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Foothill Yellow-Legged Frog Conservation Assessment in California

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Cover photo: Foothill yellow-legged frog (*Rana boylii*), by Ryan Peek.

Abstract

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The foothill yellow-legged frog (*Rana boylii*) is a stream-breeding amphibian that has experienced significant population declines over a large portion of its historical range. This frog is nearing extirpation in much of the Sierra Nevada region where existing populations are sparse. Water development and diversions are likely to be the primary cause of population declines and are currently a prominent risk factor because they result in hydrological changes that chronically affect several aspects of the species' life history. Other primary risk factors include climate change, mining and suction-dredging, introduced species, and habitat loss. Conservation approaches could include restoration of hydrologic attributes such as flow and thermal regimes on regulated rivers, restoration of associated uplands and connecting riparian corridors, and management of flow regimes to retain or restore favorable habitat conditions.

Keywords: *Rana boylii*, Sierra Nevada, risk factors, water development and diversions.

Executive Summary

The foothill yellow-legged frog (*Rana boylii*) is associated with lower elevation streams draining the Pacific slope from west-central Oregon to northwestern Baja California. This assessment focuses on what is known about the natural history of this frog rangewide, with special focus on risks and management issues that pertain to the Sierra Nevada region at the heart of the species' range. Historically common throughout its geographic distribution, the foothill yellow-legged frog now appears to be near extirpation over at least two-thirds of its range. The area over which this frog nears extirpation includes the Sierra Nevada, an area that comprises the eastern portion, or roughly one-quarter of the historical distribution. In areas where the species persists in the Sierra Nevada, populations are sparse. This pattern suggests that the species is at risk of extirpation regionally and the regional risk contributes to a broader risk of extinction. Therefore, the U.S. Forest Service initiated a multiagency effort to develop a conservation assessment focused on attenuating causative factors. This assessment has three parts: (1) a synopsis of foothill yellow-legged frog ecology designed to identify areas of vulnerability, (2) a review of foothill yellow-legged frog status across the national forests and national parks in California and specifically in the Sierra Nevada, and (3) an evaluation of current and future risk factors likely to impinge on the foothill yellow-legged frog and its habitat. This assessment is intended to form the basis for a conservation strategy for the species.

Foothill yellow-legged frogs are currently recognized as one taxonomic unit, but genetic data reveal substantial genetic variability across their geographic range that may conceal unrecognized taxa. Foothill yellow-legged frogs occupy a diverse range of ephemeral and permanent streams, rivers, and adjacent moist terrestrial habitats over the course of their complex life history. Small streams often have dense canopies that limit the light needed by algae, the food resource of tadpoles. Adults can migrate down the drainage network to channels that are broad and more sunlit. Occupied streams are often partly shaded, low gradient, and dominated by coarse, unconsolidated rocky substrates. Seasonal variation in streamflow has a strong influence on life history and movement. To avoid disturbance and optimize feeding by tadpoles, adults breed and tadpoles develop in slow water velocity habitats. Reproduction occurs in synchrony with the transition from winter and spring snowmelt freshets to summer drought. The period of fastest tadpole growth and development coincides with blooms of algae and diatoms and warm water temperatures; tadpoles do not overwinter. Mortality is high through the juvenile stage because of abiotic factors such as stranding and scouring of egg masses as well as losses to predators. Early life stages, as prey items, are likely important to trophic

transfer within stream food webs. Fall rains trigger movement of recently metamorphosed juveniles upstream and away from the active channel. Postmetamorphic stages occupy terrestrial stream-margin habitats as well as springs and seeps at varying distances from breeding and rearing sites. Radiotelemetry demonstrates that foothill yellow-legged frogs travel distances far enough to allow movement between breeding sites along a watercourse, but gene flow between breeding populations is impaired in river systems in which stream reaches have been fragmented by reservoirs.

Historical records document species presence for every major Pacific-slope Sierra watershed between the upper Sacramento River and the Tehachapi Mountains, at elevations ranging from the Central Valley floor to around 2000 m; however, Central Valley records are sparse and may not reveal the presence of effective breeding populations. In California, a little over 30 percent of the historical range of foothill yellow-legged frogs is on national forest lands. The remainder is on private, state, and other federal lands. Occupancy surveys that covered historical sites and potentially suitable habitat suggest that the species is much less widespread than it was historically in the Sierra Nevada. Fewer than 10 recent records from the Cosumnes River southward suggest near-extirpation in the southern portion of their Sierran range. Records from the 1960s and 1970s imply that populations were robust until that time, but lack of monitoring prevents precisely identifying when declines began. A similar geographic pattern of extirpation exists within California in general, with few populations remaining south of San Francisco Bay.

The most robust data implicate water development and diversions as the primary cause of declines in foothill yellow-legged frogs. Water development and diversions are a prominent risk because they result in hydrological changes that chronically affect several aspects of the frog's life history. Recent studies from both regulated and unregulated rivers have demonstrated that small-scale changes in local habitat conditions, such as water velocities, depths, and temperatures, which often result from water management activities and landscape-scale changes, can lead to (1) inconsistent environmental cues for breeding, (2) lower growth rates for tadpoles, (3) scouring or stranding of egg masses and tadpoles, (4) reductions of overall habitat suitability for breeding and rearing, (5) barriers to gene flow around reservoirs, and (6) establishment of nonnative predators in reservoirs that then spread into the rivers. Other primary risk factors that may affect persistence of populations include mining and suction-dredging, climate change, introduced species, and habitat loss. Risk factors that were deemed less critical for consideration in development of a conservation strategy, but many of which remain unstudied, include airborne contaminants, acid deposition, disease, fire management and suppression, livestock grazing, locally applied pesticides, recreational activities, research activities, restoration activities, roads, UV-B radiation, and vegetation and fuels management.

Generally, restoration of the key hydrologic attributes mechanistically linked to birth and death rates is crucial for population persistence on regulated rivers in the Sierra Nevada. Of particular importance is establishment of flow schedules and thermal regimes that mimic unimpaired patterns of seasonal and diurnal variation. Sound management of associated uplands and connecting riparian corridors is also essential. Notable information gaps exist regarding whether maintaining current levels of management for activities that affect stream and upland habitat, such as mining, livestock grazing, vegetation, and fuels and fire management, is adequate for species protection. Research to investigate information gaps is needed to assess the level of risk for several potential factors that are discussed but presently unstudied.

Contents

Introduction

Purpose of This Conservation Assessment

Since about 1970, foothill yellow-legged frogs (*Rana boylii*) have disappeared from significant areas in California and Oregon, including parts of the Sierra Nevada (Borisenko 2000, Borisenko and Hayes 1999, Fellers and Drost 1993, Jennings 1996, Jennings and Hayes 1994, Lind 2005, Sweet 1983). The foothill yellow-legged frog is currently on the U.S. Department of Agriculture (USDA) Forest Service Pacific Southwest Region (Region 5) Sensitive Species List (USDA FS 1998, 2004). The state of California considers the foothill yellow-legged frog to be a "Species of Special Concern." On July 11, 2012, the foothill yellow-legged frog was petitioned for Federal Listing under the Endangered Species Act, 16 U.S.C. § 1533(b); Section 553(e) of the Administrative Procedure Act, 5 U.S.C. § 553(e); and 50 C.F.R. § 424.14 (Adkins Giese et al. 2012).

The Sierra Nevada Forest Plan Amendment (SNFPA) Record of Decision (ROD) commits the USDA Forest Service to completing a conservation assessment for the foothill yellow-legged frog in cooperation with other federal agencies, state agencies, universities, and research scientists (USDA FS 2001). The assessment is envisioned as the first of a three-phase process that also includes a conservation strategy and a conservation agreement. The conservation assessment synthesizes available data on life history, habitat associations, distribution and abundance data, and risk factors, providing the foundation for the conservation strategy. The conservation strategy will delineate specific conservation actions and lead to an agreement among various agencies and partners to implement the strategy. Following approval of the SNFPA ROD, a working group of biologists from the USDA Forest Service, U.S. Department of the Interior National Park Service (NPS) and Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife (CDFW; formerly the California Department of Fish and Game), and academic and independent research scientists was established to develop this assessment and future strategy. This conservation assessment was developed to guide future conservation strategy and recovery planning for the Sierra Nevada populations of the foothill yellow-legged frog (Blankenship et al. 2001). Conservation assessments document all conservation- or management-pertinent information about a species, including its ecology, habitat needs, population levels, and management risks. Conservation assessments also provide management recommendations based on available knowledge. Agencies committed to this assessment include CDFW; the Pacific Southwest and Intermountain Regions of the Forest Service; Sequoia, Kings Canyon, and Yosemite National Parks; and the USFWS. Each agency has specific directives and guidelines that direct their actions in relation to management and protection of native at-risk species. These directives and guides for each participating agency are explained in appendix 1.

Geographic Scope of This Assessment

The foothill yellow-legged frog occurs along the Pacific slope, from west-central Oregon to northwestern Baja California. This conservation assessment focuses on the species' range in California; however, the information gathered here is applicable to the entire range of this frog.

Document Organization

The three main sections of this document address the ecology, status, and factors potentially presenting risks to the foothill yellow-legged frog's persistence. The ecology section details the key interactions of frogs with the abiotic and biotic environment for survival and successful reproduction. This body of knowledge is necessary to develop a successful strategy for recovery of this species. The status section provides the latest information on foothill yellow-legged frog distribution and population status, with particular focus on each of the national forests and national parks within the Sierra Nevada planning area, and how these populations have changed pre- and post-1980. The risk factor section identifies, describes, and evaluates the relative importance of primary risk factors for the species, as supported by research and expert knowledge. Primary risk factors include management activities (water development and diversion, mining, introduced species, habitat loss) and environmental factors (climate change), each of which may have played a role in current foothill yellow-legged frog population trends. Additional risk factors that were deemed a lesser threat to the conservation of the species are described in appendix 4. These sections provide the conceptual and scientific foundation for the subsequent conservation strategy.

Nomenclature for North American amphibians and reptiles follows Crother et al. (2008). However, because some of the name changes in this recent publication are very new and even controversial, the previous name is also provided in brackets for the first appearance of each species name. In addition, some of the new names result from geographic "splitting" of taxa. In those cases, names are presented as old name/new name, because determining the original geographic location from the literature for a given species, and hence the appropriate "new" name, was not always possible. For example, *Rana catesbeiana* is presented as *Lithobates* [*Rana*] *catesbeianus* and *Rana muscosa* is presented as *Rana muscosa*/*sierrae*.

Ecology

Systematics and Taxonomy

The foothill yellow-legged frog is a member of the true frog family Ranidae (fig. 1) (Jennings 2003). It is recognized as a distinct species; however, there is variation in color pattern and morphology between southern Sierra Nevada and north coast populations (Zweifel 1955), and recent studies demonstrate within-species genetic variation. In a mitochondrial DNA analysis, Lind (2005) and Lind et al. (2011) identified significant genetic partitioning between coastal and Sierra Nevada foothill yellow-legged frog populations as well as two distinct, more northerly groupings. Moreover, within the Sierra Nevada, a single sample from the southern Sierra showed significant differentiation from 10 samples from the central and northern Sierra, a pattern congruent with that of other species widespread across the Sierra (e.g., Macey et al. 2001). Conclusions about evolutionary relationships did not involve formal taxonomic description for any of these groups in either of these studies, but Lind (2005) and Lind et al. (2011) emphasized that such groupings would be critically important to consider in conservation planning, and some may ultimately be regarded as deserving formal taxonomic recognition.

Figure 1—Adult female foothill yellow-legged frog under water in the North Fork Feather River, Plumas National Forest, Butte County, California.

Description

Adult foothill yellow-legged frogs are moderate-sized (37 to 82 mm snout-urostyle length [SUL]) ranid frogs with indistinct dorsolateral folds, fully webbed feet (i.e., from toetip to toetip) with slightly expanded toe tips (fig. 2), and rather thick, rough pebbly skin (Stebbins 1951, 2003; Zweifel 1955). Dorsal color is highly variable and is usually light and dark mottled gray, olive, or brown, but variable amounts of brick red are often present, and a pale triangle is often located between the eyes and the snout (Jones et al. 2005, Nussbaum et al. 1983, Zweifel 1955). The undersurfaces of the posterior abdomen and ventral surfaces of the rear legs are varying shades of yellow, which fades to white anteriorly on the belly (Stebbins 1951, Zweifel 1955). Females attain larger sizes than males (Jennings and Hayes 1994). Mature males have a dark swollen bump or nuptial pad on the dorso-medial surface of each thumb that becomes darker, slightly larger, and rougher to the touch during the breeding season. Males also have proportionally larger forearm muscles and narrower waists than females.

Juvenile foothill yellow-legged frogs look similar to adults except for their smaller size (14 to 36 mm SUL), more contrasting dorsal coloration, and lack of significant yellow on their undersurfaces (Jones et al. 2005, Nussbaum et al. 1983, Stebbins 1951, Zweifel 1955). Undersurfaces of the youngest juveniles are cream or flesh colored and the yellow color makes its first appearance on the calves and thighs, expanding anteriorly and posteriorly as juveniles grow in size (M. Hayes, personal observation, 1994–1995).

Newly hatched tadpoles are dark brown to black and typically measure 7 to 8 mm in total length (Storer 1925, Zweifel 1955). As tadpoles grow, their coloration turns an olive color with coarse brown mottling dorsally. The ventral surface of the body is silvery and nearly opaque, and the coiled intestine is barely visible. The body is more flattened, and the tail fin, tallest at its mid-portion, has a relatively broad musculature (fig. 3) (Zweifel 1955). When viewed from above, the eyes of foothill yellow-legged frog tadpoles are dorsally positioned so they are located within the outline of the head in bird’s eye view (fig. 3). Foothill yellow-legged frog

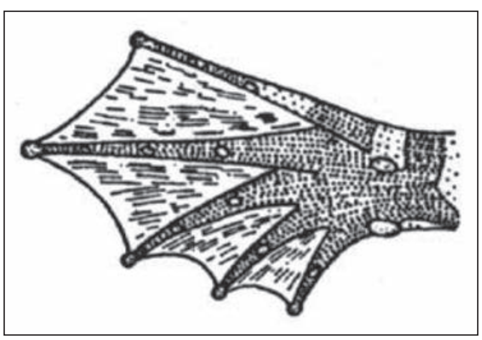

Figure 2—Hind foot webbing of adult foothill yellow-legged frog. Adapted from Zweifel (1955).

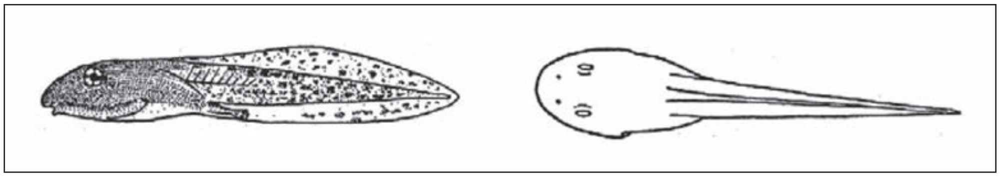

Figure 3—Appearance of foothill yellow-legged frog larva about 1 month old. Adapted from Zweifel (1955).

tadpoles have a large, downward-oriented, almost suction-like mouth (fig. 3; lateral view) with several rows of denticles or labial teeth with the number of rows increasing with development (fig. 4).

Egg masses contain from about 100 to more than 3,000 eggs, depending on the size of the female and geographic variation among populations (Kupferberg et al. 2009b). Upon deposition, the mass is compact and the jelly is highly transparent and has a hyaline blue tint. Within 6 hours, the egg mass absorbs water, loses the bluish tint, expands to a long-axis diameter of 45 to 90 mm, and resembles a cluster of grapes. Each ovum is dark brown to black in appearance and surrounded by three jelly envelopes (fig. 5). Individual eggs range from 1.0 to 2.3 mm in diameter, and the outermost of the three jelly envelopes ranges from 3.9 to more than 6 mm in diameter (Storer 1925, Zweifel 1955).

Habitat Requirements

Foothill yellow-legged frogs occur in streams flowing through a variety of vegetation types, including valley-foothill hardwood, valley-foothill hardwood-conifer, valley-foothill riparian, ponderosa pine, mixed conifer, mixed chaparral, and wet meadows (associations characterized in Sawyer and Keeler-Wolf 1995). Frogs seem to favor channels with at least some shading (>20 percent) cast by riparian vegetation (Hayes and Jennings 1988). However, when canopy closure is too great (>90 percent), foothill yellow-legged frogs are rarely found (Fitch 1936, Hayes and Jennings 1988, Moyle 1973, Van Wagner 1996). Lack of suitable breeding and basking sites, and reduced levels of appropriate food, are two possible explanations for frog avoidance of streams with dense canopy cover. In a recent landscape-scale habitat analysis of frogs in Oregon, Olsen and Davis (2009) found that stream order, minimum temperatures, precipitation frequency, stream gradient, and elevation were important variables in predicting species presence.

Breeding site selection occurs at two scales; populations congregate at suitable breeding habitat along streams and rivers, and females select specific oviposition sites within these breeding habitats (Wheeler and Welsh 2008). Site selection is not independent across these two scales. Breeding and rearing habitat is generally located in gently flowing, low-gradient stream sections with variable substrates

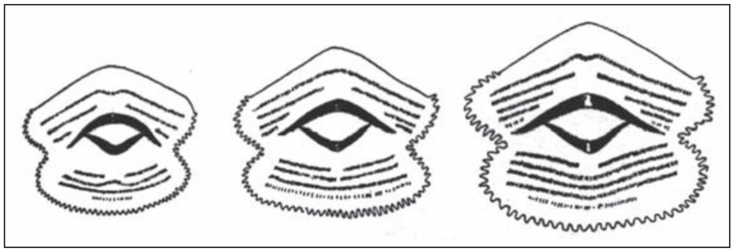

Figure 4—Tadpole tooth patterns for 8, 12, and 17 days from hatching. Drawings from Zweifel (1955).

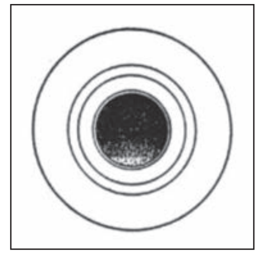

Figure 5—Ovum encased in three jelly envelopes. Adapted from Zweifel (1955).

predominated by cobble and boulder (Bondi et al. 2013, Kupferberg 1996a, Van Wagner 1996, Wheeler and Welsh 2008, Yarnell 2005). Foothill yellow-legged frogs breed at locations that provide suitable velocities and depths over a relatively broad range of discharge volumes, ranging from small tributaries to large rivers (Kupferberg 1996a, Lind 2005, Yarnell 2008). In larger channels, breeding sites are often at point bars or depositional environments near the tail-end of pools, and in proximity to tributary confluences (Fuller and Lind 1992; Kupferberg 1996a, 1996b; Peek 2010). These sites have reduced chance of scour, seem to have some degree of spatial stability on a local scale (Mount 1995), and are consequently used annually (Fuller and Lind 1992; Kupferberg 1996a, 1996b; Wheeler and Welsh 2008) over many years. In smaller streams, egg masses are located in depositional areas with cobble and boulder substrates such as runs, or the tails and outlets of pools (Van Wagner 1996). Breeding sites appear to require some degree of insolation. Removal of alders that had encroached on cobble bars in the Trinity River appeared to have a positive effect on breeding site use; within 1 year of "bank feathering" alder-removal restoration projects, 10 of 24 (42 percent) egg masses found during surveys were found at restoration sites (Lind et al. 1996). Lack of pretreatment data on restoration sites makes the significance of this response difficult to interpret, but breeding is rarely observed in well-shaded sites (Van Wagner 1996, Zweifel 1955).

Egg masses are typically attached to cobbles or boulders located near river margins in shallow and relatively slow (i.e., <5 cm sec^{-1}) moving water (table 1, fig. 6). Placement of egg masses on the lee (i.e., flow-protected) side of substrates or under overhanging rocks ensures that flow velocities at the eggs will be consistently lower than ambient stream velocities (Kupferberg 1996a, 1996b). In a habitat suitability study, suitability for oviposition was high for shallow, low-velocity habitat and cobble and boulder substrates (Bondi et al. 2013). Site preparation behavior of scraping the oviposition substrate likely occurs to ensure proper adhesion of egg masses to the substrate (Rombough and Hayes 2005a, Wheeler et al. 2003). Females

Table 1—Variation in physical conditions at *Rana boylii* oviposition

Data source	Location	Elevation	Water temperature	Depth	Velocity
		Meters	*°C*	*Centimeters*	*Meters/second*
H. Eddinger[a]	Jose Creek (Sierra National Forest)	604	12–15		
L. Conway[b]	Rose Creek (Stanislaus National Forest)	463–475	16		
L. Conway[b]	North Fork Tuolumne River (Stanislaus National Forest)	686	17–19		
Van Wagner (1996)	Clear Creek (Nevada County)	701	15	6–28	0–0.03
C. Seltenrich[c]	Stanislaus River (Tuolumne County) Mokelumne River (Calaveras County) Pit River (Shasta County)	350–930	~15	<10	"Slack water"
Bondi et al. (2013)	North Fork and Middle Fork Feather River (Butte and Plumas Counties) Middle Fork Yuba River (Nevada County) North Fork, South Fork, and North Fork/Middle Fork American River (El Dorado, Placer, and Sacramento Counties) Rubicon River (El Dorado and Placer Counties) Clavey River (Tuolumne County)		NA	14–67	0–0.15
Kupferberg (1996a)	South Fork Eel River (Mendocino County)	**363–418**	**11.5–12.0**	**4–43**	**0.01–0.14**
Fuller and Lind (1992), Wheeler et al. (2006)	Hurdygurdy Creek (Del Norte County)		**Mean = 12.4 (range 10–15)**	**7–22**	**0–0.6**
A. Lind and H. Welsh[d]	Various coastal watersheds			**1–40**	

Data from coastal sites are in bold face. Water temperature data from Kupferberg (1996a) are a range of means, not actual values from several different oviposition sites. Data from Bondi et al. (2013) represent the range of water depths and velocities that were deemed "suitable" in a habitat suitability criteria analysis.

[a] Eddinger, H. [N.d.]. Unpublished data. On file with: U.S. Department of Agriculture, Forest Service, Sierra National Forest, 1600 Tollhouse Rd., Clovis, CA 93611.

[b] Conway, L. [N.d.]. Unpublished data. On file with: U.S. Department of Agriculture, Forest Service, Stanislaus National Forest, 19777 Greenley Rd., Sonora, CA 95370.

[c] Seltenrich, C. Personal communication. Practice manager, DUDEK, 605 Third Street, Encinitas, CA 92024.

[d] Lind. A; Welsh, H. [N.d.]. Unpublished data. On file with: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1700 Bayview Dr., Arcata, CA 95521.

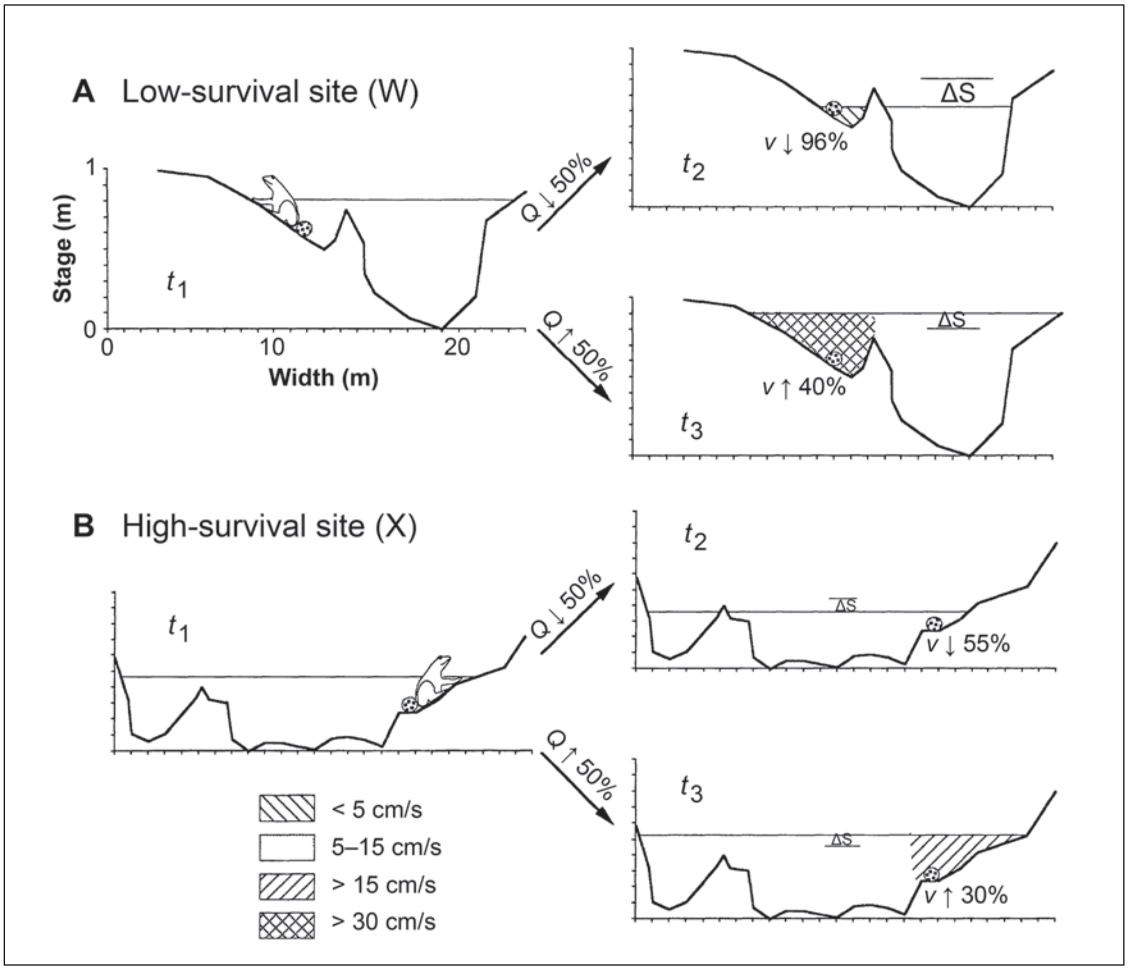

Figure 6—Sensitivity of stage height and velocity to discharge fluctuation at *Rana boylii* breeding (and early rearing) sites with different channel shapes. Frogs (not drawn to scale) are ovipositing at equal depths at discharge $Q_1 = 3\ m^3\ sec^{-1}$ in (A) a low-survival breeding site on the South Fork Eel River, and (B) a high survival site. At subsequent times (t) discharge can decrease ($Q_2 = 1.5\ m^3\ sec^{-1}$) or increase ($Q_3 = 4.5\ m^3\ sec^{-1}$). Changes in stage (s) and velocity (v) were predicted using an HEC-1 model. Channel cross-sections are drawn with a 1:10 vertical exaggeration. Adapted from Kupferberg (1996a).

may visit and "test" rub multiple oviposition locations; females may also choose sites based on the suitability of the substrate surface for oviposition (Rombough and Hayes 2005a). In a study to assess critical velocities and water depths on the Pit River during test flows, 8 of 15 egg masses survived high water velocities (up to 52 cm sec^{-1} maximum mean column velocity) (Spring Rivers Ecological Sciences 2003); however, at mean column velocities >10 cm sec^{-1}, the flow threshold at which egg masses will be scoured depends on factors such as water depth and the amount of sheltering provided by the egg mass attachment substrate (Yarnell 2014). Sustained high-flow events (i.e., over several days) will shear egg masses from their substrates (Kupferberg 1996a, 1996b; Lind et al. 1996; Van Wagner 1996; Wheeler et al. 2013) and risk of scour increases with age of the egg mass (Spring Rivers

Ecological Sciences 2003). Further studies are necessary to quantify the critical velocities and other conditions that result in separation of egg masses from their points of attachment under different conditions. Critical velocities are expected to decline with the age of egg mass because of the progressive disintegration of egg mass jelly. To survive to hatching, eggs must remain inundated as well as attached to substrates despite fluctuating water levels. Stage height and near-bank velocities are less sensitive to changes in discharge in wide, shallow channels than in deeper, more confined channels (fig. 6) (Kupferberg 1996a, 1996b; Yarnell et al. 2012). Channels with greater width:depth ratios generally facilitate greater hatching success than channels with lesser width:depth ratios, except when water levels drop and strand eggs.

Tadpole rearing sites, which are in the same or proximate habitat as egg masses, appear to also require some degree of protection from unpredictable scouring flows. Lower water velocity and shallower water depth habitats are more suitable for tadpole rearing sites (Bondi et al. 2013). Low flows are particularly important immediately after hatching, when hatchling tadpoles are not yet able to feed, are heavy with yolk, and have only modest swimming ability (Kupferberg 1996b; Kupferberg et al. 2008, 2011b). As tadpoles become exposed to higher velocities during elevated streamflows, they become less active and remain in refugia in the substrate (Kupferberg et al. 2008, 2011b). In a flume experiment, critical velocities (at which foothill yellow-legged frog tadpoles were flushed out of a microhabitat and swept downstream) varied with developmental stage, body size, population of origin, and individual activity level, but consistently fell within a range of 20 to 40 cm sec^{-1} (Kupferberg et al. 2008, 2011b). Vulnerability increased as tadpoles approached metamorphosis; critical velocities at which tadpoles were flushed decreased with increasing body size and developmental stage (Kupferberg et al. 2008, 2011b). When foothill yellow-legged frog tadpoles were experimentally relocated from low-velocity (0 to 3 cm sec^{-1}) to higher-velocity (10 to 15 cm sec^{-1}) habitat patches, fewer than 50 percent of tadpoles were able to either find a refuge in the substrate or swim cross-current to a lower velocity patch (Kupferberg et al. 2008, 2011b). Experimental work also showed that small foothill yellow-legged frog tadpoles were more vulnerable to predators and larger tadpoles experienced reduced growth at elevated velocities (Kupferberg et al. 2008, 2011b). The degree to which the substrate was embedded did not change the short-term behavioral response of foothill yellow-legged frog tadpoles to increasing velocity (Kupferberg et al. 2008, 2011b); this lack of response may place tadpoles at risk in more sediment-embedded streams, presumably because fewer refugia from high-velocity conditions exist.

The accumulation of sediment is postulated to reduce refugia for other stream-associated amphibians (Welsh and Ollivier 1998) but is unexamined for larval foothill yellow-legged frogs.

Nonbreeding active-season habitat for postmetamorphic foothill yellow-legged frogs consists of adjacent terrestrial riparian and aquatic habitats. The range of aquatic habitats in which foothill yellow-legged frogs have been found is diverse; frogs have been observed in permanent and intermittent streams with low to relatively high gradients, alluvial and bedrock channels (Leidy et al. 2009), stream-associated backwaters and isolated pools (Hayes and Jennings 1988), and slow-moving rivers with mud substrates (Fitch 1938). However, these frogs primarily inhabit relatively shallow low-gradient channels with riffles that have an unconsolidated coarse substrate (Fitch 1938; Hayes and Jennings 1988; Kupferberg 1996a, 1996b; Leidy et al. 2009; Lind et al. 1996; Moyle 1973, Storer 1925; Van Wagner 1996; Zweifel 1955). In a habitat-association study, 18 habitat variables were examined, but only the percentage of area in riffles was significantly positively correlated with foothill yellow-legged frog abundance (Hayes and Jennings 1988, Moyle 1973). The typical escape behavior of these shoreline-sitting and foraging frogs is to dive into water upon approach by a human (or presumably other predator) (Zweifel 1955). Turbulent water in riffles may reduce visibility and provide important refuge habitat for postmetamorphic foothill yellow-legged frogs (Hayes and Jennings 1988). In a study examining the distribution of foothill yellow-legged frogs relative to sediment movement, Yarnell (2000) revealed that the highest overall frog abundances occurred at sites with intermediate sediment supply rates, where enough transport occurred so that large boulders and cobbles were not buried in finer sediments, and enough deposition occurred to maintain distinct bedforms (pools, riffles, and bars). Subsequent studies by Yarnell (2005, 2008) showed that stream reaches with high aquatic and riparian habitat heterogeneity had the highest abundances of all life stages. Reaches with higher heterogeneity provide all the habitats required by each life stage in a shorter river distance and therefore less movement is required by frogs to meet life-history requirements (Yarnell 2005, 2008). Whether this heterogeneity affects overall fitness of individuals is not known. In the Coyote Creek watershed (Santa Clara County), Gonsolin (2010) documented a counterintuitive pattern. Females who traveled hundreds to thousands of meters between tributaries and mainstems to breed were larger and had better body condition than females that resided and bred within a heterogeneous stream reach.

Several studies have revealed age- and sex-specific use of habitat outside of the breeding season (Gonsolin 2010; Haggarty 2006; Van Wagner 1996; Yarnell 2000, 2005, 2008). Van Wagner (1996) encountered adult females most frequently in pools during the nonbreeding season; pools were also used as winter refugia. In the fall, juveniles were most commonly found in riffles (Van Wagner 1996). Haggarty (2006) found that adults and subadults (juveniles) showed preference for pools and riffles, whereas metamorphs (young-of-the-year) preferred glides and runs. In fall, Yarnell (2000) observed higher young-of-the-year abundance in areas with a more stable bed (i.e., low mobility) and coarse-textured substrate (low q*, points above lines in fig. 7). For adult frogs, patterns implied that preferences in channel type and surface texture varied seasonally, but females tend to travel farther than males and occupy habitats more distant from the breeding areas, such as tributaries, where predators like garter snakes are less common (Gonsolin 2010). Of all the microhabitat factors commonly measured (e.g., depth, velocity, substrate, canopy cover, aspect, presence of fish and nonnatives, mesohabitat type, Froude number, etc.), only local velocity was a significant factor in determining which habitats were occupied by which life stages (Yarnell 2005, 2008).

Overwintering is the least understood aspect of foothill yellow-legged frog habitat use. Van Wagner (1996) observed postmetamorphic frogs overwintering in velocity-protected areas of the channel (e.g., on the lee side of sedge [*Carex* spp.] tussocks). He found that adult frogs typically used root wads, woody debris, undercut banks, and large boulders adjacent to pools, whereas juvenile frogs were usually found in hollows at the stream edge created by sedges partially springing back from being pushed over during high flows. Van Wagner's (1996) observations occurred in a relatively small stream, where enough protection from scour or bedload movement may exist in selected in-channel locations during high discharge. Recent metamorphs have been caught in pitfall traps moving upland away from mainstem channels (Twitty et al. 1967); observed in wet ditches along dirt roads (Kupferberg, 2012), and in caves and tunnels (Devine Tarbell & Associates, Inc. and Stillwater Sciences 2005). In larger streams, frogs may use protected terrestrial sites that avoid the scour risk entirely. For example, in the South Santiam River in Oregon (a 6^{th}-order channel), juveniles occupy seeps above the typical winter high-flow waterline (Rombough 2006b); whether adults overwinter terrestrially at this site is unknown. Adult frogs observed moving upland along the Trinity River during fall rains may be movement into terrestrial sites (M. Hayes, personal observation, 1994; Jennings 1990), or to lateral tributaries for overwintering, where scour risk may

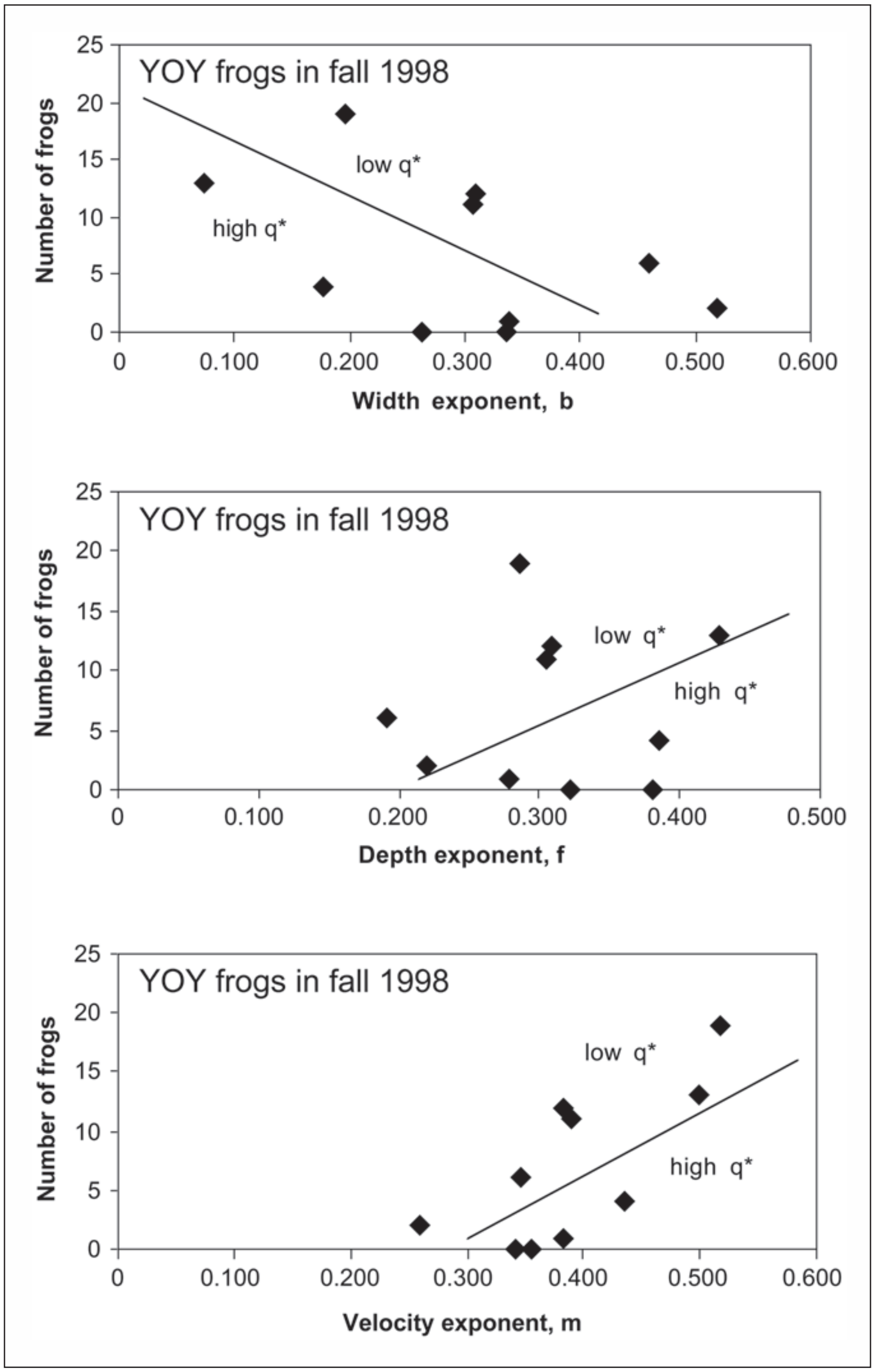

Figure 7—Variation in density of young-of-the-year (YOY) foothill yellow-legged frogs during fall 1998 with hydraulic geometry (adapted from Yarnell 2000). For each panel, the vertical axis indicates YOY density (individuals/m^2) as a function of each of hydraulic variable under two contrasting bed conditions: a coarser, more stable bed (low q*) versus a less stable, less coarse bed (high q*). Hydraulic variable exponents depicted are channel width (b), depth (f), and flow velocity (m).

be considerably lower (Kupferberg 1996a). Frogs have been observed in terrestrial habitats far from streams in the South Fork Eel and Mattole watersheds of the Coast Ranges in late fall.[1]

Life History

Foothill yellow-legged frogs initiate breeding in spring when air and water temperatures increase and streamflow declines (Gonsolin 2010; Kupferberg 1996a, 1996b; Wheeler 2007; Wheeler and Welsh 2008; Wheeler et al. 2013; Zweifel 1955); approximately 10 °C may be the minimum temperature required for oviposition (table 1). Wheeler et al. (2014) found that the average water temperature at breeding sites along the mainstem and six tributaries of the Trinity River (Trinity County) was correlated with the start of breeding activity. Breeding takes place during the transition between wet and dry seasons when unpredictable discharge presents a physical threat of scour to egg masses and hatchlings. This risky timing may represent a tradeoff; oviposition must occur early enough for tadpoles to metamorphose and juveniles to gain mass prior to overwintering (Cooper et al. 1992). When conditions are appropriate, frogs congregate at breeding sites where adult males call for mates, primarily underwater (Davidson 1995, MacTague and Northen 1993). Above-water calling also occurs, but is less frequent and faint (Davidson 1995). In a coastal population, males vocally and physically defended specific sites that included above-water calling substrates within a breeding area (Wheeler 2007, Wheeler and Welsh 2008).

