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MOUNTAIN YELLOW-LEGGED FROG CONSERVATION ASSESSMENT for the SIERRA NEVADA MOUNTAINS OF CALIFORNIA, USA

A Collaborative Inter-Agency Project

Forest Service

Pacific Southwest Region

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A Collaborative Inter-Agency Project by:
USDA Forest Service
California Department of Fish and Wildlife
National Park Service
U.S. Fish and Wildlife Service

Technical Coordinators:

Cathy Brown
USDA Forest Service
Amphibian Monitoring Team Leader
Stanislaus National Forest
Sonora, CA

Marc P. Hayes
Washington Department of Fish and Wildlife
Research Scientist
Science Division, Habitat Program
Olympia, WA

Gregory A. Green
Tetra Tech EC
Bothell, WA

Diane C. Macfarlane
USDA Forest Service
Threatened Endangered and
Sensitive Species Program Leader
Pacific Southwest Region
Vallejo, CA

Mountain Yellow-legged Frog Working Group

The following may be contact information at the time of team member involvement in the assessment.

Angermann, Jeffrey
Postdoctoral Fellow
Department of Pharmacology
University of Nevada School of Medicine
Reno, NV 89557
(775) 784-6275
(775) 752-3394 (FAX)
jangermann@medicine.nevada.edu

Becker, Dawne
Associate Biologist
California Department of Fish and Wildlife
407 West Line St., Room 8
Bishop, CA 93514
(760) 872-1110
(760) 872-1284 (FAX)
dbecker@dfg.ca.gov

Boiano, Daniel
Aquatic Ecologist
Sequoia/Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271
(559) 565-4273
(559) 565-3730 (FAX)
danny_boiano@nps.gov

Bolster, Betsy
Staff Environmental Scientist
(Statewide Coordinator for Conservation of Amphibians and Reptiles)
California Department of Fish and Wildlife
Wildlife Branch
Nongame Wildlife Program
1812 9th St.
Sacramento, CA 95811
(916) 445-3684
(916) 445-4048 (FAX)
bbolster@dfg.ca.gov

Bradford, David
Research Ecologist
Environmental Sciences Division
Office of Research and Development
U.S. Environmental Protection Agency
P.O. Box 93478
Las Vegas, NV 89193-3478
(702) 798-2681
(702) 798-2692 (FAX)
bradford.david@epa.gov

Brown, Cathy
Monitoring Team Leader
Sierra Nevada Amphibian Monitoring Program
Stanislaus National Forest
USDA Forest Service
Pacific Southwest Research Station
P.O. Box 241
Berkeley, CA 94701
(510) 559-6433
(510) 559-6499 (FAX)
cathybrown@fs.fed.us

Buma, Gerrit
District Conservationist
Minden Service Center
Natural Resource Conservation Service
Hickey Building
1702 County Road, Suite A1
Minden, NV 89423-4460
(775) 782-3661
(775) 782-3547 (FAX)
gerrit.buma@nv.usda.gov

Byers, Stephanie
Fisheries Biologist
U.S. Fish and Wildlife Service
1340 Financial Blvd., Suite 234
Reno, NV 89502
(775) 861-6329
(775) 861-6301 (FAX)
stephanie_byers@fws.gov

Carlson, Ann D.
Region 1 Aquatic Ecologist
Watershed, Wildlife, Fisheries & Rare Plants
Region 1 Regional Office
USDA Forest Service
Federal Building
200 East Broadway
P.O. Box 7669
Missoula, MT 59807
(406) 329-3087
(406) 329-3171 (FAX)
adcarlson@fs.fed.us

Davidson, Carlos
Director, Associate Professor
Environmental Studies Program
College of Behavioral and Social Sciences
San Francisco State University
1600 Holloway Avenue
San Francisco, CA 94132
(415) 405-2127
(415) 338-2880 (FAX)
carlosd@sfsu.edu

Epanchin, Peter
Museum of Vertebrate Zoology
University of California, Berkeley
3101 Valley Life Sciences Building
Berkeley, CA 94720
pnepanchin@berkeley.edu

Fellers, Gary
USGS Biological Resources Division
Point Reyes National Seashore
1 Bear Valley Road
Point Reyes, CA 94956-9799
(415) 464-5185
(415) 663-8132 (FAX)
gary_fellers@usgs.gov

Graber, David
Chief Scientist, Pacific West Region
Sequoia/Kings Canyon National Parks
National Park Service
47050 Generals Highway
Three Rivers, CA 93271-9651
(559) 565-3173
(559) 565-4283 (FAX)
david_graber@nps.gov

Hopkins, Kristina
Forest Fisheries Biologist
Supervisor's Office
Plumas National Forest
USDA Forest Service
159 Lawrence Street
Quincy, CA 95971
(530) 283-7819
(530) 293-7746 (FAX)
thopkins@fs.fed.us

Jennings, Mark R.
Herpetologist/Fishery Biologist
Rana Resources
P.O. Box 2185
Davis, CA 95617-2185
(530) 753-2727
(530) 753-2727 (FAX)
ranaresources@aol.com

Kanz, Russell
Biologist
State Water Resources Control Board
P.O. Box 2000
Sacramento, CA 95812-2000
(916) 341-5341
(916) 341-5252 (FAX)
rkanz@waterrights.swrcb.ca.gov

Kiddoo, Phillip
Research and Systems Analyst II
Great Basin Unified Air Pollution Control District
157 Short Street
Bishop, CA 93514-3537
(760) 872-8211
(760) 872-6109 (FAX)
pkiddoo@gbuapcd.org

Knapp, Roland
Associate Research Biologist
Sierra Nevada Aquatic Research Lab
University of California
HCR 79, Box 198
Mammoth Lakes, CA 93546
(760) 647-0034
(760) 935-8467 (FAX)
knapp@lifesci.ucsb.edu

Lawrence, Mike
District Ranger
Paulina Ranger District
Ochoco National Forest
7803 Beaver Creek Road
Paulina, OR 97751
(541) 477-6901
(541) 477-6949 (FAX)
mlawrence@fs.fed.us

Lehr, Stafford
Senior Fisheries Biologist
California Department of Fish and Wildlife
1701 Nimbus Rd., Suite A
Rancho Cordova, CA 95670
(530) 626-3687
slehr@dfg.ca.gov

Lind, Amy J.
Research Wildlife Biologist
Sierra Nevada Research Center
Pacific Southwest Research Station
USDA Forest Service
2121 Second Street, Suite A-101
Davis, CA 95616
(530) 759-1702
(510) 747-0241 (FAX)
alind@fs.fed.us

Macfarlane, Diane
Threatened and Endangered Species Coordinator
Ecosystem Conservation Staff
Region 5 Regional Office
USDA Forest Service
1325 Club Drive
Vallejo, CA 94592
(707) 562-8931
(707) 562-9054 (FAX)
dmacfarlane@fs.fed.us

Matthews, Kathleen
Research Fisheries Biologist
Pacific Southwest Research Station
USDA Forest Service
P.O. Box 245
Berkeley, CA 94701
(510) 559-6454
(510) 559-6440 (FAX)
kmatthews@fs.fed.us

McKenny, Heather
Aquatic Ecologist
Yosemite National Park
National Park Service
P.O. Box 700
El Portal, CA 95318
(209) 379-1438
(209) 379- 1131 (FAX)
heather_mckenny@nps.gov

Milliron, Curtis
Senior Biologist, Specialist
California Department of Fish and Wildlife
407 W. Line Street
Bishop, CA 93514
(760) 872-3058
(760) 872-1284 (FAX)
cmilliro@dfg.ca.gov

Perrot, Laurie
Environmental Coordinator
Supervisor's Office
Tahoe National Forest
USDA Forest Service
631 Coyote Street
P.O. Box 6003
Nevada City, CA 95959
(530) 478-6244
(530) 478-6109 (FAX)
lperrot@fs.fed.us

Pert, Edward
California Department of Fish and Wildlife
Habitat Conservation Planning Branch
1416 Ninth St., 12th Floor
Sacramento, CA 95814
(916) 651-8689
(916) 653-7387 (FAX)
epert@dfg.ca.gov

Pope, Karen
Wildlife Biologist
Redwood Sciences Laboratory
Pacific Southwest Research Station
USDA Forest Service
1700 Bayview Drive
Arcata, CA 95221
(707) 825-2957
(707) 825-2901 (FAX)
kpope@fs.fed.us

Smith, Dennis E.
Region 5, RHAT Fisheries Biologist
Natural Resources Management
Region 5, Regional Office
USDA Forest Service
1325 Club Drive
Vallejo, CA 94592
(916) 930-3995
(916) 498-6675 (FAX)
dennissmith@fs.fed.us

Stephens, Stan
Retired Environmental Scientist
California Department of Fish and Wildlife
1234 East Shaw Ave.
Fresno, CA 93710
(559) 999-3028 - cell
(559) 243-4020 (FAX)
sstevens@dfg.ca.gov

Thompson, Steve
Branch Chief
Wildlife Management Division
Yosemite National Park
National Park Service
P.O. Box 700 W
El Portal, CA 95318
(209) 379-3261
(209) 379-3269 (FAX)
steve_thompson@nps.gov

Vredenburg, Vance T.
Postdoctoral Scholar
Department of Integrative Biology and
Museum of Vertebrate Zoology
Univ of California, Berkeley
3101 Valley Life Sciences Building, 3160
Berkeley, CA 94720
(510) 642-7960
(510) 643-8238 (FAX)
vancev@berkeley.edu

Werner, Harold
Wildlife Ecologist
Sequoia/Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271
(559) 565-3123
(559) 565-3730 (FAX)
harold_w._werner@nps.gov

Willians, Jann O.
Fisheries Biologist
Supervisor's Office
Eldorado National Forest
USDA Forest Service
100 Forni Road
Placerville, CA 95667
(530) 621-5240
(530) 621-5297 (FAX)
jowilliams@fs.fed.us

Wong, Darrell M.
Fisheries Biologist (retired)
130 Scott Road
Bishop, CA 93514
(760) 387-2328
dwong@schat.com

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report presents a synthesis of scientific literature and expertise regarding the mountain yellow-legged frog complex in the Sierra Nevada, which is now comprised of two species, *Rana muscosa* and *R. sierrae*. These species, which inhabit largely higher-elevation (> 1,219 m [> 4,000 ft.]) aquatic habitats of the Sierra Nevada Mountains of California and Nevada, were historically abundant. It is estimated that these frogs have been extirpated over the majority (> 92 percent) of their geographic ranges, with many of the remaining populations depleted. Depletions and extirpations, first recognized during the 1970s, have accelerated markedly since the 1990s. The realization that these patterns would rapidly place these species at risk of extinction led to a multi-agency effort to develop a Conservation Strategy focused on the recovery of mountain yellow-legged frogs in the Sierra Nevada. This Conservation Assessment is the first step toward development of the Conservation Strategy and consists of three integral parts: 1) a description of mountain yellow-legged frog ecology in the Sierra Nevada to determine conditions necessary to provide for viable populations; 2) a review of the distribution and abundance of mountain yellow-legged frogs over their Sierran geographic range to describe the risk; and 3) an evaluation of 17 risk factor categories to identify which of these may constitute the greatest risk to mountain yellow-legged frogs and their habitat in the Sierra Nevada.

Mountain yellow-legged frogs in the Sierra Nevada occupy aquatic habitats for almost all their seasonal life history; they typically breed, rear, and overwinter in still- or slow-moving water habitats, and, although not well-studied, they also use flowing-water habitats. Because mountain yellow-legged frog larvae overwinter at least one year, perennial aquatic habitats that do not freeze to the bottom in winter are needed for breeding and rearing. The species generally are thought to use perennial aquatic sites for overwintering, though this is not well-studied. Larvae, metamorphs, and adults support, to some level, a segment of the high-elevation food web; invertebrates and garter snakes (*Thamnophis* spp.), for example. Benthic invertebrates appear to be the primary food source of post-metamorphic life stages (juveniles and adults) in lake-dwelling populations. Post-metamorphic stages, known to move among aquatic sites seasonally, can rapidly colonize unoccupied habitat. Such movements may maintain clusters of occupied sites that may function as metapopulations.

Mountain yellow-legged frogs in the Sierra Nevada occur on both sides of the mountain axis between the headwaters of the Feather River and the headwaters of the Kern River between 1,100 m (3,609 ft) and 3,810 m (12,500 ft), but their eastside distribution appears to be restricted to the Tahoe Basin southward. *R. sierrae* occupies the northern and central Sierra Nevada south to the vicinity of Mather Pass (Fresno County), whereas *R. muscosa* occupies the Sierra Nevada south of this area.

Based on pre-1980 information, most (84 percent) of the historical range of the species is on federal National Forest and National Park land (including parts of 10 National Forests and 4 National Parks); the remainder of the range is on private, state-owned, and other federal lands. Historical occurrence data are variable in quality; more data is available from National Parks than from National Forests. Historical abundance data are anecdotal, but mountain yellow-legged frogs were described as being among the most abundant amphibians in the Sierra Nevada; mountain yellow-legged frogs also appear to have been most abundant in the high-elevation regions. Data obtained since 1990 includes quantitative occurrence and abundance data. Status analyses indicate that *R. sierrae* and *R. muscosa* have high levels of extirpation across their Sierran ranges, 93 percent and 95 percent, respectively, including declines from an estimated 53% of areas occupied as recently as the 1990s. Abundance data indicate decreases from historical population sizes with relatively few large (> 30 adults) populations remaining across the geographic ranges of both species.

Availability of data evaluating the importance of 17 potential risk factors to mountain yellow-legged frog declines in the Sierra Nevada is highly variable. Three risk factors (introduced fishes, disease, and habitat loss and fragmentation) are likely most responsible for mountain yellow-legged frog declines. The best data support introduced fishes and the disease, chytridiomycosis, as major causes of the decline; introduced fishes also have led to habitat loss and fragmentation. Data for the remaining risk factors are poor to non-existent, and few data exist on interactions (additive, multiplicative, or synergistic effects) among the risk factors. Some risk factors (e.g., airborne contaminants) as well as interactions among risk factors merit further investigation. Thirteen risk factors (disease, fire suppression, habitat loss and fragmentation, introduced fish, livestock grazing, locally applied pesticides, mining, recreational activities, research activities, restoration, roads, vegetation and fuels management, and water development) are local or regional in their effects and have the potential to be effectively influenced by management efforts of agencies participating

in this Conservation Assessment. In contrast, the remaining four risk factors (acid deposition, airborne contaminants, climate change, and ultraviolet radiation) have effects that originate globally or extra-regionally (from the perspective of the Sierra Nevada), and as such are largely beyond the jurisdiction of agencies participating in this assessment. However, knowledge of the latter factors would facilitate a better understanding of where remediation efforts (for the factors that can be managed) will be most effective.

There is currently ongoing research on specific risk factors as well as potential recovery actions. Most notably, fish removal programs have proven highly successful at restoring mountain yellow-legged frog populations both in terms of population abundance and recolonization of fish-free habitats. Recent research on the epidemiology of chytridiomycosis in mountain yellow-legged frogs has greatly increased knowledge about the contribution of this fungus to the species' decline. Finally, several large scale programs are collecting extensive inventory and monitoring data that will greatly increase our knowledge of the species' current status.

Conservation options for consideration in a future Conservation Strategy for both species of mountain yellow-legged frog in the Sierra Nevada include management at multiple scales, identifying and managing within priority basins, increasing the amount of fishless habitat, investigating the feasibility of translocation of frogs, and further research on the species' use of stream and meadow habitats, the amphibian chytrid fungus, and airborne contaminants.

INTRODUCTION

The Purpose of this Conservation Assessment

Information from the earlier 20th century suggests that mountain yellow-legged frogs were extraordinarily abundant across high-elevation aquatic ecosystems of the Sierra Nevadan Cordillera of North America (Grinnell and Storer 1924, Zweifel 1955). Distributed almost continuously in aquatic habitat in the Sierra Nevada of California and Nevada from northwestern Plumas County to southern Tulare County (Jennings and Hayes 1994, Vredenburg et al. 2007, M. Hayes, M. Jennings, V. Vredenburg, unpubl. data), mountain yellow-legged frogs occurred mostly above 1,820 m (Storer 1925). In the Sierra Nevada, mountain yellow-legged frogs occurred predominately on public lands including ten National Forests (Lassen, Plumas, Tahoe, Lake Tahoe Basin Management Unit, Eldorado, Stanislaus, Humboldt-Toiyabe, Inyo, Sierra, and Sequoia) and four National Parks (Lassen, Yosemite, Sequoia, and Kings Canyon). Based on current understanding, there are two mountain yellow-legged frog species in the Sierra Nevada, the northern form, *Rana sierrae*, and the southern form, *Rana muscosa*, which also occurs in southern California (Vredenburg et al. 2007).

Mountain yellow-legged frogs are important components of aquatic ecosystems in the high Sierra Nevada. They play pivotal roles in high-elevation food webs: early developmental stages provide important food for garter snakes (frequently among top predators in these high-elevation systems); larval stages are key aquatic grazers; and, where fish are absent, postmetamorphic frogs are major aquatic vertebrate predators. Mountain yellow-legged frogs are thought to also play key roles in nutrient cycling within lake systems and between lake and stream systems. Thus, loss of this taxon in the Sierra Nevada would alter food webs and nutrient cycling in ways that have significant and potentially profound consequences for high-elevation Sierran systems, a pattern that already appears to be evident regionally (Finlay and Vredenburg 2007).

Since about 1970, mountain yellow-legged frogs have undergone precipitous declines (based on population sizes and numbers of populations) throughout the Sierra Nevada (Bradford et al. 1994a, Jennings and Hayes 1994, Drost and Fellers 1996, Jennings 1996, Matthews and Knapp 1999, Knapp and Matthews 2000a, Vredenburg et al. 2007, Brown et al. 2014). Moreover, declines continue to be documented (R. Knapp, V. Vredenburg, pers. comm., 2006). The most recent estimates indicate disappearance from >90 percent of historical localities for both mountain yellow-legged frog species occupying the Sierra Nevada (Vredenburg et al. 2007) including an approximately 50% decline from areas occupied as recently as the 1990s (Brown et al. 2014). Remaining populations are widely scattered and frequently consist of small numbers of breeding adults (Brown et al. 2014, CDFW unpublished data Sarah Mussulman, pers. comm., 2013). Numerous factors, both individually and in undoubtedly diverse and complex combinations, may have contributed to the species' decline. Introduction of non-native fishes, bacterial, fungal and viral pathogens, pesticides, ultraviolet radiation, acidification from atmospheric deposition, livestock grazing, recreational activities, and drought are among the potential factors affecting these species and their habitat.

In 1999, a team of agency managers and researchers agreed that a Conservation Assessment and Strategy addressing mountain yellow-legged frogs was needed to provide for their protection and conservation. The USDA Forest Service Pacific Southwest Region Ecosystem Conservation Director and the Director of the California Department of Fish and Wildlife (CDFW) approved preparation of such an assessment. In 2000, a working group consisting of biologists from the USDA Forest Service, National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), CDFW, and academic and independent research scientists was established to develop this assessment and strategy.

On 8 February 2000, the Center for Biological Diversity and the Pacific Rivers Council petitioned USFWS to list mountain yellow-legged frogs (*Rana muscosa* sensu lato) in the Sierra Nevada, then recognized as a distinct population segment (DPS) encompassing the entire Sierra Nevada, as Endangered. In their 90-Day Finding, announced on 12 October 2000, USFWS concluded that the substantial information presented might warrant listing, and initiated the process leading to developing a 12-Month Finding to better study the petition (USFWS 2000). The USFWS completed its 12-Month Finding on 16 January 2003, concluding that the petitioned action was warranted but precluded by higher priority actions to amend the Lists of Endangered and Threatened Wildlife and Plants (USFWS 2003). Following publication of this 12-Month Finding, the then recognized DPS of mountain yellow-legged frogs encompassing the entire Sierra Nevada, was added to the USFWS candidate species list (USFWS 2004). On 25 April, 2013, the USFWS proposed to list both *R. sierrae* and the northern distinct population segment of *R. muscosa* as Endangered (USFWS 2013), and the final rule was published on 29 April, 2014 (USFWS 2014).

Prompted by a 2006 lawsuit, the California Superior Court ruled in 2008 that the California Department of Fish and Wildlife (CDFW) must consider the effects of hatchery operations and fish stocking on sensitive aquatic species when making stocking decisions (Pacific Rivers Council Center for Biological Diversity v. California Department of Fish and Game. 2007. Case number 06 CS 01451, California Superior Court of Sacramento County). A joint CDFW/USFWS Hatchery and Stocking EIR/EIS was completed in January 2010 that prohibits CDFW, with limited exceptions, from stocking “nonnative” fishes in “any California fresh water body” where surveys have demonstrated the presence of any of 25 specified vertebrate species, or where a survey for those species has not been conducted. The complete EIR/EIS can be found on the CDFW document library at https://nrm.dfg.ca.gov/documents/ContextDocs.aspx?cat=Fisheries--FishProductionDistribution under subcategory HatcheryAndStockingProgram EIR/EIS.

On 14 February, 2012, the California Fish and Game Commission found that *R. muscosa* warrants state listing as an endangered species and *R. sierrae* as a threatened species (California Fish and Game Commission 2012). The Pacific Southwest Region (Region 5) has listed and managed the mountain yellow-legged frog as a Sensitive Species since 1998 (USDA Forest Service 1998, 2004a, 2007, 2013).

This Conservation Assessment was developed as a tool to guide future Conservation Strategy and recovery planning for mountain yellow-legged frogs in the Sierra Nevada (Blankenship et al. 2001). Conservation Assessments document all conservation- or management-pertinent information that is known or unknown about a species, including its ecology, habitat needs, current and historical population levels, and management risks. Conservation Assessments also provide conservation recommendations based on the best available knowledge. In turn, these recommendations are incorporated into a focused Conservation Strategy designed to benefit the species. Contributors to this Conservation Assessment include the following agencies: CDFW; the Pacific Southwest and Intermountain Regions of the USDA Forest Service; the National Park Service (NPS), including Lassen Volcanic, Yosemite, and Sequoia-Kings Canyon National Parks; and the USFWS.

The majority of work on this Conservation Assessment was accomplished prior to 2007 and since then there has been considerable new research, particularly on the disease, chytridiomycosis. Recognizing that an Assessment such as this is really a working document used to summarize existing knowledge at a specific point in time, the working team decided to include updates in the subsequent step, the Conservation Strategy. Thus, the Mountain Yellow-legged Frog Conservation Strategy contains more recent information on topics most pertinent to the species’ conservation. Only minimal new information has been added to this Conservation Assessment; in some cases, citations were added to guide readers to more recent literature.

Mission

The mission of this effort is to provide the information required for developing a Conservation Strategy that would ensure the self-sustaining, long-term viability and continued evolution of mountain yellow-legged frogs in perpetuity that represent the historical range of the geographic, genetic, and ecological diversity of both species of mountain yellow-legged frogs. The objectives of the strategy supported by this assessment are:

- Maintain viability of existing populations throughout the range of both species of mountain yellow-legged frog across the Sierra Nevada.
- Where possible, restore habitat and expand populations within individual basins throughout the recent historical range of each mountain yellow-legged frog species in the Sierra Nevada.
- Where possible, recover both species of mountain yellow-legged frog in basins where populations were historically present but are absent today.
- Fill information gaps by obtaining additional data on the existing status of both mountain yellow-legged frog species; biology of mountain yellow-legged frog populations, especially in the northern Sierra Nevada; ecology of stream populations; genetics; movement ecology; cause-and-effect research on possible stressors; and research on remediation techniques.
- Create public understanding of conservation and recovery needs. Encourage and maintain public participation in conservation actions, particularly with elements that facilitate public ownership in processes leading to such actions, and keep the public engaged in and supportive of conservation actions.
- Seek funding to implement the Conservation Strategy. Maintenance of public interest will represent a key element in this effort.

Conservation Assessment Tasks Identified by the Working Group

- Summarize current knowledge of conditions necessary to provide for viable populations of both species of mountain yellow-legged frog found in the Sierra Nevada.
- Summarize current knowledge about the status and population decline of both species of mountain yellow-legged frog found in the Sierra Nevada.
- Identify and evaluate importance of key risk factors.
- Identify knowledge gaps in biology, population status, and efficacy of potential remedial actions, and identify possible pathways for gaining additional knowledge.

