate	**Lower Change Scenario:**	**Mean Change Scenario:**	**Higher Change Scenario:**
Forest and shrub cover	Minimum projected change in land cover across all runs based on continuation of recent trends	Mean projected change in land cover across all runs based on continuation of recent trends	Maximum projected change in land cover across all runs based on continuation of recent trends
Stream temperature	Mean increase of 0.5 °C (0.9 °F) based on continuation of historical (1976–2015) trends in August stream temperature	Mean increase of 0.8 °C (1.4 °F) based on projection of mean August stream temperatures from 2030–2059 under the A1B emissions scenario	Mean increase of 2.0 °C (3.6 °F) based on second-highest projected increase in August stream temperature in Isaak *et al.* (2017)
Total annual streamflow (discharge)	25 percent increase in annual variation	50 percent increase in annual variation	100 percent increase in annual variation
Residual environmental stochasticity	25 percent increase	50 percent increase	100 percent increase

Forest and Shrub Cover

Future changes in land use and land cover (Sleeter and Kreitler 2020, unpublished data) are reflected in the PVA by changes to forest and shrub cover. Changes to forest and shrub cover are based on projections of climate change, urbanization, agricultural expansion, forest harvest, wildfire, and tree mortality from drought (Sleeter *et al.* 2019, p. 3336; Rose *et al.* 2020, p. 38). Within hydrologic sub-basins where the foothill yellow-legged frog is extant (or presumed extant), only small, gradual changes in forest and shrub cover were projected (Rose *et al.* 2020, p. 43). The North Sierra and Central Coast units have the largest projected declines, but each unit is projected to lose approximately 1–2% of forest cover in the next 40 years under the mean change scenario, with minimal additional forest and shrub cover loss under the higher change scenario (Rose *et al.* 2020, p. 38).

The use of land cover change projections in the PVA reflect some, but not all, of the impacts that future land use and land cover change would have on the foothill yellow-legged frog. Although land cover change projections included a wildfire submodel (Sleeter *et al.* 2019, p. 3336), the dramatic impact that high-severity wildfire can have on the landscape and foothill yellow-legged frog habitat quality was not reflected in the small, gradual changes in the land cover projections (Rose *et al.* 2020, p. 43). Therefore, the potential effects of high-severity wildfire are not adequately reflected in the PVA (risk of decline) results. Furthermore, the influence of projected land use and land cover change was limited to the local hydrologic sub-basin that contained each occupied stream segment. Therefore, projected changes in land use in neighboring hydrologic sub-basins were not factored into the PVA although they could have detrimental impacts. For example, increases in urbanization or agriculture in areas near, but not within, an occupied hydrologic sub-basin could influence viability by increasing recreation pressure or pesticide exposure.

Stream Temperature

Spatially-explicit increases in August stream temperatures were projected based on geospatial attributes and projected changes in August air temperature and streamflow (NorWeST dataset; Isaak *et al.* 2017, pp. 9184–9189, table 1). While population growth rate in focal streams was positively related to August stream temperatures from 1993–2015, temperatures in many streams are projected to be warmer than the historical temperatures of focal streams (Rose *et al.* 2020, pp. 49–50). Therefore, the response of population growth rate to mean August stream temperature was extrapolated (Figure 57) based on information from other foothill yellow-legged frog studies (Rose *et al.* 2020, pp. 24–25, 49–51).

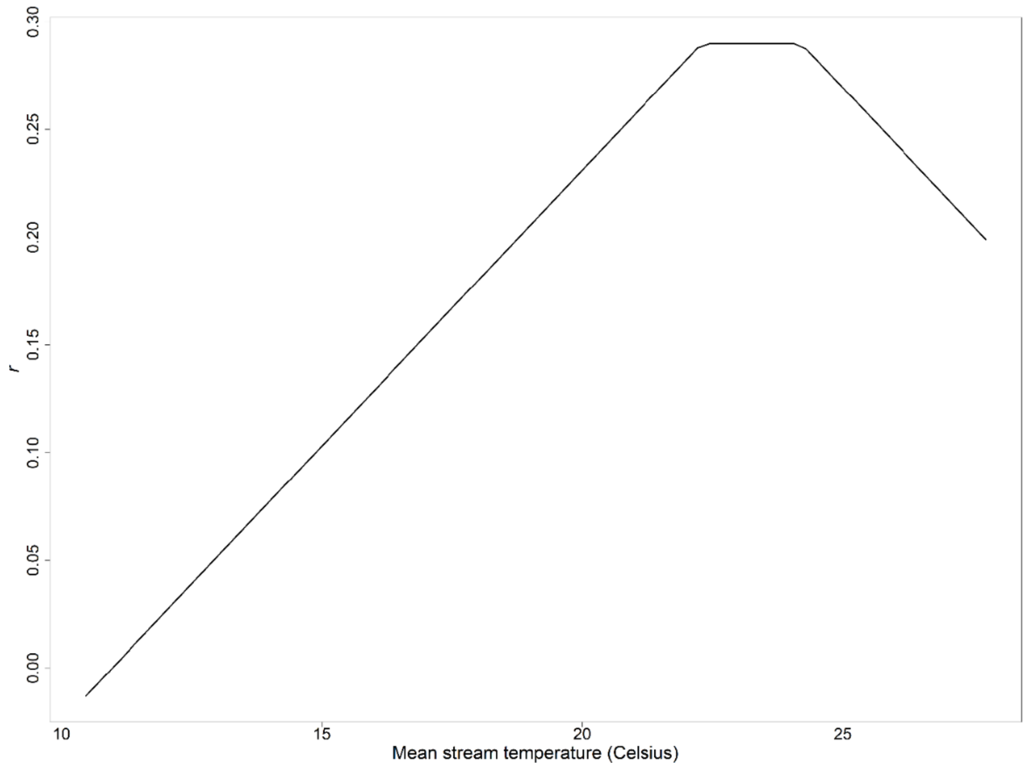


Figure 57. Extrapolation of the response of population growth rate (*r*) to mean August stream temperature, as hypothesized by Rose *et al.* (2020, pp. 24–25, 75, figure 3). Foothill yellow-legged frog population growth rate is hypothesized to plateau for temperatures above 22.3 °C (72.1 °F) and decline for temperatures above 24.2 °C (75.6 °F). Figure copied from Rose *et al.* (2020, p. 75, figure 3).

Annual Streamflow

Climate models generally project increases in winter precipitation and decreases in summer precipitation for 2041–2070 in the foothill yellow-legged frog's range, but little or no change in total annual precipitation (AdaptWest Project 2015, dataset; Pierce *et al.* 2018, p. 26, figure 16; Mote *et al.* 2019, p. ii, summary). Therefore, changes in annual streamflow under the future scenarios (Table 17) are based on expected changes in interannual streamflow variation rather than average streamflow (Grantham *et al.* 2018, p. 439; Rose *et al.* 2020, pp. 26–27). Increases in interannual variation ranging from 25 percent to 100 percent were selected based on expected increases in frequency of extreme wet and extreme dry years in California during the 21st century (Swain *et al.* 2018, p. 430; Rose *et al.* 2020, p. 26).

Residual Environmental Stochasticity

In the MPVA that modeled time series of egg mass counts in 32 focal streams, the variation in egg mass counts that was not explained by the environmental covariates was attributed to residual environmental stochasticity (Rose *et al.* 2020, p. 23). In other words, this covariate reflects the unmodeled, exogenous environmental factors that are locally influencing egg-mass density in focal populations (Rose *et al.* 2020, p. 45). Under the future scenarios, residual environmental stochasticity is projected to increase by 25 percent to 100 percent (Table 17). These increases are largely based on projections for increases in extreme inter- and intra-annual precipitation and streamflow variability, including greater frequency of extreme flood events and droughts (Grantham *et al.* 2018, p. 439; Swain *et al.* 2018, pp. 427–431; Rose *et al.* 2020, p. 23). Residual environmental stochasticity is also intended to reflect other unpredictable factors that influence foothill yellow-legged frog abundance such as nonnative species, disease outbreak, pulsed flows during breeding/rearing, or pulses of recruitment (Rose *et al.* 2020, p. 23).

9.3 Future Population Resiliency

The average risk of population decline for each analysis unit increased under the three future scenarios (Rose *et al.* 2020, p. 39). Maps of occupied stream segments, color-coded by relative risk of ≥50 percent decline (see Box 1 for explanation of relative risk and Table 13 for definitions of risk categories), under the lower, mean, and higher change scenarios are provided in Figure 58, Figure 59, and Figure 60, respectively. Under current conditions and all future scenarios, the average relative risk of decline was highest in the South Sierra and Central Coast units and was lowest in the North Coast Oregon, North Coast California, and North Sierra units (Table 18). Under the lower change scenario, decreases in resiliency, compared to current conditions, were small in most analysis units. However, decreases in resiliency were more dramatic under the mean and higher change scenarios (Table 18; Table 19). These dramatic declines in resiliency put several analysis units at risk of unit-wide extirpation or functional extirpation (i.e., such extensive reduction in condition that extirpation of the entire unit is likely to eventually occur as remnant populations experience normal environmental and demographic fluctuations) under the mean and higher change scenarios (Table 19). One of the analysis units (South Coast unit) is at risk of unit-wide extirpation under all three of the future scenarios.

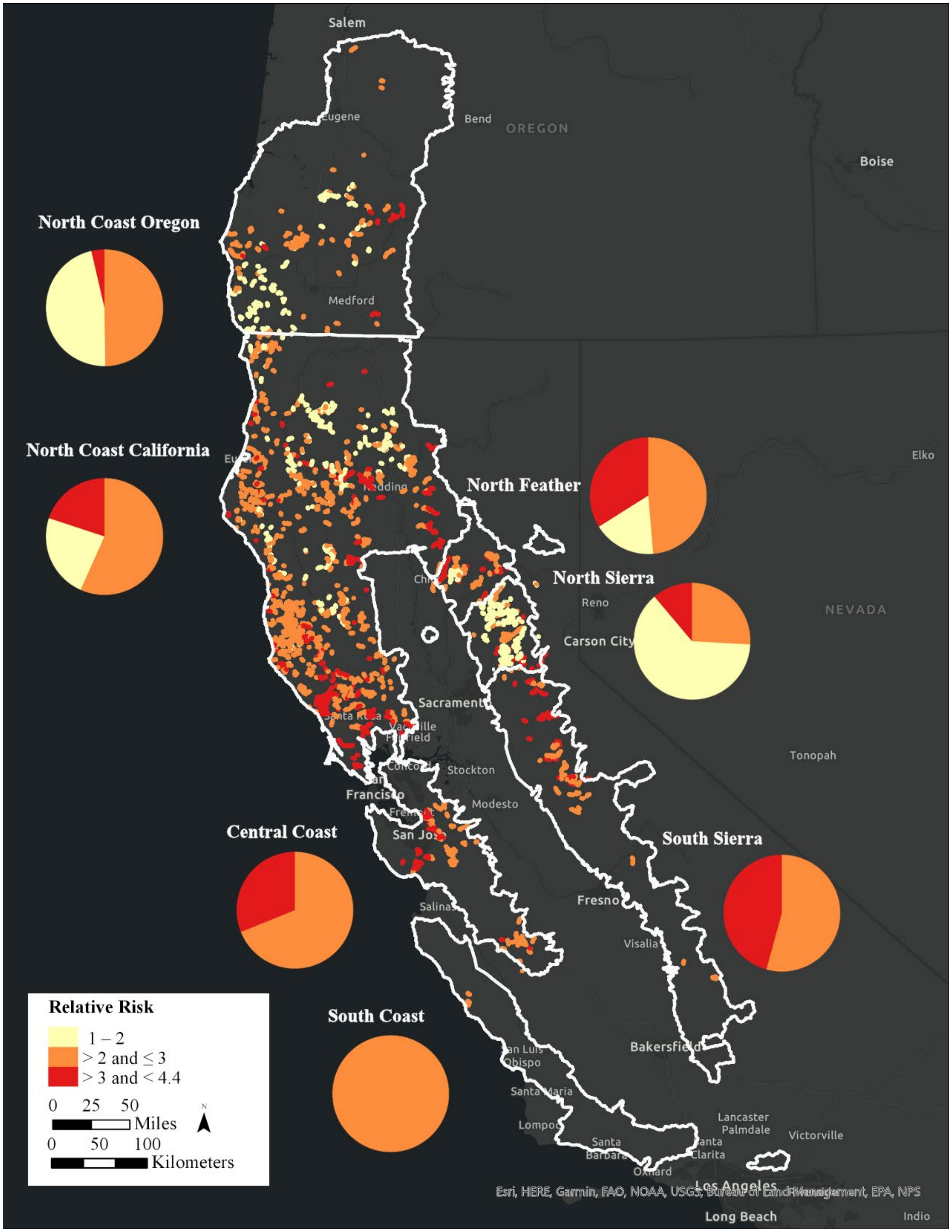


Figure 58. Lower change scenario risk of ≥50 percent decline over 40 years in stream segments occupied by the foothill yellow-legged frog (Rose *et al.* 2020, supplementary data). Relative risk (see Box 1) is binned into three categories (Table 13). Risk 1–2 = low (light yellow). Risk >2 and ≤3 = medium (orange). Risk >3 and <4.4 = high (red).

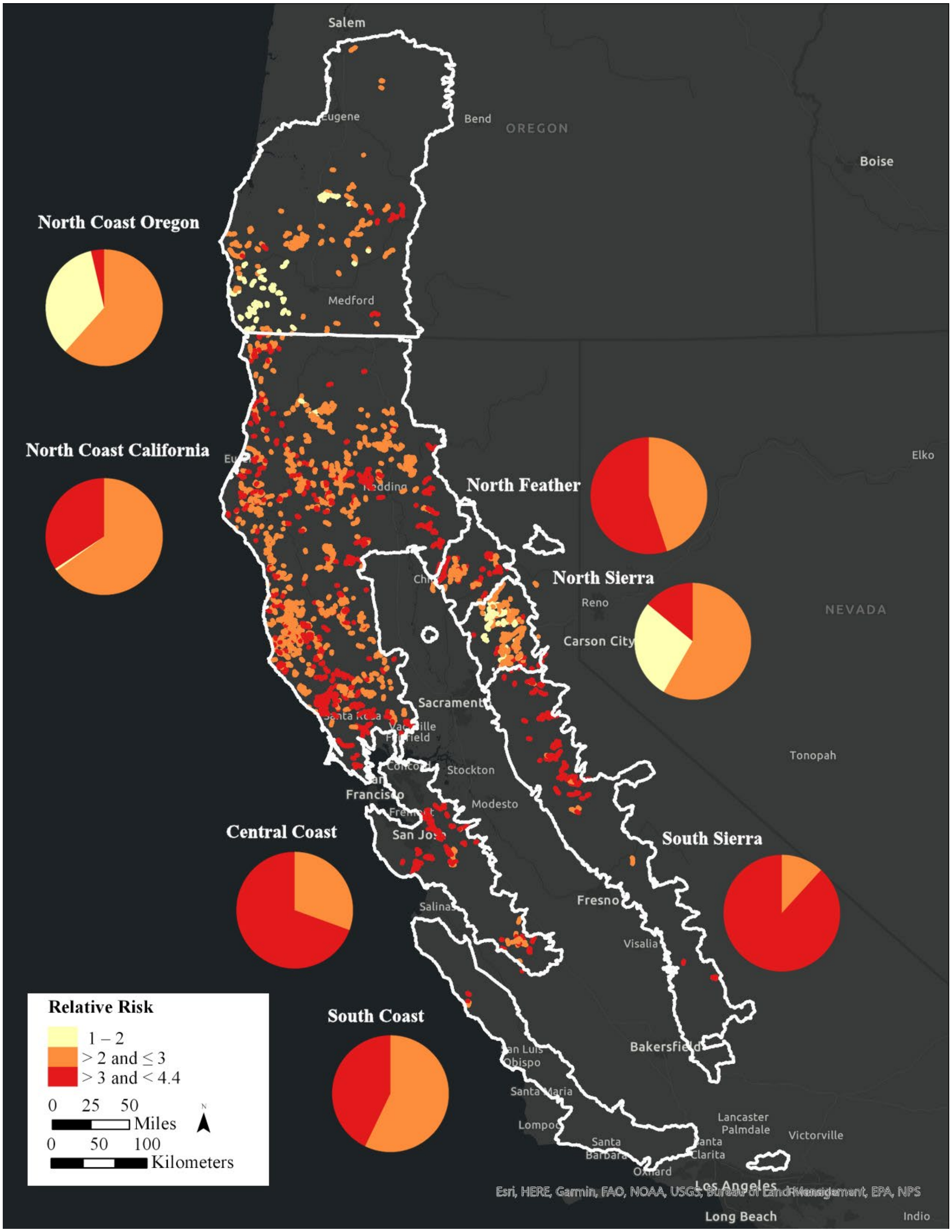


Figure 59. Mean change scenario risk of ≥50 percent decline over 40 years in stream segments occupied by the foothill yellow-legged frog (Rose *et al.* 2020, supplementary data). Relative risk (see Box 1) is binned into three categories (Table 13). Risk 1–2 = low (light yellow). Risk >2 and ≤3 = medium (orange). Risk >3 and <4.4 = high (red).

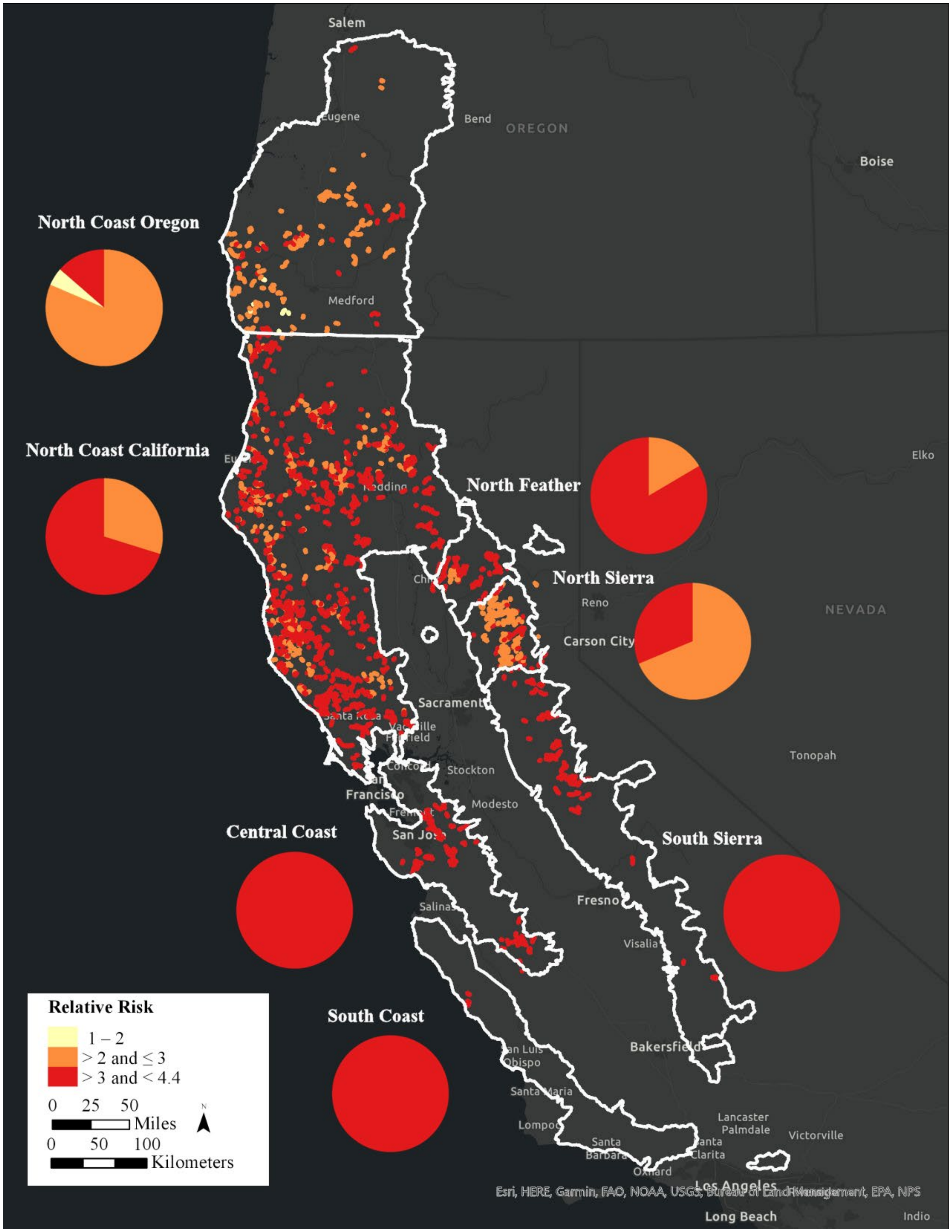


Figure 60. Higher change scenario risk of ≥50 percent decline over 40 years in stream segments occupied by the foothill yellow-legged frog (Rose *et al.* 2020, supplementary data). Relative risk (see Box 1) is binned into three categories (Table 13). Risk 1–2 = low (light yellow). Risk >2 and ≤3 = medium (orange). Risk >3 and <4.4 = high (red).

