Scientific Name:

Rana boylii

Common Name:

Foothill Yellow-legged Frog

G Rank:

G3

IUCN Red List:

Near Threatened

NATURAL HISTORY, BIOLOGY, AND STATUS

Range:

The range of the foothill yellow-legged frog includes Pacific drainages from the upper reaches of the Willamette River system, Oregon, south to the Upper San Gabriel River, Los Angeles County, California (NatureServe 2011). Two specimens were collected in 1965 in Baja California, Mexico (Loomis 1965) but subsequent searches have not detected the species in that area (Welsh 1988, Hollingsworth 2000, Grismer 2002, Stebbins 2003).

The species has disappeared from many portions of its historical range, especially in southern California, where it has been extirpated from Santa Barbara County to San Diego County (see Hayes and Jennings 1988, Jennings 1995), and has not been seen in or south of the Transverse Ranges since 1977 despite repeated searches (Sweet 1983, Jennings and Hayes 1994).

Habitat:

This species inhabits partially shaded, rocky perennial streams and rivers at low to moderate elevations, in areas of chaparral, open woodland, and forest, rivers in a variety of habitats including riparian, mixed conifer, and wet meadow types (Nussbaum et al. 1983, Stebbins 1985, Hayes and Jennings 1988). Feller (2005) describes the specific habitat needs as follows:

> Foothill yellow-legged frogs are primarily stream dwelling. Stebbins (1985) describes foothill yellow-legged frogs as stream or river frogs found mostly near water with rocky substrate, often found in or near riffles, and on open, sunny banks. Other authors have expanded this description, and/or offer variations (e.g. Storer 1925; Fitch 1938; Zweifel 1955; Hayes and Jennings 1988; Kupferberg 1996a; Lind et al. 1996; Van Wagner 1996). Although streams and rivers with year-round water are generally required, streams inhabited by the species in Oregon may dry to a series of potholes connected by trickles in the summer (Csuti et al. 2001). Critical habitat (i.e., habitat suitable for egg laying) is defined by Jennings and Hayes (1994a) as a stream with riffles containing cobble-sized (7.5 cm diameter) or larger rocks as substrate, which can be used as egg laying sites. These streams are generally small to mid sized with some shallow, flowing water (Jennings, 1988). Fuller and Lind (1992) observed subadults on partly shaded (20%) pebble/cobble river bars near riffles and pools.

Less typical streams lack a rocky, cobble substrate (Fitch 1938). Other types of riparian habitats include isolated pools and vegetated backwaters (Hayes and Jennings 1988, Ashton et al. 1998).

Biology and Taxonomy:

The foothill yellow-legged frog breeds from the latter part of March to the first of May (AmphibiaWeb 2012). Females oviposit eggs in shallow water toward the margin of streams, attached to sides of stones in the stream bed (AmphibiaWeb 2012). Eggs are laid in clusters (Wright and Wright 1949). Ashton et al. (1997) summarizes additional information on the natural history of the foothill yellow-legged frog. A more recent account but less detailed account is provided by Morey (2007).

Rana boylii was named after Dr. Charles Elisha Boyle, a California “49er” that collected the type specimens in 1850 (Jennings 1987). The foothill yellow legged frog was first described as a species by Baird (1854). A half-century of taxonomic uncertainty followed with several name changes (Zweifel 1968). Since 1955, the foothill yellow-legged frog has been recognized as a distinct species in the family Ranidae (Zweifel 1955, Collins 1990).

In a broad geographic survey of genetic data of extant foot hill yellow-legged frog populations, Lind (2005, pp. 89-90) found individuals from four clades that showed substantial genetic divergence from the rest of the samples. These divergent clades were all at the extremes of the north-south range of the foothill yellow-legged frog. (See Lind 2005 p. 106, Fig. 3.1 map). Lind states unequivocally that the populations in the southern portions of the foothill yellow-legged frog range “are quite divergent from the rest of the species and deserve special conservation focus" (Lind 2005, p.98.). Lind et al. (2011) conducted phylogenetic and population genetic analyses and sampled the ecological and distributional limits of the foothill yellow-legged frog to characterize mitochondrial DNA (mtDNA) variation in 77 frogs from 34 localities. Lind et al. (2011) evaluated 1525 base pairs and found several moderately supported, geographically-cohesive mtDNA clades for the foothill yellow-legged frog. Samples from localities at the edges of the foothill yellow-legged frog geographic range demonstrated substantial genetic divergence from each other and from more central populations. Foothill yellow-legged frog populations at the northern limit of the species in central Oregon and southern populations on both the Sierrian and coast range sides of the Central Valley are divergent from the rest of the species.

Population Status:

The foothill yellow-legged frog qualifies for endangered species status because it is experiencing range-wide population declines due to habitat loss from dams and other threats (U.S. Forest Service 2011). The area of occupancy, number of subpopulations, and habitat quality have also declined throughout its range (NatureServe 2011). Lind (2005) found that just under 50 percent of known localities still had foothill yellow-legged frog populations. AmphibiaWeb (2012) explains that there have been "notable declines in southern California and the west slope drainages of the Sierra Nevada and southern Cascade Mountains (Lind et. al. 1996)" and that it is threatened by construction of dams and predation by bullfrogs. The IUCN Red List ranks the species as Near Threatened but explains that it is close to qualifying for Vulnerable (Santos-Barrera et al. 2004). The species was a candidate for federal protection until the FWS eliminated the C2 category, but it currently receives no federal protection under the ESA.