Geographic Scope of this Assessment

This Conservation Assessment focuses on mountain yellow-legged frogs in the Sierra Nevada. As such, the assessment encompasses the entire range of *R. sierrae*, the northern species of mountain yellow-legged frog, but encompasses only the Sierran portion of the range of *R. muscosa*, the southern species of mountain yellow-legged frog. The latter species also occurs in the Transverse Ranges of southern California. Distribution of the two currently recognized species of mountain yellow-legged frogs in the Sierra Nevada is summarized in the Systematics and Taxonomy section.

Agency Direction for Species Conservation

USDA Forest Service

Generally, in accordance with legislated federal mandates, the USDA Forest Service manages aquatic habitats and provides recreational opportunities for the public. The Pacific Southwest Region (Region 5) has listed and managed the mountain yellow-legged frog as Sensitive Species since 1998 (USDA Forest Service 1998, 2013). The recent listing of the species as Endangered under the Endangered Species Act initiates management under USDA Forest Service threatened and endangered species policies (FSM 2670 and CFR 50.402). The Sensitive Species List is derived from 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:

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

FSM 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 impacted without an analysis of significance of adverse effects on the populations, their habitat, and on the viability of the species as a whole. The USDA Forest Service Manual (FSM 2670.32) provides the following direction for Sensitive Species:

1. Assist States in achieving their goals for conservation of endemic species.
2. 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.
3. Avoid or minimize impacts to species whose viability has been identified as a concern.
4. 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.
5. 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 USFWS and the States.

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 Forest Service 2001a). This 2001 Framework decision was subsequently adjusted three years later via a supplemental EIS and Record of Decision (ROD) (USDA Forest Service 2004b, 2004c). The 2004 ROD is the only binding decision. Both Framework RODs establish an Aquatic Management Strategy. Pages 32-33 of the ROD (USDA Forest Service 2004c) 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 Endangered Species Act, 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 non-native 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 stream flow.
8. Streamflow Patterns and Sediment Regimes – Maintain and restore in-stream 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. Stream Banks and Shorelines – Maintain and restore the physical structure and condition of stream banks 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 mountain yellow-legged frogs. Management direction for carrying out this decision includes S&Gs for project design and implementation. No specific guidelines exist that single out mountain yellow-legged frogs (as exist for the Yosemite toad) but two S&Gs (addressing pesticide application [98] and assessment of habitat [114]) associated with Riparian Conservation Objectives specifically identify mountain yellow-legged frogs within them. The remainder of 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.

California Department of Fish and Wildlife

Effective 1 April, 2013, *R. sierrae* is listed as a threatened species and *R. muscosa* (throughout its entire range) is listed as an endangered species under the California Endangered Species Act (CESA; Fish and Game Code §§ 2050-2115.5, California Code of Regulations Title 14 § 670.5). Section 2080 of the Fish and Game Code prohibits "take" of any species that the Fish and Game Commission determines to be an endangered species or a threatened species. Take is defined in Section 86 of the Fish and Game Code as "hunt, pursue, catch, capture, or kill, or attempt to hunt, pursue, catch, capture, or kill."

CESA allows for take incidental to otherwise lawful activities (Fish and Game Code §2081(b)). CESA emphasizes early consultation to avoid potential impacts to rare, endangered, and threatened species and to develop appropriate mitigation planning to offset project caused losses of listed species populations and their essential habitats.

Through permits or memorandums of understanding, CDFW also may authorize individuals, public agencies, universities, zoological gardens, and scientific or educational institutions to import, export, take, or possess any endangered species, threatened species, or candidate species of plants and animals for scientific, educational, or management purposes (Fish and Game Code §2081(a)).

CESA-listed species 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 the State. Sections 15063 and 15065 of the CEQA Guidelines address how an impact is identified as significant. Project-level impacts to listed (rare, threatened, or endangered) species are generally considered significant thus requiring lead agencies to prepare an Environmental Impact Report (EIR) to fully analyze and evaluate the impacts.

When CDFW proposes to undertake a project that has the potential for take of a state-listed species, if the project is part of the management of that species, i.e., for the protection, propagation, or enhancement of the species and its habitat, CDFW is not required to get a CESA Incidental Take Permit per California Code of Regulations Title 14 §783.1. However, CDFW is still required to complete its obligations under CEQA and prepare a Negative Declaration or an EIR, as appropriate, for the proposed project.

National Park Service

The guiding principles for managing biological resources on National Park 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" (NPS 2006a).

These guiding principles also commit the National Park Service (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 mountain yellow-legged frog Conservation Assessment process, and assist in conserving both species in the Sierra Nevada.

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

1. Aquatic and water ecosystems are restored/and or maintained so that physical, chemical, and biotic processes function uninfluenced by human activities.
2. Aquatic environments are inventoried and classified by physical and chemical characteristics and biotic communities present.
3. 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.
4. Impacts of acid deposition and contaminants from external influences are detected and evaluated.
5. Lakes with exotic trout are restored to natural conditions.
6. Extant native species or genetically unique groups are restored to their former range.
7. Waters incapable of sustaining fish populations through natural reproduction will be allowed to become fishless.

One of the primary objectives of Yosemite National Park's General Management Plan (GMP; NPS 1980) is to preserve and restore native wildlife and the ecosystems in which they occur. The Resources Management Plan for Yosemite National Park (NPS 1993) developed in support of the GMP, specifically addresses management of aquatic ecosystems and recovery of the mountain yellow-legged frog. The plan's management strategies that directly relate to the frogs ecology and risk factor analysis include: 1) determining the historical and present distribution of the frog including their distributional status and habitat requirements; 2) monitoring and restoring natural diversity of aquatic species, habitats, and ecosystem dynamics; 3) determining the feasibility of removing nonnative fish; 4) evaluating and mitigating human-related impacts to the frog; and 5) exploring reintroduction where losses have occurred.

Broad-based replication of historical surveys were initiated in the 1990s that have provided insights into the status of the amphibian assemblages found in Yosemite National Park (Drost and Fellers 1994,

R. Knapp, pers. comm.; see also Status section for Yosemite National Park). All three National Parks also have contributed to comparative studies addressing the causes of decline in mountain yellow-legged frogs (Fellers et al. 2001, 2004, Knapp and Matthews 2000a, Knapp et al. 2007), and ongoing studies on amphibians, including mountain yellow-legged frogs, occur in all three parks. Additionally, Sequoia and Kings Canyon NPs have completed a comprehensive restoration plan for the mountain yellow-legged frog involving fish removal from selected lakes (NPS 2013). Yosemite National Park has facilitated research into understanding system-level effects of fish stocking and removal (Knapp et al. 2005). This work has contributed to promoting and expanding introduced fish removal efforts within all three National Parks (R. Knapp, pers. comm., 2005). Index sites for the federal Amphibian Research and Monitoring Initiative (ARMI) are present on the National Parks within the range of the mountain yellow-legged frogs. The goal of this initiative is to provide timely, reliable information on the status of amphibians in the United States so that causes of declines can be understood and appropriate management responses initiated (Hall and Langtimm 2001).

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
- habitat conservation

The recovery of threatened and endangered species, and the ecosystems on which they depend, fall under USFWS responsibilities under the Endangered Species Act (ESA). Both *R. sierrae* and the northern distinct population segment of *R. muscosa* are listed as Endangered under the Endangered Species Act (USFWS 2014, also see discussion above).

Document Organization

The three main sections of this document address the ecology of mountain yellow-legged frogs, their status, and an assessment of the factors that might present a risk to their continued survival in the Sierra Nevada. The ecology section details the species' ecological requirements, an understanding of which is necessary to develop a successful strategy for their recovery. The status section summarizes information on mountain yellow-legged frog distribution and population abundance within the Sierra Nevada. Appendix B discusses how these populations have changed pre- and post-1980 in each of the National Forests and National Parks. Finally, the Risk Factor section evaluates the relative importance of key risk factors for mountain yellow-legged frogs. Risk factors include management activities (e.g., fish introduction, pesticide use, fire suppression, habitat restoration, vegetation management) and environmental factors (e.g., disease, climate change) which may have played a role in current mountain yellow-legged frog trends in the Sierra Nevada and may be important for future population recovery. Together, these sections provide the conceptual and scientific foundation for the subsequent Conservation Strategy.

The mountain yellow-legged frog was divided into two species, *R. sierrae* occurring in the northern and central part of the Sierra Nevada, and *R. muscosa* in the more southern part (Vredenburg et al. 2007, see Systematics and Taxonomy in Ecology Section for specific geographic ranges). Most data currently available on these species was collected prior to their division into two species, and thus does not differentiate between them. In this document, the general term, mountain yellow-legged frog, refers to the complex of both species in the Sierra Nevada. In the few cases where the specific species is known or can be extrapolated (e.g., the location of the study occurs only within the range of one of the species), then the scientific name of the species is used. In general, for some of the ecological and status information, the species can be inferred; for most of the risk factors, the species complex is addressed.

ECOLOGY

Systematics and Taxonomy

Systematics and taxonomy provide the genetic and geographic foundation for discussing all aspects of the ecology of mountain yellow-legged frogs in the Sierra Nevada.

Mountain yellow-legged frogs are members of the true frog family Ranidae (Jennings 1987). Based on morphology, mountain yellow-legged frogs were historically included within a group of six western North American ranid frog species termed the *Rana boylii* group, which also included the foothill yellow-legged frog (*R. boylii)* and four Mexican species (Zweifel 1955). Discrepancies with this arrangement highlighted by osteological (Chantell 1970) and immunological data (Wallace et al. 1973) led Case (1978a) to re-examine group composition using allozymes, and re-define it to exclude the Mexican ranids, and include the remaining Pacific Coast ranid frog species then recognized (i.e., red-legged frogs [*R. aurora* sensu lato; i.e., pre-Shaffer et al. 2004], Cascades frogs [*R. cascadae*], and spotted frogs [*R. pretiosa* sensu lato; i.e., pre-Green et al. 1997]). Although the analysis of Case (1978a) was controversial (Farris et al. 1979, Post and Uzzell 1981, Uzzell and Post 1986), later work using allozymes (Green 1986), RNA (Hillis and Davis 1986), and DNA (Macey et al. 2001) have each corroborated the hypothesis that North American Pacific Coast ranids form a cohesive (monophyletic) group (i.e., sharing the same recent common ancestor). Aside from the fact that membership in the *Rana boylii* group continues to increase simply due to genetic partitioning of largely cryptic taxa (e.g., Green et al. 1997, Vredenburg et al. 2007, M. Blouin, pers. comm. for *R. cascadae*), some controversy remains regarding the relationship of mountain yellow-legged frogs to other members of the group. Based on protein and chromosome data, Case (1978a) and Green (1986) both indicated that *R. muscosa* (sensu lato) was most closely allied to *R. boylii*, but more recent genetic work using mitochondrial DNA suggests a much closer relationship to red-legged and Cascades frogs (Macey et al. 2001). The work of Shaffer et al. (2004) appears to corroborate the latter hypothesis, at least in part, that *R. muscosa* appears related to the California red-legged frog (*R. draytonii*).

Camp (1917) originally described mountain yellow-legged frogs as two subspecies of the foothill yellow-legged frog: *R. boylii sierrae* and *R. boylii muscosa*. However, nearly all subsequent workers treated frog populations in the Sierra Nevada as *R. sierrae* and frog populations in southern California as *R. muscosa* (Stejneger and Barbour 1923, 1933, 1939, 1943, Pickwell 1947, Wright and Wright 1949, Stebbins 1951, 1954). In reviewing yellow-legged frog systematics, Zweifel (1955) lumped *R. sierrae* and *R. muscosa* (Zweifel gave the name "*muscosa*" priority over "*sierrae*" based on pagination sequence in the original [i.e., Camp] description). In a largely morphological assessment, Zweifel (1955) felt differences were too minor to support meaningful taxonomic distinction. However, mitochondrial DNA work supports at least some of the partitioning recognized by investigators preceding Zweifel, and reveals that frogs in southern California differ significantly from Sierran frogs (Macey et al. 2001). The analysis of Macey et al. (2001) also revealed a discontinuity among frogs in the Sierra Nevada that suggested that frogs from the southern Sierra Nevada were more closely related to those in southern California than those in the northern and central Sierra Nevada. Vredenburg et al. (2007) pointed out that this discontinuity was consistent with largely ignored morphological data that Camp (1917) and Zweifel (1955) had collected, and using new molecular (mitochondrial DNA), morphological, habitat, and male advertisement call data, found unequivocal support for recognizing two mountain yellow-legged frog species: *Rana sierrae*, with a distribution in the northern and central Sierra Nevada, and *Rana muscosa*, with a distribution in the southern Sierra Nevada and southern California. The contact zone for these two newly recognized species is in the vicinity of Mather Pass and the Monarch Divide, Fresno County (Vredenburg et al. 2007).

Based on ecological and behavioral data, Cory (1962a and 1962b) had earlier also advanced the intriguing hypothesis that Sierran populations of mountain yellow-legged frogs represent a series of cryptic species each restricted to a separate river system draining the Sierran slope and each derived from the population of foothill yellow-legged frogs in the lower elevations of that river system. The independently derived species aspect of Cory's hypothesis has since been refuted by chromosomal, morphological, and protein data (Houser and Sutton 1969, Haertel et al. 1974, Case 1978b), but the work of Macey et al. (2001) and Vredenburg et al. (2007) support his notion that Sierran populations represent more than one species, albeit with fewer units than Cory envisioned. However, Vredenburg et al. (2007) also identified substantial genetic subdivision within the two newly recognized mountain yellow-legged frog species. In particular, Vredenburg et al. (2007) found that *R. sierrae* is well differentiated into three clades: one that occupies the Feather River drainage; one that ranges from Diamond Mountains (Plumas County) to the Ritter Range (Madera County); and a third that ranges from the Merced River (Mariposa County) to the Monarch Divide (Fresno County), and east of the Sierran crest from the Glass Mountains (Mono County) southward into northern Inyo County. Vredenburg et al. (2007) also found that in the Sierra Nevada, *R. muscosa* (sensu stricto) is comprised of two well differentiated clades: one that ranges south of the Monarch Divide to the headwaters of the Kern River to Mount Whitney (Tulare County); and a second that is restricted to the remainder of the Kern River watershed but overlaps the first clade near Lake South America in the headwaters of the Kern River. A third clade of *R. muscosa*, in the Transverse Ranges of southern California, occurs outside the Sierra Nevada. These subdivisions may be critical to conservation actions.

The recent listing of both mountain yellow-legged frog species in the Sierra Nevada as Endangered considers the northern (Sierra Nevada) population of *R. muscosa* a distinct population segment (DPS) from the southern California population based on geographic separation and differences in vocalization, habitats, management requirements, and genetics (USFWS 2013). The proposed critical habitat designation recognized the five clades for the two species in the Sierra Nevada described in Vredenburg et al. (2007).

Description

Because the recognition of two species of mountain yellow-legged frogs is relatively recent, most available data describes a composite of both species. Hence, except where differences between the two species are identified explicitly, composite data are presented. This does not mean that other differences between the two species do not exist; they are simply unidentified at this time.

Mountain yellow-legged frogs are a moderate-sized (ca. 40-85 mm snout-vent length [SVL]) ranid frog (Figure 1). As is common among western North American ranid frogs, females are larger, on average, than males, and males have swollen, darkened thumb bases (Zweifel 1955), called nuptial pads. Wright and Wright (1949) reported that males attain 72 mm SVL and females attain 85 mm SVL. Dorsolateral folds are present, but usually not prominent (Stebbins 2003). Both species lacks vocal sacs (Hayes and Krempels 1986), and have smoother tympana than the foothill yellow-legged frog (*R. boylii*), with which they may be confused (Zweifel 1955, Stebbins 2003). The two species of mountain yellow-legged frog are similar in appearance but *R. muscosa* (sensu stricto) has longer limbs than *R. sierrae*; the morphological feature that best distinguishes the two species is the ratio of the length of the lower leg (fibulotibia) to SVL, which is typically ≥ 0.55 in *R. muscosa*, but < 0.55 in *R. sierrae*, though limited overlap exists (Vredenburg et al. 2007). Mountain yellow-legged frogs can produce an odiferous skin secretion when disturbed (Zweifel 1968), the smell of which has been compared to garlic (Stebbins 2003).

Adult coloration is highly variable, with a dorsal pattern ranging from a few large to many small discrete dark spots within a variably colored mosaic of pale spots of different sizes and shapes (Stebbins 2003). Irregular lichen-like patches (origin of the name "*muscosa*") or a poorly defined reticulum also may exist (Zweifel 1955). Dorsal coloration is usually a mix of brown and yellow, but often with gray, red, or green-brown; some individuals may be a dark brown with little pattern (Jennings and Hayes 1994). The venter and undersurfaces of the hind limbs are yellow, which ranges in hue from pale lemon yellow to an intense sun yellow (Wright and Wright 1949), and may include a faint orange tint in the largest individuals, which are invariably females (M. Hayes, unpubl. data). The throat is white or yellow, sometimes with a mottling of dark pigment (Zweifel 1955).

Figure 1 – Mountain yellow-legged frog adult
Photographed by Isaac Chellman

The larvae (tadpoles) of mountain yellow-legged frogs are generally mottled brown in dorsal coloration, with a golden tint and a faintly yellow venter (Figure 2; Zweifel 1955, Stebbins 2003, Altig et al., undated). Larval body shape is generally depressed, with a low dorsal fin that originates near the tail-body junction (Altig et al., undated). Larvae range in size up to 72 mm total length (Wright and Wright 1949, Stebbins 2003). A maximum of 8 labial tooth rows (2-4 upper and 4 lower) exist (Stebbins 2003, Altig et al., undated); labial tooth row numbers increase during larval development (Zweifel 1955) and the maximum number of tooth rows is found during Gosner (1960) stages 30-36 (Altig et al., undated).

Available egg mass descriptions, most of which are for what is now recognized as *R. sierrae* (except for some observations of Vredenburg et al. 2004), indicate that egg masses are an irregular round or oval shape, may or may not be attached, and have prominent individual egg capsules (Livezey and Wright 1945, Wright and Wright 1949, Zweifel 1955, Pope 1999a). One *R. sierra* egg mass from Convict Creek was reported to have 120 eggs (O. Smith in Wright and Wright 1949) and Livezey and Wright (1945) reported a mean of 233 eggs for 6 *R. sierrae* masses (range: 100-350). Based on having observed egg masses with as few as 15 eggs, Vredenburg et al. (2005) thought that clutch size might average smaller. As Zweifel (1955) estimated the egg complement of one *R. sierrae* from Calaveras County at 800 eggs, clutch size may differ substantially from the ripe egg complement females carry. Moreover, the comment of Vredenburg et al. (2005) is based on numbers that now represent both species (V. Vredenburg, pers. comm., 2006), so species differences in clutch size may exist. Based on a sample of 145 *R. sierrae* egg masses from the Dusy Basin (Fresno County), Pope (1999a) saw egg mass volume roughly double during development (early: mean = 84 cm^3; late: mean = 198 cm^3). However, variability in egg mass size was large (i.e., well over an order of magnitude; early range: 8-294 cm^3: late range: 30-693 cm^3; Pope 1999a), with the smallest masses being no larger than a walnut and the largest grapefruit-sized. Thus, variability in egg mass size appears to be a combination of clutch size, hydration during early development, and age of the egg mass. The possibility also cannot be excluded that the smallest "masses" represent fragments that were somehow separated from the remainder of the mass during the oviposition process (e.g., Kagarise Sherman 1980). Vredenburg et al. (2004) also found that the mean diameter of 247 egg masses from 6 populations of *R. sierrae* averaged significantly larger than 312 egg masses from 7 populations of *R. muscosa*. Whether this difference is a species characteristic or reflects the demographic structure of compared populations that may be linked to geographic clines is unclear.

Based on one *R. sierrae* egg mass from Convict Creek, Mono County, each egg is 1.8-2.3 mm in diameter, and has a dark animal pole, a gray-tan vegetal pole, and a vitelline capsule and three jelly envelopes that have an outside diameter of 6.4-7.9 mm surrounding each egg (O. Smith in Wright and Wright 1949). Zweifel (1955) found that 41 eggs from a *R. sierrae* from Calaveras County ranged from 2.0-2.3 mm in diameter and 14 eggs from a *R. sierrae* from Nevada County ranged from 2.3-2.6 mm in diameter. As the latter data were from females rather than from newly laid egg masses, egg mass diameter at oviposition may differ. The vitelline capsule and envelopes are clear, transparent, and, when fresh, are easily observed in adequate light (Wright and Wright 1949).

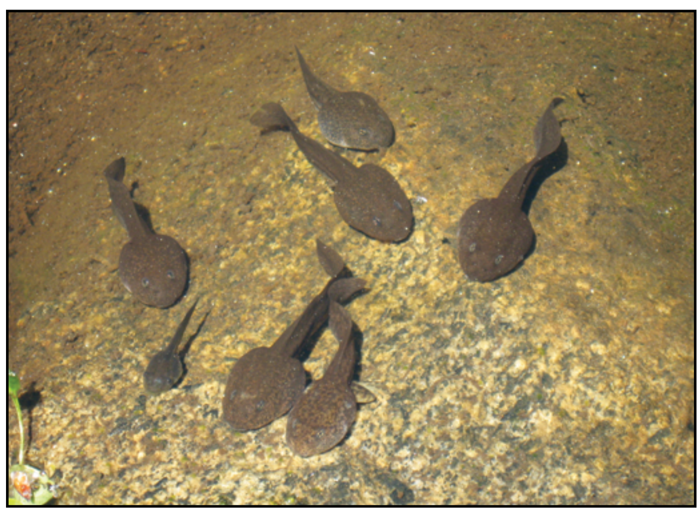

Figure 2 – Mountain yellow-legged frog larva (tadpoles)
Photographed by Stephanie Barnes

Habitat Requirements

Mountain yellow-legged frogs in the Sierra Nevada live in high mountain lakes, ponds, tarns, and streams, largely in areas that were glaciated (Zweifel 1955) as recently as 18,000 years ago (Phillips et al. 1996, Phillips 2001). Zweifel (1955) considered these species to be strongly associated with montane riparian habitats in lodgepole pine (*Pinus contorta*), yellow pine (*Pinus ponderosa* complex), sugar pine (*Pinus lambertiana*), white fir (*Abies concolor*), whitebark pine (*Pinus albicaulis*), and wet meadow vegetation types (also Zeiner et al. 1988).

In general, more studies have addressed mountain yellow-legged frogs in high elevation lentic habitats than in stream or meadow habitats and in the southern parts of their range more than in the central and northern parts. Thus, more is known about habitat usage in high elevation lakes in the southern portion of the species' Sierran range.

Mountain yellow-legged frogs often use alpine lakes with grassy or muddy margins (Zweifel 1955), but are not limited to such lakes. Vredenburg et al. (2004) found that *R. muscosa* (sensu stricto) tended to use stillwater habitats more frequently than *R. sierrae*, but it is unclear whether this difference is simply the result of stillwater habitat being more frequent within the geographic range of *R. muscosa* or an actual phylogenetic difference in habitat selection behavior. Deepwater (> 2.5 m maximum depth) lakes and ponds with open shorelines and lacking introduced fishes are often used (Grinnell and Storer 1924, Mullally and Cunningham 1956, Bradford 1982, 1983, Matthews and Pope 1999, Knapp and Matthews 2000a, 2000b, Knapp et al. 2003, Knapp 2005). In extensive studies in Yosemite National Park and portions of the John Muir Wilderness and Kings Canyon National Park, Knapp (2005) and Knapp et al. (2003) found that the probability of mountain yellow-legged frog occurrence in water bodies increased sharply with depths up to roughly 4-5 m, but was relatively constant thereafter. Use of deeper stillwater habitat likely reflects irregular patterns of oxygen depletion in shallow lakes that can lead to overwintering mortality (Bradford 1982, 1983). During the day, adults frequently sit on rocks along shorelines having little or no vegetation (Grinnell and Storer 1924, Storer 1925, Wright and Wright 1933, Mullally and Cunningham 1956). Both larvae and adults prefer open gently sloping shorelines with shallow water (i.e., 5-8 cm [2-3 in]); open areas on the margins of glaciated lakes support some of the highest densities of frogs (Grinnell and Storer 1924, Storer 1925, Zweifel 1955, Mullally and Cunningham 1956). Use of open habitats is likely related to ensuring adequate insolation of different life stages. For example, *R. sierrae* eggs laid in exposed shallows can grow faster than eggs laid either in deeper water or more shaded sites (Pope 1999a). Larvae that use shallows can increase their assimilation rate of food and thus also increase growth rates, and basking adult females likely increase the rate of development of their ova (Bradford 1982, 1983, Jennings and Hayes 1994). The data of Pope (1999a) imply that frogs select oviposition sites with the right thermal characteristics because the egg masses she studied were located such that their exposure to the east was maximized. Shallows also may provide a refuge if predatory fishes occur in adjacent deeper water (Jennings and Hayes 1994). In the Yosemite study, Knapp (2005) also noted that the likelihood of mountain yellow-legged frog occurrence increased linearly between where shoreline habitat consisted of an exclusively boulder configuration to one with exclusively meadow margins. Meadow margins may confer a refuge- or food-related advantage.