Table 18. Relative risk of decline summary for current condition and three future scenarios. See Box 1 for explanation of relative risk and Table 13 for information about risk bins (i.e., 1–2, 2–3, and >3). In the pie charts, light yellow = risk 1–2 (low risk category), orange = risk >2 and ≤3 (medium risk category), and red = risk >3 and <4.4 (high risk category).

Analysis Unit	Current Condition	Lower Change Scenario	Mean Change Scenario	Higher Change Scenario
North Coast Oregon	**Mean:** 1.95 **1–2:** 55% **2–3:** 42% **>3:** 3% 	**Mean:** 2.09 **1–2:** 47% **2–3:** 50% **>3:** 4% 	**Mean:** 2.23 **1–2:** 35% **2–3:** 62% **>3:** 4% 	**Mean:** 2.57 **1–2:** 5% **2–3:** 81% **>3:** 14% 
North Coast California	**Mean:** 2.40 **1–2:** 28% **2–3:** 56% **>3:** 16% 	**Mean:** 2.49 **1–2:** 23% **2–3:** 57% **>3:** 20% 	**Mean:** 2.84 **1–2:** 1% **2–3:** 65% **>3:** 34% 	**Mean:** 3.20 **1–2:** 0% **2–3:** 30% **>3:** 70% 
North Feather	**Mean:** 2.68 **1–2:** 15% **2–3:** 54% **>3:** 31% 	**Mean:** 2.69 **1–2:** 17% **2–3:** 49% **>3:** 34% 	**Mean:** 3.08 **1–2:** 0% **2–3:** 45% **>3:** 55% 	**Mean:** 3.37 **1–2:** 0% **2–3:** 17% **>3:** 83% 
North Sierra	**Mean:** 1.87 **1–2:** 65% **2–3:** 26% **>3:** 9% 	**Mean:** 1.99 **1–2:** 63% **2–3:** 26% **>3:** 11% 	**Mean:** 2.41 **1–2:** 28% **2–3:** 58% **>3:** 14% 	**Mean:** 2.81 **1–2:** 0% **2–3:** 69% **>3:** 31% 

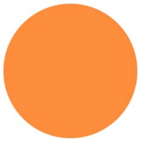
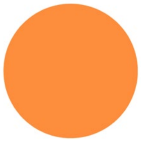
Analysis Unit	Current Condition	Lower Change Scenario	Mean Change Scenario	Higher Change Scenario
South Sierra	**Mean:** 2.94 **1–2:** 0% **2–3:** 63% **>3:** 37% 	**Mean:** 3.10 **1–2:** 0% **2–3:** 54% **>3:** 46% 	**Mean:** 3.35 **1–2:** 0% **2–3:** 12% **>3:** 88% 	**Mean:** 3.63 **1–2:** 0% **2–3:** 0% **>3:** 100% 
Central Coast	**Mean:** 2.76 **1–2:** 0% **2–3:** 84% **>3:** 16% 	**Mean:** 2.95 **1–2:** 0% **2–3:** 69% **>3:** 31% 	**Mean:** 3.14 **1–2:** 0% **2–3:** 31% **>3:** 69% 	**Mean:** 3.42 **1–2:** 0% **2–3:** 0% **>3:** 100% 
South Coast	**Mean:** 2.54 **1–2:** 0% **2–3:** 100% **>3:** 0% 	**Mean:** 2.71 **1–2:** 0% **2–3:** 100% **>3:** 0% 	**Mean:** 2.98 **1–2:** 0% **2–3:** 57% **>3:** 43% 	**Mean:** 3.29 **1–2:** 0% **2–3:** 0% **>3:** 100% 

Table 19. Summary of resiliency in the seven foothill yellow-legged frog analysis units. Functional extirpation is defined as such extensive reduction in condition that extirpation of the entire unit is likely to eventually occur as remnant populations experience normal environmental and demographic fluctuations. The qualitative terms that describe current resiliency (column 2) and change in resiliency (columns 3–6) are defined in Table 15 and Table 16, respectively.

Analysis Unit	Current Condition	Lower Change Scenario	Mean Change Scenario	Higher Change Scenario
North Coast Oregon	Intact	Slightly reduced from current	Slightly reduced from current	Markedly reduced from current
North Coast California	Intact	Slightly reduced from current	Markedly reduced from current	Greatly reduced from current Risk of functional extirpation
North Feather	Reduced	No change	Markedly reduced from current Risk of functional extirpation	Greatly reduced from current Risk of functional extirpation or extirpation
North Sierra	Intact	Slightly reduced from current	Markedly reduced from current	Greatly reduced from current
South Sierra	Substantially Reduced	Slightly reduced from current	Markedly reduced from current Risk of functional extirpation or extirpation	Greatly reduced from current Risk of functional extirpation or extirpation
Central Coast	Substantially Reduced	Slightly reduced from current	Markedly reduced from current Risk of functional extirpation or extirpation	Greatly reduced from current Risk of functional extirpation or extirpation

Analysis Unit	Current Condition	Lower Change Scenario	Mean Change Scenario	Higher Change Scenario
South Coast	Extensively Reduced	Slightly reduced from current Risk of extirpation	Markedly reduced from current Risk of extirpation	Greatly reduced from current Risk of extirpation

North Coast Oregon

The PVA results for three future scenarios suggest that there is a range of future conditions for the foothill yellow-legged frog in the North Coast Oregon unit. Over the next 40 years, average risk of population decline in this unit may increase only slightly from current condition (by 7 percent under the lower change scenario), or risk of decline may increase more substantially (by 14 percent under the mean change scenario or by 32 percent under the higher change scenario) (Table 18). Under current conditions, 55 percent of occupied stream segments in this unit are in the low risk category for relative risk of decline (see Box 1 for explanation of relative risk and Table 13 for definitions of risk categories). This proportion decreases to 47 percent under the lower change scenario, 35 percent under the mean change scenario, and 5 percent under the higher change scenario. Relative to the other analysis units, the North Coast Oregon unit has the lowest risk of decline under the mean and higher change scenarios and has the second-lowest risk of decline under current conditions and the lower change scenario. The projected increases in risk of decline between current condition and the mean and higher change scenarios are least severe in the North Coast Oregon unit.

Under current conditions, resiliency in the North Coast Oregon unit is intact, largely because of the number and distribution of occupied stream segments that are in the low relative risk of decline category in the southwestern and central portions of the unit. The projected increases in average relative risk of decline under the three future scenarios suggest that foothill yellow-legged frog occupancy and connectivity are likely to decline in the North Coast Oregon unit, particularly along the eastern boundary (Figure 58; Figure 59; Figure 60). However, the southwestern corner of the unit appears to remain a stronghold for the species, even under the higher change scenario (Figure 60). Compared to the other units, occupied stream segments in the North Coast Oregon unit appear to be less affected by the projected changes in environmental covariates under the future scenarios. Percent forest and shrub cover is projected to change very little by 2060 (< 0.3 percent of total area under the mean change scenario) in the North Coast (California and Oregon data summarized together) (Sleeter and Kreitler 2020, unpublished data). This unit could also be more resilient to projected changes in climate variables (i.e., stream temperature and annual streamflow). For example, projected increases in stream temperature over the next 40 years could increase population growth rates in cool streams. The North Coast Oregon unit also contains relatively few occupied stream segments that are regulated (two percent) and mean degree of regulation, which is linked to residual environmental stochasticity, is low (0.7) among the regulated streams (Rose *et al.* 2020, pp. 33, 71, table 7).

Future resiliency in the North Coast Oregon unit could be affected by threats that are not fully reflected in the PVA future scenarios. Synergistic effects of interactions among current and emerging threats (e.g., nonnative species, disease, and future climate change) are beyond the scope of the future scenarios. The increasing wildfire trend in this unit (Figure 38; Figure 39) may harm future resiliency if large, high-severity burns become increasingly common. However, increases in low- and moderate-severity wildfires in the North Coast Oregon unit could increase future resiliency by improving or re-establishing habitat where vegetation has become overgrown (R. Huff 2021, *in litt.*).

In summary, the projected increases in risk of decline suggest that the resiliency of the North Coast Oregon unit will decrease in the future, but decreases in resiliency are expected to be modest in comparison to other analysis units (Table 19). Under the lower change scenario, foothill yellow-legged frog resiliency in this unit would be slightly reduced from current condition (see Table 16 for descriptions of terms used to describe future change in resiliency). Under the mean change scenario, resiliency would be reduced more than under the lower change scenario; but the overall change from current condition might not be particularly noticeable. Under the higher change scenario, resiliency in the North Coast Oregon unit would be markedly reduced from current condition.

North Coast California

The PVA results for three future scenarios suggest that there is a wide range of future conditions for the foothill yellow-legged frog in the North Coast California unit. Over the next 40 years, average risk of population decline in this unit may increase slightly (by 4 percent under the lower change scenario), or risk of decline may increase substantially (by 18 percent under the mean change scenario and 33 percent under the higher change scenario) (Table 18). Under current conditions, 28 percent of occupied stream segments in this unit are in the low risk category for relative risk of decline (see Box 1 for explanation of relative risk and Table 13 for definitions of risk categories). This proportion decreases to 23 percent under the lower change scenario. Under the mean change scenario, nine occupied stream segments (one percent) are in the low risk category and none under the higher change scenario. The proportion of stream segments in the high risk of decline category increases from 16 percent to 34 percent under the mean change scenario and to 70 percent under the higher change scenario. Relative to the other analysis units, the North Coast California unit has the fifth-highest risk of decline under current conditions and all future scenarios.

Under current conditions, resiliency in the North Coast California unit is intact, largely because this unit contains the majority of presumed occupied stream segments, contains populations with high abundances, and has good connectivity across a large geographic area. The projected increases in average relative risk of decline under the three future scenarios suggest that occupancy, abundance, and/or connectivity are likely to decline throughout the unit, particularly in the regions just north of the San Francisco Bay and Central Valley (Figure 58; Figure 59; Figure 60). Under the lower change scenario, overall occupancy and/or abundance would decline slightly from current condition, but numerous stream segments remain in the low risk category (Figure 58). This could mean that the North Coast California unit is relatively resilient to small changes in climate variables (i.e., stream temperature and annual streamflow). It could also be related to the relatively low proportion of occupied stream segments that are regulated (7.4

percent) and relatively low degree of regulation among regulated streams (mean = 8.2), which is linked to residual environmental stochasticity (Rose *et al.* 2020, pp. 33, 71, table 7). Under the mean and higher change scenarios, increases in average relative risk of decline are likely to have more substantial impacts on occupancy, abundance, and/or connectivity (Figure 59; Figure 60). These increases in average relative risk of decline are also large relative to increases in other analysis units under the mean and higher change scenarios (Table 18).

Future resiliency in the North Coast California unit could also be affected by threats that are not fully reflected in the PVA future scenarios, such as high-severity wildfire or synergistic effects of threat interactions (e.g., illegal cannabis cultivation in combination with nonnative species and climate change). Wildfire trends (1950–2018) indicate that area burned annually is increasing in this unit (Figure 38; Figure 39). Increasing water demand and climate change projections for California also suggest that future conditions may necessitate increases in hydrological infrastructure and water storage capacity, which is linked to degree of regulation (Sections 7.1 and 7.13). Across all North Coast California unit watersheds, climate-induced surface water stress (i.e., where human demand outpaces natural supply) is projected to increase by 5–15 percent (from 1900–1970 levels) by mid-century (Averyt *et al.* 2013, p. 7, figure 7).

In summary, the projected increases in risk of decline and the increasing risk of serious threats suggest that the resiliency of the North Coast California unit will decrease in the future (Table 19). Under the lower change scenario, foothill yellow-legged frog resiliency in this unit would be only slightly reduced from current condition (see Table 16 for descriptions of terms used to describe future change in resiliency). Under the mean change scenario, resiliency would be markedly reduced from current condition. Under the higher change scenario, resiliency would be greatly reduced from current condition. The reduction in resiliency under the higher change scenario would put the North Coast California unit at risk of functional extirpation in 40 years.

North Feather

The PVA results for three future scenarios suggest that there is a range of future conditions for the foothill yellow-legged frog in the North Feather unit. Over the next 40 years, average risk of population decline in this unit may remain the same as current condition (lower change scenario), or risk of decline may increase substantially (by 15 percent under the mean change scenario and by 26 percent under the higher change scenario) (Table 18). Under current conditions, 15 percent of occupied stream segments in this unit are in the low risk category for relative risk of decline (see Box 1 for explanation of relative risk and Table 13 for definitions of risk categories). This proportion increases slightly to 17 percent under the lower change scenario, but then drops to zero under the mean and higher change scenarios (Figure 58; Figure 59; Figure 60). The proportion of stream segments that are in the high risk category increases from 31 percent under current conditions to 55 percent under the mean change scenario and 83 percent under the higher change scenario. Relative to the other analysis units, the North Feather unit has the third- or fourth-highest risk of decline under current conditions and all future scenarios. However, the North Feather unit consistently has the highest average relative risk of decline among the four northern analysis units.

Under current conditions, resiliency in the North Feather unit is reduced, largely because of the unit's relatively intermediate occupancy that covers only a small geographic area, relatively high risk of decline, and high degree of hydrological alteration. Under the lower change scenario, average relative risk of decline does not change from that of current condition (Table 18); therefore, resiliency measures in the North Feather unit may remain static. This could be related to how streams in the North Feather unit are colder, on average, than anywhere else in the species' range (Supplementary Table 1; Rose *et al.* 2020, pp. 71–72, table 7, table 8). Projected increases in future stream temperatures are likely to benefit many of the North Feather unit populations by increasing population growth rates. However, under the mean and higher change scenarios, the negative effects of increases in streamflow variability and residual environmental stochasticity likely outweigh the benefit of warmer stream temperatures. Thus, the projected increases in average relative risk of decline under the mean and higher change scenarios are likely to decrease occupancy, abundance, and connectivity dramatically.

Future resiliency in the North Feather unit could also be negatively affected by synergistic effects of threat interactions or threats that are not fully reflected in the PVA future scenarios. Trends indicate that area burned annually by wildfires has been growing sharply in the North Feather unit (Figure 38; Figure 39) and negative consequences from wildfire-related sedimentation to foothill yellow-legged frog reproduction have been documented in this unit (Section 7.9). Increasing water demand and climate change projections also suggest that future conditions may necessitate increases in hydrological infrastructure and water storage capacity, which is linked to degree of regulation (Sections 7.1 and 7.13). In North Feather unit watersheds, climate-induced surface water stress is projected to increase by 10–15 percent (from 1900–1970 levels) by mid-century (Averyt *et al.* 2013, p. 7, figure 7).

In summary, the projected increases in risk of decline and the increasing risk of serious threats suggest that the resiliency of the North Feather unit will either remain about the same or will decrease in the future (Table 19). Under the lower change scenario, foothill yellow-legged frog resiliency in this unit would be about the same as current condition (see Table 16 for descriptions of terms used to describe future change in resiliency). Under the mean change scenario, resiliency would be markedly reduced from current condition. Under the higher change scenario, resiliency would be greatly reduced from current condition. The decreases in resiliency under the mean and higher change scenarios would put this small North Feather unit at risk of functional extirpation or extirpation in 40 years.

North Sierra

The PVA results for three future scenarios suggest that there is a wide range of future conditions for the foothill yellow-legged frog in the North Sierra unit. Over the next 40 years, average risk of population decline in this unit may increase only slightly (by 7 percent under the lower change scenario), or risk of decline may increase substantially (by 29 percent under the mean change scenario and by 50 percent under the higher change scenario) (Table 18). Under current conditions, 65 percent of occupied stream segments in this unit are in the low risk category for relative risk of decline (see Box 1 for explanation of relative risk and Table 13 for definitions of risk categories). This proportion decreases slightly to 63 percent under the lower change scenario. Under the mean change scenario, 28 percent are in the low risk category and none under the higher change scenario. Relatively few occupied stream segments (<15 percent) in this unit are in the high risk category under the lower and mean change scenarios (11 and 14 percent, respectively). This proportion increases to 31 percent under the higher change scenario. Relative to the other analysis units, the North Sierra unit has the lowest risk of decline under the lower change scenario and has the second-lowest risk of decline under the mean and higher change scenarios. However, projected increases in average relative risk between current condition and the mean and higher change scenarios are sharpest in the North Sierra unit.

Under current conditions, resiliency in the North Sierra unit is intact, largely because this unit has high occupancy and the lowest average risk of decline among the seven analysis units. The projected increases in relative risk of decline under the three future scenarios suggest that occupancy, abundance, and connectivity, which is already poor in this unit, are likely to decline in the future (Figure 58; Figure 59; Figure 60). While stream segments in the North Sierra unit appear to be fairly resilient to projected conditions under the lower change scenario, dramatic declines in occupancy, connectivity, and/or abundance would be expected under the mean and higher change scenarios.

Future resiliency in the North Sierra unit could also be negatively affected by synergistic effects of threat interactions or threats that are not fully reflected in the PVA future scenarios. Increasing water demand and climate change projections suggest that future conditions in California may necessitate increases in hydrological infrastructure and water storage capacity (Sections 7.1 and 7.13), which is linked to degree of regulation. In North Sierra unit watersheds, climate-induced surface water stress is projected to increase by 10–15 percent (from 1900–1970 levels) by mid-century (Averyt *et al.* 2013, p. 7, figure 7). Future increases in high-severity wildfires may also be a concern; however, wildfire trends in this unit have been stable between 1950 and 2018 (Figure 38).

In summary, the projected increases in risk of decline and the increasing risk of serious threats suggest that the resiliency of the North Sierra unit will decrease in the future (Table 19). Under the lower change scenario, foothill yellow-legged frog resiliency in this unit would be slightly reduced from current condition (see Table 16 for descriptions of terms used to describe future change in resiliency). Under the mean change scenario, resiliency would be markedly reduced from current condition. Under the higher change scenario, resiliency would be greatly reduced from current condition.