Jennings and Hayes (1994) comprehensively evaluated the status in California: they reviewed all available reports, surveys, and CDFG files and data, conducted field reconnaissance from 1988-1991, and searched museum specimens and field notes of naturalists as well as relied on their 25 years of field experience for historical locations. Jennings and Hayes (1994) found that the species had disappeared from 45 percent of its historic range in California, about 66 percent of its historic range in the Sierra Nevada, and 24 percent of historical sites in the north coast (Jennings and Hayes 1994). And Fellers (2005) found that only 30 of the 213 sites in California with foothill yellow-legged frogs had populations estimated to be 20 or more adult frogs. Indeed, a large decline has occurred in southern California (Sweet 1983, Jennings and Hayes 1994). This species has probably been extirpated from the Tehachapi Mountains southward and the southern Sierra Nevada (Drost and Fellers 1996). There have also been severe declines in the central Sierra foothills (Moyle 1973, Drost and Fellers 1996). It is still present but nowhere abundant in coastal California from Monterey County southward to northwestern San Luis Obispo County (NatureServe 2011), and in the greater San Francisco Bay Area. In view of these trends, Jennings and Hayes (1994) recommended endangered status in southern and central California south of the Salinas River, Monterey County, and threatened status in the "west slope drainages of the Sierra Nevada and southern Cascade Mountains east of the Sacramento-San Joaquin River axis."

Although formerly regarded as at least locally abundant in southwestern Oregon (Fitch 1936, 1938), it is now rare or absent through the entire western half of the Oregon range (Fellers 2005). This frog has disappeared from more than 55 percent of historical locations in Oregon and is presumed extirpated from most of the northern and far eastern portions of the range in Oregon (Leonard et al. 1993, Borisenko and Hayes 1999, Csuti et al. 2001, Jones et al. 2005).

The species is most likely now extirpated from Mexico (Welsh 1988, Hollingsworth 2000, Santos-Barrera et al. 2004).

THREATS

NatureServe (2011) summarizes the threats to the foothill yellow-legged frog, which include stream scouring (negatively impacts frogs in streambed hibernation sites), stabilization of historically fluctuating stream flows as a result of dam construction, introduced incompatible aquatic animals, riverine and riparian impacts of non-selective logging practices, and other habitat degradation and disturbance caused by livestock grazing and in-stream mining. A detailed examination of the threats faced by foothill yellow-legged frogs is provided by Olson and Davis (2009).

Habitat alteration and destruction:

Dams

Lind (2005) found that former yellow-legged frog localities throughout California where frogs are now extirpated were characterized by higher numbers of all dams upstream, greater number of very large dams upstream, greater maximum height of dams upstream and closer proximity to upstream dams. On the main stem of the Trinity River, northern California, unnatural flow regimes and loss of habitat caused by dam construction are the greatest threats (Ashton et al. 1997). Potential breeding habitat was reduced by 94 percent after dam construction (Lind et al. 1996). Controlled flows allowed encroachment of riparian vegetation and retarded cobble/gravel bar formation. Since dam construction water releases have been reduced to 10-30 percent of pre-dam flows, based on both total yearly volume and magnitude of periodic high flows (Lind et al. 1996). High aseasonal flow releases from dams in late spring sometimes result in scouring of egg masses, whereas receding high flows, if poorly timed, can leave egg masses stranded “high and dry” (Lind et al. 1996). Bobzien and DiDonato (2007) concluded from frog breeding surveys in Alameda Creek in Alameda County, California, that unnatural and consistently higher discharge and irregular flows associated with dam releases appears to be a major factor in poor reproductive conditions for the frog, when compared to stream reaches with natural hydrology.

Mount et al. (2006), based on review of the literature and FERC-related reports, found foothill yellow-legged frog egg masses are negatively affected by pulsed flows (large magnitude flow fluctuations in rivers with dams) via scouring if flows occur during or after oviposition and desiccation if oviposition occurs during high flows and subsequently drops. Tadpole stranding and potential negative effects on metamorphs have been documented in multiple studies. South Fork Eel River population monitoring shows that the magnitude and timing of spring pulse flows are key factors in survival of eggs and tadpoles. While large magnitude spring pulses decrease egg survival, smaller pulses later in the spring cause even higher mortality. Fluctuations in population growth are associated with spring pulse events three years prior. Experiments suggest that during pulse flows tadpoles seek refuge from higher velocities in the substrate, but many are swept downstream. Tadpoles confined to refugia face energetic costs in terms of growth and development. Kupferberg et al. (2011) explored the effects of pulsed flows from dams on foothill yellow-legged frog tadpoles, and found that typical velocity increases in near shore habitats (provided for recreational flows for white water boating or peaking releases for hydroelectric power generation) caused tadpoles approaching metamorphosis to be displaced, and that tadpoles exposed to repeated sub-critical velocity stress grew significantly less and experienced greater predation than tadpoles reared at ambient velocities.

Dams not only eliminate habitat and cause local extirpations, and they also interfere with normal dispersal and movements, which can impede recolonization after local extirpations (Fellers 2005, Peek 2010). Kupferberg et al. (2009b) found that water control management that avoids aseasonal flow fluctuations would benefit foothill yellow-legged frogs, and other taxa, whose lifecycles are synchronous with the natural timing of runoff in California's rivers. Most recently, Kupferberg et al. (2012) found that the foothill yellow-legged fro is more likely to be absent downstream of large dams than in free-flowing rivers, and breeding populations are on average 5 times smaller in regulated rivers than in unregulated rivers.