Mountain yellow-legged frogs also use streams (Vredenburg et al. 2004, MGW Biological 2008, Foote et al. 2013) though less is known about the species' use of these habitats. Adults use streams that vary from high-gradient channels replete with pools, rapids, and small waterfalls to reaches with marshy edges and sod banks (Zweifel 1955, Foote et al. 2013, K. Matthews, unpubl. data). As a consequence, the aquatic substrates in these streams vary from bedrock to boulders, rubble, and fine sand (Zweifel 1955, Foote et al. 2013, K. Matthews, unpubl. data). Stream intersections having irregular banks and variable water depths may be higher quality habitat because some of the highest densities of frogs have been recorded there (Mullally and Cunningham 1956). Moreover, Mullally and Cunningham (1956) found frogs unusually abundant at the rocky outlet of lakes and the streams extending from there, and emphasized the apparent importance of rocky habitat. Anecdotal observations suggest that mountain yellow-legged frogs favor low to moderate gradient streams with low to moderate flows, perhaps due to scour risk at high flows (Storer 1925, Stebbins 1951, Heller 1960, Matthews et al. 2004 unpubl., Vredenburg et al. 2004, MGW Biological 2008). Lower frog densities in high-gradient streams have been related to the lack of suitable (i.e., low flow) overwintering habitat (Mullally and Cunningham 1956), but it may just be a consequence of an inability to reproduce successfully in high-gradient streams (R. Knapp, pers. comm., 2000). Mullally and Cunningham (1956) rarely found mountain yellow-legged frogs in the smallest creeks. Stream-dwelling mountain yellow-legged frogs on the Plumas National Forest (in the northern part of *R. sierrae's* range) have been found in first order headwater streams to primarily second order streams (T. Hopkins, pers. comm.). MGW Biological (2008) conducted a three-year telemetry study on the movement patterns, home range, habitat associations, and distribution of what were considered mountain yellow-legged frogs in a northern Sierra Nevada stream on the Plumas National Forest. (It should be noted that there is some question on the taxonomy of the frogs in this stream. Genetic analysis suggested that both *R. sierrae* and *R. boylii* may have been present.) Substrate on the creeks was predominately boulder and bedrock. Vegetation along the stream banks was variable and included dense patches of annual sedges and willows (*Salix* spp.), various types of brush, and bare stream banks. Canopy cover ranged from 0% to about 50%. Large woody debris was frequent. Frogs were typically observed in the main stream channel fully or partially above water (77% of 747 relocations). In the few cases when frogs were found away from the main channel, they were almost always associated with water. Some habitat usage was assessed though not evaluated relative to available habitat. Frogs were predominately found in shade (77% of 728 relocations) though this is confounded with differences in the amount of sunlight available at the locations where frogs were found. Frogs were often observed after the ends of riffles in pools and were predominately associated with rocks (74% of 733 relocations). Other habitat types where frogs were found included reeds, brush, bedrock, cobble boulders, wood, mud banks, a combination of two or more of these habitat types, or in water.

Adults can breed in a diversity of aquatic habitats both lentic and lotic. Eggs have been found in the shallows of lakes or ponds or in inlet streams (Zweifel 1955, Pope 1999a), and in both small and medium streams (J. Williams, pers. comm., 2007, T. Hopkins, pers. comm., 2007). Using a five-category oviposition habitat scoring system (spring, creek, lake, marsh, or pond/marsh), Vredenburg et al. (2004) found that *R. muscosa* (sensu stricto) laid eggs predominantly in spring habitat, whereas *R. sierrae* laid eggs mostly in marsh or pond/marsh habitats. On the Plumas NF, breeding locations have been found in low gradient channels in wet meadows, man-made ponds, and larger pools with high flows at the confluence with another stream. MGW Biological (2008) found Ranid egg masses at the confluence of a first order and second order stream. Mountain yellow-legged frogs also reproduce in slow moving streams on the Eldorado National Forest (J. Williams, pers. comm., 2007). Mountain yellow-legged frogs deposit their eggs underwater in clusters attached to rocks, gravel, vegetation, or under banks, or unattached in shallows (Zweifel 1955, Pope 1999a, Vredenburg et al. 2004). In Middle Creek on the Eldorado National Forest, egg masses have been observed under suspended logs mid-channel. The channel was about 5 to 6 feet wetted width and about 3 feet deep (J. Williams, pers. comm., 2007). Breeding sites are generally located in, or connected to, seasonally perennial waters that are deep enough (i.e., typically > 2 m) to not freeze to the bottom during winter (Bradford 1982, 1983) because larvae typically overwinter at least once prior to metamorphosis. Successful breeding has rarely been observed in ponds < 2 m deep (Pope 1999a), but larvae having relatively high tolerance to hypoxia relative to adults (Bradford 1982, 1983) may allow irregular recruitment from such habitat. Lacan et al. (2008) found successful recruitment only in sites that retained water for the duration of the 2-3 year larval period, even if the amount of water was small. They found little evidence of winterkill in sites with shallow water, and concluded that desiccation of tadpoles in habitats that dry during the summer was an important cause of mortality. They note, however, that the presence of introduced trout may have excluded frogs from preferred deeper permanent lakes.

In the high Sierra Nevada stillwater habitats, larvae and postmetamorphic life stages (i.e., adults and juveniles) of both species generally overwinter in aquatic habitats under ice (Grinnell and Storer 1924, Mullally 1959, Bradford 1982, 1983, Matthews and Pope 1999). Dehydration intolerance (Hillman 1980) may constrain adult frogs to aquatic hibernation. Both adults and larvae are recorded as overwintering (up to 9 months) at the bottoms of lakes (minimally 1.7 m deep; preferably at least 2.5 m deep) (Bradford 1982, 1983), or in rocky streams (Vredenburg et al. 2005). Frogs can also overwinter in bedrock crevices (Matthews and Pope 1999), which may allow them to survive in shallower water bodies that freeze to the bottom in winter (Pope 1999a). Use of these overwintering habitats may be a response to the presence of introduced fish that cannot survive in ponds that completely freeze (Vredenburg et al. 2005). The telemetry study on the Plumas NF found that stream-dwelling Ranid frogs usually overwintered in rock crevices, undercut banks, and seeps within mud holes (MGW Biological 2008). These areas may also have out-of-water overwintering space that adults could potentially use (K. Matthews, unpubl. data). No data exist on the range of variation in overwintering habitat in streams.

Life History

Mountain yellow-legged frogs emerge from overwintering sites at spring thaw or snowmelt (Camp 1917, Zweifel 1955, Heller 1960, Pope 1999a, Vredenburg et al. 2005, D. Bradford, pers. comm., 2002). At this time, frogs using stillwater habitats may be observed sitting on the margins of receding sheet ice (Bradford 1984a).

Breeding activities occur earlier (April-May) at lower elevations and progressively later (June-July) at higher elevations (Wright and Wright 1933, Stebbins 1951, Zweifel 1955). Timing of the onset of breeding depends on snowfall levels and temperature patterns during thaw, which affects when ponds, lakes, and streams lose ice (Vredenburg et al. 2005). In years with exceptionally heavy snowpacks, frog populations at high elevations may be active for only about 90 days during the warmest part of summer (Bradford 1982, 1983, Vredenburg et al. 2005). Data on the emergence pattern from stream habitat are lacking (K. Matthews, pers. comm., 2006).

Egg masses are frequently laid communally (Zweifel 1955, Pope 1999a). In the Dusy Basin, Pope (1999a) found that *R. sierrae* eggs masses likely found within 1-2 days of oviposition hatched in 15 to 20 days over a water temperature regime during which daily means climbed rapidly from around 5°C to 14-17°C over the first week. Zweifel (1955) had eggs hatch in 18-21 days during laboratory breeding experiments at water temperatures intended to mimic field temperatures at 5-13.5°C. This data is lacking for stream dwelling populations.

Warmer microhabitat selection allows larvae to maintain relatively high body temperatures (Bradford 1984a). Before spring overturn, larvae stay in warmer water below the thermocline; after spring overturn, they move to warm shallows daily, exploiting daily changes in water temperatures. Larvae may form diurnal aggregations in shallow water that may number in the hundreds, and voluntarily elevate their body temperatures to as high as 27°C (Bradford 1984a). Despite such behavior, larvae typically overwinter at least twice for 6- to 9-month intervals (Cory 1962b, Bradford 1982, 1983) before attaining metamorphosis because the active season is short and water temperatures are warm for only a relatively brief seasonal interval (Mullally and Cunningham 1956). The time required to develop from fertilization to metamorphosis may vary from 1 to as much as 4 years and depends on a temperature regime that is largely a function of elevation (Storer 1925, Wright and Wright 1933, Zweifel 1955, Cory 1962b, Bradford 1982, 1983, Bradford et al. 1993, Knapp and Matthews 2000a, Vredenburg et al. 2005). Whether overwintering actually occurs in the lower elevation populations in the northern portion of the range of *R. sierrae* (e.g., Plumas National Forest) or whether larvae metamorphose in one year has been questioned (K. Matthews, pers. comm., 2006). Larvae can survive hypoxia for months, which may allow survival in shallow lakes that freeze to the bottom (Bradford 1982, 1983, Pope 1999a, Matthews and Pope 1999, also Lacan et al. 2008). In *R. muscosa* (sensu stricto) from Southern California, overwintering results in larval death when aquatic habitat becomes ephemeral in some years (Mullally 1959). Desiccation mortality in ephemeral sites also has been observed in *R. sierrae* (Lacan et al. 2008, C. Brown, pers. comm., 2013), though aquatic habitats used by the Sierran mountain yellow-legged frog likely become ephemeral much less frequently. However, drought potentially induced by patterns of climate change (see Climate Change under Risk Factors) has the potential to alter the historical pattern.

After metamorphosis, the time required to reach maturity has been estimated to be 3-4 years (Zweifel 1955), but this assessment is speculative. Adult annual survivorship is high (Pope 1999a, Matthews and Pope 1999, Matthews and Preisler 2010, Foote et al. 2013), and assessment of longevity based on skeletochronological data of 149 individuals (74 females, 44 males, and 31 juveniles) confirmed that mountain yellow-legged frogs are relatively long-lived (Matthews and Miaud 2007). Skeletochronological ages of post-metamorphic frogs ranged from 0-10 years ($\bar{x}$= 4.1 years) for females and 0-8 years ($\bar{x}$= 4.0 years) for males; given that the larval stage can last up to four years, this would put the maximum age of frogs from this sample at 14 years. Matthews and Miaud (2007) also found that frogs from lower elevation sites were consistently larger at a given age, indicating slower growth at higher elevations. During the active season, postmetamorphic frogs appear to maximize body temperatures at nearly all times of the day by basking in the sun, moving between water and land (depending on which is warmer), and concentrating in the warmer shallows along the shoreline (Bradford 1984a, Pope 1999a, Matthews and Pope 1999). Bradford (1984a) found that most mountain yellow-legged frogs would bask in the sun on wet soil in the morning, move to shallow water in the afternoon, and then move to deeper water at night. Adults are often seen on wet substrates within 1 m of the water's edge (Zweifel 1955).

As temperatures drop to freezing or below (generally October to November), frogs become less active as the winter season approaches (Zweifel 1955, Bradford 1982, 1983, Pope 1999a, Matthews and Pope 1999). Mountain yellow-legged frogs appear to display strong site fidelity and return to the same breeding, overwintering and summer habitats annually (Pope 1999a, Matthews and Preisler 2010).

Population Dynamics

Demographic data on historical populations of mountain yellow-legged frogs are anecdotal and limited. Essentially, no data actually precede the fish-planting era in high mountain lakes and streams (the earliest recorded plantings date from the mid-1800s [see review in Knapp 1996]). Nevertheless, mountain yellow-legged frog data from the earliest 20th-century dates available describe them as having been abundant in aquatic habitats from the high Sierra Nevada. Grinnell and Storer (1924) reported that it [now *R. sierrae*] was "…the ***commonest*** amphibian in most parts of the Yosemite section. Its total range is…less than that of the Pacific tree-toad [= Pacific treefrog (*Pseudacris regilla*)]; but its numbers, especially at the higher altitudes, far exceed those of the smaller species. This frog is the species ***most likely*** to come to the attention of fishermen and others who may walk along the banks of Sierran streams and lakes."(*italics* ours) In the same work, Grinnell and Storer (1924) added, "Certain of the lakes in the higher parts of the Yosemite contain ***large numbers*** of Yellow-legged Frogs in…tadpole and adult conditions" (*italics* ours).

Investigators in the 1950s also implied that mountain yellow-legged frogs occurred in large numbers. On 26 April 1953, Richard Zweifel (pers. comm., 2005) visited French Joe Meadow, Tulare County; his field notes state, "*Rana sierrae* [now *R. muscosa* (sensu stricto)] was abundant here." He further elaborated that, "Young *Rana sierrae* were found to be very abundant in a small, weedy pond in the meadow…Another nearby pond contained very few frogs but many large tadpoles." In an October (1953) search along about a mile of San Antonio Creek below the meadow at Dorrington (Calaveras County), Zweifel (1955) described the mountain yellow-legged frog as "common". Zweifel's field notes referring to mountain yellow-legged frogs from 4 October 1953 state, "Small frogs, some with tail incompletely resorbed, very abundant. Also many large tadpoles. Larger frogs including a gravid female also taken." Zweifel (pers. comm., 2005) indicated that he worked downstream from the Dorrington Trout Ranch on San Antonio Creek; his field notes indicated that, "Frogs [referring to mountain yellow-legged frogs] were abundant along the stream here and on down where the gradient was less steep." Mullally and Cunningham (1956) stated that, "…a great many [mountain yellow-legged frogs]…were noted…near Pine Creek Pass at…11,170 ft." Where numbers are mentioned, they have qualitative descriptors like "hundreds" (Cory 1989) or "thousands" (e.g., NPS 1999). How current populations compare to historical numbers is unknown, but they are believed to be smaller due to fish introductions, disease, decreased habitat quality, or other factors.

Two studies (Sixty Lakes Basin, Vredenburg 2004, Vredenburg et al. 2010; Dusy Basin, Kings Canyon National Park, Matthews and Pope 1999, Pope 1999a, Pope and Matthews 2001, 2002) addressing *R. muscosa* (sensu stricto) and *R. sierrae* were conducted in basins that may have approximated historical conditions. Today few populations of these sizes exist and most populations are much smaller (e.g., 20-30 or fewer adults; Foote et al. 2013, Brown et al. 2014, CDFW unpublished data Sarah Mussulman, pers. comm., 2013, see Status section). In both Sixty Lakes and Dusy Basin, population abundances are now greatly reduced because of infection by the chytrid fungus, *Batrachochytrium dendrobatidis* (Bd) (Vredenburg et al. 2010). Even prior to the arrival of Bd, the presence of fish in these basins appeared to have altered mountain yellow-legged frog habitat use (see Introduced Fish and Other Predators section). Descriptions of the mountain yellow-legged frog populations in the two basins prior to the arrival of Bd follow.

In the Sixty Lakes Basin, all bodies of water within the basin (n Â 81) were monitored each year over the interval 1996-2008 (Vredenburg et al. 2010); from 1996-2001, 1,800 frogs were marked with passive inductance transponders (PIT tags) in 15 lakes (Vredenburg 2004, V. Vredenburg, pers. comm., 2006). Egg masses were recorded in 20 of the 81 sites. Egg mass counts at the different sites ranged from about 10 to > 350. Hatching success was extremely high (98-100 percent in 99.5 percent of the 2000 egg masses surveyed, 1996-2001). After breeding, adult frogs, which exhibited sex ratios near 1:1, dispersed to additional aquatic habitats and were found in 41 of the sites, including all sites from which breeding was recorded. Survival of adults appeared high with between-year recapture rates for large adults close to 75 percent; subadult survival was estimated to be lower. Survival of larvae appeared more variable and tadpoles appeared at highest risk in their first winter; in one lake, larval numbers increased from ca. 2,000 tadpoles in 1999 to more than 15,000 tadpoles in 2001. Densities of post-metamorphic frogs and tadpoles were significantly greater in fish-free lakes than in introduced trout-occupied lakes (Vredenburg 2004). Bd arrived in Sixty Lake Basin in 2004 (see Vredenburg et al. 2010).

In the Dusy Basin, 582 frogs were marked over a 2-year period in the 11 lakes within the basin (Pope 1999a). Breeding occurred in 8 lakes within the basin and most of the 154 egg masses (90 percent) were deposited in 2 lakes. Adults were found in all 11 lakes and moved among them during the summer. Seventy-eight percent of adult frogs marked in the first year of the study were recaptured in the second year, but subadult frogs were much less likely to be recaptured (Pope 1999a). Following a summer drought in 1999, about 90 percent of the first- to third-year larvae were killed due to either desiccation or winter freezing (Matthews and Pope, unpubl. data). Similar to the pattern that Vredenburg (2004) observed, summer frog densities were negatively correlated with the presence of introduced trout across the 11 lakes surveyed (Pope 1999a, Pope and Matthews 2001). Frog densities were positively correlated with water temperature, air temperature, maximum lake depth, and Pacific chorus frog presence (Pope 1999a, Pope and Matthews 2002). Matthews and Preisler (2010) contains additional data on the frog population in Dusy Basin.

Multiple site occupancy within local watersheds (Pope 1999a, Vredenburg 2004, Brown et al. unpublished data) suggests that metapopulations characterize the demographic structure of mountain yellow-legged frog populations (Bradford et al. 1993). Metapopulation theory states that species persistence depends on the extinction-colonization balance among interconnected populations. Individual sub-populations may go extinct from a variety of natural chance effects (e.g., severe winters, prolonged drought), but animals from nearby extant populations within the interconnected matrix eventually recolonize sites at which animals were extirpated (Levins 1970, see review in Hanski and Gilpin 1991). Many of the remaining populations of mountain yellow-legged frogs of both species are small and isolated (see Status section). Small populations are generally recognized as being more vulnerable to extinction than larger populations (Pimm 1991, Noss and Cooperrider 1994), especially where isolated from nearby populations that could provide a rescue effect (Brown and Kodric-Brown 1977).

Of four major factors that Noss and Cooperrider (1994) identified as predisposing small populations to extinction, one factor, high environmental variation (e.g., extreme weather conditions), is intrinsic to mountain yellow-legged frog habitat regardless of human-influenced habitat disturbances. Bradford et al. (1993) pointed out that population fluctuations induced by severe climatic variation and other factors may be characteristic in high-elevation populations of mountain yellow-legged frogs. His identification of several instances of mass mortality, including winterkill due to oxygen depletion during a particularly severe winter (Bradford 1982, 1983), heavy Brewer's blackbird predation on metamorphosing tadpoles, and large numbers of dead and diseased frogs (Bradford 1991) supports this idea.

A second major factor that Noss and Cooperrider (1994) identified as predisposing small populations to extinction is disruption of the extinction-colonization balance among interconnected populations (i.e., derailment of the metapopulation dynamic). Notably, Bradford suggested that mountain yellow-legged frog persistence in the high Sierra might be compromised where their ability to recolonize vacant waters is limited or prevented by introduced fish (Bradford et al. 1993, see discussion in the Introduced Fish and Other Predators section). Not only is this hypothesis consistent with mountain yellow-legged frog populations seeming to be most successful in lakes where predatory fishes are absent (Bradford 1989, Bradford et al. 1993, 1998; Knapp 1996, Pope 1999a, Knapp and Matthews 2000a, 2000b), but the rapid recolonization of mountain yellow-legged frogs in lakes where fish have been removed supports the idea (Vredenburg 2004, Knapp et al. 2007). It should be noted that there was no evidence that mountain yellow-legged frogs avoided fish bearing streams in the northern part of their range (J. Arrigoni, pers. comm., 2007); this merits further study.

The final two factors that Noss and Cooperrider (1994) cite as facilitating extinction in small populations, chance variation in population parameters (e.g., sex ratios) and genetic deterioration (e.g., inbreeding depression or genetic drift), also may have occurred, particularly in remaining small isolated populations. Data are lacking to verify these patterns.

That mountain yellow-legged frogs generally operate as metapopulations represents an important, but incompletely examined assumption. Research found that mountain yellow-legged frogs recolonized unoccupied sites following fish removal (Vredenburg et al. 2005, Knapp et al. 2007). A review of amphibian demography has revealed that while many amphibians seem to function as metapopulations, criteria for metapopulation structure are rarely examined (Smith and Green 2005). Understanding the degree to which mountain yellow-legged frog populations in the Sierra Nevada operate as metapopulations is basic to informing conservation approaches for this species.

Movement

In one telemetry study in lentic habitats, mountain yellow-legged frogs typically moved a few hundred meters during the active season (Matthews and Pope 1999, K. Matthews, unpubl. data). Distances greater than 1 km have been recorded which include overland travel (Matthews and Pope 1999, Vredenburg et al. 2005, *contra* Mullally and Cunningham 1956). Moreover, given Barrowclough's (1978) caution that without extraordinary effort, population movement distances are consistently underestimated, the limited available data undoubtedly underestimate the movement patterns and capabilities of mountain yellow-legged frogs. At the scale of distances between lakes in many high Sierran basins, these data indicate that the frog is capable of recolonizing other aquatic sites on a local scale. Nonetheless, more detailed movement information will be necessary to fully understand the species' seasonal movement dynamics, especially in the context of local variation in habitat conditions, which are diverse across high Sierran systems (see Matthews and Preisler 2010).

Vredenburg (2004) confirmed the idea that Sierran mountain yellow-legged frogs can engage in local-scale movements when he discovered that frogs can rapidly recolonize vacant sites (i.e., three lakes from which trout were removed in the Sixty Lakes Basin, Kings Canyon National Park), as long as source populations occur in nearby lakes (in this case, < 0.4 km upstream). This result has now been found in multiple such studies (e.g., Knapp et al. 2007). Knapp et al. (2003) found that the probability a site would be used for breeding was a function of the distance to nearby occupied sites. Finally, studies in Dusy Basin found that after breeding, some adults disperse into nearby aquatic habitats (Pope and Matthews 2001, Matthews and Preisler 2010). This body of work supports the idea that mountain yellow-legged frog population dynamics appear to be operating at scales larger than a single water body.

Adults move between breeding, feeding or non-breeding active season, and overwintering habitats during the course of the year (Pope 1999a, Matthews and Preisler 2010). Adults sometimes travel over ice or snow to reach preferred breeding sites early in the season without apparent ill effects (Pope 1999a, Vredenburg et al. 2005). Mullally and Cunningham (1956) reported that frogs avoid crossing dry ground over short distances, but mountain yellow-legged frogs have been documented moving overland at distances of 66-400 m (Matthews and Pope 1999, Vredenburg et al. 2005). However, the physical conditions under which movement actually occurred are unclear. Movement of adults between habitats used in their seasonal rounds may be a function of the relative proximity of habitats that can fulfill their seasonal requirements (i.e., breeding, foraging, or overwintering); if all habitats that adults need are close by, seasonal movements may not be as great. In this context, fish occupancy in selected water bodies may force frogs to move greater distances to fulfill their habitat needs. In support of this hypothesis, evidence exists that frogs can recognize breeding habitat as fish-occupied (Vredenburg 2004, V. Vredenburg, pers. comm., 2005).