South Sierra

The PVA results for three future scenarios suggest that there is a relatively limited range of future conditions for the foothill yellow-legged frog in the South Sierra unit. Over the next 40 years, average risk of population decline in this unit may increase slightly (by 6 percent under the lower change scenario), or risk of decline may increase more substantially (by 14 percent under the mean change scenario and by 24 percent under the higher change scenario) (Table 18). Under current conditions and all future scenarios, all occupied stream segments in this unit are in the medium or high risk categories for relative risk of decline (see Box 1 for explanation of relative risk and Table 13 for definitions of risk categories). Under current conditions, 37 percent of occupied stream segments in this unit are in the high risk of decline category. This proportion increases to 46 percent under the lower change scenario, 88 percent under the mean change scenario, and 100 percent under the higher change scenario. Relative to the other analysis units, the South Sierra unit has the highest risk of decline under current conditions and all future scenarios.

Under current conditions, resiliency in the South Sierra unit is substantially reduced because of the unit's low occupancy, documented history of extirpations, poor connectivity, high relative risk of decline, and severity of threats. The projected increases in average relative risk of decline under the three future scenarios suggest that occupancy and connectivity will continue to decline throughout the unit, especially in the northern part of the unit (Figure 58; Figure 59; Figure 60), where occupancy is currently highest (Figure 55). While the increase in risk of decline is projected to be slight under the lower change scenario, this slight increase could still be very damaging because resiliency is already substantially reduced under current conditions. The more dramatic declines in occupancy and connectivity that would be expected under the mean and higher change scenarios could be devastating for the South Sierra unit.

Future resiliency in the South Sierra unit could also be negatively affected by synergistic effects of threat interactions or threats that are not fully reflected in the PVA future scenarios. Wildfire trends indicate that area burned annually (Figure 38; Figure 39) and the proportion of burned area that is high severity (Figure 41) has been increasing in the South Sierra unit (Section 7.9). Increasing water demand and climate change projections also suggest that future conditions may necessitate increases in hydrological infrastructure and water storage capacity, which is linked to degree of regulation (Sections 7.1 and 7.13). In South Sierra unit watersheds, climate-induced surface water stress is projected to increase by 5–25 percent (from 1900–1970 levels) by mid-century (Averyt *et al.* 2013, p. 7, figure 7).

In summary, the projected increases in risk of decline and the increasing risk of serious threats suggest that the resiliency of the South Sierra unit will continue to decrease in the future (Table 19). Under the lower change scenario, foothill yellow-legged frog resiliency in this unit would be slightly reduced (see Table 16 for descriptions of terms used to describe future change in resiliency), but this reduction could still be very damaging for the South Sierra unit because resiliency is already substantially reduced (see Table 15 for definition of resiliency category). Under the mean change scenario, resiliency would be markedly reduced from current condition. Under the higher change scenario, resiliency would be greatly reduced from current condition. The reductions in resiliency under the mean and higher change scenarios would put the South Sierra unit at risk of functional extirpation or extirpation in 40 years.

Central Coast

The PVA results for three future scenarios suggest that there is a relatively limited range of future conditions for the foothill yellow-legged frog in the Central Coast unit. Over the next 40 years, average risk of population decline in this unit may increase slightly (by 7 percent under the lower change scenario), or risk of decline may increase more substantially (by 14 percent under the mean change scenario and by 24 percent under the higher change scenario) (Table 18). Under current conditions and all future scenarios, all occupied stream segments in this unit are in the medium or high risk categories for relative risk of decline (see Box 1 for explanation of relative risk and Table 13 for definitions of risk categories). Under current conditions, 16 percent of occupied stream segments in this unit are in the high risk category. This proportion increases to 31 percent under the lower change scenario, 69 percent under the mean change scenario, and 100 percent under the higher change scenario. Relative to the other analysis units, the Central Coast unit has the second-highest risk of decline under current conditions and all future scenarios.

Under current conditions, resiliency in the Central Coast unit is substantially reduced because of the unit's low occupancy, documented history of extirpations, mostly poor connectivity, relatively high risk of decline, and severity of threats. The projected increases in average relative risk of decline under the three future scenarios suggest that occupancy and connectivity will continue to decline throughout the unit, especially in the northern cluster of occupied stream segments (Figure 58; Figure 59; Figure 60), where connectivity is already poor. While the increase in risk of decline is projected to be slight under the lower change scenario, the more dramatic declines in occupancy and connectivity that would be expected under the mean and higher change scenarios could be devastating for the Central Coast unit.

Future resiliency in the Central Coast unit could also be negatively affected by synergistic effects of threat interactions or threats that are not fully reflected in the PVA future scenarios. Increasing water demand and climate change projections suggest that future conditions may necessitate increases in hydrological infrastructure and water storage capacity, which is linked to degree of regulation (Sections 7.1 and 7.13). In Central Coast unit watersheds, climate-induced surface water stress is projected to increase by 5–20 percent (from 1900–1970 levels) by mid-century (Averyt *et al.* 2013, p. 7, figure 7). Future increases in high-severity wildfires may also be a concern, despite wildfire trends in the Central Coast unit being stable between 1950 and 2018 (Figure 38). During the unprecedented 2020 wildfire season, numerous wildfires burned in the Central Coast unit including three large wildfires[24] that burned approximately 14 percent of the unit (CAL FIRE 2020, incident reports retrieved from https://www.fire.ca.gov/incidents/2020/; CAL FIRE 2021a, p. 9).

In summary, the projected increases in risk of decline and the increasing risk of serious threats suggest that the resiliency of the Central Coast unit will continue to decrease in the future (Table 19). Under the lower change scenario, foothill yellow-legged frog resiliency in this unit would be slightly reduced (see Table 16 for descriptions of terms used to describe future change in resiliency), but this reduction could still be very damaging for the Central Coast unit because resiliency is already substantially reduced. Under the mean change scenario, resiliency would be markedly reduced from current condition. Under the higher change scenario, resiliency would be greatly reduced from current condition. The reductions in resiliency under the mean and higher change scenarios would put the Central Coast unit at risk of functional extirpation or extirpation in 40 years.

South Coast

The PVA results for three future scenarios suggest that there is a limited range of future conditions for the foothill yellow-legged frog in the South Coast unit. Over the next 40 years, average risk of population decline in this unit may increase slightly (by 6 percent under the lower change scenario), or risk of decline may increase more substantially (by 17 percent under the mean change scenario and by 29 percent under the higher change scenario) (Table 18). Under current conditions and all future scenarios, all seven occupied stream segments in this unit are in

---

[24] Mineral Fire in Fresno County (12,006 hectares (29,667 acres)); San Mateo-Santa Cruz Unit (CZU) Lightning Complex in Santa Cruz and San Mateo counties (35,009 hectares (86,509 acres)); and Santa Clara Unit (SCU) Lightning Complex in Santa Clara, Alameda, Contra Costa, San Joaquin, Merced, and Stanislaus counties (160,508 hectares (396,624 acres)) (CAL FIRE 2020, incident reports retrieved from https://www.fire.ca.gov/incidents/2020/; CAL FIRE 2021a, p. 9)

the medium or high risk categories for relative risk of decline (see Box 1 for explanation of relative risk and Table 13 for definitions of risk categories). Under the mean change scenario, three of the seven occupied stream segments are in the high risk category. This proportion increases to 100 percent under the higher change scenario. Relative to the other analysis units, the South Coast unit has the third- or fourth-highest risk of decline under current conditions and all future scenarios.

Under current conditions, resiliency in the South Coast unit is extensively reduced because of the unit's low occupancy (seven stream segments), documented history of extirpations, insufficient connectivity, medium relative risk of decline, and severity of threats. With only two creeks that are known to be occupied, it is questionable whether the South Coast unit currently supports a viable population of foothill yellow-legged frogs. Therefore, additional declines in occupancy, like those that would be expected with the projected future increases in risk of decline, would likely lead to extirpation of the South Coast unit.

The future resiliency of the South Coast unit could also be negatively affected by synergistic effects of threat interactions or threats that are not fully reflected in the PVA future scenarios. Wildfire trends indicate that area burned annually has been increasing most sharply in the South Coast unit (Figure 38; Figure 39). Furthermore, wildfires in this unit have been trending towards higher-severity burns with proportions of burn areas classified as high severity reaching 80 percent in recent years (Figure 42). Increasing water demand and climate change projections also suggest that future conditions may necessitate increases in hydrological infrastructure and water storage capacity, which is linked to degree of regulation (Sections 7.1 and 7.13). In South Coast unit watersheds, climate-induced surface water stress is projected to increase by 5–20 percent (from 1900–1970 levels) by mid-century (Averyt *et al.* 2013, p. 7, figure 7).

In summary, the projected increases in risk of decline and the increasing risk of serious threats suggest that the resiliency of the South Coast unit will continue to decrease in the future (Table 19). Projected magnitudes of change in average relative risk of decline under the future scenarios are commensurate with those in other analysis units (e.g., South Sierra unit) (Table 18). However, the current resiliency of the South Coast unit is so extensively reduced that additional reductions would not substantially change overall condition. Any reductions in resiliency under the three future scenarios put the South Coast unit at increased risk of extirpation within 40 years.

9.4 Future Redundancy

We assessed future foothill yellow-legged frog redundancy (i.e., ability to withstand catastrophic events) both at the coarse scale of analysis units within the species' range (paragraph immediately below) and at a finer scale within each individual genetic clade (Table 20). As described in the current condition chapter (Section 8.6), there are six, substantially-divergent genetic clades, each representing a distinguishable portion of the species' genetic diversity. Therefore, it is appropriate to consider redundancy within each of the six genetic clades, as well as at the rangewide scale of analysis units.

At the coarsest scale, under current conditions, there are seven regions (analysis units) where foothill yellow-legged frogs are extant but only three appear to have intact resiliency. Under the three future scenarios, the number of analysis units that contain extant populations may decrease and resiliency in extant units will decline. Under the lower change scenario, the South Coast unit would be at risk of extirpation and two or three units would maintain intact resiliency. Under the mean change scenario, four of the seven analysis units would be at risk of functional extirpation or extirpation, and zero to three units would maintain intact resiliency. Under the higher change scenario, five of seven analysis units would be at risk of functional extirpation or extirpation, and none of the units would have intact resiliency.

To assess the future condition of redundancy for each genetic clade, we considered the (1) current number of occupied stream segments (proxy for subpopulations), (2) spatial distribution of occupied stream segments, (3) expected change in population resiliency (from current condition) under each future scenario (Section 9.3), and (4) potential for functional extirpation or extirpation under each future scenario. These factors were assessed in terms of their potential influence on the ability of foothill yellow-legged frog metapopulations to survive and recover from a plausible catastrophic event.

Under current conditions, we determined that long-term viability after a catastrophic event would be likely in the North Coast clade (North Coast California and North Coast Oregon units) and might be possible in the North Sierra clade. Because of the good functional connectivity across a large area, the North Coast clade would also likely be able to recover (i.e., repopulate extirpated or functionally extirpated areas) after an event, depending upon the event location. The North Sierra clade, however, would have limited ability to recover because of poor functional connectivity. Under the lower change scenario, resiliency in the North Coast and North Sierra clades would be slightly reduced from current condition. With slight reductions in resiliency, we expect that future redundancy would not notably change under the lower change scenario. Under the mean and higher change scenarios, resiliency decreases more substantially in the North Coast and North Sierra clades. The North Coast clade is so large that a single catastrophic event would be unlikely to lead to extirpation of the entire clade, but its ability to recover would decrease under the mean and higher change scenarios. The ability of the North Sierra clade to survive and/or recover from, a catastrophic event would decrease under the mean and higher change scenarios.

As the smallest clade, the North Feather is vulnerable to functional extirpation or extirpation from large catastrophic events, regardless of population resiliency, and its highly-regulated streams decrease its ability to recover after a catastrophic event. Under the lower change scenario, North Feather resiliency would not change from current condition. Therefore, redundancy would be limited under both current condition and the lower change scenario. Under the mean and higher change scenarios, resiliency would decrease substantially in the North Feather clade, making functional extirpation or extirpation possible, even in absence of a catastrophic event. Future redundancy in the North Feather clade could range from poor under the mean change scenario to zero under the higher change scenario (Table 20).

Current redundancy is poor in the South Sierra and Central Coast clades because of substantially reduced resiliency and patchy distribution of occurrences. With slight reductions in resiliency under the lower change scenario, we expect that future redundancy would remain poor in the South Sierra and Central Coast clades. While a single catastrophic event would be unlikely to extirpate the entirety of either unit under current conditions or the lower change scenario, limited connectivity would make it extremely unlikely that extirpated areas would be recolonized naturally. Under the mean and higher change scenarios, resiliency would decrease substantially in the South Sierra and Central Coast clades, making functional extirpation or extirpation possible, even in absence of a catastrophic event. Future redundancy in these clades could range from poor under the lower and mean change scenarios to zero under the higher change scenario (Table 20).

Current redundancy within the South Coast clade is nearly absent. Not only is the resiliency in this clade extensively reduced, but there are only two known populations (comprised of seven stream segments) that are very close in proximity. The entire South Coast clade would be at risk of extirpation from a single catastrophic event under current conditions and the three future scenarios (Table 20).

Table 20. Summary of current and future redundancy for the six foothill yellow-legged frog genetic clades. In this table, ability to survive a catastrophic event refers to the likelihood that a clade will maintain a level of long-term viability (i.e., not be extirpated or functionally extirpated) following a catastrophic event. The ability to recover refers to a clade's ability to repopulate extirpated or functionally extirpated areas after a catastrophic event. The terms, functional extirpation and extirpation, refer to the entire genetic clade, not individual populations or occurrences. Functional extirpation is defined as such extensive reduction in clade condition that extirpation of the entire clade is likely to eventually occur as remnant populations experience normal environmental and demographic fluctuations.

Clade	Current Condition	Lower Change Scenario	Mean Change Scenario	Higher Change Scenario
North Coast ability to survive a catastrophic event	Good	Good	Good	Good
North Coast ability to recover after catastrophic event	Good depending on location	Good depending on location	Limited depending on location	Poor depending on location
North Feather ability to survive a catastrophic event	Limited	Limited	Poor Functional extirpation plausible after event	Poor or no ability Extirpation plausible after event
North Feather ability to recover after catastrophic event	Limited	Limited	Poor	Poor or no ability
North Sierra ability to survive a catastrophic event	Good depending on scale	Good depending on scale	Limited	Poor
North Sierra ability to recover after catastrophic event	Limited	Limited	Limited	Poor
South Sierra ability to survive a catastrophic event	Poor	Poor	Poor Functional extirpation plausible after event	Poor or no ability Extirpation plausible after event
South Sierra ability to recover after catastrophic event	Poor	Poor	Poor	Poor or no ability

Clade	**Current Condition**	**Lower Change Scenario**	**Mean Change Scenario**	**Higher Change Scenario**
Central Coast ability to survive a catastrophic event	Poor	Poor	Poor Functional extirpation plausible after event	Poor or no ability Extirpation plausible after event
Central Coast ability to recover after catastrophic event	Poor	Poor	Poor	Poor or no ability
South Coast ability to survive a catastrophic event	No ability Extirpation plausible after event	No ability Extirpation plausible after event	No ability Extirpation plausible after event	No ability Extirpation plausible after event
South Coast ability to recover after catastrophic event	No ability	No ability	No ability	No ability

9.5 Future Representation

Representation describes the ability of a species to adapt to both near-term and long-term changes in its physical (e.g., climate conditions, habitat conditions, habitat structure, etc.) and biological (e.g., pathogens, competitors, predators, etc.) environments. This ability of a species to adapt to these changes is often referred to as "adaptive capacity." To assess the future condition of representation for the foothill yellow-legged frog, we considered the effects that the future scenarios could have on the diversity of ecological conditions and of genetic material throughout the range of the species.

Under current conditions, there is a considerable range of ecological conditions under which foothill yellow-legged frogs occur. There are also six divergent genetic clades (McCartney-Melstad *et al.* 2018, p. 112; Peek 2018, p. 76), but only two of the clades host populations with intact resiliency. The clades that are most genetically divergent (i.e., South Sierra, Central Coast, and South Coast), and thus could contribute most to the overall adaptive capacity (McCartney-Melstad *et al.* 2018, p. 120; Peek 2018, p. 77), are also the clades with the lowest levels of population resiliency under current and future conditions (Table 19). The foothill yellow-legged frog has likely already lost a lot of diversity (and thus, adaptive capacity) due to large extirpations in the southern clades. In spite of a trend toward increasing genetic diversity in the North Coast clade, the foothill yellow-legged frog is exhibiting an overall trend of decreasing genetic diversity (McCartney-Melstad *et al.* 2018, pp. 120–121; Peek 2018, p. 74).

The condition of future representation is likely to be lower than current representation. While the species' range will continue to host a wide range of ecological conditions, trends of declining occupancy are likely to continue, and extirpation of entire genetic clades is possible within 40 years (Table 19; Table 20). Under all future scenarios, the South Coast genetic clade could be lost within 40 years. Under the mean and higher change scenarios, four (North Feather, South Sierra, Central Coast, and South Coast) of the six genetic clades could be extirpated, functionally extirpated, or at risk of becoming functionally extirpated. The North Coast California analysis unit could also be at risk of functional extirpation under the higher change scenario. Furthermore, extreme (potentially catastrophic) events are becoming increasingly likely to occur due to climate change (OCCRI 2019, pp. 5–7, tables 2 and 3; Public Policy Institute of California 2020, not paginated), which increases the risk of large losses in genetic diversity.

A continuation of the trend toward decreasing genetic diversity in the future will decrease the foothill yellow-legged frog's adaptive capacity, and thus increase extinction risk in the face of future changes. It is of particular concern that the genetic diversity of the southern clades is at the greatest risk of being lost. The southern clades are where populations may be better adapted to persist under future climate conditions because streams are warmer and more intermittent. These conditions may increase throughout the species' range as temperatures increase and precipitation becomes more variable.

CHAPTER 10 Synthesis and Viability Summary

10.1 Overall Condition of Each Analysis Unit

In this section, we consider each analysis unit individually. The following subsections summarize each unit's current and potential future condition in terms of resiliency, redundancy, and representation. These summaries synthesize information from previous chapters to evaluate the probability of persistence (viability) of each analysis unit.

North Coast Oregon

Under current conditions, resiliency is intact in the North Coast Oregon unit. While condition is uncertain in large parts of the analysis unit because of limited survey information, there are numerous occupied stream segments in the central and southwestern portions of the unit that are both well-distributed and in the low risk of decline category. The North Coast Oregon unit has the second-lowest average relative risk of population decline among the seven analysis units and the lowest average relative risk of decline under the mean and higher change future scenarios. Compared to the other units, the PVA results suggest that occupied stream segments in the North Coast Oregon unit may to be less affected by projected changes under the future scenarios.

While there is enough information to determine that current resiliency in the North Coast Oregon unit is intact, there remains considerable uncertainty in the current and future status of occupancy, abundance, and connectivity across the entire unit. The unit has likely undergone declines and some range contraction, particularly in the northern portion of the species' historical range in Oregon (near the Willamette Valley), but declines appear to be less severe than previously described (see subsection titled "Analysis Unit Occupancy and Abundance" under Section 8.2 for details). For example, 2019–2020 environmental DNA surveys (National Genomics Center for Wildlife and Fish Conservation 2021, unpublished data) detected the foothill yellow-legged frog in areas that were previously assumed to be extirpated. Reviewers of version 1.0 of this SSA Report also emphasized the need for additional surveys to better determine the status of occupancy in Oregon (A. Duarte 2021, *in litt.*; J. Keehn 2021, *in litt.*; D. Olson 2021, *in litt.*). There is also uncertainty in the severity of negative effects from threats in the North Coast Oregon unit (e.g., altered hydrology, nonnative species, agriculture, mining, urbanization (including roads and recreation), drying and drought). However, some threats appear to be less severe in this unit compared to other analysis units. For example, altered hydrology is lowest in this unit (Supplementary Table 1) and Oregon's cooler and wetter climate reduces the likelihood of large-scale extirpations from drying and drought. While projected future conditions (under all three scenarios) will increase the risk of population declines in the North Coast Oregon unit, the future resiliency of this unit will largely depend on the abundances of frogs in extant populations, which are unknown. If population abundances are low, even small increases in risks of decline could result in extirpations, whereas small increases in risks might have little impact on large populations.