Logging

Timber harvest decreases populations of aquatic amphibians like the foothill yellow-legged frog by increasing water temperatures to lethal levels and by causing siltation of streambeds (Corn and Bury 1989). High levels of silt inhibit the attachment of frog egg masses to the substrate (Applegarth 1994, Ashton et al. 1997), and excessive accumulation of silt on the egg masses likely has adverse effects on embryo development (Jennings and Hayes 1994). Silt also reduces the interstitial spaces available for use by tadpoles, reduces algal growth on which the tadpoles feed (Power 1990), and can have a significant negative impact on adult frog food resources (e.g., aquatic macro-invertebrates; Petts 1984). Sediment impacts likely adversely affect preferred foothill yellow-legged frog habitat through bed aggradation, surface texture fining or changes in hydraulic geometry (Yarnell 2000).

Livestock Grazing

Livestock grazing likely results in bank erosion, degrading shorelines and increasing stream sedimentation (Davis and Olson 2009). These effects could directly impact instream habitats for frogs. The Sierra Nevada Ecosystem Project, an assessment of the Sierra Nevada ecoregion, concluded that more open vegetation resulting from overgrazing can expose amphibians to predation and desiccation, and direct trampling by livestock is likely an important cause of amphibian mortality (SNEP 1996). Borisenko and Hayes (1999) found locations with frogs had significantly less grazing than locations without frogs. They reported grazing or agricultural concerns for the Coos, Hooskanadan, Pistol and Rogue Rivers. Masters (1997b) described the negative impacts of cattle grazing on habitat used by foothill yellow-legged frogs in Jackson Creek, in the Umpqua National Forest, Oregon:

> Direct impacts of cattle in riparian areas include crushing eggs and tadpoles of foothill yellow-legged frogs, as well as juveniles and adults…Indirect impacts include alteration and/or elimination of vegetation, alteration of the microhabitat

> conditions, degradation of water quality, alteration of the structure and composition of the vegetation, and introduction of non-native vegetative species…Increased sedimentation covers up the cobble-sized rocks that the foothill yellow-legged frog requires for breeding, tadpole development, and juvenile and adult habitat. The cowpies and urine degrade the water quality…sedimentation, resulting from cattle grazing…reduces the interstital spaces available for use by tadpoles and it may inhibit attachment of egg masses.

Mining

Ashton et al. (1997) explained that mining can have deleterious effects on egg masses and tadpoles, as well as disturbing postmetamorphic behavior patterns. In southwestern Oregon, suction-dredging/placer-mining is an extensive historic in-stream activity, allowed by the 1872 Mining Act (Olson and Davis 2009). In Josephine County, Oregon, there are 1600 mining permits on U.S. Forest Service land (D. Clayton, pers. commun., as cited in Olson and Davis 2009). Yet the actual extent of mining across the frog's range in Oregon is unknown, and much is uncontrolled (Olson and Davis 2009).

Gravel extractions are another type of mining to be considered. Stream substrates are removed, processed and relocated during the mining procedures, and all life history stages of foothill yellow-legged frogs would be at risk of direct mortality if such mining occurred at occupied sites (Olson and Davis 2009). The tailings of abandoned mines often have contaminants, such as mercury used to historically extract gold as would settling ponds (Olson and Davis 2009). Mining activities likely contributed to the extirpation of the yellow-legged frog population from Baja (Welsh 1988).

Roads and Urbanization

Roads and urbanization are logical potential threats to this frog (Davis and Olson 2009). The human population continues to increase within its range and this results in continued expansion of urban and agricultural areas and construction of new roads. Road construction crossing streams likely adversely affects frogs due to sedimentation during road building, maintenance or failures. As explained above, sediments can embed stream substrates and removes interstitial spaces used by these frogs. The use of culverts that do not easily pass frogs also impacts population connectivity. Proximity to cities and increasing road density were negatively associated with frog occurrence in the initial threat assessment for Oregon conducted by Olson and Davis (2009). Lind (2006) similarly found that foothill yellow-legged frog presence was associated with less urban development nearby, using data from both Oregon and California.

Recreation

There are potential threats related to recreation (Olson and Davis 2009). Jet boats create waves that could potentially result in dislodgement and loss of egg masses, stranding of tadpoles, disruption of adult basking behavior, and erosion of shorelines (Borisenko and Hayes 1999). Borisenko and Hayes (1999) reported jet boats passing every five minutes with wakes up to a meter high breaking on shore in the lower Rogue River, and no frogs in that area. They also reported recreation concerns for the Chetco River. Vehicles driven along stream gravel bars and recreationists fishing, swimming, walking or camping along shores likely adversely affects frogs, including disruption of frog basking opportunities (Borisenko and Hayes 1999). Damage to montane stream habitat from off-road vehicles is credited as a partial cause of the extirpation of the foothill yellow-legged frog from some southern California coastal streams (Sweet 1983). Off-road vehicle activity also likely eliminated a frog population from Corral Hollow in San Joaquin County. M.R. Jennings documented motorcycle use in riparian zones that crushed juvenile and adult foothill yellow-legged frogs (SNEP 1996).

Disease or predation:

Chytrid fungus has been found in this species, but its population effects are unknown (Fellers 2005). Chytrid fungus was found in foothill yellow-legged frogs and Pacific treefrogs in 10 of 12 sites sampled in the Diablo Mountains, San Benito County, and western San Joaquin foothills, Fresno County, California, in 2006 (Lowe 2007). In laboratory experiments, Davidson et al. (2007) found that chytrid infection reduced growth of newly metamorphosed foothill yellow-legged frogs by approximately one-half and that exposure to the pesticide carbaryl likely increases susceptibility to chytrid infection.

In the main stem of the Trinity River, there is evidence of fungal infections of amphibian egg masses, possibly *Saprolegnia* sp. (Blaustein et al. 1994, Kiesecker and Blaustein 1997). Fungal infection has been observed on foothill yellow-legged frog egg masses (Ashton et al. 1997).