Oviposition occurs between late March and June, depending on location and seasonal conditions. Most observations in the Sierra Nevada occurred in May and early June (fig. 8). Duration of breeding activity varies by population, with some breeding intervals as short as 2 weeks (Storer 1925, Zweifel 1955), and others lasting up to 31 days (Van Wagner 1996). Weather patterns may determine breeding chronology; breeding is more protracted during cold, rainy springs than warm, dry ones (Kupferberg 1996a, Wheeler and Welsh 2008). Breeding on the Stanislaus River below New Melones Reservoir can occur as late as July, likely owing to the relatively low temperature of water released, which comes from the bottom of the reservoir. In a study of the mainstem and six tributaries of the Trinity River (Trinity County), Wheeler et al. (2014) found that oviposition occurred later at breeding sites with colder average water temperatures. GANDA (2008) provided detailed

[1] Welsh, H. 1985. Unpublished data. Research wildlife biologist, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. On file with: Pacific Southwest Research Station, 1700 Bayview Dr., Arcata, CA 95521.

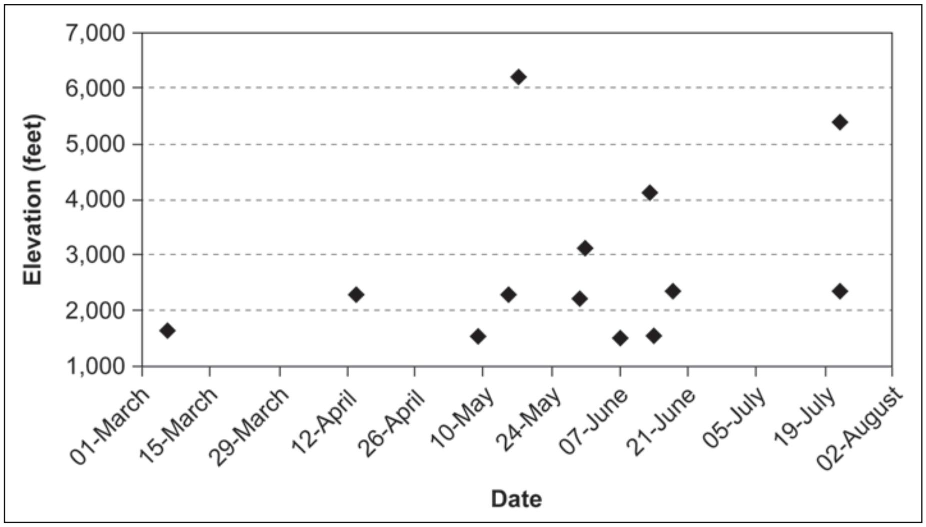

Figure 8—Variation in dates at which *Rana boylii* oviposition was observed in Sierran streams at different elevations.

observations regarding the timing of breeding for a population on the North Fork Feather River. In late April/early May of 2004 and 2005, when mean daily tributary temperatures were ≥10 °C, females left home ranges on tributaries to breed on the mainstem river. Most of the frogs laid eggs when mean mainstem temperatures were between 10 and 16 °C, and discharge was between baseflow and less than 55 percent above baseflow. Length of stay by females at river breeding sites was extended by high flows; females may be waiting for suitable flows prior to oviposition. On one reach of the North Fork Feather River, where relatively few males were present, females also remained at breeding sites longer, indicating that sex ratio may influence breeding site tenure. Overall population size may influence the length of the breeding season, as larger populations (>100 breeding adults) in Oregon appeared to consistently have a longer breeding interval than smaller populations.[2] Typically, larger females breed earlier, and the number of eggs per clutch decreases as the breeding season progresses (Gonsolin 2010, Kupferberg et al. 2009b).

Rates of embryonic development are highly temperature-dependent. Thermal tolerance experiments on foothill yellow-legged frog embryos (Gosner [1960] stages 4 to 12) revealed a critical minimum at ~6 °C, and a critical maximum at 26 °C (Zweifel 1955). Zweifel (1955) found significant acceleration in embryonic development with relatively small increases in temperature; he reported a large range of

[2] Hayes, M. 1994–1996. Unpublished data. On file with: Washington Department of Fish and Wildlife, 600 Capitol Way North, Olympia, WA 98501.

variation in the length of embryonic development across the species' range (5 to 30+ days), which he presumed was a reflection of temperature variation during embryonic development. At water temperatures of 16 to 20 °C in the South Fork Eel River, hatching occurred over a 1- to more than 3-week period, with colder water temperatures resulting in longer times to hatching (Kupferberg et al. 2011a). In the Trinity River mainstem, eggs hatch in 27 to 36 days (A. Lind, personal observation, 1991).

Length of the tadpole period is 3 to 4 months (Zweifel 1955) and varies in relation to both temperature and the quantity and quality of algal food (Catenazzi and Kupferberg 2013, Kupferberg et al. 2011a). Kupferberg et al. (2011a) found that a diet rich in diatoms from the genus *Epithemia*, which host cyanobacterial nitrogen-fixing endosymbionts, ameliorated the effects of cold temperature on the length of the larval period. Tadpoles reared in a cool, shady stream (maximum 30-day average [M30DAT] = 16 °C) were able to reach metamorphosis only with supplemented algae harvested from a warm, sunny site after 122.2 ± 0.6 days. At M30DAT = 21.6 °C, tadpoles metamorphosed 79.3 ± 1.7 days after oviposition (Kupferberg et al. 2011a). These results are consistent with many anurans, for which temperature and diet strongly influence larval growth and development, with cooler water temperatures lengthening the time to metamorphosis (e.g., Álvarez and Nicieza 2002, Licht 1974). Foothill yellow-legged frogs from some Sierra Nevada rivers that receive hypolimnetic water from upstream reservoirs appear to have extended tadpole periods, and recently metamorphosed frogs have been observed into late October (Seltenrich 2002). However, in laboratory experiments, tadpoles reared from eggs collected at Sierran sites exhibited a capacity for higher growth and faster development than those from coastal populations (Kupferberg et al. 2011a).

Growth is most rapid during the year after metamorphosis (see table 2 and fig. 9). Growth rates may vary by location; Gonsolin (2010) found that frogs on Coyote Creek (Santa Clara County) had higher growth rates than Sierra Nevada and Coast Range populations and suggested that warm water temperature and higher food availability may explain these differences. Frogs from a Sierran population grew faster than those from a coastal population, and females grew faster than males (GANDA 2015). Reproductive organs mature in the first summer after metamorphosis, but first breeding activity usually occurs in the second year following metamorphosis (Zweifel 1955). However, Jennings (1988) observed males reproducing as early as 6 months after metamorphosis, and Van Wagner (1996) found that juveniles that attained 35 mm in snout/urostyle length (SUL) by late fall were at spawning locations the following spring. Reports of size at maturity

Table 2—Mean growth rates of foothill yellow-legged frogs from Clear Creek, Nevada County, California

	Age class		
Gender	**Juvenile**	**1-year old**	**≥ 2 years old**
	Millimeters SUL/day (standard error)		
Male	0.041± 0.034 (59)	0.019 ± 0.016 (26)	0.007 ± 0.016 (11)
Female	0.090 ± 0.031 (?)	0.026 ± 020 (21)	0.013 ± 0.008 (9)

SUL = snout/urostyle length.

Data are pooled across years for age and sex classes. Sample sizes (n) are in parentheses. The range of number of days for which growth rates were calculated is 30 to 363 (adapted from Van Wagner 1996).

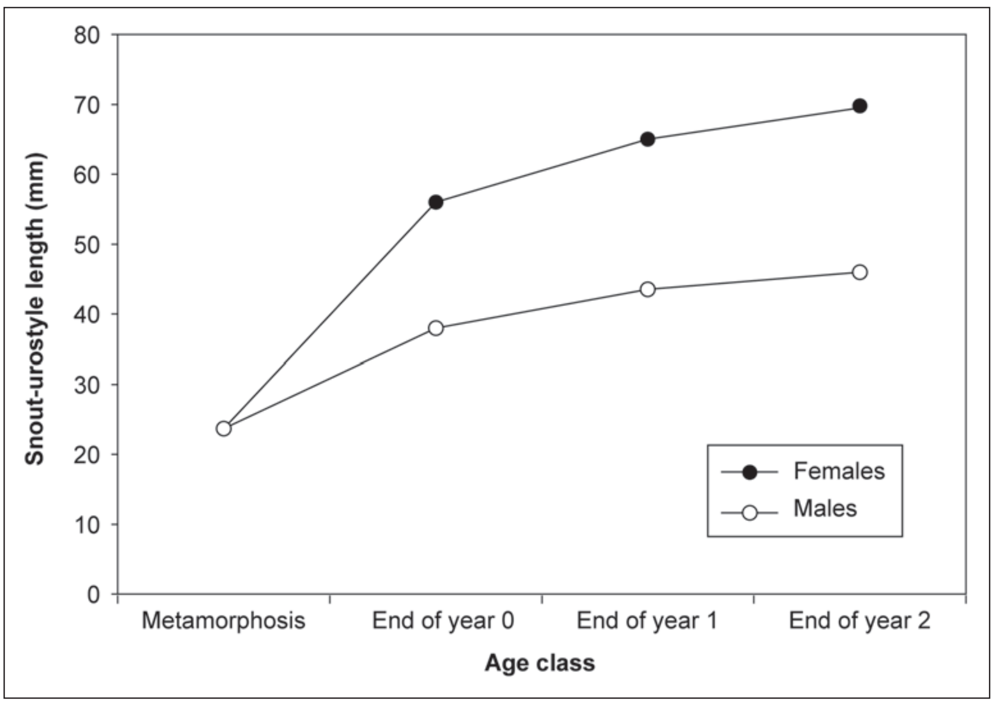

Figure 9—Composite growth curves for foothill yellow-legged frogs from Clear Creek, Nevada County, California. Points are values calculated from mean growth rates of each age class multiplied by 365 days. Adapted from Van Wagner (1996).

for foothill yellow-legged frogs vary by study, specifically for females; minimum size at maturity can vary with sex, environmental conditions, and the degree to which a population may be stressed. Because studies reported size at maturity at various locations throughout the species' range, discrepancies in size at maturity may also be due to geographic influences (e.g., elevation and or latitude/longitude). In general, males mature at a body size of about 40 mm SUL, and females mature between 40 to 50 mm SUL (Van Wagner 1996, Wheeler 2007, Wheeler and Welsh 2008, Zweifel 1955). Foothill yellow-legged frog longevity estimates are based on a few individuals recaptured during long-term studies. In the Sierra Nevada, Van Wagner (1996) reported a recaptured female to be at least 3 years old, and GANDA (2015) estimated a maximum age of 13 years for males and females in a Sierran population, and maximum ages of 12 years for males and 11 years for females in a coastal population. In a northwestern California coastal population, Wheeler determined the longevity for males to be at least 6 years, and for females to be at least 7 years, based on recaptures.[3]

The least understood aspect of foothill yellow-legged frog life history is the annual disappearance of frogs preceding overwintering. The cues for this disappearance are unclear, but movements observed during fall rains and periods of declining temperatures suggested that relative humidity and precipitation are possible triggers for movement (Bourque 2008; see also “Habitat Requirements” section).

Population Dynamics

Frog density or density index information, and egg mass counts are two types of data that provide some insight into population changes. However, no historical data exist to compare with current population levels of foothill yellow-legged frogs and no data pre-date the interval when foothill yellow-legged frog populations began to decline in California. Some data exist on differences in population densities relative to the season and degree of disturbance, human-induced and otherwise.

In a 3-year mark-recapture study on Clear Creek (Nevada County), Van Wagner (1996) observed postmetamorphic “densities” (expressed as the number of frogs per meters of stream length) that ranged from 0.19 frogs/m of stream in early summer to 0.61 frogs/m in fall; densities were highest in the fall as a result of recent

[3] Wheeler, C. 2008. Unpublished data. On file with: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1700 Bayview Dr., Arcata, CA 95521.

Table 3—Postmetamorphic *Rana boylii* population density above and below barriers to native and nonnative fish movement in three northern California drainages

	Fish absent (n = 30)	Fish present (n = 18)
R. boylii mean density (frogs/m of stream)	0.72	0.22
Range in frog density	0.47–0.97	0.07–0.37

Differences in frog density were significant (two-tailed Mann-Whitney U-test; $P < 0.001$) (adapted from Hayes and Jennings 1986).

recruitment of the new annual cohort, and spring/summer densities were lowest owing to the presumed attrition of juveniles during overwintering. Van Wagner's (1996) density estimates were similar to less labor-intensive counts obtained from similarly sized streams in three inner Coast Range drainages of the Sacramento Valley (table 3).

Egg mass counts, recorded as the number of egg masses laid per length of stream (table 4), provide estimates that may better reflect effective population sizes (N_e), the number of individuals actually contributing to reproduction over time. Individually marked gravid females have been recaptured over several consecutive years, suggesting that females reproduce every year (C. Wheeler, personal observation, 2003–2008). Each female is assumed to lay one mass of eggs and a successful male may mate with more than one female during the breeding season (Wheeler 2007, Wheeler and Welsh 2008), so the egg mass counts best reflect the number of

Table 4—Egg mass densities (number of egg masses per linear kilometer of streambank) of foothill yellow-legged frogs in California

Watershed (upstream dam or reach name)	No./km	Standard error	Length	Years sampled	Data source
			Kilometers		
Regulated coastal:					
Trinity (Lewiston Dam)	0.45	0.17	22.5, 33.3	1991–1994, 2004–2006	Lind 2005; Ashton, Bettaso, and Welsh[a]
Eel (Scott Dam)	2.9	—	12.8	2010	Catenazzi[b]
Alameda (Calaveras Dam)	3.7	1.6	1.9	2003–2010	Bobzien and DiDonato 2007
Regulated Sierran:					
North Fork of North Fork American (Lake Valley Canal Diversion Dam)	0.5	—	4	2008	Nevada Irrigation District and PG&E 2010
Middle Fork American (French Meadows Dam)	0.65	—	3.1	2007	Placer County Water Agency 2008
McCloud (McCloud Dam)	1.23	—	9.73	2008	PG&E and Stillwater Sciences 2009
South Fork Yuba (Spaulding Dam)	1.9	—	10	2008	Nevada Irrigation District and PG&E 2010
North Fork Feather (Cresta Dam)	2.1	0.4	7.6	2002–2010	PG&E 2010
Butte Creek (Forks of Butte Diversion)	4.1	—	1.9	2006	PG&E 2007
Middle Fork Stanislaus (Sand Bar Dam)	6.2	3.6	1.0	2001–2003	PG&E 2004a
Pit (Pit 4 Dam)	8	2.7	7	2002–2005	PG&E 2004b; M. Ellis[c]

Table 4—Egg mass densities (number of egg masses per linear kilometer of streambank) of foothill yellow-legged frogs in California (continued)

Watershed (upstream dam or reach name)	No./ km	Standard error	Length	Years sampled	Data source
			Kilometers		
Butte Creek (Centerville Dam)	9.1	—	5.9	2006	PG&E 2007
Rubicon (Hell Hole Dam)	9.2	—	7.9	2007	Placer County Water Agency 2008
North Fork Feather (Poe Dam)	10.5	1.7	8.3	2001–2010	PG&E 2010
Middle Fork Yuba (Milton Diversion Dam)	13	—	4	2008	Nevada Irrigation District and PG&E 2010
W Br. Feather (Hendricks Head Dam)	15.1	—	3.4	2006	PG&E 2007
Unregulated coastal:					
Coyote (U.S. Coyote Lake)	11.2	—	7.8	2004–2005	Gonsolin 2010
Eel (Ten Mile Creek)	12.3	2.6	4	1993–2003, 2008–2010	Kupferberg 1996a; unpublished data[d]
Alameda (Camp Ohlone)	21.9	4.3	1.6	1997–2010	Bobzien and DiDonato 2007
Smith (Hurdygurdy Creek)	34.6	4.5	4.8, 1.7	1991–1992, 1998-2000; 2002–2007	Lind 2005; Wheeler and Welsh 2008
Trinity (South Fork Trinity)	69.9	22.5	15.6, 5.9	1992–1994, 2004–2006	Lind 2005; Ashton, Bettaso, and Welsh[a]
Eel (SF Eel)	105.7	6.5	5.2	1992–2010	Kupferberg 1996a
Unregulated Sierran:					
San Joaquin (Jose Creek)	4.6	—	1.2	1995, 2002	Lind et al. 2003b
Tuolumne (North Fork Tuolumne)	9	—	0.3	2001	Lind et al. 2003b
Yuba (Shady Creek)	14.4	—	3.2	2003	Yarnell 2005
Stanislaus (Rose Creek)	29	—	0.65	2001	Lind et al. 2003b
Yuba (Clear Creek)	29	9.5	0.82	1992–1994	Van Wagner 1996

— = No standard error for sites with fewer than 3 years of data.

Table adapted from Kupferberg et al. (2012).

[a] Ashton, D.; Bettaso, J.; Welsh, H. [N.d.]. Unpublished data. On file with: USDA, Forest Service, Pacific Southwest Research Station, 1700 Bayview Dr., Arcata, CA 95521.

[b] Catenazzi, A. [N.d.]. Unpublished data. On file with: Department of Zoology, Southern Illinois University, Carbondale, IL 62901.

[c] Ellis, M. [N.d.]. Personal communication. Ecologist, Spring Rivers Ecological Sciences, P.O. Box 153, Cassel, CA 96016.

[d] Kupferberg, S. [N.d.]. Unpublished data. On file with: Questa Engineering, 1220 Brickyard Cove Road, Suite 206, Pt. Richmond, CA 94807.

reproductive females. Further, comparison of these data with census counts reveals a disparity between census counts and estimates of breeding female population size using egg mass data; studies have typically detected more egg masses than the number of female frogs observed. Populations appear to have higher densities in coastal rivers and streams compared to those in the Sierra, and egg mass densities are five to six times higher in unregulated rivers compared to systems with dams and diversions (table 4).

Annual fluctuations in a population based on egg mass counts on the unregulated South Fork Eel River appeared to be unlinked to the magnitude of winter peak discharge, but rather were most tightly correlated with the negative effects of high spring flow events 3 years prior (Kupferberg et al. 2008). The 3-year time lag may reflect the time most females need to recruit into the breeding population at northern latitudes.

The extent to which groups of frogs at breeding sites scatter within a stream system function as metapopulations is unknown, and population dynamics may be site -specific. On larger, high-gradient Sierran rivers, breeding sites are highly discontinuous, separated by hundreds to thousands of meters (GANDA 2008). However, frogs have been reported traveling such distances (see “Movement” section). Genetic (mtDNA, RAPD) evidence has demonstrated significant isolation by distance between individuals greater than 10 km apart in a coastal river (Dever 2007). In Sierran rivers with hydroelectric projects and reservoirs spaced between study reaches, foothill yellow-legged frog populations had lower genetic diversity and greater genetic drift that was not associated with isolation by distance in comparison to free-flowing rivers within the same watersheds (Peek 2010). This lack of gene flow suggests that if isolated populations are extirpated, the likelihood of recolonization of unoccupied sites is quite low. Moreover, these results imply that the likelihood that foothill yellow-legged frogs are capable of negotiating potential barriers such as reservoirs and dams is small. If recolonization typically results from rare long-distance movements, then reservoirs with introduced predators may be barriers. A generic matrix population model for foothill yellow-legged frogs has been developed as a tool for assessing foothill yellow-legged frog population dynamics in streams subjected to different types and severities of hydrologic alteration. However, complete demographic data for a particular stream are still needed to effectively test the general predictions of this model (Kupferberg et al. 2009b).

Movement

Unless disturbed, hatchling tadpoles remain with the egg mass remnants for several days, and then disperse into the interstices of the local gravel bed, often moving downstream in areas of moderate flow (Ashton 1995–1996). Following metamorphosis, Twitty et al. (1967) observed an upstream bias in movement; >90 percent of recently metamorphosed frogs moved upstream.

Data on postmetamorphic foothill yellow-legged frog movements come primarily from mark-recapture and radiotelemetry investigations in the Coast Range and Sierra Nevada. In general, adult frogs moved greatest distances in the spring when moving to and away from breeding sites (Van Wagner 1996, Wheeler et al. 2006). Several studies found that females moved greater distances than males; females have been reported to move thousands of meters (Bourque 2008, GANDA 2008, Gonsolin 2010, Wheeler et al. 2006), with a maximum observed distance of 7 km (Bourque 2008). Movement was more restricted during the nonbreeding season (Van Wagner 1996), and males may remain near the breeding area for months after breeding activity ends (Wheeler et al. 2006). Frogs typically remained near the stream channel (<12 m), using watercourses as movement corridors (Bourque 2008). Movements in the spring were not associated with weather variables; however, fall/winter movements were associated with increasing rain and humidity (Bourque 2008).

Juveniles and adults have been observed moving into upland habitats, off-channel pools, or smaller tributary streams during the nonbreeding season (GANDA 2008). Young-of-the-year metamorphs have been recaptured in upland traps during the fall (Twitty et al. 1967) and adults have also been observed moving upslope during fall rains (M. Hayes, personal observation, 1994) (Jennings 1990). Frog movement away from the river channel may be a behavioral response to avoid high discharge events, may represent movements into overwintering sites, or some combination of both.

Feeding

Food habit studies indicate that postmetamorphic foothill yellow-legged frogs are generalist predators primarily of insects; they eat mostly terrestrial but also aquatic invertebrates. Stomach contents have included grasshoppers, beetles, mosquitoes, hornets, bees, wasps, termites, ants, water striders, other flies, moths, aquatic snails, true bugs, and spiders (Fitch 1936, Haggarty 2006, Storer 1925, Van Wagner 1996). Haggarty (2006) found no differences in the selection of prey by age class.

Foothill yellow-legged frog tadpoles feed on periphyton scraped from rocks or plants (Nussbaum et al. 1983). Tadpoles grow faster and larger when they eat a diet rich in diatoms (which have high protein and lipid contents), and are known to prefer this food type to lower quality algae (Kupferberg 1997b, Kupferberg et al. 1996b). When availability of high-quality algae is reduced, as occurs in the presence of bullfrog (*Lithobates* [*Rana*] *catesbeianus*) tadpole grazing, foothill yellow-legged frog mass at metamorphosis has been observed to decline by about one quarter (Kupferberg 1997a). Regulated stream environments with altered hydrologic and thermal regimes may be dominated by low-quality periphyton, and tadpoles may not grow or may even lose weight by feeding on mucilaginous stalked diatoms (Furey et al. 2014). Large metamorphic size may increase survival probability, decrease the time to maturity, and increase male mating success and female fecundity (Berven 1981, 1982, 1990; Berven and Gill 1983; Howard 1978; Pough and Kamel 1984; Semlitsch et al. 1988; Smith 1987). Foothill yellow-legged frog tadpoles have also been observed actively congregating on dead tadpoles of their own species, and dead, open bivalve mollusks (A. Lind, personal observation, N.d.). They appeared to be feeding either on diatoms or algae attached to the carcasses or directly on the necrotic tissue. Besides a rich nutrient and protein source, another possible advantage of consuming dead tadpoles is to consume tissue rich in thyroid hormone, which enhances development (Crump 1990).

Mortality

Floods or dam releases have been documented as the primary cause of egg mortality in several studies (Kupferberg 1996a, Kupferberg et al. 2012, Lind et al. 1996). Extreme floods in southern California in 1969 may have been responsible for the regional extirpation of this species (Sweet 1983). In one study, large-magnitude flows reduced egg survival, but smaller-magnitude flows later in the season appeared to cause higher mortality (Kupferberg et al. 2008). Kupferberg et al. (2012) found that variability in spring and summer flows was correlated with high egg mass and tadpole mortality. Furthermore, population size on the unregulated South Eel River was correlated with spring freshets 3 years prior, suggesting that spring flows directly influence egg and tadpole survival (Kupferberg et al. 2008); this population has likely remained stable despite occasional low-recruitment years because of the lengthy recurrence interval between large, late-spring storms (Kupferberg 1996a, 1996b). Decreasing river levels can desiccate eggs through stranding (Kupferberg 1996a, 1996b, Wheeler et al. 2013). In regulated systems such as the mainstem Trinity River, Poe and Cresta reaches of the North Fork Feather River, Pit River, and South Fork American River, stranding likely occurred as a result of the timing of flow releases and cessation of spill, in which relatively high water stage prior to oviposition was followed by a drop in stage immediately after oviposition (Wheeler et al. 2013) (table 2.6 in Kupferberg et al. 2009b). When the mean and maximum scouring and stranding survival rates compiled from these regulated rivers were used in a population projection model instead of scouring and stranding rates observed in unregulated rivers, probability of extinction over 30 years increased from 2.2 to 4.6 times. Scouring and stranding events occur more frequently early in the breeding season when large females breed, so the lower fecundity of late-breeding females compounds the effect of the losses to scouring and stranding. The 30-year extinction rates increased 17-fold when the diminished contribution to future generations from the most fecund females was accounted for (Kupferberg et al. 2009b). Flow regimes on many regulated rivers appear to exceed the capacity of foothill yellow-legged frog populations to rebound from embryonic mortality caused by extreme discharge fluctuation.

Hydrologic factors also influence mortality posthatching. Summer pulsed flows may scour and strand tadpoles, as tadpoles have limited abilities for sustained swimming at flow velocities typical near shore during a pulsed flow (Kupferberg et al. 2011b). Depending on the frequency and duration of summer pulsed flows, a range of tadpole mortality estimates (best-case to worst-case scenarios, one low-mortality to four high-mortality pulses) caused risk of extinction to increase 3.2- to 20-fold beyond background rates in a population viability analysis (PVA) (Kupferberg et al. 2009b). When the negative effects of cold water temperatures on larval survival were incorporated in the PVA, the 30-year extinction rate increased 2.4 times. In a series of field experiments, thermal regime influenced the recruitment success of foothill yellow-legged frog populations; in colder tributaries, tadpoles did not attain metamorphosis (Catenazzi and Kupferberg 2013) and tadpole mortality increased when water temperatures deviated from temperatures preferred by tadpoles (16.5 to 22.2 °C). In three Sierran watersheds (Tuolumne, American, and Feather), where *R. boylii* populations occur in both regulated and free-flowing river reaches, Kupferberg et al. (2011a) found that maximum average temperature during the warmest 30-day period (M30DAT) was a useful metric to characterize the period critical for recruitment. Based on thermal monitoring of sites used for breeding and cooler sites farther upstream where frogs were sparse and tadpoles absent, the realized thermal niche for successful reproduction was 17.6 to 24.2 °C (average of 2009 and 2010, 1 dry and 1 wet year). The densest Sierran populations were in reaches where M30DAT ≥20 °C. In field tadpole-rearing experiments, peak production of metamorphs (combined highest survival and largest size) was at M30DAT = 20 to 22 °C.

Among the documented predators of foothill yellow-legged frogs at various life stages are aquatic insects including caddisfly larvae (Limnephilidae), waterstriders

(Gerridae), and veliid bugs (Veliidae) (Kupferberg 1996a, Rombough and Hayes 2005c); signal crayfish (*Pacifastacus leniusculus*) (Rombough and Hayes 2005c, Wiseman et al. 2005); introduced bullfrogs (Crayon 1998); California tiger salamander (*Ambystoma californiense*) larva (Fidenci 2006); garter snakes, predominantly the aquatic garter snake (*Thamnophis atratus)* and the Sierran garter snake (*T. couchii)* (Fitch 1936, 1940, 1941; Jennings and Hayes 1994; Lind and Welsh 1994; Nussbaum et al. 1983; Stebbins 1951; Zweifel 1955); North American river otters (*Lutra canadensis*) (Rose 2015); mallard ducks (*Anas platyrhynchos*) (Rombough et al. 2005b); Sacramento pikeminnow (*Ptychocheilus grandis*) (Ashton and Nakamoto 2007, Brown and Moyle 1997, Corum 2005); and other fish species are suspected to be predators (Hayes and Jennings 1988, Rombough and Hayes 2005c).

Numerous parasites have been documented for foothill yellow-legged frogs, but the extent of their effects on survival is unknown. Foothill yellow-legged frogs are apparently susceptible to a variety of helminths (Bursey et al. 2010, Walker 1965) as well as other parasites (Walton 1964). The copepod *Lernaea cyprinacea*, a known parasite of *Rana chalconota* (a Javanese ranid frog), has been shown to cause limb deformities (Leong 2001). A widespread introduced parasite of fish (Piasecki et al. 2004), *L. cyprinacea* has been recorded along the South Fork of the Eel River from foothill yellow-legged frogs as well as co-occurring California roach (*Lavinia symmetricus*) and American bullfrogs (Kupferberg et al. 2009a). Kupferberg et al. (2009a) observed this copepod in approximately 10 percent of metamorphs sampled on the South Fork of the Eel River; affected individuals had morphological deformities, most frequently on the hind limbs. Because this parasite has the potential to cause significant tadpole mortality, its prevalence and effects on survival warrant further study. Occurrence of *L. cyprinacea* among Sierran foothill yellow-legged frog populations has been reported in the Clavey and Rubicon Rivers (Kupferberg et al. 2009a, Peek 2014).

Summary of the Ecology

Several features of foothill yellow-legged frog ecology are pertinent to the development of a conservation strategy. Foothill yellow-legged frogs occupy low-gradient streams and adjacent terrestrial stream-margin habitats across the foothills of the Sierra Nevada, and interior and west-side Coast Ranges of California. Considerable genetic differentiation exists between coastal and Sierra Nevada populations as well as between northern and southern populations within the Sierra Nevada. Stream hydrology, especially the predictable seasonal variation in flow and complex interactions among seasonal flows, stream substrates, and riparian habitat strongly structure the spatial distribution and population dynamics of this species.

Reproduction and early rearing depend on low flows that occur during the descending limb of the seasonal hydrograph and on structurally sheltered portions of stream channels such as gravel and cobble bars. The spatial and temporal distribution of frogs varies seasonally; adult frogs congregate at common breeding sites during the reproductive season and then disperse following reproductive activity. Seasonal movements occur among breeding, postbreeding summer, and overwintering habitats. In larger streams, tributary streams may be important seasonal refuges for postmetamorphic life stages. Foothill yellow-legged frogs are vulnerable to various predators, which include several introduced species. High egg mass and tadpole mortality caused by scouring and stranding following high waterflow events or unseasonal (nonnatural) dam releases have the capacity to cause profound changes in long-term population viability.

Status

The following sections provide comparisons between more recent (1980 to 2001) and historical (prior to 1980) distributions and abundances. Limited additional locality data for the period after 2001 are also presented.

The following information was compiled from national forest biologists, National Park Service biologists, and other academic and independent biologists working in the Sierra Nevada, and from literature and museum sources. Documentation from museum collections is listed according to the standard symbolic codes for each institution (app. 2) and the pertinent specimen number(s). More detailed documentation by administrative unit (including national forests outside the Sierra Nevada region) is provided in appendix 3.

Rangewide Overview

Sweet (1983), the first to provide substantive comment on declines in the foothill yellow-legged frog, documented its complete disappearance from southern coastal California. From data collected through the early 1990s, Jennings and Hayes (1994) estimated that foothill yellow-legged frogs had been extirpated over roughly half of their California range and extirpated across about two-thirds of their Sierra Nevada historical range (Jennings 1996). Examining historically occupied sites in the late 1990s, Borisenko and Hayes (1999) and Borisenko (2000) obtained a similar estimate for contraction in its Oregon range.

The fairly recent work of Lind (2005) is the only assessment undertaken for foothill yellow-legged frogs across their entire geographic range, excluding a lone locality record for northwestern Mexico (Loomis 1965). That assessment revealed that foothill yellow-legged frogs had disappeared from 51 percent of their historical localities in the Sierra Nevada. However, the degree of disappearance across the geographic range may be underestimated. Ongoing surveys suggest that local extirpation of foothill yellow-legged frogs is continuing, and the species appears to be moving slowly, but inexorably toward extirpation across its range in a northerly direction (Jennings 2006).

California

Pre-1980—
Historical data indicate that foothill yellow-legged frogs were widespread throughout Pacific drainages in California (Stebbins 1951, 2003) with some topographic relief southward to the San Gabriel River system (Jennings and Hayes 1994; Storer 1923, 1925; Zweifel 1955 (fig. 10). Historical data provide anecdotal information on abundance. Cope (1879) stated that, "During my expedition to Oregon in 1879, I… found [foothill yellow-legged frog] rather abundant in the mountainous regions of northern California…," a comment he later repeated (Cope 1883).

Pre-1980 collections also reinforce the notion that this species was historically abundant. On 17 October 1893, Henry Henshaw collected 19 foothill yellow-legged frogs during a short visit to Orrs Creek, a tributary of the Russian River (USNM 20885–20903); from 11–23 June 1911, Walter Taylor and Norman Stern "casually" collected 35 foothill yellow-legged frogs on the Kern River near Bodfish (MVZ 2965–2999); Joseph R. Slevin collected 112 foothill yellow-legged frogs at Skaggs Spring (Sonoma County) over 3 days (17, 19, and 20 April 1911) (CAS 28165-28276); on 4 May 1911, Slevin also collected 40 foothill yellow-legged frogs from near Willits in Mendocino County (CAS 28718–28757); and on 11 September 1922, John Van Denburgh and Slevin collected 17 foothill yellow-legged frogs along Whiskey Creek, 4.8 km east of Raymond in Madera County (CAS 55746–55762). Large pre-1980 collections were not restricted to the interval around 100 years ago. On 28 April 1928, Charles Hibbard collected 57 foothill yellow-legged frogs from Lagunitas Creek in Marin County (CAS 63665–63721); on 8 June 1950, Richard Zweifel collected 30 foothill yellow-legged frogs from the North Fork of the San Gabriel River (MVZ 51314–51343); on 31 May 1952, Zweifel also collected 27 foothill yellow-legged frogs from Last Chance Creek in Plumas County (MVZ 58058–58084); and on 9 October 1955, Thomas Rodgers collected 50 foothill yellow-legged frogs at a location 1.6 km south of Denny in Trinity County (CSUC 1264–1313).

Over 4,000 specimens representing about 500 localities across the geographic range in California were obtained starting with the earliest collection in 1850

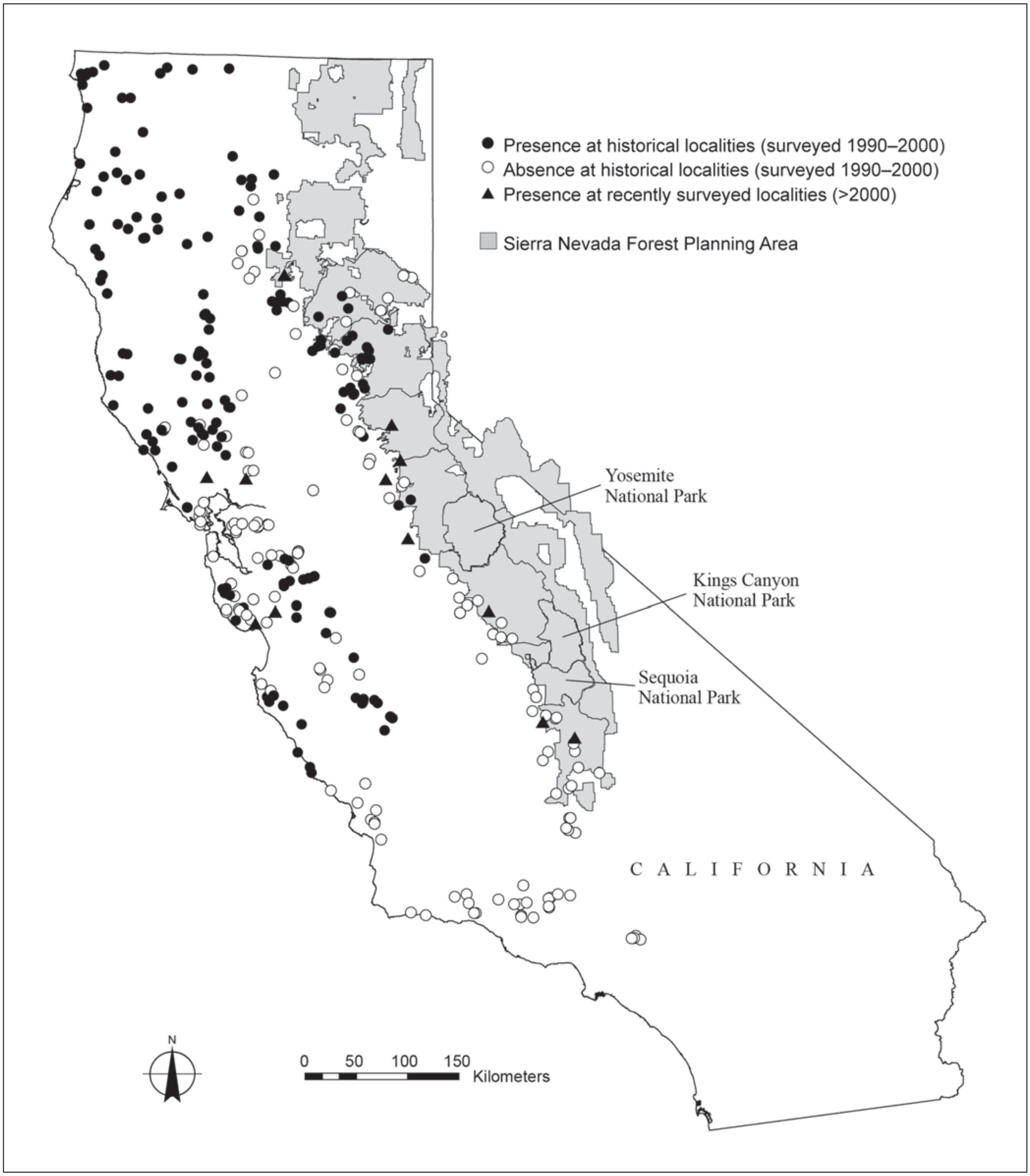

Figure 10—Status of the foothill yellow-legged frog (*Rana boylii*) in California based on an update of Lind (2005). Lind (2005) assessed status prior to year 2000. This map overlays new sightings from post-2000 localities on that previous analysis.