The North Coast Oregon unit has likely lost some of its historical redundancy, but there are 227 stream segments that have had "recent" (2000–2020) detections of the species (Rose *et al.* 2020,

p. 70, table 6)[25] and inclusion of new detection data would increase the number of occupied stream segments to at least 350. Occupied stream segments are also distributed over a large geographic area, which increases the unit's probability of persistence in the face of catastrophic events. Because a catastrophic event (e.g., large, high-severity wildfire) would be unlikely to extirpate the entire unit, redundancy appears to be adequate.

Current representation is high in the North Coast Oregon unit. There are occupied streams in both coastal and interior ranges and across the latitudinal and longitudinal breadths of the North Coast Oregon unit. However, representation is at risk of declining in the future, especially if genetic connectivity is already limited (as suggested by McCartney-Melstad *et al.* (2018, p. 117, figure 3)) and genetic drift occurs.

The available information suggests that declines in resiliency, redundancy, and representation are likely in the North Coast Oregon unit, but unit-wide extirpation or functional extirpation is unlikely in 40 years. Threats in this unit are less severe and populations will likely be more resilient to future changes than populations in other parts of the species' range.

North Coast California

Under current conditions, resiliency and redundancy are relatively high in the North Coast California unit. Despite several documented extirpations, this unit contains the most abundant foothill yellow-legged frog populations and the majority (n = 1,443) of stream segments that have had "recent" (2000–2020) detections of the species. Stream segments with recent detections also have good connectivity and are distributed over a large area, which will allow this unit to survive and recover from catastrophic events. Although average risk of decline is higher in this unit than in the North Coast Oregon and North Sierra units, the North Coast California unit contains 382 stream segments in the low risk of decline category. As a whole, this unit may be the most resilient unit in the species' range and does not currently appear to be at risk of regional extirpation. However, occupancy and population density vary greatly among populations in this unit (Rose *et al.* 2020, pp. 63–64, table 1).

Representation is also high in the North Coast California unit. Like the North Coast Oregon unit, there are occupied streams in both coastal and interior mountain ranges and across the latitudinal and longitudinal breadths of the large North Coast California unit. Genetic analyses determined that the North Coast clade (comprised of the two North Coast analysis units) has the greatest intra-clade genetic diversity and may be experiencing a trend of increasing genetic diversity, potentially as a result of a range expansion from multiple source populations (McCartney-Melstad *et al.* 2018, pp. 120–121; Peek 2018, p. 74). The good connectivity and large latitudinal gradient in the North Coast California unit may also provide adaptive capacity for responding to the effects of climate change.

While most factors point toward a high probability of persistence of the North Coast California unit, the modeled risk of population decline results, and level of threats, are concerning. Under current and future conditions, the large majority of stream segments with recent detections are in

---

[25] Rose *et al.* (2020) reported 231 occupied stream segments, but we removed four stream segments from the data presented in this report, based on expert reviewer comments that the species in these stream segments were likely misidentified as foothill yellow-legged frogs. Also note the 227 occupied stream segments do not include new detection data that became available during 2021. However, the new data are depicted in Figure 47 and Figure 55.

the medium or high risk of decline categories. Under the higher change scenario, 70 percent are in the high risk category. Like in the rest of the range, altered hydrology is among the most impactful threats to the foothill yellow-legged frog in the North Coast California unit. Illegal cannabis cultivation is also a major issue in this unit; illegal water diversions and pesticides for cannabis are reportedly linked to local population declines (Service 2019, *in litt.*, p. 33). Other major threats that likely have or are contributing to declines include nonnative species, agriculture, mining, urbanization (including roads and recreation), and high-severity wildfire.

The available information suggests that resiliency will decrease in the North Coast California unit, but the unit's high level of current resiliency (particularly from high abundances and numerous populations with good connectivity) may allow this unit to maintain sufficient viability into the future. High resiliency, redundancy, and representation means that unit-wide extirpation or functional extirpation is unlikely to occur in 40 years. However, with current levels of threats and projected increases in threats from the effects of climate change, functional extirpation of this unit is possible under the higher change scenario. This major loss of viability would not only depend on future environmental conditions, but also on how strongly conditions affect population resiliency and on current population abundances. For example, high risks of population decline in the North Coast California unit may lead to decreases in abundance only for populations with initially high abundances but cause extirpations in populations with initially low abundances. Because population abundances are unknown for most streams and abundance varies widely among North Coast California populations with egg mass counts (Rose *et al.* 2020, pp. 63–64, table 1), the extent to which local extirpations are likely is uncertain. Numerous extirpations would decrease redundancy and representation, as well as resiliency. While this unit has sufficient viability for the 40-year time horizon, uncertainty in how viability could change in the future suggests that populations should be closely monitored in the North Coast California unit.

North Feather

Under current conditions, resiliency in the North Feather unit is reduced. The North Feather unit is the smallest analysis unit and contains 118 stream segments that have had "recent" (2000–2020) detections of the species. This unit has undergone range contraction in the eastern portion of the species' historical range in Plumas County. Abundances of foothill yellow-legged frogs in the North Feather unit are largely unknown but egg mass densities are very low in the two regulated stream reaches that have long-term monitoring (Rose *et al.* 2020, pp. 63–64, table 1). Functional connectivity is also uncertain because of limited genetic sampling, but the high degree of regulation in this unit suggests that breaks in genetic connectivity may be common. The North Feather unit has the greatest average risk of population decline among the four northern analysis units under current conditions and all future scenarios. Threats are severe in the North Feather unit (along with the North Sierra unit) because it is in the most hydrologically altered part of the foothill yellow-legged frog's range (Supplementary Table 1) and potentially is among the most impacted by historical mining (Hayes *et al.* 2016, pp. 53–54). Other threats, including nonnative species (bullfrogs and crayfish), agriculture, urbanization, recreation, high-severity wildfire, and the effects of climate change are also affecting extant populations in this unit.

Reduced resiliency in the North Feather unit is concerning because this unit is small and faces severe threats. Under current conditions and the lower change scenario, fewer than 18 percent of stream segments with recent detections are in the low risk of decline category. Under the mean change and higher change scenarios, most of the stream segments with recent detections in the North Feather unit are in the high risk of decline category and none are in the low risk category. Because of these risks of decline and the small size of the unit, the North Feather unit could become functionally extirpated within 40 years under the mean change scenario or be extirpated within 40 years under the higher change scenario. Risk of extirpation will, in part, depend on factors that are currently uncertain, such as current population abundances, future success of recent headstarting conservation efforts (efforts described in Table 9), and population-level response to future climate change.

Redundancy has decreased in the North Feather unit. The extant North Feather populations occupy an area small enough that a large catastrophic event, such as a high-severity wildfire or drought, could result in functional extirpation of the analysis unit. Furthermore, the unit's highly-regulated streams decrease its ability to recover after a catastrophic event. Therefore, redundancy is limited under current conditions and the lower change scenario. Under the mean and higher change scenarios, resiliency would decrease substantially, making functional extirpation or extirpation possible, even in absence of a catastrophic event. Thus, future redundancy in the North Feather unit could range from poor under the mean change scenario to zero under the higher change scenario.

Like resiliency and redundancy, representation in the North Feather unit has also declined due to range contraction and extirpations. The eastern extirpations and the small size of the North Feather genetic clade limit the amount of representation in the unit. If genetic connectivity is poor in the North Feather unit (as suggested by the high degree of regulation), populations could be losing genetic diversity through genetic drift and inbreeding (Peek *et al.* 2021, p. 14).

The available information suggests that declines in resiliency, redundancy, and representation are likely in the North Feather unit. This unit is at risk of unit-wide extirpation or functional extirpation within 40 years, either through random environmental or demographic stochasticity, or from a catastrophic event. However, more information is needed to estimate the likelihood of unit-wide extirpation or functional extirpation. Additional information regarding population abundances and genetic connectivity in this unit would be helpful for better understanding of the current and future viability of the North Feather unit.

North Sierra

Under current conditions, resiliency is intact in the North Sierra unit. This unit has the greatest proportion of stream segments that have had "recent" (2000–2020) detections of the species (relative to the number of potential stream segments) and more than half of all known occurrences have had recent detections. The North Sierra unit also has the lowest average risk of population decline among the seven analysis units under current conditions and the lower change scenario. The relatively low risk of population decline in the North Sierra unit across all scenarios is somewhat surprising considering its high level of altered hydrology. In addition, the analysis units to the north (North Feather unit) and south (South Sierra unit) have much greater risks of decline. However, the pattern in risk of decline across the three Sierra Nevada units matches the observed patterns in occupancy and abundance.

While current resiliency is intact in the North Sierra unit, this unit is vulnerable because of poor connectivity and severe threats. Threats are severe because (along with the North Feather unit) this unit is in the most hydrologically altered part of the foothill yellow-legged frog's range (Supplementary Table 1) and potentially most impacted by historical mining (Hayes *et al.* 2016, pp. 53–54). Urban land cover is also projected to increase by 50 percent between 2020 and 2060 in the North Sierra unit (Sleeter and Kreitler 2020, unpublished data). Other threats, including nonnative species, agriculture, recreation, and the effects of climate change are also affecting extant populations in this unit.

Current redundancy is relatively high in the North Sierra unit. Although this unit is second-smallest in size, it has the second-highest number of stream segments that have had detections of the species during 2000–2020 (n = 302) and only two confirmed extirpated occurrences. However, the small size of and poor connectivity in this unit threaten the unit's ability to survive or recover from a catastrophic event. Relatively high resiliency under current conditions and the lower change scenario suggests that the North Sierra unit could survive a catastrophic event, but poor connectivity might prevent the foothill yellow-legged frog from repopulating extirpated areas. Redundancy will be limited or poor under the mean or higher change scenarios, respectively.

Representation is likely decreasing in the North Sierra unit. Although this unit has high occupancy, genetic study revealed that North Sierra populations in regulated watersheds are exhibiting a declining trend in genetic diversity (Peek *et al.* 2021, p. 14). With projected declines in future resiliency and poor genetic connectivity, representation is expected to continue to decline through genetic drift and inbreeding.

The available information suggests that declines in resiliency, redundancy, and representation are likely in the North Sierra unit, but unit-wide extirpation or functional extirpation is unlikely within 40 years. However, the severity of threats, uncertainty in population response to future threat regimes, and poor connectivity suggest that North Sierra unit populations should be closely monitored for changes in status. If precipitous declines in occupancy or abundances are observed, unit-wide extirpation or functional extirpation could become likely within the 40-year time horizon. Restoring connectivity among regulated watersheds would greatly improve the North Sierra unit's long-term viability and protect its current level of representation.

South Sierra

Under current conditions, resiliency in the South Sierra unit is substantially reduced. This unit has undergone range contraction in its southern extent and the proportion of extirpated occurrences is second only to the South Coast analysis unit (CDFW 2019b, pp. 37–38). In the southern two-thirds of the South Sierra unit, a total of eight stream segments (in three isolated population fragments) have had detections of foothill yellow-legged frogs during 2000–2020. Both structural and functional connectivity are poor in the South Sierra unit. While abundances are largely unknown, they appear to be small relative to northern populations (Lind *et al.* 2003, p. 26; Rose *et al.* 2020, pp. 63–64, table 1). The South Sierra unit has the highest average risk of decline among the seven analysis units under current conditions and all future scenarios. There are no stream segments in the low risk category under current conditions or any future scenario and all segments are in the high risk category under the higher change scenario.

Threats are numerous and severe in the South Sierra unit; they include altered hydrology, agriculture (including airborne pesticide drift and illegal cannabis cultivation), nonnative species, disease and parasites, mining, urbanization (including roads and recreation), high-severity wildfire, drought, extreme flooding, and the effects of climate change. Although the proportion and degree of regulated streams (occupied and unoccupied) in the South Sierra unit is lower than in the other Sierra Nevada Mountain units (Supplementary Table 1), focal streams in the South Sierra exhibited the greatest residual environmental stochasticity in the MPVA (Rose *et al.* 2020, p. 66, table 3). Among the seven analysis units, percent of forest and shrub cover is second-lowest and mean August stream temperature (occupied and unoccupied streams) is highest in the South Sierra unit (Supplementary Table 1). Streams in the South Sierra unit are also subject to drying, which shortens the hydroperiod; negatively affects habitat elements that are hydrology-dependent; limits recruitment, survival, and connectivity; and exacerbates the effects of other threats. The proximity of foothill yellow-legged frog habitat downwind of the San Joaquin Valley (greatest use of airborne pesticides) is also a serious concern for foothill yellow-legged frog viability in the South Sierra unit. With current levels of threats and projected increases in threats from the effects of climate change, the South Sierra unit could become functionally or completely extirpated within 40 years under either the mean change or higher change scenarios.

Range contraction and extensive extirpations indicate that this analysis unit has lost redundancy, as well as resiliency. Redundancy is poor in the South Sierra unit because of the patchy distribution of stream segments with detections during 2000–2020and substantially reduced resiliency. Despite the South Sierra unit's large size, there are 153 occupied (or presumed occupied) stream segments, all of which are in the medium risk or high risk categories for relative risk of decline. Of the 256 total CNDDB Element Occurrences in this unit, fewer than half have had positive detections of the foothill yellow-legged frog since 2000 (CDFW 2020, dataset). Additional reductions in resiliency under the future scenarios will further weaken the South Sierra unit's ability to survive catastrophic events. While a single catastrophic event would be unlikely to extirpate the entirety of the unit under current conditions or the lower change scenario, limited connectivity would make it extremely unlikely that extirpated areas would be recolonized naturally. Under the mean change or higher change scenarios, functional extirpation or total extirpation, respectively, would be plausible from a catastrophic event.

Like resiliency and redundancy, representation in the South Sierra unit has also declined due to range contraction and extirpations. Extirpations throughout the southern two-thirds of this unit suggest that considerable representation has been lost. The South Sierra unit also has relatively low genetic diversity and a trajectory of genetic diversity loss (Peek 2018, p. 74).With projected declines in future resiliency and poor functional connectivity, representation is expected to continue to decline through additional extirpations, genetic drift, and inbreeding.

The available information suggests that declines in resiliency, redundancy, and representation are likely to continue in the South Sierra unit. This unit is at risk of unit-wide extirpation or functional extirpation within 40 years, either through random environmental or demographic stochasticity, or from a catastrophic event. Based on the extent of extirpations and number of co-occurring threats, mitigation of multiple threats may be necessary to maintain existing populations and necessary prior to population reestablishment in extirpated areas.

Central Coast

Under current conditions, resiliency in the Central Coast unit is substantially reduced. This unit has undergone range contraction in portions of its northern and central regions, leaving two clusters of stream segments that have had “recent” (2000–2020) detections of the species. The smaller southern cluster appears to have functional connectivity, but all four localities sampled in the larger northern cluster were genetically different one another (McCartney-Melstad *et al.* 2018, p. 117, figure 3), indicating a lack of functional connectivity. Central Coast unit populations in unregulated streams (or streams with less than 5 percent degree of regulation) that have time-series data of egg mass counts have average abundances of approximately 18 breeding females per km (Rose *et al.* 2020, pp. 63–64, table 1), which is much lower than abundances in many northern California streams with similar levels of regulation. The Central Coast unit has the second-greatest average risk of population decline among the seven analysis units under current conditions and all future scenarios. None of the stream segments with recent detections are in the low risk category under current conditions or any future scenario and all segments are in the high risk category under the higher change scenario.

Threats are numerous and severe in the Central Coast unit; they include altered hydrology, disease (including chytridiomycosis mortality events), drought, nonnative bullfrogs, urbanization (including roads and recreation), agriculture, illegal cannabis cultivation, extreme flood events, high-severity wildfire, and the effects of climate change. Human land use of the area within and around the Central Coast unit is particularly high and the proportion of forest and shrub cover is lowest in the Central Coast unit. Like the other southern analysis units, streams in the Central Coast unit are subject to drying, which shortens the hydroperiod; negatively affects habitat elements that are hydrology-dependent; limits recruitment, survival, and connectivity; and exacerbates the effects of other threats. With current levels of threats and projected increases in threats from the effects of climate change, the Central Coast unit could become functionally or completely extirpated within 40 years under either the mean change or higher change scenarios.

Range contraction and extirpations indicate that this analysis unit has lost redundancy, as well as resiliency. Redundancy is poor in the Central Coast unit because of the patchy distribution of stream segments with recent detections and substantially reduced resiliency. There are 175 occupied (or presumed occupied) stream segments in the Central Coast unit, all of which are in the medium risk or high risk categories for relative risk of decline. Of the 170 total CNDDB Element Occurrences in this unit, fewer than half have had positive detections of the foothill yellow-legged frog since 2000 (CDFW 2020, dataset). Additional reductions in resiliency under the future scenarios are likely to further weaken the Central Coast unit’s ability to withstand catastrophic events. While a single catastrophic event would be unlikely to extirpate the entirety of the unit under current conditions or the lower change scenario, limited connectivity would make it extremely unlikely that extirpated areas would be recolonized naturally. Under the mean change and higher change scenarios, functional extirpation or total extirpation, respectively, would be plausible from a catastrophic event.

Like resiliency and redundancy, representation in the Central Coast unit has also declined due to range contraction and extirpations. Extirpations of San Francisco Bay area populations could indicate that considerable representation has been lost in this unit because the Bay area is ecologically different from the rest of the Central Coast unit. The Central Coast unit has relatively low genetic diversity (McCartney-Melstad *et al.* 2018, supplemental information, table s4) and a trajectory of genetic diversity loss (Peek 2018, p. 76). With projected declines in future resiliency and limited genetic connectivity, representation is expected to continue to decline through additional extirpations, genetic drift, and inbreeding, especially in the northern cluster of stream segments.

The available information suggests that declines in resiliency, redundancy, and representation are likely to continue in the Central Coast unit. This unit is at risk of unit-wide extirpation or functional extirpation within 40 years, either through random environmental or demographic stochasticity, or from a catastrophic event. Based on the extent of extirpations and number of co-occurring threats, mitigation of multiple threats may be necessary to maintain existing populations and necessary prior to population reestablishment in extirpated areas.

South Coast

Under current conditions, resiliency, redundancy, and representation are poor in the South Coast analysis unit. Foothill yellow-legged frogs are mostly extirpated in this unit and there have only been detections of the species in seven stream segments since the year 2000. These seven stream segments are in two creeks (and a tributary to one of the creeks) that are proximate to one another but appear to have lost genetic connectivity between them. Although the creeks are unregulated, risk of population decline is medium or high (relative to populations across the species' range) under current conditions and all future scenarios. Furthermore, the close proximity of the seven stream segments makes the South Coast unit especially vulnerable to extirpation from a catastrophic event. The South Coast unit also has the lowest intra-clade genetic diversity (McCartney-Melstad *et al.* 2018, p. 123) and a trajectory of genetic diversity loss (Peek 2018, p. 76).

There are numerous, severe threats to foothill yellow-legged frogs in the South Coast unit such as altered hydrology, drought, nonnative species, disease, urbanization (including roads and recreation), illegal cannabis cultivation, extreme flood events, high-severity wildfire, and the effects of climate change. Like the other southern analysis units, streams in the South Coast unit are subject to drying, which shortens the hydroperiod; negatively affects habitat elements that are hydrology-dependent; limits recruitment, survival, and connectivity; and exacerbates the effects of other threats. The South Coast unit is also experiencing an increasing trend in both wildfire burn area and wildfire burn severity. Based on the extent of extirpations, it is uncertain whether foothill yellow-legged frogs could persist elsewhere in this unit without threat mitigation.