Known from related species are the bacterial disease "red leg" (*Aeromonas hydrophila*) (e.g., *Rana muscosa*, Bradford 1991) and iridoviruses (*Ranavirus* species), which are a complex of viruses found in frogs and fish (Mao et al. 1999).

Inadequacy of existing regulatory mechanisms:

The foothill yellow-legged frog is considered "vulnerable" in Oregon (Olson and Davis 2009), and it is a California Species of Special Concern. But the frog is not state protected in either state and therefore receives no formal protection.

The frog is a U.S. Forest Service sensitive species on national forests in Oregon and California and on BLM land in Oregon (Olson and Davis 2009). But sensitive species designations afford little protection, requiring only that the impacts be considered but not preventing actions that would harm the boreal toad. Thus, the Forest Service or the BLM can conclude in a Biological Evaluation that individuals or populations will be harmed or destroyed by an action, but still carry out this action.

Some populations of this species occur in national forests in California and Oregon. Specifically, Since 1990, foothill yellow-legged frogs have been observed at 24 localities (= populations) on the three Southern Sierra Nevada National Forests: 21 on the Stanislaus, one on the Sierra, and two on the Sequoia (Lind 2003). It also occurs in a few national, regional and state parks, and on properties owned by The Nature Conservancy. But these protected lands do not provide adequate protection from threats such as pesticides or nonnative predators.

Conservation of foothill yellow-legged frogs may be enhanced by maintaining or restoring channels with shapes that provide stable breeding sites over a range of river stages (Kupferberg 1996, Yarnell 2005). New breeding habitat can be created; populations have responded to "bank feathering" restoration projects within one year of construction (Lind et al. 1996). Reintroduction at unoccupied historic sites should also be considered (Lind and Shaffer 2005). But without a federal recovery plan or other mandatory efforts to restore habitat, such methods are unlikely to be utilized.

Other factors:

Climate Change and UV-Radiation

Climate change and UV-B radiation appear to be contributing factors in the decline of this species (Fellers 2005, Olson and Davis 2009). Davidson et al. (2002) examined the spatial patterns of declining frogs in California and hypotheses of spatial patterns of ultraviolet radiation effects and climate change. For foothill yellow-legged frogs, they found a north-to-south gradient of increasing frog losses, consistent with climate change hypotheses (more losses at drier sites to the south), but increasing frog declines at lower elevations, which was at odds with the UV-B hypothesis. Lind (2005) considered climate change as a potential threat to foothill yellow-legged frog, due to precipitation being associated with frog presence.

Kupferberg et al. (2009a) presented data supporting a link between periods of unusually warm summer water temperatures during 2006 and 2008 in a northern California river, outbreaks of the parasitic copepod *Lernaea cyprinacea*, and malformations in tadpoles and young of the year foothill yellow-legged frogs.

Pollution

According to Fellers (2005), in the Sierra Nevada foothills of California, air-borne pesticides (that move east on the prevailing winds blowing across the highly agriculturalized Central Valley) are likely to be the primary threat to foothill yellow-legged frogs (LeNoir et al. 1999, Sparling et al. 2001, Hayes et al. 2002b, Sparling and Fellers 2007, Sparling and Fellers 2008). It is unknown whether pesticides are contributing to the decline of foothill yellow-legged frogs in Oregon (especially east of the agricultural parts of the Willamette Valley), but it should be examined (Fellers 2005). The populations of foothill yellow-legged frogs in greatest decline are all downwind of highly impacted (mostly agriculturalized) areas, while the largest, most robust frog populations are along the Pacific coast (Fellers 2005).

Davidson et al. (2002) found evidence that airborne agrochemicals have played a significant role in the decline of the species. Davidson (2004) examined the association between the spatial patterns of declines for five California amphibian species and historical patterns of pesticide use in California from 1974 to 1991, and found that historical pesticide use was a strong, significant variable in population declines for the foothill yellow-legged frog, especially so for organophosphates and carbamates. In particular, they found that sublethal exposure to the pesticide carbaryl likely inhibits the innate immune defense of foothill yellow-legged frogs and increase susceptibility to disease. Sparling and Fellers (2007) found that environmental concentrations of the pesticides chlorpyrifos, malathion and diazinon and their oxons can be harmful to populations of the frog. Sparling and Fellers (2009) established the chronic toxicity of chlorpyrifos and endosulfan, two of the insecticides most commonly used in the Central Valley and found in the mountains, which likely contributes to observed declines in the frog. Kerby (2007) examined the sublethal effects of four pesticides on foothill yellow-legged frogs and found significant alteration of behavior and development.

Ashton et al. (1997) mentioned the potential for spills of toxic materials into streams along roads along the Trinity River in northern California. Bury (1972) found that spilled diesel fuel had negative impacts on foothill yellow-legged frog tadpoles and partially transformed individuals but apparently little impact on adults.

Mercury contamination is another threat to the frog. Hothem et al. (2010) found mercury concentrations in the foothill yellow-legged frog that were high enough to pose a potential hazard to human or wildlife consumption, with the total Hg concentration exceeding the FDA criterion (1.0 μg/g) for regulation of commercial fish in at least one sample at 24 percent of the yellow-legged frog sites, with 13 of the sites (62 percent) exceeding the EPA Hg criterion (0.3 μg/g) for issuance of health advisories for fish consumption. Research shows that mercury likely adversely affects amphibian development and can decrease survival through metamorphosis (Unrine et al. 2004). Other effects can include impaired reproduction, growth inhibition, behavioral modification, and various sublethal effects (Zillioux et al. 1993).