Movement data is also available for lotic habitat in the northern part of the species' range. In July-November 2003, movement data on adult Ranid frogs (probable *R. sierrae*, K. Matthews, pers. comm., 2012) were collected along a 2.9-kilometer stream reach of the Plumas National Forest (K. Matthews, pers. comm., 2006). Located in a seasonally dry meadow within Ponderosa pine (*Pinus ponderosa*)/white fir (*Abies concolor*) forest, the reach was low-gradient, meandering, and perennial. Thirteen different adult *R. sierrae* radio-tracked over varying intervals from July to early September were invariably found near water (almost never more than 1 meter away from the stream), and they were in the stream > 80 percent of the time. Frogs moved overall linear distances ranging from 22 to 94 meters in July-August, and 5 to 54 meters in August-September. Four additional *R. sierrae* were radio-tracked from September to November, during which time frogs showed substantially decreased levels of movement; all were located within 2 to 15 meters of the location at which they were found in September. These data suggest that stream-dwelling *R. sierrae* move over a relatively localized area during the non-breeding active season.

In addition, the MGW Biological (2008) study radio-tracked movements of fifty Ranid frogs (47 females and 3 males) at a stream course in the Plumas National Forest from July 2005 to September 2007. Most frogs were found along the stream course, only 14% (of 747 relocations) were found more than 0.2 m away from the stream, and the maximum distance away from the main stream was 22 m. The maximum single movement by a frog averaged 485 m (SE = 83.9, range = 2.9-2282) and the maximum distance traveled by any frog along the stream course was 3.3 km. Most frogs exhibited similar large-scale seasonal movement patterns. Most of the summer (late June to October), frogs remained in the same general area (within 50 m). After the first major precipitation event, they moved downstream (sometimes large distances up to 2 km) and remained in these locations until early to late May. Then, in May, they moved again downstream to the confluence of Spanish Creek or into Spanish Creek. Presumably after breeding (though this was not observed), frogs then moved back upstream. The short off-creek movements occurred mostly in the winter when there were off-creek refugia available.

Almost no data exist on the dispersal of recently metamorphosed juvenile mountain yellow-legged frogs away from natal and rearing sites (Bradford et al. 1993). Bradford et al. (1993) observed juveniles in small intermittent streams, but the observational context is ambiguous. Juveniles could have been dispersing to permanent water (Bradford et al. 1993) because the intermittent habitat was a pathway or was being vacated as unsuitable, or the intermittent habitat might represent suitable active-season habitat in which juveniles might have refuge from selected predators more typically associated with permanent waters.

Feeding

Few diet studies addressing Sierra Nevada mountain yellow-legged frogs exist. Adult mountain yellow-legged frogs were thought to feed preferentially upon terrestrial insects and adult stages of aquatic insects while on the shore and in shallow water (Bradford 1982, 1983). However, an analysis of *R. muscosa* (sensu stricto) across stillwater habitats in the Sixty Lakes Basin showed that adult frogs were heavily dependent on benthic invertebrates (Finlay and Vredenburg 2007). The pattern may vary with habitat type. Stream-dwelling Southern California mountain yellow-legged frog have been reported to have a diet heavy in terrestrial invertebrates, including ants, bees, beetles, dragonflies, flies, true bugs, and wasps (Long 1970). Adult frogs have been observed eating Yosemite toad (*Bufo canorus*) larvae (Mullally 1953) and Pacific treefrog larvae (*Pseudacris regilla*) (Mullally 1953, Zeiner et al. 1988, Pope 1999b); they are also cannibalistic (Heller 1960).

Presence of anuran prey, such as the Pacific treefrog, may be an important factor in mountain yellow-legged frog selection of active season habitat because anurans may provide highly nutritious food when compared to other available prey (Pope and Matthews 2002). Few observations of mountain yellow-legged frogs eating the early life stages of Yosemite toad might be interpreted to reflect general unpalatability of those life stages, but a report of another western ranid frog consuming toadlets (*Bufo boreas*) (Pearl and Hayes 2002) may require reconsideration of this view if selected early life stages of Yosemite toads prove relatively palatable; the observations of Mullally (1953) support this hypothesis. Yosemite toads have also been in decline in Sierran ecosystems (Kagarise Sherman and Morton 1993, Brown et al. 2012), can be extraordinarily abundant at metamorphosis, and historically had a high level of co-occurrence with mountain yellow-legged frogs (Mullally 1953, Karlstrom 1962), so verification of this possibility may add to current explanations of mountain yellow-legged frog declines.

Larvae graze on algae and diatoms along rocky bottoms in streams, lakes, and ponds (Zeiner et al. 1988). However, older Sierra Nevada mountain yellow-legged frog larvae can be highly opportunistic, and have been observed cannibalizing thousands of conspecific eggs (Vredenburg 2000) in a manner that has the potential to significantly alter recruitment in some ponds. Larvae have also been seen feeding on the carcasses of dead metamorphosed frogs (Vredenburg et al. 2005).

Mortality

Known predators of Sierran mountain yellow-legged frogs include the western terrestrial garter snake (*Thamnophis elegans*) (Grinnell and Storer 1924, Mullally and Cunningham 1956, Jennings et al. 1992, Matthews et al. 2002), the common garter snake (*Thamnophis sirtalis*) (Feldman and Wilkinson 2000), Brewer's blackbirds (*Euphagus cyanocephalus*) (Bradford 1991), Clark's nutcrackers (*Nucifraga columbiana*) (Camp 1917), and coyotes (*Canis latrans*) (Moore 1929). Two anecdotal reports also exist of black bear (*Ursus americanus*) feeding on mountain yellow-legged frogs (Vredenburg et al. 2005). Introduced rainbow trout, golden trout (*O. mykiss* ssp. *aguabonita, gilberti, and whitei*), brook trout or charr (*Salvelinus fontinalis*), and brown trout (*Salmo trutta*) have been observed to prey on all life stages of mountain yellow-legged frogs (Grinnell and Storer 1924, Needham and Vestall 1938, Knapp 1996). Vredenburg (2004) confirmed introduced rainbow trout (*Oncorhynchus mykiss*) predation on larval mountain yellow-legged frogs in an experimental field enclosure. California Newts

(Taricha torosa) were documented preying on Ranid egg masses in Bean Creek on the Plumas National Forest (MGW Biological 2008). Additionally, mountain yellow-legged frog cannibalism has been observed (Heller 1960, Vredenburg 2000, Vredenburg et al. 2005).

Western terrestrial garter snakes apparently depend extensively on mountain yellow-legged frogs as a food (Jennings et al. 1992, Matthews et al. 2002). As a result, they represent an important source of mortality because they are 30 times as likely to be found in lakes with amphibians as in lakes lacking them (Jennings et al. 1992, Matthews et al. 2002).

Mountain yellow-legged frogs are also susceptible to mortality from diseases (see Disease under Risk Factors). Bradford (1991) observed a large-scale die-off of mountain yellow-legged frogs, which exhibited red-leg symptoms associated with a bacterium (*Aeromonas hydrophila*). In this case, the cause of mortality is ambiguous because red-leg symptoms can occur as a secondary manifestation linked to a variety of pathogens (Green et al. 2002). The chytrid fungus, *Batrachochytrium dendrobatidis* (Bd, Berger et al. 1998, Longcore et al. 1999), has played a large role in the widespread mountain yellow-legged frog declines throughout the Sierra Nevada (Rachowicz et al. 2006, Briggs et al. 2010, Vredenburg et al. 2010). A second infectious disease, an iridovirus, has appeared in Kings Canyon populations of the mountain yellow-legged frog. These diseases and other potential ones in related amphibians are detailed in the Disease section under Risk Factors.

Unpredictable aspects of the environment in which mountain yellow-legged frogs live can also influence mortality. Life history characteristics (e.g., aquatic overwintering under ice-capped conditions and multi-year larval development) may make the mountain yellow-legged frog particularly susceptible to large-scale die-offs (Center for Biological Diversity and Pacific Rivers Council 2000; see also previous section on Population Dynamics). In shallow lakes, overwintering frogs may succumb more easily to oxygen depletion than larvae (Bradford 1983) and introduced fish presence may force the use of shallow lakes (see Habitat Requirements and Movement sections). Additionally, in drought years, larvae in shallow rearing sites may be lost to desiccation (Mullally 1959).

Key Ecological Factors to Consider in the Conservation Strategy

Many factors contribute to the long-term viability of the mountain yellow-legged frog, but the following components of its natural history were identified as central to the conservation of the species:

- Resource needs of each life history stage (eggs, larvae, metamorphs, juveniles, adults) vary and should each be considered in the Conservation Strategy. Long-term viability requires successful breeding, and recruitment and survival of new individuals. The apparently long lifespan of the frog may sustain populations during stochastic environmental events that naturally occur (e.g., prolonged drought, extreme cold periods, severe predation events on non-adult life stages) as long as such events are not too protracted and assuming that older individuals are capable of successful reproduction.
- Conservation efforts should address the key habitat components of both species of mountain yellow-legged frog. Both species need access to several different habitats annually to complete their seasonal life history, as well as to survive the inter-year climatic variation that may alter the seasonal pattern of habitat use. These habitats include deep lakes, shallower lakes and ponds, and streams that provide:
    - Habitat for oviposition and prehatching development (e.g., shallow habitat within lakes, ponds, and streams)
    - Permanent water for rearing the multi-year tadpole stage and enabling metamorphosis (e.g., deep lakes, streams with shallow rearing habitat)
    - Active-season habitat, which includes feeding and refuge habitats, for adults and subadults (all types of aquatic habitats)
    - Overwintering habitat for all life history stages (e.g., deep lakes and streams that do not freeze over winter)

- The two mountain yellow-legged frog species in the Sierra Nevada display considerable genetic differentiation across their range, so developing a strategy at the scale of their geographic ranges is important. Goals are to:
  - Preserve the genetic variability present throughout the range of the significant genetic subunits of both species in the Sierra Nevada
  - Move towards re-establishing and preserving the gene flow that was historically present

  To accomplish this, the strategy should seek to:
  - Conserve populations throughout the historical range
  - Preserve connecting habitat providing the potential for immigration, emigration, and recolonization

  Spatial scales over which populations function remain largely unknown; genetic data are needed to effectively and precisely define that scale and its variation.
- Genetics must also be considered if translocation becomes an option.
- Conservation actions for both species should integrate strategies at multiple scales.

In summary, the Conservation Strategy should provide mechanisms to manage both species throughout their entire ranges, for all life history stages, and for all required habitats (e.g., lakes, streams, ponds). The strategy should provide mechanisms to manage both species at multiple scales and should seek to stabilize populations and increase abundances by protecting existing populations and increasing the connectivity among them.

STATUS

This section provides a general summary of the status of the mountain yellow-legged frog complex in the Sierra Nevada comparing recent and historical population distribution and abundance. Historical data is defined to be prior to 1980. Originally, locality data was compiled through 2001, and thus the recent period was defined to be 1980 to 2001. Substantial new information has been collected since 2001, a subset of which also is presented. As dramatic changes in the species' status have recently been quantified (Vredenburg et al. 2007, Brown et al. 2014), the description of changes within the time interval treated as recent is particularly important.

In 2001, information was compiled from the Center for Biological Diversity and Pacific Rivers Council petition to the US Fish and Wildlife Service to list the Sierra Nevada mountain yellow-legged frog (J. Miller, pers. comm., 2001, permitted use of this information from the Center for Biological Diversity), from National Forest, National Park Service, and California Department of Fish and Wildlife biologists, from academic researchers working in the Sierra Nevada, and from literature and museum sources. Data collected after 2001 have been compiled to a limited extent and are described in this assessment to varying degrees.

Where documentation from museum collections is mentioned, records are listed in parentheses with the standard symbolic codes for each institution (Appendix A) followed by the pertinent specimen number(s). Appendix B provides status information partitioned by individual administrative units or political entity, (i.e., individual National Forests and National Parks, and the state of Nevada).

Pre-1980

As defined here, "historical" data for the mountain yellow-legged frog in the Sierra Nevada comprise over 2,000 specimen and sighting records representing over 400 localities that date from 1876 to 1979. These historical data are a combination comprised mostly of collections, but also include scattered sighting information recorded in peer-reviewed and other literature, National Forest or National Park databases, and a few other miscellaneous sources. As a consequence, these data are a composite of mostly verifiable and some unverifiable information (i.e., data of a form that cannot be independently verified by others); the few unverifiable data are assumed to represent valid data on the mountain yellow-legged frog.

Literature indicates that populations in the Sierra Nevada were distributed from near Antelope Lake, Plumas County, (G. Fellers in Vredenburg et al. 2005, also see Foote et al. 2014), south to Taylor and French Joe Meadows, Tulare County, (Zweifel 1955), with disjunct populations north of the Feather River, Plumas, Sierra, and Butte Counties (Koo and Vindum 1999), and an isolate on Breckenridge Mountain in Kern County (Figure 3). However, a verifiable historical record based on two frogs collected 1.6 km east of Drakesbad (UMMZ 200265-200266) indicate that the distribution of the mountain yellow-legged frog actually extended to the extreme north reaches of the Feather River within the southern end of Lassen National Park (M. Hayes, M. Jennings, V. Vredenburg, unpubl. data). The known elevational range was from ca. 1,370 m at San Antonio Creek in Calaveras County to over 3,650 m at Desolation Lake in Fresno County (Zweifel 1955, Mullally and Cunningham 1956). Its documentation in Pinkard Creek meadow at 1,044 m in Butte County (Koo and Vindum 1999) is believed to extend the lower limit of the historical elevational range rather than represent recent range expansion. Except for near Lake Tahoe (Zweifel 1955, Jennings 1984, Panik 1995) and Fish Lake (Esmeralda County), Nevada (Giuliani 1994), the historical range was exclusively in California. Except for disjunct populations north of the Feather River (Hayes and Cliff 1982, Koo and Vindum 1999) and on Breckenridge Mountain, the species' historical distribution was thought to be relatively continuous in the Sierra Nevada at a basin scale (Center for Biological Diversity and Pacific Rivers Council 2000). It is currently unknown whether populations north of the Feather River actually represent a historical discontinuous distribution or represent regionally limited historical surveys (Koo and Vindum 1999).

Population-level historical information on the mountain yellow-legged frog in the Sierra Nevada is entirely qualitative and available for only a few localities, all within Yosemite National Park, and hence, represents exclusively the recently recognized species, *R. sierrae*; these extend over a timeline between 1914 and the late 1950s. The earliest records regarding abundance were those made during the transect survey across the Yosemite portion of the Sierra Nevada conducted from 1914 through 1920 by field teams from the

Museum of Vertebrate Zoology at Berkeley (Grinnell and Storer 1924). *Rana sierrae* were described as "the most abundant amphibian" along the Yosemite section of their survey (Grinnell and Storer 1924). Numerous frogs were found in lakes and streams throughout the high-elevation portion of the Yosemite transect, from Westfall Meadow and Porcupine Flat east to the head of Lyell Canyon and Tioga Pass. "Hundreds of frogs" were found at Young Lake, and frogs were "very numerous" at Westfall Meadow (C. Camp field notes 1915, as cited in Drost and Fellers 1994). Camp (1917) also noted that "...in some of the lakes, it was found in great numbers…" which referred at least in part to his observations at Tenaya Lake (C. Camp field notes at MVZ). During 1939, the Park Service initiated their own series of collections and observations (NPS 1999); most sites for which the Park Service obtained information overlapped with previous collection locations, but these new data also had a few qualitative assessments of relative abundance. In particular, *R. sierrae* were described as "especially numerous" at Upper McCabe Meadows and "thousands" were counted near Middle McCabe Lake. The species was also described as "abundant" in lakes and streams in Virginia Canyon from 3,290-3,415 m, and "very numerous" in Upper Virginia Canyon's lakes, ponds, and streams (NPS 1999). Mullally and Cunningham (1956) remarked that some of the "densest aggregations of frogs ever noted" were within lakes close to Ostrander Lake just south of Glacier Point. David Wake, senior research herpetologist at the University of California at Berkeley Museum of Vertebrate Zoology, reported that while hiking near Tioga Pass during the summer of 1959, he saw so many mountain yellow-legged frogs that "it was difficult to walk without stepping on them" (Parker 1994). Population levels comparable to those observed in Yosemite National Park may have been present across the historical ranges of *R. muscosa* (sensu stricto) and *R. sierrae*.

Post-1980

Beginning in the 1980s, investigators began to repeatedly report that mountain yellow-legged frogs had disappeared from a significant portion of their historical range in the Sierra Nevada (Hayes and Jennings 1986, Jennings and Hayes 1994, Bradford et al. 1994a, Jennings 1995, 1996, Stebbins and Cohen 1995, Drost and Fellers 1996, Knapp and Matthews 2000a, 2000b, Vredenburg et al. 2005, 2007). Some investigators suggested that some declines occurred prior to 1980 (Grinnell and Storer 1924, Cory 1963; see summary in Hayes and Jennings 1986); infrequent reports imply that declines were small through the 1970s, but increased in size and magnitude during the 1980s and 1990s as more researchers spent time in the field. Few rangewide estimates of population disappearance have been attempted, but those available indicate an extremely rapid decline within the last 20 years with estimated declines of roughly 50 percent based on the assessment interval 1988-1992 (Jennings and Hayes 1994), over 92 percent based on a "current" interval defined as 1995-2005 (Vredenburg et al. 2007), and over 50% in watersheds occupied as recently as the 1990s (Brown et al. 2014). Figure 3 depicts an estimate of the current level of disappearance across the geographic range of the mountain yellow-legged frog in the Sierra Nevada.

Although historical data is limited, several recent range-wide survey efforts have provided a more complete picture of the current distribution of mountain yellow-legged frogs. A rangewide compilation done with a composite of data through 2002 revealed that roughly 210 sites (not defined) on Sierra Nevada National Forests had mountain yellow-legged frogs, though not all of these had evidence of reproduction (USFWS 2003). In National Parks, 758 sites had mountain yellow legged-frogs in the late 1990s, most of which occurred within 59 different basins (scale not specified) and hence, had multiple breeding populations that were hydrologically connected (USFWS 2003). Of these 758 sites, evidence of reproduction existed at 330 (USFWS 2003). Overall, USFWS (2003) estimated that 22 percent of known sites where mountain yellow-legged frogs were extant in the Sierra Nevada occurred on National Forests (whether or not evidence of reproduction existed), whereas the remaining 78 percent of sites were concentrated within the National Parks (including those with and those without evidence of reproduction). More recent data are available.

In 2002, the USDA Forest Service implemented a long-term bioregional monitoring program designed to assess the status and trend of mountain yellow-legged frog breeding populations on national forest lands across the taxa's range in the Sierra Nevada (Sierra Nevada Amphibian Monitoring Program [SNAMPH], Brown and Olsen 2013, Brown et al. 2014). Small watersheds (2-4 km^2) are surveyed throughout the Sierran range of the mountain yellow-legged frog over a proposed 5-year cycle, with 20 percent revisited annually. Watersheds were selected using an unequal probability sample based on historical occupancy. Recently occupied watersheds were known to be occupied between 1990 and 2001, historically occupied watersheds were known to be occupied only prior to 1990, and the remaining are those where occupancy was unknown or frogs have not previously been found. Population status and trends are measured by breeding occupancy (number of occupied watersheds, number of occupied sites/watershed). All lentic and a sample of lotic sites are surveyed within each watershed. From 2002 through 2009, 208 watersheds were surveyed across the Sierran range of the mountain yellow-legged frog containing >2900 meadows, lakes, ponds or stream reaches. Breeding was found in an estimated 4% (se=1%) of watersheds rangewide and the frog has declined in distribution. Breeding was found in an estimated 47% (se = 4%) of watersheds with known presence of frogs from 1990-2001 and in an estimated 2% (se = 3%) of watersheds with locality data only prior to 1990. Mountain yellow-legged frogs of any life stage were found in an estimated 5% (se=0%) of watersheds rangewide, 65% (se=4%) of watersheds with known presence of frogs from 1990-2001, and 2% (2%) of watersheds with locality data prior to 1990 (Brown et al. 2014). Numbers of occupied watersheds by forest are summarized in Appendix B.

In 2002, CDFW initiated surveys of montane lakes designed to detect mountain yellow-legged frogs. Over the period 2003-2006, CDFW conducted 3,148 surveys of 2,666 sites on the 10 National Forests that encompass the mountain yellow-legged frog's range in the Sierra Nevada. A site was defined as any lentic water body roughly within the distributional range of the mountain yellow-legged frog identifiable on a USGS 7.5-minute topographic map, or any marsh, meadow, stream, or pond discovered in the field with fish or herpetofauna present. Mountain yellow-legged frogs were detected at just under 15 percent of sites (n = 395) over nine of the National Forests; mountain yellow-legged frogs were not detected at any of the 256 sites surveyed in the Lake Tahoe Basin Management Unit. Detections were not evenly distributed across the range of the species in the Sierra Nevada. Notably, almost 20 percent (n = 352) of the 1,769 sites surveyed in the central and southern part of the taxa's Sierran range (from the Eldorado National Forest to the Sequoia National Forest) had detections, whereas frogs were detected at fewer than 5 percent (n = 43) of the 897 sites in the northern part of the range (from the Lassen National Forest to the Lake Tahoe Basin Management Unit, including the Plumas and Tahoe National Forests). CDFW found no mountain yellow-legged frogs during surveys of 31 sites on federal lands not comprising either National Forest or National Park lands. Notwithstanding that CDFW surveys represent a composite of historical and non-historical sites (sites not previously surveyed for frogs), these data also suggest that mountain yellow-legged frogs have declined significantly across their range in the Sierra Nevada.

Regional estimates of disappearance, which exist for Yosemite and Sequoia-Kings Canyon National Parks and the John Muir Wilderness (Bradford et al. 1994a, Drost and Fellers 1996, Knapp and Matthews 2000a), agree with rangewide estimates in general magnitude. Obtained in the interval 1989-1999, these data suggest levels of disappearance ranging from 65 percent to 95 percent, with the higher estimates reflecting areas more intensely stocked with fish (i.e., John Muir Wilderness) and lower estimates reflecting the historically less heavily stocked National Parks (Knapp and Matthews 2000a). Details for these areas are provided in Appendix B. Finally, annual resurveys in Sequoia-Kings Canyon and Yosemite National Parks indicate a rate of population extinction of 5-10% per year (R. Knapp, pers. comm., 2013).

Few large populations remain across the mountain yellow-legged frog's geographic range in the Sierra Nevada. Based on the USDA Forest Service's 2002-2009 monitoring, Brown et al. (2014) estimated that 57% (se=14%) of occupied watersheds had <10 tadpoles and <10 adults or subadults, and only 9% (se=5%) of occupied watersheds had large populations, defined to be >500 tadpoles or >100 adults or subadults. CDFW has found similar small populations in many of the sites they have surveyed (CDFW unpublished data Sarah Mussulman, pers. comm., 2013). Up to 2002, a moderate number of large populations were known to exist in the southern Sierra Nevada (Sierra, Sequoia and Inyo National Forests, and Sequoia-Kings Canyon National Parks); but several of the largest populations have collapsed since 2002 (Vredenburg et al. 2010, R. Knapp, V. Vredenburg, pers. comm., 2006).

Conclusions About Status

Several basic conclusions can be made about the status of mountain yellow-legged frogs in the Sierra Nevada:

- Once among the most common amphibians in high-elevation aquatic ecosystems of the Sierra Nevada, mountain yellow-legged frogs are in severe decline. The most recent data estimate declines in numbers of populations of over 90 percent with >50% in areas occupied as recently as 1990. Further, annual resurveys in two national parks indicate a rate of population extinction of 5-10% per year.
- Not only have the number of occupied localities declined, but the sizes of extant populations appear to have dropped to precariously low levels in many places. More than half of existing populations are very small (20 animals) and large populations (>30 adults) are rare.
- Many mountain yellow-legged frog populations appear to be isolated; if mountain yellow-legged frogs generally function as metapopulations, the reduced connectivity among remaining populations results in lower chances of recolonization following extirpation events. Regardless of whether mountain yellow-legged frogs function as metapopulations, few clustered populations make mountain yellow-legged frogs highly vulnerable to local extirpation and loss of genetic diversity.
- Recent data from SNAMPH and CDFW high lake surveys suggest that populations in the northern portion of the range of *R. sierrae* and in the very southern portion of *R. muscosa* in the southern Sierra Nevada may be particularly at risk due to their small size and isolation.