The projected future increases in risk of decline and the increasing risk of serious threats (including projected increases in threats from the effects of climate change) suggest that the South Coast unit is at high risk of unit-wide extirpation. With a total of two creeks that are known to be occupied, it is questionable whether this unit has any viability. Therefore, additional declines in occupancy, like those that would be expected with the projected future increases in risk of decline, would likely lead to extirpation of the South Coast unit.

10.2 Viability Summary

The goal of this SSA report is to describe the viability of the foothill yellow-legged frog in a manner that addresses the needs of the species in terms of resiliency, representation, and redundancy. We used the SSA framework and the best available information to describe the current condition and project the future condition of foothill yellow-legged frog across the range of the species. These methods allowed us to summarize and compare relative risks of extirpation among regions under current conditions and how we expect conditions may change over the next 40 years under three plausible future scenarios. As new information becomes available, our projections of risk for regional extirpations or functional extirpations may need to be modified.

Threats

As a stream-dependent species, the foothill yellow-legged frog relies on a number of specific habitat conditions that are tied to the natural hydrological cycle (e.g., spring recession flow, temperature, substrate, water depth, synchronous food availability, etc.) to complete its life cycle. Reproduction and recruitment of juvenile foothill yellow-legged frogs into a population is dependent upon habitat quality (including spatial and temporal conditions associated with the natural hydrological cycle) and on the magnitudes and combinations of threats. Many threats also decrease juvenile and adult survival, which have a larger effect on population abundance and viability.

Altered hydrology (including the creation of dams and water impoundments, disruption of natural flow and sediment transport regimes below dams, etc.) has been identified as a major driver of foothill yellow-legged frog population declines and as an impediment to dispersal and metapopulation connectivity. While breeding still occurs in many altered ("regulated") streams, the density of egg masses observed in regulated streams is more than ten times less than in unregulated (free-flowing) streams (Rose *et al.* 2020, p. 30). In some cases, hydrologically altered streams are also hypothesized to be population sinks where female emigrants from nearby populations lay eggs, but recruitment typically fails due to poor conditions (Rose *et al.* 2020, pp. 47–48).

In addition to altered hydrology, the foothill yellow-legged frog faces a variety of other threats, many of which are rangewide but others that are regionally specific. The rangewide threats (e.g., climate change, altered hydrology, nonnative species, agriculture, etc.) vary in magnitude across the species' range, at both a regional scale and a local scale. The major threats that are regionally specific (e.g., drought, extreme flood events, and chytridiomycosis) mostly affect populations in the southern part of the range (South Sierra, Central Coast, and South Coast units). However, these regional threats, especially drought, are beginning to threaten northern populations (North Coast Oregon, North Coast California, North Feather, and North Sierra units) or are increasingly likely to threaten northern populations in the future as a result of climate change.

Precipitous declines in the southern analysis units during the twentieth century led to rapid extirpations of the species from large portions of the historical range. The complexity of multiple interacting threats makes it difficult to determine the relative influences of co-occurring threats and identify the most influential factor(s) that led to historical extirpations. The species' history of sudden, rapid extirpations suggests that the foothill yellow-legged frog may be at risk of extensive declines that could occur with limited warning. Thus, there is considerable uncertainty in the future condition of seemingly healthy populations because severe population declines could be triggered by chance events, a tipping point in threat accumulation, or other unidentified vulnerabilities.

Based on climate change projections over the next 40 years, environmental conditions that the foothill yellow-legged frog relies upon to complete its life cycle are likely to shift and become more erratic. Increases in extreme inter- and intra-annual precipitation and streamflow variability, including greater frequency of extreme floods and droughts, are projected (Grantham *et al.* 2018, p. 439; Swain *et al.* 2018, pp. 427–431). Stream water temperatures, especially in streams that are already warm, are also projected to increase (Isaak *et al.* 2017, pp. 9184–9189, table 1; NorWeST dataset), which could exacerbate other threats, such as nonnative species and disease.

Resiliency

Foothill yellow-legged frog population condition varies widely across the species' range. The current and projected future conditions of populations are substantially lower in the southern part of the foothill yellow-legged frog's range (South Sierra, Central Coast, and South Coast units) than in the northern part (North Coast Oregon, North Coast California, North Feather, and North Sierra units). This latitudinal difference in condition aligns with our threat assessment, which identified a greater number of influential threats affecting populations in the southern part of the range. However, population resiliency varies widely within and among the four northern analysis units. Although the four northern analysis units are less affected by several threats (e.g., climate change, chytridiomycosis, urbanization), there have been numerous declines and many streams (14 percent of northern analysis unit stream segments with detections during 2000–2020) are currently in the high risk of decline category.

Under current conditions and all future scenarios, the southernmost and most genetically distinct analysis unit (South Coast unit) is at high risk of unit-wide extirpation. Under the lower change scenario, population resiliency is projected to decrease slightly in most analysis units. Under the mean change and higher change scenarios, resiliency is expected to decrease more steeply. Under the mean change scenario, population resiliency is projected to decrease in all analysis units and the average relative risk of population decline within 40 years increases by 18 percent from current condition. All three of the southern analysis units would be at risk of unit-wide extirpation under the mean change scenario and the North Feather unit would be at risk of functional extirpation within 40 years. Under the higher change scenario, the average relative risk of population decline within 40 years increases by 33 percent from current condition. Under this scenario, all but the North Coast Oregon and North Sierra units would be at risk of unit-wide extirpation or functional extirpation within 40 years.

Redundancy

Redundancy, measured through the quantity and spatial distribution of resilient metapopulations, is especially important to foothill yellow-legged frog viability in the face of climate change. Over the next 40 years, wet and dry climate extremes are projected to increase in the species' range, including the occurrence of potentially catastrophic events (e.g., large droughts, extreme flood events, high-severity wildfires). Based on our assessment, there is a much greater number and greater distribution of stream segments with recent (2000–2020) detections (used as a proxy for subpopulations, a group of which would comprise a metapopulation) in the northern half of the species' range. The southern half of the range, and parts of the northern half, have limited to no ability to survive a catastrophic event under current conditions. Furthermore, the lack of functional connectivity through most of the range will impede recolonization of extirpated areas. Therefore, all but the North Coast genetic clade would be unlikely to recover after a catastrophic event. With projected declines in population resiliency under the three future scenarios, the foothill yellow-legged frog's ability to survive catastrophic events is expected to decrease over the next 40 years under all three future scenarios. In turn, lack of recovery following future catastrophic events will accelerate declining resiliency.

Representation

Representation describes the species' adaptive capacity, or ability to adapt to both near-term and long-term changes in its physical and biological environments. To assess the foothill yellow-legged frog's adaptive capacity, we considered the diversity of ecological conditions and genetics, as well as population resiliency, throughout the range of the species. As a wide-ranging species, the foothill yellow-legged frog occupies a considerable range of ecological conditions and is comprised of six divergent genetic groups ("clades"). The good connectivity and large latitudinal gradient in the North Coast clade may provide adaptive capacity for responding to the effects of climate change. The northern Sierra clades (i.e., North Feather and North Sierra clades) might also have unique adaptive potential in the face of climate change because of their admixture history (mixture of genetic material from neighboring clades) and intermediacy to the South Sierra and North Coast clades (McCartney-Melstad *et al.* 2018, p. 121; Peek 2018, pp. 62–64, figure 3.2).

However, the adaptive capacity of the foothill yellow-legged frog is constrained by declining population resiliency and poor genetic connectivity throughout most of the species' range. The species is exhibiting an overall trend of decreasing genetic diversity (McCartney-Melstad *et al.* 2018, pp. 120–121; Peek 2018, p. 74). Furthermore, the genetic clades that could contribute most to overall adaptive capacity (i.e., most genetically divergent) (McCartney-Melstad *et al.* 2018, p. 120; Peek 2018, p. 77) are also the clades with the lowest levels of viability under current and future conditions (i.e., South Sierra, Central Coast, and South Coast clades).

A continuation of the trend toward decreasing genetic diversity in the future will decrease the foothill yellow-legged frog's representation, and thus increase extinction risk in the face of future changes. Depending upon the future scenario, extirpation of up to four of the six genetic clades is plausible within 40 years. It is of particular concern that the genetic diversity of the southern genetic clades is at the greatest risk of being lost. Not only are the southern clades the most genetically divergent, but they also contain populations that could be better adapted to persist under future climate conditions because they inhabit streams that are warmer and more intermittent. These conditions may become more common throughout the species' range as temperatures increase and precipitation becomes more variable.

References

Adams, A.J., S.J. Kupferberg, M.Q. Wilber, A.P. Pessier, M. Grefsrud, S. Bobzien, V.T. Vredenburg, and C.J. Briggs. 2017a. Extreme Drought, Host Density, Sex, and Bullfrogs Influence Fungal Pathogen Infections in a Declining Lotic Amphibian. Ecosphere 8(3):e01740. 20 pp.

Adams, A.J., A.P. Pessier, and C.J. Briggs. 2017b. Rapid Extirpation of a North American Frog Coincides with an Increase in Fungal Pathogen Prevalence: Historical Analysis and Implications for Reintroduction. Ecology and Evolution 7(23):10216–10232. DOI 10.1002/ece3.3468

AdaptWest Project. 2015. Gridded current and future climate data for North America at 1km resolution, interpolated using the ClimateNA v5.10 software (T. Wang *et al.* 2015). Available at adaptwest.databasin.org. Downloaded April 17, 2020.

Angeler, D.G. and J.M. Moreno. 2006. Impact-recovery patterns of water quality in temporary wetlands after fire retardant pollution. Canadian Journal of Fisheries and Aquatic Sciences 63:1617–1626.

Arnold, S.J. and R.J. Wassersug. 1978. Differential predation on metamorphic anurans by garter snakes (*Thamnophis*): social behavior as a possible defense. Ecology 59(5):1014–1022.

Ashton, D.T., A.J. Lind, and K.E. Schlick. 1997. Foothill Yellow-Legged Frog (*Rana boylii*) Natural History. USDA Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, CA.

Averyt, K., J. Meldrum, P. Caldwell, G. Sun, S. McNulty, A. Huber-Lee, and N. Madden. 2013. Sectoral contributions to surface water stress in the coterminous United States. Environmental Research Letters 8(3):035046 (9 pp.).

Baird, S.F. 1854. Descriptions of New Genera and Species of North American Frogs. Proceedings of the Academy of Natural Sciences of Philadelphia 7:62.

Bauer S.D., J.L. Olson, A.C. Cockrill, M.G. van Hattem, L.M. Miller, M. Tauzer, and G. Leppig. 2015. Impacts of Surface Water Diversions for Marijuana-Cultivation on Aquatic Habitat in Four Northwestern California Watersheds. PLoS ONE 10(3):e0120016. 25 pp.

Bedsworth, L., D. Cayan, G. Franco, L. Fisher, and S. Ziaja. 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission. Publication number: SUMCCCA4-2018-013. 133 pp.

Beever, E.A., J. O'Leary, C. Mengelt, J.M. West, S. Julius, N. Green, D. Magness, L. Petes, B. Stein, A.B. Nicotra, and J.J. Hellmann. 2016. Improving conservation outcomes with a new paradigm for understanding species' fundamental and realized adaptive capacity. Conservation Letters 9(2):131–137.

Blaustein, A.R., D.G. Hokit, R.K. O'Hara and R.A. Holt. 1994. Pathogenic Fungus Contributes to Amphibian Losses in the Pacific Northwest. Biological Conservation 67(3):251–254.

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(5):1460–1468.

Bondi, C.A., S.M. Yarnell, and A.J. Lind. 2013. Transferability of Habitat Suitability Criteria for a Stream Breeding Frog (*Rana boylii*) in the Sierra Nevada, California. Herpetological Conservation and Biology 8(1):88–103.

Borisenko, A.N. and M.P. Hayes. 1999. Status of the of the foothill yellow-legged frog (*Rana boylii*) in Oregon. Final report prepared for The Nature Conservancy under contract to the United States Fish and Wildlife Service. 38 pp. plus appendices.

Bourque, R.M. 2008. Spatial Ecology of an Inland Population of the Foothill Yellow-Legged Frog (*Rana boylii*) in Tehama County, California. Master's Thesis, Humboldt State University, Arcata, CA.

Bourque, R.M. 2018. Unpublished data entitled, Foothill yellow-legged frog (*Rana boylii*) spatial ecology overview. PowerPoint presentation presented at The Wildlife Society *Rana boylii* Workshop, 2018.

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(3):682–691.

Brehme, C.S., S.A. Hathaway, and R.N. Fisher. 2018. An Objective Road Risk Assessment Method for Multiple Species: Ranking 166 Reptiles and Amphibians in California. Landscape Ecology 33:911–935.

Brooks, C.P. 2003. A scalar analysis of landscape connectivity. Oikos 102(2):433–439.

Brown, L.R. and T. Ford. 2002. Effects of flow on the fish communities of a regulated California river: implications for managing native fishes. River Research and Applications 18:331–342.

Bureau of Land Management. 2008. Special Status Species Management. Manual 6840 for the Bureau of Land Management, Rel. 6-125, December 12, 2008.

Bureau of Land Management. 2009. BLM Special Status Animal Species by Field Office. California. 22 pp. <https://www.blm.gov/programs/fish-and-wildlife/threatened-and-endangered/state-te-data/california> Accessed October 19, 2021.

Bureau of Land Management. 2014. Record of Decision & Approved Resource Management Plan for Clear Creek Management Area. Prepared by U.S. Department of the Interior Bureau of Land Management Hollister Field Office, Hollister, California, February 2014. 152 pp.

Bury, R.B. 1972. The Effects of Diesel Fuel on a Stream Fauna. California Department of Fish and Game Bulletin 58:291–295.

Byrne, A.Q., V.T. Vredenburg, A. Martel, F. Pasmans, R.C. Bell, D.C. Blackburn, M.C. Bletz, J. Bosch, C.J. Briggs, R.M. Brown, and A. Catenazzi. 2019. Cryptic Diversity of a

Widespread Global Pathogen Reveals Expanded Threats to Amphibian Conservation. Proceedings of the National Academy of Sciences 116(41): 20382–20387.

California Fish and Game Commission. 2020. Notice of findings for foothill yellow-legged frog (*Rana boylii*). State of California. Notice dated March 10, 2020.

Calfee, R.D. and E.E. Little. 2003. The effects of ultraviolet-B radiation on the toxicity of firefighting chemicals. Environmental Toxicology and Chemistry 22(7):1525–1531.

CAL FIRE (California Department of Forestry and Fire Protection). 2020. Incident reports from the 2020 incident archive. State of California. <https://www.fire.ca.gov/incidents/2020/> Accessed January 22, 2021.

CAL FIRE (California Department of Forestry and Fire Protection). 2021a. 2020 Fire Siege Report. Prepared by G. Morris III and C. Dennis. www.fire.ca.gov.

CAL FIRE (California Department of Forestry and Fire Protection). 2021b. California Forest Practice Rules 2021. Title 14, California Code of Regulations Chapters 4, 4.5, and 10. Prepared for the California Licensed Timber Operators and California Registered Professional Foresters. www.fire.ca.gov.

California Wildfire and Forest Resilience Task Force. 2021. California's Wildfire and Forest Resilience Action Plan: A Comprehensive Strategy of the Governor’s Forest Management Task Force. January 2021. 46 pp. <https://www.fire.ca.gov/media/ps4p2vck/californiawildfireandforestresilienceactionplan.pdf> Accessed October 15, 2021.

Carey, M.P., B.L. Sanderson, T.A. Friesen, K.A. Barnas, and J.D. Olden. 2011. Smallmouth bass in the Pacific Northwest: a threat to native species; a benefit for anglers. Reviews in Fisheries Science 19(3):305–315.

Catenazzi, A., and S.J. Kupferberg. 2013. The Importance of Thermal Conditions to Recruitment Success in Stream-Breeding Frog Populations Distributed Across a Productivity Gradient. Biological Conservation 168:40–48.

Catenazzi, A., and S.J. Kupferberg. 2017. Variation in Thermal Niche of a Declining River-breeding Frog: From Counter-Gradient Responses to Population Distribution Patterns. Freshwater Biology 62:1255–1265.

Catenazzi, A., and S.J. Kupferberg. 2018. Consequences of Dam-Altered Thermal Regimes for a Riverine Herbivore’s Digestive Efficiency, Growth and Vulnerability to Predation. Freshwater Biology 63(9):1037–1048. doi: 10.1111/fwb.13112

CDFW (California Department of Fish and Wildlife). 2018. Considerations for Conserving the Foothill Yellow-Legged Frog. California Department of Fish and Wildlife, May 14, 2018. http://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=157562 Accessed September 12, 2019.

CDFW (California Department of Fish and Wildlife). 2019a. Provisional Fish Release Plans for the Current Fiscal Year. Updated August 30, 2019. <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=74004&inline > Accessed October 1, 2020.

CDFW (California Department of Fish and Wildlife). 2019b. Status Review of the Foothill Yellow-legged Frog (*Rana boylii*) in California. Report to the Fish and Game Commission. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=174663&inline. Accessed March 26, 2020.

CDFW (California Department of Fish and Wildlife). 2020. California Natural Diversity Database (CNDDB). Periodic publication. Version dated September 1, 2020. Retrieved September 1, 2020.

CDPR (California Department of Pesticide Regulation). 2019a. Agreement Reached to End Sale of Chlorpyrifos in California by February 2020. Press Release, October 9, 2019. <https://www.cdpr.ca.gov/docs/pressrls/2019/100919.htm> Accessed September 30, 2020.

CDPR (California Department of Pesticide Regulation). 2019b. The top 100 sites used by pounds of active ingredients statewide in 2017 (all pesticides combined). <ftp://transfer.cdpr.ca.gov/pub/outgoing/pur/data/2017_PUR_report_textfiles/top100lists/top_100_sites_by_pounds/> Accessed March 11, 2020.

Central Valley Landscape Conservation Project. 2017. Climate change vulnerability assessment (January 2017 version): yellow-legged frog. <http://climate.calcommons.org/cvlcp/vulnerability-assessments> Accessed June 29, 2020.

CNRA (California Natural Resources Agency), California Environmental Protection Agency, and Department of Food and Agriculture. 2020. Water resilience portfolio, January 2020 draft. In Response to the Executive Order N-10-19. < https://waterresilience.ca.gov/> Accessed May 14, 2020. 147 pp.

Clayton, D. and M. Miller. 2005. Yellow-legged Frog Oviposition Site Surveys on the Lower Rogue River and Tributaries in 2005. Rogue River-Siskiyou National Forest report. 10 pp.

Cohen, J.M., M.D. Venesky, E.L. Sauer, D.J. Civitello, T.A. McMahon, E.A. Roznik, and J.R. Rohr. 2017. The thermal mismatch hypothesis explains host susceptibility to an emerging infectious disease. Ecology Letters 20:184–193.Conservation Biology Institute. 2011. Smallmouth bass (*Micropterus dolomieu*) distribution in California as of 2002. <https://databasin.org/datasets/e4e65d7a51f8417dbd2a5dd1e3fc424b/> Accessed August 16, 2021.

Cook, D.G., S. White, and P. White. 2012. *Rana boylii* (Foothill Yellow-legged Frog) Upland Movement. Herpetological Review 43(2):325–326.

Cooper, A.R., D.M. Infante, W.M. Daniel, K.E. Wehrly, L. Wang, and T.O. Brenden. 2017. Assessment of dam effects on streams and fish assemblages of the conterminous U.S.A. Science of the Total Environment 586:879–889.