<u>Exotic Species</u>

A host of vertebrates and perhaps some aquatic invertebrates feed on foothill yellow-legged frogs (Fellers 2005), but it is the nonnative predators that are threatening the species. It is well documented that adults, larvae, and/or eggs are vulnerable to an array of non-native predators such as predatory fishes, bullfrogs, and crayfish (Moyle 1973, Lind et al. 1996, Kupferberg 1996, Ashton et al. 1997, Lind et al. 2003, Fellers 2005, Paoletti 2009, Paoletti et al. 2011). Rombough et al. (2005) found that foothill yellow-legged frog abundance and production was inversely related to abundance of smallmouth bass (*Micropterus dolomieu*) and American bullfrogs (*R. catesbeiana*). Predation by feral pigs is a concern in some locations (Ely 1993, 1994).

Dam-controlled flows and lack of winter flooding likely results in stable pool areas with established aquatic vegetation (Lind et al. 1996, Kupferberg 1996), and this can increase suitable habitat for exotic species such as bullfrogs (Ashton et al. 1997). Decreased flows can force frogs into permanent pools where they are more susceptible to predation (Hayes and Jennings 1988).

Kupferberg (1997) found that bullfrog larvae perturbed aquatic community structure and exerted detrimental effects on foothill yellow-legged frog populations in northern California. Interspecific matings between male foothill yellow-legged frog and female bullfrogs have been observed; these interactions with non-native bullfrogs might reduce the reproductive output of foothill yellow-legged frogs (Lind et al. 2003).

References:

Airola, D. A. 1980. California wildlife habitat relationships program – northeast interior zone. Volume II – reptiles and amphibians.

AmphibiaWeb: Information on amphibian biology and conservation. [web application]. 2012. Berkeley, California: AmphibiaWeb, *available at*: http://amphibiaweb.org/ (last visted June 20, 2012).

Applegarth, J. S. 1994. Special status amphibians and reptiles of the Eugene District: A guide for their conservation. Division of Resources, Eugene District Office, U. S. Bureau of Land Management, Eugene, Oregon.

Ashton, D. T., A. J. Lind, and K. E. Schlick. 1998. *Rana boylii* – foothill yellow-legged frog. Natural history review. USDA Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, California.

Baird, S. F. 1854. Descriptions of new genera and species of North American frogs. Proceedings of the Academy of Natural Sciences of Philadelphia 7(2): 59-62.

Blaustein, A. R., D. G. Hokit, R. K. O'Hara, and R. A. Holt. 1994b. Pathogenic fungus contributes to amphibian losses in the Pacific Northwest. Biological Conservation 67(3): 251-254.

Bobzien, S. and J. E. DiDonato. 2007. The Status of the California Tiger Salamander (*Ambystoma californiense*), California Red-Legged Frog (*Rana draytonii*), Foothill Yellow-Legged Frog (*Rana boylii*), and Other Aquatic Herpetofauna in the East Bay Regional Park District, California. East Bay Regional Park District.

Borisenko A.N. and M.P. Hayes. 1999. Status of the foothill yellow-legged frog (Rana boylii) in Oregon. Final Report to The Nature Conservancy under contract to the US Fish and Wildlife Service with assistance from the Oregon Department of Fish and Wildlife, the US Army Corps of Engineers, and the United States Geological Survey. 39 p. Available from: Oregon State Office of US Fish and Wildlife Service, 2600 SE 98th Avenue, Portland, OR 97266.

Bury, R. Bruce. 1972. The effects of diesel fuel on a stream fauna. California Department of Fish and Game Bull. 58: 291-295.

Bury, R. B. 1997. Biogeography of the herpetofauna in the Siskiyou Mountains region (Oregon-California border). *In*: Beigel, J. K., E. S. Jules, and B. Snitkin (editors), Proceedings of the First Conference on Siskiyou Ecology, May 30-June 1, 1997. Siskiyou Regional Education Project.

California Department of Fish and Game (CDFG). 1984. Foothill yellow-legged frog. California's wildlife, Vol. I, amphibians and reptiles.

Cockran, C. C. and C. Thoms. 1996. Amphibians of Oregon, Washington, and British Columbia: A field identification guide. Lone Pine Publishing. Vancouver, British Columbia, Canada. 175 pp.

Collins, J. T. 1990. Standard common and current scientific names for North American amphibians and reptiles. Third Edition. Society for the Study of Amphibians and Reptiles, Herpetological Circular No. 19. 41 pp.

Corn, P. S. and R. B. Bury. 1989. Logging in western Oregon: responses of headwater habitats and stream amphibians. Forest Ecology and Management 29: 1-19.

Corum, S. 2003. [North Coast] Effects of Sacramento Pikeminnow on Foothill Yellow-Legged Frogs in Coastal Streams. California State University, Humboldt. Masters Thesis, pp. 1-42.

Csuti, B., T. A. O'Neil, M. M. Shaughnessy, E. P. Gaines, and J. C. Hak. 2001. Atlas of Oregon wildlife: Distribution, habitat, and natural history. Second edition. Oregon State University Press, Corvallis, Oregon.

Davidson, C. 1995. Frog and toad calls of the Pacific Coast. Library of Natural Sounds, Cornell Laboratory of Ornithology. Ithaca, New York.

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

Davidson, C., H.B. Shaffer, and M.R. Jennings. 2002. Spatial tests of the pesticide drift, habitat destruction, uv-b, and climate-change hypotheses for California amphibian declines. Conservation Biology 16(6): 1588–1601.

Davidson, C., M.F. Bernard, H.B. Shaffer, J.M. Parker, C. O'Leary, J.M. Conlon, and L.A. Rollins-Smith. 2007. Effects of chytrid and carbaryl exposure on survival, growth and skin peptide defenses in foothill yellow-legged frogs. Environmental Science and Technology 41: 1771-1776.