(USNM 3350); relatively large numbers were still being collected in the 1970s. The first indications of declines came as a result of the work of Sweet (1983), who initiated his studies on foothill yellow-legged frog distribution in southern coastal California during the late 1970s, when declines of this species across that region were already widespread. An initial disbelief at not finding frogs led Sweet to do extensive resurveys, especially in Santa Barbara County (Sweet 1985); these surveys did not detect the presence of foothill yellow-legged frogs. The last known southern California sighting deemed reliable, though not verifiable by a photograph or specimen, was made on 6 July 1977 along Piru Creek, 1 to 2 km south of Frenchman's Flat (Los Angeles County) (Jennings and Hayes 1994). Areas outside of southern coastal California were not systematically surveyed to determine the status of foothill yellow-legged frogs until after 1980.

1980 to present—

The surveys begun by Sweet (1983) during the late 1970s that indicated the disappearance of the foothill yellow-legged frog in southern California extended into the 1980s: these surveys were also unsuccessful in detecting frogs.

In an assessment addressing the entire California range through the early 1990s, Jennings and Hayes (1994) added that foothill yellow-legged frogs also seemed to have disappeared from much of the central Coast Ranges and most of the southern Sierra Nevada (see also Jennings 1995, 1996; and fig. 10). Overall, this assessment implied that the species had disappeared from about half its geographic range (based on tallying individual localities) in California (Jennings 1995). The foothill yellow-legged frog is now a California Species of Special Concern, though Jennings and Hayes (1994) recommended endangered status for this species in southern and central California south of the Salinas River in Monterey County, and threatened status in the west-slope drainages of the Sierra Nevada and southern Cascade Range east of the Sacramento-San Joaquin River axis.

In a statewide evaluation, Fellers (2005) noted that, since 1993, his field crews had conducted extensive surveys for foothill yellow-legged frogs in California, visiting 804 sites in 40 counties (California has 57 counties overall, and several desert and east-side counties lack historical records or habitat for foothill yellow-legged frogs). At least one foothill yellow-legged frog was found at 26.5 percent of sites (n = 213) and 70 percent (n = 28) of the counties visited. A distribution of sites and counties visited was not provided, but Fellers (2005) stated that foothill yellow-legged frog sites are unevenly distributed across California. He added that extant sites were most numerous in northwest California, about 40 percent of surveyed sites, whereas the Cascade Range and south Coast Range (south of San Francisco Bay) each had about 30 percent occupancy and the Sierra Nevada had about

12 percent occupancy. Comparison to the Jennings (1995) assessment may be inappropriate because limitations of the historical record prevent knowing whether all the sites that Fellers' crews surveyed were occupied in the recent past. Lack of data on detectability as a function of effort or other covariates for both surveys further confounds comparison. Nevertheless, the patterns of occupancy he reports are cause for concern because even in the region with the least-altered habitat (i.e., the northwest coast), occupancy was still less than half of surveyed sites.

Fellers (2005) also provided insight into abundance at surveyed sites. Of the 213 sites at which he found at least one frog, he observed 20 or more adults at only 14 percent (n = 30) of sites. As expected, the largest numbers were observed in the northwest coast region, where six sites had adult frog numbers over 100 and an additional nine sites had more than 50 frogs. Fellers' assessment is in general agreement with casual and systematic observations of other investigators. Kupferberg et al. (2012) compiled egg mass surveys for 27 northern California populations (coastal and Sierran) and found that the foothill yellow-legged frog still occurs in significant numbers in some coastal drainages in the Coast Range north of the Salinas River, but the species was on average five to six times less abundant where anthropogenic threats, i.e., flow regulation, were present, similar to those described in the "Risk Factors" section.

Sierra Nevada

Pre-1980—

Historical data show that foothill yellow-legged frogs occurred in west-side streams at low to moderate elevations all along the west slope of the Sierra Nevada (Jennings and Hayes 1994; Stebbins 1951, 2003; Storer 1925; Zweifel 1955) (fig. 10). In the Sacramento Valley hydrographic basin, low-elevation areas make up a large portion of the valley floor, where presumably suitable foothill yellow-legged frog breeding habitat once existed. The scarcity of records undoubtedly underestimates the historical distribution of the species in this region, as all records are pre-1930, prior to the major hydrological changes and expansion of exotic aquatic predators that changed much of the lowland Central Valley in California to its present condition (Moyle 2002). However, no quantitative abundance data exist for the Sierran slope prior to the introduction of exotic fishes and major hydrological changes. Storer (1925) suggested that the species was widespread on the Sierran slope, and Zweifel (1955) stated that the species was at least moderately abundant at scattered locations over that region. Moyle (1973), whose data were collected after significant incursion by introduced fish fauna, demonstrated that the species was still moderately abundant in foothill streams in the 1970s. However, Moyle's data were obtained at the time when the range had been reduced because the historical record shows that the species extended to the valley floor margin at least in the 1920s, 1930s, and 1940s (Storer 1925, Wright and Wright 1949). Whether the species occasionally turning up on the Central Valley floor during the latter part of the historical era were waif dispersal events, as Livezey (1962) suggests, or part of the historical pattern that helped maintain populations in areas of suitable habitat on the Central Valley floor (see Grinnell et al. 1930), as noted previously, is unclear.

1980 to present—

Surveys extending back to the 1990s suggest that foothill yellow-legged frogs have disappeared from most of the southern half of the Sierran slope, from approximately Madera County southward (Jennings 1995, 1996; Jennings and Hayes 1994). These data generally agree with the more recent survey efforts of Lind (2005) (fig. 10), demonstrating that foothill yellow-legged frog populations have become even more sparse over this portion of the Sierran slope. Further, evidence exists of considerable local extirpation from different drainage systems in the northern half of the Sierra Nevada, a pattern that becomes less widespread as one moves north (Lind 2005) (fig. 10). In Fellers' (2005) assessment (which included data collected since 1993), occupancy of foothill yellow-legged frog sites in the Sierra Nevada was about 12 percent, but historical occupany of these sites is unknown. Lind (2005) used a randomized selection of 47 historically occupied sites from across the Sierra Nevada and found that 51 percent (n = 24) of the sites were currently unoccupied.

Summary of Status

Foothill yellow-legged frogs, once common across stream ecosystems of the lower west-slope Sierra Nevada, have become increasingly rare. The most recent analyses reveal that foothill yellow-legged frogs have disappeared from 51 percent of their historical localities in the Sierra Nevada. Disappearance is more pronounced with decreasing latitude and the species is near extirpation over roughly the southern half of its Sierran range. The low number of frogs at occupied sites over the Sierran range and documented patterns of population declines in Sierra Nevada merit focused conservation efforts.

Risk Factors Affecting the Status of the Species

Many factors, individually and probably in combination, have contributed to the species' decline. However, frog populations are more often absent from historically occupied locations when close to a large dam (Kupferberg et al. 2012, Lind 2005). Water development and diversion, introduction of predators, drought and climate change, livestock grazing, pesticides, ultraviolet radiation, pathogens, acidification from atmospheric deposition, nitrate deposition, and recreational activities have all been identified as potential factors affecting this species and its habitat (Borisenko 2000, Borisenko and Hayes 1999, Jennings 1996, Jennings and Hayes 1994, Lind 2005, Olson and Davis 2009, Sweet 1983).

Risk factors include environmental conditions and human activities that may adversely affect individuals or populations of foothill yellow-legged frogs, or their habitat. The following are the 17 risk factors identified and evaluated in this foothill yellow-legged frog conservation assessment:

- Acid deposition
- Airborne contaminants (including pesticides)
- Climate change
- Disease
- Fire management
- Habitat loss, urbanization, and fragmentation
- Introduced species
- Locally applied pesticides
- Livestock grazing
- Mining
- Recreational activities (including packstock)
- Research activities
- Restoration
- Roads
- UV-B radiation
- Vegetation and fuels management
- Water development and diversion

Weighing the importance of each risk factor provides the rationale for the conservation actions to be developed in the conservation strategy. The following evaluation criteria were used to assess the importance of each risk factor relative to other risk factors (table 5):

- Spatial extent of the risk
- Duration and persistence of the risk
- Intensity of the risk
- Ecological permanence of the risk
- Was risk management addressed or is it addressable?
- Agency jurisdiction
- Is risk quantifiable? What is the weight of evidence?

Table 5—Evaluation criteria for assessing relative importance of risk factors

Criteria	Definition
Spatial extent of risk factor	Geographic area affected by the risk factor. The larger the affected area, the greater the importance of the risk factor.
Duration/persistence of risk factor	The time period and periodicity over which the species is affected by the risk factor. The longer the time period and the shorter the periodicity between impacts, the greater the importance of the risk factor.
Intensity of risk factor	The impact severity. The likelihood that the risk factor will result in a rapid decline in the species or its habitat. The higher the intensity, the greater the importance.
Ecological permanence of risk factor	The degree to which a system can recover ecologically and the length of time it would require. The more permanent the impact, the greater the importance.
Potential for management to reverse or reduce risk factor and degree of management effectiveness	The degree to which management is needed or can be applied to reduce or reverse the effects of the risk factor. For example, management can alter fish stocking levels, but may have limited capability to address disease epidemics. The more management is needed and can be effective, the greater the importance.
Jurisdiction of participating agencies	Political complexities and feasibility of applying or influencing management. The greater the ability to apply or influence management, the greater the importance.
Quantifiable/weight of evidence	Certainty and reliability of information linking the risk factor with the declines in the species. The greater the certainty, the greater the importance.

Five risk factors were regarded to be of current or future concern for species persistence, as supported by research and expert knowledge. These primary risk factors are described in the following section. The other 12 risk factors are described in appendix 4 and a summary of all risk factors can be found in table 6. The five major risk factors, in order of greatest concern, include:

- Water development and diversion
- Climate change
- Habitat loss, urbanization, and fragmentation
- Introduced species
- Mining

Table 6—Evaluation summary of risk factors for the foothill yellow-legged frog (*Rana boylii*, RABO) (continued)

Risk factor	Spatial extent of the risk	Duration and persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/degree of management effectiveness and jurisdiction	Quantifiable/weight of evidence
Water development and diversion	Rangewide but effects linked to specific local projects.	Long-term and persistent except for small fish-related projects.	High, but variable based on scale and dam operations; larger projects generally present greater threats.	Permanent if project is permanent.	Yes, where projects are removed or flow regimes and impoundment management can be significantly improved; effectiveness of improved dam operations is probably high if populations are extant and low if population reestablishment/recolonization is needed. Participating agencies have opportunities to revise flow regimes through FERC relicensing of hydropower projects.	Effects on RABO well-documented; also excellent documentation of habitat changes likely to directly influence RABO habitat.
Climate change	Global, regional effects documented.	Long-term and persistent; changes regional hydrology.	Probably high, extent of effect poorly understood.	Permanent within human time scale, i.e., on time scales that management addresses.	No, and beyond jurisdictional scope of agencies, but agency-influenced management of flow regime could ameliorate effects on water temperature; public awareness may bring about change.	Climate change is well-documented; effects on RABO are not; science needs to inform; interactions with other factors potentially numerous.
Mining	Widespread but localized to individual mining operations; most at low elevations.	Long-term and persistent if operation remains active or mine is not decommissioned, though sometimes long after operation ceases.	Variable, potentially high with acid mine drainage.	Likely somewhat reversible.	Yes, potentially effective through regulation of mining activities.	Few data relative to RABO, negative acid mine drainage effects documented for other amphibian species.

Table 6—Evaluation summary of risk factors for the foothill yellow-legged frog (*Rana boylii*, RABO) (continued)

Risk factor	Spatial extent of the risk	Duration and persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/degree of management effectiveness and jurisdiction	Quantifiable/weight of evidence
Introduced fish and other predators	Regionally widespread in RABO habitat; generally worse in lowlands.	Long-term and persistent in RABO habitat.	Variable, potentially high with direct and indirect effects.	Potentially, but constant exotic recolonization through stream network likely an issue.	Yes, effectiveness untested, but may be difficult owing to recolonization through stream network.	Bullfrog and crayfish effects have been documented. Fish-RABO interactions just beginning to be studied; magnitude of effect probably species-specific.
Habitat loss, urbanization, and fragmentation	Urbanization now limited, but likely to be important in the next few decades; most loss and fragmentation a function of other risk factors, especially water development.	Typically long-term and persistent.	High where habitat is lost.	Reversibility depends on basis of habitat loss; not well understood.	Yes, effectiveness depends on basis of losses.	No data exist for habitat loss to RABO from urbanization or land use conversion; or evidence of fragmentation effects on RABO from land use conversion; basic data needed to inform issue.
Airborne contaminants including pesticides	Regional, minor extra-regional contribution; variable due to composition and regional loading.	Long-term with seasonal flows linked to annual snow-melt and precipitation events. Persistence depends on chemical use and type.	Unknown, interactive or immuno-suppressive effects likely, but unstudied.	Unknown; may accumulate or flush; effect chemical-dependent.	No, and beyond jurisdictional scope of agencies, but agency-influenced public awareness may bring about change.	Strong evidence of airborne transport and deposition in Sierra Nevada, indirect evidence from correlative data with RABO less frequent in areas upwind from agriculture.
Acid deposition	Probably limited, but condition is vulnerable because of low acid neutralizing capacity.	Unknown, if conditions change cumulative effects may be persistent and long-term.	Low for direct effects, but unidentified interactions with other factors may exist.	Little basis for evaluation.	Little basis for evaluation.	Direct evidence for risk factor limited; threshold tolerance levels to pH for RABO unknown; limited experimental data from other species implies interactive effects likely.

Table 6—Evaluation summary of risk factors for the foothill yellow-legged frog (*Rana boylii*, RABO) (continued)

Risk factor	Spatial extent of the risk	Duration and persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/degree of management effectiveness and jurisdiction	Quantifiable/weight of evidence
Disease	Globally widespread, but poor understanding of distribution in RABO.	Unknown.	Seems low, but incompletely understood.	Unlikely, but incompletely understood.	Unclear and unknown; depends on transmission and other factors not currently understood.	Limited evidence of chytrid and that it does not seem to be a problem; interaction with other factors poorly understood.
Fire management	Rangewide, but depends on local fire events.	Long-term, seasonal and sporadic, depends on climate.	Likely variable, but not well understood.	Reversible, but recovery likely to vary with local conditions; not well understood.	Yes, effectiveness likely depends on implementation approach; not well understood.	Unstudied relative to RABO; studies on fire management and its effects on riparian and aquatic habitat provide insight. Interaction with other factors needs study.
Livestock grazing	Widespread regionally and over range of RABO.	Seasonally and long-term.	Likely low but depends on grazing level; poorly understood.	Likely reversible, but different grazing levels result in different recovery rates.	Yes, effectiveness depends on management implementation, poorly studied.	Grazing effects on RABO largely unstudied; only negative correlation to livestock grazing exists. Basic data needs to inform.
Locally applied pesticides	Local and variable in composition and loading levels, documentation limited to use patterns.	Short-term for most in current use; persistence depends on chemical use and type.	Probably low, but largely unstudied.	Probably reversible, but poorly known and effect chemical-dependent.	Yes, potentially effective through regulation of application (amount, timing, and constituent).	No field data. Toxicity data on other species indicates surfactants used with pesticides more toxic than pesticides, chemical-dependent toxicity.
Recreational activities (including packstock)	Widespread regionally though localized to use sites.	May be persistent and long term; depends on use.	May be locally high; depends on use levels.	May be reversible, likely depends on length of time impacted.	Yes, potentially effective but untested for RABO.	Anecdotal documentation; effects inferred primarily from impacts on habitat. Basic data needs to inform.

Table 6—Evaluation summary of risk factors for the foothill yellow-legged frog (*Rana boylii*, RABO) (continued)

Risk factor	Spatial extent of the risk	Duration and persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/degree of management effectiveness and jurisdiction	Quantifiable/weight of evidence
Research activity	Localized at research sites, sometimes representing widespread arrays.	Typically seasonal, potential for long-term; depends on objectives.	Likely low, but unstudied; disease transmission a possible threat.	Likely reversible; recovery likely issue-dependent.	Yes, probably effective, but unstudied.	Issues hypothetical and unstudied. Needs basic data to inform.
Restoration	Localized at restoration sites, extent project-dependent.	Seasonal, whether long-term or persistent depends on type.	Likely low, but almost entirely unstudied.	Likely reversible; unstudied.	Yes, through the regional planning process and permitting.	One study suggested that caution is needed in planning where restoration target is not RABO; otherwise unstudied.
Roads	Widespread but localized to the road matrix.	Persistent and long term except where roads are decommissioned.	Likely variable depend on road type and use level.	Reversible where roads are decommissioned.	Yes, through various planning processes.	Roads unstudied for their effects on RABO, but effects demonstrated and broadly studied for other species.
UV-B radiation	Global, but locally and regionally mitigated by elevation, dissolved organic carbon.	Persistent and long-term; persistence in future depends on continued influence on atmosphere.	Low for direct effects, but unidentified synergisms with other factors possible.	Permanent in the short term; long term depends on human actions.	No, and beyond jurisdictional scope of agencies, but agency-influenced public awareness may bring about change.	Evidence of direct effect controversial; indirect effects or interactions with other factors unstudied for RABO. Effects for other species demonstrated.
Vegetation and fuels management	Rangewide, but project-specific in effects.	Sporadic, but potentially long term.	Unknown, likely variable but unstudied.	Likely reversible, recovery likely to vary by project, but unstudied.	Yes, effectiveness likely depends on implementation approach.	Unstudied relative to RABO; fire and vegetation studies imply possible effects. Basic data needed to inform.

FERC = Federal Energy Regulatory Commission.

Water Development and Diversion

Water developments on natural waterways have greater potential to alter habitat for the foothill yellow-legged frog than any other risk factor. In California, the Mediterranean climate produces a very distinct hydrologic signature with high and variable waterflows in the fall, winter, and spring; and low, receding, stable flows in the summer. Native biotas, including foothill yellow-legged frogs, are adapted to this "natural flow regime," especially spring (rain or snowmelt) recession flows (Yarnell et al. 2010). Modifications to that hydrologic regime can disrupt species responses to environmental cues and have direct effects on survival of aquatic life stages.

Water developments exist as two major types: impoundments and diversions. Impoundments block streams with a structure such that natural flows are impeded and water is pooled upstream. Impoundment size varies throughout the foothill yellow-legged frog range, ranging from smaller dams created for water gaging stations and improved fisheries to larger dams created for hydroelectric generation or flood control. Diversions are created for the purpose of removing and delivering water to offsite locations. Some diversions are associated with impoundments, whereas others involve pumping water directly from the waterway or indirectly through groundwater pumping. The California Water Plan Update (CDWR 1998) reports that dams and diversions are found on most Sierra Nevada streams (Moyle and Randall 1998), and a majority of these alterations exist within the elevational range of the foothill yellow-legged frog.

Impoundments—

In a recent study, regulation of flows downstream of dams was associated with lower abundances, where breeding populations were on average five times smaller in regulated rivers than in unregulated rivers (Kupferberg et al. 2012). Lind (2005) (also summarized in Kupferberg et al. 2012) previously found an impoundment effect on foothill yellow-legged frogs; the species was associated with streams lacking dams or with streams with small dams located far upstream of sites occupied by foothill yellow-legged frogs. Large regulated streams typically have substantially lower numbers of foothill yellow-legged frogs than unregulated streams (table 4). At least one large reservoir (≥ 0.12 km^3 [100,000 ac-ft]) exists in the foothill region of every major Sierran stream below 600 m (1,968 ft). Several major streams (e.g., Pit River, Feather River, American River, Mokelumne River, Tuolumne River, San Joaquin River) have two or more reservoirs (of varying size) in linear sequence, and a few large reservoirs also occur at higher elevations on major stream tributaries (table 7). Additionally, several hundred medium-sized (< 0.12 km^3 [100,000 ac-ft] and ≥ 0.03 km^3 [25,000 ac-ft]) and small reservoirs (< 0.03 km^3 [25,000 ac-ft]) are broadly distributed at elevations below 1828 m (6,000 ft) over the Sierra Nevada (Mount 1995). In Oregon, proximities to hydropower and dams with reservoirs larger than 50 ha were negatively associated with frog occurrence (Olson and Davis 2009).

Reservoir placement on Sierran streams has converted many lotic aquatic habitats to lentic conditions, resulting in habitat with reduced flows, increased depths, and altered temperature and dissolved oxygen regimes (Mount 1995; Petts 1980, 1984). These changes result in direct loss of required habitat for stream-dwelling foothill yellow-legged frogs, which have evolved to inhabit free-flowing, well-oxygenated water with coarse substrates (see “Habitat Requirements” section). In an evaluation of the distribution of reservoirs in the Sierra Nevada, Kondolf et al. (1996) found that reservoirs had eliminated an estimated 9,972 km (6,209 mi) of aquatic habitat. Given the distribution of reservoirs, foothill yellow-legged frogs could have been historically present in much of this lost habitat. Sierran reservoirs currently inundate at least eight sites once occupied by foothill yellow-legged frogs (table 8).

Regulation of flows downstream of impoundments may result in altered timing, duration, and magnitude of stream discharge, creating conditions in which runoff is not synchronous with the species’ life-history requirements (Kupferberg et al. 2008, Yarnell et al. 2010). Greater short-term (diel, weekly, or monthly) variation in flows affects foothill yellow-legged frog egg mass and tadpole survival. Lind et al. (1996) observed high losses of foothill yellow-legged frog egg masses following relatively high, periodic releases of water from Lewiston Dam on the Trinity River that deviated in timing from pre-dam flow patterns. Egg mass mortality related to aseasonal releases has been documented on other regulated California streams (table 2.6 in Kupferberg et al. 2008; Kupferberg et al. 2012; Mount 1995; Spring Rivers Ecological Sciences 2003) as well as for freshets occurring during seasonal intervals on hydrologically unaltered streams (Kupferberg et al. 2008 and studies cited therein). Kupferberg et al. 2012 found that variability in timing and magnitude of flows was associated with mortality of early life stages; egg mass survival was negatively correlated with the ratio of maximum:minimum discharge after the initiation of oviposition. In an examination of the effect of flow augmentation for whitewater rafting, foothill yellow-legged frog egg mass density decreased along a regulated river reach, whereas density increased on a reach with stable flows, typical of summer flows in an unregulated river (Kupferberg et al. 2012). Short-term flow variation may also affect tadpole or metamorphosing stages by stranding

Table 7—Large reservoirs (≥ 0.12 km^3 [100,000 ac-ft]) on major streams within the Sierra Nevada Planning Area

Stream	Reservoir	Year completed (year filled)	Elevation	Volume
			Meters (feet)	*Cubic kilometers (acre-feet)*
Sacramento River	Shasta	1945 (1954)	325 (1,067)	5.61 (4,552,000)
Feather River	Oroville	1968 (1969)	274 (900)	4.36 (3,537,580)
North Fork	Almanor	1927 (1964)	1,366 (4,482)	1.61 (1,308,000)
Bucks Creek	Bucks	1928 (1951)	1,581 (5,168)	0.13 (105,600)
Yuba (North Fork)	Bullards Bar	1970 (1971)	581 (1,907)	1.20 (969,900)
Yuba (South Fork)	Spaulding	1946 (1946)	1,643 (5,390)	0.18 (144,591)
Bear River	Camp Far West	1963 (1964)	79 (260)	0.13 (104,000)
American River	Folsom	1956 (1956)	142 (466)	1.21 (977,000)
Middle Fork	French Meadows	1966 (1966)	1,604 (5,263)	0.17 (136,400)
South Fork	Union Valley	1963 (1963)	1,484 (4,870)	0.34 (277,300)
Rubicon River	Hell Hole	1966 (1967)	1,411 (4,630)	0.26 (207,600)
Mokelumne River	Camache	1963 (1966)	72 (236)	0.51 (417,120)
Mokelumne River	Pardee	1929 (1951)	173 (568)	0.24 (197,950)
North Fork	Salt Springs	1931 (1951)	1,204 (3,949)	0.17 (141,857)
Calaveras River	New Hogan	1963 (1965)	169 (554)	0.39 (317,100)
Stanislaus River	New Melones	1963 (1965)	346 (1,135)	2.99 (2,420,000)
North Fork	New Spicer Meadows	1990 (1990)	1,986 (6,516)	0.23 (190,000)
Tuolumne River	New Don Pedro	1970 (1974)	253 (830)	2.50 (2,030,000)
Tuolumne River	Hetch-Hetchy	1923 (1952)	1,180 (3,870)	0.44 (360,400)
Tuolumne River	Cherry	1957 (1957)	1,437 (4,715)	0.33 (268,000)
Merced River	Lake McClure	1926 (1926)	264 (867)	1.26 (1,024,600)
Chowchilla River	Eastman	1975 (1978)	137 (450)	0.19 (150,000)
San Joaquin River	Millerton	1942 (1946)	177 (581)	0.64 (520,000)
San Joaquin River	Mammoth Pool	1960 (1960)	1,015 (3,330)	0.15 (122,700)
San Joaquin River	Shaver	1927 (1951)	1,637 (5,370)	0.17 (135,400)
South Fork	Thomas A. Edison	1954 (1956)	2,329 (7,642)	0.15 (125,000)
Kings River	Pine Flat	1954 (1956)	296 (970)	1.23 (1,000,000)
Helms Creek	Courtright	1958 (1962)	2,497 (8,192)	0.15 (123,200)
North Fork	Wishon	1958 (1959)	1,999 (6,560)	0.16 (128,300)
Kaweah River	Kaweah	1962 (1964)	229 (752)	0.23 (185,600)
Kern River	Isabella	1953 (1953)	803 (2,635)	0.70 (568,000)

Note: Streams are ordered north to south. Reservoir elevation and volume are at full pool based on data from original construction. Streams indented on the list are tributaries of the non-indented stream above them.

Table 8—Reservoirs on major streams within the Sierra Nevada Planning Area for which foothill yellow-legged frog (*Rana boylii*) records exist where the historically occupied site is now inundated by the reservoir

		Rana boylii record		
Stream	**Reservoir**	**Year**	**Collection**	**Years prior to reservoir filling**
Sacramento	Shasta	1884	USNM 13795, 13929	70
Pit	Pit 7	1953	FMNH 71474	12
Feather	Oroville	1941	MVZ 34837–34839	28
		1946	MVZ 51662	23
		1961	CSUC 1197	8
Butte	De Sabla	1945	MVZ 42726, 42739	0
Little Butte	Paradise	1960	CSUC 1563–1564	4
Yuba	New Bullards Bar	1899	USNM 38817–38819	73
Tuolumne	Don Pedro	1932	USNM 88468–88473	42
Merced	Lake McClure	1915	MVZ 5779–5780	11
Kings	Pine Flat	1910	CAS 17952	46
Kern	Isabella	1891	USNM 18951–18952	63

Note: Streams are ordered north to south.

(Kupferberg et al. 2008 and studies cited therein) or sweeping individuals into less suitable (e.g., predator-rich) habitats. Experiments simulating high pulse flows suggested that foothill yellow-legged frog tadpoles seek refuge from higher velocities in the substrate, but many were swept downstream (Kupferberg et al. 2008, 2011b). Furthermore, large spring flow pulses have been documented to decrease survival of embryonic stages, but smaller pulses later in spring appeared to cause even higher mortality, presumably because surviving tadpoles are directly affected by flows (Kupferberg et al. 2008).

Population viability analyses suggested that small population sizes combined with the mortality effects on early life stages associated with pulse flows can have negative consequences on cumulative risk of extinction (Kupferberg et al. 2009b). When evaluated using the mean number of breeding females observed per kilometer, the 30-year probability of extinction increased substantially (fourfold) in regulated rivers, and 13-fold with a starting population size equal to that in a Sierran river (Cresta reach of North Fork Feather), where frogs have been declining over the past decade. Modeled populations were unable to persist when hydrologic stressors were combined because the effects on population dynamics were multiplicative. For example, egg mass scouring, which occurs most frequently early in the breeding season, eliminates the reproductive effort of highly fecund large females. When these two effects were considered together, a disproportionate increase in the 30-year risk of extinction became manifest, five times greater than the sum of the first-order effects. When tadpole mortality from a single annual summer pulsed flow was combined with high rates of egg mass stranding and scouring, the multiplicative increase in extinction risk was twice as high as the additive effects. The results of the population modeling effort illustrates that any one anthropogenic hydrologic impact (e.g., cold water temperature effects on development, abrupt cessation of spring spills causing mass mortality through stranding, reduced availability of suitable breeding habitat) cannot be assessed in isolation. Each impact may result in population-level consequences that would underestimated if not considered in concert.

Loss of variation in flows may have long-term impacts on riparian vegetation, sediment transport, and stream channel morphology. Lind et al. (1996) found significant changes in riparian habitat along the Trinity River downstream of Lewiston Dam that resulted from reduced and more stable year-round flows. Reduced flows may be insufficient to effectively scour banks and set-back succeeding vegetation, leading to substantial encroachment by riparian vegetation (Mount 1995) and less available habitat for foothill yellow-legged frogs. In a stream restoration project on the Trinity River mainstem, 10 of 24 foothill yellow-legged frog egg masses were found at bank feathering (vegetation removal treatment) sites within a year of implementation; encroaching bank vegetation at untreated sites may have limited foothill yellow-legged frog reproduction (Lind et al. 1996). Reservoirs trap large amounts of sediment, which may affect the distribution of substrate particle sizes downstream of dams (Ligon et al. 1995). In general, smaller particles (finer than gravels) are reduced downstream from dams because most available flows can only entrain those substrate sizes and these same smaller substrates settle out rapidly in the inflow to the impoundment upstream (Mount 1995). The availability and distribution of diverse stream substrates is important to foothill yellow-legged frogs because the life stages have different substrate requirements; e.g., cobble and boulder substrates are used for oviposition sites and provide refuge habitat for tadpoles (see “Ecology” section). Sufficient sediment is also needed for bedform development within the channel, such as riffles, and for cross-sectional channel shapes favorable to oviposition and tadpole rearing (see “Ecology” section). Streams below dams that are typically perennial may be converted to spatially intermittent or ephemeral (seasonally intermittent), or naturally ephemeral streams may dry up faster than they did historically (Mount 1995); channel drying may increase the risk of egg mass and tadpole desiccation and predation (see Kupferberg 1996a, 1996b).

Impoundments can alter downstream water temperatures for many kilometers. These effects largely depend on the volume of water released and the elevation in the reservoir's water column from which flows are released. For example, dams that release water from a location deep in the reservoir (hypolimnetic) promote cooling downstream, whereas dams that release water from surface spillways may have a warming effect (Petts 1984). Many combinations are possible if dams have more than one release point. Likewise, varying effects on both foothill yellow-legged frogs and associated instream biota are possible depending on whether the water is warmed or cooled, and the downstream extent of the thermal alteration. Wheeler et al. (2014) found that oviposition and metamorphosis were delayed for foothill yellow-legged frog populations on cold tributaries and the regulated mainstem Trinity, where summer water temperatures are unseasonably low owing to hypolimnetic releases. At cooler temperatures, foothill yellow-legged frog growth and development rates may be inhibited, both directly as a function of temperature, and indirectly as a function of food resources. The composition of the periphyton flora is sensitive to flow regulation. For example, spread of the invasive benthic diatom, *Didymosphenia geminata*, which has been found in several Sierran regulated rivers, is associated with cool summer water temperatures and artificially stable base flows (Kirkwood et al. 2009, Kumar et al. 2009). *Didymosphenia,* which produces copious amounts of inedible mucilaginous stalk material, can displace more nutritious algal taxa and does not provide adequate nutrition for growth of foothill yellow-legged frog tadpoles (Furey et al. 2014, Kupferberg et al. 2011a). Water temperatures that remain colder than natural conditions may delay metamorphosis of tadpoles, increasing risk of predation (Lind et al. 1996), especially because of small tadpole size (Kupferberg et al. 2011a). Metamorphs on the mainstem Trinity, which is cooled by water released from the Trinity Dam, were generally smaller compared to metamorphs from tributaries (Wheeler et al., 2014); however, the potential mechanisms for these differences (e.g., food quality and quantity, feeding rate) remain unexamined. Catenazzi and Kupferberg (2013) found that, in a thermal gradient, foothill yellow-legged tadpoles selected temperatures between 16.5 and 22.2 °C and mortality was higher when temperatures deviated from preferred temperatures. Supplementing tadpole diet lessened the negative effects of cold temperatures on tadpole survival to metamorphosis, but tadpoles were smaller at colder sites compared to those at warmer sites (Catenazzi and Kupferberg 2013).

Dam and reservoir-induced changes in habitat can influence native species composition and affect food resources for postmetamorphic stages, competitive relationships, and predator assemblages. For example, regulated flows may modify macroinvertebrate species composition and density (e.g., Hax and Golladay 1998), resulting in changes in food availability. Such effects have not been studied for foothill yellow-legged frogs. Reservoir construction also creates habitat for introduced species (Fuller et al. 2011, Moyle 2002) (see “Introduced Fish and Other Predators” section). These may include a diverse assemblage of warmwater fishes (e.g., bass [*Micropterus*], sunfish [*Lepomis*], crappies [*Pomoxis*], catfish/bullheads [Ictaluridae], carp [*Cyprinus carpio*]), coldwater fishes (e.g., rainbow trout and brown trout [*Oncorhynchus mykiss*, *Salmo trutta*]), bullfrogs (*Lithobates catesbeianus*), and several species of crayfish. If impoundments are sufficiently large and deep to allow stratification, both warm- and coldwater fisheries may occur, resulting in a potential barrier to both the presence and the up- and downstream movement of foothill yellow-legged frogs. Nonnative, coldwater fisheries are often established downstream of impoundments as a result of hypolimnetic releases of water. Populations of coldwater species that occurred only seasonally in some streams may become permanently established with year-round coldwater flows below dams (Moyle 2002).

Impoundments fragment riverine habitat and disrupt dispersal routes for juvenile and adult frogs. These effects are significant in the Sierra Nevada because large reservoirs are located in the lower foothill region of almost every major stream draining the western slopes of this mountain range (tables 7 and 8). Kondolf et al. (1996) evaluated the distribution of reservoirs in the Sierra Nevada and found that they had created more than 150 spatial gaps in riparian areas greater than 0.5 km (0.3 mi) long. This is greater than the maximum movement range of foothill yellow-legged frogs in several studies (see “Movement in Ecology” section). Peek (2010) analyzed foothill yellow-legged frog populations relative to stream habitat connectivity and gene flow in three regulated and three unregulated rivers in the northern Sierra Nevada. In this study, more foothill yellow-legged frogs were found in river reaches closer to tributary streams in regulated versus unregulated rivers, suggesting that populations in regulated rivers may be more concentrated and spatially fragmented than populations in unregulated rivers. Gene flow and genetic drift were generally lower in regulated versus unregulated rivers (Peek 2010). Reservoirs are inhospitable to foothill yellow-legged frogs yet favorable to exotic aquatic predators, and generally fragment Sierran streams into headwater and downstream regions. These artificially disjunct regions possess habitat that may be suitable to one particular foothill yellow-legged frog life stage but perhaps not another. For example, very small headwater subbasins may offer overwintering habitat for adults but be too cool and shaded to create the habitats with high algal productivity needed by grazing tadpoles. In general, the areas upstream of reservoirs provide more suitable habitat than the areas downstream because of the establishment of nonnative species in downstream reaches (Moyle 2002). Lind (2005) stated that the likelihood of foothill yellow-legged frog extirpation was higher when the area of the stream network above reservoirs was small. The current distribution of foothill yellow-legged frogs in the Sierra Nevada is largely upstream of reservoirs in systems that have a substantial length of stream network that still lies within their elevational range. Downstream of reservoirs with hypolimnetic releases, it may take 10 to 20 km for water to warm to the lower limit of the thermal niche for reproduction of foothill yellow-legged frogs (PCWA 2011, PG&E and Stillwater Sciences 2009b). In regulated river reaches, intact tributary streams may provide key refugia when mainstem habitat quality has been compromised (Peek 2010).

Diversions—
Water diversions may cause streams to dry up more rapidly than they did when undiverted. For example, removal of water from diversions currently causes sections of the San Joaquin River to seasonally dry across the Central Valley floor (Moyle 2002). Diversion of water may also result in modifications to stream habitat (e.g., local reaches may become less lotic in nature). Even small operations, such as those used to divert water for growing marijuana (*Cannabis sativa*), may have significant impacts on foothill streams with limited summer flows (E. Gonsolin, pers. comm., 2006). Suspected direct effects of water diversions that may occur include the removal of foothill yellow-legged frogs, tadpoles, or egg masses by water pumps, or impingement and mutilation of animals on pump screens. Diversions used for interbasin movement of water may introduce fish and other predators, or transfer disease-bearing vectors and disease-contaminated water. Open-channel canals that are used to move water from one location to another (e.g., from an upstream to a downstream impoundment) may impede movements and survival.

Extent of risks related to water development and diversions—
The risk to foothill yellow-legged frogs from flow alteration resulting from water impoundments and diversions is high. Negative effects have been well studied and water projects are widespread across this species' range in the Sierra Nevada and elsewhere.

Conservation options related to water development and diversions—
Addressing management of water development and diversions for the foothill yellow-legged frog is within the jurisdiction of agencies involved in this assessment through regional planning, permitting, and the Federal Energy Regulatory Commission (FERC) hydropower project relicensing process. Coordination among resource agencies and research will more effectively address knowledge gaps and facilitate the feedback of information to refine management approaches. Owing to

the recent focus on foothill yellow-legged frogs during FERC hydropower project relicensing, several new tools for evaluating effects of new flow regimes on habitat and strand/scour risk of aquatic life stages have been developed (Bondi et al. 2013; Yarnell et al. 2011, 2012). These tools may help water managers develop flow regimes (timing and patterns) that may reduce impacts on foothill yellow-legged frogs. A summary of conservation options for foothill yellow-legged populations in regulated rivers was presented by Kupferberg et al. (2009a) (see table 9).