The severity of this pattern of decline merits focused conservation efforts in all parts of the frog's range. In particular, a conservation strategy needs to:

- Protect the few remaining populations of both mountain yellow-legged frog species to retain the frogs in their respective areas, increase their abundance, and preserve genetic and other connectivity within and between existing populations; and
- Maintain recolonization potential and provide for recolonization opportunities throughout the range of both species.

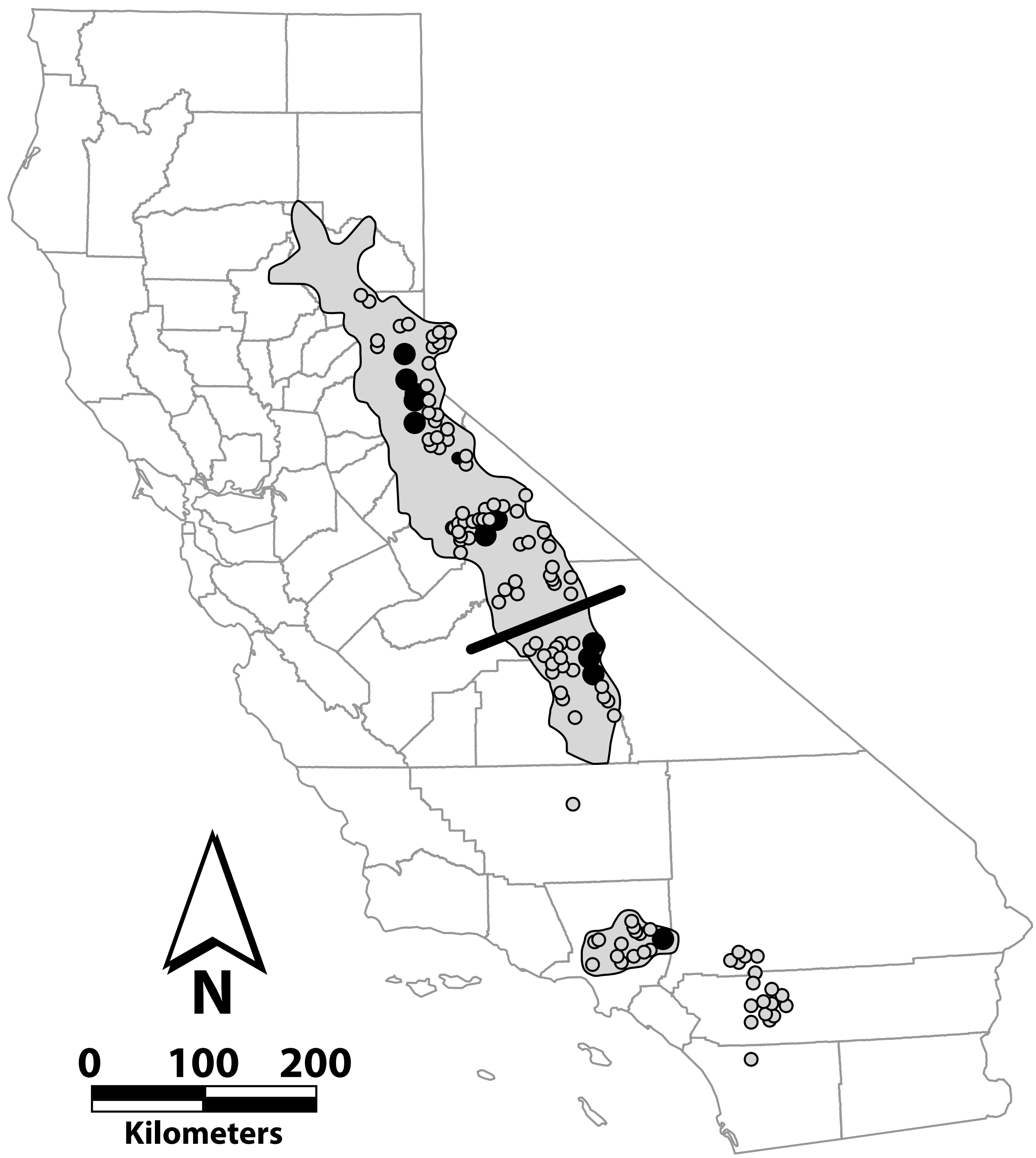

Figure 3 – Range (shaded area) of *Rana muscosa* and *Rana sierrae* based on all museum specimens at California Academy of Sciences and Museum of Vertebrate Zoology. The boundary between the two species is shown with a bold line. Two disjunct isolated localities are shown separated from the range because they are isolated from all other documented sites (Breckenridge Mountain, Kern County, and Palomar Mountain, San Diego County). The circles show 225 historical collection sites (1899–1994) that were resurveyed between 1995 and 2005 (○, extinctions, n=211; ●, extant populations, n=14). From Vredenburg et al. (2007). This Conservation assessment addresses these species in the Sierra Nevada portion of their range.

RISK FACTORS AFFECTING THE STATUS OF THE SPECIES

Risk factors include environmental conditions and human activities that may adversely affect mountain yellow-legged frog individuals, populations, or their habitat. Risk factors are not equally important in contributing to declines, so this section organizes them into three groups:

- Focal risk factors - those factors for which either substantial data either directly indicate or indirectly suggest a link to declines, presented in relative order of importance.
- Other risk factors within agency jurisdiction – those factors for which available data do not suggest a substantial effect or for which limited or no data exist.
- Other risk factors beyond agency influence – those factors for which available data do not suggest a substantial effect or for which limited or no data exist.

Order of presentation within the “Other Risk Factor” groupings is alphabetical and should not be interpreted as reflecting some order of importance. The following 17 risk factors are identified and evaluated in this Conservation Assessment:

Focal Risk Factors

- Introduced fish and other predators
- Disease
- Habitat loss and fragmentation

Other Risk Factors Within Agency Jurisdiction

- Fire suppression activities
- Habitat Restoration
- Livestock grazing
- Locally applied pesticides
- Mining
- Recreational activities (incl. packstock)
- Research activities
- Roads
- Vegetation and fuels management
- Water development and diversion

Other Risk Factors Beyond Agency Influence

- Acid deposition
- Airborne contaminants (incl. pesticides)
- Climate change
- UV-B radiation

Substantial new information is now available since this Conservation Assessment was updated in 2007, particularly for introduced fish and amphibian diseases, including chytridiomycosis. New research pertinent to the conservation of these species is summarized in the Mountain Yellow-legged Conservation Strategy.

Focal Risk Factors

Introduced Fish and Other Predators

Non-native predators occur across much of the historical range of the mountain yellow-legged frog. Although these non-native predators are predominantly introduced salmonid fishes (rainbow trout, golden trout, brook trout or charr, and brown trout), the American bullfrog and selected centrarchid fishes have become established in some areas in the low-elevation portion of the mountain yellow-legged frog's historical range. Mountain yellow-legged frogs have a long larval stage (2 or more years) which requires the use of perennial waters; this requirement in combination with the highly aquatic adult stage makes this species vulnerable to introduced aquatic predators (Bradford 1989, Bradford et al. 1993). Predation by introduced fish is one of the best-documented causes of the decline of mountain yellow-legged frogs in the Sierra Nevada, and all the salmonids are likely predators on various life stages of mountain yellow-legged frogs (Grinnell and Storer 1924, Needham and Vestal 1938, Bradford 1989, Knapp and Matthews 2000a, 2000b). Biologists have long suspected that introduced fish species were limiting the distribution of mountain yellow-legged frogs in the Sierra Nevada (Grinnell and Storer 1924, Yoon 1977, Hayes and Jennings 1986), but evidence for this problem as well as its extent across the Sierra Nevada was not accumulated until recently (Bradford 1989, Bradford et al. 1993, Bradford et al. 1998, Knapp and Matthews 2000a, 2000b, Knapp et al. 2001, Vredenburg 2004, Knapp et al. 2007).

Until the late 19th century, fish were absent from most of the high-elevation habitat occupied by mountain yellow-legged frogs (Moyle 1976, Jennings 1988, Knapp 1996, Moyle et al. 1996), but introduction of salmonid fishes became a widespread phenomenon over much of western North America during the early 20th century (Pilliod and Peterson 2001). Such introductions appear to have resulted in significant predation on frogs, have probably prevented re-colonization of locally depleted or extirpated populations, and have altered lake food webs and nutrient cycles (Bradford 1989, Bradford et al. 1993, Jennings 1996, Knapp 1996, Knapp et al. 2001, Schindler et al. 2001, Vredenburg 2004, Finlay and Vredenburg 2007).

Several studies in the Sierra Nevada found co-occurrence between native amphibians and introduced fishes to be rare or non-existent (Bradford 1989, Bradford et al. 1993, Knapp and Matthews 2000a). In a survey of 133 lakes in Sequoia and Kings Canyon National Parks, Zardus et al. (1977) found mountain yellow-legged frog larvae exclusively where fish were absent. In a second study in Sequoia and Kings Canyon National Parks, Bradford (1989) found the same pattern across 67 lakes. In a third study of 33 lakes in Kings Canyon National Park, 7 of which were occupied by fish, Bradford et al. (1998) found that larvae were rare or absent in trout lakes but were relatively common in lakes lacking trout. Where native amphibians and introduced fish co-occur, they seem to utilize different microhabitats. In one such lake, mountain yellow-legged frog larvae were found in shallows inaccessible to fish (Bradford et al. 1998). At other sites, mountain yellow-legged frogs have used small fishless ponds and then moved to fish-occupied lakes as the ponds dried (Bradford et al. 1993). Cory (1962b, 1963) found that when approached from a landward direction, adults from sites where they coexisted with fish consistently displayed an escape behavior not found in populations with trout; rather than swim out into a water body following an evasive dive, they would immediately turn shoreward and seek a near-shore refuge.

A comprehensive study in the southern Sierra Nevada (Knapp and Matthews 2000a) highlights the influence of introduced salmonid fishes on the mountain yellow-legged frog at a landscape scale. Fish stocking in the Sierra Nevada continues on National Forest lands, but nearly all stocking was halted in the National Parks in 1977, and fish stocking was always less intensive on National Park lands. As a result, National Parks have many more water bodies that lack fish than National Forests. Comparing 1,059 lakes in Kings Canyon National Park to 1,205 lakes in the immediately adjacent John Muir Wilderness (National Forest land), Knapp and Matthews (2000a) found that mountain yellow-legged frog larvae and adults occupied only 3 and 4 percent, respectively, of surveyed water bodies on National Forest lands, whereas larvae and adults were found in 20 and 31 percent respectively of surveyed water bodies on National Park lands. Moreover, population abundance was correspondingly much lower on the National Forest lands. Knapp and Matthews (2000a, 2000b) concluded that fish presence was an important (and perhaps the primary) reason for the decline of mountain yellow-legged frogs in the Sierra Nevada.

Most of the studies to date address areas where mountain yellow-legged frogs primarily use lentic habitat. There is very little information on the effects of fish stocking in areas where the species use predominantly lotic systems. In one study in the perennial reaches of Slate Creek on the Plumas National Forest, mountain yellow-legged frogs showed no preference for or avoidance of fish-bearing water; sightings of frogs occurred on fish-bearing and fishless waters in almost the exact same proportion as the availability of these habitats (J. Arrigoni, pers. comm., 2007).

Results of fish removal experiments also implicate introduced fish in the decline of mountain yellow-legged frog populations. Further, the rapid population increases following fish removal document the potential for recovery of the frog when introduced trout are eradicated (Vredenburg 2004, NPS 2006b, Knapp et al. 2007). Vredenburg (2004) and Knapp et al. (2007) removed fish from selected lakes and compared them to both fishless and unmanipulated fish-occupied control lakes. In both studies, after fish were removed, the number of post-metamorphic frogs and tadpoles increased significantly and were significantly greater in fish-removal lakes than fish-occupied control lakes. Based on the success of these trials, described below, subsequent fish removal restoration has been implemented with similar success. More recent fish removal activity is summarized in the Conservation Strategy under development.

Vredenburg (2004) removed fish from 5 lakes in Kings Canyon National Park and compared them to 8 control lakes containing fish and 8 control lakes with no fish. One year after removal, postmetamorphic frog and tadpole numbers were significantly different than in control lakes with fish and three years after removal, frog population numbers were similar to those in the control lakes with no fish. Knapp et al. (2007) removed fish from 6 lakes in 2 basins (John Muir Wilderness and Kings Canyon National Park). In this study as well, frog population density increased significantly following fish removal. For example, in one removal lake, frog density increased by 40-fold and tadpole densities increased by 39-fold. Additionally, to test the mechanism driving these population increases, the study compared the change in mountain yellow-legged frog density between 1997 and 2005 in 22 fishless control lakes and three of the fish-removal lakes. Results show the average change in tadpole density in the control lakes and fish-removal lakes was +2.3-fold and +35.2-fold, respectively ($P = 0.025$), and the average change in frog density in the control lakes and fish removal-lakes was +0.4-fold and +24.9-fold, respectively ($P = 0.0004$; Knapp et al. 2007). This provides strong support for the hypothesis that changes in mountain yellow-legged frog populations in fish-removal lakes are the result of fish eradication and not regionally favorable conditions for population growth. Finally, Knapp et al. (2007) found frogs dispersing to previously unoccupied habitats. Since these studies, fish eradication has occurred in multiple locations including in Sequoia and Kings Canyon National Parks (SEKI), the eastern Sierra Nevada (CDFW and USDA Forest Service), and El Dorado National Forest. The success of these efforts has been striking. For example, survey results from 6 lakes where fish were eradicated showed an average 18-fold increase in the density of tadpoles and frogs detected in 2006 versus 2001; one lake showed a 62-fold increase (NPS 2006b).

In addition to direct predation on mountain yellow-legged frogs, introduced fish also may have indirect effects. Bradford et al. (1993) showed that presence of introduced fish in streams locally fragmented the distribution of mountain yellow-legged frogs, presumably by interfering with dispersal and recolonization routes. Introduced fish are thought to have eliminated frogs (via predation) from larger lakes, isolating adjacent remaining small populations and thus increasing their vulnerability to extirpation (Knapp and Matthews 2000a, 2000b). This fragmentation potentially eliminates any rescue effect via immigration by preventing recolonization.

Introduced fish also impact aquatic communities which may have an indirect effect on mountain yellow-legged frogs. In their study of 33 lakes in Kings Canyon National Park, Bradford et al. (1998) found limited co-occurrence with fish and all large, mobile, or conspicuous aquatic taxa; large-bodied microcrustaceans (*Hesperodiaptomus*, *Daphnia middendorffiana*) and many epibenthic or limnetic macroinvertebrates (baetid and siphlonurid mayfly nymphs, notonectids, corixids, limnephilid caddis larvae, and dytiscid beetles) were rare or absent in trout lakes but were relatively common in lakes lacking trout. Further, Knapp et al. (2005) found that sites that continued to have stocked fish had 16 percent fewer species than never-stocked sites. However, they also found that the observed to expected ratio of species in earlier stocked but now fishless sites was significantly higher than sites that continued to have stocked fish, leading them to conclude that the fauna was capable of rapid recovery following fish removal. Moreover, for earlier stocked but now fishless sites, lake species composition recovered to resemble that of never-stocked lakes in less than 2 years after fish were removed. Knapp et al. (2001, 2005) also noted that the capacity for recovery appeared impaired in systems where fish stocking had occurred over an extended timeline, which suggests that where restoration efforts are attempted, prioritization based on capacity for recovery may be important.

Both the removal of anuran larvae (Ranvestel et al. 2004) and frogs, and the addition of fish (Schindler et al. 2001) have the potential to alter aquatic systems in unobvious ways. For example, effects from the loss of mountain yellow-legged frogs may cascade through the food web. Western terrestrial garter snakes are thought to have disappeared from a number of high-elevation locations because larvae and juvenile mountain yellow-legged frogs were a mainstay in their diet at those sites (Jennings et al. 1992, Matthews et al. 2002). Based on studies of the larvae of other ranid frogs (Seale 1980, Kupferberg 1997a), mountain yellow-legged frog larvae (along with co-occurring anurans [Pacific tree frogs and Yosemite toads]) undoubtedly play an important role in both cycling nutrients within and, after metamorphosis, between bodies of water. Only limited data exist on some of these and other possible fish-induced changes in systems occupied by mountain yellow-legged frogs.

Introduced fish may be vectors of introduced parasites and pathogens (Kennedy et al. 1991, Kennedy 1993). Laboratory experiments showed that the water mold, *Saprolegnia ferax*, can be transmitted from hatchery fish to western toad embryos (Kiesecker et al. 2001) (See Disease section).

Introduced bullfrogs (*R. catesbeiana*), native to the eastern United States but introduced in the west, also may affect mountain yellow-legged frogs. Bullfrog invasions are associated with declines of many native amphibians including foothill yellow-legged frogs (*Rana boylii*; California, Kupferberg 1997b in Casper and Hendricks 2005) and northern red-legged frogs (*Rana aurora*; Oregon, Kiesecker and Blaustein 1997b, 1998 in Casper and Hendricks 2005). Adult bullfrogs are known to be voracious, opportunistic predators (Schwalbe and Rosen 1988 in Casper and Hendricks 2005) that employ a sit-and-wait approach and will readily attack any live animal smaller than themselves, including conspecifics and other anuran species (Bury and Whelan 1984 in Casper and Hendricks 2005). Bullfrogs may locate smaller frogs for prey by orienting to breeding (Green and Pauley 1987, Harding 1997 in Casper and Hendricks 2005) or distress calls (Collins and Collins 1991 in Casper and Hendricks 2005). One study found a negative correlation between the presence of introduced exotics such as bullfrogs and fishes and native amphibians in California (Fisher and Shaffer 1996 in Casper and Hendricks 2005), but their analysis did not discriminate between the two exotics. Hayes and Jennings (1986 in Casper and Hendricks 2005) concluded that predation by introduced fish was the most likely cause of declining western North American ranid frogs, though they thought the data were insufficient to distinguish this from the competing hypotheses of introduced bullfrogs and habitat alteration. Because bullfrogs are likely to co-occur with mountain yellow-legged frogs only at lower elevations, the potential for impact is restricted to these portions of the mountain yellow-legged frog's range.

Both natural and man-made habitats pose a risk for bullfrog invasions. Thus, there is concern that watershed restoration techniques that develop ponds may create suitable habitat for bullfrog colonization in watersheds occupied by mountain yellow-legged frogs. It has been found that bullfrogs are adept at colonizing newly created ponds (Merovich and Howard 2000 in Casper and Hendricks 2005) and the juvenile stage is likely where most dispersal occurs. Some ponds that have been created as "borrow sites" for soil collected to fill in gullies for "pond-plug" restoration have been invaded by bullfrogs on the Plumas National Forest (T. Hopkins, pers. comm., 2009). Studies of the effects of bullfrogs on mountain yellow-legged frogs and their habitats have not occurred to date.

Several native predators are sufficiently abundant at high elevations to have some impact on mountain yellow-legged frog recruitment and survival (see Mortality in Ecology section). Whether native predators are likely to accelerate extirpation of depleted mountain yellow-legged frog populations or switch to alternative prey because of a prey rarefaction phenomenon is not known.

Extent of Risks Related to Introduced Fish and Other Predators

The risk from fish stocking is high. Fish stocking is widespread throughout the species' geographic range and has played a major role in the decline of mountain yellow-legged frogs in the Sierra Nevada as demonstrated by both correlative and experimental studies. Fish introductions likely have caused local extinctions and may have precluded successful recolonization of areas where extirpations occurred historically even in the absence of fish.

There is no evidence that native predators have had a significant impact on this species, but the possibility should be considered that alteration in the food web, such as that to which introduced fish have contributed, has the potential to put one or more native predators at an advantage that might be a detriment to mountain yellow-legged frogs.

Conservation Options Related to Introduced Fish and Other Predators

The documented effects of introduced fish on mountain yellow-legged frogs warrant significant management consideration. Fish stocking in aquatic water bodies is a management action over which CDFW has direct control. The rapid recovery of frog populations following fish removal demonstrates that altered stocking practices or fish eradication are effective restoration tools. Because this risk factor occurs over essentially the entire geographic and altitudinal range of mountain yellow-legged frogs, actions taken on this factor have the potential to be far-reaching.

Fish stocking also needs management consideration for its potential detrimental indirect effects, especially disease transmission (see Disease section). Finally, interactions between introduced fish and other stressors remain too little studied to inform management about what options may exist other than fish removal.

Disease

Amphibian diseases, particularly chytridiomycosis, are currently an area of active research and there is substantial new information since this section was updated in 2007. The Mountain Yellow-legged Conservation Strategy provides the update for new disease research pertinent to the conservation of these species.

Since 1993, new aquatic pathogens have been observed killing amphibian species in the Sierra Nevada and worldwide (Carey et al. 1999). Of greatest concern is the amphibian chytrid fungus, *Batrachochytrium dendrobatidis* (*Bd*) (Longcore et al. 1999), which has seriously affected many amphibians globally (Berger et al. 1999, Daszak et al. 1999, Fellers et al. 2001, Bradley et al. 2002, Bell et al. 2004), and is the pathogen that evidence has most consistently linked with declines among anurans (Green et al. 2002, Daszak et al. 2003). Chytrid fungi are ubiquitous in soil, but the aquatic chytrid infecting frogs has been discovered fairly recently (Berger et al. 1998); it may be a recently emerged clone (Morehouse et al. 2003) that may have had its origin in the widespread use and distribution of the African clawed frog (*Xenopus laevis*) for pregnancy testing during the early 20th century (Weldon et al. 2004). The chytrid fungus often alters the keratin-rich mouthparts of tadpoles (Vredenburg and Summers 2001, Rachowicz 2002), but has only been recorded to produce morbidity, not mortality, among larval anurans (Berger et al. 1999, Green et al. 2002, Rachowicz and Vredenburg 2004). However, the chytrid then progresses to establish in the keratin-rich skin of post-metamorphic anurans, eventually killing them in many cases (Berger et al. 1999, Green et al. 2002, Rachowicz and Vredenburg 2004). Chytrid epizootics have been described as insidious; because observing field casualties is rare, many chytrid epizootics may have gone undetected (Green et al. 2002). Sobering data from the tropics have shown that the progression of a chytrid epizootic can be extremely sudden, with populations crashing in one season (Lips et al. 2006). Chytrid epizootics among anurans in the western United States have features of an introduced, highly lethal infectious disease to which affected populations seem to lack innate resistance (Green et al. 2002). Chytrid fungal epizootics are the only infectious disease currently associated with population declines of multiple amphibian species (Green et al. 2002).

Studies have confirmed that *Bd* is a major contributor to observed declines in mountain yellow-legged frogs (Rachowicz et al. 2006) and is now present throughout most of the mountain yellow-legged frog's range. Initial discoveries involved larvae (Fellers et al. 2001, Vredenburg and Summers 2001); Fellers et al. (2001) found that 67 percent of larval mountain yellow-legged frogs collected and analyzed were infected with *Bd* and 41 percent of larvae examined in the field had abnormalities of the oral disc, suggesting potential infection. Subsequently, Rachowicz et al. (2006) unequivocally identified *Bd* as the proximate cause of declines in mountain yellow-legged frogs across much of the Sierra Nevada. Initial field diagnosis of *Bd* relied on oral disc anomalies of tadpoles where loss of pigmentation characteristic of chytridiomycosis typically appears as gaps in pigment in the upper and/or lower jaw sheaths (Rachowicz 2002, L. Rachowicz, pers. comm.). However, real time PCR assays are now used to detect the infection (Boyle et al. 2004, Rachowicz and Briggs 2007).

The mountain yellow-legged frog's life history may make the species particularly susceptible to this aquatic chytrid fungus because tadpoles remain in the aquatic habitat for 3-4 years before metamorphosing and post-metamorphic mountain yellow-legged frogs are almost always near water (Fellers et al. 2001). Mountain yellow-legged frog tadpoles have been successfully infected after serial inoculation with *Bd* zoospores in the laboratory; infected tadpoles then successfully transmitted *Bd* to uninfected tadpoles and frogs, and tadpoles with chytridiomycosis then metamorphosed and died (Rachowicz and Vredenburg 2004). Cannibalization of dead frogs by tadpoles is typical (Vredenburg et al. 2005); this behavior would place potentially uninfected tadpoles in the proximity of dead but infected frogs, which may help maintain the infection in populations. *Bd* prefers cooler temperatures (Longcore et al. 1999, Piotrowski et al. 2004) and the geographic range of the mountain yellow-legged frog includes the climatically coolest regions of the Sierra Nevada (Stebbins 2003) which may predispose them to successful attack.