Drost, C. A., and G. M. Fellers. 1996. Collapse of a regional frog fauna in the Yosemite area of the California Sierra Nevada, USA. Conservation Biology 10: 414-425.

Duellman, W. E. and L. Trueb. 1986. Biology of the amphibians. McGraw-Hill Publishing Company. New York, NY. 670 pp.

Ely, E. 1992. Federal candidate herpetological survey. Submitted to Hollister Resource Area Bureau of Land Management, Hollister, California.

Ely, E. 1993. Current status of *Rana aurora*, *Rana boylii*, and *Bufo boreas* at Pinnacles National Monument, California. Unpublished report provided by K. Hutchinson, Monument Superintendent.

Ely, E. 1994. Report and findings 1994 amphibian surveys, Pinnacles National Monument, California. Unpublished report prepared for the National Park Service, Point Reyes, California.

Emlen, S. T. 1968. Territoriality in the bullfrog, Rana catesbeiana. Copeia 1968: 240-243.

Evenden, F. G., Jr. 1948. Food habitats of *Triturus granulosus* in western Oregon. Copeia 1948(3): 219-220.

Fellers, G. M. 2005. *Rana boylii* Baird, 1854(b). Pages 534-536 in M. Lannoo, editor. Amphibian declines: the conservation status of United States species. University of California Press, Berkeley.

Fitch, H.S. 1936. Amphibians and reptiles of the Rogue River Basin. American Midland Naturalist 17: 634-652

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

Fuller, D.D. and A.J. Lind. 1992. Implications of fish habitat improvement structures for other stream vertebrates. Pp. 96–104. *In* Harris, R. and D. Erman (Eds.), Proceedings of the Symposium on Biodiversity of Northwestern California, Santa Rosa, California.

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

Grismer, L. L. 2002. Amphibians and reptiles of Baja California including its Pacific islands and islands in the Sea of Cortes. University of California Press, Berkeley. xiii + 399 pp.

Hayes, M. P. 1985. *Rana catesbeiana* (Bullfrog). Food. Herpetological Review 16(4): 109.

Hayes, M. P. and M. R. Jennings. 1986. Decline of ranid frog species in western North America: are bullfrogs (*Rana catesbeiana*) responsible? Journal of Herpetology 20(4): 490-509.

Hayes, M. P., and M. R. Jennings. 1988. Habitat correlates of distribution of the California red-legged frog (RANA AURORA) and the foothill yellow-legged frog (*Rana boylii*): implications for management. Pages 144-158 in Szaro, R.C., et al., technical coordinators. Management of amphibians, reptiles, and small mammals in North America. USDA For. Serv., Gen. Tech. Rep. RM-166.

Hayes, T., K. Haston, M. Tsui, A. Hoang, C. Haeffle and A. Vonk. 2002. Atrazine-induced hermaphroditism at 0.1 ppb in American leopard frogs (*Rana pipiens*): laboratory and field evidence. Environmental Health Perspectives .

Hollingsworth, B. 2000. Amphibians of Baja California and nearby islands in the Gulf of California and Pacific Ocean. San Diego Natural History Museum.

Jennings, M. R. 1987. A biography of Dr. Charles Elisha Boyle, with notes on his 19th century natural history collection from California. Wassman J. Biol. 45: 59-68.

Jennings, M.R. 1988. Natural history and decline of native ranid frogs in California. Pp. 61–72. *In* De Lisle, H.F., P.R. Brown, B. Kaufman and B.M. McGurty (Eds.), Proceedings of the Conference on California Herpetology. Southwestern Herpetologists Society, Special Publication, Number 4, Van Nuys, California.

Jennings, M. R., and M. P. Hayes. 1994. Amphibian and reptile species of special concern in California. Final Report submitted to the California Department of Fish and Game, Inland Fisheries Division. Contract No. 8023. 255 pp.

Jones, L.L.C., W. P. Leonard, and D. H. Olson, editors. 2005. Amphibians of the Pacific Northwest. Seattle Audubon Society, Seattle, Washington. xii + 227 pp.

Kerby, J.L. 2007. Pesticide effects on amphibians: A community ecology perspective; DAI-B 68(02): 130.

Kiesecker, J. M. and A. R. Blaustein. 1997. Influences of egg laying behavior on pathogenic infection of amphibian eggs. Conservation Biology 11(1): 214-220.

Kupferberg, S. J. 1996a. Hydrologic and geomorphic factors affecting conservation of a river-breeding frog (*Rana boylii*). Ecological Applications 6(4): 1322-1344.

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

Kupferberg, S.J., 1997. Bullfrog (Rana catesbeiana) invasion of a California river: The role of larval competition. Ecology 78: 1736–1751.

Kupferberg, S., Catenazzi, A., Lunde, K., Lind, A., and Palen, W. 2009a. [North Coast] Parasitic copepod (*Lernaea cyprinacea*) outbreaks in Foothill Yellow-legged Frogs (*Rana boylii*) linked to unusually warm summers and amphibian malformations in Northern California. Copeia 2009(3): 529-537.

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

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

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

LeNoir, J.S., L.L. McConnell, G.M. Fellers, T.M. Cahill and James N. Seiber. 1999. Summertime transport of current-use pesticides from California's Central Valley to the Sierra Nevada Mountain Range, USA. Environmental Toxicology and Chemistry 18: 2715–2722.

Leonard, W.P., H.A. Brown, L.L.C. Jones, K.R. McAllister and R.M. Storm. 1993. Amphibians of Washington and Oregon. Seattle Audubon Society, Trailside Series. Seattle Audubon Society, Seattle, Washington.

Lind, A. 2003. [Sierra Nevada] The Distribution and Habitat of Foothill Yellow-legged Frogs (*Rana boylii*) on National Forests in Southern Sierra Nevada Mountains of California. Report to the FHR Program of Region 5 of the USDA Forest Service. pp. 1-31.