Climate Change

Temperatures in California are estimated to increase from 1.5 to 4.5 °C by the end of the 21st century (Cayan et al. 2008). Climate models predict more variable annual precipitation and decreased spring and summer runoff as a result of lower annual snowpack (Johnson et al. 1999, Smith and Tirpak 1989, USEPA 1997). Moreover, more precipitation in early spring has been predicted to come in the form of rain rather than snow. Consequently, the hydrograph will shift to earlier snowmelt, lower snowpack, more winter rain, and higher winter storm runoff events (Maurer et al. 2007, Stewart 2009, Young et al. 2009). The low-flow season will likely be longer, so water temperatures may be higher, which may result in stress for species adapted to more moderate temperature regimes. Whether hydroelectric power project operations will exacerbate or ameliorate the effects of climate change is not known. Given that many miles of Sierran rivers downstream of dams are now too cold for foothill yellow-legged frogs, a possibility that requires investigation is that warming water temperatures may create suitable habitat in some managed systems.

Changes in frequency, duration, and magnitude of droughts or severe winters resulting from climate variability may have considerable negative impacts on foothill yellow-legged frog populations. Population declines of foothill yellow-legged frogs have been attributed in part to extended drought (Jennings and Hayes 1994). Decreases in summer runoff may result in the loss of foraging and refuge habitat for adults and juveniles. Changes in temperature may affect parasite prevalence (Kupferberg et al. 2009a) and pathogen virulence (Carey et al. 1999), making foothill yellow-legged frogs more susceptible to disease. Further, experimental increase in stream water temperature has been shown to decrease invertebrate density and biomass in invertebrates (Hogg and Williams 1996) and may have a negative impact on the foothill yellow-legged frog prey base.

Changes in climatic patterns, particularly those linked to precipitation, may have substantial impacts on foothill yellow-legged frogs. Low precipitation and increased variability in precipitation were both negatively related to frog presence (Lind 2005). Evidence also suggests that low precipitation may exacerbate dam

Table 9—A summary of potential mitigation and restoration options for *Rana boylii* in regulated rivers

Project operations	Short-term impacts	Long-term impacts	Mitigation/restoration
Intentional aseasonal flows (power generation, recreation, outmigration of salmonid smolts); unintentional spill of water over dam	• Scouring or desiccation of egg masses[a b] /tadpoles[c] • Export spring and summer algal productivity,[d e] reduced resources for tadpoles, reduced insect abundance,[e] food web repercussions	• Discharge decoupled from environmental cues (e.g., rainfall, air temperature) triggering inappropriate behavioral responses by adults, juveniles, delayed onset of breeding[a f] • Smaller population sizes[a b]	• Mimic natural hydrograph to degree possible • Flow regimes and ramping rates to minimize impacts during breeding and rearing periods • Change management of water elevation in upstream reservoir
Intentional dewatering of stream channels for rescue operations	• Desiccation of egg masses/tadpoles	Unknown	• Observe minimum instream flow requirements • Post-event ramping rates that minimize disturbance
Unintentional powerhouse outages resulting in rapid increase in flows in bypass reaches, followed by rapid decrease in flows	• Changes in margin water temperature, depth, and velocity, • Scouring/desiccation of eggs/tadpoles, depending on ramping rate, magnitude of change, channel shape	Unknown	• Change timing of planned outages (for repairs, etc.) to outside of breeding and rearing season
Reduced winter/spring flows	• Absence of scouring/depositional flows that prevent riparian encroachment • Reduced breeding habitat, greater distances between breeding sites[c]	• Vegetation encroachment, altered channel morphology, reduced breeding habitat • Population loss/fragmentation,[c] reduced gene flow, altered metapopulation dynamics	• Mimic natural hydrograph to degree possible • Restore some components of spring snow-melt hydrograph[g]
Altered summer baseflows	• Lower water temperatures • Change in available habitat (channel shape)	• Promotes habitats that support non-native predatory fish, amphibians, and invertebrates, increased predation on eggs, tadpoles	• Adjust water release temperatures (mix of depths) • Develop basin-scale plans for fish stocking relative to frog needs
Movement of water among river basins	• Potential for increased disease and parasite transmission	Unknown	• Reassess water redistribution to eliminate, or shift timing to decrease disease (fall, winter)

[a] GANDA 2008.
[b] Kupferberg et al. 2008.
[c] Lind et al. 1996.
[d] Spring Rivers Ecological Sciences 2003.
[e] GANDA 2006.
[f] Bourque 2008.
[g] McBain and Trush, Inc. 2009.
Source: reproduced from Kupferberg et al. 2008.

effects (Lind 2005). Climate change is predicted to reduce the habitat suitability for foothill yellow-legged frogs at lower latitudes and elevations. Current foothill yellow-legged frog distribution (fig. 10) may be a sign that climate change has already influenced the species (Lind et al. 2005). Although other factors may confound the influence of climate change on distribution patterns, short-term oscillations and drought severity have been greater at lower latitudes in California (Cook et al. 2004), where foothill yellow-legged frogs appear to be in dramatic decline (see "Status" section). Davidson et al. (2002) found no relationship between foothill yellow-legged frog-occupied sites and elevation. Severe drought may also lead to water-management decisions that may affect frog populations. For example, water held in reservoirs may be diverted to ameliorate the impact of dry conditions on agricultural and municipal water supplies; this can exacerbate the already low water levels and promote even warmer summer water temperatures.

Extent of risks related to climate change—
Climate change may be a factor in the decline of foothill yellow-legged frogs, and the higher frequency of weather extremes expected under future climate change (e.g., extended droughts and large-magnitude, shorter duration flows), may contribute to future population declines. This risk is greatest in the southern portions of the Sierra Nevada and California, where populations are rare and small, other risks are present, and climate change will have the greatest impact on habitat.

Conservation options related to climate change—
Agencies may implement management practices at the local scale to ameliorate the predicted effects of climate change on foothill yellow-legged frogs and their habitat. For example, by carefully setting minimum streamflow requirements during relicensing of FERC-licensed hydropower projects, agencies can balance water temperature needs of native warm and cold-water associated aquatic species in regulated rivers. A more complete understanding of how habitat modifications linked to climate change may affect foothill yellow-legged frog population dynamics, and how climate change may interact with other risk factors, will be needed to focus conservation efforts.

Habitat Loss, Urbanization, and Fragmentation

Direct habitat loss is one of the most visible causes of amphibian population declines (Cushman 2006, Lehtinen et al. 1999, Stuart et al. 2004). Habitat loss for many amphibians can be attributed to the conversion of wetlands to urban or agricultural use (Corn 1994); foothill yellow-legged frogs are no exception. Habitat loss is frequently a consequence of other risk factors and is discussed in corresponding sections (see "Water Development and Diversion" and "Livestock Grazing" sections). However, the elevational range of foohill yellow-legged frogs, in the Sierra Nevada and elsewhere, overlaps with large areas of private land and urban/suburban development in foothill communites. Conversion of land for agricultural and urban use has been implicated as a factor in the decline of foothill yellow-legged frogs (Lind 2005). In Oregon, Olson and Davis (2009) found that proximity to cities and agricultural lands was negatively associated with frog occurrence. Habitat loss will continue in the future as a result of increasing urbanization and the associated spread of invasive plants.

Urbanization in the west-slope Sierra Nevada foothills exists in the form of a series of more than 40 small towns with populations over 1000, many of them located in the old gold mining districts. Of the nearly 1 million inhabitants of the Sierra Nevada west slope, about half live in these small towns (CDFI 2013). Significant growth, largely around these small urban centers, is projected for the west slope, and by 2050, the human population is anticipated to reach 2 million (CDFI 2013). This growth pattern is expected to result in habitat changes near these urban areas that may influence local foothill yellow-legged frog populations. Urbanization along Sierran foothill streams increasingly isolates foothill yellow-legged frog populations, which appear smaller today than historically, making populations more vulnerable to extirpation from random events (Noss and Cooperrider 1994, Pimm 1991).

Habitat loss or alteration can also be facilitated by invasive plant species (Bossard et al. 2000). Invasive plants replacing native vegetation can transform vast areas in a few decades (Lovich and DeGouvenain 1998) and may have contributed to the decline of northern leopard frogs in Nevada (Hitchcock 2001). Invasive plants can degrade habitat quality by limiting the quantity or quality of food resources for larval or postmetamorphic frogs (Brown et al. 2006; Maerz et al. 2005a, 2005b). The effects of invasive plants on foothill yellow-legged frogs are unstudied, but observation of aggressive colonization of river bar habitat by butterfly bush (*Buddleja davidi*) (M. Hayes, personal observation, 1999), a landscape species only recently recognized for its invasive potential (King County 2012), suggests that invasive plant impacts may need attention. Invasive exotic plants may fragment habitat by converting patches of riparian areas to unsuitable habitat for foothill yellow-legged frogs.

Extent of risks related to habitat loss, urbanization, and fragmentation—The greatest risk to populations and habitats of foothill yellow-legged frogs from urbanization relates to water issues and is described in the "Water Development and

Diversions" section. The effects of habitat loss resulting from human population growth, land development, and non-native plant invasion are currently unknown.

Conservation options related to habitat loss, urbanization, and fragmentation—

On Forest Service and National Park Service lands, restrictions on land development and control of invasive plants are within agency purview and can be addressed in the regional planning process. However, most urbanization and development lies in municipal jurisdictions, so coordination among city, county, state, and federal agencies will be necessary to effectively limit habitat loss and fragmentation.

Introduced Species

Introduced species have long been recognized as a major risk factor to native populations (Soulé 1990). Amphibians have been widely cited as being vulnerable to exotic predators such as fish, crayfish, and bullfrogs (e.g., Adams 1999; Drost and Fellers 1996; Fisher and Shaffer 1996; Jennings and Hayes 1994; Kiesecker and Blaustein 1997b). Several introduced species such as crayfish, bullfrogs, and introduced fish, which occur within the range of the foothill yellow-legged frog, may be particularly problematic.

Crayfish did not historically occur with the foothill yellow-legged frog across much of the frog's California range and may pose the greatest introduced species threat. Several introduced crayfish, including two subspecies of the signal crayfish (*Pacifastacus. l. trowbridgii* and *P. l. leniusculus*), the red or Louisiana swamp crayfish (*Procambarus clarkii*), and the northern or virile crayfish (*Orconectes virilis*), collectively now co-occur with the frog in California (see McGriff 1982). Crayfish are primarily scavengers but will graze on algae and other vegetation, and will prey upon invertebrates, fish, reptiles, and amphibians (Gamradt and Kats 1996, McGriff 1982). With video cameras mounted near foothill yellow-legged frog egg masses, Wiseman et al. (2005) documented crayfish predation on embryos in the North Fork Feather River. In southern California, red swamp crayfish locally reduced California newt (*Taricha torosa*) recruitment to zero (Gamradt and Kats 1996). Guan and Wiles (1997) found that introduced *P. leniusculus* outcompeted two native benthic fish species for shelter, and that fish mortality was significantly higher with crayfish present. Effects of predation and competition may be magnified when other non-native predators are present (Gamradt and Kats 1996). Also, crayfish expansion and abundance in Sierran streams is linked to altered flow regimes (Light 2003), so water management could exacerbate these patterns.

Expansion by the American bullfrog (*Lithobates catesbeianus* [formerly *Rana catesbeiana*]) into riverine environments may have negatively affected the foothill yellow-legged frog. It now occurs nearly throughout the foothill yellow-legged frog's geographic and elevation range (Hayes and Jennings 1988, Kupferberg 1996b). The successful expansion of the bullfrog's range is due to several influences, including climate-related factors. Kupferberg (1996a, 1996b) showed that drought-year freshets allowed bullfrogs to exploit habitat farther upstream, whereas more substantial freshets in non-drought years appeared to keep bullfrogs in check. Foothill yellow-legged frogs colonized portions of Butte Creek (Butte County) where bullfrogs were removed by high flows during floods in 1987 (Hill 2002). With climate warming trends, within-year attainment of metamorphosis in bullfrogs appears to be expanding north geographically and upward in elevation (M. Hayes, unpublished data, 1994–1999[4]; M.R. Jennings, unpublished data, 2004–2013[5]), which may increase the success of bullfrogs in river environments.

It is difficult to disentangle impacts attributable to bullfrogs because habitat alteration and fish introductions are almost invariably confounded with bullfrog presence or abundance (Hayes and Jennings 1986, 1988). Bullfrogs may have contributed to the decline of foothill yellow-legged frogs via predation (Moyle 1973; but see Hayes and Jennings 1986 for caveats on this interpretation). Bullfrog tadpoles, the largest among North American anurans, are known to prey upon other amphibian larvae (Corse and Metter 1980, Kiesecker and Blaustein 1997b, Stebbins 2003), and an anecdotal observation documents adult bullfrog predation on postmetamorphic foothill yellow-legged frogs (Crayon 1998). In field manipulations and enclosure experiments in northwestern California, Kupferberg (1997a) showed decreased survivorship and mass at metamorphosis in foothill yellow-legged frog tadpoles where bullfrog tadpoles were present, reflecting a competitive disadvantage in resource utilization. An observation of reproductive interference involving male foothill yellow-legged frogs in amplexus with subadult bullfrogs suggests another mechanism that may result in wasted reproductive effort (Lind et al. 2003a); however, the extent of such interactions beyond these observations is unknown (see Pearl et al. 2005). Assuming that scale effects are insignificant, reaches on the mainstem South Eel River, which have a complement of exotic species that include bullfrogs and introduced pike minnows, have substantially lower foothill yellow-legged frog production than upstream reaches of the mainstem lacking these exotics. Reaches with bullfrogs had an average of 12.3 egg masses per kilometer,

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[4] Hayes, M. 1994–1999. Unpublished data. On file with: Washington Department of Fish and Wildlife, 600 Capitol Way North, Olympia, WA 98501.

[5] Jennings, M. 2004–2013. Unpublished data. On file with: Rana Resources, Davis, CA.

whereas those without exotics had an average of 106.3 egg masses per kilometer (Catenazzi and Kupferberg 2013; S. Kupferberg, unpublished data, 1992–2014[6]).

Several species of fishes were introduced into California beginning in the 1800s to promote game fishing, provide forage for game fishes, or serve as biological control agents (Dill and Cordone 1997). Foothill yellow-legged frog abundance was negatively correlated to abundance of 9 out of 11 fish species in the Sierran foothills (table 10). Smallmouth bass, green sunfish, mosquitofish, and trout feed on aquatic insects or insect larvae (Moyle 2002) and may compete with foothill yellow-legged frogs for food resources. These species may also exploit stream habitats used by foothill yellow-legged frogs. Adult smallmouth bass have been documented eating amphibian larvae (Kiesecker and Blaustein 1998) and preying on foothill yellow-legged frogs (Rombough 2006a). Foothill yellow-legged frog tadpoles do not respond to chemical or visual cues from smallmouth bass (Paoletti et al. 2011). These findings suggest that smallmouth bass may be a significant threat to foothill yellow-legged frogs in Oregon, where smallmouth bass have dramatically expanded (Simon and Markle 1999). Synergistic negative effects may occur when bullfrogs and smallmouth bass are both present (see Hayes and Jennings 1986 and Kiesecker and Blaustein 1998 for a discussion). The Sacramento pikeminnow co-exists with foothill yellow-legged frogs in portions of its range, but this species has been introduced into several coastal California streams, where it has been observed eating tadpoles and frogs (Corum 2005). Green sunfish are suspected predators of frog eggs, and trout likely prey on all life stages. Fish may act as vectors of disease; two studies have demonstrated that pathogens can be transferred between amphibians and fish (Kiesecker et al. 2001, Mao et al. 1999), but transfer of disease from fish has not been studied specifically for foothill yellow-legged frogs.

Extent of risks related to nonnative species—
The presence of nonnative species within the foothill yellow-legged frog's range likely presents a significant risk to existing populations. Some evidence exists suggesting that bullfrogs, crayfish, and smallmouth bass in particular may have negative effects on foothill yellow-legged frog populations; however, the particular degree of risk to the species is not known. The impact of nonnative species, particularly introduced fishes, on amphibians has been studied extensively in lentic but not stream systems. Many of these studies have demonstrated a negative effect on presence and densities of frog populations.

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[6] Kupferberg, S. 1992–2014. Unpublished data. On file with: Questa Engineering, 1220 Brickyard Cove Road, Suite 206, Pt. Richmond, CA 94807.

Table 10—Spearman rank correlation between the numerical abundance of the vertebrate macrofauna and the abundance (coded) of the foothill yellow-legged frog as recorded by Moyle (1973) from the foothills of the Sierra

Species	Common name	Sample size (n)	Correlation coefficient (ρ)	Probability (*P*)
Catostomus occidentalis	Sacramento sucker	71	-0.404**	<0.001
*Gambusia affinis**	Mosquito fish	62	-0.835**	<0.001
*Ictalurus catus**	White catfish	41	-0.798**	<0.001
Lavinia exilicauda	Hitch	40	-0.760**	<0.001
Lavinia symmetricus	California roach	55	-0.316	0.020
*Lepomis cyanellus**	Green sunfish	88	-0.742**	<0.001
*Lepomis macrochirus**	Bluegill	59	-0.827**	<0.001
*Micropterus dolomieu**	Smallmouth bass	35	-0.538**	0.001
Mylopharadon conocephalus	Hardhead	38	-0.607**	<0.001
Oncorhynchus mykiss	Rainbow trout	44	-0.425	0.005
Ptychocheilus grandis	Sacramento pikeminnow	66	-0.541**	<0.001
Lithobates [*Rana*] *catesbeianus**	American bullfrog	90	-0.800**	<0.001

Note: Sample size is based on the total number of sites where either the foothill yellow-legged frog or the species being compared was present. A single asterisk (*) indicates introduced species. A double asterisk (**) identifies significant correlations in a two-tailed test adjusted for 24 comparisons ($\alpha = 0.002$; 11 below and 13 comparisons of physical habitat variables not presented here). Probability (*P*) is the probability of obtaining the calculated Spearman correlation coefficient (ρ). Adapted from Hayes and Jennings (1988).

Conservation options related to introduced species—
Direct eradication of introduced species populations may not be within the practical scope of management of the agencies contributing to this document. However, these agencies may have opportunities to reduce the effects of introduced species through restoration actions. Examples include managing flow regimes in regulated rivers to benefit multiple native species, modifying fish-stocking programs, regulating the use of live bait, and minimizing human-induced dispersal of existing introduced species. Consideration of the risks associated with introduced species is important in the development of a conservation strategy for the foothill yellow-legged frog.

Mining

Mining may have contributed to habitat loss and fragmentation for foothill yellow-legged frogs. Several types of mining have occurred in the Sierra Nevada and elsewhere; aggregate, hardrock, hydraulic, and suction-dredge mining are discussed as potential contributors to the declines of foothill yellow-legged frogs and current or future threats of various mining practices to populations are reviewed.

Aggregate mining is mechanical extraction of materials from unconsolidated matrices from streams or stream terraces for use in construction of various infrastructures, including roads. Industries that conduct aggregate mining often prefer instream to terrace mining because the extracted aggregate requires minimal sorting and washing (CSLC 1993). Instream mining affects stream geomorphology by changing sediment transport regimes, eroding beds and banks, and incising channels (CSLC 1993). Terrace mining, which occurs outside of the wetted perimeter of the river but within the flood plain or adjacent terrace features, may create large ponds filled by groundwater; in flood events, these ponds may become connected to the river (CSLC 1993). Instream and terrace mining may increase sedimentation downstream of mining activities (Mount 1995), alter or eliminate refuge habitat (see "Ecology" section), and increase exposure to bullfrogs and nonnative warmwater fishes that may enter or exit created ponds during freshets (Fuller et al. 2011, Moyle 2002). Aggregate operations are typically associated with large riverine channels in the lower elevational range of foothill yellow-legged frogs, although some aggregate operations also exist in selected portions of larger streams at middle and higher elevations, e.g., the upper Feather River system. Over the range of the foothill yellow-legged frog in the Sierra Nevada, major sand and gravel aggregate operations exist in every river system in which foothill yellow-legged frogs were historically recorded (Mount 1995).

Hardrock mining involves digging by various means (e.g., picks and shovels, rock drills, dynamite) into solid rock to find minerals (CSLC 1993). This form of mining often involves digging shafts that go either straight down to follow ore bodies and veins, or at least somewhat horizontally into rock faces. Shafts and tunnels, typically supported with large timbers to prevent cave-ins, would eventually flood as they hit the water table, which can be a source of pollution; even slightly acidic water can solubilize potentially toxic metals such as copper (Deanovic et al. 1999). Many shaft or tunnel hardrock mines exist in Sierra Nevada national forests, but the extent of overlap within the Sierran range of foothill yellow-legged frogs is unclear. Most of these mines are at low- to mid-elevations within the species' range; however, the hardrock operations with the highest potential of affecting foothill yellow-legged frogs occur in the northern Sierra Nevada.

Hydraulic mining consists of methods that use water, typically under pressure, to erode hillsides of placer (gravel, sand, or silt) and other unconsolidated deposits (CSLC 1993). This extreme approach drastically alters water quality and stream geomorphology (CSLC 1993, Larson 1996). This method exposes rock to immediate weathering and erosion, increasing pollutants such as acid, cadmium, mercury, and asbestos in waterways (CSLC 1993). The practice was outlawed in 1884, but its effects on water pollution may still be apparent in northern Sierra streams such as portions of the mid-elevation Feather River (Larson 1996) and in parts of the Trinity and Sacramento River drainages of northern California. Water developments in some streams (e.g., Englebright Reservoir on the Yuba River) were constructed largely for the purpose of trapping potentially polluting sediments mobilized during high-water events that date from the hydraulic mining era (Childs et al. 2003). Further, the extensive use of mercury in the mining and recovery of gold during the late 19th and early 20th centuries has led to widespread mercury contamination of water, sediment, and biota in the Sierra Nevada foothills. Study of the watersheds of the Bear and Yuba Rivers revealed significant mercury levels in aquatic food chains; analysis of Pacific chorus frogs, foothill yellow-legged frogs, and American bullfrogs detected mercury contamination (Alpers et al. 2001). The results suggest that historical use of mercury still affects the Bear and Yuba Rivers and their associated aquatic communities. A recent study in the Cache Creek watershed of northern Sacramento Valley of California demonstrated that three species of frogs (bullfrogs, foothill yellow-legged frogs, and Pacific chorus frogs) were bioaccumulating mercury at levels above those typically resulting in Environmental Protection Agency health advisories for fish. The primary source of mercury in this watershed is also believed to be hydraulic mining, though geothermal springs and agricultural runoff may also contribute (Hothem et al. 2010). Much of the historical hydraulically mined region of California is within the elevation range where foothill yellow-legged frogs are (or were) present, so effects of this practice on the species, albeit unstudied, were likely significant.

Suction-dredge mining is a method in which water, sediment, and rocks are vacuumed from portions of streams and rivers, sorted to obtain gold, and the spoils redeposited in the stream (CSLC 1993, Harvey and Lisle 1998). A moratorium in California currently prohibits CDFW from issuing suction-dredge permits (California Fish & Game Code §5653.1, subdivision a), and use of related equipment in any river, stream, or lake through 30 June 2016 (California Fish & Game Code §5653.1, subdivision b). However, suction-dredge mining may be permitted in the future. Suction dredging may increase suspended sediment, modify stream geomorphology, directly remove aquatic organisms, and rearrange the substrate of streams (CDFG 1994, 2012). This form of mining may have effects on reproduction by disturbing adults during courtship and breeding activities, or disrupting habitat during the reproductive season. Dredging up stream substrates can result in displacement, burial, or suffocation of eggs or tadpoles (CDFG 1994, Harvey and Lisle 1998). Depending on the size and stage of foothill yellow-legged frog tadpoles, they would not be able to swim away from the strong current created by suction dredging, as they can be entrained into flows as slow as 0.33 ft per sec (Kupferberg et al. 2011b). In response to elevated currents, these tadpoles seek shelter in interstitial spaces in the substrate. Because of this behavior, this species is particularly vulnerable to suction of sediments. Sweet (1992) observed mortality of eggs and larvae of the stream-breeding arroyo toad (*Anaxyrus californicus*); mortality was a direct effect of increased sedimentation that resulted from suction dredge mining. Suction dredging may cause movement of instream habitat features such as rock substrates and woody debris, which may be used by foothill yellow-legged frogs for overwintering (see "Ecology" section). Dredging may also affect the foothill yellow-legged frog prey base. The composition of the invertebrate fauna changes in dredge-disturbed areas; however, the recovery to a predredging community appears to be rapid (Harvey 1986, Somer and Hassler 1992).

Extent of risks related to mining—
Considerable overlap exists between mining activities and foothill yellow-legged frog habitat, so mining may pose a potentially significant risk. Historical (and a few current) aggregate and hardrock mining and historical hydraulic mining practices have altered physical habitat structure and water quality in streams occupied by foothill yellow-legged frogs. Bioaccumulation of heavy metals has been demonstrated, but the overall contribution of mining activities to foothill yellow-legged frog habitat degradation and declines is unknown. Instream aggregate and suction-dredge mining, in particular, pose the greatest threat to foothill yellow-legged frogs, given the potential effects of these practices on populations. The risk of suction-dredge mining is low under the current moratorium, but may increase substantially should the moratorium be lifted. One of the most significant problems should the moratorium be lifted is the inherent difficulty of enforcing proposed environmental regulations. By its nature, the activity is widely dispersed in remote areas where the lack of visibility to law enforcement is a prime concern.

Conservation options related to mining—
Mining activities are directly within the jurisdiction of the agencies participating in this assessment. An assessment of the overlap of mining activities with foothill yellow-legged frog localities and habitats, and research examining the potential effects of mining on foothill yellow-legged frogs is needed.

Summary of Risk Factors

This conservation assessment reviewed the ecology of the foothill yellow-legged frog and evaluated 17 risk factors that resulted in conservation options for consideration in the development of a conservation strategy. Of risk factors examined, water development (impoundment and diversion) was identified as the primary risk factor and is, at least in part, responsible for species' decline in the Sierra Nevada and elsewhere. Extensive research has demonstrated that this risk factor can have severe impacts on frog populations and that proper management is critical for persistence of the species. Studies have shown that frogs more often occur and have higher abundances along streams lacking large dams. Ill-timed waterflows can result in scouring or stranding of egg masses, and high-water events and dam releases are a primary cause of egg mass mortality. Cold-water releases from upstream reservoirs impair growth, development, and survival of tadpoles. Water development, management of flow regimes, and dams that block sediment flow collectively alter downstream channel morphology; these changes may result in the modification or fragmentation of critical habitats used by frogs. Management of regulated streams to mimic the natural flow regime is ideal, but frequently impractical or infeasible implement. Instead, by focusing on reducing impacts during critical times (e.g., refraining from high pulse flows during the brief spring reproductive season and avoiding cold-water releases during tadpole development) and by using tools that evaluate effects of present flow regimes on habitat and strand/scour risk, water managers may develop flow regimes that minimize effects on foothill yellow-legged frogs.

Climate change, mining, introduced species, and habitat loss were identified as high risk factors. Modification of precipitation patterns, and therefore water availability, is a potential outcome of climate change. Impacts of climate variability on foothill yellow-legged frogs may include alteration of the frequency, duration, and magnitude of droughts, severe winters, and late-spring freshets. Ensuing variability in the timing and magnitude of streamflows may result in mortality to vulnerable life stages of foothill yellow-legged frogs analogous to the effects of hydrological management. Variable water temperature as a result of climate change may also affect rate of and size at metamorphosis. Drought conditions may increase the susceptibility of frogs to disease or contaminants, and reduce their prey base. Climate change is a global problem and the impacts of this risk factor are unknown and cannot easily be assessed. Management options relative to this factor are beyond the scope of agency jurisdiction; however, agencies can ameliorate impacts of climate change by reducing the impacts of other risk factors such as water development. Mining activities, especially suction-dredge mining, frequently overlap with foothill yellow-legged frog habitat. Various mining methods may cause direct frog mortality, and studies have demonstrated bioaccumulation of mine-related contaminants in foothill yellow-legged frogs. Research has shown that mining activities do alter the stream environment by modifying stream morphology, increasing sediment loads, and introducing contaminants, but the contribution to declines and extent of the impacts on foothill yellow-legged frogs remains unstudied. A current moratorium restricting suction dredging in California reduces the threat of this factor, but if that moratorium is lifted, the risk is potentially high. Introduced crayfish, bullfrogs, and fish are identified as a major risk factor, and studies support the impacts of these nonnative species on the foothill yellow-legged frog. Introduced species may prey on frogs, compete for resources, and act as disease vectors. Eradication or management efforts to control the distribution of introduced species may reduce the impact of this risk factor. Habitat loss, alteration, and fragmentation occur in various forms that encompass many, if not most, of the other risk factors examined in this assessment. Also, development of land commonly occurs in the Sierran foothills, and therefore overlaps with foothill yellow-legged frog habitat. Agency regulation of urbanization and land development may minimize the threat of human encroachment upon frogs and their critical habitats.

Other risk factors may alter and degrade stream habitat, but data are lacking to establish the extent of risk to foothill yellow-legged frogs. These factors include fire management; livestock grazing; recreational, research, and restoration activities; roads; and vegetation and fuels management (see app. 4). Activities related to these risk factors may modify stream hydrology and geomorphology and may increase sediment loads. Airborne contaminants, locally applied pesticides, contaminants introduced by fire suppression, vegetation and fuels management, livestock use, recreational activities, and roads may reduce water quality; however, data are lacking to ascertain the extent of risk to foothill yellow-legged frogs. Based on studies of the impact of disease (particularly chytridiomycosis) on other amphibian species, this factor may pose some risk but also lacks species-specific information. Although many of these factors have extensive overlap with foothill yellow-legged frogs and have the potential for impact, they were ultimately considered lower risk because current management practices protect stream habitat and adjacent riparian zones; this safeguards or reduces impacts on frogs as long as they are implemented by agencies. Re-evaluation of changes in current practices may be required as new information becomes available. Several risk factors fall largely outside the purview of participating agencies (acid deposition, airborne contaminants including pesticides, climate change, and increased UV-B exposure). However, agencies participating in this assessment could, in partnerships, contribute to and guide the development of extraregional management strategies to address these risk factors.

Future Conservation and Management

The review of the species ecology, current status of the species, and evaluation of the risk factors identified in this assessment suggest that waterflow management, followed by stream habitat management and watershed management, would have the most significant effect on conservation of foothill yellow-legged frogs. The following options are intended to facilitate the development of a conservation strategy.

Waterflow Management

- Maintain or restore hydrological functions of streams to mimic natural flow and temperature regimes to the degree practicable, with the specific objectives of:
    - Minimizing flow-related impacts (e.g., pulse flows and overly fast changes in waterflows and depths) during the spring reproductive season.
    - Minimizing thermal-related impacts (e.g., unseasonably cold water temperature resulting from hypolimnetic release) during the tadpole growth and development period.
    - Allowing for seasonally appropriate high flows to maintain natural channel geomorphology.

Stream Habitat and Nonnative Species Management

- Maintain or restore riparian vegetation that is characteristic of channels with dynamic flow regimes (e.g., reduce vegetation encroachment to enhance breeding habitat).
- Carefully evaluate the potential impacts of any new mining permits requested in key streams and watersheds.
- Evaluate the distribution and abundance of introduced species (e.g., bullfrogs, crayfish, and smallmouth bass) and consider mitigation actions to the degree practicable in key streams and watersheds.

Watershed-Scale Management

- Identify key watersheds that are likely to have the greatest contribution to sustaining the species throughout its range, with selections considering current population status, habitat conditions, geographic location, and current and projected future risks.
- Develop target watershed conditions (e.g., vegetation conditions) that are conducive to supporting sustainable populations in key watersheds.

- Watershed management approaches will be most robust if they reflect consideration of (1) habitat quality, quantity, and diversity within individual streams; and (2) connectivity among populations within and among watersheds to enhance gene flow and recolonization potential.

Population and Habitat Monitoring

- Consider developing a multiscale monitoring approach that integrates habitat and population measures to track status and trends and to mitigate uncertainty in our understanding of risk factors and the fate of existing populations.

Future Research Priorities

Although much still exists to learn about the ecology and life history of the foothill yellow-legged frog, selected key information gaps have the greatest bearing on helping management determine how best to meet population and habitat conservation objectives.

- Additional study on the mechanism(s) underlying the effects of flow and thermal regimes on size at metamorphosis, a trait related to adult fitness (i.e., effect of water temperature on development, growth, or feeding rate; effect of flow and water temperature on quality and quantity of food resources).
- Influence of climate change on hydrology and resulting changes in dam operations.
- Impacts of recreational activities (including suction-dredge mining); use, construction, or maintenance of roads or trails near frog habitat; and movement of pathogens or diseases related to human activity.
- Effects of predation by fish, crayfish, and American bullfrogs on foothill yellow-legged frog survival in regulated and unregulated streams and potential mitigation.
- Effects of pesticides (local and airborne), fire management, and livestock grazing to gain a better understanding of the relative level of risk of these factors.
- Identification of cumulative effect thresholds for population persistence at watershed and basin scales.

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English Equivalents

When you know:	**Multiply by:**	**To get:**
Millimeters (mm)	0.00394	Inches
Centimeters (cm)	.394	Inches
Kilometers (km)	.621	Miles
Degrees Celsius: (°C)	1.8 °C + 32	Degrees Fahrenheit

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Appendix 1: Agency Direction

USDA Forest Service

The U.S. Department of Agriculture, Forest Service, Pacific Southwest Region (Region 5) listed the foothill yellow-legged frog (*Rana boylii*) on its Sensitive Species List in 1998 (USDA FS 1998). The Sensitive Species List is developed based on the Forest Service Manual (FSM 2670.5) for those plant and animal species identified by a regional forester for which population viability is a concern, as evidenced by:

- Significant current or predicted downward trends in population numbers or density.
- Significant current or predicted downward trends in habitat capability that would reduce a species' existing distribution.

Forest Service Manual 2672.1 states that sensitive species of native plants and animals must receive special management emphasis to ensure their viability and to preclude trends toward endangerment that would result in the need for federal listing. Sensitive species cannot be affected without an analysis of significance of adverse effects on the populations, their habitat, and on the viability of the species as a whole. The Forest Service Manual (FSM 2670.32) provides the following direction for sensitive species:

- Assist states in achieving their goals for conservation of endemic species.
- As part of the National Environmental Policy Act process, review programs and activities through a biological evaluation to determine their potential effect on sensitive species.
- Avoid or minimize impacts to species whose viability has been identified as a concern.
- If impacts are unavoidable, analyze the significance of potential adverse effects on the population or its habitat within the area of concern and on the species as a whole.
- Establish management objectives in cooperation with the states when a project on National Forest System lands may have a significant effect on sensitive species population numbers or distribution. Establish objectives for Federal candidate species, in cooperation with the U.S. Fish and Wildlife Service and the states.

For all Forest Service planned, funded, executed, or permitted programs and activities, a review for possible effects on endangered, threatened, proposed, or sensitive species is conducted through a Biological Assessment (FSM 2670) and Evaluation (FSM 2672.4). Biological Assessment and Evaluation objectives (FSM 2672.41) are to:

1. Ensure that Forest Service actions do not contribute to loss of viability of any native or desired nonnative plant or animal species or contribute towards trends for federal listing of any species.
2. Comply with the requirements of the Endangered Species Act (ESA) that actions of federal agencies not jeopardize federally listed species or adversely modify their critical habitat.
3. Provide a process and standard by which threatened, endangered, proposed, and sensitive species receive full consideration in the decisionmaking process.

Land and Resource Management Plans for forests in the Sierra Nevada were changed in January 2001 by the Sierra Nevada Forest Plan Amendment (SNFPA). This amendment is sometimes referred to as “The Framework” (USDA FS 2001). This 2001 Framework decision was subsequently adjusted 3 years later via a supplemental Environmental Impact Statement (EIS) and Record of Decision (ROD) (USDA FS 2004). The 2004 ROD is the only binding decision. Both Framework RODs establish an Aquatic Management Strategy. Pages 32–33 of the ROD (USDA FS 2004) state that the strategy for aquatic management includes broad goals (below) representing endpoints toward which management moves watershed processes and functions, habitats, attributes, and populations. These goals define a comprehensive framework for establishing desired conditions at larger scales, including river basin, watershed, and landscape scales. Moving ecosystem conditions toward these goals will restore and maintain the physical, chemical, and biological integrity of the region’s waters as mandated by the Clean Water Act, and will support the Forest Service mission to provide habitat for riparian- and aquatic-dependent species under the National Forest Management Act, the Organic Act, the Safe Drinking Water Act, the ESA, and the Electric Consumers Protection Act. The following are Aquatic Management Strategy goals:

1. Water quality—Maintain and restore water quality to meet the goals of the Clean Water Act, providing water that is fishable, swimmable, and suitable for drinking after normal treatment.
2. Species viability—Maintain and restore habitat to support viable populations of native and desired nonnative plant, invertebrate, and vertebrate riparian-dependent species. Prevent new introductions of invasive species.

Where invasive species are adversely affecting the viability of native species, work cooperatively with appropriate state and federal wildlife agencies to reduce impacts to populations of native species.

3. Plant and animal community diversity—Maintain and restore the species composition and structural diversity of plant and animal communities in riparian areas, wetlands, and meadows to provide desired habitats and ecological functions.
4. Special habitats—Maintain and restore the distribution and health of biotic communities in special aquatic habitats (such as springs, seeps, vernal pools, fens, bogs, and marshes) to perpetuate their unique functions and biological diversity.
5. Watershed connectivity—Maintain and restore spatial and temporal connectivity for aquatic and riparian species within and between watersheds to provide physically, chemically and biologically unobstructed movement for their survival, migration and reproduction.
6. Floodplains and water tables—Maintain and restore the connections of floodplains, channels, and water tables to distribute flood flows and sustain diverse habitats.
7. Watershed condition—Maintain and restore soils with favorable infiltration characteristics and diverse vegetation cover to absorb and filter precipitation and to sustain favorable conditions of streamflow.
8. Streamflow patterns and sediment regimes—Maintain and restore instream flows sufficient to sustain desired conditions of riparian, aquatic, wetland, and meadow habitats and keep sediment regimes as close as possible to those with which aquatic and riparian biota evolved.
9. Streambanks and shorelines—Maintain and restore the physical structure and condition of streambanks and shorelines to minimize erosion and sustain desired habitat diversity.