The epidemiology of *Bd* is under investigation. Translocation of infected tadpoles to uninfected waters (Waldman et al. 2001, see also Research Activities section), transport of *Bd* through recreational human activities (e.g., fishing; see Recreation Activities section), and the abilities of stocked fishes (see Introduced Fish and Other Predators under Risk Factors) and native waterfowl to act either as reservoirs or transport vectors are areas that need investigation to understand the epidemiology of *Bd* in the context of mountain yellow-legged frogs. Of particular concern is that some vectors can carry light infections without manifesting the symptoms of chytridiomycosis (Mazzoni et al. 2003, Speare and Berger 2003, Daszak et al. 2004, Hanselmann et al. 2004). Reeder et al. (2012) found that the sympatric Pacific chorus frog (*Pseudacris regilla)* appears to be unaffected by *Bd* and may be a reservoir species. Mazzoni et al. (2003) revealed that bullfrogs farmed for food can serve as a vector for *Bd*, a condition that has been experimentally verified (Daszak et al. 2004); bullfrogs are not typically sympatric with mountain yellow legged frogs (Stebbins 2003). Gin (undated) reported significantly heavier nematode burdens in mountain yellow-legged frogs from Milestone Basin, a location where mountain yellow-legged frogs were infected with *Bd*, versus the Sixty Lakes Basin, an uninfected site. Gray treefrogs (*Hyla chrysoscelis*) developed more slowly when reared with the pathogen, but only when eastern newts (*Notophthalmus viridescens*) were present, which suggests that complex predator-by-pathogen interactions are possible (Parris and Beaudoin 2004).

An important area under investigation is resistance to *Bd* infection. Species in the western United States in which chytrid epizootics have been identified, such as the mountain yellow-legged frog, have been characterized as lacking innate resistance (Green et al. 2002), but demographic trends among selected Australian frogs in which declines associated with chytrid infection appear slightly older imply that resistance may exist (Berger et al. 1999, Retallick et al. 2004). Studies have investigated the role of antimicrobial peptides that occur in frog skin as a potential source of protection against diseases like chytridiomycosis (Rollins-Smith et al. 2002a, 2000b, 2003). For reasons that are unclear, chytridiomycosis activates little or no cellular immune response (neutrophils or macrophages) to infection (Carey 2000). Ten peptides in 8 peptide families derived from 5 species of ranid frogs (northern leopard frog [*R. pipiens*], American bullfrog [*R. catesbeiana*], crawfish frog [*R. areolata*], Columbia spotted frog [*R. luteiventris*], and montane brown frog [*R. ornativentris*]), 4 of which occur in North America, have been shown to inhibit chytrid growth. In laboratory studies, these peptides appeared effective at low concentrations (2-25µM) and more effective at lower temperatures (10 C vs. 22 C: Rollins-Smith et al. 2002a). Further, a 4-year mark-capture study of the Australian frog *Taudactylus eungellensis* conducted from 1994-1998 revealed a stable level of *B. dendrobatidis* infection (18 percent of individuals) in a post-decline population; and no difference was found in survivorship between infected and non-infected individuals (Retallick et al. 2004). This suggests that frogs should have some ability to resist chytrid infection. While peptide defense seems to combat fungal infections, it appears ineffective against *Aeromonas* bacteria and perhaps other non-fungal diseases (Rollins-Smith et al. 2002a). Uncertainty exists about the concentrations of these peptides in free-ranging anurans, and precisely what influences their production warrants further study. Because infections continue to spread in some species despite this potential defense, either other environmental factors may be contributing to the decline or this defense may be compromised in ways not yet understood (Rollins-Smith et al. 2002a). If interacting stressors somehow limit peptide production, some infectious diseases may continue to proliferate.

Other diseases also have been identified as potentially important factors in anuran declines. The family Iridoviridae contains five genera of large viruses, some of which infect ectothermic vertebrates (i.e., amphibians, fish, and reptiles; Chinchar 2002, Green et al. 2002). In a review of amphibian mortality events in the U.S., iridoviruses were the cause of 25 of 44 such events (reported across the United States between 1996 and 2001, Green et al. 2002). All iridovirus-caused mortality events in the United States have involved larval or metamorphosing salamanders, frogs, and toads (Green et al. 2002, R. Knapp, pers. comm.). However, iridovirus-caused mortality has been reported for adults of some European ranid frogs (Fijan et al. 1991, Cunningham et al. 1996). In the U.S., iridovirus-caused amphibian mortality events are much more common in salamanders than in frogs and toads (Green et al. 2002). However, Roland Knapp (pers. comm., 2002) has observed ongoing *Ranavirus* (a genus of iridovirus) outbreaks in Sierra Nevada yellow-legged frog populations in Upper Basin in Kings Canyon National Park. This virus is associated with mass mortality events in the field and was lethal to over 90 percent of larvae that were infected in the laboratory. Iridoviruses may move between fish and amphibians under natural conditions (Mao et al. 1999), raising the possibility that stocked fish species may act as vectors for iridoviruses (see Introduced Fishes and Other Predators).

A pathogenic water mold is also implicated in amphibian declines. *Saprolegnia ferax*, a fungus that attacks living amphibian embryos, has been documented to cause massive die-offs of eggs in Cascades frogs and western toads (*B. boreas*) in Oregon (Blaustein et al. 1994, Kiesecker and Blaustein 1997a). This water mold commonly infects fish, and laboratory experiments have shown that this fungus can be transmitted from hatchery trout to western toad embryos (Kiesecker et al. 2001), again raising the specter of stocked fish vectors (see Introduced Fishes and Other Predators). The possibility also exists that disease could be spread from sick populations of frogs to healthy ones through human transport of infected animals. Increased anthropogenic activity, a corollary to continuing human population growth (McKee 2003), increases the potential for the human-mediated spread of disease. To date, *Saprolegnia ferax* has not been implicated in declines of mountain yellow-legged frogs, with the caveat that little effort has been devoted to looking for this pathogen across the species' range.

A condition termed "red-leg disease" has also been recorded in Sierran mountain yellow-legged frogs. Bradford (1991) documented the loss of a Sierra Nevada population of mountain yellow-legged frogs; he speculated that the die-off resulted from the combined effect of red-leg disease and predation by Brewer's blackbirds. However, red-leg disease is actually a set of symptoms, the most prominent of which is that the ventral surface of the thighs and sometimes the forearms become abnormally red with enlarged capillaries and hemorrhages (thus the namesake). Emaciation and sluggishness also characterized most frogs Bradford (1991) found with this ventral reddening. Red-leg symptoms have also been noted in the decline of populations of the Yosemite toad (*B. canorus*) in the Sierra Nevada and the boreal toad (*B. boreas boreas*) in the Rockies (Carey 1993, Kagarise Sherman and Morton 1993). Red-leg symptoms were historically thought to result from a pathogenic manifestation of the ubiquitous freshwater bacterium *Aeromonas hydrophila* (Nyman 1986, Bradford 1991). However, meta-analysis of the red-leg condition has revealed these symptoms can be associated with a suite of different pathogens, and may be simply be a secondary manifestation; as a consequence, the actual cause of declines where the red-leg condition has been observed should be viewed as ambiguous in the absence of some kind of confirming biochemical or histological diagnosis (Green et al. 2002).

In their meta-analysis of amphibian mortality events, besides chytrid fungi and iridoviruses, Green et al. (2002) identified a third important pathogen, a previously undescribed Mesomycetozoan fungus close to *Dermocystidium*. This fungus was associated with mortality events involving larvae in 4 species of amphibians, 2 of which were ranid frogs and 1 of which was the American bullfrog. This pathogen has not been reported from mountain yellow-legged frogs and is currently too poorly understood for predictions to be made regarding its occurrence.

Technically not pathogens, trematodes have gained the attention of amphibian biologists studying declines because of the ability of some to induce deformities; other environmental agents (e.g., chemicals) could induce somewhat similar symptoms. Trematodes or flukes are a diverse group of parasitic flatworms with complex life cycles involving two or more hosts, and are common parasites of different life stages of many anuran species. Sessions and Ruth (1990) first inferred a relationship between parasitic infection and amphibian limb deformities after studying trematode parasites in Pacific chorus frog populations in California. Johnson et al. (1999) also found this correlation of limb abnormality with the presence of the trematode *Ribeiroia ondatrae* in several California species (Pacific treefrog, American bullfrog, and western toad). The trematode *Langeronia brenesi* occurs in southern California populations of mountain yellow-legged frogs, but appears not to cause major deformity (Goodman 1989). If trematode infections causing deformities are common, they may contribute to anuran decline by rendering frogs more susceptible to predation (Johnson et al. 1999). Other factors may also exacerbate the likelihood of trematode infection (Johnson et al. 1999).

Significant questions remain regarding the taxonomy of aquatic pathogens (especially viruses), their epidemiology, and their relationship to the ecology of montane amphibian species, including the mountain yellow-legged frog. If the pathogens of interest are native to the Sierra Nevada (unknown for the chytrid), they may take advantage of environmental stressors that render amphibians more susceptible to disease. A number of environmental stressors could theoretically have such an effect, including UV-radiation, climate change, chemical pollution, extremely cold temperatures, or even excessive handling (Carey 1993, Kagarise Sherman and Morton 1993, Carey and Byrant 1995, Drost and Fellers 1996, Jennings 1996, Carey et al. 1999, Taylor et al. 1999a). Finally, caution is also needed in evaluating factors that alone may act as environmental stressors, but may attenuate the effect of a pathogen (Parris and Baud 2004).

Extent of Risks Related to Disease

Disease, particularly chytridiomycosis, is a serious contributor to mountain yellow-legged frog declines. Major population crashes have resulted from chytridiomycosis infections, and the amphibian chytrid fungus, *Bd*, has been confirmed as a widespread threat to mountain yellow-legged frog persistence. Other pathogens may be contributors to declines, but their status is unknown. Other factors may also modulate the effects of *Bd* and other pathogens, but these effects have not been studied in the mountain yellow-legged frog.

Because many of the remaining mountain yellow-legged frog populations are small and isolated, the effects of disease may be exacerbated. Local extirpations resulting from disease could further isolate remaining populations, increasing the likelihood of extinction for the mountain yellow-legged frog in the Sierra Nevada.

Conservation Options Related to Disease

Evidence of disease documented thus far and the potential of other pathogens warrants management consideration. Little can be done to manage for this risk factor unless vectors of these pathogens over which management influence can be brought to bear are identified. Research on the amphibian chytrid fungus, *Bd*, as a prime factor in declines is extensive and ongoing; the focus of this research is to elucidate the dynamics of this disease in the Sierra Nevada to inform and guide strategies for conservation, particularly measures that can mitigate the effects of the disease. Actions should also be taken to reduce other environmental stressors that may facilitate or augment the effects of these pathogens; interactive effects between pathogens and other stressors remain largely unstudied. In particular, too few data exist to inform management about which stressors interact with disease and how they might be effectively reduced to prevent the onset of disease and alleviate its effects.

Habitat Loss and Fragmentation

Direct habitat loss is one of the most visible causes of amphibian population declines (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), but except along the lower and mid-elevation areas and selected higher elevation areas within the altitudinal range of mountain yellow-legged frogs (e.g., vicinity of Lake Tahoe, near Quincy), opportunities for urbanization are generally lacking because much of the higher elevation range of the species is on federal lands and within wilderness areas or national parks. Moreover, where the few opportunities for urbanization do exist, potential losses resulting from urbanization are confounded with other factors, such as exotic aquatic predators, that could just as easily explain habitat losses at those sites. No studies have attempted to disentangle the factors potentially confounded with habitat losses attributable to urbanization for mountain yellow-legged frogs. As a result, whether any declines of mountain yellow-legged frogs are attributable to urbanization *per se* is not clear. Opportunities for habitat loss via agricultural use, which has occurred as livestock grazing across a broad elevational range, are discussed in the Livestock Grazing section. As with urbanization, little opportunity has existed for habitat losses to occur that are linked to agricultural uses outside of livestock grazing across the mountain yellow-legged frog's range. Other opportunities for habitat loss or fragmentation are a function of other risk factors discussed in their respective sections (for example see sections on Introduced Fish and Other Predators, Water Development and Diversion, and Roads).

Mountain yellow-legged frog may be losing little habitat *per se* through anthropogenic factors, but most of the risk factors discussed in this document are increasingly fragmenting its populations; these populations appear smaller today than historically and are therefore more vulnerable to extirpation from random events (Pimm 1991, Noss and Cooperrider 1994) such as prolonged drought, exceptionally heavy winter snowpacks (Bradford 1983), or disease outbreaks. As declines continue to isolate populations, the frog becomes more vulnerable to extirpation of the species in entire regions. Because mountain yellow-legged frogs are thought to be fairly long-lived, the negative effects of disturbance and isolation may take several decades before population declines are apparent.

Extent of Risks Related to Habitat Loss and Fragmentation

Habitat loss is high risk, but only in the context of losses discussed under different risk factors rather than direct loss *per se* through urbanization and development. Habitat loss via urbanization and development is not currently considered to be significant, but may have some unknown level of local importance in specific parts of the mountain yellow-legged frog's geographic range; development in the mid-elevation Sierra Nevada may increase the importance of this factor in the future. Alterations of habitat via other risk factors (e.g. fish stocking) may fragment mountain yellow-legged frog populations. This isolation of existing populations may be a high risk to the species.

Conservation Options Related to Habitat Loss and Fragmentation

Development and urbanization are directly within the jurisdiction of agencies participating in this Conservation Assessment through agency planning processes and should be considered in management for the mountain yellow-legged frog. In addition, the cumulative impacts of the various risk factors that lead to increased fragmentation of mountain yellow-legged frog populations should be considered. Species conservation approaches should not only protect existing populations, but also provide mechanisms for re-establishing mountain yellow-legged frogs in nearby areas.

Other Risk Factors Within Agency Jurisdiction

Fire Suppression

In 2000 and 2002, extensive and damaging fires burned across large areas of western and southeastern North America that increased public awareness about the consequences of large fires (Pilliod et al. 2003). This attention resulted in fire and forest management policy changes on private, state, and federal lands. In 2001, Congress approved a National Fire Plan (NFP) to reduce fire risk and restore healthy fire-adapted ecosystems on federal lands through proactive fuel reduction (Pilliod et al. 2003). Implementing the NFP focused attention on major information gaps regarding the effects of proposed fire management activities on native fauna and flora, and in particular amphibians (Pilliod et al. 2003) like the mountain yellow-legged frog. Issues related to fire management are diverse, but this section focuses specifically on direct fire suppression activities that may affect mountain yellow-legged frogs.

Fire crews and other fire personnel attempt to minimize impacts to aquatic species and their habitats, but inadvertent impacts may occur. In particular, direct fire suppression activities that could affect mountain yellow-legged frogs include water drafting from ponds and streams, water application, retardant application, construction of hand lines, construction of dozer lines, and increased human presence. No data are available specific to mountain yellow-legged frogs for any of these activities, but anecdotal data on amphibians exist for a few activities and studies exist that provide insight on possible effects for a few others.

Water drafting from ponds and streams and application of water has the potential to directly impact aquatic habitat quality or its occupant amphibians. During the severe 1987-1991 drought in California, fire suppression personnel in the Sierra Nevada were forced to take water from locations where aquatic amphibians and reptiles had often concentrated. Large removals of water from those locations had the potential to stress the occupant species by further reducing available aquatic refuge habitat and/or making it accessible to aquatic-edge foraging predators (D. Holland, pers. comm., 1994). In a particular instance, a variety of aquatic amphibians and reptiles were concentrated in a pond from which water was being drafted for fire suppression and many animals were taken up by the helicopter water bucket and subsequently rained onto the fire site when it was emptied (D. Holland, pers. comm., 1994).

The construction of fire lines or firebreaks by firefighters using hand tools or machinery such as bulldozers may be extensive and result in similar habitat changes as those associated with road and road construction (see Roads section). Over 240 km of 1 m to 10 m wide fire line was constructed for a 57,000-ha wildfire in California in 1999 (Ingalsbee and Ambrose 2002). Fire line or firebreak restoration features, such as water bars and revegetation, may mitigate erosion rates and road-like effects (Pilliod et al. 2003). Sedimentation may be the most detrimental road-like effect of constructing fire lines on amphibians because unpaved roads are responsible for greater increases in sediment mobility and erosion than either logging or fire *per se* (Rieman and Clayton 1997). It should be noted, however, that firelines are much smaller than unpaved roads and do not receive vehicular traffic. Further, implementation of erosion control measures is a mandatory part of fire suppression rehabilitation activities. Mechanized equipment is not used in wilderness areas for fire suppression.

Application of retardant has become an important wildlife issue (Pilliod et al. 2003). In large wildfires, large amounts of ammonia-based fire retardants and surfactant-based fire-suppressant foams are dropped from air tankers and sprayed from fire engines to slow or stop the spread of fire. Some fire retardants are toxic or hazardous to aquatic organisms (Gaikowski et al. 1996, MacDonald et al. 1996, Buhl and Hamilton 2000). During application, fire personnel make efforts to avoid riparian areas, but accidental contamination of aquatic habitats has occurred, especially from aerial applications (Minshall and Brock 1991). For example, during fire-suppression activities a direct "hit" of fire-retardant was dropped adjacent to the Buck's Lake Wilderness in a small mountain yellow-legged frog breeding pond. No studies occurred to determine the effects, but there was a noticeable decline in the tadpoles within this pond (T. Hopkins, pers. comm., 2007). Although there is evidence of retardant and suppressant toxicity to aquatic organisms, there are few studies addressing whether effects are commonplace or pose a threat to amphibians. Amphibians appear less sensitive to ammonia toxicity than fishes (Pilliod et al. 2003).

The release of yellow prussiate of soda (sodium ferrocyanide), an ingredient of fire retardants and suppressants used as a corrosion inhibitor for equipment, has been shown to be highly toxic to fish and amphibians, especially on exposure to sunlight, and may pose a greater problem (Pilliod et al. 2003). Little and Calfee (2000) found that fire retardants and foam suppressants with sodium ferrocyanide under natural light conditions were highly toxic to northern leopard frogs and boreal (= western) toads relative to treatments with the same formulations, but without sodium ferrocyanide or without exposure to light. In the presence of ambient (solar) ultraviolet light, sodium ferrocyanide is oxidized, releasing substantial free cyanide (Pilliod et al. 2003). Still, science is needed to inform this issue because basic information on the toxicity of fire retardants and foam suppressants is unavailable for most amphibian species in western North America, including mountain yellow-legged frogs.

Concerns regarding the effects of aerial application of fire retardant on aquatic systems and threatened, endangered or candidate species were addressed in the National Forest Service Chief's Decision Notice and Finding of No Significant Impact (USDA Forest Service 2008). This directs tanker pilots to avoid aerial application of retardant or foam within 300 feet of waterways. A "waterway" is considered to be any body of water including lakes, rivers, streams and ponds irrespective of whether they contain aquatic life. This is considered binding direction, subject to qualifications and exceptions only as noted in the Decision Notice.

Extent of Risks Related to Fire Suppression

The impact of fire management and suppression activities on mountain yellow-legged frogs is unknown. The risk for mountain yellow-legged frogs is potentially higher in the more forested parts of its range at lower elevations and more northern areas where populations are generally at lower elevations. In the parts of the species' range that occurs in wilderness areas, fire suppression activities are rarely conducted and mechanized equipment generally is not used (e.g., mechanized equipment generally is not allowed in wilderness areas). Based on the known effects of fire suppression activities, these activities could potentially impact mountain yellow-legged frogs.

Conservation Options Related to Fire Suppression

Agencies should continue to manage fire suppression and their mode of application for the mountain yellow-legged frog. Management can influence the degree that these activities affect the species and they are within the jurisdiction of agencies participating in the assessment. Science is needed to determine how fire suppression techniques affect mountain yellow-legged frogs. Until significant science becomes available to inform this issue, minimum-impact fire suppression techniques may represent the best alternative to protecting mountain yellow-legged frogs and their habitat.

Habitat Restoration

Restoration refers to a large suite of activities that may involve remediation or restoration of degraded habitats, some of which have the potential to influence mountain yellow-legged frogs. Historically limited, habitat restoration has become a prominent activity addressing degraded habitat, and is expected to become even more important in the future. Habitat restoration efforts may be diverse, but several categories of restoration may be important to mountain yellow-legged frogs. These include:

- Fish removal from mountain yellow-legged frog habitats – Fish removal may be the most significant restoration activity for mountain yellow-legged frogs. Population densities have increased significantly following fish removal and frogs have dispersed to previously unoccupied habitats. Based on the success of experiments (Vredenburg 2004, Knapp et al. 2007), this form of restoration has been expanded. See sections on Introduced Fish and Other Exotic Predators.
- Removal of human-constructed fish barriers to enhance fish passage – Removal of human constructed fish barriers to enhance fish passage represents a very large class of restoration efforts in western North America. Where viable mountain yellow-legged frog populations exist upstream from barriers proposed for removal, barrier removal may place the mountain yellow-legged frog population at risk. Examples of such restorations exist on the Plumas (T. Hopkins, pers. comm., 2006) and Inyo National Forests (C. Milliron, pers. comm., 2006).
- Stream restoration activities that create ponded habitats – Some stream restoration activities involve creation of ponded habitats. While ponded habitat *per se* may represent a benefit, ponded habitat with an inappropriate structure constructed within the dispersal range of bullfrog-occupied sites may negatively influence mountain yellow-legged frogs. Examples of such restorations are on the Plumas National Forest (T. Hopkins, pers. comm., 2006).
- Meadow restoration efforts designed to set back succession – Meadow restoration efforts designed to set back succession focus on encroaching tree vegetation, particularly by lodgepole pine into meadow systems (see Sharsmith 1961).
- Efforts designed to restore meadow hydrologies - Restoration efforts designed to restore meadow hydrologies are diverse and beyond the scope of this document, but are intended to reverse the secondary effects of management activities such as excessive historical livestock grazing.

Science is needed to evaluate both the positive and negative effects of various types of restoration on mountain yellow-legged frogs; other than for fish removal, no data currently exist.

Extent of Risks Related to Restoration

Restoration is a significant activity that is anticipated to increase. Fish removal restoration in multiple experiments has successfully led to increased mountain yellow-legged frog populations. Implementing other restoration activities on habitat may have short-term negative effects on mountain yellow-legged frogs, but these are likely more than counterbalanced by the likely positive effects of restoration on mountain yellow-legged frog habitat. This would not be true, however, for restorations that expand the range of introduced predators (e.g., fish barrier removal). The anticipated positive effects and potential negative effects are unexamined.

Conservation Options Related to Restoration

Agencies should continue to guide and manage restoration efforts for the mountain yellow-legged frog. Restoration of fish-less waters would greatly contribute to the conservation of this species. Restoration, through regional planning processes, is under the jurisdiction of agencies participating in this Conservation Assessment. Science and monitoring is needed to inform precisely how different types of restoration may affect mountain yellow-legged frogs and their habitat, from both short- and long-term perspectives.

Livestock Grazing

In the Sierra Nevada Ecosystem Project's *Final Report To Congress* (SNEP Report), Kattelman (1996) stated that livestock grazing has "affected more area in the Sierra Nevada than any other management practice". Livestock grazing has the potential to affect all life stages of mountain yellow-legged frogs from the breeding period until frogs disappear into aquatic overwintering sites in the fall. However, livestock grazing is more likely to occur in certain habitat types used by mountain yellow-legged frogs than others. For example, frogs found in meadows, riparian zones of streams, and lakes in meadows may be more likely to encounter livestock grazing impacts than those found in the deeper alpine lakes the species commonly inhabits. High-elevation riparian habitats may be particularly vulnerable to disturbance, presumably because of their short growth season and consequently slow rates of recovery.