Lind, A.J. 2005. Reintroduction of a declining amphibian: determining an ecologically feasible approach for the foothill yellow-legged frog (Rana boylii) through analysis of decline factors, genetic structure, and habitat associations. Ph.D. Dissertation, University of California, Davis. (March) 169 pp.

Lind, A. J. and H. H. Welsh, Jr. 1994. Ontogenetic changes in foraging behaviour and habitat use by the Oregon garter snake, *Thamnophis atratus hydrophilus*. Animal Behaviour 48: 1261-1273.

Lind, A.J., and B.H. Sheffer. 2005. Reintroduction of a declining amphibian: Determining an ecologically feasible approach for the foothill yellow-legged frog (Rana boylii) through analysis of decline factors, genetic structure, and habitat associations. Dissertation Abstracts International. Section B: Physical Sciences and Engineering: 66(4) 1853.

Lind, A.J., H.H. Welsh Jr., and R.A. Wilson. 1996. [North Coast] The effects of a dam on breeding habitat and egg survival of the foothill yellow-legged frog (*Rana boylii*) in Northwestern California. Herpetological Review 27 (2).

Lind, A.J., J.B. Bettaso and S.M. Yarnell. 2003. Natural history notes: *Rana boylii* (foothill yellow-legged frog) and *Rana catesbeiana* (bullfrog). Reproductive behavior. Herpetological Review 34: 234–235.

Lind, A. J., P. Q. Spinks, G. M. Fellers, and H. B. Shaffer. 2011. Rangewide Phylogeography and Landscape Genetics of the Western U.S. Endemic Frog *Rana Boylii* (Ranidae): Implications for the Conservation of Frogs and Rivers. Conserv. Genet. 12:269–284.

Loomis, R. B. 1965. The yellow-legged frog, *Rana boylei*, from the Sierra San Pedro Martir, Baja California Norte, Mexico. Herpetologica 21: 78-80.

Lowe, J. 2007. Chytrid Distribution in Foothill Yellow-legged Frogs and Pacific Tree Frogs in the Diablo Mountains and San Joaquin Valley Foothills of Central Coastal California. Presented at California-Nevada Amphibian Populations Task Force Meeting, January 18-20, 2007, Las Vegas, Nevada. Bureau of Land Management, Hollister Field Office, CA.

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

Mao, J., D.E. Green, G.M. Fellers and V.G. Chincar. 1999. Molecular characterization of iridoviruses isolated from sympatric amphibians and fish. Virus Research 63: 45–52.

Martof, B. S. 1953. Territoriality in the green frog, *Rana clamitans*. Ecology 34: 165-174.

Masters, C. 1997. Amphibian and reptile habitat monitoring in relation to cattle grazing on the Tiller Ranger District of the Umpqua National Forest. Unpublished report provided by D. Otsby, Forest Supervisor.

Milne, L. and M. Milne. 1980. The Audubon Society field guide to North American insects and spiders. Alfred A. Knopf, Inc. New York. 990 pp.

Morey, S. 2007. Life history account for Foothill Yellow-legged Frog, *available at* http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=79&ved=0CFkQFjAIOEY&url=http%3A%2F%2Fnrm.dfg.ca.gov%2FFileHandler.ashx%3FDocumentVersionID%3D17711&ei=sFTVTuudJ83CsQLiscT7Dg&usg=AFQjCNED6S9_fXT5GBfiq_p6WtTsVcMZ_A (last visited Nov. 29, 2011).

Mount, J., S. Yarnell, S. Kupferberg, and A. Lind. 2006. Pulsed Flow Effects on the Foothill Yellow-Legged Frog (*Rana boylii*): Integration of Empirical, Experimental and Hydrodynamic Modeling Approaches. Prepared by Center for Watershed Sciences, U.C. Davis, for California Energy Commission Public Interest Energy Research (PIER) Program.

Moyle, P. 1973. [Sierra Nevada] Effects of Introduced Bullfrogs, *Rana catesbeiana*, on the Native Frogs of the San Joaquin Valley, California. Copeia. 1973(1): 18-22.

Moyle, P. B. and L. R. Brown. 1997. Invading Species in the Eel River, California: Successes, Failures, and Relationships With Resident Species. Environmental Biology of Fishes 49: 271-291.

NatureServe. 2011. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: November 29, 2011).

Nussbaum, R.A., E.D. Brodie, Jr., and R.M. Storm. 1983. Amphibians and Reptiles of the Pacific Northwest. University Press of Idaho, Moscow, Idaho. 332 pp.

Olson, D.H. and R.J. Davis. 2009. Conservation Assessment for the Foothill Yellow-legged Frog (Rana boylii) in Oregon, *available at* http://www.fs.fed.us/r6/sfpnw/issssp/documents/planning-docs/ca-ha-aneides-flavipunctatus-2008-10-07.doc (last visited Nov. 30, 2011).

Palen, W. J., S. J. Kupferberg, and M.E. Power. 2007. Evaluating the accuracy of amphibian monitoring designs in the context of hydroelectric dam relicensing: A retrospective analysis of a 16-year *Rana boylii* egg mass census.

Paoletti, D. P. 2009. Responses of Foothill Yellow-legged Frog (Rana boylii) larvae to an introduced predator. Unpubl. Master's thesis, Oregon State University, Corvallis, Oregon.