Cooper, S.D., P.S. Lake, S. Sabater, J.M. Melack, and J.L. Sabo. 2013. The effects of land use changes on streams and rivers in mediterranean climates. Hydrobiologia 719:383–425.

Cordone, A.J., and D.W. Kelley. 1961. The Influence of Inorganic Sediment on the Aquatic Life of Streams. California Fish and Game 47(2):189–228.

Crayon, J.J. 1998. *Rana catesbeiana* (Bullfrog). Diet. Herpetological Review 29(4):232.

CROP Project. 2019. Trespass Grow Fact Sheet, August 2019. Organization founded by the Community Governance Partnership and California Wilderness Coalition. <https://www.cropproject.org/resources> Accessed December 11, 2019.

Davidson, C. 2004. Declining Downwind: Amphibian Population Declines in California and Historical Pesticide Use. Ecological Applications 14(6):1892–1902.

Davidson, C., H.B. 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(6):1588–1601.

Davidson, C., M.F. Benard, H.B. Shaffer, J.M. Parker, C. O'Leary, J.M. Conlon, and L.A. Rollins-Smith. 2007. Effects of Chytrid and Carbaryl Exposure on Survival, Growth and Skin Peptide Defenses in Foothill Yellow-legged Frogs. Environmental Science and Technology 41(5):1771–1776.

Davis, R. and D. Olson. 2008. Field validation of a landscape habitat model for the foothill yellow-legged frog (*Rana boylii*) in Oregon. U.S. Department of Agriculture, Forest Service, Umpqua National Forest, Roseburg, Oregon. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Center, Corvallis, Oregon.

Dever, J.A. 2007. Fine-scale Genetic Structure in the Threatened Foothill Yellow-legged Frog (*Rana boylii*). Journal of Herpetology 41(1):168–173.

Dillingham, C.P. 2019. 2019 Cresta Reach Survey and in-situ captive propagation. Final Report. U.S. Department of Agriculture, Forest Service, Plumas National Forest.

Drennan, J.E., K.A. Marlow, K.D. Wiseman, R.E. Jackman, I.A. Chan, and J.L. Lessard. 2015. *Rana boylii* Aging: A Growing Concern. Abstract of paper presented at the CA/NV Amphibian and Reptile Task Force Annual Meeting 8–10 January 2015, Malibu, CA.

Escriva-Bou, A., E. Hanak, and J. Mount. 2019. California's water grid. September 2019. PPIC (Public Policy Institute of California) Water Policy Center. <https://www.ppic.org/water/> Accessed April 28, 2020.

Esri Inc. 2018. ArcGIS Pro. Version 2.3.3. Esri Inc. <https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview>.

Fellers, G.M. 2005. *Rana boylii* Baird, 1854(b). Pp. 534–536 *In* M. Lannoo (editor) Amphibian Declines: The Conservation Status of United States Species. University of California Press, Berkeley, California.

Fellers, G.M., L.L. McConnell, D. Pratt, and S. Datta. 2004. Pesticides in mountain yellow-legged frogs (*Rana muscosa*) from the Sierra Nevada Mountains of California, USA. Environmental Toxicology and Chemistry 23(9):2170–2177.

Finger, Susan, B. Poulton, S. Hamilton, K. Buhl, S.D. Yankton, N. Vyas, E. Hill, D. Larson, and N.D. Jamestown. 1997. Toxicity of fire retardant and foam suppressant chemicals to plant and animal communities. Prepared for the Interagency Fire Coordination Committee, Boise, Idaho.

Fitch, H.S. 1936. Amphibians and reptiles of the Rogue River basin, Oregon. The American Midland Naturalist 17(3):634–652.

Fitch, H.S. 1938. *Rana boylii* in Oregon. Copeia 1938(3):148.

Frost, D.R. 2019. Amphibian Species of the World: an Online Reference. Version 6 (Accessed 12 September 2019). Electronic Database accessible at http://research.amnh.org/herpetology/amphibia/index.html. American Museum of Natural History, New York, U.S.A.

Fuller, T.E., K.L. Pope, D.T. Ashton, and H.H. Welsh. 2011. Linking the distribution of an invasive amphibian (*Rana catesbeiana*) to habitat conditions in a managed river system in northern California. Restoration Ecology 19(201):204–213.

Furey, P.C., S.J. Kupferberg and A.J. Lind. 2014. The Perils of Unpalatable Periphyton: *Didymosphenia* and Other Mucilaginous Stalked Diatoms as Food for Tadpoles. Diatom Research 29(3):267–280.

Gabriel W. and R. Burger. 1992. Survival of small populations under demographic stochasticity. Theoretical Population Biology 41:44–71.

Gamradt, S.C. and L.B. Kats. 1996. Effect of Introduced Crayfish and Mosquitofish on California Newts. Conservation Biology 10(4):1155–1162.

GANDA (Garcia and Associates). 2004. Results of 2003 surveys and monitoring for foothill yellow-legged frog *(Rana boylii*) within the Rock Creek-Cresta Project Area, North Fork Feather River, Recreation and Pulse Flow Biological Evaluation. Job 332/52. Report prepared for the Pacific Gas and Electric Company, San Ramon, California. Original report dated November 2003; revised report dated May 2004.

GANDA (Garcia and Associates). 2008. Identifying Microclimatic and Water Flow Triggers Associated with Breeding Activities of a Foothill Yellow-Legged Frog (*Rana boylii*) Population on the North Fork Feather River, California. Report prepared for the California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2007-041.

GANDA (Garcia and Associates). 2010. Feasibility Study for the Reintroduction of the Foothill Yellow-legged Frog (*Rana boylii*) within the Mt. Tamalpais Watershed, Marin County, California. November 2010. Job 548. Report prepared for the Marin Municipal Water District, Corte Madera, California.

GANDA (Garcia and Associates). 2018. Draft Results of 2017 Surveys for Foothill Yellow-legged Frog (*Rana boylii*) on the Cresta and Poe Reaches of the North Fork Feather River. March 2018. Job 708/145. Report prepared for Pacific Gas and Electric Company, San Ramon, California.

GANDA (Garcia and Associates). 2020. Results of 2019 surveys for Foothill Yellow-legged Frog (*Rana boylii*) on the Cresta and Poe reaches of the North Fork Feather River. Job 708/281. Draft report prepared for the Pacific Gas and Electric Company, San Ramon, California.

Gonsolin, T.T. 2010. Ecology of Foothill Yellow-legged Frogs in Upper Coyote Creek, Santa Clara County, CA. Master's Thesis. San Jose State University, San Jose, California.

Goodman, D. 1987. The demography of chance extinction. Pp. 11–34 *In* M.E. Soulé (editor) Conservation Biology: The Science of Scarcity and Diversity. Sinauer Associates, Sunderland, Massachusetts.

Gosner, K.L. 1960. A simplified table for staging anuran embryos and larvae with notes on identification. Herpetologica 16(3):183–190.

Grantham, T.E., D.M. Carlisle, G.J. McCabe, and J.K. Howard. 2018. Sensitivity of streamflow to climate change in California. Climatic Change 149(3):427–441.

Greimel, F., L. Schülting, W. Graf, E. Bondar-Kunze, S. Auer, B. Zeiringer, and C. Hauer. 2018. Hydropeaking impacts and mitigation. Pp. 91–110 *In* Riverine Ecosystem Management, Aquatic Ecology Series 8, https://doi.org/10.1007/978-3-319-73250-3_5.

Griffith, G.E., J.M. Omernik, D.W. Smith, T.D. Cook, E. Tallyn, K. Moseley, and C.B. Johnson. 2016. Ecoregions of California (poster): U.S. Geological Survey Open-File Report 2016–1021, with map, scale 1:1,100,000, http://dx.doi.org/10.3133/ofr20161021.

Hale, R.C., M.J. La Guardia, E. Harvey, and T.M. Mainor. 2002. Potential role of fire retardant-treated polyurethane foam as a source of bromated diphenyl ethers to the U.S. environment. Chemosphere 46:729–735.

Halstead, B.J., C.S. Goldberg, R.B. Douglas, P.M. Kleeman, and D.W. Ulrich. 2020. Occurrence of a suite of stream-obligate amphibians in timberlands of Mendocino County, California, examined using environmental DNA. Northwestern Naturalist 101(3):194–209.

Hartl, D.L. and G.C. Clark. 1997. Principles of Population Genetics. Third edition. Sinauer Associates, Sunderland, Massachusetts.

Harvey, B.C. and T.E. Lisle. 1998. Effects of Suction Dredging on Streams: a Review and an Evaluation Strategy. Fisheries 23(8):8–17.

Hayes, M.P., and M.R. Jennings. 1986. Decline of Ranid Frog Species in Western North America: Are Bullfrogs (*Rana catesbeiana*) Responsible? Journal of Herpetology 20(4):490–509.

Hayes, M.P., and M.R. Jennings. 1988. Habitat Correlates of Distribution of the California Red-legged Frog (*Rana aurora draytonii*) and the Foothill Yellow-Legged Frog (*Rana boylii*): Implications for Management. Pp. 144–158 *In* R.C. Szaro, K.E. Severson, and D.R. Patton (Technical Coordinators) Management of Amphibians, Reptiles, and Small Mammals in North America, General Technical Report. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Hayes, M.P., C.A. Wheeler, A.J. Lind, G.A. Green, and D.C. Macfarlane (Technical Coordinators). 2016. Foothill Yellow-Legged Frog Conservation Assessment in California. Gen. Tech. Rep. PSW-GTR-248. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California.

Heard, M. 1904. A California frog ranch. Out West 21:20–27.

Hemphill, D.V. 1952. The Vertebrate Fauna of the Boreal Areas of the Southern Yolla Bolly Mountains, California. PhD dissertation. Oregon State University, Corvalis, Oregon.

Hogg, I.D. and R.H. Norris. 1991. Effects of runoff from land clearing and urban development on the distribution and abundance of macroinvertebrates in pool areas of a river. Marine and Freshwater Research 42(5):507–518.

Hothem, R.L., A.M. Meckstroth, K.E. Wegner, M.R. Jennings, and J.J. Crayon. 2009. Diets of Three Species of Anurans from the Cache Creek Watershed, California, USA. Journal of Herpetology 43(2):275–283.

Howard, J., K. Klausmeyer, and K. Fesenmyer. 2013. Below the Surface: California's Freshwater Biodiversity. The Nature Conservancy of California. San Francisco, California. 20 pp.

Huss, M., L. Huntley, V. Vredenburg, J. Johns, and S. Green. 2013. Prevalence of *Batrachochytrium dendrobatidis* in 120 Archived Specimens of *Lithobates catesbeianus* (American Bullfrog) Collected in California, 1924–2007. EcoHealth 10:339–343. DOI: 10.1007/s10393–013–0895–6.

ICF International. 2012. Final Santa Clara Valley Habitat Plan. August 2012. Prepared for the City of Gilroy, City of Morgan Hill, City of San José, County of Santa Clara, Santa Clara Valley Transportation Authority, and Santa Clara Valley Water District. San Francisco, California.

IPCC (Intergovernmental Panel on Climate Change). 2015. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. ISBN 978-92-9169-143-2. 151 pp.

Isaak, D.J., S.J. Wenger, E.E. Peterson, J.M. Ver Hoef, D.E. Nagel, C.H. Luce, S.W. Hostetler, J.B. Dunham, B.B. Roper, S.P. Wollrab, G.L. Chandler, D.L. Horan, and S. Parkes-Payne. 2017. The NorWeST Summer Stream Temperature Model and Scenarios for the Western U.S.: A Crowd-Sourced Database and New Geospatial Tools Foster a User Community and Predict Broad Climate Warming of Rivers and Streams. Water Resources Research 53:9181–9205.

Jennings M.R. 1995. Native ranid frogs in California. Pp. 131–134 *In* E.T. LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac (editors) Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. Government Printing Office, U.S. Department of the Interior, National Biological Service, Washington, D.C.

Jennings M.R. 1996. Status of amphibians. Pp. 921–944 *In* Sierra Nevada Ecosystem Project: final report to Congress, vol. II, Assessments and scientific basis for management options. University of California Davis, Centers for Water and Wildland Resources, Davis, California.

Jennings, M.R., and M.P. Hayes. 1994. Amphibian and Reptile Species of Special Concern in California. Contract No. 8023. Final Report submitted to the California Department of Fish and Game, Inland Fisheries Division, Rancho Cordova, California.

Jones and Stokes. 2006. Final East Contra Costa County Habitat Conservation Plan and Natural Community Conservation Plan. October 2006. (J&S 01478.01.) San Jose, California.

Kamoroff, C., N. Daniele, R.L. Grasso, R. Rising, T. Espinoza, and C.S. Goldberg. 2020. Effective Removal of the American Bullfrog (*Lithobates catesbeianus*) on a Landscape Level: Long Term Monitoring and Removal Efforts in Yosemite Valley, Yosemite National Park. Biological Invasions 22:617–626.

Kennedy, T.A., J.D. Muehlbauer, C.B. Yackulic, D.A. Lytle, S.W. Miller, K.L. Dibble, E.W. Kortenhoeven, A.N. Metcalfe, and C.V. Baxter. 2016. Flow management for hydropower extirpates aquatic insects, undermining river food webs. BioScience 66(7):561–575.

Kerby, J.L., and A. Sih. 2015. Effects of Carbaryl on Species Interactions of the Foothill Yellow Legged Frog (*Rana boylii*) and the Pacific Treefrog (*Pseudacris regilla*). Hydrobiologia 746(1):255–269.

Kiernan, J., P. Moyle, and P. Crain. 2012. Restoring native fish assemblages to a regulated California stream using the natural flow regime concept. Ecological Applications 22:1472–1482.

Kiesecker, J.M. and A.R. Blaustein. 1998. Effects of Introduced Bullfrogs and Smallmouth Bass on Microhabitat Use, Growth, and Survival of Native Red-Legged Frogs (*Rana aurora*). Conservation Biology 12(4):776–787.

Kindlmann, P., and F. Burel. 2008. Connectivity measures: a review. Landscape Ecology 23(8):879–890.

Kupferberg, S.J. 1996a. Hydrologic and geomorphic factors affecting conservation of a river-breeding frog (*Rana boylii*). Ecological Applications 6:1332–1344.

Kupferberg, S.J. 1996b. The ecology of native tadpoles (*Rana boylii* and *Hyla regilla*) and the impacts of invading bullfrogs (*Rana catesbeiana*) in a northern California river. PhD dissertation. University of California, Berkeley, California.

Kupferberg, S.J. 1997a. Bullfrog (*Rana catesbeiana*) Invasion of a California River: The Role of Larval Competition. Ecology 78(6):1736–1751.

Kupferberg, S.J. 1997b. The Role of Larval Diet in Anuran Metamorphosis. American Zoology 37:146–159.

Kupferberg, S.J., A. Catenazzi, K. Lunde, A. Lind, and W. Palen. 2009a. Parasitic Copepod (*Lernaea cyprinacea*) Outbreaks in Foothill Yellow-legged Frogs (*Rana boylii*) Linked to

Unusually Warm Summers and Amphibian Malformations in Northern California. Copeia 2009(3):529–537.

Kupferberg, S.J., A. Catenazzi, and M.E. Power. 2011a. The Importance of Water Temperature and Algal Assemblage for Frog Conservation in Northern California Rivers with Hydroelectric Projects. Final Report to the California Energy Commission, PIER. CEC-500–2014–033.

Kupferberg, S.J., A. Lind, J. Mount, and S. Yarnell. 2009b. Pulsed Flow Effects on the Foothill Yellow-Legged Frog (*Rana boylii*): Integration of Empirical, Experimental, and Hydrodynamic Modeling Approaches. Final Report to the California Energy Commission, PIER. CEC-500–2009–002.

Kupferberg, S.J, A.J. Lind, and W.J. Palen. 2009c. Pulsed Flow Effects on the Foothill Yellow-legged Frog (*Rana boylii*): Population Modeling. Final Report to the California Energy Commission, PIER. CEC-500–2009–002a.

Kupferberg, S.J., A.J. Lind, V. Thill, and S.M. Yarnell. 2011b. Water Velocity Tolerance in Tadpoles of the Foothill Yellow-legged Frog (*Rana boylii*): Swimming Performance, Growth, and Survival. Copeia 2011(1):141–152.

Kupferberg, S.J., W.J. Palen, A.J. Lind, S. Bobzien, A. Catenazzi, J. Drennan, and M.E. Power. 2012. Effects of Flow Regimes Altered by Dams on Survival, Population Declines, and Range-wide Losses of California River-Breeding Frogs. Conservation Biology 26(3):513–524.

Lind, A.J. 2005. Reintroduction of a Declining Amphibian: Determining an Ecologically Feasible Approach for the Foothill Yellow-legged Frog (*Rana boylii*) Through Analysis of Decline Factors, Genetic Structure, and Habitat Associations. PhD Dissertation. University of California, Davis.

Lind, A.J., L. Conway, H. (Eddinger) Sanders, P. Strand, and T. Tharalson. 2003b. Distribution, Relative Abundance, and Habitat of Foothill Yellow-legged Frogs (*Rana boylii*) on National Forests in the Southern Sierra Nevada Mountains of California. Report to the FHR Program of Region 5 of the U.S.DA Forest Service.

Lind, A.J., H.H. Welsh, Jr., and C.A. Wheeler. 2016. Foothill Yellow-legged Frog (*Rana boylii*) Oviposition Site Choice at Multiple Spatial Scales. Journal of Herpetology 50(2):263–270.

Lind, A.J., H.H. Welsh, Jr., and R.A. Wilson. 1996. The Effects of a Dam on Breeding Habitat and Egg Survival of the Foothill Yellow-Legged Frog (*Rana boylii*) in Northwestern California. Herpetological Review 27(2):62–67.

Lind, A.J. and S.M. Yarnell. 2008. Habitat suitability criteria for the foothill yellow-legged frog in the northern Sierra Nevada and Coast Ranges of California. Final DeSabla-Centerville Project Foothill Yellow-legged Frog Habitat Suitability Criteria Report, February 15, 2008. 41 pp.

Lindauer, A.L., P.A. Maier, and J. Voyles. 2020. Daily fluctuating temperatures decrease growth and reproduction rate of a lethal amphibian fungal pathogen in culture. BMC Ecology 20(18):1–9.

Linnell, M.A. and R.J. Davis. 2021. Historical disturbances to rivers appear to constrain contemporary distribution of a river-dependent frog. bioRxiv 2021.01.22.427759, preprint (not peer-reviewed). https://doi.org/10.1101/2021.01.22.427759.

Loomis, R.B. 1965. The yellow-legged frog, *Rana boylii*, from the Sierra San Pedro Mártir, Baja California Norte, México. Herpetologica 21(1):78–80.

Lowe, J. 2009. Amphibian chytrid (*Batrachochytrium dendrobatidis*) in postmetamorphic *Rana boylii* in inner Coast Ranges of central California. Herpetological Review 40(2):180–182.

MacTague, L., and P.T. Northen. 1993. Underwater vocalization by the foothill yellow-legged frog (*Rana boylii*). Transactions of the Western Section of the Wildlife Society 29:1–7.

Matthies, D., I. Bräuer, W. Maibom, and T. Tscharntke. 2004. Population size and the risk of local extinction: empirical evidence from rare plants. Oikos 105(3):481–488.

Mendocino and Humboldt Redwood Companies. 2021. Management Plan. July 21, 2021. 39 pp.

McCartney-Melstad, E., M. Gidiş, and H.B. Shaffer. 2018. Population Genomic Data Reveal Extreme Geographic Subdivision and Novel Conservation Actions for the Declining Foothill Yellow-legged Frog. Heredity 121:112–125.