No descriptive or cause-effect research relating livestock grazing to mountain yellow-legged frog populations exists. Effects arising from grazing activities on mountain yellow-legged frog habitat may have contributed to their decline at specific locations, and disturbance of habitat occupied by mountain yellow-legged frogs attributable to certain managed livestock grazing practices, particularly those used in the past, has been anecdotally documented in many Sierra Nevada National Forests. As early as 1980, Hansen noted that mountain yellow-legged frogs on the Kern Plateau in the Sequoia National Forest "may be of considerably more limited occurrence than in the past due to habitat modifications, particularly cattle grazing in the meadows" (Hansen 1980). Similar impacts were reported at a number of localities on the Kern Plateau (Christopher 1994), in Cottonwood Basin and McAfee Meadow Research Natural Area on the east slope of the White Mountains (Giuliani 1996), in Crooked Meadows (Knapp 1993a), in Dry Creek (Knapp 1993b), in Cold Meadow (R. Knapp, pers. comm., 1994), in Boulder Creek (T. Hopkins, pers. comm., 2001), and at the headwaters of Rock Creek (T. Hopkins, pers. comm., 2002). Improved livestock grazing management on NFS lands over the last decade has been implemented to mitigate or reverse many historical negative effects (A. Yost, pers. com.).

Historical and Current Grazing in the Sierra Nevada

Before 1905, unregulated, unsustainable grazing practices existed over much of the Sierra Nevada, resulting in widespread damage to rangelands and riparian systems (Menke et al. 1996). Historical evidence indicates that heavy livestock use in the Sierra Nevada led to sod destruction in meadows, which reduced or eliminated protective vegetative, while hoof shear, trampling and chiseling contributed to gully erosion by exposing soils to erosive flows (Hagberg 1995). Impacts were particularly intense during the period between the Gold Rush and establishment of the Forest Reserves in 1905 and the USDA Forest Service in 1908. Between 1870 and 1908, transient sheep grazing in the high-elevation meadows of the Sierra Nevada caused heavy damage from overuse. By 1930, degraded forage conditions due to overstocking became apparent.

Between 1950 and 1970, livestock numbers were reduced due to allotment closures, uneconomical operations, and replacement of sheep by cattle, with cattle becoming the dominant livestock. Increased emphasis on resource protection and riparian enhancement between 1970 and 1990 resulted in projects incorporating riparian pastures, exclosures, and in-stream rehabilitation structures, as well as reductions in livestock use (Menke et al. 1996). From 1981 to 1998, livestock numbers decreased from 163,000 head to about 97,000 (USDA Forest Service 2001a). A suite of factors contributed to this decline, including seasonal use changes, implementation of standards and guidelines in forest land and resource management plans, management for threatened and endangered species, management for water quality, uneconomical operations, urbanization, generational shifts away from rural agricultural lifestyles and economies, and fluctuations in the livestock market (USDA Forest Service 2001a). Implementation of the Sierra Nevada Forest

Plan Amendment beginning in 2001 (USDA Forest Service 2001a) imposed standards that further modified grazing management and resulted in reduced livestock numbers; 2009 statistics for the Pacific Southwest Region document that current permitted numbers are approximately 73,500 head, which accounts for an additional reduction of 25 percent since 2001 (A. Yost, pers. com.).

Grazing occurs on about 65% of national forest lands within the Sierra Nevada range of the mountain yellow-legged frog on 10 National Forests (Lassen, Plumas, Tahoe, Eldorado, Lake Tahoe Basin Management Unit, Sierra, Stanislaus, Inyo, Humboldt-Toiyabe, and Sequoia) (adapted from SNFPA FEIS GIS data 2002). Approximately 79 active grazing allotments exist on USFS-administered lands within this range. In 2009, it was estimated that approximately 29 of these allotments (36 percent) supported extant mountain yellow-legged populations within their boundaries (USFWS 2009). The 1996 SNEP Report indicated that current livestock management continued to impact many mid-to-high elevation rangelands and restoration efforts remained far from complete (Menke et al. 1996); however, as of the early 2000s, livestock numbers have been greatly reduced from historical levels and multiple watershed restoration projects have been implemented.

Effects on Habitat: Meadow and Riparian Ecosystems

The impacts of livestock grazing on high elevation wetland and riparian ecosystems are well documented (Menke et al. 1996). Under some management practices, livestock tend to concentrate in riparian areas (Belsky et al. 1999) and can remove and trample riparian and wetland vegetation (Kauffman and Krueger 1984, Marlow and Pogacnik 1985). Chronic trampling in wet and mesic meadows can reduce infiltration by increasing compaction, which can increase bare ground and decrease site productivity; a pattern that can be reversed by natural freeze and thaw cycles if trampling ceases. Olson-Rutz et al. (1996a, 1996b) noted that decreased cover and increased bare soil were correlated with packstock grazing intensity and duration. Vegetation removal and trampling by livestock in a montane riparian habitat also had the secondary effects of altering micro-channel characteristics resulting in increased velocity of runoff because of fewer micro-channels with deeper flows (Flenniken et al. 2001). The cumulative effects of overgrazing may have resulted in insufficient residual vegetation and decreased vegetative cover that may have reduce food resources and increased xeric and predator-exposed habitat for mountain yellow-legged frog life stages (see Habitat Requirements in Ecology section).

Livestock also can alter the physical and hydrological characteristics of stream margins, springs, and other riparian areas. The typically high soil moisture along stream banks and other aquatic edge habitats makes these areas easier to trample (Marlow and Pogacnik 1985). Trampling often increases bank erosion, filling in pools and making stream channels wider and shallower (Duff 1977, Kauffman et al. 1983, Kauffman and Krueger 1984, Bohn and Buckhouse 1985). Livestock grazing also has the potential to increase erosion of connecting stream channels, lowering the water table, and eliminating ephemeral and even permanent water bodies (Meehan and Platts 1978, Armour et al. 1991). Mountain yellow-legged frogs require permanent water for tadpoles and pools of minimum depth for overwintering (see Habitat Requirements in Ecology section), so lowered water tables and sedimentation from grazing has the potential to reduce available permanent water habitat for the species. Repeated over-utilization and trampling also may result in alterations to aquatic micro-topography (e.g., undercut banks) (Duff 1977, Platts 1981) used by the mountain yellow-legged frog for egg deposition, larval development, and refuges for post-metamorphic frogs (USDA Forest Service 2001a). In Crooked Meadows, Knapp (1993b) noted a negative correlation between grazing impacts and mountain yellow-legged frog numbers. Knapp found no frogs in the lower portion of the meadow, which was incised due to grazing practices, and the stream was wide and shallow without undercut banks. Most of the frogs were found in ungrazed portions of the meadow which had deep, narrow streams and overhanging banks providing cover from predators. The depth of the largest pond in the meadow had been reduced by sediment deposition from grazing practices. Knapp suggested that this habitat alteration might have decreased the overwinter survival of larvae because a minimum depth of unfrozen water may be needed for overwintering (see Habitat Requirements in Ecology section).

Developing springs for stock water can affect native plant and terrestrial species habitat by altering or de-watering riparian areas. How this may affect mountain yellow-legged frogs is unknown. Although much of the frog's aquatic habitat is supplied by snowmelt, the contribution from springs is unknown. Further, knowledge of overwintering habitat use patterns remains incomplete, and springs could be used as overwintering sites in greater frequency than is currently recognized; research is needed to inform this issue. Mountain yellow-legged frogs have been found to breed in stock ponds created for cattle (T. Hopkins, pers. comm., 2009).

The 1996 SNEP Report noted that livestock numbers compatible with grazing capacity and knowledge of sustainable methods has led to better range management in the Sierra Nevada, particularly over the last 20 years. Moderate livestock grazing has the potential to increase native plant species diversity in wet and mesic meadows by decreasing litter accumulations, particularly in *Carex* spp.-dominated communities by allowing live native plant cover to increase on the site (Menke et al. 1996).

Livestock management that uses appropriate intensity, timing, and duration may result in a trend toward restored ecosystems in wet and mesic meadows on National Forests. For example, implementation of allowable use standards is the most important consideration for the health of a riparian area (Clary and Webster 1989). Maintaining a minimum stubble height (or otherwise defining a maximum level of utilization) on a site helps to maintain forage vigor, retain sufficient forage to reduce cattle browsing of willows, and to stabilize sediments (Clary and Leininger 2000). A 10-cm residual stubble height is recommended by Clary and Leininger (2000) as a standard for improved riparian grazing management; it is this standard that is implemented via the SNFPA (USDA 2001a, 2004b, 2004c).

Ideally, livestock use allotments when soil and vegetation conditions are conducive to support grazing. Livestock seasonal turnout dates fluctuate depending on a combination of factors such as elevation, annual precipitation, soil moisture, and the phenology of key forage species. Readiness dates vary from 1 May to 1 August for montane meadows above 1,219 m (4,000 ft). Portions of an allotment may have deferred use with animals herded at lower elevations until higher elevation meadows are ready. However, animals turned out on the range may reach portions of the allotment prior to range readiness.

Rangeland and livestock managers have the ability to incorporate intensive livestock herding as part of riparian grazing management, although increased livestock transportation costs and shortages of experienced range riders can make such approaches difficult to implement. Besides herding, water developments, fencing and exclosures, and alternative grazing strategies can reduce the amount of time livestock graze in riparian systems, thereby limiting impacts in these areas (Kauffman and Krueger 1984).

Current SNFPA grazing standards and guidelines (S&Gs) for herbaceous and woody vegetation utilization are based on current science (e.g., Clary and Leininger 2000), consider soil stability and desired plant communities, and are designed to improve or maintain range ecological conditions. Standards for managing habitat for threatened, endangered, and sensitive species also have been incorporated. These objectives may help maintain habitat requirements of the mountain yellow-legged frog; however, research is needed to determine the degree of residual vegetation or utilization that may benefit or affect the mountain yellow-legged frog (USDA Forest Service 2001a). Research on the effects of livestock grazing under the current SNFPA grazing S&Gs on populations and habitats of the sympatric Yosemite toad was conducted by the Forest Service (Tate et al. 2010, Lind et al. 2011, Roche et al. 2012a, Roche et al. 2012b, McIlroy et al. 2013). From 2005-2010, no differences were detected in Yosemite toad occupancy or density among fenced, partially fenced, and unfenced meadows using the current SNFPA grazing S&Gs. How applicable the results from this study are to mountain yellow-legged frogs is unknown.

Data on meadow condition from the USDA Forest Service Region 5 long-term meadow monitoring collected from 1999 to 2010 (D. Weixelman, pers. comm., April 2010) indicated that most meadow plots (61.0 percent) are in a moderate quality condition class. Slightly under one-quarter of meadow plots (23.1 percent) are in a high quality condition class, and 15.3 percent are in a low condition class. This analysis is based on 392 plots across 9 of the 10 Sierran National Forests where the mountain yellow-legged frog occurs (all except the Humboldt-Toiyabe National Forest). Data on trends in meadow condition class, which are collected in a 5-year staggered rotation, are available for 226 plots on eight of these National Forests (too few resampled plots exist on the Lake Tahoe Basin Management Unit to allow a comparison). Significant changes have occurred in condition class on meadow plots on the Eldorado, Lassen, and Tahoe National Forests. The Eldorado and Tahoe National Forests both displayed an upward trend (i.e., more meadows with high quality conditions), whereas the Lassen National Forest displayed a significant downward trend (i.e., more meadows in lower condition classes). The remaining five National Forests (Inyo, Plumas, Sequoia, Sierra, and Stanislaus) show approximately equal numbers of plots increasing versus decreasing in condition class and the remainder not changing. Hence, most meadows appear to be in an intermediate quality condition class, and overall, limited change in condition class seems to have occurred within the first six years of monitoring.

Direct Impacts to Mountain Yellow-legged Frogs

Livestock trampling may have the potential to directly kill all life stages of the mountain yellow-legged frog. Mountain yellow-legged frogs, particularly immobile embryonic stages, may be especially susceptible to trampling during their breeding and early rearing season. One mountain yellow-legged frog adult was found crushed in a cow hoof print on the Tahoe National Forest (A. Berg, pers. comm., 2002).

Trampling risk may depend on the timing and duration that cattle are grazing the allotment. Guthery and Bingham (1996) developed a theoretical model based on concerns for threatened, endangered, and sensitive plant and animal species (primarily focusing on ground nests and trampling of animals, but not specifically anurans) to predict the probability of trampling loss by cattle. The study found that trampling varies with livestock density and frequency of the grazing event, but is independent of herd movement or grazing system. Mountain yellow-legged frog life history suggests that the risk of trampling may be higher than levels indicated in this study simply because the study used randomly placed inanimate objects to test the model. Conversely, frogs have the ability to move out of the way.

Another potential but undocumented direct effect of livestock is the entombment of overwintering mountain yellow-legged frogs through livestock-induced collapse of undercut stream banks that are being used as overwintering sites. Use of such habitats is suspected based on observations of mountain yellow-legged frogs moving to such locations in the fall (see Ecology section). The potential for this condition to be a problem may be higher in the northern portion of the range of *R. sierrae*, where the species commonly uses stream habitats (T. Hopkins, pers. comm., 2007).

Effects on Populations: Disease Transfer and Water Pollution

Livestock can introduce pathogens (e.g., fecal coliforms, other bacteria) and nutrients that may promote algae growth to heavily used streams and water sources (Stephenson and Street 1978, Kattelman 1996). There is potential risk of pathogen transmission from livestock fecal material to mountain yellow-legged frogs; however, no evidence exists linking livestock to the transmission of pathogens such as the chytrid fungus, which is responsible for current mountain yellow-legged frog population declines.

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. The amount of manure and its dilution ratio may determine the potential degree of risk to mountain yellow-legged frogs. Cold, snowmelt mountain streams and oligotrophic mountain lakes may support few bacteria in their sediments in the absence of significant nutrient inputs.

Extent of Risks Related to Livestock Grazing

Localized risks related to some grazing practices, such as those used in the past, are potentially high for the mountain yellow-legged frog. Allotments managed under some grazing regimes have the potential to have persistent declines in habitat quality. Livestock grazing remains widespread across the mountain yellow-legged frog's geographic range, and is prevalent in meadows and along riparian corridors. Mountain yellow-legged frog populations are most at risk where they occur in meadows and streams rather than the more commonly used alpine lake habitats.

Some grazing management practices have the potential to cause a persistent decline in habitat quality. Others have the potential to have positive impacts on mountain yellow-legged frog habitat. Science is lacking on this issue.

Conservation Options Related to Livestock Grazing

Potential effects of livestock grazing should be addressed for conservation of mountain yellow-legged frogs. Management can influence the degree that this activity affects these species and is within the jurisdiction of agencies participating in the assessment. At a minimum, agencies should continue to manage this activity to reduce its potential impact to these species and their habitat. Research conducted by the Forest Service to address the effects of current grazing practices on the sympatric Yosemite toad (Roche et al. 2012a, Roche et al. 2012b, McIlroy et al. 2013) contributes to our understanding of grazing and amphibians generally; however, because of ecological differences between the two species, research focused on mountain yellow-legged frogs may ultimately be required to fully understand the potential impacts to these species.

Locally Applied Pesticides

National Forests in the Sierra Nevada occasionally use pesticides to control rodents, insects, fungi, noxious weeds, and brush. The SNFPA (USDA Forest Service 2004c) Riparian Conservation Objectives (RCO) and standards and guidelines limit the use of pesticides on NFS lands, especially where mountain yellow-legged frogs are present. Herbicides are typically used in conifer plantations for controlling brush, throughout the National Forest for controlling noxious weeds where they occur, and near buildings and other facilities for controlling weeds and pests. Herbicides are also used for forestry practice applications on private timberlands that adjoin or interdigitate with National Forest lands in the Sierra Nevada. Many of these companies use herbicides for brush control (D. Bakke, pers. comm., 2004). Most of the conifer plantations where herbicides are used lie below the elevation range of the mountain yellow-legged frog, although there are some plantations that intersect with the lower elevation populations. The license requirements of hydropower projects also include the use of pesticides at their facilities, such as along canals and at reservoirs, and this includes the development of a pesticide plan in coordination with the USDA Forest Service and sometimes other agencies.

National Forest herbicide projects typically use several types of herbicides within each project, each type having a specific surfactant and marking dye. Each of these chemicals has compositions which may have different potential effects to amphibians, and are analyzed separately and in combination. 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 include: R-11, methylated seed oil (Hasten), methylated seed oil/silicone blend (Syl-tac), and dyes include highlight blue, bas-oil red, and colorfast purple. Surfactants assist the herbicide to adhere to plant surfaces, and dyes assist with viewing where areas have been recently sprayed. As new herbicides are developed in the future, the list of popular herbicides types and brands will change and evolve.

In the past, aerial spraying was experimented with, and through water quality testing it was found that herbicides were entering the watercourses (USDA 2001b). In recent years, nearly all herbicide application on the National Forest has been conducted via backpack sprayers, as this mode of ground application affords greater control of the spray direction and coverage. Buffers from streams and water bodies are designated during the NEPA process for each project to facilitate protection of aquatic species from adverse effects. Buffer distances are individualized site-specifically depending on potential toxic effects of each herbicide type, the potential for them to enter the groundwater or move off-site, and the known aquatic species that could be affected downstream.

Glyphosate has been studied for its potential to affect amphibians. In general, the isopropylamine salt of glyphosate, the active ingredient in Roundup® and Rodeo®, 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), used to bind the chemicals to plant materials, which have been shown to be toxic to aquatic life, including several species of ranid frogs (Folmar et al. 1979, Mitchell et al. 1987, Servizi et al. 1987, Wan et al. 1989, Mann and Bidwell 1999, Smith 2001, Howe et al. 2004). Surfactants may affect aquatic organisms by damaging gills (SERA 2003a), which may be why tadpoles were found to be more sensitive than juveniles or adults to the full Roundup formulation of Glyphosate (Bidwell and Gorrie 1995, Mann and Bidwell 1999). A study showing high toxicity of larval and post-metamorphic northern leopard frogs to Roundup® may also be a function of POEA (Relyea 2005a); this study did not separate the effects of glyphosate and surfactant. Nevertheless, several studies (Sullivan et al. 1981, Hildebrand et al. 1982, Mitchell et al. 1987, Giesy et al. 2000, 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. As glyphosate binds tightly to organic matter and soil, its movement through the soil is largely impeded and its detection in aquatic habitats would not be expected following terrestrial applications (D. Bakke, pers. comm., 2004). Past water quality monitoring in Region 5 of the USDA Forest Service has concluded that glyphosate (and triclopyr) are rarely detected in surface water when these herbicides are used with stream buffers (USDA Forest Service 2001b). Persistence and impacts of glyphosate formulations in shallow water pools, which constitute breeding habitat for some frogs (though not mountain yellow-legged frogs) and rearing habitat for early life stages, may be another matter. Bidwell and Gorrie (1995) expressed concerns that these pesticides could concentrate in shallow lentic systems beyond safety margins, a concern that was based on their possible use as a herbicide applied directly to emergent aquatic weeds in an aquatic environment. Aerial applications of glyphosate-based herbicide formulations represent some risk to amphibians that breed in lentic habitats because of the unpredictability of drift.

Triclopyr (Garlon®) and clopyralid (Transline®) are used to control noxious weeds. Both pesticides are applied from backpack sprayers, and use near water is avoided. The toxicity of triclopyr to African clawed frog (*Xenopus laevis*) embryos, especially in its formulation marketed as Garlon® 4, is similar to the toxicity of surfactants used with various herbicides (Perkins et al. 2000). Further, field evaluation indicates that it can depress growth rates in brook trout at typical application levels (Kreutzweiser et al. 1995). Garlon® 3A is the amine formulation of triclopyr (triclopyr TEA); it is water soluble, less volatile (D. Bakke, pers. comm., 2004), and less toxic than Garlon 4 (Perkins et al. 2000) because it tends not to penetrate tissue 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 at higher doses (2.4 and 4.8 ppm). Tadpoles whose behavioral responses were affected recovered within 3 days. No effects to either embryos or tadpoles were observed from exposure to hexazinone.

Borax, a fungicide under the trade name Sporax®, is the second most common pesticide used in the Sierra Nevada. Over 3,084 kg (6,800 lbs) were used in 2003 to control the fungus that causes annosus root disease, *Heterobasidion annosum* (see Otrosina and Ferrell 1995). Borax is applied directly to the surface of cut tree stumps to kill any fungus that might eventually spread to live trees. Because it is topically applied, and is readily absorbed into the wood, it is unlikely to transport to water bodies where it might pose a concern to aquatic life. Studies have shown borax to be practically nontoxic to fish and aquatic invertebrates (Information Ventures 1995).

Rodenticides, such as strychnine and bromadiolone, are used occasionally in the Sierra Nevada. Insecticide use is limited primarily to controlling mosquitoes around recreation areas and facilities, to control insects in conifer nurseries, and in research experimentation. Most of the insecticide used is potassium salts of fatty acids.

Additive, multiplicative, or synergistic effects of herbicides with other risk factors have only recently begun to be studied among amphibians, and remain unstudied in mountain yellow-legged frogs. Both Chen et al. (2004) and Edginton et al. (2004) found the Vision® formulation of glyphosate increased in toxicity to the embryonic and larval stages of green frogs (*Rana clamitans*) and northern leopard frogs at higher pH treatments (^{3} 7.5). Relyea (2005b) also emphasized the importance of examining pesticide effects in a community context. In an outdoor mesocosm experiment using larvae of three anuran species (gray treefrog [*Hyla versicolor*], American toad [*Bufo americanus*], and northern leopard frog), zooplankton, and algae, where combinations of predators (no predators; red-spotted newts [*Notophthalmus viridescens*]; and larval diving beetles [*Dytiscus* sp.]) and pesticides (no pesticides, the insecticide Malathion®, and the herbicide Roundup®) were manipulated, Roundup® (at a level of 1.3 mg of active ingredient/L) had substantial direct negative effects on the tadpoles, reducing total tadpole survival and biomass by 40 percent. However, Roundup® had no indirect effects on the amphibian community via predator survival or algal abundance.

Extent of Risks Related to Locally Applied Pesticides

The effects of locally applied pesticides on mountain yellow-legged frogs are not known. Some level of risk of various pesticides to mountain yellow-legged frogs is suggested from data on other amphibians, but no data currently exist evaluating the level of risk of these pesticides to mountain yellow-legged frogs *per se*. Aerial application poses potentially the greatest threat to anurans because of the unpredictability of pesticide drift and the likelihood that it may reach aquatic habitats. Since 2000, the NFS has not and is not likely to employ aerial application of pesticides, thus minimizing this aspect of the threat. In response to a new invasive insect infestation, the NFS might choose to aerially apply a bacteria or virus targeting the insect, as opposed to application of chemical pesticides (D. Bakke, pers.com, 2009).

Conservation Options Related to Locally Applied Pesticides

Agencies participating in this Conservation Assessment have direct jurisdiction over the application of locally applied pesticides and thus can influence the impact of this activity on mountain yellow-legged frogs. Management should continue to regulate this activity to reduce its impact to this species.

Mining

Mining encompasses activities that have potential to degrade, fragment, or eliminate habitat, and some mining has occurred within the range of mountain yellow-legged frogs in the Sierra Nevada. The effects of any type of mining on mountain yellow-legged frogs are unstudied, but five types of mining (aggregate, hardrock, hydraulic, placer, and suction-dredge) are discussed for their potential to affect mountain yellow-legged frogs. Two other forms of mining (open pit and solution) are not discussed because they do not occur in the Sierra Nevada.

Aggregate Mining

Aggregate mining is mechanical extraction of materials from unconsolidated matrices from streams or stream terraces for use in construction of various infrastructure, 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 floodplain, may create large ponds filled by groundwater; in flood events, these ponds may become connected to the river (CSLC 1993). Hence, instream and terrace mining may increase sedimentation downstream of mining activities, alter or eliminate habitat, and increase exposure to bullfrogs and non-native, warmwater fishes that may establish in groundwater-filled ponds.

Aggregate operations are typically associated with large riverine channels, downstream of much of the range of mountain yellow-legged frogs in the Sierra Nevada. Some effects resulting from aggregate operations may exist in selected portions of the upper Feather River system, where such operations occur within the historical range of *R. sierrae*. The USDA Forest Service also maintains small quarries for road construction, maintenance, and road treatments; some of these quarries would be categorized as small aggregate mining operations, and some occur within the geographic ranges occupied by both mountain yellow-legged frog species. Though aggregate mining effects on mountain yellow-legged frogs are unstudied, their impacts are probably slight.