In addition, the 2004 SNFPA ROD includes Riparian Conservation Objectives (RCO), and associated standards and guidelines (S&Gs) specific to aquatic-dependent species, including foothill yellow-legged frogs. Management direction for carrying out this decision includes S&Gs for project design and implementation. The RCO S&Gs rely on minimizing the risk and impacts from project-related activities on aquatic- or riparian-dependent species without specifically identifying the species involved.

National Park Service (NPS)

The guiding principles for managing biological resources on NPS lands include maintenance of animal populations native to park ecosystems, or more specifically:

> …preserving and restoring the natural abundances, diversities, dynamics, distributions, habitats, and behaviors of native plant and animal populations and the communities and ecosystems in which they occur; restoring native plant and animal populations in parks when they have been extirpated by past human-caused actions; and minimizing human impacts on native plants, animals, populations, communities, and ecosystems, and the processes that sustain them (USDI NPS 2006).

These guiding principles also commit the NPS to "work with other land managers to encourage the conservation of the populations and habitats of these species outside parks whenever possible," including a commitment to "participate in local and regional scientific and planning efforts, identify ranges of populations of native plants and animals, and develop cooperative strategies for maintaining or restoring these populations in the parks." Subsequently, these principles direct the NPS to participate in the foothill yellow-legged frog conservation assessment process, and assist in conserving the species in the Sierra Nevada.

The resource management plan for the Sequoia and Kings Canyon National Parks (USDI NPS 1999) discusses stressors contributing to the decline of foothill yellow-legged frogs, but it does not provide management language specific to this species. The plan provides resource goals for aquatic/water resources that have direct relevance to foothill yellow-legged frog conservation issues. The following resource goals have a direct bearing on foothill yellow-legged frog ecology and risk factor analysis:

- Aquatic and water ecosystems are restored or maintained so that physical, chemical, and biotic processes function uninfluenced by human activities.
- Aquatic environments are inventoried and classified by physical and chemical characteristics and biotic communities present.
- A long-term monitoring program is developed to record ambient conditions and to document changes and trends in physical and chemical characteristics and biotic communities.
- Impacts of acid deposition and contaminants from external influences are detected and evaluated.
- Lakes with exotic trout are restored to natural conditions.
- Extant native species or genetically unique groups are restored to their former range.

- Waters incapable of sustaining fish populations through natural reproduction will be allowed to become fishless.

The resource management plan for Yosemite National Park (2003) notes under Aquatic Ecosystem/Fisheries Management that management must provide for "…self-perpetuating populations of (native) aquatic species" through restoration. Under "Disappearing Amphibians," the plan puzzles over the worldwide decline of amphibians. It notes the decline and disappearance of several amphibian species in the park, including the foothill yellow-legged frog, and the urgent need for research to identify the cause(s). Yosemite National Park is collaborating with the City of San Francisco Public Utilities, U.S. Fish and Wildlife Service, and the Stanislaus National Forest on the Upper Tuolumne River Ecosystem Project. Through this multiagency project, studies are being conducted on the ecological effects of controlled riverflows from the Hetch Hetchy Reservoir. The goal of these studies is to make informed recommendations for water releases from the dam that would maximize ecological benefits. Restoration of the foothill yellow-legged frog is among the park's top priorities for this project. Although the foothill yellow-legged frog was never very widespread in Yosemite, its loss from the fauna of the park is ecologically significant.

Further, the three national parks that encompass a small portion of the historical range of the foothill yellow-legged frog (Yosemite, Kings Canyon, and Sequoia) play a pivotal role in implementation of the federal Amphibian Research and Monitoring Initiative (ARMI) developed in 2000 (Hall and Langtimm 2001). The goal of the initiative was to provide timely, reliable information on the status of amphibians in the United States so that causes of declines could be understood and appropriate management responses initiated. Prior to this initiative, broad-based replication of historical surveys that was initiated in the 1990s has provided invaluable insights into the status of the amphibian assemblages found in Yosemite National Park, which included the foothill yellow-legged frog (Drost and Fellers 1994, 1996; USDI NPS 1999; see also "Status" section for Yosemite National Park in app. 3).

California Department of Fish and Wildlife

The state of California considers the foothill yellow-legged frog to be a "Species of Special Concern" (SSC). This is an administrative designation and carries no formal legal status. The intent of designating SSCs is to:

- Focus attention on animals at conservation risk by the department, other state, local and federal governmental entities, regulators, land managers, planners, consulting biologists, and others;

- Stimulate research on poorly known species; and
- Achieve conservation and recovery of these animals before they meet California ESA criteria for listing as threatened or endangered.

An SSC is a species, subspecies, or distinct population of an animal native to California that currently satisfies one or more of the following (not necessarily mutually exclusive) criteria:

- Is extirpated from the state or, in the case of birds, in its primary seasonal or breeding role;
- Is listed as federally, but not state-, threatened or endangered;
- Meets the state definition of threatened or endangered but has not formally been listed;
- Is experiencing, or formerly experienced, serious (noncyclical) population declines or range retractions (not reversed) that, if continued or resumed, could qualify it for state threatened or endangered status; and
- Has naturally small populations exhibiting high susceptibility to risk from any factor(s), which if realized, could lead to declines that would qualify it for state threatened or endangered status.

SSCs tend to have a number of factors in common, as follows:

- Occur in small, isolated populations or in fragmented habitat, and are threatened by further isolation and population reduction;
- Show marked population declines. Taxa that show a marked population decline, yet are still abundant, may not meet the SSC definition, whereas marked population decline in uncommon or rare species may meet the SSC definition. Note that population estimates are unavailable for the vast majority of California taxa;
- Depend on a habitat that has shown substantial historical or recent declines in size and/or quality or integrity. This criterion infers the population viability of a species based on trends in the habitats in which it specializes. Coastal wetlands, particularly in the urbanized San Francisco Bay and south-coastal areas, alluvial fan sage scrub and coastal sage scrub in the southern coastal basins, vernal pools in the Central Valley, arid scrub in the San Joaquin Valley, and riparian habitat statewide, are examples of California habitats that have seen dramatic reductions in size in recent history;

- Occur only or primarily in or adjacent to an area where habitat is being converted to uses incompatible with the animal's survival;
- Have few California records, or which historically occurred in the state but for which there are no recent records; and
- Occur largely in areas where current management practices are inconsistent with the animal's persistence.

More information about SSCs is available at https://www.dfg.ca.gov/wildlife/nongame/ssc/.

SSCs should be considered during the environmental review process. The California Environmental Quality Act (CEQA; California Public Resources Code §§ 21000–21177) requires state agencies, local governments, and special districts to evaluate and disclose impacts from "projects" in California. Section 15380 of the CEQA guidelines clearly indicates that SSCs should be included in an analysis of project impacts if they can be shown to meet the criteria of sensitivity outlined therein.

Sections 15063 and 15065 of the CEQA guidelines, which address how an impact is identified as significant, are particularly relevant to SSCs. Project-level impacts on listed (rare, threatened, or endangered) species are generally considered significant, thus requiring lead agencies to prepare an environmental impact assessment to fully analyze and evaluate the impacts. In assigning "impact significance" to populations of nonlisted species, analysts usually consider factors such as population-level effects, proportion of the taxon's range affected by a project, regional effects, and impacts to habitat features.

More information about CEQA and CEQA guidelines is available at http://resources.ca.gov/ceqa/.

Sport take of foothill yellow-legged frogs with a fishing license is prohibited (Title 14, Section 5.05) and scientific take is regulated by permit (Title 14, Section 650).

U.S. Fish and Wildlife Service

The overarching mission of the U.S. Fish and Wildlife Service (USFWS) is "working with others, to conserve, protect and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people." The long-term goals of the USFWS relevant to this assessment include:

- Recovery of threatened and endangered species,

- Protection and conservation of trust species (i.e., threatened species, endangered species, and other species of concern), and
- Habitat conservation.

The recovery of threatened and endangered species, and the ecosystems on which they depend, fall under USFWS responsibilities under the ESA. The foothill yellow-legged frog has recently been petitioned for listing (Adkins Giese et al. 2012).

Appendix 2: Museum Standard Symbolic Codes

Documentation of records from museum collections in the text are listed according to the standard symbolic code for each institution based on Leviton et al. (1985), and its update (Leviton et al. 1988). Institutions lacking a standard symbolic code for which one was added are indicated by an asterisk.

Institution	Symbolic code
American Museum of Natural History (New York)	AMNH
California Academy of Sciences (San Francisco)	CAS
California Academy of Sciences–Stanford University Collection	CAS-SU
California State University–Chico*	CSUC
Field Museum of Natural History	FMNH
Los Angeles County Natural History Museum	LACM
Museum of Vertebrate Zoology (University of California at Berkeley)	MVZ
San Diego Natural History Museum	SDNHM
Sacramento State University	SSU
Texas Cooperative Wildlife Collection (Texas A&M University)	TCWC
University of Kansas Natural History Museum	KU
University of Michigan Museum of Zoology	UMMZ
University of Nevada at Reno	UNR
United States National Museum (Smithsonian Institution)	USNM

Literature Cited

Leviton, A.E.; Gibbs, R.H., Jr. 1988. Standards in herpetology and ichthyology. Standard symbolic codes for institutional resource collections in herpetology and ichthyology. Suppl. no. 1: additions and corrections. Copeia. 1988: 280–282.

Leviton, A.E.; Gibbs, R.H., Jr.; Heal, E.; Dawson, C.E. 1985. Standards in herpetology and ichthyology: part I. Standard symbolic codes for institutional resource collections in herpetology and ichthyology. Copeia. 1985: 802–832.

Appendix 3: Status—Federal Administrative Units

This appendix provides information on status for individual national forest administrative units within the state of California and National Park Service administrative units within the Sierra Nevada Planning Area that encompass at least a portion of the recent historical range of the foothill yellow-legged frog (*Rana boylii*). Records were derived from museum and Forest Service databases and records. Results of more recent visual survey efforts were included if data were readily available; i.e., an exhaustive search was not made of unpublished reports. When available, we provided links to additional data sources. For regions outside of the Sierra Nevada Planning Area, we presented records within the boundaries of national forests. A significant proportion of the geographic range of foothill yellow-legged frogs occurs in the downstream portion of drainages whose headwaters occur in these administrative units. We address all historical foothill yellow-legged records for those drainages under each administrative unit, indicating which records occur within versus outside of the administrative unit discussed. The sequence of the presentation of administrative units is from north to south.

Six Rivers National Forest

Pre-1980—

Three records exist from the Six Rivers National Forest for the 1940s. On 16 July 1941, Ruth F. Myers and George S. Myers collected a foothill yellow-legged frog along a small stream along California highway SR-96, in Hoopa, 17.5 mi north of the town of Willow Creek (CAS 7400). On 23 March 1947, D.V. Brown collected one frog at an unknown location 3 mi south of Willow Creek (CAS 9529). On 27 March 1947, Brown collected one frog along Tectah Creek, a tributary of the Klamath River (CAS 9527).

Four records from Six Rivers National Forest were made during the 1950s. On 23 June 1952, Lloyd Tevis collected two specimens at an unnamed site located 0.5 mi northeast of the town of Willow Creek (CAS 218346, 218347). On 17 August 1955, an unnamed individual collected one foothill yellow-legged frog along the Smith River (KU 50347). On 10 June 1956, A.C. Browne collected four frogs at an unknown site, 2 mi west of Gasquet School, and 12 mi northeast of Crescent City (CAS 188217–188220). On 7 August 1956, E.W. Jameson, Jr. collected one frog at Patrick Creek (CAS 218389).

Two collections were recorded for the 1970s. On 16 August 1973, an unnamed individual collected one frog at a location 18 mi northeast of Gasquet along California highway SR-199 (TCWC 44325). On 19 March 1977, Thomas G. Balgooyen collected one foothill yellow-legged frog near Boise Creek Campground on California highway SR-299 (CAS 195723).

1980 to present—

Two records based on foothill yellow-legged frog specimens at Six Rivers National Forest were made in the 1980s. In 1986, Gregory K. Pregill collected two frogs on 26 August on Patrick Creek along highway SR-199 (SDNHM 65210 and 65211) and two frogs on 27 August at Hiouchi Campground along highway SR-199 (SDNHM 65213 and 65214).

One record of collection was made in the 1990s. On 24 April 1991, Marc R. Jennings and Marc P. Hayes collected one frog at an unnamed tributary of Hurdygurdy Creek in Del Norte County (CAS 178765).

In 1986, Amy J. Lind and Hartwell H. Welsh, Jr., of the U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station (PSW), documented foothill yellow-legged frog breeding sites along Hurdygurdy Creek, a tributary of the South Fork Smith River. From 1987 to 2000, they recorded frog and egg mass locations along a 4.7 km (2.9 mi) study reach of Hurdygurdy Creek. Additional frog and egg mass surveys were conducted along Hurdygurdy Creek from 2001 to 2008 by Clara A. Wheeler and Welsh of PSW. Data are available through PSW's Redwood Sciences Laboratory.

In 1994 and 1995, Lind and Welsh detected egg masses along Red Cap Creek. In 1995, herpetological surveys were conducted by the Six Rivers National Forest along the North Fork Eel River between 17 May and 31 October. A total of 520 sightings were documented (USDA Forest Service NRIS database). Specific locations are available through the Six Rivers National Forest. On 23 July 1997, J. Donahue detected one foothill yellow-legged frog along Berry Creek, a tributary of the Mad River. On 23 April 1999, Sean Thobaben observed one frog at Boise Creek, a tributary of the Klamath River.

On 30 March 2001, William C. Flaxington observed one foothill yellow-legged frog on the bank of the Smith River at the Jedediah Smith Campground in Jedediah Smith Redwoods State Park. On 17 January 2002, Flaxington also observed one frog beside Walker Road along a tributary of the Smith River in Jedediah Smith Redwoods State Park. On 18 February 2009, Flaxington observed another frog along Cedar Creek in Jedediah Smith Redwoods State Park.

Thirty additional records of foothill yellow-legged frogs in Six Rivers National Forest during the 1990s and 2000s (USDA Forest Service NRIS database) indicate observations along Patrick Creek, Lower Middle Fork Smith River, Lost Creek (a tributary of Mad River), West Fork Van Duzen River, Shanty Creek (a tributary of Van Duzen River), Mill Creek (a tributary of Van Duzen River), Reynolds Creek (a tributary of Klamath River), Slate Creek (a tributary of Klamath River), Horse Linto Creek, Mingo Creek (a tributary of South Fork Trinity River), Hardscrabble Creek (a tributary of Smith River), and Kettenpom Creek.

Shasta-Trinity National Forest

Pre-1980—

Shasta Reservoir and Sacramento River tributaries—Likely the oldest data on foothill yellow-legged frogs from the area currently under Shasta-Trinity National Forest administration in this region date from observations made by Edward D. Cope, who stated that "the specimen [of foothill yellow-legged frog]…from El Dorado County, California [referring to one of the two type specimens collected by Charles E. Boyle; see Jennings 1987]…was for a long time the only one [i.e., record] in our collection [referring to the United States National Museum]. During my expedition to Oregon in 1879, I found it [the foothill yellow-legged frog] rather abundant in the mountainous regions of northern California" (Cope 1883, 1889). Cope did not provide precise locations, but he is known to have stopped at Baird (Cope 1879), the historical salmon hatchery facility that is now inundated by the McCloud River arm of Shasta Lake. On 8 January 1884, Charles H. Townsend collected at least 11 foothill yellow-legged frogs at Baird (USNM 13795, 13929), collections that Cope discussed in 1889 (Cope 1889). This collection is the oldest for foothill yellow-legged frogs known from this region.

One record from the 1890s exists for the Shasta area now under Shasta-Trinity National Forest administration. Cloudsley L. Rutter collected one foothill yellow-legged frog at Sims on the Sacramento River mainstem on 9 July 1898 (USNM 38816). This location is above the inundation footprint of Shasta Lake.

Two records from this region of the Shasta-Trinity National Forest were made in the 1900s, when Sterling A. Bunnell, Jr. collected three foothill yellow-legged frogs at a location 24.1 km (15 mi) east and 14.5 km (9 mi) north of the Baird hatchery facility on 1 June 1904 (MVZ 43327–43329). The precise location of this record is vague, but it is believed to be found along Potem Creek, a Pit River tributary. This location is probably above the inundation footprint of Shasta Lake. The second record involves two foothill yellow-legged frogs that Francis X. Williams collected at Sweetbriar Camp on the Sacramento River mainstem on 20 August 1907 (CAS 13299–13300). This location is upstream of the inundation footprint of Shasta Lake.

No foothill yellow-legged frog records from the 1910s exist for this region of the Shasta-Trinity National Forest, but one record was made from non-Forest Service lands during that decade. On 4 October 1911, J. Slevin collected three foothill yellow-legged frogs at Redding on the Sacramento River (CAS 30663–30665).

One record from the 1920s exists from the Shasta area of the Shasta-Trinity National Forest. On 21 August 1922, Raymond L. Dice collected one foothill yellow frog near Delta at the mouth of Dog Creek on the Sacramento River (UMMZ 56966).

No records of foothill yellow-legged frogs were made from this region of the Shasta-Trinity National Forest that date from the 1930s and 1940s.

Seven records from the 1950s exist for the Shasta area now under Shasta-Trinity National Forest administration. On 14 October 1950, Joseph B. Gorman, Jr., collected three foothill yellow-legged frogs from Low Pass Creek (MVZ 52327–52329), a tributary of Squaw Creek; and one foothill yellow-legged frog along Squaw Creek proper (MVZ 52330). The next day, Gorman collected one more foothill yellow-legged frog from Low Pass Creek (MVZ 52331), three foothill yellow-legged frogs from Bars Creek (MVZ 52332–52334), and one foothill yellow-legged frog from Dinner Gulch (MVZ 52335); the latter two drainages are also tributaries of Squaw Creek. On 27 March 1951, Gorman re-collected Squaw Creek, where he took one foothill yellow-legged frog (MVZ 84542). On 23 September 1951, Gorman also collected two more foothill yellow-legged frogs from Dinner Gulch at roughly the same locality (MVZ 55441–55442). On 24 March 1952, Gorman also collected two additional foothill yellow-legged frogs from Low Pass Creek (MVZ 55440, 55555). On 20 June 1952, Robert C. Stebbins collected two foothill yellow-legged frogs along Salt Creek, 2.7 km (1.7 mi) by road east-northeast of Highway 99 (MVZ 57039-57040). On 8 August 1952, one foothill yellow-legged frog was collected (collector unknown) along Salt Creek, 24.1 km (15 mi) east-southeast of Delta (USNM 543578). On 25 June 1953, Slevin also collected one foothill yellow-legged frog from Low Pass Creek (CAS 84959). On 24 October 1959, B. Lang collected 10 foothill yellow-legged frogs along Brock Creek (CSUC 1150–1159). Because Brock Creek is a tributary of the Pit River that is now entirely isolated by Shasta Lake, the imprecision of this location makes it unclear whether some or all the foothill yellow-legged frogs collected were within the inundation footprint of Shasta Lake. Additionally, two records exist from the 1950s for non-Forest Service lands. On 5 April 1953, Clifford H. Pope collected one foothill yellow-legged frog along the Pit River 12.8 km (8 mi) north-northwest of Round Mountain (FMNH 71474). On 31 May 1953, Richard Russell collected 13 foothill yellow-legged frogs from private lands along Cold Creek, an upper Sacramento River tributary, 3.2 km (2 mi) south of the Mount Shasta Fish Hatchery (UMMZ 119016).

Five records from the 1960s exist for the Shasta area now under Shasta-Trinity National Forest administration. On 25 June 1961, D. Collette collected two foothill yellow-legged frogs along Zinc Creek, 9.2 km (5.75 mi) north of Jones Valley

(CSUC 1624–1625). Because Zinc Creek is a tributary of Squaw Creek that is now entirely isolated by Shasta Lake, the imprecision of the Zinc Creek location makes it unclear whether the site of collection was located within the inundation footprint of Shasta Lake. On 11 August 1961, Stebbins re-collected Bars Creek, where he took two foothill yellow-legged frogs (MVZ 54343, 55392). On 3 August 1963, Charles S. Thaeler, Jr. collected one foothill yellow-legged frog along Squaw Creek 0.5 km (0.3 mi) south and 0.5 km (0.3 mi) west of Madrone Guard Station (MVZ 75818). On 2 September 1966, Raymond B. Huey re-collected the Dinner Gulch locality, from which he collected one foothill yellow-legged frog (MVZ 81261). On 18 May 1968, Alexander K. Johnson collected one foothill yellow-legged frog from an unspecified locality along Squaw Creek above Shasta Lake (MVZ 84452). Additionally, one record from the 1960s exists for non-Forest Service lands. On 14 November 1969, James F. Lynch collected one foothill yellow legged frog from Soda Creek-Sacramento River confluence in Castle Crags State Park (MVZ 86997).

Two records from the 1970s exist for the Shasta area now under Shasta-Trinity National Forest administration. On 14 September 1970, Ronald A. Nussbaum collected seven foothill yellow-legged frogs on Nosoni Creek at its crossing with Gilman Road (UMMZ 133393); Nosoni Creek is a tributary of the McCloud River. On 20 March 1977, Thomas G. Balgooyen collected one adult foothill yellow-legged frog on Salt Creek along Gilman Road near Shasta Reservoir (CAS 195725). Some additional data are available for the 1970s. During June–August 1974, M. Hayes conducted stream surveys on the upper McCloud River for about 8 river kilometers (5 river miles) below the confluence of Claiborne Creek and the McCloud River, a portion of which encompassed The Nature Conservancy McCloud River Preserve at that time; during these surveys, foothill yellow-legged frogs were found to be moderately common along this reach, with 3 to 22 postmetamorphs being observed per 100 m of stream.

Trinity Reservoir and Trinity River tributaries—Only four records of foothill yellow-legged frog collections prior to 1980 exist for the Trinity River region of the Shasta-Trinity National Forest. On 16 October 1959, E. Harrington collected a specimen from Eagle Creek (CAS 188223). In October 1959, B. Kesse collected three frogs from Rush Creek (CAS 86108-86110). On 17–18 June 1967, an unnamed individual collected one frog from an unnamed creek near Salt Creek Camp, 4.5 mi southeast of Peanut (LSU 16327), and another frog on an unnamed creek 9.5 mi west of Peanut (LSU 16328).

1980 to present—

Shasta Reservoir and Sacramento River tributaries—Few records of foothill yellow-legged frogs from the 1980s exist for the Shasta area of the Shasta-Trinity National Forest. On 20 June 1981, M. Jennings collected one foothill yellow-legged frog on Deep Creek along Deep Creek Campground (MVZ 158969). This record, the upstream-most in the Pit River system, was one of two adult foothill yellow-legged frogs observed on that date (Jennings 1982).

Several records of foothill yellow-legged frog observations were documented during the 1990s in the Shasta area of Shasta-Trinity National Forest. On 15 April 1996, Jack Miller observed one adult frog at Ney Springs, one adult frog along Castle Creek, one adult frog along North Salt Creek, two adult frogs along Mears Creek, two adults along Mosquito Creek, 13 adult frogs on Slate Creek, two adult frogs on North Fork Slate Creek, three frogs on Little Slate Creek, three adults along Whitlow Creek, one adult frog on Campbell Creek, and five frogs on Boulder Creek. On 15 April 1996, C. Luke observed one frog at Sims Flat and two frogs at Conant River Access. On 16 April 1996, J. Miller observed one adult frog along Shotgun Creek, one adult frog on Little Castle Creek, and three frogs along Castle Creek, and C. Luke observed one frog along Castle Creek.

In the 2000s, several observations of foothill yellow-legged frogs were documented in the Shasta region of Shasta-Trinity National Forest. On 16 March 2007, Michael Peters observed four foothill yellow-legged frogs along Cornish Creek between the Upper Sacramento Ditch Trail and the Sacramento River. On 21 June 2009, Peters observed one foothill yellow-legged frog along Cornish Creek. On 9 March 2010, Peters observed two frogs along Cornish Creek. On 16 January 2011, Peters observed one frog along Dry Creek, below the Dry Creek Trailhead in Lake Shasta National Recreation Area. On 30 April 2011, Peters observed two foothill yellow-legged frogs along Dry Creek upstream of Westside Road and one frog along a small tributary of Dry Creek.

During the relicensing of the three dams along the Pit River encompassed in Pacific Gas and Electric Company's Pit 3,4,5 hydroelectric project, foothill yellow-legged breeding sites have been located throughout the middle Pit 4 reach (Spring Rivers Ecological Sciences 2003, 2004). Some sightings of adult frogs have occurred in the Pit 5 reach and none have been found in the most-upstream Pit 3 reach. Surveys for foothill yellow-legged frogs were also conducted for Pacific Gas and Electric Company's McCloud/Pit Project. Foothill yellow-legged frog egg masses, tadpoles and young-of-year were observed along Lower McCloud River. In 2007, one adult foothill yellow-legged frog was observed on 4 June. No life stages of foothill yellow-legged frogs were detected at the Pit River (Pit 6, Pit 7 reaches), or Iron Canyon Creek sites (PG&E and Stillwater Sciences 2009b).

Trinity Reservoir and Trinity River tributaries—In October 1990, M.R. Jennings collected four foothill yellow-legged frogs at a location along California highway SR-299, 22 to 23 mi west of Big Bar Ranger Station (CAS 178749, 178750, 180305, 183178). On 11 March 1996, an unnamed individual observed two foothill yellow-legged frogs along Fawn Creek.

From 1991 to 1994, A. Lind, H. Welsh, Jr., and Randolph Wilson (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory) conducted surveys for foothill yellow-legged frogs along the mainstem Trinity between Lewiston and Helena (Lind et al. 1996). In 1994 and 1995, Lind and Welsh surveyed breeding sites along the mainstem and South Fork of the Trinity River. In 1994, a total of two egg masses were observed at mainstem sites and 20 at South Fork sites. In 1995, no egg masses were detected at mainstem sites and a total of three egg masses were observed at South Fork sites.

From 2004 to 2009, Jamie Bettaso, Don Ashton, and H. Welsh, Jr., conducted foothill yellow-legged frog egg mass surveys along sections of the mainstem, North Fork, and South Fork of the Trinity River. From 2006 to 2009, they also surveyed breeding sites along Canyon Creek and in 2008 and 2009 they added surveys at known breeding sites along the upper Trinity River, Stuart’s Fork, and Weaver Creek. Reproduction was detected at all sites, but egg mass counts varied by tributary. Egg masses were particularly sparse along the managed mainstem Trinity; they found fewer than two egg masses per river kilometer on the mainstem compared to 34 to 165 egg masses per kilometer on the South Fork and 39 to 83 egg masses per kilometer on the North Fork (Wheeler et al. 2013; additional data available from Bureau of Reclamation, Trinity River Restoration Program).

On 23 June 2011, R.J. Adams observed several frogs along the South Fork Trinity River near Little Rock Picnic Area by the town of Hyampom.

Fifteen additional records from surveys of the Shasta-Trinity National Forest during the 1990s and 2000s (USDA Forest Service NRIS database) document observations of foothill yellow-legged frogs at Sulphur Creek, South Fork Sacramento, Big Canyon Creek, and Charlie Creek within the Shasta region and at East Fork South Fork Trinity River, French Gulch (a tributary of Clear Creek), Lower Browns Creek, Lower North Fork Trinity River, East Fork Hayfork Creek, and Olson Creek (a tributary of Hayfork Creek, and Pelletreau Creek (a tributary of South Fork Trinity River) within the Trinity region.

Lassen National Forest

Pre-1980—

Only three pre-1980 records of foothill yellow-legged frogs exist for the Lassen National Forest. The oldest record for the Lassen National Forest appears to be from Rice Creek, a tributary of the North Fork of the Feather River, where Charles M. Miller collected one foothill yellow-legged frog on 21 July 1938 (MVZ 34703). On 20 March 1965, Kenneth Evans collected three foothill yellow-legged frogs on Little Butte Creek at its intersection with Hupp Coutolenc Road (CSUC 1568–1570). The latter site is located on an isolated patch of the Lassen National Forest that is administered by the Plumas National Forest. Over the interval 1973 to 1978, M. Hayes revisited the Coon Hollow localities and Hupp Coutolenc Road localities four times; one to four foothill yellow-legged frogs were recorded at each visit to the Coon Hollow locality, but no foothill yellow-legged frogs were found near the Hupp Coutolenc Road crossing despite searches that extended along Little Butte Creek 0.8 km (0.5 mi) up and downstream from the collection record. Hence, by the end of the 1970s, foothill yellow-legged frogs may have been extirpated from at least one site on the Lassen National Forest.

Several additional pre-1980 records exist for drainages that extend onto Lassen National Forest lands, but these records are located downstream of the current national forest boundary; some records also exist for drainages that extend a shorter distance up the Sierran slope so that they do not extend onto national forest lands. Both types of records encompass eight drainage basins that are primary tributaries of the Sacramento River, including Battle, Big Chico, Butte, Cow, Dye, Mill, Paynes, Rock, and Stillwater Creeks; some records also exist for the mainstem Sacramento River. Discussion of these records is alphabetized by the drainage system in which they occur.

Battle Creek—On 28 May 1926, Jean M. Linsdale collected one foothill yellow-legged frog at the mouth of Battle Creek near the Sacramento River (MVZ 10137). On 31 March 1932, Henry S. Fitch collected one foothill yellow-legged frog on the North Fork of Battle Creek (MVZ 14973). On 24 March 1964, E. Bryant collected one foothill yellow-legged frog near the Darrah Springs springhead close to the Darrah Springs Fish Hatchery (CSUC 1143); Darrah Springs flows into Baldwin Creek, a tributary of Battle Creek.

Big Chico Creek—On 21 October 1945, Thomas L. Rodgers collected 12 foothill yellow-legged frogs from Big Chico Creek, 12.8 km (8 mi) northeast of Chico (MVZ 42727–42738).

Butte Creek—On 2 January 1946, B. Matthews collected one foothill yellow-legged frog near the Centerville Covered Bridge over Butte Creek (MVZ 51657). On 22 April 1952, P. Moretti collected one foothill yellow-legged frog 11.2 km (7 mi) east of Chico on the north side of Butte Creek (MVZ 56838).

Cow Creek—On 13 November 1945, Robert C. Stebbins collected one foothill yellow-legged frog on Dry Creek 12.8 km (8 mi) northeast of the junction of Highways 99 and 299 (MVZ 42167); Dry Creek is a tributary of Little Cow Creek, which flows into Cow Creek. On 3 May 1953, Richard Zweifel collected four foothill yellow-legged frogs 1.6 km (1 mi) northeast of Ingot along Little Cow Creek (MVZ 59621–59624). On 27 March 1954, M. Hammon collected one foothill yellow-legged frog 8 km (5 mi) southwest of Whitmore along South Cow Creek (CSUC 1207).

Dye Creek—On 1 April 1970, Reginald H. Barrett collected 14 foothill yellow-legged frogs on Dye Creek 9.6 km (6 mi) east and 5.6 km (3.5 mi) north of Gerber (MVZ 89694–89707).

Mill Creek—Between 8 and 13 June 1912, Tracy I. Storer and Walter P. Taylor collected six foothill yellow-legged frogs 3.2 km (2 mi) northeast of Tehama (MVZ 4063–4068).

Paynes Creek—On 12 May 1924, Adrey E. Borell collected two foothill yellow-legged frogs at 105 m (400 ft) elevation along Paynes Creek (MVZ 9968–9969). On 14 May 1924, Borell collected another foothill yellow-legged frog at 92 m (350 ft) elevation along Paynes Creek (MVZ 9970). On 18 May 1924, Joseph Grinnell collected one foothill yellow-legged frog at Dale’s Ranch on Paynes Creek (MVZ 9974). Borell also collected one foothill yellow-legged frog at the same locality on each of two dates: 29 May and 1 June 1924 (MVZ 9975–9976). On 5 June 1924, Borell also collected four foothill yellow-legged frogs 8 km (5 mi) west of the Paynes Creek Post Office (MVZ 9977–9980). From 8 to 14 June 1924, Borell collected three foothill yellow-legged frogs from Lyman’s, a location on Paynes Creek, 6.4 km (4 mi) northwest of Lyonsville (MVZ 10024–10026). On 19 July 1926, T. Storer collected one foothill yellow-legged frog at 305 m (1,000 ft) elevation along Paynes Creek (CAS 218321). On 15 February 1931, Lawrence V. Compton collected one foothill yellow-legged frog on an unnamed tributary of Paynes Creek at Meadow Ranch, 4.8 km (3 mi) west of the Paynes Creek Post Office (MVZ 12597).

Rock Creek—On 2 April 1950, W. T. Byerly collected two foothill yellow-legged frogs from Cohasset Pioneer Springs on the Anderson Fork (MVZ 56831–56832), a tributary of Rock Creek.

Sacramento River proper—On 4 October 1911, J. Slevin collected three foothill yellow-legged frogs along the Sacramento River at Redding (CAS 30663–30665). On 14 May 1924, A. Borell collected three foothill yellow-legged frogs along the Sacramento River 8 km (5 mi) north of Tehama (MVZ 9971–9973). On 28 August 1926, Carl L. Hubbs collected one foothill yellow-legged frog along the Sacramento River below Red Bluff (UMMZ 71494). On 5 April 1928, J. Linsdale collected four foothill yellow-legged frogs along the Sacramento River 12.8 km (8 mi) north of Red Bluff (MVZ 10902–10905).

From 1973 to 1976, M. Hayes made 16 different visits to the Borell, Hubbs, Linsdale, and Slevin collection localities on the Sacramento River that comprised over 142 hours of effort, but no foothill yellow-legged frogs were found; American bullfrogs were the only ranid frog recorded during these sites visits. Extensive hydrological alteration and widespread warmwater fish and bullfrog introduction over the Sacramento Valley (Moyle 2002) since these mainstem records were made (all prior to 1930) make it possible that, by the mid-1970s, foothill yellow-legged frogs had been extirpated on the mainstem Sacramento River.

Stillwater Creek—On 3 May 1953, R. Zweifel collected one foothill yellow-legged frog along Salmon Creek, 6.4 km (4 mi) west-southwest of Bella Vista (MVZ 59625). Salmon Creek is a tributary of Stillwater Creek, which is a primary tributary of the Sacramento River.

1980 to present—

Scattered records for foothill yellow-legged frogs on the Lassen National Forest are a composite of few collections and a larger number of sightings based on various surveys and data compiled through the Federal Energy Regulatory Commission (FERC) relicensing process. Surveys on the Lassen National Forest that the California Academy of Sciences conducted over the period 2001 to 2003 document four localities based on specimens. On 16 August 2001, Guin Wogan collected one adult foothill yellow-legged frog on mossy rocks in falls near a large pool at 1,145 m (4,360 ft) elevation in Mill Creek (CAS 221024). On 28–29 May 2003, Daniel G. Mulcahy collected foothill yellow-legged frogs from three localities in the Antelope Creek system: at 368 m (1,400 ft) elevation on Antelope Creek (CAS 226962), and 375 m (1,430 ft) and 394 m (1,500 ft) elevation on Indian Creek (CAS 226983–226984).

Several records documented since 1980 exist for drainages that extend onto Lassen National Forest, but these are from elevations below national forest lands.

Dye Creek—During a site visit to the Dye Creek Ranch on 11 September 1996, M. Jennings collected one juvenile foothill yellow-legged frog on the North Fork of Dye Creek on the Dye Creek Ranch (CAS 203175). Foothill yellow-legged frogs were only observed some distance up the foothill canyon of Dye Creek, but not on the portion of Dye Creek that emerges from the foothill canyon onto the Sacramento Valley floor (Jennings 2007). Foothill yellow-legged frogs became more abundant in tributaries of the Dye Creek mainstem where bullfrogs were sparse; there dozens of foothill yellow-legged frogs were observed over short reaches. This single-day survey covered more than 3.2 km (2 mi) of Dye Creek and its tributaries.

Plumas National Forest

Pre-1980—

Many historical collections of foothill yellow-legged frogs are known from the Plumas National Forest and other lands either in inholdings or the west-slope Sierra below the Plumas National Forest boundary. The earliest record from the vicinity of what was to be the Plumas National Forest is a collection of nine foothill yellow-legged frogs made by C. Rutter on 2 September 1899 along Spanish Creek at Quincy (CAS-SU 1696–1704); this collection locality is on private land. On 26 May 1912, Walter Penn Taylor collected two foothill yellow-legged frogs from Chambers Ravine, 6.4 km (4 mi) north of Oroville (MVZ 4057–4062). The earliest record from the Plumas National Forest proper consists of one foothill yellow-legged frog collected at Meadow Valley along Spanish Creek by Edwin C. Van Dyke in June 1924 (CAS 63818). No additional foothill yellow-legged frog records exist for the Plumas National Forest from the 1920s.

One record of foothill yellow-legged frogs exists for the Plumas National Forest from the 1930s. T. Storer collected three foothill yellow-legged frogs from Last Chance Creek at a point 9.6 km (6 mi) south of Milford on 18 July 1932 (CAS 218328–218330). One additional record of foothill yellow-legged frogs was made on non-Forest Service land below the Plumas National Forest boundary during the 1930s. On 9 April 1937, Victor C. Twitty collected 13 foothill yellow-legged frogs along Cherokee Creek in Sawmill Canyon (CAS-SU 2576–2588). By the end of the 1930s, foothill yellow-legged frogs had been recorded from two localities on the Plumas National Forest, and three additional localities at elevations below Plumas National Forest lands.

Two records of foothill yellow-legged frogs exist for the Plumas National Forest from the 1940s. Walter W. Dalquest collected six foothill yellow-legged frogs from Dooley Creek, a tributary of Last Chance Creek, at a point 2.4 km (1.5 mi) west-southwest of McKesick Peak on 15 July 1941 (MVZ 35914–35919). In 1942 (no specific date), Robert R. Miller collected one foothill yellow-legged frog 14.4 km (9 mi) north-northwest of Beckwourth (UMMZ 91679). Eight additional records of foothill yellow-legged frogs were made on non-Forest Service land below the Plumas National Forest boundary during the 1940s. On 9 March 1941, Harvey I. Fisher collected three foothill yellow-legged frogs at Bidwell Bar Park on the Feather River (MVZ 34837–34839); Lake Oroville now inundates this locality. On 14 September 1945, T. Rodgers collected one foothill yellow-legged frog from Mud Creek at Richardson Springs (MVZ 42725). On 21 October 1945, Rodgers also collected two foothill yellow-legged frogs from Butte Creek at De Sabla, 12.8 km (8 mi) north of Paradise (MVZ 32726, 32739); De Sabla Reservoir inundates this locality today. On the same date, Rodgers collected 12 foothill yellow-legged frogs along Big Chico Creek, 12.8 km (8 mi) northeast of Chico (MVZ 42727–42738). On 2 January 1946, B. Matthews collected one foothill yellow-legged frog along Butte Creek at the Centerville Covered Bridge (MVZ 51657). On 20 March 1948, a collector by the name of Isaac collected one foothill yellow-legged frog 12 km (7.5 mi) east of Chico (CSUC 1261). On 23 March 1946, P. Collett and B. Matthews each collected one foothill yellow-legged frog on Little Butte Creek below Magalia Dam (MVZ 51658–51659). On 18 May 1946, A. Santos collected one foothill yellow-legged frog at Cherokee along the North Fork of the Feather River, 32 km (20 mi) southeast of Chico. By the end of the 1940s, foothill yellow-legged frogs had been recorded from five localities on the Plumas National Forest, and 11 additional localities at elevations below Plumas National Forest lands.