McDonald, S.F., S.J. Hamilton, K.J. Buhl, and J.F. Heisinger. 1996. Acute toxicity of fire control chemicals to *Dapnia magna* (Straus) and *Selenastrum capricornutum* (Printz). Ecotoxicology and Environmental Safety 33:62–72.

Miller R.R. 2010. Is the past present? Historical splash-dam mapping and stream disturbance detection in the Oregon Coastal Province. Masters Thesis. Oregon State University. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/4m90f001t.

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. Fire Research Consensus Working Group Final Report (September 2018).

Mote, P.W., J. Abatzoglou, K.D. Dello, K. Hegewisch, and D.E. Rupp. 2019. Fourth Oregon Climate Assessment Report, State of Climate Science: 2019. Oregon Climate Change Research Institute. occri.net/ocar4.

Moyle, P.B. 1973. Effects of Introduced Bullfrogs, *Rana catesbeiana*, on the Native Frogs of the San Joaquin Valley, California. Copeia 1973(1):18–22.

Moyle, P.B., and P.J. Randall. 1998. Evaluating the Biotic Integrity of Watersheds in the Sierra Nevada, California. Conservation Biology 12(6):1318–1326.

Nagy, R., A. Fusaro, W. Conard, and C. Morningstar. 2020. *Procambarus clarkii* (Girard, 1852). U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida. Revised January 15, 2020.

<https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=217> Accessed March 4, 2020.

National Interagency Fire Center. 2020. Interagency Fire Perimeter History. Data maintained by the Wildland Fire Management Research, Development, & Application program data team. Feature Layer updated through calendar year 2018 on March 31, 2020. <https://data-nifc.opendata.arcgis.com/datasets/nifc::interagency-fire-perimeter-history-all-years?geometry=121.519%2C28.102%2C-104.975%2C51.366&orderBy=UNIT_ID&selectedAttribute=SOURCE> Accessed October 6, 2020.

National Genomics Center for Wildlife and Fish Conservation. 2021. Unpublished data, eDNA results for foothill yellow-legged frog in southwest Oregon using water samples from a Pacific lamprey study. USDA Forest Service Rocky Mountain Research Station, Missoula, Montana. Data sent Kelli Van Norman of the Bureau of Land Management via email attachment to Jeffrey Dillon of the U.S. Fish and Wildlife Service on April 5, 2021.

National Marine Fisheries Service (also known as NOAA Fisheries). 2008. Biological Opinion & Magnuson-Stevens Fishery Conservation & Management Act Essential Fish Habitat Consultation on the "Willamette River Basin Flood Control Project." July 11, 2008. Prepared by NOAA's National Marine Fisheries Service, Northwest Region. Log Number: F/NWR/2000/02117.

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.

Nowakowski, A.J., S.M. Whitfield, E.A. Eskew, M.E. Thompson, J.P. Rose, B.L. Caraballo, J.L. Kerby, M.A. Donnelly, and B.D. Todd. 2016. Infection risk decreases with increasing mismatch in host and pathogen environmental tolerances. Ecology Letters 19:1051–1061.

Nussbaum, R.A., E.D. Brodie, Jr., and R.M. Storm. 1983. Pp. 162–165 *In* Amphibians & Reptiles of the Pacific Northwest. University Press of Idaho, Moscow, Idaho.

Oakland Zoo. 2019. Oakland Zoo Quarterly Report *Rana boylii* 9.30.19. Conservation Society of California, Oakland Zoo, Oakland, California.

OCCRI (Oregon Climate Change Research Institute). 2019. Oregon Climate Change Effects, Likelihood, and Consequences Workshop. Fall 2019 workshop summary report prepared by The Oregon Climate Change Research Institute, Corvallis, Oregon. 71 pp.

ODFW (Oregon Department of Fish and Wildlife). No year. Oregon bass fishing. Flyer downloaded from <https://myodfw.com/articles/how-fish-bass> Accessed March 12, 2021.

ODFW (Oregon Department of Fish and Wildlife). 2009. 25-Year Angling Enhancement Plan. Recreational Fisheries Program Fish Division. <https://www.dfw.state.or.us/resources/fishing/docs/25_Year_Recreational_Angling_Enhancement%20Plan.pdf> Accessed October 1, 2020.

OEHHA (Office of Environmental Health Hazard Assessment). 2018. Indicators of Climate Change in California. California Environmental Protection Agency, OEHHA, Sacramento, California. 326 pp.

Olson, D.H., and J.I. Burton. 2019. Climate associations with headwater streamflow in managed forests over 16 years and projections of future dry headwater stream channels. Forests 10(11):968.

Olson, D.H., and R. Davis. 2007. 2007 Federal Surveys for Distribution of Foothill Yellow-legged Frogs (*Rana boylii*) in Oregon November 6, 2007. U.S. Department of Agriculture Forest Service, Region 6. 12 pp.

Olson, D.H., and R. Davis. 2009. Conservation Assessment for the Foothill Yellow-legged Frog (*Rana boylii*) in Oregon. Version 2.0, April 22, 2009. U.S. Department of Agriculture, Forest Service Region 6 and U.S. Department of Interior Bureau of Land Management Interagency Special Status Species Program.

Olson, E.O., J.D. Shedd, and T.N. Engstrom. 2016. A Field Inventory and Collections Summary of Herpetofauna from the Sutter Buttes, an “Inland Island” within California’s Great Central Valley. Western North American Naturalist 76(3):352–366.

Omerick, J.M. and G.E. Griffith. 2014. Ecoregions of the Conterminous United States: Evolution of a Hierarchical Spatial Framework. Environmental Management 54:1249–1266.

ORBIC (Oregon Biodiversity Information Center). 2019. Oregon Biodiversity Information Center Rare Species Dataset. Institute for Natural Resources, Portland State University, Portland, Oregon. Dated September 5, 2019.

Pacific Gas and Electric Company. 2015. 2014 Amphibian Survey for Foothill Yellow-legged Frog (*Rana boylii*), Sierra Nevada Yellow-legged Frog (*Rana sierrae*) and Yosemite Toad-Western Toad (*Anaxyrus canorus – Anaxyrus boreas*) for the Mokelumne River Project (FERC Project No. 137). Report prepared by Pacific Gas and Electric Company, San Ramon, California. 98 pp.

Pacific Lumber Company. 1999. Habitat Conservation Plan for the Properties of the Pacific Lumber Company, Scotia Pacific Holding Company, and Salmon Creek Corporation. February 1999. 138 pp.

Padgett-Flohr, G.E., and R.L. Hopkins. 2009. *Batrachochytrium dendrobatidis*, a Novel Pathogen Approaching Endemism in Central California. Diseases of Aquatic Organisms 83:1–9.

Paoletti, D.J., D.H. Olson, and A.R. Blaustein. 2011. Responses of Foothill Yellow-legged Frog (*Rana boylii*) Larvae to an Introduced Predator. Copeia 2011(1):161–168.

Parks, S.A., and J.T. Abatzoglou. 2020. Warmer and drier fire seasons contribute to increases in area burned at high severity in western U.S. forests from 1985 to 2017. Geophysical Research Letters 47(22):e2020GL089858. 10 pp.

Pearson, R.G., J.C. Stanton, K.T. Shoemaker, M.E. Aiello-Lammens, P.J. Ersts, N. Horning, D.A. Fordham, C.J. Raxworthy, H.Y. Ryu, J. McNees, and H.R. Akçakaya. 2014. Life history and spatial traits predict extinction risk due to climate change. Nature Climate Change 4:217–221. https://doi.org/10.1038/nclimate2113.

Peek, R.A. 2010. Landscape Genetics of Foothill Yellow-legged Frogs (*Rana boylii*) in Regulated and Unregulated Rivers: Assessing Connectivity and Genetic Fragmentation. Master's Thesis. University of San Francisco, San Francisco, California.

Peek, R.A. 2012. Analysis of long-term river regulation effects on genetic connectivity of foothill yellow-legged frogs (*Rana boylii*) in the Alameda Creek watershed. Draft Report prepared for San Francisco Public Utilities Commission, San Francisco, California.

Peek, R.A. 2018. Population Genetics of a Sentinel Stream-breeding Frog (*Rana boylii*). PhD dissertation. University of California, Davis, California.

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(20):4636–4647.

Peek, R.A., S.M. O'Rourke, and M.R. Miller. 2021. Flow modification associated with decreased genetic health of a river-breeding frog, *Rana boylii*. Ecosphere 12(5):e03496. 18 pp.

Pierce, D.W., J.F. Kalansky, and D.R. Cayan, (Scripps Institution of Oceanography). 2018. Climate, drought, and sea level rise scenarios for the fourth California climate assessment. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CNRA-CEC-2018-006.

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.

Pintor, L.M., A. Sih, and J.L. Kerby. 2009. Behavioral correlations provide a mechanism for explaining high invader densities and increased impacts on native prey. Ecology 90(3):581–587.

Power, M.E., Bouma-Gregson, K., Higgins, P. and Carlson, S.M. 2015. The thirsty Eel: summer and winter flow thresholds that tilt the Eel River of northwestern California from salmon-supporting to cyanobacterially degraded states. Copeia 2015(1):200–211.

Power, M.E., S.J. Kupferberg, S.D. Cooper, and M.L. Deas. 2016. Pp. 713–752 *In* H. Mooney and E. Zavaleta (editors). Ecosystems of California. Univ of California Press.

PRISM Climate Group. 2012. PRISM (Parameter-elevation Regressions on Independent Slopes Model) 30-year normals data, 1981–2010, 800-meter resolution. Oregon State University. Created July 11, 2012. <http://prism.oregonstate.edu> Accessed August 21, 2019.

Public Policy Institute of California. 2020. California's Future. Public Policy Institute of California (PPIC), San Francisco, California. PPIC Sacramento Center, Sacramento, California. Funded by the PPIC Corporate Circle and the PPIC Donor Circle. January 2020 Briefing Kit. <ppic.org> Accessed April 28, 2020.

Raffel, T.R., J.M. Romansic, N.T. Halstead, T.A. McMahon, M.D. Venesky, and J.R. Rohr. 2013. Disease and Thermal Acclimation in a More Variable and Unpredictable Climate. Nature Climate Change 3:146–151.

Railsback, S.F., B.C. Harvey, S.J. Kupferberg, M.M. Lang, S. McBain, and H.H. Welsh, Jr. 2016. Modeling Potential River Management Conflicts between Frogs and Salmonids. Canadian Journal of Fisheries and Aquatic Sciences 73:773–784.

Riley, S.P.D., G.T. Busteed, L.B. Kats, T.L. Vandergon, L.F.S. Lee, R.G. Dagit, J.L. Kerby, R.N. Fisher, and R.M. Sauvajot. 2005. Effects of urbanization on the distribution and abundance of amphibians and invasive species in southern California streams. Conservation Biology 19(6):1894–1907.

Rodríguez-Prieto, I. and E. Fernández-Juricic. 2005. Effects of direct human disturbance on the endemic Iberian frog Rana iberica at individual and population levels. Biological Conservation, 123(1):1–9.

Rombough, C.J. 2006a. Distribution of foothill yellow-legged frogs (*Rana boylii*) in Cow Creek: evidence of smallmouth bass (*Micropterus dolmieu*) influence. Draft Senior Thesis, Oregon State University, Department of Fisheries and Wildlife, Corvallis, Oregon.

Rombough, C. 2006b. Winter Habitat Use by Juvenile Foothill Yellow-legged Frogs (*Rana boylii*): The Importance of Seeps. *In* Abstracts from the 2006 Annual Meetings of the Society for Northwestern Vertebrate Biology and the Washington Chapter of the Wildlife Society. Northwest Naturalist 87(2):159.

Rombough, C.J., and M.P. Hayes. 2005. *Rana boylii* (foothill yellow-legged frog): predation: eggs and hatchlings. Herpetological Review 36(2):163–164.

Rose, J.P., S.J. Kupferberg, and B.J. Halstead. 2020. Identifying drivers of population viability for the Foothill Yellow-legged Frog, *Rana boylii*, using time series of egg mass counts. Final U.S. Geological Survey Restricted-File Federal Interagency Report to the Sacramento Fish and Wildlife Office. 105 pp. and supplementary data.

Rose, J.P., S.J. Kupferberg, C.A. Wheeler, P.M. Kleeman, and B.J. Halstead. 2021. Estimating the survival of unobservable life stages for a declining frog with a complex life history. Ecosphere 12(2):e03381. 18 pp. and 7 pp. of supplementary material.

Scheele, B.C., F. Pasmans, L.F. Skerratt, L. Berger, A. Martel, W. Beukema, A.A. Acevedo, P.A. Burrows, T. Carvalhos, A. Catenazzi, I. De la Riva, M.C. Fisher, S.V. Flechas, C.N. Foster, P. Frías-Álvarez, T.W.J. Garner, B. Gratwicke, J.M. Guayasamin, M. Hirschfeld, J.E. Kolby, T.A. Kosch, E. La Marca, D.B. Lindenmayer, K.R. Lips, A.V. Longo, R. Maneyro, C.A. McDonald, J. Mendelson III, P. Palacios-Rodriguez, G. Parra-Olea, C.L. Richards-Zawacki, M-O. Rödel, S.M. Rovito, C. Soto-Azat, L.F. Toledo, J. Voyles, C. Weldon, S.M. Whitfield, M. Wilkinson, K.R. Zamudio, and S. Canessa. 2019. Amphibian Fungal Panzootic Causes Catastrophic and Ongoing Loss of Biodiversity. Science 363(6434):1459–1463.

Service (U.S. Fish and Wildlife Service). 2008. Biological Opinion on the Continued Operation and Maintenance of the Willamette River Basin Project and Effects to Oregon Chub, Bull Trout, and Bull Trout Critical Habitat Designated Under the Endangered Species Act. July 11, 2008. Prepared by the Oregon Fish and Wildlife Office. Consultation File Number: 8330.F0224(07); Tails Number: 13420-2007-F-0024.

Service (U.S. Fish and Wildlife Service). 2016. U.S. Fish and Wildlife Service Species Status Assessment framework: an integrated analytical framework for conservation. Version 3.4.

Service (U.S. Fish and Wildlife Service). 2018. 2018 Reinitiated Biological Opinion (BO) for the Nationwide Aerial Application of Fire Retardants on National Forest System Lands. July 6, 2018. Consultation 09E30000–2012-F-0001-R001 conducted by U.S. Fish and Wildlife Service (assistance from Regions 1, 2, 6, and 8), Falls Church, Virginia.

Service (U.S. Fish and Wildlife Service) and Hoopa Valley Tribe. 1999. Trinity River Flow Evaluation. Final Report. U.S. Fish and Wildlife Service, Arcata, California.

Shaffer, M. 1987. Minimum viable populations: coping with uncertainty. Pp. 69–86 *In* M.E. Soulé (editor) Viable Populations for Conservation. Cambridge University Press. Accessed March 3, 2021 from https ://archive. org/details/isbn 978052133657 4.

Shaffer, M.L. and B.A. Stein. 2000. Safeguarding Our Precious Heritage in Precious Heritage. Pp. 301–321 *In* B.A. Stein, L.S. Kutner, J.S. Adams (editors) Precious Heritage: The Status of Biodiversity in the United States. The Nature Conservancy & Association for Biodiversity Information. Oxford University Press, New York, New York.

Silver, C.S. 2017. Population-level Variation in Vocalizations of *Rana boylii*, the Foothill Yellow-legged Frog. Master's Thesis. California State University, Chico, Chico, California.

Sleeter, B.M. and J. Kreitler. 2020. Unpublished data summarizing land-use and land-cover change based on the Land Use and Carbon Scenario Simulator model (Sleeter *et al.* 2019). Data for 2000–2100, BAU (business-as-usual) scenario, within the range of the foothill yellow-legged frog and surrounding areas.

Sleeter, B.M., D.C. Marvin, D.R. Cameron, P.C. Selmants, A.L.R. Westerling, J. Kreitler, C.J. Daniel, J. Liu, and T.S. Wilson. 2019. Effects of 21st-century climate, land use, and disturbances on ecosystem carbon balance in California. Global Change Biology 25:3334–3353.

Smalling, K.L., G.M. Fellers, P.M. Kleeman, and K.M. Kuivila. 2013. Accumulation of pesticides in pacific chorus frogs (*Pseudacris regilla*) from California's Sierra Nevada Mountains, USA. Environmental Toxicology and Chemistry 32(9):2026–2034.

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(1):302–320.

Sparling, D.W., and G.M. Fellers. 2007. Comparative Toxicity of Chlorpyrifos, Diazinon, Malathion and Their Oxon Derivatives to *Rana boylii*. Environmental Pollution 147:535–539.

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(8):1696–1703.

Sparling, D.W., G.M. Fellers, and L.L. McConnell. 2001. Pesticides and Amphibian Declines in California, USA. Environmental Toxicology and Chemistry 20(7):1591–1595.

Sparling, D.W., J. Bickham, D. Cowman, G.M. Fellers, T. Lacher, C.W. Matson, and L. McConnell. 2015. In situ effects of pesticides on amphibians in the Sierra Nevada. Ecotoxicology 24(2):262–278.

State Water Resources Control Board. 2020. Draft Statewide national pollutant discharge elimination system (NPDES) permit for suction dredge mining discharges to waters of the United States. NPDES number CAG370001. Dated May 8, 2020. State Water Resources Control Board, Sacramento, California.

Stebbins, R.C. 2003. A Field Guide to Western Reptiles and Amphibians, Third Edition. Houghton Mifflin Company, New York, New York.

Steel, A.E., R.A. Peek, R.A. Lusardi, and S.M. Yarnell. 2018. Associating metrics of hydrologic variability with benthic macroinvertebrate communities in regulated and unregulated snowmelt-dominated rivers. Freshwater Biology 63:844–858.

Stevenson, L.A., R.A. Alford, S.C. Bell, E.A. Roznik, L. Berger, and D.A. Pike. 2013. Variation in Thermal Performance of a Widespread Pathogen, the Amphibian Chytrid Fungus *Batrachochytrium dendrobatidis*. PLoS ONE 8(9): e73830. 14 pp.

Storer, T.I. 1925. A Synopsis of the Amphibia of California. University of California Publication Zoology 27:1–342.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union 38(6):913–920.

Swain, D.L., B. Langenbrunner, J.D. Neelin, and A. Hall. 2018. Increasing precipitation volatility in twenty-first-century California. Nature Climate Change 8:427–433.

Swales, S. 2010. California forest management practices and the conservation of anadromous salmonids. Fisheries Branch Administrative Report No. 2010-3. California Department of Fish and Game, Sacramento, California. 55 pp.

Sweet, S.S. 1983. Mechanics of a Natural Extinction Event: *Rana boylii* in Southern California. Abstract of paper presented at the Joint Annual Meeting of the Herpetologists' League and Society for the Study of Amphibians and Reptiles 7–12 August 1983, Salt Lake City, Utah.

Thomson, R.C., A.N. Wright, and H.B. Shaffer. 2016. California Amphibian and Reptile Species of Special Concern. University of California Press, Berkeley, California.

Tischendorf, L., and L. Fahrig. 2000. On the usage and measurement of landscape connectivity. Oikos 90(1):7–19.

Twitty, V.C., D. Grant, and O. Anderson. 1967. Amphibian orientation: an unexpected observation. Science 155(3760):352–353.

U.S. Environmental Protection Agency. 2010a. Memorandum: Endosulfan: The Health Effects Division's REVISED Human Health Risk Assessment. June 30, 2010, DP Barcode: D372569.

U.S. Environmental Protection Agency. 2010b. Final Product Cancellation Orders: Endosulfan. Federal Register Document 2010–28138, 75 FR 69065–69069, November 10, 2010.

U.S. Environmental Protection Agency. 2020. ECOTOX User Guide: ECOTOXicology Knowledgebase System. Version 5.3. <http:/www.epa.gov/ecotox/> Accessed September 30, 2020.