Paoletti, D.J., Deanna H. Olson, and Andrew R. Blaustein. 2011. Responses of Foothill Yellow-legged Frog (Rana boylii) Larvae to an Introduced Predator. Copeia 2011 (1): 161–168, *available at* http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=29&ved=0CFwQFjAIOBQ&url=http%3A%2F%2Fwww.fs.fed.us%2Fpnw%2Flwm%2Faem%2Fdocs%2Folson%2F2011_paoletti_olson_blaustein_copeia.pdf&ei=MlPVTvDkCfSPsAKQ9vmWDw&usg=AFQjCNFMDJ0Hr_E53NxTcB7Q54yRwI2evA (last visited Nov. 29, 2011).

Peek, R. 2010. [Sierra Nevada] Landscape Genetics of Foothill Yellow-Legged Frogs (*Rana boylii*) in regulated and unregulated rivers: Assessing connectivity and genetic fragmentation. University of San Francisco. Masters Thesis, pp. 1-69.

Petts, G. E. 1984. Impounded rivers: perspectives for ecological management. John-Wiley and Sons. Chichester, England. 285 pp.

Power, M. E. 1990. Resource enhancement by indirect effects of grazers: Armored catfish, algae, and sediment. Ecology 71(3): 897-904.

Rombough, Chris, Marc P. Hayes, and Nancy L. Duncan. 2005. Foothill yellow-legged frog abundance in Cow Creek. Northwestern Naturalist 86(2): 114-16.

Santos-Barrera, G., G. Hammerson, G. Fellers 2004. *Rana boylii*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.2. <www.iucnredlist.org>. Downloaded on 29 November 2011.

Sierra Nevada Ecosystem Project (SNEP). 1996. Sierra Nevada Ecosystem Project Report. University of California, Davis, Centers for Water and Wildland Resources.

Sparling, D.W., and G.M. Fellers. 2007. Comparative toxicity of chlorpyrifos, diazinon, malathion and their oxon derivatives to Rana boylii. Environmental Pollution 147: 535-539.

Sparling, Donald W. and G.M. Fellers. 2009. Toxicity of two insecticides to California, USA, Anurans and its relevance to declining amphibian populations. Environmental Toxicology & Chemistry 28(8): 1696.

Sparling, D.W., G.M. Fellers and L.L. McConnell. 2001. Pesticides and amphibian declines in California, USA. Environmental Toxicology and Chemistry 20: 1591–1595.

Stebbins, R. C. 1985. A field guide to western reptiles and amphibians. Second edition. Houghton Mifflin Company, Boston, Massachusetts. xiv + 336 pp.

Stebbins, R. C. 2003. A field guide to western reptiles and amphibians. Third edition. Houghton Mifflin Company, Boston.

Storer, T. I. 1925. A synopsis of the amphibia of California. University of California Publication Zoology 27: 1-342.

Sweet, S. 1983. Mechanics of a natural extinction event: Rana boylii in southern California. Abstract of paper present at 26th annual meeting of SSAR and 31st annual meeting of HL, Salt Lake City, Utah, 7-12 August 1983.

Twitty, V. C., D. Grant, and O. Anderson. 1967. Amphibian orientation: An unexpected observation. Science 155(3760): 352-353.

Unrine, J. M., C.H. Jagoe, W.A. Hopkins, and H.A. Brant. Adverse effects of ecologically relevant dietary mercury exposure in southern leopard frog (*Rana sphenocephala*) larvae. Environmental Toxicology and Chemistry 23: 2964–2970.

U.S. Forest Service. 2011. Foothill Yellow-legged Frog (*Rana boylii*) Ecology, River Regulation, and Conservation, *available at* http://www.fs.fed.us/psw/topics/wildlife/herp/rana_boylii/ (last visited Nov. 29, 2011).

Van Wagner, T. J. 1996. Selected life-history and ecological aspects of a population of foothill yellow-legged frogs (*Rana boylii*) from Clear Creek, Nevada County, California. Master's Thesis, Department of Biological Sciences, California State University, Chico. 143 pp.

Welsh, H. H. 1988. An ecogeographic analysis of the herpetofauna of the Sierra San Pedro Martir region, Baja California, with a contribution to the biogeography of the Baja California herpetofauna. Proceedings of the California Academy of Sciences 46(1): 1-72.

Werschkul, D. F. and M. T. Christensen. 1977. Differential predation by *Lepomis macrochirus* on the eggs and tadpoles of *Rana*. Herpetologica 33: 237-241.

Wiseman, K. 2004. [Sierra Nevada] Foothill Yellow-Legged Frog (*Rana boylii*) Predation by the Introduced Signal Crayfish (*Pacifasticus leniusculus*) in the North Fork Feather River, CA. Oral presentation at California/Nevada Declining Amphibians Population Task Force Annual Meeting. Reno, NV.

Wright, A. H. and A. A. Wright. 1949. Handbook of frogs and toads of the United States and Canada. Comstock Publishing Company, Inc., Ithaca, New York.

Yarnell, S.M. 2000. The Influence of Sediment Supply and Transport Capacity On Foothill Yellow-Legged Frog Habitat, South Yuba River, California. Master's Thesis, Geology Department, University of California, Davis.

Zeiner, D. C., W. F. Laudenslayer, Jr., and K. E. Mayer, eds. 1988. California's wildlife, volume 1, amphibians and reptiles. California Department of Fish and Game. 272 pp.

Zillioux, E. J., D.B. Porcella, and J.M. Benoit. 1993. Mercury cycling and effects in freshwater wetland ecosystems. Environmental Toxicology and Chemistry 12: 2245–2264.

Zweifel, R. G. 1955. Ecology, distribution, and systematics of frogs of the *Rana boylii* group. Univ. of California Publ. Zool. 54: 207-292.

Zweifel, R. G. 1968. *Rana boylii* Baird, Foothill yellow-legged frog. Catalogue of American Amphibians and Reptiles. Pp. 71.1-71.2.