Four records of foothill yellow-legged frogs exist for the Plumas National Forest from the 1950s, three of which were new. On 19 June 1951, George B. Rabb re-collected the Meadow Valley locality, where he took one foothill yellow-legged frog (UMMZ 104997). On 7 July 1951, Rabb also collected one foothill yellow-legged frog along Rock Creek at a point 8 km (5 mi) southwest of Quincy (UMMZ 104998). On 31 May 1952, R. Zweifel collected 28 foothill yellow-legged frogs at a different locality along Last Chance Creek: 8.8 km (5.5 mi) west of McKesick Peak (MVZ 58058–58172). On the same date, Frederick L. Turner collected one foothill yellow-legged frog 1.6 km (1 mi) east of Blairsden (LACM 8502). Nine additional records of foothill yellow-legged frogs were made on non-Forest Service land below the Plumas National Forest boundary during the 1950s. On 2 April 1950, W. T. Byerly collected two foothill yellow-legged frogs along the Anderson Fork at Cohasset Pioneer Springs (MVZ 56831–56832). On 14 April 1950, G. Snow collected one foothill yellow-legged frog along Rich Gulch at Yankee Hill (MVZ

56836). On 15 April 1950, E. Schneegas collected one foothill yellow-legged frog at this same locality (MVZ 56833). On 20 April 1950, H. Meyer collected one foothill yellow-legged frog at Cole Canyon Falls, 4.8 km (3 mi) south of Pentz (MVZ 56837). On 1 March 1952, R. Zweifel collected four foothill yellow-legged frogs along Butte Creek 2.6 km (1.6 mi) by road west of De Sabla (MVZ 58033–58036). On 1 April 1952, H. Wiedman collected one foothill yellow-legged frog along Rock Creek 0.8 km (0.5 mi) east of Richardson Springs (MVZ 56834). On 22 April 1952, P. Moretti collected two foothill yellow-legged frogs along Butte Creek, 11.7 km (7 mi) east of Chico (MVZ 56838). On 28 March 1953, C. Dart collected one foothill yellow-legged frog at Forbestown on an unnamed tributary of the South Fork of the Feather River (CSUC 1425). On 2 May 1953, Zweifel also collected one foothill yellow-legged frog along Butte Creek at Magalia (CSUC 59657). On 6 May 1954, J. Campbell collected one foothill yellow-legged frog along Mud Creek above Richardson Springs (CSUC 1557). By the end of the 1950s, foothill yellow-legged frogs had been recorded from eight different localities on the Plumas National Forest, and 20 additional localities at elevations below Plumas National Forest lands.

Three records of foothill yellow-legged frogs exist for the Plumas National Forest from the 1960s; all were new. On 9 May 1961, Vicki Jones collected one foothill yellow-legged frog along the Middle Fork of the Feather River 1.6 km (1 mi) downstream of Feather Falls (CSUC 1197); Lake Oroville inundated this locality during its filling over the years 1967–1969. On 8 July 1961, D. Collett collected one foothill yellow-legged frog at a new locality along Spanish Creek: a location 9.6 km (6 mi) above Quincy (CSUC 1179); some uncertainty exists regarding the language “above” used to record this locality; the most likely interpretation is one that refers to elevation on Spanish Creek above Quincy. On 9 July 1961, C. Williams collected two foothill yellow-legged frogs at McNair, a locality along Sulfur Creek, 11.2 km (7 mi) south of Blairsden (CSUC 1146–1147). Nineteen additional records of foothill yellow-legged frogs were made on non-Forest Service land below the Plumas National Forest boundary during the 1960s. On 22 February 1960, T. Rodgers collected one foothill yellow-legged frog on Little Butte Creek 183 m (200 yd) below Magalia Reservoir (CSUC 1426). On 12 March 1960, R. Russel collected four foothill yellow-legged frogs on Big Chico Creek below 10-Mile House (CSUC 1553–1556). On 24 March 1960, Rodgers collected two foothill yellow-legged frogs along Big Chico Creek at Salmon Hole (CSUC 1561–1562). On 1 April 1960, N. Jensen collected 27 foothill yellow-legged frogs along Mud Creek 0.8 km (0.5 mi) upstream from Richardson Springs (CSUC 1511–1537). On 30 April 1960, N. Jensen collected two foothill yellow-legged frogs where Little Butte Creek enters Paradise Reservoir (CSUC 1563–1564). On 26 May 1960, R. Parker collected one foothill yellow-legged frog along the Anderson Fork, a tributary of Rock Creek, 12.8 km (8 mi) northeast of the Chico Airport (CSUC 1199). On 2 May 1961, M. Attinger and N. Polston each collected one foothill yellow-legged frog along Mud Creek above Richardson Springs (CSUC 1558–1559). On 4 May 1961, D. Tener collected one foothill yellow-legged frog at this same locality (CSUC 1560). On 7 May 1961, G. Beem collected two foothill yellow-legged frogs on Butte Creek near Chico (CSUC 1430–1431). On 8 May 1961, D. Winter collected three foothill yellow-legged frogs on Big Chico Creek, 1.6 km (1 mi) above its confluence with Mud Creek (CSUC 1424, 1525–1526). On 9 May 1961, three foothill yellow-legged frogs were collected along Butte Creek 0.4 km (0.25 mi) above De Sabla (CSUC 1427–1429). On 3 July 1961, D. Collett collected two foothill yellow-legged frogs along Butte Creek, 5.6 km (3.5 mi) upstream of Centerville School (CSUC 1422–1423). On 26 July 1961, Darryl Torgerson collected two foothill yellow-legged frogs along the West Branch of the Feather River, 4.8 km southeast of Stirling City (CSUC 1144–1145). On 23 March 1962, M. Frost collected one foothill yellow-legged frog along Rock Creek, 9.6 km (6 mi) north of Chico (CSUC 1206). On 2 May 1963, G. Gaetsen collected one foothill yellow-legged frog at Bear Hole along Big Chico Creek (CSUC 746). On 21 May 1963, R. Barden collected five foothill yellow-legged frogs along Big Chico Creek above Salmon Hole (CSUC 747–751). On 22 May 1963, P. Croner collected two foothill yellow-legged frogs along Big Chico Creek, 16 km (10 mi) upstream of the Bidwell Park golf course (CSUC 744–745). On 3 July 1963, D. Collette collected three foothill yellow-legged frogs in the upper Centerville Canal at De Sabla (CSUC 1171–1173). On 23 March 1964, an unnamed collector collected one foothill yellow-legged frog at the end of Helltown Road, 3.2 km (2 mi) northeast of Centerville (CSUC 1380). In spring (date not specified) of 1964, Christopher Dokos collected two frogs from Magalia Reservoir (CSUC 1382–1383). By the end of the 1960s, foothill yellow-legged frogs had been recorded from 12 different localities on the Plumas National Forest, and 39 additional localities at elevations below Plumas National Forest lands.

Three records of foothill yellow-legged frogs exist for the Plumas National Forest from the 1970s, but all represent sight records of previously collected sites. Over the interval 1973–1978, M. Hayes visited three of the historical localities on Plumas National Forest lands collected during the 1950s: the Meadow Valley and Rock Creek localities collected by Rabb, and the Last Chance Creek locality collected by Zweifel. A few (one to three) foothill yellow-legged frogs were recorded on each of four visits. Five records of foothill yellow-legged frogs were made on non-Forest Service land below the Plumas National Forest boundary during the 1970s; one represents a new record vouchered by a specimen, the remaining four are sight records from previously collected sites. On 29 November 1971, Theodore J. Papenfuss collected one foothill yellow-legged frog along the Little North Fork of the Feather River, 3.2 km (2 mi) upstream from the junction with the Middle Fork of the Feather River (MVZ 117615). Over the interval 1973–1978, M. Hayes visited four historical localities along Big Chico Creek at elevations below Plumas National Forest lands; these included Bear Hole, Salmon Hole, 1.6 km (1 mi) above its confluence with Mud Creek, and below 10-Mile House. All were visited at least eight times each. Foothill yellow-legged frogs were recorded at three of the four Big Chico Creek localities, all above where the stream enters its foothill canyon (i.e., in upstream progression, Salmon Hole, Bear Hole, and below 10-Mile House), but were absent from the valley floor location above the confluence of Big Chico Creek with Mud Creek, where only American bullfrogs were present. By the end of the 1970s, foothill yellow-legged frogs had been recorded from 12 different localities on the Plumas National Forest, and 40 additional localities at elevations below Plumas National Forest lands. Foothill yellow-legged frogs seem to have disappeared from at least one valley floor site at that time, but available data imply that the species was still present over its Sierra range in this region.

1980 to present—

Systematic surveys on the Plumas National Forest were not initiated until the 1990s. From 1998 to 1999, field crews from the California Academy of Sciences (CAS) spent significant time surveying for amphibians and reptiles on the Plumas National Forest (Koo and Vindum 1999). Crews consisted of two to four people. In 1998, crews spent 64 days conducting surveys between 27 April and 22 October; in 1999, 46 days were spent conducting surveys between 5 June and 5 October. Surveys in 1998 and 1999 covered about 35 and 30 sites, respectively, with potential habitat for foothill yellow-legged frogs; this included 24 sites (both years combined) where the species has been recorded historically. Foothill yellow-legged frogs were recorded at only 45 percent (n = 11) of the sites where they were historically found (voucher specimen numbers indicated in parentheses). Foothill yellow-legged frogs were recorded at all six historical sites in the Canyon Creek drainage (including Onion [CAS 206277, 206309] and Slate Creeks; [CAS 205984, 206276, 206297, 206308, 209249]) and both historical sites in the South Fork Feather River drainage (including Oroleve Creek; CAS 206366); however, they were detected at two of four sites in the Middle Fork of the Feather River (i.e., two unnamed tributaries east of Milsap

Bar; CAS 205588, 205590), only one of seven sites in the East Branch of the North Fork Feather River (i.e., Spanish Creek; CAS 206271), and none were found in either of the two historical sites in Little Butte Creek or the one historical site in each of Dry Creek (3.2 km [2 mi] southwest of Forbestown), the North Fork Yuba River, and the West Branch Feather River.

Since the CAS surveys, the Plumas National Forest has continued to conduct extensive amphibian surveys to detect additional foothill yellow-legged frog locations. Plumas National Forest surveys since the CAS surveys, found that all sites (or drainages) in which foothill yellow-legged frogs were detected during CAS surveys still appear to have foothill yellow-legged frogs present. Without a detailed study design and rigorous statistical analysis, population estimates cannot be made from the data collected on the forest. In the last 10 years, foothill yellow-legged frogs have been detected at several locations in addition to the 24 historical sites (contact K. Hopkins or G. Garcia, Plumas National Forest, for details on locations).

Extensive surveys and monitoring of the frog populations in the Poe and Cresta reaches of the North Fork Feather River have been conducted by Garcia and Associates for Pacific Gas and Electric Company and the California Energy Commission since 2001 (GANDA 2005, 2006, 2008). The population on the Poe reach has been increasing over this period. In comparison, the Cresta population, which experienced 4 years of monthly spring and summer whitewater boating flows, declined significantly relative to Poe (PG&E data analyzed in Kupferberg et al. 2012). In 2006, surveys conducted for Pacific Gas and Electric Company's De Sabla-Centerville Project relicensing revealed the presence of all life stages of foothill yellow-legged frogs along both Butte Creek and West Branch Feather River, but in varying abundances (Pacific Gas and Electric Company 2008). These data along with other amphibian data collected during recent hydropower relicensing activities (FERC project nos. 2088, 2107, 1962) have not yet been incorporated into Plumas National Forest and other databases (GIS, NRIS).

Mendocino National Forest

Pre-1980—

The first and only records of foothill yellow-legged frog specimens sampled on the Mendocino National Forest prior to the 1980s were three frogs collected by Edward L. Kessel on 19 November 1960; two were collected at an unnamed site located 1 mi south of Red Bridge (CAS 88627 and 88628) and one frog was collected at a site 1 mi north of Red Bridge (CAS 88629).

1980 to present—

One record exists of specimens collected in Mendocino National Forest in the 1980s. On 8 April 1989, M. Jennings collected four foothill yellow-legged frogs on an unnamed western tributary of the South Fork of Stony Creek at Davis Flat (CAS 173738, 173739, 180303, 180304).

Numerous specimens were collected from Mendocino National Forest during the 1990s. J.V. Vindum collected one frog on Beaver Creek (CAS 185330) on 4 July 1992, and one frog on 29 August 1992 on Buck Rock Creek (CAS 186226). In 1995, Jens V. Vindum collected one frog on Mendocino Pass Rd. (CAS 198828). In 1996, Vindum collected two frogs on 11 May; one was captured 2.6 mi west of Soda Creek (CAS 201244) and the other along Soda Creek (CAS 201248) and one frog on 18 August at Black Butte River (CAS 201571). On 24 February 1997, Vindum also collected one frog at North Fork Campground (CAS 202581) and one frog at Brittan Ranch (CAS 202583). On 29 March 1997, Vindum collected one frog at Brittan Ranch (CAS 202599). On 12 May 1997, John J. Crayon collected one frog along the north fork of Cache Creek at Spanish Creek (CAS 203612) and on 14 May 1997, he collected one specimen along Wolf Creek at Salt Lick Canyon (CAS 203682). On 25 April, 1997, M. Jennings collected one frog at Bear Creek, 0.4 mi upstream from Wilbur Springs Road Bridge (CAS 203203) and on 10 June 1997, he collected one frog along Bear Creek at Thompson Canyon (CAS 203204). On 12 May 1997, Jennings also collected one frog along the north fork of Cache Creek at Spanish Creek (CAS 203613). Jennings and J. Crayon collected two frogs on the east fork of Middle Creek on 14 May 1997 (CAS 203652 and 203680). On 12 May 1997, Norman J. Scott, Jr. collected one frog along Spanish Creek, 0.2 mi above the confluence, 10.7 mi north-northeast of Clearlake Oaks (CAS 203675). On 14 May 1997, Scott, also collected three frogs from the west fork of Middle Creek at South Fork, 6.7 mi north-northeast of Upper Lake (CAS 203664, 203665, 203685). On 24–26 May 1999, Michelle S. Koo and R.S. Lucas collected one frog along Wolf Creek (CAS 209138), one frog in Quartz Canyon, along a tributary of Wolf Creek (CAS 209147), and two frogs along East Fork Middle Creek (CAS 209152, 209167). On 14 June 1999, R.S. Lucas and Vindum collected one frog along Bar Creek (CAS 208976). They collected one frog on 15 June 1999 along an unnamed creek (CAS 208990), one frog on 16 June 1999 at Pothole Creek (CAS 209003), and one frog on 18 June 1999 at South Fork Bear Creek (CAS 209038). Lucas and Vindum collected one frog on 19 June 1999 on Black Butte River, ca. 100 m upstream of Cold Creek confluence (CAS 209051) and one frog on 24 June 1999 on Black Butte River, downstream of The Basin (CAS 209128). From 15–17 September 1999, Lucas and Vindum collected three frogs along South Fork Stony Creek (CAS 209515, 209520, 209536) and one frog along Stony Creek (CAS 209542).

Surveys by various individuals during the 1990s produced additional records of foothill yellow-legged frog detections in Mendocino National Forest (USDA Forest Service NRIS database). On 1 January 1994, Art Shapiro observed foothill yellow-legged frogs on Little Stony Creek between Ruby King Mine and the cattle guard. On 10 April 1995, George Elliot observed an unknown number of frogs at the north end of Davis Flat OHV area along an unnamed creek. Teresa Sue observed one frog at Alder Springs, near Camp Ellendale on 3 July 1996. On 16 October 1996, Lee Morgan observed numerous frogs (ca. 100) at Wolf Creek, upstream and adjacent to the Spring Valley subdivision. Linda Angerer observed one frog at Middle Creek on 1 January 1997 and one frog at Thomas Pocket, an undeveloped campground on 24 July 1997. On 8 June 1997, Mike Ramsey observed two frogs (suspected to be foothill yellow-legged frogs) at Thomes Creek.

Numerous collections occurred during the 2000s. On 31 July 2000, R. Lucas, R. Stoelting, Chris R. Feldman, and J. Vindum collected one frog along the North Fork Stony Creek (CAS 212559). On 1 August 2000, Stoelting and Vindum collected one frog along Mill Creek, upstream of Mill Creek Campground (CAS 212578) and Lucas and Feldman collected one frog from an unnamed creek between Wolf Glade and Diversion Dam Campground (CAS 212585). On 3 August 2000, Lucas and Feldman collected one frog from Corbin Creek (CAS 212626). On 5 August 2000, Feldman and Vindum collected one frog along Thomes Creek (CAS 212653) and one frog along Willow Creek, upstream of Thomes Creek confluence (CAS 212659). On the same day, Stoelting and Lucas collected one frog along Thomes Creek (CAS 212672). On 7 August 2000, Stoelting and Feldman collected one frog along Sullivan Creek, upstream of Little Stony Creek confluence (CAS 212693), and Lucas and Vindum collected one specimen from Little Stony Creek, between the Sullivan and Trout Creek confluences (CAS 212713). On 8 August 2000, Feldman and Vindum collected one frog along Little Stony Creek, upstream of Trout Creek confluence (CAS 212727), and Lucas and Stoelting collected one frog along Little Stony Creek, downstream of Little Stony Creek Campground (CAS 212734). On 9 August 2000, Lucas and Feldman collected one frog along Little Sullivan Creek (CAS 212749). Between 6–7 June 2001, Lucas and Vindum collected five frogs along Rice Creek, a tributary of the Eel River (CAS 219461, 219462, 219466, 219481, 291485). From 9–14 June 2001, Lucas and Vindum collected six frogs on the State Game Refuge; one frog was collected at each location including Trout Creek (CAS 219509), Eel River (CAS 219528), Horse Creek (CAS 219543), Corbin Creek (CAS 219556), Anderson Creek (CAS 219570), and Rattlesnake Creek (CAS 219585). On 15 June 2001, Lucas and Vindum collected one frog along Panther Creek (CAS 219590). On 21 August 2001, Wilkinson and Vindum collected one frog along an unnamed tributary to the Middle Fork Eel River in the Blands Cove area (CAS 220681). On 22 August 2001, Wilkinson and Vindum collected one frog along Rattlesnake Creek (CAS 220692). They collected one frog along Hammerhorn Creek (CAS 220714) on 23 August 2001, and two frogs on 24 August 2001, one along Maple Creek (CAS 220742) and one on Alder Creek (CAS 220749). Wilkinson and Vindum collected one frog on 25 August 2001 at Balm of Gilead Creek in the Yolla Bolly Wilderness (CAS 220765) and one frog on 26 August 2001 along the Middle Fork Eel River (CAS 220778). On 28 August 2001, Wilkinson and Vindum collected two frogs, one along Skeleton Creek (CAS 220801) and one along an unnamed tributary to Skeleton Creek (CAS 22803). On 29 August, they collected one frog along Copper Butte Creek in the Snow Mountain Wilderness (CAS 220806), one frog along the Eel River between the Copper Butte and Berry Creek confluences (CAS 220812), and one frog along Berry Creek (CAS 220814). On 30 August, Wilkinson and Vindum collected one frog along Thistle Glade Creek (CAS 220837) and one frog along Hummingbird Creek (CAS 220841) within the Snow Mountain Wilderness. On 31 August, they collected one specimen at Deer Creek (CAS 220844). On 7–8 August 2001, Wogan and Lucas collected one frog along Blue Slides Creek (CAS 220934) and one frog along Rice Fork of the Eel River (CAS 220946). On 11 August 2001, Wogan and Lucas collected one frog along an unnamed tributary of the Eel River (CAS 220989). Wogan and Lucas collected four frogs from 14 through 16 August 2001; one frog was collected from each location including a drainage adjacent to Forest Road 24N35 (CAS 221011), Murphy Canyon Creek (CAS 221015), Dark Canyon Creek (CAS 221023) and Mill Creek (CAS 221024). On 22 February 2002, Vindum collected one frog along Forest Road M4 (CAS 223704). On 2 May 2004, Vindum collected one frog along a tributary between Howard Lake and Howard Creek (CAS 238631).

On 26 June 2011, R.J. Adams observed 12 foothill yellow-legged frogs at Sulfur Creek, Vichy Springs in Ukiah.

Surveys during the 1990s and 2000s (USDA Forest Service NRIS database) document additional foothill yellow-legged frog localities in Mendocino National Forest. Frogs were detected at Auger Creek (a tributary of Thomes Creek), Trout Creek (a tributary of Eel River), and Lower Grindstone Creek.

Tahoe National Forest

Pre-1980—

Scattered pre-1980 records of foothill yellow legged frogs exist for the Tahoe National Forest. All records are for the tributary network of the Yuba River system; some records do exist for the northern portion of the American River system on Tahoe National Forest lands, but all these were recorded post-1980.

Yuba River—On 17 April 1960, B. Parker collected three foothill yellow-legged frogs along Willow Creek, 3.2 km (2 mi) north of Camptonville (CSUC 1176–1178). On the same date, R. Parker collected six foothill yellow-legged frogs on the Middle Fork Yuba River, 16 km (10 mi) south of Downieville (CSUC 1200–1205). On 1 July 1961, Harold Houser collected seven foothill yellow-legged frogs in Washington Creek, 1.6 km (1 mi) south of Washington (CSUC 1164–1170). On 2 July 1961, Houser also collected four foothill yellow-legged frogs along the South Yuba River, 6.4 km (4 mi) east of Washington (CSUC 1139–1142). On 3 July 1961, Houser further collected three foothill yellow-legged frogs along the South Yuba River, 4.8 km (3 mi) above its confluence with Canyon Creek (CSUC 1136–1138). On 9 July 1961, C. Williams collected 14 foothill yellow-legged frogs along the North Fork of the Yuba River at Ramshorn Creek (CSUC 1217–1230). On 1 June 1966, Houser collected 12 foothill yellow-legged frogs on the Middle Yuba River below Graniteville (CSUC 1609–1620). On 17 July 1969, Houser also collected two foothill yellow-legged frogs 16 km (10 mi) north of Washington along South Poorman Creek (CSUC 1814–1815).

Eleven historical records of foothill yellow-legged frogs also exist for portions of drainages below Tahoe National Forest lands. The oldest of these records is from 22 August 1899, when William F. Atkinson collected three foothill yellow-legged frogs from Bullards Bar (USNM 38817–38819); Bullards Bar Reservoir now inundates this locality. On 1 July 1903, J. G. Carlson collected one foothill yellow-legged frog along Deer Creek near Olympic Park, Nevada City, along the road to the Champion Mine (CAS 4753); this specimen was lost in the earthquake and fire of 1906 in San Francisco, but John Van Denburgh verified its identity against other foothill yellow-legged frog specimens currently in the CAS collection. On 22 September 1938, Joel Hedgepeth collected two foothill yellow-legged frogs along the Yuba River at Moonshine Creek (USNM 312034–312035). On 11 September 1943, Margaret Storey collected five foothill yellow-legged frogs along Dry Creek, 4.8 km (3 mi) west of Challenge along the road between Brownsville and Challenge (CAS-SU 8605–8608, CAS 200842). On 15 April 1951, William Kamp collected one foothill yellow-legged frog from a stream on Dean Ranch in the Sutter Buttes (CSUC 1106). On 2 March 1952, R. Zweifel collected nine foothill yellow-legged frogs along South Honcut Creek, a tributary of the lower mainstem Feather River, 4.2 km (2.6 mi) east-northeast of Rackerby (MVZ 58049–58057). On the same date, Zweifel collected one foothill yellow-legged frog from Robinson Ravine, a tributary of South Honcut Creek, 5.0 km (3.1 mi) east of Bangor (MVZ 58037). On 12 April 1953, Malcolm A. Miller collected one foothill yellow-legged frog along the North Fork American River, just above its confluence with the Middle Fork American River (CAS 218322). On 20 March 1960, B. Lang collected one foothill yellow-legged frog along New York Creek, a tributary of Dry Creek, 3.2 km (2 mi) southwest of Forbestown (CSUC 1160). On 23 September 1967, J. K. Barca collected two foothill yellow-legged frogs along Poorman Creek, 0.8 km (0.5 mi) west-northwest of Washington (CAS 181267–181268). On 15 July 1973, Susan M. Case collected 13 foothill yellow-legged frogs near Washington along the South Yuba River and Washington Creek in the course of her studies on western North American ranid frogs (MVZ 136314–136326).

1980 to present—

North Yuba River—Ten localities were recorded in the North Yuba River system. On 17 May 1997, Marilyn M. Tierney collected one foothill yellow-legged frog on an unnamed tributary of Woodruff Creek along Mountain House Road, 4.9 km (3.05 road mi) from Hwy 49 and 4.6 km (2.85 mi) south of Goodyears Bar (CAS 202880). On the same date, Tierney also collected one foothill yellow-legged frog at the mouth of Humbug Creek along the North Yuba River (CAS 202875). On 20 May 1997, Tierney collected one foothill yellow-legged frog along another unnamed tributary of Woodruff Creek 6.4 km (4 mi) from Hwy 49 (CAS 202918). On 16 June 1997, Tierney collected one foothill yellow-legged frog along Kanaka Creek below the Silver Dollar Mine (CAS 203363). On 21 July 1997, Carol L. Spencer collected one foothill yellow-legged frog along Woodruff Creek, 0.96 km (0.6 mi) south of Goodyears Bar and 1.3 km (0.8 mi) south of Hwy 49 (CAS 203285). On the same date, Spencer also collected one foothill yellow-legged frog along Fiddle Creek at the Fiddle Creek trailhead (CAS 203284). On 21 August 1997, Spencer also collected one foothill yellow-legged frog from Youngs Ravine, ca. 100 m upstream from Forest Road 491-2 and Brandy City Road (= Forest Road 491-4) (CAS 203371). On 14 July 1998, Jeffrey A. Wilkinson collected a foothill yellow-legged frog at the mouth of Humbug Creek locality along the North Yuba River (CAS 205943). On the same date, Wilkinson also collected two foothill yellow-legged frogs along the south bank of the mainstem North Yuba River at 630 m (2,400 ft) elevation (CAS 205944, 205946); and another along St. Catherine Creek north of the north Yuba River trail (CAS 205945). On 15 July 1998, Wilkinson collected one foothill yellow-legged frog from the creek in Devil's Canyon, a tributary of the North Yuba River (CAS 205953).

Middle Yuba River—One locality was recorded on the Middle Yuba River system. On 20 May 1997, M. Tierney collected one foothill yellow-legged frog on Grizzly Creek at Pike City Road (CAS 202921). Between 2008 and 2010, the Nevada Irrigation District and Pacific Gas and Electric Company conducted surveys on the Middle Yuba and had a high number of detections in the Milton Diversion Dam Reach (Nevada Irrigation District and Pacific Gas and Electric Company 2010).

South Yuba River—Two localities were recorded on the South Yuba River system. On 28 August 1997, Carol L. Spencer collected one foothill yellow-legged frog along the mainstem South Yuba River, ca. 200 m downstream of Keleher Picnic Area (CAS 203444). On the same date, Spencer collected another foothill yellow-legged frog on the east bank of the mainstem South Yuba River east of Golden Quartz Picnic Area (CAS 203450).

North Fork American River—One locality was recorded on the North Fork American River system. On 2 July 1998, Michelle S. Koo collected one foothill yellow-legged frog along North Shirttail Creek upstream from Sugar Pine Reservoir (CAS 205873).

Middle Fork American River—Two localities were recorded on the Middle Fork American River system. On 30 June 1998, M. Koo collected one foothill yellow-legged frog along Skunk Canyon Creek, ca. 16 km (10 mi) upstream from Mosquito Ridge Road (CAS 205859); Skunk Canyon Creek is a tributary of the North Fork of the Middle Fork of the American River. On 27 July 1998, Koo also collected one foothill yellow-legged frog along North Fork of the Middle Fork of the American River at the crossing of Mosquito Ridge Road (CAS 206178).

Systematic surveys on the Tahoe National Forest were not initiated until the 1990s. During 1998–1999, field crews from the California Academy of Sciences (CAS) spent significant time surveying for amphibians and reptiles on the Tahoe (Koo and Vindum 1999). Crews consisted of two to four people. During this interval, foothill yellow-legged frogs were recorded at a number of localities on the North, Middle, and South Yuba Rivers, and on the North and Middle Forks of the American River, including several localities for which historical records were lacking.

In the 2000s, numerous surveys were conducted on the Tahoe National Forest; many of these were associated with hydropower relicensing studies. In 2007, the Placer County Water Agency (PCWA) conducted surveys on the Rubicon and Middle Fork American Rivers; frogs were detected in varying abundances along the study reaches and breeding was observed primarily in the lower portions of the Rubicon and Middle Fork American River bypass reaches as well as along American Canyon Creek, Gas Canyon, Todd Creek, and Otter Creek (PCWA 2008). From 2008 to 2010, the Nevada Irrigation District and Pacific Gas and Electric Company conducted surveys on the Middle Yuba and South Yuba; foothill yellow-legged frogs or evidence of reproduction (egg masses and tadpoles) were observed along various reaches of the two tributaries (Nevada Irrigation District and Pacific Gas and Electric Company 2010). In 2011, the Yuba County Water Agency (YCWA) performed foothill yellow-legged frog surveys on Oregon Creek, and, in 2012, YCWA surveyed sites along the Middle, North, and mainstem Yuba River. Most of the reaches surveyed were influenced by the Yuba River Development Project. One or more life stages were detected on some reaches influenced by the project as well as both reaches that were not influenced by the project (YCWA 2012). Results from additional surveys during hydropower relicensing studies in the South and Middle Forks of the Yuba River, the Bear River, the North Fork Middle Fork and the Middle Fork of the American River, and the Rubicon River (including tributary streams within these watersheds) (FERC Project Nos. 2310, 2266, 2079) are not included here but will be available upon completion of those relicensing studies and the filing of new license applications for these projects in 2011.

Eldorado National Forest

Pre-1980—

Few historical records exist for the foothill yellow-legged frog on the Eldorado National Forest. The forest database lacks pre-1980 records for this species (Williams 2006), but two pre-1980 records exist for Eldorado National Forest lands. The oldest of these records dates from 31 July 1916, when Joseph S. Dixon collected two foothill yellow-legged frogs at Fyffe (current location of the 20-Mile Guard Station) along the South Fork of the American River (MVZ 6109–6110). The second record dates from 19 May 1935, when B.A. Wiley collected four foothill yellow-legged frogs at a location somewhat farther upstream, 4 km (2.5 mi) west of Kyburz along the South Fork of the American River (MVZ 19053–19056).

Several additional pre-1980 records exist for drainages that extend onto Eldorado National Forest lands, but these records are located downstream of the current national forest boundary. Records exist for two major hydrographic basins: the American (including Middle and South Forks) and Cosumnes Rivers. Note that because the Middle Fork American River is a tributary of the North Fork American River, the decision on where to place records from the North Fork American River downstream of its confluence with the Middle Fork American River, was arbitrary because North Fork American River records on a national forest upstream of the confluence are entirely on the Tahoe National Forest, whereas Middle Fork American River records on a national forest upstream of the confluence are entirely on the Eldorado National Forest. Placement here was based on latitude. Hence, all records from the North Fork American River below its confluence with the Middle Fork American River are discussed here, whereas all records from the North Fork American River above its confluence with the Middle Fork American River are discussed under the Tahoe National Forest account. Records are grouped by the major hydrographic basins noted above.

American River—The oldest record from the American River is also the oldest record for the species, and consists of the type specimen that Charles E. Boyle collected in the spring of 1850 in the vicinity of Coloma (USNM 3370), presumably along the South Fork of the American River (Jennings 1987). Today, this locality is likely within the boundary of James W. Marshall State Historical Monument. All other records date from much later. On 14 November 1938, Thomas P. Maslin collected nine foothill yellow-legged frogs along Dry Creek, 11.2 km (7 mi) west and 1.6 km (1 mi) south of Placerville (MVZ 27306–27314). Dry Creek is a tributary to Weber Creek, which is a tributary of the South Fork of the American River. On 19 April 1946, Jerry B. Kimsey collected one foothill yellow-legged frog along the North Fork of the American River at Auburn (MVZ 51660). On 11 April 1952, J. Gorman, Jr. collected six foothill yellow-legged frogs 4.8 km northwest of Cool along the North Fork of the American River (MVZ 58290–58295). On 1 June 1952, R. Zweifel collected four foothill yellow-legged frogs along Weber Creek 3.5 km (2.2 mi) west-southwest of Placerville (MVZ 58038–58040, 58085). On 1 May 1953, Zweifel also collected one foothill yellow-legged frog 6.4 km (4 mi) northwest of Coloma along the South Fork of the American River (MVZ 59654). On 31 March 1961, E.K. Teberg collected one foothill yellow-legged frog along an unnamed creek 3.2 km (2 mi) south of El Dorado (MVZ 187310). This unnamed creek is a tributary of Slate Creek, which is a tributary to Dry Creek.

Cosumnes River—On 22 July 1942, Ralph G. Miller collected one foothill yellow-legged frog along Squaw Hollow Creek near Placerville (UMMZ 91972), a tributary of Martinez Creek, which is a tributary of the North Fork of the Cosumnes River. On 19 October 1942, Miller also collected one foothill yellow-legged frog along Martinez Creek proper, 6.4 km (4 mi) south of El Dorado (UMMZ 91971).

No foothill yellow frog records date from the 1970s from either the Eldorado National Forest or lands lower in elevation than Eldorado National Forest lands. Whether this means that foothill yellow-legged frogs had begun to decline in this region at that time is unclear, because systematic surveys in the region were not conducted until the 1990s.

1980 to present—

Martin (1992) and Canorus Limited made what are thought to be the first detections of foothill yellow-legged frogs on the Eldorado National Forest since 1980 on each of Bark Shanty, Camp, and Snow Creeks; the latter is a tributary to Camp Creek. Based on its elevation at 1911 m (6,270 ft), the Bark Shanty Creek record is thought to have represented Sierra Nevada mountain yellow-legged frogs (*Rana sierrae*), but this has never been confirmed, and native ranid frogs may no longer be extant at this location.

In 1994, one adult foothill yellow-legged frog was sighted on Sopiago Creek (EA Consulting, Inc. 1994), a 3rd-order tributary of the Cosumnes River. No other sightings of foothill yellow-legged frogs have been made on Sopiago Creek despite significant survey efforts.

Hydropower utilities involved in relicensing or in hydropower settlement conditions have been regularly collecting foothill yellow-legged frog occupancy and monitoring data in the following river systems: the Middle Fork of American River, the South Fork of the American River, and the North Fork of the Mokelumne River.

Currently, four major hydrographic basins have foothill yellow-legged frog populations:

- The Middle Fork of the American River and its tributaries, including the Rubicon River and Otter Creek.
- South Fork American River and its tributaries, including Silver Creek and Soldier Creek.
- The Cosumnes River system, especially Camp Creek and its tributaries.
- North Fork Mokelumne and its tributaries, especially Camp, Green, and East Panther Creeks.

Stanislaus National Forest

Pre-1980—

A number of historical foothill yellow-legged frog records exist for the Stanislaus National Forest; all are from the Middle or South Forks of the Tuolumne River or the North Fork of the Merced River.

Tuolumne River—Four historical records for the Stanislaus National Forest exist from the Tuolumne River system. The earliest record from this system on the Stanislaus is that of William D. Clarke, who collected two foothill yellow-legged frogs along the South Fork Tuolumne River at Berkeley-Tuolumne Camp along Big Oak Flat Road on 12 June 1948 (MVZ 45819–45820). On 31 August 1962, Robert M. Winokur collected one foothill yellow-legged frog along the South Fork Tuolumne River, 6.4 km (4 mi) west of Harden Flat along Hwy 120 (MVZ 146338). On each of 8 July 1972 and 2 August 1974, Susan M. Case collected one foothill yellow-legged frog along the Middle Fork Tuolumne River, 457 m (500 yd) east of Middlefork Camp. Additionally, over the interval 8–15 July 1972, Case also collected nine foothill yellow-legged frogs at Middlefork Camp along the Middle Fork Tuolumne River (MVZ 136239, 136241–136248).

North Fork Merced River—Two records exist for the Stanislaus National Forest on the North Fork Merced River. The earliest record from the North Fork Merced River as well as the earliest from the Stanislaus National Forest consists of six foothill yellow-legged frogs that T. Storer collected along Smith Creek, 9.6 km (6 mi) northeast of Coulterville on 5 June 1915 (MVZ 5687–5692). Smith Creek is a tributary of the North Fork of the Merced River. On 7 August 1950, William E. Duellman collected one foothill yellow-legged frog at Bower Cave along the North Fork of the Merced River (UMMZ 102405). On 8 March 1953, an unspecified collector took another foothill yellow-legged frog from Bower Cave (MVZ 59599); and on 30 May 1959, Richard E. Graham collected two more foothill yellow-legged frogs from Bower Cave (MVZ 69454–69455).

Several additional pre-1980 records exist for drainages that extend onto Stanislaus National Forest lands, but these records are located downstream of the current national forest boundary. Records exist for five major hydrographic basins; in north to south order, these are the Mokelumne, Calaveras, Stanislaus, Tuolumne, and Merced Rivers. Records for the Stanislaus National Forest for the Merced River are exclusively from the north bank or tributaries on the north side of the river; south bank or south side tributaries are discussed under the Sierra National Forest because the Merced River proper represents the boundary between these two national forests. The records for these hydrographic basins are discussed in alphabetical order.

Calaveras River—On 10 and 23 March 1953, R. Zweifel collected two foothill yellow-legged frogs along Big Trees Creek along State Hwy 4 at the south boundary of Calaveras Big Trees State Park (MVZ 59572–59573). Big Trees Creek is a tributary of San Antonio Creek, which flows into the South Fork of the Calaveras River.