U.S. Forest Service. 2005a. Forest Service Sensitive Species that are not listed or proposed under the ESA. October 31, 2005. 95 pp. <https://www.fs.fed.us/biology/tes/index.html> Accessed October 20, 2021.

U.S. Forest Service. 2005b. Chapter 2670 - Threatened, endangered and sensitive plants and animals. *In* Forest Service Manual, FSM 2600 - Wildlife, Fish, and Sensitive Plant Habitat Management. National Headquarters, Washington DC. Amendment number 2600-2005-1.

U.S. Forest Service. 2018. VegBurnSeverity. Edition 18_1. U.S. Forest Service Pacific Southwest Region, McClellan, California. <http://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327833> Accessed October 6, 2020.

U.S. Forest Service and Bureau of Land Management. 1994. Standards and Guidelines for Management of Habitat for Late-Successional and Old-Growth Forest Related Species Within the Range of the Northern Spotted Owl, Attachment A to the Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents Within the Range of the Northern Spotted Owl. <https://www.fs.fed.us/r6/reo/library/> Accessed October 18, 2021.

U.S. Geological Survey. 2020. *Faxonius neglectus* (Faxon, 1885). U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida. Revised January 8, 2020. <https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=2267> Accessed March 4, 2020.

van Wagner, T.J. 1996. Selected Life-History and Ecological Aspects of a Population of Foothill Yellow-legged Frogs (*Rana boylii*) from Clear Creek, Nevada County, California. Master's Thesis. California State University Chico, Chico, California.

Voyles, J., L.R. Johnson, C.J. Briggs, S.D. Cashins, R.A. Alford, L. Berger, L.F. Skerratt, R. Speare, and E.B. Rosenblum. 2012. Temperature alters reproductive life history patterns in *Batrachochytrium dendrobatidis*, a lethal pathogen associated with the global loss of amphibians. Ecology and Evolution 2(9):2241–2249.

Voyles, J., L.R. Johnson, J. Rohr, R. Kelly, C. Barron, D. Miller, J. Minster, and E.B. Rosenblum. 2017. Diversity in growth patterns among strains of the lethal fungal pathogen *Batrachochytrium dendrobatidis* across extended thermal optima. Oecologia 184(2):363–373.

Welsh Jr., H.H., and L.M. Ollivier. 1998. Stream amphibians as indicators of ecosystem stress: a case study from California’s redwoods. Ecological Applications 8(4):1118–1132.

Westphal, M. and E. Nix. 2020. Resurveys for Foothill Yellow-legged Frog, *Rana boylii*, in the Southern Diablo Range. Presentation given at the California and Nevada Amphibian Populations Task Force Meeting in January 2020, San Diego, California.

Wheeler, C.A., J.B. Bettaso, D.T. Ashton and H.H. Welsh, Jr. 2015. Effects of Water Temperature on Breeding Phenology, Growth, and Metamorphosis of Foothill Yellow-legged Frogs (*Rana boylii*): A Case Study of the Regulated Mainstem and Unregulated Tributaries of California's Trinity River. River Research and Applications 31:1276–1286.

Wheeler, C.A., A.J. Lind, H.H. Welsh, Jr., and A.K. Cummings. 2018. Factors that Influence the Timing of Calling and Oviposition of a Lotic Frog in Northwestern California. Journal of Herpetology 52(3):289–298.

Wheeler, C.A., and H.H. Welsh, Jr. 2008. Mating Strategy and Breeding Patterns of the Foothill Yellow-legged Frog (*Rana boylii*). Herpetological Conservation and Biology 3(2):128–142.

Wheeler, C.A., H.H. Welsh, Jr., and T. Roelofs. 2006. Oviposition Site Selection, Movement, and Spatial Ecology of the Foothill Yellow-legged Frog (*Rana boylii*). Final Report to the California Department of Fish and Game Contract No. P0385106, Sacramento, California.

Wiener, J.G., C.C. Gilmour, and D.P. Krabbenhoft. 2003. Mercury strategy for the bay-delta ecosystem: a unifying framework for science, adaptive management, and ecological restoration. Final report to the California Bay Delta Authority. University of Wisconsin-La Crosse, La Crosse, Wisconsin.

Wiens, J.D., R.G. Anthony, and E.D. Forsman. 2014. Competitive interactions and resource partitioning between northern spotted owls and barred owls in western Oregon. Wildlife Monographs 185(1):1–50.

Wilson, T.S., B.M. Sleeter, and D.R. Cameron. 2017. Mediterranean California’s water use future under multiple scenarios of developed and agricultural land use change. PLoS ONE 12(10):e0187181. 21 pp.

Wiseman, K.D., K.R. Marlow, R.E. Jackman, and J.E. Drennan. 2005. *Rana boylii* (foothill yellow-legged frog): predation. Herpetological Review 36(2):162–163.

Wolf, S., Hartl, B., Carroll, C., Neel, M. C. & Greenwald, D. N. 2015. Beyond PVA: Why Recovery Under the Endangered Species Act is More Than Population Viability. BioScience 65:200–207.

Wright, S. 1978. Variability within and among natural populations (Vol. 4). Evolution and the Genetics of Populations: A Treatise in Four Volumes. Paperback edition (1984). University of Chicago Press.

Yap, T.A., M.S. Koo, R.F. Ambrose, and V.T. Vredenburg. 2018. Introduced Bullfrog Facilitates Pathogen Invasion in the Western United States. PLoS ONE 13(4):e0188384. 13 pp.

Yarnell, S.M. 2000. The influence of sediment supply and transport capacity on foothill yellow-legged frog habitat, South Yuba River, California. Master's Thesis. University of California Davis, Davis, California.

Yarnell, S.M. 2005. Spatial Heterogeneity of *Rana boylii* Habitat: Physical Properties, Quantification and Ecological Meaningfulness. PhD Dissertation. University of California Davis, Davis, California.

Yarnell, S.M. 2008. Quantifying physical habitat heterogeneity in an ecologically meaningful manner: a case study of the habitat preferences of the foothill yellow-legged frog (*Rana boylii*). *In* A. Dupont and H. Jacobs (editors) Landscape Ecology Research Trends. Nova Science Publishers, New York. 24 pp.

Yarnell, S.M., R.A. Peek, D. Rheinheimer, A. Lind, and J.H. Viers. 2013. Management of the spring snowmelt recession: an integrated analysis of empirical, hydrodynamic, and hydropower modeling applications. California Energy Commission. Publication number: CEC-500-2014-030. 149 pp.

Yarnell, S.M., E.D. Stein, J.A. Webb, T. Grantham, R.A. Lusardi, J. Zimmerman, R.A. Peek, B.A. Lane, J. Howard, and S. Sandoval-Solis. 2020. A functional flows approach to selecting ecologically relevant flow metrics for environmental flow applications. River Research and Applications 36(2):318–324.

Zimmerman, J.K.H., D.M. Carlisle, J.T. May, K.R. Klausmeyer, T.E. Grantham, L.R. Brown, and J.K. Howard. 2018. Patterns and magnitude of flow alteration in California, USA. Freshwater Biology 63:859–873.

Zweifel, R.G. 1955. Ecology, Distribution, and Systematics of Frogs of the *Rana boylei* Group. University of California Publications in Zoology 54(4):207–292.

Zweifel, R.G. 1968. *Rana boylii*. Catalog of American Amphibians and Reptiles. American Society of Ichthyologists and Herpetologists. 71, 2 pp.

In litteris

Alvarez, Jeff. 2018. The Wildlife Project. Email sent to workshop participants on November 15, 2018. Subject: Critical information: FOOTHILL YELLOW-LEGGED FROG workshop.

Blinn, Brenda. 2019. California Department of Fish and Wildlife. Email sent to Joseph Terry of U.S. Fish and Wildlife Service on November 1, 2019. Subject: Photos of dead FOOTHILL YELLOW-LEGGED FROG from Coyote Creek.

Bourque, Ryan. 2019. Senior Environmental Scientist, California Department of Fish and Wildlife, Eureka, California. Email sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on December 10, 2019. Subject: TWS RABO Workshop presentation notes and citation info.

CAL FIRE (California Department of Forestry and Fire Protection). 2021. Letter addressed to Stephanie Prevost of the U.S. Fish and Wildlife Service dated May 7, 2021, sent by

Dennis O. Hall, Assistant Deputy Director of CAL FIRE, via email attachment. Subject: Comments on Foothill Frog Species Status Assessment.

Dillon, Jeffrey. 2020. Endangered Species Division Manager, Oregon Fish and Wildlife Office, U.S. Fish and Wildlife Service, Portland, Oregon. Email attachment sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on February 28, 2020. Title: Draft Oregon Threat Write-up.

Duarte, Adam. 2021. Research Wildlife Biologist, U.S. Forest Service Pacific Northwest Research Station, Olympia, Washington. Excel spreadsheet ("FYLF Reviewer Comment Matrix.xlsx") of comments on the draft SSA for the foothill yellow-legged frog (version 1.0) sent via email to Stephanie Prevost of the U.S. Fish and Wildlife Service on May 7, 2021.

Green Diamond Resource Company. 2020. Email attachment sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on April 29, 2020. Subject: Status Review (12-month finding) of the Foothill Yellow-legged Frog (*Rana boylii*).

Grefsrud, Marcia. 2018. California Department of Fish and Wildlife. Email sent to Brenda Blinn of California Department of Fish and Wildlife on October 24, 2018. Subject: Foothill yellow-legged frog Coyote Creek.

Huff, Robert D. 2021. Conservation Planning Coordinator for the Interagency Special Status/Sensitive Species Program, Oregon/Washington Bureau of Land Management and Region 6 U.S. Forest Service. Excel spreadsheet ("FYLF Reviewer Comment Matrix-FS-BLM-final-comments.xlsx") of comments on the draft SSA for the foothill yellow-legged frog (version 1.0) sent via email to Stephanie Prevost of the U.S. Fish and Wildlife Service on May 6, 2021.

Keehn, Jade E. 2021. Wildlife Conservation Biologist, Oregon Department of Fish and Wildlife, Southwest Region. Excel spreadsheet ("FYLF Reviewer Comment Matrix_ODFW_05072021.xlsx") of comments on the draft SSA for the foothill yellow-legged frog (version 1.0) sent via email to Stephanie Prevost of the U.S. Fish and Wildlife Service on May 7, 2021.

Kupferberg, Sarah. 2020a. Independent scholar and consulting ecologist, Berkeley, California. Email and attachments sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on February 27, 2020. Subject: *Rana boylii*, feedback request.

Kupferberg, Sarah. 2020b. Independent scholar and consulting ecologist, Berkeley, California. Email sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on March 10, 2020. Subject: Quick *Rana boylii* life history questions.

Kupferberg, Sarah and Andrea Adams. 2020. Independent scholar and consulting ecologist (Kupferberg) and University of California, Santa Barbara (Adams). Email and attachments sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on November 2, 2020. Subject: Records for recent South Coast RABO observations.

Olson, Deanna. 2021. Research Ecologist, U.S. Forest Service Pacific Northwest Research Station, Corvallis, Oregon. Excel spreadsheet ("RABO FYLF Reviewer Comment Matrix_Olson.xlsx") of comments on the draft SSA for the foothill yellow-legged frog (version 1.0) sent via email to Stephanie Prevost of the U.S. Fish and Wildlife Service on May 6, 2021.

Parker, Michael S. 2021. Professor, Southern Oregon University, Ashland, Oregon. Email and attachment sent to Nadine Kanim of the U.S. Fish and Wildlife Service on October 7, 2021. Subject: Drought conditions in southern Oregon and foothill yellow-legged frogs.

Peek, Ryan. 2019. University of California, Davis. Email sent to Julie Woodruff of Sequoia Ecological Consulting, Inc. on July 26, 2019. Subject: Tadpoles being misidentified as foothill yellow-legged frog.

Peek, Ryan. 2020. University of California, Davis. Email sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on March 11, 2020. Subject: Quick *Rana boylii* life history questions.

Peek, Ryan. 2021a. University of California, Davis. Email sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on May 19, 2021. Subject: Follow-up to SSA comments.

Peek, Ryan. 2021b. University of California, Davis. Excel spreadsheet ("FYLF Reviewer Comment Matrix_Peek.xlsx") of comments on the draft SSA for the foothill yellow-legged frog (version 1.0) sent via email to Stephanie Prevost of the U.S. Fish and Wildlife Service on May 16, 2021.

Rousser, Margaret. 2020. Oakland Zoo Conservation Manager, Conservation Society of California, Oakland, California. Email sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on March 11, 2020. Subject: Quick *Rana boylii* life history questions.

Service (U.S. Fish and Wildlife Service). 2019. Foothill Yellow-legged Frog (*Rana boylii*) Conservation Strategy – DRAFT. Includes notes by the Science Applications Program of the U.S. Fish and Wildlife Service for interagency meetings on August 29, 2018 (Appendix A) and April 30, 2019 (Appendix B). 47 pp.

Van Norman, Kelli. 2021. Inventory and Monitoring Coordinator for the Interagency Special Status/Sensitive Species Program, Oregon/Washington Bureau of Land Management and Region 6 U.S. Forest Service. Excel spreadsheet ("FYLF Reviewer Comment Matrix-FS-BLM-final-comments.xlsx") of comments on the draft SSA for the foothill yellow-legged frog (version 1.0) sent by Robert D. Huff via email to Stephanie Prevost of the U.S. Fish and Wildlife Service on May 6, 2021.

Westphal, Michael. 2019. Wildlife Biology Program Lead, Bureau of Land Management, Marina, California. Email sent to Stephanie Prevost of the U.S. Fish and Wildlife Service on August 22, 2019. Subject: Question for FYLF Technical Group.

Personal communications

Kupferberg, Sarah. 2019. Independent scholar and consulting ecologist, Berkeley, California. Foothill yellow-legged frog Technical Group conference call on September 20, 2019. Notes recorded by Stephanie Prevost of the U.S. Fish and Wildlife Service.

Peek, Ryan. 2019. University of California Berkeley, California. Foothill yellow-legged frog Technical Group conference call on September 20, 2019. Notes recorded by Stephanie Prevost of the U.S. Fish and Wildlife Service.

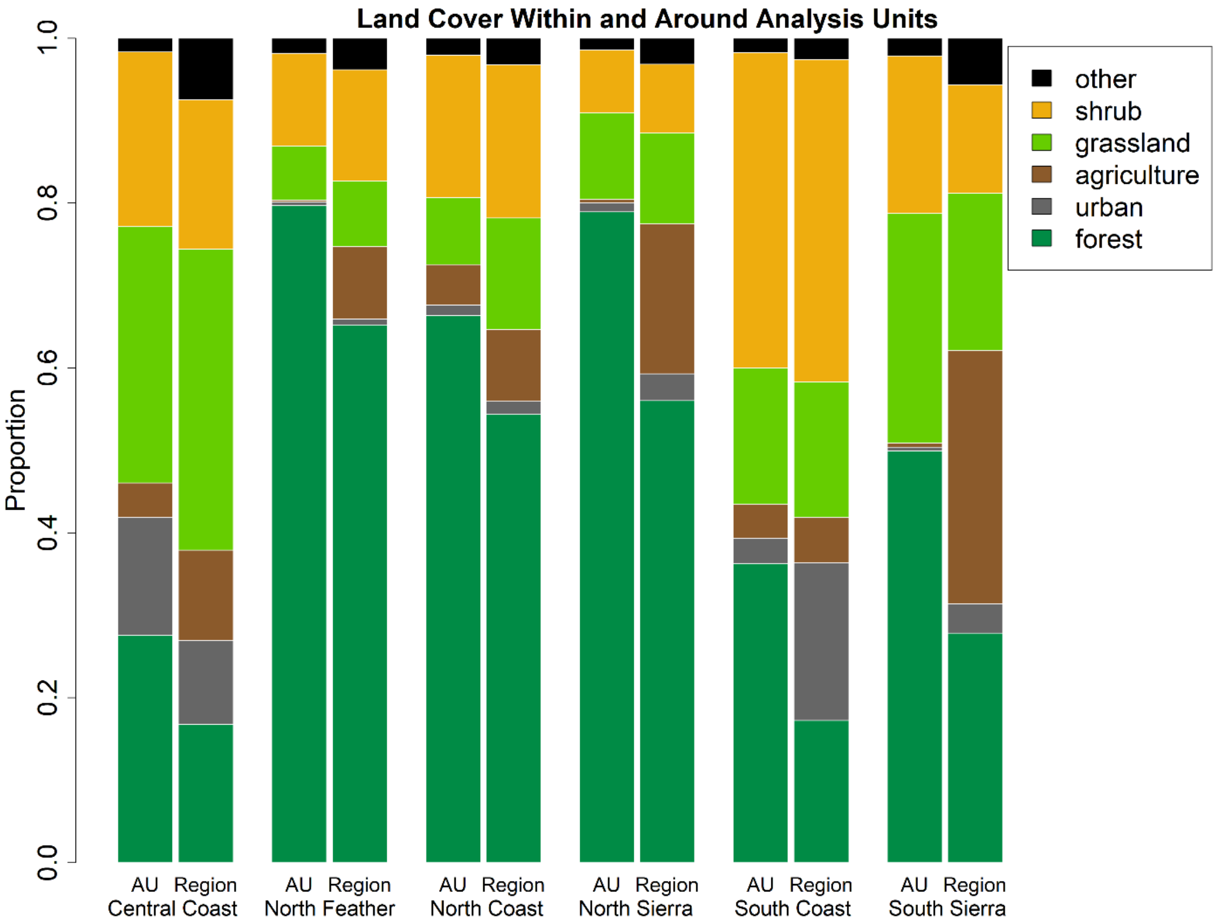
Rousser, Margaret. 2019. Conservation Society of California, Oakland, California. Foothill yellow-legged frog Technical Group conference call on September 20, 2019. Notes recorded by Stephanie Prevost of the U.S. Fish and Wildlife Service.

Appendix A

Supplementary Tables and Figures

Supplementary Table 1. Summary of forest and shrub land cover (Sleeter and Kreitler 2020, unpublished data) and hydrological characteristics for all National Hydrography Dataset (NHD) stream segments (including streams that do and do not have historical or current records of foothill yellow-legged frog) (Rose *et al.* 2020, p. 72, table 8) within each analysis unit. SD = standard deviation. *Percent forest and shrub cover for the North Coast California unit and North Coast Oregon unit is the same because land cover data for these two units were summarized together.

Analysis unit	**Percent forest and shrub cover**	**Percent of NHD stream segments that are regulated**	**Mean upstream degree of regulation (SD)**	**Mean August stream temperature in degrees Celsius (SD)**
North Coast Oregon	84*	3.6	1.1 (8.5)	14.9 (2.9)
North Coast California	84*	4.2	2.5 (25.6)	16.2 (3.1)
North Feather	91	8.3	11.0 (60.2)	14.5 (3.0)
North Sierra	86	10.8	5.8 (20.6)	16.0 (3.1)
South Sierra	69	5.6	3.0 (21.6)	17.5 (2.9)
Central Coast	49	5.7	10.3 (123.6)	19.4 (2.8)
South Coast	74	3.9	18.3 (151.4)	17.8 (1.8)



Supplementary Figure 1. Mean land cover for 2001–2019 (Sleeter and Kreitler 2020, unpublished data) for the foothill yellow-legged frog analysis units and for the greater analysis unit regions. Each greater analysis unit region includes the analysis unit plus the surrounding area that was delineated by the CDFW for management purposes (CDFW 2019b, p. 27, figure 6). AU = analysis unit. Region = greater analysis unit region. Land cover data for the North Coast California unit and North Coast Oregon unit were summarized together and labeled as "North Coast."