Merced River—On each of 17 and 24 May 1915, Charles L. Camp collected one foothill yellow-legged frog at Pleasant Valley (MVZ 5779–5780), a locality discussed in Grinnell and Storer (1924). Pleasant Valley is a historical gold mining camp located at roughly the intersection of Piney Creek and the Merced River, but which Lake McClure (Exchequer Reservoir) inundates today. On 3 June 1915, Camp also collected one foothill yellow-legged frog on an unnamed tributary of Cuneo Creek (MVZ 5686); Cuneo Creek is a tributary of Maxell Creek, which flows into the Merced River. On 11 May 1919, T. Storer collected one foothill yellow-legged frog on Blacks Creek, a tributary of Maxwell Creek, 1.6 km (1 mi) west of Coulterville (MVZ 7186). Grinnell and Storer (1924) discussed observing foothill yellow-legged frog tadpoles of considerable size at this same locality on the previous day. On 18 August 1940, Robert R. Miller collected one foothill yellow-legged frog tadpole from Maxell Creek at the bridge just below Coulterville (UMMZ 89806).

Mokelumne River—The only historical record for the Mokelumne River system and the oldest record for this region is an old record from Licking Fork (Licking Creek). This record consists of three foothill yellow-legged frogs that W. Atkinson collected on 2 October 1899 (USNM 38822–38824).

Stanislaus River—On 23 March 1953, R. Zweifel collected five foothill yellow-legged frogs from Angels Creek, 1.9 km (1.2 mi) west-southwest of Murphys (MVZ 59567–59571). Angels Creek is a primary tributary of the Stanislaus River. On 10 May 1953, Zweifel also collected two foothill yellow-legged frogs along Moran Creek, 2.4 km (1.5 mi) east and 4.8 km (3 mi) north of Avery (MVZ 59574–59575). Moran Creek is a tributary of Mill Creek, which flows into the North Fork Stanislaus River.

Tuolumne River—On 16 August 1932, Charles H. Burt collected six foothill yellow-legged frogs along Woods Creek, 3.2 km northwest of Jacksonville (USNM 88468–88473). On 18 August 1940, R. Miller collect one adult and 17 tadpole foothill yellow-legged frogs along Moccasin Creek, 14.4 km (9 mi) southeast of Jacksonville (UMMZ 89807). On each of 14 May 1949 and 23 April 1950, W. Clarke collected one foothill yellow-legged frog along Woods Creek near Sawmill Flat (MVZ 50250, 50963). On 15 April 1951, Clarke also collected one foothill yellow-legged frog along Turnback Creek, a tributary of the Tuolumne River (MVZ 53992).

Historical records for foothill yellow frogs on the Stanislaus National Forest extend to the 1960s and early 1970s, whereas records below Stanislaus National

Forest lands extend only to the 1950s. Lack of systematic surveys and an incomplete historical record make it ambiguous as to whether foothill yellow-legged frogs had begun to decline regionally prior to 1980.

1980 to present—

Scattered sightings of foothill yellow-legged frogs exist for the Stanislaus National Forest and vicinity since 1980, but the earliest systematic surveys date from 1993 (Lind et al. 2003b). Records exist for the Calaveras, Clavey, Merced, Stanislaus, and Tuolumne Rivers. Two of the historical (pre-1980) sites have foothill yellow-legged frog sightings since 1980, but surveys since 1993 have identified 19 previously known sites (Lind et al. 2003b). No post-1980 records exist for the Mokelumne River, but whether the Mokelumne River system was even surveyed or the 1899 historical record for the Mokelumne was known to surveyors is unclear. Lind et al. (2003b) emphasized that summarized data are based on uneven survey efforts from composite sources. Post-1980 records from each of these systems are briefly discussed.

Calaveras River—Lind et al. (2003b) reported the sighting of one foothill yellow-legged frog adult from San Antonio Creek, but the date, number of visits, and surveyor were not indicated. Moreover, the data provided in Lind et al. (2003b) do not specify whether the San Antonio Creek locality is the same as the historical locality of R. Zweifel. Marc Hayes visited the historical Zweifel San Antonio Creek locality on single visits in 2003, 2004, and 2005 totaling 14 hours of search time during the months of June or July, but only a few juvenile American bullfrogs were found during two of the site visits. Some possibility exists that foothill yellow-legged frogs have been extirpated from the Calaveras River.

Clavey River—Lind et al. (2003b) reported foothill yellow-legged frogs records from three localities on the Clavey River system (Bull Meadow Creek, the Clavey River mainstem, and a Hull Creek tributary) from visits over the interval 1995–2001; notably, historical records of foothill yellow-legged frogs are lacking from the Clavey River system. Bull Meadow Creek was visited five times in 1997, three times in 1998, and twice in 2001. Nine foothill yellow-legged frog juveniles and 142 tadpoles were observed over the composite of the five visits in 1997, five adults were observed over the three visits in 1998, and two adults and 84 tadpoles were observed over the two visits in 2001. One adult foothill yellow-legged frog, one juvenile, 180 tadpoles, and one egg mass were observed on three visits to the Clavey River in 2002. In 2009 and 2010, Kupferberg and Catenazzi found breeding sites with egg masses, tadpoles, and metamorphs on the Clavey at five separate elevations (385, 398, 432, 714, and 734 m). One adult foothill yellow-legged frog was observed on one visit to the Hull Creek tributary in 1995. Overall, though reproduction seems to be occurring on at least the Clavey River mainstem and Bull Meadow Creek, low numbers of postmetamorphic foothill yellow-legged frogs were generally observed in the Clavey River system between 1995 and 2002.

Merced River—One record exists from the 1980s, Robert L. Seib collected one foothill yellow-legged frog from Sherlock Creek, 4.8 km (3 mi) northeast of Bear Valley (MVZ 175103); Sherlock Creek is a primary tributary of the Merced River. Lind et al. (2003b) commented on foothill yellow-legged frog records from Bull Creek, a tributary of the North Fork of the Merced River from six visits over the interval 1995–2003. One or two adult foothill yellow-legged frog and one or no juveniles were observed at each visit, implying low numbers of postmetamorphic frogs; no evidence of reproduction (egg masses or tadpoles) was found at this location.

Stanislaus River—Lind et al. (2003b) reported foothill yellow-legged frogs from 12 localities on the Stanislaus River system between 1993 and 2002. Two sites, Rose Creek, a tributary of the mainstem Stanislaus River, and the Sand Bar Dam reach of the mainstem Middle Fork Stanislaus River, had evidence of reproduction; and a third site, Skull Creek, a tributary of the North Fork Stanislaus River, may have had foothill yellow-legged frog tadpoles present, but the species identity of the tadpoles observed was in question. The number of adults observed during individual surveys was always less than 10, and juveniles were likewise fewer than during individual surveys except for Rose Creek in 1999, and the mainstem Middle Fork Stanislaus River in 2001. Additionally, on 19 September 1993, B. Keimel collected one adult foothill yellow-legged frog on Coyote Creek in the reach between the Natural Bridge to 100 m downstream of Krappeau Gulch (CAS 201798). Overall, numbers of adults and juveniles at occupied sites on the Stanislaus River were low, and evidence of recruitment success was limited to 3 sites of the 12 occupied sites surveyed.

Tuolumne River—Lind et al. (2003b) commented on foothill yellow-legged frogs from four localities in the Tuolumne River system between 1993 and 2002. Two sites, the North Fork Tuolumne River mainstem, and Hunter Creek, a tributary of the mainstem Tuolumne River, had evidence of reproduction. Numbers of adult and juvenile foothill yellow-legged frogs observed during individual surveys was always less than eight. A single juvenile foothill yellow-legged frog was found in the spring of 2008 upstream of Early Intake on the mainstem Tuolumne and a few tadpoles were found at nearby sites in 2010 by Kupferberg and 2012 by Mike Horvath of the San Francisco Public Utilities district. On 14 May 2010, D. Ashton observed tadpoles, one juvenile, and one adult along Drew Creek (a tributary of

Tuolumne River). Overall, numbers of adults and juveniles at occupied sites on the Tuolumne River were low, and indication of recruitment success was limited to one site. Survey data conducted from 2008 to 2010 are reported in San Francisco Public Utilities Commission (2014).

Yosemite National Park

Pre-1980—

Few historical records exist for foothill yellow-legged frogs for Yosemite National Park; this partly reflects the limited habitat available for foothill yellow-legged frogs within this park. Foothill yellow-legged frog localities discussed by Grinnell and Storer (1924) for the east-west transect encompassing Yosemite National Park are all outside national park boundaries, and they did not document foothill yellow-legged frogs within Yosemite National Park; the Blacks and Smith Creeks and Pleasant Valley localities they addressed are discussed under the Stanislaus National Forest; the Felicana Mountain locality they discussed is addressed under the Sierra National Forest account. One historical record for foothill yellow-legged frogs from within Yosemite National Park is documented: on 31 July 1948, Carl L. Hubbs collected one foothill yellow-legged frog along the Merced River, 0.8 km (0.5 mi) below Cascade Creek at an elevation of 1042 m (3,420 ft) (UMMZ 99298).

1980 to present—

Systematic surveys of the amphibian fauna of Yosemite National Park were initiated in the early 1990s. Gary Fellers, his associate Charles Drost, and his field crews conducted surveys meant to replicate the west-to-east transect that Joseph Grinnell and his students sampled encompassing the region of the Sierra including Yosemite National Park (Drost and Fellers 1994, 1996). Drost and Fellers (1994, 1996) found no foothill yellow-legged frogs within Yosemite National Park boundaries.

Subsequent surveys conducted by National Park Service personnel through 2006 have also failed to reveal foothill yellow-legged frogs within the boundaries of Yosemite National Park. These surveys were largely focused on species other than foothill yellow-legged frogs; nevertheless, some survey effort was focused in areas that would have represented historical foothill yellow-legged frog habitat, i.e., along the lower portion of the Merced River within Yosemite National Park and its few larger tributaries in that area. Based on available data, foothill yellow-legged frogs are likely to be extirpated from Yosemite National Park.

Sierra National Forest

Pre-1980—

Few historical records for foothill yellow-legged frogs exist for the Sierra National Forest; all are in the Merced, San Joaquin, or Kings River systems. The oldest record from the Sierra National Forest is two foothill yellow-legged frogs that J. Gorman, Jr. collected 7.1 km (4.4 mi) northeast of Briceburg along the Merced River on 11 July 1952 (MVZ 59479–59480). On 19 April 1953, R. Zweifel collected foothill yellow-legged frogs at three additional localities in the Merced River system: two foothill yellow-legged frogs at Fish Camp along Big Creek (MVZ 59588–59589); six additional foothill yellow-legged frogs along the Merced River 3.1 km (1.9 mi) east of Indian Lodge (MVZ 59590–59595); and two foothill yellow-legged frogs along Feliciana Creek, 3.2 km (2 mi) east of Briceburg (MVZ 59596–59597). On 2 September 1953, John D. Cunningham collected three foothill yellow-legged frogs at an unspecified locality on the road to Huntington Lake (LACM 13578–13580). On 6 September 1953, Alan E. Leviton and H. Magarian collected four foothill yellow-legged frogs along the Middle Fork of the Kings River at Davis Creek (CAS-SU 13090–13093).

However, the oldest records from streams below the Sierra National Forest boundary consists of 14 foothill yellow-legged frogs that Halstead G. White collected at Dunlap along Mill Creek, a tributary of the Kings River, on 27 and 30 September and 1 October 1916 (MVZ 6230–6243). White also collected two foothill yellow-legged frogs at Minkler along Byrd Slough, also a tributary of the Kings River, on 11–12 October 1916 (MVZ 6244–6245).

On 5 December 1970, Joseph W. Crim took one foothill yellow-legged frog 4 km (2.5 mi) up the North Fork of the Kings River toward Balch Camp (MVZ 94419). In 1970, Moyle (1973) sampled 49 stream crossings of either the mainstem or tributaries of the Merced, San Joaquin, or Kings Rivers for fishes and frogs, and recorded foothill yellow-legged frogs at 24 percent (n = 12) of the crossing points. All points at which Moyle sampled frogs during this study were downstream of Sierra National Forest lands. By the end of the 1970s, six foothill yellow-legged frog localities had been documented from the Sierra National Forest, and 14 additional foothill yellow-legged frog localities were documented from drainages downstream or outside of Sequoia National Forest lands. However, by the late 1970s, declines were evident, as foothill yellow-legged frogs had not been recorded in at least 10 historical localities for several years (Hansen 2006, Holland 2006).

1980 to present—

In the most recent analysis, Lind et al. (2003b) reported that none of the six historical localities on the Sierra National Forest have foothill yellow-legged frogs. They further reported that the only drainage confirmed to have foothill yellow-legged frogs on the Sierra National Forest is Jose Creek, a tributary of the San Joaquin River that is isolated by the presence of upper Redinger Lake at its mouth. Surveys of Jose Creek have been conducted with varying degrees of intensity since U.S. Geological Survey (USGS) personnel, under the direction of G. Fellers, confirmed a population there in 1994. Surveys have detected some adults, juveniles or tadpoles in every year between 1994 and 2003, but the maximum number of adults found was 19 in 1994, and numbers of adults in any post-1994 survey have never exceeded seven Surveys of historical sites downstream of Sierra Forest Service lands since 1995 have failed to detect foothill yellow-legged frogs (Hansen 2006). Foothill yellow-legged frogs on the Sierra National Forest appear to be rare and limited in distribution, and may be near extirpation in the region.

Sequoia and Kings Canyon National Parks

Pre-1980—

Three pre-1980 records of foothill yellow-legged frogs exist from Sequoia and Kings Canyon National Parks. All three records are for Sequoia National Park, and all three date from the 1930s; no historical records exist for Kings Canyon National Park. The oldest of these records dates from 1 July 1935, when Theodore H. Eaton, Jr. collected one foothill yellow-legged frog from the North Fork of the Kaweah River at 762 m (2,500 ft) elevation (MVZ 21820). On 5 August 1935, Eaton also collected one foothill yellow-legged frog from Alder Creek at 518 m (1,700 ft) elevation (MVZ 21817). On 7–8 August 1935, Eaton also collected five foothill yellow-legged frogs at 610 m (2,000 ft) elevation along the North Fork of the Kaweah River (MVZ 21818–21819, 25167–25169). Historical records are lacking for Sequoia National Park for the 1940s, 1950s, 1960s, and 1970s.

1980 to present—

No collections or sightings of foothill yellow-legged frogs exist from Sequoia National Park in the interval from 1980 to present.

Sequoia National Forest

Pre-1980—

Historical foothill yellow-legged frog records on Sequoia National Forest extend back 115 years, prior to the existence of either the Sequoia National Forest or the Forest Service (the latter was founded in 1905). Theodore S. Palmer, a member of the Mount Whitney Expedition, made the earliest collections of this species on 23 June 1891, when he collected two frogs along the Kern River at “Old Kernville” (USNM 18951–18952). The north arm of Isabella Lake (a reservoir), built in the interval 1948–1953, inundates this site today. On 4 July of the same year, Albert K. Fisher, another member of the Mount Whitney Expedition, collected one frog along the North Fork of the Kern River 40 km (25 mi) north of Old Kernville (USNM 18953). However, the oldest foothill yellow-legged frog records from the region come from private lands along Tejon Creek, where Henry W. Henshaw collected eight frogs in 1875 (USNM 8683, 322025–322031). Through 1900, two foothill yellow-legged frog sites were documented that ultimately (post-1905) would represent localities on the Sequoia National Forest, and one foothill yellow-legged frog locality was documented on lands that would ultimately be outside the Sequoia National Forest.

No additional collections were made on the Sequoia National Forest until nearly 20 years later, when Edwin C. Van Dyke collected one adult on 10 July 1910 in the lower Kings River Canyon (CAS 17952) in an area now inundated by Pine Flat Reservoir, which was completed in 1954. Two additional sites on the Sequoia National Forest were collected in 1911. From 11 to 19 June 1911, Walter P. Taylor and N. Stern collected 30 foothill yellow-legged frogs at or near Bodfish in the Kern River Canyon (MVZ 2965–2994); Taylor and Stern collected five additional frogs at a location 19.3 km below Bodfish over the interval 21–23 June 1911 (MVZ 2995–2999). Additionally, one locality was collected from private lands in the vicinity of the Sequoia National Forest in the 1910s; T. Storer collected one frog from Fay Creek, a tributary of the South Fork of the Kern River, on 13 July 1911 (MVZ 3011). By the end of the 1910s, five foothill yellow-legged frog localities had been documented from the Sequoia National Forest, and two additional foothill yellow-legged frog localities were documented from drainages downstream or outside of Sequoia National Forest lands.

No collections of foothill yellow-legged frogs were made on the Sequoia National Forest or adjacent private lands during the 1920s. Early on, Storer (1925) thought that a hiatus in the foothill yellow-legged frog range might exist at the southern end of the San Joaquin Valley, based on the failure to find the species in the vicinity of old Fort Tejon despite intensive collecting. As Storer was meticulous, it is difficult to believe that he was unaware of the 1875 Henshaw collections from Tejon Creek; however, if this was the case, foothill yellow-legged frogs may have been extirpated from this area at an early date. Regardless of precisely what the situation was, few historical data exist for foothill yellow-legged frog-occupied streams south of the Kern River.

Foothill yellow-legged frogs were recorded at one new locality on the Sequoia National Forest during the 1930s. On 25 November 1938, Alexander J. Calhoun collected two frogs along the Kern River, 28.9 km downstream of Hobo Hot Springs (CAS 159509, CAS-SU 6444). One new locality was also collected in the 1930s on private lands at elevations below Sequoia National Forest lands; on 9 June 1938, Joseph T. Marshall, Jr. collected one foothill yellow-legged frog along an unnamed tributary of Cottonwood Creek (MVZ 26205). Cottonwood Creek is a moderate-sized stream that independently flows into the Tulare Lake Basin (sink) on the San Joaquin Valley floor. By the end of the 1930s, six foothill yellow-legged frog localities had been documented from the Sequoia National Forest, and three additional foothill yellow-legged frog localities were documented from drainages downstream or outside of Sequoia National Forest lands.

Four localities on the Sequoia National Forest were collected during the 1940s, three of which were new. Robert R. Miller re-collected the Old Kernville locality on 27 April 1940 (UMMZ 92311); on 10 August 1940, Miller also collected a foothill yellow-legged frog along the South Fork of the Kern River 8 km east of Onyx (UMMZ 89801) and on 20 August 1940, he collected another frog from Picacho Creek in the Kern River Canyon east of Bakersfield (UMMZ 89808). Additionally, F.E. Durham collected three foothill yellow-legged frogs along the North Fork of the Kern River, 0.8 km (0.5 mi) north of the Kern County line on 24 August 1946 (LACM 1663–1665). Five additional collections were made from private lands in the 1940s. Miller also collected two frogs from Cedar Creek at a locality between 6.4 and 8.0 km (4.0 and 5.0 mi) east of Glennville on 12 August 1940 (UMMZ 89802, 139744); on the same date, he also collected two frogs from the White River, 32 km southeast of Porterville (UMMZ 89803, 139729) and two additional frogs from Deer Creek, 6.4 km below highway to Cal Hot Springs (UMMZ 89804, 139745); H. Fitch collected two frogs from Tehachapi Creek on 16 May 1947 (MVZ 44909–44910); and J. Gorman, Jr. collected two frogs from along the South Fork of the Kern River, 3.2 km east of Onyx on 4 August 1949 (MVZ 52197–52198). By the end of the 1940s, nine foothill yellow-legged frog localities had been documented from the Sequoia National Forest, and eight additional foothill yellow-legged frog localities were documented from drainages downstream or outside of Sequoia National Forest lands.

Five new localities on the Sequoia National Forest were collected during the 1950s. In the course of his work on yellow-legged frogs (Zweifel 1955), R. Zweifel collected seven foothill yellow-legged frogs on the North Fork of the Middle Fork of the Tule River, six frogs 14 km east-northeast of Springville on the road to Camp Wishon (MVZ 56596–56602) and one frog at Camp Wishon (MVZ 58171), all on

27 April 1952. On 29 April 1952, Zweifel also collected one frog on Clear Creek at Hobo Hot Springs (MVZ 56611). On the same date, Zweifel and Keith Murray collected five foothill yellow-legged frogs from Cowflat Creek in the Kern River Canyon, 32 km east-northeast of Bakersfield (MVZ 56612–56615, 58170). Then, on 26 April 1953, Zweifel collected six more frogs on Salmon Creek in the Kern River Canyon 4 km southeast of Fairview. Eleven additional records were made on private or non-Forest Service lands during the 1950s. In June 1950, Lawrence Herbst collected two foothill yellow-legged frogs at Glennville along Angel Creek (LACM 13628, 74421); Angel Creek is a tributary of Poso Creek that flows into the Tulare Lake basin on the San Joaquin Valley floor. On 27 April 1952, Keith F. Murray collected one frog along the Middle Fork of the Tule River 6.1 km east of Springville (MVZ 56609); on the same date, Murray and Zweifel collected four foothill yellow-legged frogs 8 km east-northeast of Springville (MVZ 56605–56607, 56610); and Zweifel also collected two foothill yellow-legged frogs 13.7 km (8.5 mi) northwest of Woodlake along Cottonwood Creek (MVZ 56603-56604). On 1 May 1952, Zweifel collected two foothill yellow-legged frogs 9.6 km northwest of Tehachapi (MVZ 56616–56617); on the same date, Zweifel collected seven additional foothill yellow-legged frogs 9.6 km east-southeast of Caliente; on 2 July 1952, K. Murray collected five foothill yellow-legged frogs 12.8 km east of Caliente (MVZ 59921–59925); on 7 February 1954, Robert Glaser collected eight foothill yellow-legged frogs along Canebrake Creek, 14.5 km east-northeast of Onyx; and on 11 April 1959, four foothill yellow-legged frogs were collected 6.1 km northwest of Tehachapi (LACM 16602–16605). By the end of the 1950s, 14 foothill yellow-legged frog localities had been documented from the Sequoia National Forest, and 19 additional foothill yellow-legged frog localities were documented from drainages downstream or outside of Sequoia National Forest lands.

Foothill yellow-legged frogs were recorded from two new localities on the Sequoia National Forest during the 1960s. Two frogs were taken at Fairview Camp along the North Fork of the Kern River (LACM 91148–91149), and one frog was 19.9 km east-northeast of Springville on Camp Wishon Road (LACM 91150). Two additional collections were made from private lands in the 1960s. R. Stebbins collected two localities along Caliente Creek: two frogs were collected 4.8 km west of Loraine (MVZ 81767–81768) and four more frogs were collected 7.2 km west of Loraine (MVZ 81769–81772). By the end of the 1960s, 16 foothill yellow-legged frog localities had been documented from the Sequoia National Forest, and 21 additional foothill yellow-legged frog localities were documented from drainages downstream or outside of Sequoia National Forest lands.

Only one foothill yellow-legged frog locality was collected on the Sequoia National Forest during the 1970s. On 6 December 1970, David B. Wake collected one frog along the Middle Fork of the Tule River 9.3 km (5.8 mi) northeast of Springville (MVZ 94422), and Robert Hansen (2006) stated that foothill yellow-legged frogs were extant along the North Fork of the Middle Fork of the Tule River through the mid-1970s, but were apparently extirpated by the late 1970s. In 1970, Moyle (1973) sampled 21 stream crossings of either the mainstem or tributaries of the Kaweah, Tule, or Kern Rivers for fishes and frogs, and recorded foothill yellow-legged frogs at 19 percent (n = 4) of the crossing points, two of which represented previously documented localities. All points at which Moyle sampled frogs during this study are downstream of Sequoia National Forest lands. By the end of the 1970s, 17 foothill yellow-legged frog localities had been documented from the Sequoia National Forest, and 23 additional foothill yellow-legged frog localities were documented from drainages downstream or outside of Sequoia National Forest lands. However, by the late 1970s, declines were evident, as foothill yellow-legged frogs had not been recorded in at least four historical localities for several years (Hansen 2006, Holland 2006).

1980 to present—

No collections and few sightings of foothill yellow-legged frogs exist for the Sequoia National Forest and vicinity from 1980 to the present.

In the most recent analysis, Lind et al. (2003b) stated that none of the historical localities on the Sequoia National Forest have foothill yellow-legged frogs, but only six historical localities were reported. Which of these 6 are represented among the 17 reported in the previous section or even if some do not overlap these 17 is unclear. The two most recently occupied localities on the Sequoia National Forest consist of unnamed tributaries of the North Fork Kern River, which have been given the names Ash and Jywood Creeks (Lind et al. 2003b), have each been surveyed multiple times from 1998 to 2002. Based on Lind et al. (2003b), the last foothill yellow-legged frogs reported to be seen at Ash Creek were three adult foothill yellow-legged frogs that Patrick Kleeman of the USGS found on 12 September 1998. However, because Lind et al. (2003b) reported that not all data were available from USGS surveys conducted annually at Ash and Jywood Creeks since 1997, it is unclear whether the 1998 Kleeman sightings are actually the last known. However, no frogs were observed at the Ash Creek locality during three different surveys of the site that either A. Lind and/or T. Tharalson conducted in 2002–2003, so some likelihood exists that foothill yellow-legged frogs have been extirpated from Ash Creek. In Jywood Creek, at least two adult foothill yellow-legged frogs were observed during every survey between 1998 and September 2002 (Lind et al.

2003b). In 2003, Tharalson observed two frogs in Jywood Creek for which a positive identification could not be obtained. Regardless of the precise situation, known foothill yellow-legged frogs on the Sequoia National Forest appear to be very few and limited in distribution, and may be near extirpation in the region.

Los Padres National Forest

Pre-1980—

The earliest specimen of foothill yellow-legged frog on the Los Padres National Forest was collected by Barton W. Evermann on 2 September 1914 along Sespe Canyon (CAS 39253). No other frogs were collected from the forest until the 1940s. Few records exist of foothill yellow-legged frogs collected from Los Padres National Forest during the 1940s. On 6 September 1948, Robert Sanders collected one frog within Sespe Gorge (CAS 10223). In 1949, Sanders collected four frogs along Piru Creek, 19.6 km (12.2 mi) north of Piru (CAS 10224–10227) on 7 May. On 15 June 1949, he collected two frogs along Piru Creek, 16.3 km (10.1 mi) north of Piru (CAS 10228, 11550). On 22 June, Sanders collected four frogs at Lion Canyon just above Sespe Creek (CAS 10229, 11549).

There is only one record of collection on the Los Padres National Forest during the 1960s. An unnamed individual collected one frog at Piru Creek near Frenchman Flats on 27 March 1960 (TCWC 20690). No frogs were collected during the 1970s.

Surveys in the 1970s by Samuel Sweet documented foothill yellow-legged frog declines in southern California (Sweet 1983). The last documented sighting of a foothill yellow-legged frog in southern California occured on 6 July 1977 along Piru Creek (Jennings and Hayes 1994).

1980 to present—

No collections are documented for the Los Padres National Forest from 1980 to the present.

Only two relatively recent records of foothill yellow-legged frog detections exist from Los Padres National Forest; in August 1999, tadpoles and individuals of undetermined life stage were detected along San Carpoforo Creek, a coastal tributary of Big Sur (USDA Forest Service NRIS database).

Angeles National Forest

Pre-1980—

All records of foothill yellow-legged frogs collected in the Angeles National Forest date before 1980. On 11 August 1940, John C. Marr collected four frogs from the San Gabriel River in the San Gabriel Mountains (CAS 7225–7228). On 26 June 1969, Michael C. Long collected three frogs from Bear Creek, 0.40 km (0.25 mi) north of the west fork of the San Gabriel River (CAS 199437–199439). Foothill yellow-legged frogs were historically found in Elizabeth Lake Canyon and Camp Rincon in the San Gabriel Mountains (Sweet 1983).

1980 to present—

No records of foothill yellow-legged frogs specimens collected from 1980 to the present exist.

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Appendix 4: Other Risk Factors

Airborne Contaminants Including Pesticides

The transport and deposition of pesticides from the Great Central Valley to the Sierra Nevada is well documented (Aston and Sieber 1997, Datta et al. 1998, Lenoir et al. 1999, McConnell et al. 1998) and pesticide residues have been detected in the bodies of Sierran anurans (Cory et al. 1970, Fellers et al. 2004). Pesticides currently used in the Central Valley can drift from sources to the Sierra Nevada on wind currents or storm systems (Aston and Seiber 1997, Cahill et al. 1996, Seiber et al. 1998, Zabik and Seiber 1993). Between 48 and 69 million kg (107 and 152 million lb) of pesticide active ingredient were recorded as having been used annually from 1990 to 2012 in the Central Valley; use fluctuated prior to peaking in 2005, declined through 2009, and increased once again through 2012 (CDPR 1989–2012).

Data from the Sierra Nevada implicate pesticide drift as a factor for frog declines, in general (Sparling et al. 2001), and specifically for foothill yellow-legged frogs in the Sierran portion of the species' range (Davidson et al. 2002). Sparling et al. (2001) found depressed cholinesterase activity in Pacific chorus frog tadpoles in the Sierra Nevada east of the Central Valley when compared with sites along the coast or east of the valley; cholinesterase activity is a good bioindicator of exposure to organophosphorus pesticides (Ludke et al. 1975). Davidson et al. (2002) and Davidson (2004) examined 70 historical locations for presence of foothill yellow-legged frogs and analyzed the spatial patterns of declines. Declines had a strong positive association with the amount of upwind agricultural land use; there was approximately four times as much agricultural land use upwind of sites where foothill yellow-legged frogs had disappeared compared to sites where the species was still present (Davidson et al. 2002). In Oregon, proximity to agricultural areas was negatively associated with frog presence; however, how this relates to chemical applications has not been determined (Olson and Davis 2009).

Two studies on the effects of pesticides (endosulfan, chlorpyrifos, malathion, and diazinon and their oxons) on foothill yellow-legged frogs demonstrated negative effects on tadpole growth and development and depressed cholinesterase (ChE) levels in metamorphs that survived pesticide treatments (Sparling and Fellers 2007, 2009). Delays in development can result in smaller size at metamorphosis (Hayes et al. 2006) and may increase the likelihood of tadpole mortality from predation or desiccation by drought. Pesticides in combination have been shown to induce damage to the frog thymus, which increases immunosuppression and susceptibility to disease (Hayes et al. 2006). In an experiment, newly metamorphosed foothill yellow-legged frogs exposed to the insecticide carbaryl did not increase mortality relative to controls but did reduce production of skin peptides shown to suppress growth of the often-lethal chytrid fungus, *Batrachochytrium dendrobatidis* (Davidson et al. 2007). Furthermore, exposure to a cocktail of pesticides may have lethal effects that are not observed when single pesticide applications are examined (as in Davidson et al. 2007), which may lead to gross underestimations of the role of pesticides in amphibian declines (Hayes et al. 2006).

Extent of risks related to airborne contaminants—
Currently, insufficient evidence exists to suggest that airborne contaminants are a significant threat to foothill yellow-legged frogs. The correlation between areas exposed to contamination in Sierra Nevada and foothill yellow-legged frog declines is merely suggestive.

Conservation options related to airborne contaminants—
Research is needed to further determine the level of risk airborne contaminants pose to foothill yellow-legged frogs, and possible interactions with other risk factors. The species' proximity to extensive sources of contamination merits further study to determine the risk.

Acid Deposition

Acidic deposition has affected amphibian populations in the Eastern United States and Europe (Freda 1990). Lakes and streams in the Sierra Nevada have low buffering capacity, potentially making them sensitive to increases in the acidity of precipitation (Landers et al. 1987, Melack et al. 1985). In the 1980s, Sierran lakes had limited acidity (summertime pHs of 6 to 8), but more recent precipitation samples document that acidity has increased at some sampling stations in the Sierra Nevada (e.g., at ca. 2100 m elevation near Lake Tahoe) (see Byron et al. 1991). Snow samples have also shown increased acidity (pH 5.1 to 5.9) (Laird et al. 1986).

Acidification in streams may be less likely than in still-water habitats, because biological and physical processes rapidly change stream waters (Hynes 1970); however, acid pulses at snowmelt can occur. Factors that influence the buffering capacity of streams include streamflow and source (e.g., relative contribution of snowmelt and groundwater) (Williams and Melack 1997). Williams and Melack (1997) found an inverse relationship between buffering capacity and streamflow volume. Acidification may potentially affect foothill yellow-legged frogs that occur in streams with flows large enough to flush acidifying ions (like sulfate) that have insufficient buffering, but are too low-flow to adequately dilute acidifying effects. The degree to which foothill yellow-legged frogs and their habitats are influenced by acidification has not been examined.

Sublethal, interactive effects of acidification with other factors, such as nitrates and UV-B radiation (Hatch and Blaustein 2000, Long et al. 1995) and dissolved aluminum (Bradford and Gordon 1992, Bradford et al. 1994, Freda 1991) have been observed for other amphibians. In experiments using Cascades frog tadpoles, Hatch and Blaustein (2000) found reduced survivorship at pH 5 when nitrate was added; and in one of the 2 years of experiments they also found a significant effect on survivorship between the pH-nitrate interaction at elevated levels of UV-B. Bradford and Gordon (1992) and Bradford et al. (1994) examined the tolerance of mountain yellow-legged frog and Yosemite toad embryos and tadpoles to aluminum at different acidic pHs in the laboratory and found that there were sublethal effects; there was a reduction of body size of tadpoles and earlier hatching time for embryos. Such interactions remain unstudied for foothill yellow-legged frogs.

Acid deposition does not currently seem to be a significant risk to foothill yellow-legged frogs in the Sierra Nevada, but potential impacts have not been examined. An increasing human population in California has the potential to amplify acid deposition. Furthermore, foothill yellow-legged frogs generally occur at lower elevations (see "Status" section), in areas closer to potential sources of airborne acidifying compounds.

Conservation options related to acid deposition—
At this time, acid deposition does not warrant consideration in this conservation assessment. Should the risk level for this factor increase, effective management would require coordination with agencies outside the jurisdiction of those involved in this assessment. It will be important for agencies responsible for foothill yellow-legged frog management to participate in guiding the development of management and science to inform this issue.

Disease

Since 1993, new aquatic pathogens have been observed killing amphibian species in the Sierra Nevada and worldwide (Carey et al. 1999). However, the amphibian chytrid fungus *Batrachochytrium dendrobatidis* ("chytrid") is currently of greatest concern (Longcore et al. 1999) and has been implicated in declines of many amphibians globally (e.g., Bosch et al. 2001, Lips et al. 2004, Muths et al. 2003), and in the Sierra Nevada of California (Briggs et al. 2010, Rachowicz et al. 2006, Vredenburg et al. 2010).

Chytridiomycosis has been suspected as one of the contributing factors responsible for the near extinction of foothill yellow-legged frog populations in the southern portion of their range in the Sierra Nevada, and current efforts are underway to determine how widespread chytrid may be in California populations. In an examination of chytrid prevalence in museum specimens, Padgett-Flohr and Hopkins (2009) found chrytrid prevalence in two museum specimens collected in 1966 from Santa Cruz and Alameda Counties. Chytrid has been found in some coastal California populations of foothill yellow-legged frogs (South Fork Eel River: Kupferberg 2006; Lowe 2009, Diablo range: Saulino 2006). However, evidence of mortality in the species has been limited (Kupferberg 2006, Padgett-Flohr 2006), and experimental data show that newly metamorphosed foothill yellow-legged frogs exposed to chytrid zoospores showed no difference in mortality relative to unexposed controls (Davidson et al. 2007). Foothill yellow-legged frog skin peptides appear to defend frogs from chytrid fungus infection, but exposure to the pathogen may have nonlethal effects such as decreased growth rates in juvenile frogs (Davidson et al. 2007). However, in 2013, a die-off of juvenile foothill yellow-legged frogs was observed along Alameda Creek and was attributed to an outbreak of chytrid (Kupferberg 2015). This suggests that this species is susceptible to lethal infection, particularly if other stressors such as drought conditions and nonnative species occur.

Several other pathogens including molds, bacteria, and viruses are suspected but not all confirmed to infect foothill yellow-legged frogs. *Saprolegnia ferax,* a species of water mold, has been documented to cause die-offs of eggs in Cascades frogs (*Rana cascadae*) and Western toads (*Anaxyrus* [*Bufo*] *boreas*) in Oregon (Blaustein et al. 1994b, Kiesecker and Blaustein 1997a); however, high prevalence of *S. ferax* and die-offs of eggs have not been documented for foothill yellow-legged frogs. Red-leg “disease” symptoms, caused by a freshwater bacterium, *Aeromonas pseudomonas*, were observed in a bullfrog population in Burney Creek (a tributary to Pit River) near foothill yellow-legged frog sites (Willis [N.d.]); symptoms of *Aeromonas* spp. have not been documented in foothill yellow-legged frogs. Iridoviruses caused 25 of 44 amphibian mortality events in the United States between 1996 and 2001 (Green et al. 2002). Mortality events linked to iridoviral infections involved tadpole or metamorphosing amphibians (Green et al. 2002; Knapp, 2002), but mortality in adult frogs has been reported in European ranids (Cunningham et al. 1996; Fijan et al. 1991). Ongoing iridovirus (genus *Ranavirus*) outbreaks have been observed in Sierra Nevada yellow-legged frog populations (Knapp 2002) but have not yet been documented in foothill yellow-legged frogs. Iridoviruses may move between fish and amphibians under natural conditions (Mao et al. 1999), raising the possibility that stocked fish may act as vectors for iridoviruses (see “Introduced Fishes and Other Predators”).

Technically not pathogens, trematodes are common parasites of different life stages of many anuran species and some have the ability to induce deformities. Sessions and Ruth (1990) inferred a relationship between parasitic infection and amphibian limb deformities in Pacific chorus frog populations in California. Johnson et al. (1999) also found limb abnormality correlated with the presence of the trematode *Ribeiroia ondatrae* in several California species (Pacific chorus frog, American bullfrog, and western toad). However, the frequency of limb abnormality from the presence of the *R. ondatrae* in ranid frogs is low, and has only been examined in one foothill yellow-legged frog population (Kupferberg et al. 2009a) where deformed individuals lacked trematode infection. The trematode *Gorgoderina multilobata* is known to infect foothill yellow-legged frogs (Ingles and Langston 1933), but deformities are unreported for this species.

Extent of risks related to disease—
Risk from disease, including chytridiomycosis, for foothill yellow-legged frog populations in California appears limited, but much remains unknown about the role of recently emerging diseases in foothill yellow-legged frog population declines. Lower growth rates of juveniles resulting from chytrid infection may potentially have indirect effects on their survival. The effects of interactions between pathogens and other factors (e.g., pesticide exposure) are not well understood but may have consequences such as increased susceptibility to disease.

Conservation options related to disease—
Based on current knowledge, disease does not warrant management consideration at this time. Research is needed to determine prevalence, effects of various diseases, and interactions between disease and other risk factors, to assess the degree of this risk to foothill yellow-legged frog populations. Agencies should participate in guiding the development of the management and science to further inform this issue.

Fire Management and Suppression

Fire-suppression activities that may occur in the Sierra Nevada and could affect foothill yellow-legged frogs include water drafting from streams (or sometimes ponds), water application, retardant application, construction of hand or mechanical lines, and increased human presence in fire camps within riparian zones. Fire crews and other fire personnel attempt to minimize impacts to aquatic and semiaquatic species and their habitats, but inadvertent direct impacts can occur. For example, in 1994, water was drafted for fire suppression by helicopter from a pond containing aquatic amphibians and reptiles; animals were accidentally taken up in the water bucket and subsequently rained onto the fire site when it was emptied (Holland 2005). Mechanical fuels treatments, direct burning and back burning in riparian areas, fire salvage activities, and prescribed fires in the uplands can lead to direct burning of frogs, and pile burning in riparian areas may directly trap and kill frogs.

Application of retardant has become an important wildlife issue (Pilliod et al. 2003) and some fire-suppressant cocktails have been found to be toxic or hazardous to aquatic organisms (Buhl and Hamilton 2000, Gaikowski et al. 1996, McDonald et al. 1996). In large wildfires, ammonia-based fire retardants and surfactant-based fire-suppressant foams may be dropped from air tankers or sprayed from fire engines to slow or stop the spread of fire. Fire personnel make efforts to avoid riparian areas, but accidental contamination of aquatic habitats has occurred, especially from aerial applications (Minshall and Brock 1991). Amphibians appear less sensitive to ammonia toxicity than fishes, and problems may be restricted to smaller lentic bodies of water (Pilliod et al. 2003), and may be less of a problem for foothill yellow-legged frogs.

During fire suppression, the construction of fire lines or firebreaks may be extensive and result in habitat changes similar to those associated with roads and road construction (see “Roads” section). Fire line or firebreak restoration features, such as water bars and revegetation, may mitigate erosion rates and road-like effects (Pilliod et al. 2003), but such features are not consistently implemented. Sedimentation may be the primary road-like risk of fire lining to foothill yellow-legged frogs; fine sediment may reduce refuge habitat by filling interstitial spaces in the coarse-substrate dominated streams characteristically used by foothill yellow-legged frogs (see “Ecology” section).

Prescribed fire can dramatically alter vegetation and soils and disturb foothill yellow-legged frog habitat if implemented during the time when fires would not naturally occur or with high fuel loading, which can lead to high fire intensities. However, prescribed fire can also benefit foothill yellow-legged frogs by reducing the risk of future high-intensity wildfire and preventing vegetation encroachment on stream margin habitat. Wildfire suppression policies that began early in the last century have resulted in landscape-scale habitat changes; forests have become denser, with high fuel loads, making them susceptible to catastrophic wildfires that can produce some of the most intensive and extensive changes in watershed condition of any disturbance (Kattelmann 1996). Dense forest stands also result in reduced water yields, which consequently alter peak flows and increase sediment yields in streams.

Extent of risks related to fire management—

Too few data exist on the impact of fire suppression activities on amphibians to effectively evaluate the risk to foothill yellow-legged frogs. Based on the known effects of fire suppression, the possibility exists that these activities could affect foothill yellow-legged frogs, and risk is potentially high as these frogs occur in fire-prone lower elevations.

Conservation options related to fire management—

Research is needed to inform how fire suppression and presuppression techniques may influence foothill yellow-legged frogs. Minimum-impact fire suppression and presuppression techniques may represent the best alternative for protecting foothill yellow-legged frogs and their habitat.

Livestock Grazing

The Sierra Nevada Ecosystem Project's *Final Report to Congress* (known as the SNEP Report) (Kattelmann 1996) states that livestock grazing has "affected more area in the Sierra Nevada than any other management practice." Historically, unregulated, unsustainable grazing practices existed over much of the Sierra Nevada, resulting in widespread damage to rangelands and riparian systems. Livestock numbers on federal land have decreased owing to public land management decisions and economic shifts in rural communities. Seasonal restrictions, limits on maximum annual use, riparian and streambank cover standards, and fencing have reduced grazing impacts in riparian and meadow ecosystems (USDA FS 2001).

Livestock tend to concentrate in riparian areas that contain the primary source of forage on most allotments in the Sierra Nevada (Belsky et al. 1999, Kauffman and Krueger 1984, Menke et al. 1996). The magnitude of impacts can depend on a variety of factors including riparian community type and stocking and utilization rates (Green and Kauffman 1995; Kauffman et al. 1983a, 1983b; Myers and Swanson 1991; Schulz and Leininger 1990). Both negative and positive associations between livestock grazing and amphibian populations and habitat have been found (Adams et al. 2009, Bull and Hayes 2000, Burton et al. 2009, Jansen and Healey 2003, Knutson et al. 2004, Lind et al. 2011, Roche et al. 2012). For the foothill yellow-legged frog, a retrospective study in Oregon found a negative association between grazed lands and frog occupancy (Borisenko and Hayes 1999).

All life stages of foothill yellow-legged frogs are vulnerable to trampling by livestock. Mortality risk from livestock trampling is expected to be greatest for less mobile life stages (i.e., egg masses and tadpoles), when densities are highest such as during breeding congregations, and when juveniles are metamorphosing along aquatic margins (see "Ecology" section). Trampling risk may therefore depend on the timing and duration of cattle presence in a grazing allotment.

Some concern exists regarding livestock transport of pathogens (e.g., fecal coliforms, other bacteria, *Batrachochytrium dendrobatidis* [*Bd*]) between streams, and nutrient inputs that may promote algal growth in heavily used streams and water sources (Kattelmann 1996, Stephenson and Street 1978). Potential risk of pathogen transmission exists from livestock fecal material or transport on hooves or other body parts (e.g., transport of *Bd* zoospores). No studies have investigated the link between livestock and the transmission of disease-causing pathogens. Bacteria and nutrients from feces can reach a water source by direct deposit or overland flow from upland runoff. Fecal material can accumulate in streambed sediments and be dislocated by flow changes or cattle trampling. Amount of manure and its dilution ratio may determine the degree of risk to foothill yellow-legged frogs. Streams in the foothill yellow-legged frog range may support few bacteria in their sediments in the absence of significant nutrient inputs. Increased nutrient loads from livestock excrement may cause excessive amounts of aquatic vegetation, which may overconsume oxygen.

Livestock grazing may affect habitat by altering riparian vegetation. Grazing can modify vegetation successional pathways, changing plant communities toward early-seral or disturbance-adapted species (Kauffman and Krueger 1984). Grazing has also been found to reduce overhanging vegetation along streams, simplify vertical and horizontal vegetation structure, alter individual plant phenology, and reduce herbaceous vegetation and shrub diversity, productivity, and cover (Belsky et al. 1999). Grazing and trampling of riparian vegetation can eliminate plant cover used for refuge, but could also limit woody plant establishment on river bars, which may enhance foothill yellow-legged frog breeding and rearing habitat.

Livestock grazing affects riparian area soils and associated hydrologic processes by increasing overland flow, peak flows, and flood velocity; decreasing summer and late-season flows; increasing bare ground and erosion; increasing soil compaction; decreasing soil fertility and infiltration; and reducing litter layers and organic soil inputs (Belsky et al. 1999). Modification of the soil surface influences water and sediment yields and may consequently cause changes in stream channel morphology. If alteration of the hydrologic regimes results in higher peak flows or shifts in timing of seasonal flows, there could be negative effects on foothill yellow-legged frog egg masses and tadpoles. Livestock grazing can result in widening and shallowing of the streambed channel (Kauffman and Krueger 1984), and may reduce the number of pools, forming channels with fewer meanders and unvegetated gravel bars (Belsky et al. 1999, Kauffman and Krueger 1984). Foothill yellow-legged frogs use shallow water areas along gravel/cobble bars as breeding habitat, so formation of these stream features may be a positive consequence of grazing, at least at certain grazing intensities, for this species. Stream widening may increase exposure to solar radiation and subsequently increase water temperatures. The effects of increasing water temperatures on foothill yellow-legged frog reproduction, tadpole development, and spatial distribution within river networks have recently been investigated (Catenazzi and Kupferberg 2013, Kupferberg et al. 2011a). In Sierran rivers, egg masses and tadpoles occur and can be abundant at sites where the average water temperature during the warmest 30-day period of summer reaches 24 °C (e.g., at North Fork Feather River at Poe Powerhouse, Clavey River near the confluence with Tuolumne, the most downstream breeding site of the Rubicon) (Kupferberg et al. 2011a); however, in the Eel River watershed, population densities were low along reaches that exceeded a July (2010) mean water temperature of 19 °C (Catenazzi and Kupferberg 2013).

Vegetation removal and trampling disturbance resulting from livestock activity may cause soil erosion and increased sedimentation. High sediment loads can lead to higher levels of embeddedness of streambed substrates by filling interstitial spaces, which are used by larval foothill yellow-legged frog tadpoles for instream cover. Excess sediment may reduce interstitial flow and decrease dissolved oxygen in microhabitats used by larvae. Fish reared in low-oxygen spawning gravels showed reduced rates of food consumption, growth, and survival (Belsky et al. 1999); low dissolved oxygen may have similar effects on larval foothill yellow-legged frogs. Sediment accumulation on substrates may also reduce algal growth, the primary food source of larval foothill yellow-legged frogs.

Extent of risks related to grazing—

Studies are lacking to specifically assess the risk of grazing effects on foothill yellow-legged frogs. Grazing is widespread throughout the historical range of the foothill yellow-legged frog, but its prevalence, and therefore its risk, varies. Potential risk is high because of the overlap in habitat use between livestock and foothill yellow-legged frogs; however, properly managed grazing may have neutral or even positive effects on frog habitat.

Conservation options related to grazing—

As grazing allotments are permit based, livestock grazing represents a fundamental management consideration over which national forests and national parks have jurisdiction. The type and extent of grazing allowed can directly influence the degree to which foothill yellow-legged frogs and their habitat may be affected. To minimize trampling risk, livestock could be kept away from occupied habitat to mitigate impacts during critical foothill yellow-legged frog breeding, rearing, and metamorphic seasons. However, the actual degree of risk from grazing to foothill yellow-legged frogs under current policies is unknown.

Locally Applied Pesticides

National forests in the Sierra Nevada occasionally use pesticides to control rodents, insects, and fungi, and to eliminate noxious weeds and brush. Pesticides are used in conifer plantations and private timberlands for controlling brush (Bakke 2004), throughout the national forests for controlling noxious weeds, and near buildings and other facilities. Hydropower projects also include the use of pesticides at their facilities, such as along canals and at reservoirs. Currently, nearly all herbicide application on national forests is conducted via backpack sprayers, which allows for control of the spray direction and coverage. Buffers from streams and water bodies are designated during the National Environmental Protection Act (NEPA) process for each project to facilitate protection of aquatic species from adverse effects. Buffer distances are site-specific depending on potential toxic effects of each herbicide type, the potential for them to enter the groundwater or move offsite, and the known aquatic species that could be affected downstream. The Sierra Nevada Forest Plan Amendment (USDA FS 2004) requires 500-ft (152-m) buffers from known locations of foothill yellow-legged frogs on national forest lands.

The most common pesticides used on national forests, in descending order of frequency, are glyphosate, triclopyr, clopyralid, hexazinone, aminopyralid, chlorsulfuron, imazapyr, and aluminum phosphide (for burrowing rodents). Common surfactants, which help herbicides adhere to plant surfaces, include R-11, methylated seed oil (Hasten), and methylated seed oil/silicone blend (Syl-tac). Dyes used to view recently sprayed areas include Highlight Blue, Bas-Oil Red, and Colorfast Purple.

The active ingredient in Roundup® and Rodeo®, an isopropylamine salt, has been found to be practically nontoxic to frogs (Mann and Bidwell 1999). These commercial pesticides, however, may contain (e.g., Roundup) or be combined with (e.g., Rodeo) surfactants such as polyethoxylated tallowamine (POEA), which have been shown to be toxic to aquatic life, including several species of ranid frogs (Folmar et al. 1979, Howe et al. 2004, Mann and Bidwell 1999, Mitchell et al. 1987, Servizi et al. 1987, Smith 2001, Wan et al. 1989). Surfactants may damage gills (SERA 2003a), which may be why tadpoles were found to be the most sensitive life stage to the Roundup formulation of glyphosate (Bidwell and Gorrie 1995, Mann and Bidwell 1999). High toxicity of Roundup to tadpole and postmetamorphic northern leopard frogs may be a function of POEA, but this study did not isolate the effects of glyphosate and surfactant (Relyea 2005b). Other studies (Giesy et al. 2000, Hildebrand et al. 1982, Mitchell et al. 1987, Sullivan et al. 1981, Thompson et al. 2004, Wojtaszek et al. 2004) have concluded that glyphosate-based herbicides under normal usage do not pose a hazard to aquatic environments, where both the glyphosate and surfactant would be diluted by large or flowing bodies of water or protected by a terrestrial buffer. Water quality monitoring in the Pacific Southwest Region of the Forest Service has concluded that glyphosate and triclopyr are rarely detected in surface water when these herbicides are used with stream buffers (USDA FS 2001).

Triclopyr (Garlon®) is used to control noxious weeds and approaches toxicity to African clawed frog (*Xenopus laevis*) embryos, especially in its formulation marketed as Garlon 4 (Perkins et al. 2000). Field evaluation of this herbicide suggested that it can depress growth rates in brook trout at typical application levels (Kreutzweiser et al. 1995). Garlon 3A, the amine formulation of triclopyr (triclopyr TEA), is water soluble, less volatile (Bakke 2004), and less toxic than Garlon 4 (Perkins et al. 2000) because it does not appear to penetrate tissues or bioaccumulate (SERA 2003b). Berrill et al. (1994) measured the toxicity of three chemicals, including triclopyr and hexazinone, to embryos and tadpoles of three frog species. Embryos were not affected by triclopyr, whereas tadpoles became unresponsive to prodding (reflecting avoidance response) at exposures of 1.2 ppm (or higher) and mortality occurred at higher doses (2.4 and 4.8 ppm). Tadpoles whose behavioral responses were affected recovered within 3 days. No effects on either embryos or tadpoles were observed from exposure to hexazinone.

Additive, multiplicative, or synergistic effects of herbicides with other risk factors have only recently begun to be studied among amphibians and remain unstudied in foothill yellow-legged frogs. Both Chen et al. (2004) and Edginton et al. (2004) found the Vision® formulation of glyphosate increased in toxicity to embryonic and tadpole stages of green frogs (*Lithobates* [*Rana*] *clamitans*) and northern leopard frogs at higher pH treatments (≥ 7.5). Relyea (2005b) found that high mortality of tadpoles and postmetamorphic northern leopard frogs exposed to Roundup may have been a function of relatively high pH (8.0) tap water used in the experiments. Relyea (2005a) also examined herbicide effects in a community context using outdoor mesocosms; he manipulated combinations of predators and pesticides and found that Roundup (at a level of 1.3 mg of active ingredient/L) had direct negative effects on the tadpoles, reducing total tadpole survival and biomass by 40 percent. Roundup did not have indirect effects on the amphibian community via predator survival or algal abundance.

Extent of risks related to locally applied pesticides—
Locally applied pesticides are not known to have affected foothill yellow-legged frogs, but the extent of this risk factor is likely to be limited. Data on other amphibians suggest some level of risk of various pesticides, but no data exist evaluating the threat to foothill yellow-legged frogs.

Conservation options related to locally applied pesticides—
Management should continue to regulate the application of locally applied pesticides to reduce its impact on this species. Research is needed to inform knowledge gaps regarding species-specific application-level toxicities of pesticides and how they interact with other risk factors. Agencies participating in this conservation assessment have direct jurisdiction over this activity.

Recreational Activities

Approximately 30 percent of foothill yellow-legged frog geographic range in California is on national forest lands; about 8 percent is on Bureau of Land Management, National Park Service, and other federal lands; and the remaining 60 percent lies on private lands (USDA Forest Service GIS data available 2001). The Sierra Nevada region is the backdrop for a broad range of outdoor recreation, most of which occurs on national forest and national park lands (USDA FS 2004). Recreational activities include camping, hiking, fishing, off-highway vehicle (OHV) use, packstock use, suction-dredge mining (see above in “Mining” section), mountain biking, and whitewater boating. High overlap exists between foothill yellow-legged frog habitats and areas commonly used for these activities. Foothill yellow-legged frogs inhabit streams and their near vicinities (see “Habitat Requirements” under “Ecology” section), areas that are attractive to humans and receive a disproportionate amount of recreational use through whitewater boating in streams, and trail networks and campsites in or near riparian areas (Vinson 1998). Recreational activities have the potential for significant impacts directly on foothill yellow-legged frogs and indirectly on their habitats.

The impacts of most recreational activities (e.g., hiking, bicycling, fishing, and off-highway vehicles) on foothill yellow-legged frogs have not been examined, and studies of amphibians with similar life histories are lacking. One recreational activity that has been evaluated for the species is the effect of manufactured pulsed flows, created for whitewater boating, on foothill yellow-legged frogs (GANDA 2005; Kupferberg et al. 2008, 2009b) (see “Water Development and Diversion” section). Aseasonal pulse flows, managed to accommodate whitewater boating, can have negative consequences, such as scouring or stranding early life stages of the foothill yellow-legged frog (Kupferberg et al. 2008 and studies cited therein) that may result in significant impacts on population densities (Kupferberg et al. 2012) (see “Water Development and Diversion” section).

Recreational activities may result in direct effects such as crushing, trampling, and improper handling (e.g., see Kagarise-Sherman and Morton 1993). Packstock, like livestock, have the potential to damage or destroy eggs, tadpoles, and juveniles (see Bartelt 1998). Packstock on federal lands appear to be primarily a higher elevation phenomenon; however, we currently have little information regarding their occurrence across the low-elevation range of the foothill yellow-legged frog.

Vegetation may be reduced as a result of trampling (Dale and Weaver 1974) by hikers, bicyclists, packstock, and OHVs. Low vegetation (e.g., sedges) along stream margins may be used as refuge and concealment by foothill yellow-legged frogs (see “Ecology” section). Packstock in particular apply intense downward force that can damage vegetation, compact soils, and reduce organic litter material (Weaver and Dale 1978). Terrestrial cover used by foothill yellow-legged frogs may be more important during the warmest part of the nonbreeding season, and may increase in importance with decreasing latitude (Lind, pers. obs., 2006). Establishment of trails and camps also disturbs vegetation and soil structure, resulting in changes in habitat structure and microclimate (Boyle and Samson 1985, Garton et al. 1977, Knight and Cole 1991). Heavy recreational use can mimic damage to vegetation and soils that results from grazing (Obedzinski et al. 2001). Studies in wilderness areas have found that even light-use recreation can create considerable and rapid impact, and recovery may require lengthy periods of non-use (Cole and Marion 1988). Impacts of low-intensity use of campsites include loss of vegetation cover, soil compaction resulting in slowed infiltration rates, and pronounced increases in soil pH, organic matter content, and nutrient content (Cole and Fichtler 1983).

Recreational activities may affect stream hydrology and water quality. Hydrologic effects include diversion of water, down-cutting, and lowering of water tables. Changes in hydrology that induce shallowing and warming or aseasonal drying of stream shoreline habitat may affect foothill yellow-legged frogs. Disruption of hydrology is more likely to occur in shallower systems such as those that are used for oviposition or rearing, or low-volume springs or seeps, which may be important nonbreeding season habitat for juveniles (Rombough 2006b). Localized water pollution from camp-related substances such as detergent, sunscreen and insect repellent may occur through swimming and washing, and nitrogen may be introduced into streamwater from human wastes (Rouse et al. 1999). Contact with these substances may place foothill yellow-legged frogs at risk owing to their permeable skin. Water quality may also be reduced by trampling or disturbance of streambanks by recreationists (e.g., increased sediment and nutrients).

The potential for human activity to attract certain predators is a concern that has often been considered in studies of birds (e.g., Nelson and Hamer 1995, Niehaus et al. 2004), but remains unexamined for amphibians, including foothill yellow-legged frogs. Some predators, particularly corvids, may be attracted to areas of high human use, resulting in concentrations of the predators at greater than background levels (Lawrence 1973). Whether such attraction poses a significant threat to local foothill yellow-legged frog populations is unstudied.

Extent of risks related to recreational activities—

The impacts of most recreational activities on foothill yellow-legged frogs remain unstudied. The exception is the effects of aseasonal pulsed flows for whitewater boating; risk is high for foothill yellow-legged populations located on streams that are regulated to accommodate recreational boating. In high-use areas, various recreational activities may add to cumulative impacts on already stressed small populations. Dispersed activities like hiking, fishing, camping, and mountain biking may pose a moderate localized risk to the species.

Conservation options related to recreational activities—

Research is needed to investigate the extent of impacts of recreational activities and how best to manage them. Meanwhile, management should address the potential for localized recreational impacts to foothill yellow-legged frog habitat, and should focus on mitigating probable effects. Recreational activities are within the purview of agencies participating in this assessment.

Research Activities

Researchers have the potential to negatively affect anuran populations by handling or marking animals, attracting predators, or spreading pathogens among water bodies via clothing and equipment. Researchers have studied foothill yellow-legged frogs intensively at several sites over several-year periods (Kupferberg 1996a, 1996b; Kupferberg et al. 2008; Van Wagner 1996; Wheeler and Welsh 2008; Yarnell 2000). Intensive study in these populations included marking individual animals using different methods, handling animals for measurement, and monitoring specific locations with high (daily or every few day) frequency. Incidentally, none of these studies found that research activities had any negative impact on frogs; however, they did not quantitatively assess effects.

Historically, handling and marking of animals has been viewed as innocuous, but a study addressing marking techniques (Murray and Fuller 2000) and pathogen epidemiology has forced reassessment of this view. Excluding the possibility of disease transfer, capture and noninvasive processing (e.g., measuring and weighing) of frogs is likely harmless. A review of studies involving toe-clipping to individually mark animals revealed an incremental decrease in survivorship with each additional toe clipped, where previous analyses of the same data had revealed no effect across low numbers of clips (McCarthy and Parris 2004). This analysis did not address the effects of single clips, often used to obtain samples for genetic or aging (skeletochronological) studies; the consequences of single clips, if any, remain unknown. No effects on survival or body condition have been found using passive integrative transponder (PIT) tags, but comparison to unmarked reference animals have been restricted to laboratory analyses (Perret and Joly 2002). Research activities that involve movement of researchers (e.g., wading gear, dry suits) or equipment (e.g., dip nets, gill nets) between water bodies have the potential to move pathogens. Current research protocols contain provisions (largely specific equipment cleaning procedures) to limit the spread of pathogens into and between the environments of amphibians (Padgett-Flohr et al. [N.p.]).

Research activities that involve manipulation of stream habitat may negatively affect foothill yellow-legged frogs if the habitat enhancement for the target species is unfavorable to them. For example, when the instream flow incremental methodology (IFIM) is used to conduct fish habitat studies in regulated rivers, dam operations are often manipulated to release specific discharge levels to allow for habitat mapping. When field efforts that are routine elements of hydropower relicensing studies are ill-timed, mortality to early life stages of foothill yellow-legged frogs can occur; egg masses on the Pit River were scoured from attachment substrates during a fish habitat study (Spring Rivers Ecological Sciences 2003).

Extent of risks related to research activity—
Researchers typically have their study species' best interest in mind when designing their studies, so research activity is unlikely to be a significant factor in the decline of foothill yellow-legged frogs.

Conservation options related to research activity—
When research activities in regulated rivers involve flow manipulation, precautionary timing of the artificial fluctuations in discharge should be practiced to minimize potential effects. Agencies should promote thoughtfully designed research projects and identify measures to reduce potential disease transmission.

Restoration Activities

Restoration represents a very broad class of activities that can apply to many habitat types. For foothill yellow-legged frogs, restoration activities that may have effects (negative or positive), are those that are implemented in stream and riparian corridors where breeding, rearing, or overwintering occur. Methods that are most likely to affect foothill yellow-legged frogs include restoration of flow regime in regulated river systems, and restoration of fish habitat through the improvement of fish passage structures or the addition of large wood for fish refugia.

Restoration of natural flow regimes in regulated rivers may be the single most important approach to achieve positive effects for foothill yellow-legged frog populations (see the "Water Development and Diversion" section). In regulated stream systems, managing water velocities to emulate naturally occurring flows may lower mortality of egg masses and tadpoles and increase the quality and quantity of breeding and rearing habitat. Based on the results of habitat associations studies by Yarnell (2005, 2008), restoration activities that increase the heterogeneity of aquatic and riparian habitats may benefit foothill yellow-legged frogs. Managed flow regimes in regulated rivers, however, are often reconciling multiple resource goals (e.g., channel morphology, water temperatures for cold water-associated fish species, recreation, and amphibian population and habitat), so it is difficult to sort out their effectiveness for particular species. New flow regimes are currently being implemented in regulated rivers under Federal Energy Regulatory Commission (FERC) relicensing of water projects throughout California. These changes will provide opportunities for study and assessment of the effectiveness of these regimes.

During a fish habitat improvement project, Fuller and Lind (1992) found that this restoration effort may have negatively affected foothill yellow-legged frogs. Foothill yellow-legged frogs were observed breeding (based on eggs or tadpoles) for 3 consecutive years prior to placement of a flow-deflecting structure that was designed largely as a flow refuge for small salmonids. After the placement of the structure, they found no evidence of foothill yellow-legged breeding over the next 3 years (Fuller and Lind 1992). Fuller and Lind (1992) recognized the limitations of their uncontrolled, unreplicated study but emphasized that their results highlight the fact that attention should be given to entire local faunal assemblages rather than to a single target species when implementing restorations.

Extent of risks related to restoration activities—
Effects of most restoration activities on foothill yellow-legged frogs are unstudied, but their effects are anticipated to be both spatially and temporally localized.

Moreover, the long-term benefits of most restoration projects are anticipated to outweigh any short-term negative effects associated with the restoration activity.

Conservation options related to restoration activities—
Restoration activities are within the jurisdiction of agencies participating in this assessment, largely through the planning process that individual projects must follow prior to implementation. However, systematic study of the effects of different types of restoration on foothill yellow-legged frogs is almost nonexistent and is needed to inform how to better design restoration activities. Efforts to manipulate thermal regime via flow releases from dams to decrease temperature to accommodate cold-water fish species may have unintended negative consequences for foothill yellow-legged frog recruitment.

Roads

Roads have been shown to have several negative ecological effects (Forman and Alexander 1998) on aquatic and riparian ecosystems (Trombulak and Frissell 2000) and forested landscapes (DeMaynadier and Hunter 2000). Olson and Davis (2009) found that increasing road density was negatively associated with foothill yellow-legged frog occurrence in Oregon. Every major river system draining the Pacific slope of the Sierra has either a major highway or road up the drainage. Foothill yellow-legged frogs occur primarily on national forests and private lands, which may include numerous roads. National forests generally contain many unpaved roads with lower levels of traffic than in or near urban areas, but the presence of even a few roads may affect frog habitat. Populations of foothill yellow-legged frogs occurring on private lands, which include 60 percent of the species historical range, may be most susceptible to impacts associated with roads.

The extent of the impacts of roads (presence, construction, or use) on foothill yellow-legged frogs and their habitat has not been studied, but likely depends on factors such as road density, road type, and traffic intensity. Studies have shown inverse relationships between amphibian densities with road density and traffic intensity (see Fahrig et al. 1995 and Vos and Chardon 1998). Road-related activities may cause direct mortality; mass mortalities of frogs have been documented for other species during dispersal (Fahrig et al. 1995; Hine et al. 1981; see also Trombulak and Frissell 2000). Traffic mortality can decrease population size and reduce movement between resources and conspecific populations (Carr and Fahrig 2001).

Sedimentation was identified as a factor that negatively affected foothill yellow-legged frog occupancy in Oregon (Borisenko 2000, Borisenko and Hayes 1999). Transfer of sediment (and other material) to streams is an inevitable consequence of roads and their construction (Bryer et al. 2006, Richardson et al. 1975, Spellerberg 1998). The surfaces of unpaved roads can route fine sediments to streams, increasing turbidity of the water (Reid and Dunne 1984). Road construction in Redwood National Park introduced large amounts of sediment into neighboring streams, and densities of amphibians appeared to be lower in these streams compared to nearby control streams (Welsh and Ollivier 1998). High concentrations of suspended sediment may directly kill aquatic organisms and impair aquatic productivity (Newcombe and Jensen 1996) and inhibit growth and survival of aquatic plants, macroinvertebrates, and fish (Newcombe and MacDonald 1991, Power 1990, Waters 1995). Frog egg masses may collect sediment which if excessive, may result in egg suffocation (Jennings and Hayes 1994); the effects may be intensified if the sediments contain toxic materials (Maxell and Hokit 1999). Increased sedimentation also may reduce availability of important food resources (algae) for tadpoles (Power 1990).

Vehicular emissions and road runoff contain chemical pollutants (e.g., heavy metals, salt, organic molecules, ozone, and nutrients) (Trombulak and Frissell 2000) that can reduce survival, cause deformities, elevate levels of stress hormones, and inhibit growth and metamorphosis (Lefcort et al. 1997, Mahaney 1994, Welsh and Ollivier 1998).

Roads can affect foothill yellow-legged frogs by altering stream hydrology and geomorphology. The presence of roads is highly correlated with changes in the hydrologic and geomorphic processes that shape aquatic and riparian systems (Trombulak and Frissell 2000). A study on road networks constructed for forestry land use in the Pacific Northwest showed that roads can influence peak flows (floods) and debris flows in stream channels; these processes have major influences on riparian vegetation (Jones et al. 2000) as well as aquatic and riparian patch dynamics critical to stream ecosystems (Pringle et al. 1988). The effects of flow fluctuations on foothill yellow-legged frogs have been previously discussed (see “Water Development and Diversions” section). Hydrologic effects are likely to persist as long as the road remains a physical feature altering flow routing, even long after abandonment and revegetation of the road surface (Trombulak and Frissell 2000).

Roads may fragment habitat and restrict foothill yellow-legged frog movement and migration. A study on the moor frog (*Rana arvalis*) showed that roads in a moderately fragmented habitat increased isolation, and hence contributed to fragmentation (Vos and Chardon 1998). The study also concluded that even in a relatively large and stable habitat patch, the effects of habitat fragmentation on frog populations were strongly negative (Vos and Chardon 1998). Many populations of foothill yellow-legged frogs are already small and fragmented (see "Status" section), so further effects that result from fragmented habitat may be critical. If the species operates as metapopulations (Bradford 1991), road barriers could prevent recolonization of locations where extirpations have occurred. Seasonal movements made by foothill yellow-legged frogs are associated with stream corridors (see "Ecology" section) and roads affect the physical connectivity of lotic habitats at road-stream crossings. Some of this issue is analogous to fish passage issues created by culverts, which have been structurally improved to allow fish passage (Boubée et al. 1999, Hansen et al. 2011, Price et al. 2010), but whether these efforts effectively translate to allow passage for foothill yellow-legged frogs is unknown. Culvert passage typically involves lower order streams (per Strahler 1952) and is not likely a significant issue for premetamorphic life stages because foothill yellow-legged frogs typically breed in higher order (larger) streams. Postmetamorphic life stages that use lower order streams as seasonal refuge habitat may be more likely to be affected (see "Ecology" section). Passage issues for stream-associated amphibians are rarely examined (e.g., Sagar et al. 2007) and for foothill yellow-legged frogs remain unstudied.

Extent of risks related to roads—
The substantial road matrix within the Sierran range of foothill yellow-legged frogs and their proximity to stream habitats used by foothill yellow-legged frogs suggest that roads are a potentially significant risk. This is supported by the existing science on the direct and indirect negative effects of roads on other amphibian and aquatic species. Hence, some risks from roads are likely, but no data exist on the specific impacts of roads on foothill yellow-legged frogs.

Conservation options related to roads—
Through their jurisdiction over road development and maintenance, and patterns of road use, agencies participating in this conservation assessment can have a significant influence over how roads may affect foothill yellow-legged frogs. However, significant science is needed to inform precisely how road-related management can be best implemented to minimize negative effects to foothill yellow-legged frogs.

UV-B Radiation

Increases in mid-range ultraviolet radiation (UV-B; 290 to 320 nanometers) resulting from depletion of atmospheric ozone are hypothesized to contribute to amphibian declines, a pattern consistent with their apparent global nature (Blaustein and Wake 1990, Wake 1991). Experimental and field studies addressing UV-B are controversial and have produced mixed results (Licht and Grant 1997); effects of increased UV-B on amphibian growth and survivorship appear to vary across conditions (e.g., species, life stages, habitats, and conditions such as dissolved organic content of water), making it difficult to assess the role of this risk factor in declines (Licht 2003, Palen et al. 2005). Differences in responses among species have been attributed in part to differences in the behavioral, physiological, and molecular defenses these amphibians possess against UV-B (Blaustein and Belden 2003).

Much of the research on UV-B effects on amphibians has involved experiments examining the vulnerability of the eggs and embryos of several western North America species. Exposure to elevated UV-B resulted in reduced hatching success, reduced tadpole growth rates, or sometimes increased physical abnormalities in Cascades frogs and western toads (Blaustein et al. 1994a), long-toed salamanders (Belden et al. 2000), and California newts (*Taricha torosa*) (Anzalone et al. 1998). No effects were observed on Pacific treefrogs (Anzalone et al. 1998, Blaustein et al. 1994a, Ovaska et al. 1997), Columbia spotted frogs or Oregon spotted frogs (Blaustein et al. 1998), northern red-legged frogs (Blaustein et al. 1996, Ovaska et al. 1997), or western toads (Corn 1998). Experiments revealed that foothill yellow-legged frog embryos also lacked sensitivity to UV-B (Neumann 1997). UV-B exposure may have sublethal effects; Belden and Blaustein (2002) found depressed growth rates in red-legged frog embryos and tadpoles, and Fite et al. (1998) observed retinal damage in Cascades frog adults.

Several studies have demonstrated that UV-B effects are more likely in combination with another stressor. Long et al. (1995) found that embryos of northern leopard frogs exposed to levels of UV-B and low pH, that were nonlethal when each was individually applied, produced significant mortality when the two stressors were applied simultaneously. A similar synergism between UV-B and low pH was observed for common frog, *Rana temporaria*, embryos (Pahkala et al. 2002). Kiesecker and Blaustein (1995) found that boreal toad and Cascades frog embryos exposed to UV-B had higher mortality caused by the pathogenic water mold *Saprolegnia ferax* compared to embryos subjected to each treatment alone.

Environmental information suggests that habitat conditions for large geographic areas in western North America limit UV-B exposure (Licht 1996, 2003). Dissolved organic material (DOM) or dissolved organic carbon (DOC) can absorb UV-B (Morris et al. 1995, Scully and Lean 1994) and reduce it to levels below those that Blaustein et al. (1994a) found to affect embryos (Palen et al. 2002). The distribution of amphibians may also be influenced by site-specific UV-B levels (Adams et al. 2001, Nagl and Hofer 1997). UV-B transmission in lotic habitats occupied by foothill yellow-legged frogs is likely to be lower than in lentic habitats owing to a combination of turbulence and small suspended particulates that attach to egg masses (Kupferberg 2006).

There has not been a severe increase in UV-B levels at high elevations in the Sierra Nevada (≤ 5 percent) over the past several decades (Jennings 1996), suggesting that UV-B has not contributed directly to the decline of foothill yellow-legged frogs, especially in lower elevation areas that are more insulated from UV-B. Davidson et al. (2002) examined the spatial pattern of declines in foothill yellow-legged frogs to determine if these patterns could be explained by a UV-B effect (e.g., an increase in declines at higher elevations and lower latitudes, coincident with altitudinal and latitudinal patterns of increased UV-B); they found no significant pattern of change in occupancy with elevation. However, UV-B levels may still be increasing (Middleton et al. 2001) so continued monitoring may be important.

Extent of risks related to UV-B radiation—
Increased UV-B radiation does not appear to be a primary factor in the rangewide decline of foothill yellow-legged frogs. However, the relationship between UV-B, other stressors, and foothill yellow-legged frog declines is unstudied, so UV-B has the potential to contribute to declines in ways that remain unidentified. As levels of ambient UV-B appear to be on the increase (Middleton et al. 2001), the effects of increased UV-B on foothill yellow-legged frogs may occur at some threshold level that becomes manifest in the future.

Conservation options related to UV-B radiation—
At this time, UV-B radiation does not warrant management consideration. Should the risk level for this factor increase, effective management would require coordination of agencies outside the jurisdiction of those involved in this assessment. Agencies responsible for foothill yellow-legged frog management should participate in guiding the development of the management and science to inform this issue.

Vegetation and Fuels Management

Vegetation and fuels management encompasses management activities that alter vegetation structure and composition, which includes timber harvest, thinning, fuels management, salvage logging, and prescribed fire. Changes in vegetation, shade, and woody debris can alter habitat quality. Modification of vegetation can also influence soil stability, erosion, and sediment loading to aquatic habitats. These activities can pose a risk to foothill yellow-legged frogs in areas of their range where such activities are permitted.

Prescribed fire is one method of fuel reduction in the United States, although the effects of such controlled burns on fauna, including foothill yellow-legged frogs, are poorly understood (Pilliod et al. 2003). Prescribed fire may benefit foothill yellow-legged frogs by reducing the risk of future high-intensity wildfire; however, these controlled fires could also damage foothill yellow-legged frog habitat if not properly implemented. Prescribed fire can greatly alter vegetation and soils and may disturb frogs if applied when fires would not naturally occur and at high fuel loads that lead to high fire intensities. A large part of the foothill yellow-legged frog range is on granitic soils where erosion rates on such soils have been shown to be 66 times higher in burned areas than on undisturbed watersheds, and burning may elevate annual sediment yields for 10 years or more (Megahan et al. 1995).

Historical timber harvesting lacked standards and guidelines to provide protection for riparian areas or stream-associated fauna. Present-day practices limit harvest from riparian management zones, but erosion and sedimentation resulting from timber harvest activities may affect foothill yellow-legged frogs. Ashton et al. (2006) suggest that sedimentation can be a significant problem for foothill yellow-legged frogs in some streams, and deserves management attention. Issues related to increased sedimentation were addressed in other risk factor sections (see “Livestock Grazing” and “Roads” sections).

Extent of risks related to vegetation management—
Based on the known effects of vegetation and fuel management activities in stream ecosystems, these activities could affect foothill yellow-legged frogs; however, there is currently no species-specific data to substantiate any effects. Current practices may limit effects, but this needs to be evaluated with studies on species-specific population and habitat changes and responses.

Conservation options related to vegetation management—
Vegetation and fuels management are major activities that are directly within the jurisdiction of agencies participating in this conservation assessment. Research is needed to inform how vegetation and fuels management may affect foothill yellow-legged frogs and their habitat, including where these activities may amplify or reduce the effects of other risk factors.

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