Hardrock Mining

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 involved digging shafts that went straight down to follow ore bodies and veins, or at least somewhat horizontally into rock faces. Shafts and tunnels were often supported with large timbers to prevent cave-ins. Most shaft or tunnel mines would eventually flood as they hit the water table, which is potentially a source of pollution where even slightly acidic water can solubilize potentially toxic metals. Many shaft or tunnel hardrock mines exist in Sierra Nevada National Forests. Though it is unclear precisely how many of these overlap the range of mountain yellow-legged frogs, most occur at lower elevations, largely outside the range of mountain yellow-legged frogs in the Sierra Nevada. Most hardrock mining operations that have the potential to impact mountain yellow-legged frogs occur in the lower elevation range of *R. sierrae* in the northern Sierra Nevada on the Plumas National Forest and in the ranges of both *R. muscosa* (sensu stricto) and *R. sierrae* on the Inyo National Forest.

Hydraulic Mining

Hydraulic mining consists of methods that use water, typically under pressure, to erode away hillsides of placer (gravel, sand, or silt) and other unconsolidated deposits (CSLC 1993). Its extreme approach drastically alters water quality and stream geomorphology (CSLC 1993, Larson 1996). A historically important practice introduced to California in 1853, it was outlawed in 1884, but its effects on water pollution may still be apparent in portions of those northern Sierra streams (e.g., mid-elevation Feather River) most affected by this practice (Larson 1996). This method, which exposes rock that would have otherwise remained concealed from immediate weathering and erosion, increases pollutants such as acid, cadmium, mercury, and asbestos in waterways (CSLC 1993). Effects of a few of these pollutants on amphibians are discussed in the Acid Deposition section. Except for portions of the Feather River system on the Lassen and Plumas National Forests where hydraulic mining was important, most of area that was hydraulic mined is below the elevation where mountain yellow-legged frogs were present, so the effects of this practice on mountain yellow-legged frogs were likely only locally significant.

Placer mining

Placer mining encompasses those types of mining where materials of interest are deposited in unconsolidated substrate (e.g., sand, gravel) or on the surface and are picked up without resorting to mechanically assisted (e.g., suction dredges) or extraordinary means (e.g., explosives). Historically, placer mining was a dominant form of mining (Larson 1996); today, placer mining is almost exclusively recreational.

Suction-Dredge Mining

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). An estimated 90% of current suction dredging occurs through recreational rather than commercial use. Because nozzles are currently restricted to 6 inches or smaller, it is believed that the areas disturbed by the activity are relatively small and recover quickly (CDFG 1994). Furthermore, suction dredging activities are highly regulated and many streams are permanently or seasonally closed (CDFG 1994). Suction dredging has burgeoned over the last decade and is expected to vary over time with changes, largely unpredictable, in the value of gold.

Suction dredging may increase suspended sediment, change stream geomorphology, directly remove aquatic organisms (potentially including frogs), and rearrange the substrate of streams (CDFG 1994). The increase in sedimentation downstream of suction dredging activities may result in burying and suffocating eggs and larvae (CDFG 1994, Harvey and Lisle 1998). Suction dredging activities have the potential to trap and kill embryos, larvae, juveniles, or adults (see CDFG 1994). Although the composition of invertebrate fauna changes in dredged areas, the recovery to a pre-dredging species composition seems rapid (Harvey 1986, Somer and Hassler 1992). The potential cumulative effects of suction dredging may pose a greater risk by altering geomorphology and water quality, and the timing of the effects may be critical as to their detrimental effects on mountain yellow-legged frog populations. For example, dredging activities during the egg laying season may be much more detrimental than the same activities that occur in winter.

Suction dredging is most prevalent in the foothill region of the Sierra Nevada, and thus poses a risk primarily to mountain yellow-legged frog populations at the lower elevations of the species' range. The degree to which mountain yellow-legged frogs experience direct, indirect, or cumulative effects as a result of suction dredging needs study.

Extent of Risks Related to Mining

Mining may pose local risks to mountain yellow-legged frogs at specific localities. Overlap in habitat use with suction-dredge gold miners is not well understood; this type of mining is on the increase. Impacts may results from selected hardrock mining operations where they overlap with the frog. Many mining-related impacts and habitat alterations occurred historically and remain today.

Conservation Options Related to Mining

Agencies should continue to manage mining where it overlaps with mountain yellow-legged frogs to reduce and mitigate potential impacts to populations and habitats. Mining is within the jurisdiction of agencies participating in this assessment. Science is needed to inform how certain types of mining may influence mountain yellow-legged frogs.

Recreational Activities Including Packstock

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 Forest Service 2004b). Recreational activities can take many forms, ranging from developed or dispersed camping to hiking, fishing, off-highway vehicle use, packstock use, suction dredging, and mountain biking. Mountain yellow-legged frog populations and habitats may be affected by these activities as well as corollary activities and conditions such as presence of roads associated with recreation facilities, species collections, the release of exotic pets, and the misguided release of rehabilitated wildlife into non-native habitats.

Mountain yellow-legged frogs occur away from major population centers with roughly 85 percent of their geographic range on public lands. Of the range on public lands, 18 and nearly 66 percent occur, respectively, on National Park and National Forest lands. Of the nearly 66 percent of the range on National Forest lands, much occurs in wilderness areas (USDA Forest Service GIS data available 2001). Within designated wilderness areas, major activities are limited to non-motorized and dispersed activities such as hiking, backpacking, fishing, and camping. Outside these areas, recreational activities (e.g., developed campgrounds and motorized activities) have the potential for greater impact. Thirteen percent of the mountain yellow-legged frog range lies on private lands, which is frequently the least protected and potentially subject to all types of recreation as well as conversion to other land uses (e.g., agriculture and urbanization). Any recreational activities have the potential to contribute to localized impacts on the species or its habitat. Moreover, recreational use is expected to increase in the future, and consequently, the impact on the species is also expected to increase (USDA Forest Service 2004b).

Packstock grazing is the only grazing currently permitted in national parks in the Sierra Nevada (USFWS 2009). Use of packstock in the Sierra Nevada has increased since World War II as a result of improved road access, and increases in leisure time and disposable income (Menke et al. 1996). Demand for recreational activities including packstock use and recreational riding is expected to increase (USDA 2001a). Packstock includes horses, mules, llamas, and goats; and packstock grazing tends to be a high-elevation phenomenon associated with access to more remote locations for longer dispersed camping forays. Packstock tend to graze close to lakes, meadows, ponds, and trails, where suitable forage often exists.

High overlap exists between mountain yellow-legged frog habitats and areas commonly used for recreation. Mountain yellow-legged frogs inhabit high mountain lakes, ponds, streams and tarns associated with montane riparian habitat (see Habitat Requirements under Ecology section). These areas are also attractive for human recreation and receive a disproportionate amount of recreational use through trail networks and campsites located near streams, creeks, rivers, and lakes (Vinson 1998).

To date, no studies have examined the impacts of recreational activities on mountain yellow-legged frogs. Moreover, few studies have examined recreational impacts on amphibians with similar life histories. However, some information exists on the effects that selected recreational activities may have on the aquatic habitats that mountain yellow-legged frogs use. Using this literature together with knowledge of the ecology of the species, an extrapolation of the potential effects of recreation is possible. Because various recreational activities have similar effects on frogs and frog habitat, they are addressed based on their impacts.

Direct Effects

Recreational activities may directly disturb mountain yellow-legged frogs. All life history stages of mountain yellow-legged frogs, but especially larvae and juveniles, may be injured or killed through crushing, trampling, or other means by recreational hikers, bikers, anglers, pets, and off-highway vehicles (OHV). Packstock have been documented to kill larvae and juvenile frogs by trampling (V. Vredenburg, pers. comm., 2002). Anglers, hikers, and their pets have been observed trampling and disturbing western toad (*B. boreas*) egg masses, tadpoles, and metamorphosing froglets at a site in Oregon (C. Brown, pers. comm., 2008.). The abundance of Iberian frogs (*R. iberica*) decreased with proximity to recreational activities and the time frogs spent in refugia was affected by the amount of human activity (Rodríguez-Prieto and Fernández-Juricic 2005). Vehicles have the potential to disrupt feeding or breeding. A study on the effects of OHV use in the Mojave Desert in California showed that vehicles created noise levels which caused hearing loss in some of the desert herpetofauna (Brattstrom and Bondello 1983). Moreover, the noise caused premature emergence of Couch's spadefoot toads (*Scaphiopus couchi*) that were aestivating until the arrival of rain for breeding; a situation that could result in death (Brattstrom and Bondello 1983, Lovich and Bainbridge 1999). It has been speculated that vibrations caused by vehicles passing near breeding sites of Yosemite toads may reduce their reproductive efficiency and that males stopped calling when vehicles drove by on nearby roads (Karlstrom 1962). Simply handling amphibians, not an infrequent phenomenon among recreationists, may also contribute to their decline (Kagarise Sherman and Morton 1993).

An activity of particular concern for mountain yellow-legged frogs is recreational fishing, the demand for which is the primary stimulus for fish stocking. Studies have shown that non-native predatory fish contribute to the decline of frog populations via predation, restricting habitat, and limiting dispersal (Bradford 1989, Bradford et al. 1993, Bradford et al. 1998, Knapp and Matthews 2000a, 2000b, Knapp et al. 2001, Pilliod and Peterson 2001, Vredenburg 2004, Knapp et al. 2007, see section on Introduced Fish and Other Predators). Activities associated with recreational fishing also may be a source of introduced parasites and pathogens (Kennedy et al. 1991, Kennedy 1993, see Disease section). Introduced trout have been shown to serve as a vector spreading pathogens lethal to embryos of the western toad (Kiesecker et al. 2001). There is also potential to spread disease pathogens via fishing lines, lures, and clothing of fishermen. Anglers have been observed using toads and larvae as bait (G. Milano, pers. comm., 2002); use of mountain yellow-legged frog life stages as bait has not been directly observed, but the levels and extent of recreational fishing across the mountain yellow-legged frog's range make this a possibility.

Effects on Habitat

Recreation also can indirectly affect mountain yellow-legged frog populations by altering their habitat. Establishment of trails and camps has been shown to disturb vegetation and soil structure, resulting in changes in habitat structure and microclimate (Garton et al. 1977, Boyle and Samson 1985, Knight and Cole 1991). These activities, as well as dispersed camping and other activities that occur near high-elevation meadows, ponds, lakes, and streams, can result in increases in erosion and sedimentation, bank trampling, and vegetation disturbance. Heavy recreational use can mimic damage to vegetation and soils caused by grazing (Obedzinski et al. 2001). The impact of recreational use, specifically camping, in designated wilderness and National Parklands in the western United States has been addressed in a number of studies (see for example, Cole and Fichtler 1983, Cole 1986, Stohlgren and Parsons 1986). Generally, such studies have found that recreation creates considerable impacts rapidly with light use, whereas recovery occurs only after lengthy periods of no use (Cole and Marion 1988). For three wilderness areas studied in the western United States, the impacts on campsites used for only a few nights per year (less than 10) had already reached a threshold beyond which further increases in use had little effect on impact severity. These impacts included 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).

There are studies examining the effects of recreational packstock grazing on alpine meadow habitat (Olson-Rutz et al. 1996a, 1996b, Moore et al. 2000, Cole et al. 2004). Olson-Rutz et al. (1996a, 1996b) noted that decreased cover and increased bare soil were correlated with grazing intensity and duration. An experiment that compared three types of meadows in Yosemite National Park with grazed versus ungrazed reference areas found significant changes in meadow structure resulting from horse and mule packstock grazing after four years (Moore et al. 2000, Cole et al. 2004). Notably, bare ground increased and productivity declined, and species composition changed on all three meadow types after two years. Plant foliar cover decreased after three years in the wettest of the three meadow types, that dominated by tufted hairgrass (*Deschampsia cespitosa*). No change in species richness was observed, but those changes often require longer than four years (Moore et al. 2000). Moore et al. (2000) also showed that meadow productivity data were directly applicable to packstock management by defining the relationship in productivity against grazing intensity. This could then be used to anticipate levels in productivity expected for particular levels of grazing intensity. In particular, they found that the wetter the meadow type, the less biomass could be removed to achieve an equivalent level of decline in productivity. Moore et al. (2000) also found that the rule-of-thumb dictum of leaving 50 percent of biomass at the end of the grazing period to maintain nutrient levels after decomposition resulted in an over 25 percent decline in productivity over the study period on all three meadow types. How these changes in meadow condition may affect mountain yellow-legged frogs is unstudied.

Relatively little is known about the natural resilience of high-elevation ecosystems in the Sierra Nevada following disturbance (Stohlgren and Parsons 1986). However, at high elevations, riparian habitats may be more sensitive to disturbance because of the short growing season. Recreational activities may affect various components of mountain yellow-legged frog habitat including: 1) hydrology; 2) breeding area morphology; 3) water quality; and 4) cover—in and out of water.

Hydrology

Many riparian species are sensitive to changes in hydrologic regimes that affect flooding periodicities and water table depth (Obedzinski et al. 2001). Persistence of water is crucial to the survival and recruitment of mountain yellow-legged frogs, which are almost always found within a meter of water (Stebbins 1951, Mullally and Cunningham 1956, Karlstrom 1962; see Habitat Requirements in Ecology section). Water depth is especially important because the frogs utilize water for both refuge and overwintering, and require bodies of water that typically neither freeze to the bottom in winter nor dry out completely in summer (V. Vredenburg, pers. comm., 2002). Larvae may overwinter in the same body of water 2-4 years before reaching metamorphosis (Cory 1962b, Bradford 1982, 1983, Bradford et al. 1993, Knapp and Matthews 2000a), so persistence of a minimum depth is also important. In addition, the tadpoles prefer shallow shoreline areas at the edges of lakes where the water temperature is warmer (Bradford 1984a). Consequently, any changes in hydrology which induce premature drying or shallowing of water bodies or reduction of shallow shoreline habitat are likely to have a significant impact on the species.

Recreational activities such as hiking, camping, or OHV use that occur near meadows, ponds, lakes, and streams can affect hydrology and available water in several ways. For instance, packstock camps in the Bob Marshall Wilderness of Montana exhibit large areas of bare ground, increased soil compaction, and slower rates of water infiltration (Cole and Fichtler 1983). Other activities can also result in soil compaction, increased runoff, vegetation alteration, modification of pool mudflats, and bank trampling, all of which may result in increases of erosion, sedimentation, and the filling in of ponds, lakes, or pools in streams. Major effects of recreation activities on hydrology may include diversion of water, downcutting, and eventually lowering of water tables, leaving formerly suitable habitat susceptible to desiccation or freezing. Effects to habitat resulting from disruption of hydrology are more likely in shallower areas such as those that are used by larvae and as oviposition sites, or in small streams rather than in deeper lakes.

Breeding Area Morphology

Mountain yellow-legged frogs often breed in inlet streams, springs, or along lake shorelines (V. Vredenburg, pers. comm., 2002). These wet, shallow areas are especially prone to damage from trampling by hikers, packstock, or OHVs. Trampling by packstock can be particularly detrimental in sensitive lake habitat because their mass per unit area is much greater than that of hikers or backpackers alone. Location of trails can increase the problem when they funnel humans and their animals into mountain yellow-legged frog breeding habitat. Sequoia and Kings Canyon National Parks began restricting stock use in 1998 to protect a known mountain yellow-legged frog oviposition site (V. Vredenburg, pers. comm., 2002). In addition, since most large lakes are now inhabited by fish introduced for recreational purposes, mountain yellow-legged frogs may breed more frequently in shallower, fish-free waters which are more susceptible to freezing or desiccation.

Water Quality

Besides the physical effects related to riparian zone soil and vegetation, localized water pollution as a result of camp use also may pose a threat. Commonly used camp-related substances such as sunscreen and insect repellent may be introduced into the environment through swimming and washing. Contact with these substances may place amphibians such as mountain yellow-legged frogs at risk because of their permeable skin. Schlumpf et al. (2001) found that several compounds which are frequently used in sunscreens pose some risk, primarily estrogenic activity, to tested lab animals. Other water pollutants such as nitrogen may enter bodies of water via human wastes (Rouse et al. 1999). Water quality can also be affected when hikers, packstock, or OHVs trample or disturb bank areas. Bank disturbance causes erosion, which, in turn, can locally increase siltation, sediment loading, or even nutrients. The negative impacts of increased sedimentation on stream-dwelling fish, macroinvertebrates, and periphyton are well known (Power 1990, Newcombe and MacDonald 1991, Waters 1995), but knowledge of similar impacts on amphibians remain limited (Gillespie 2002). Increases in sedimentation may reduce the availability or quality of oviposition sites, or larval refugia or rearing sites (Welsh and Ollivier 1998). Increased sedimentation may also reduce availability of important food resources such as algae for larval amphibians (Power 1990).

Cover

Cover provides several important functions for mountain yellow-legged frogs including refuge from predators, mediation of microclimatic conditions, and habitat for prey. Mountain yellow-legged frogs seem to prefer sloping banks with rocks or vegetation close to the water's edge (Stebbins 2003) and can often be observed resting in clumps of vegetation. Because vegetation cover is reduced by trampling (Dale and Weaver 1974), hikers, bikers, packstock, and OHVs may destroy vegetation near banks that frogs may use for cover. Packstock are especially problematic because they apply more downward force when walking than hikers and thus cause more damage to vegetation, induce soil compaction, and reduce organic litter material (Weaver and Dale 1978). Mountain yellow-legged frogs usually jump into the water when disturbed and take refuge under rocks or crouch at the bottom of the lake or stream (see Habitat Requirements under Ecology section). Thus, cover within bodies of water also may be important, especially in the shallows that likely provide a refuge from fish predators located in adjacent deeper water (Jennings and Hayes 1994). Recreational activities that occur near banks or shores may alter levels of siltation or alter the existence of rocks or vegetation below the surface, thereby affecting in-water cover. Increases in sedimentation may alter larval refugia or rearing sites (Welsh and Ollivier 1998). In some cases, frogs have been known to overwinter in bedrock crevices in shallow water, which allows them to survive in water that freezes to the bottom in winter (Matthews and Pope 1999). Increases in sedimentation could fill these crevices, thereby reducing available overwintering sites. For the spotted tree-frog (*Litoria spenceri)*, a stream-dweller that breeds in shallow pools, a reduction in habitat quality resulting from increased sedimentation may also increase the vulnerability of its larvae to other threats such as predation from introduced fish (Gillespie 2002). This could be particularly significant for the mountain yellow-legged frog, which is preyed upon by introduced trout (see Introduced Fish and Other Predators).

Extent of Risks Related to Recreational Activities

The risk level of recreational impacts to the mountain yellow-legged frog is unknown. The nature of many recreational activities places them in direct contact with mountain yellow-legged frogs or their habitat. Recreational activities may be localized, but if improperly managed, their adverse effects are likely to be persistent and long term. In high-use areas, recreational activities are likely to add to cumulative impacts on already stressed small populations. Fish stocking for recreational fishing (see Introduced Fish and Other Predators section) and developed camping pose the greatest risk to the mountain yellow-legged frog. Dispersed activities like hiking, camping, and mountain biking may pose a more moderate risk to the species across its range because these recreational activities may have localized impacts; however, the degree of impact is largely a function of the volume of human use. No data exists for this risk factor relative to the mountain yellow-legged frog.

Conservation Options Related to Recreational Activities

Agencies should continue to manage recreational activities to reduce and mitigate potential impacts to the mountain yellow-legged frog. Recreational activities are within the direct purview of agencies participating in this assessment. Studies on the extent and scope of recreational impacts to mountain yellow-legged frog are needed.

Research Activities

Researchers have the potential to negatively affect frog populations by handling or marking animals, attracting predators in number or frequencies greater than typical background levels, or spreading pathogens among water bodies via clothing and equipment. Currently, no evidence exists to suggest that research activities have negatively affected mountain yellow-legged frog populations. Kathleen Matthews, Karen Pope, and Vance Vredenburg studied mountain yellow-legged frogs intensively at two separate sites in Kings Canyon National Park over several years without apparent ill effects to their study populations. Intensive study included marking individual animals with PIT tags, attaching radio transmitters to selected animals, removing fish from selected water bodies, and monitoring specific locations with high (daily or every few day) frequency. In the Tablelands of Sequoia National Park, where a complete disappearance of frogs was reported from one lake, live frogs were monitored using exclusively visual surveys and contact with aquatic environments was restricted to the removal of dead frogs (Bradford 1991).

Historically, handling and marking of animals has been viewed as innocuous, but recent work addressing marking techniques (Murray and Fuller 2000) and pathogen epidemiology has suggested a re-assessment of this view. A review of studies involving toe-clipping to mark individual animals has 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 does not address the effects of single clips, often used to obtain samples for genetic or aging (skeletochronological) studies, leaving ambiguous their effects, if any. No effects on survival or body condition have been found using PIT tags, but comparison to unmarked reference animals has been restricted to laboratory analyses (Perret and Joly 2002), leaving open the question of how well such analyses translate to field conditions. Further, the poorly understood epidemiology of aquatic pathogens (e.g., chytrids, water molds; see Section on Disease) has focused attention on their transmission between water bodies, and between carrier and diseased and healthy animals. Research activities that simply 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 if attention to their vector potential is not addressed. Current research activities on amphibians contain provisions (largely specific equipment cleaning approaches) to limit the spread of potential pathogens into and between the environments of these amphibians (G. Padgett-Flohr, pers. comm., R. Knapp, pers. comm., V. Vredenburg, pers. comm.); these provisions represent broad-brush approaches that reflect general limited knowledge on pathogen transport and transmission. Refinement of these approaches will be needed as new knowledge on patterns of pathogen transmission is acquired.

The potential for researchers to attract certain predators through their activities 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 mountain yellow-legged frogs. Some predators, particularly Gray Jays, Clark's nutcrackers and other corvids, have the potential to be attracted to research activities in numbers potentially greater than background levels because they habituate well to human activities and are attracted to food carried by humans (Lawrence 1973); whether such attraction would pose a significant threat to local mountain yellow-legged frog populations is unknown.

Extent of Risks Related to Research Activities

Researchers typically have their study species' best interest in mind when designing their studies, so research activity is not likely to be a significant factor in the decline of mountain yellow-legged frogs. However, precisely how research activity might contribute to declines is unstudied.

Conservation Options Related to Research Activities

Given that field research activity represents the most fundamental way that scientific information can be gathered on mountain yellow-legged frogs, research activities should be addressed, if only to diminish potential risks. Agencies participating in this conservation assessment have a large amount of control over the extent and distribution of research activities. There is a potential conflict between protecting the species and developing the science necessary to guide protective management. Thus, as risks from research become better understood, agencies need to develop management solutions to address those practices that pose high risk to the mountain yellow-legged frog. Agencies should promote prophylactic measures against potential disease transmission.

Roads

Roads have become an increasingly common feature of most landscapes, and their presence has been shown to have several negative ecological effects (Forman and Alexander 1998) especially evident within aquatic or riparian ecosystems (Trombulak and Frissell 2000). Roads have been constructed throughout the mountain yellow-legged frog range, especially the lower elevations. Based on data available in 2003, the roughly 66 percent of the mountain yellow-legged frog's range on National Forest lands contains approximately 2100 km of paved roads (primary/secondary highways and improved paved roads), 2300 km of gravel roads, 15,000 km of dirt roads (dirt and unimproved dirt roads), and 7500 km of trails (USDA Forest

Service GIS data available 2001). Portions of the mountain yellow-legged frog range also are in wilderness areas and national park lands, where some roads exist but information on road coverage is limited or lacking.

No studies have yet identified the impacts of road construction or road use on mountain yellow-legged frogs, but a few studies have addressed road effects on other anurans and amphibians. Some studies also have examined road effects on riparian habitat, which may have indirect effects on frog populations. Most research on anurans has been done for species that occur near urban areas or cross roads with substantial traffic. Because mountain yellow-legged frogs generally are in more remote areas, they rarely negotiate high traffic roads. Even so, many of the same impacts apply. Roads have seven general effects: mortality from construction, mortality from collision with vehicles, modification of animal behavior, alteration of the physical environment, alteration of the chemical environment, spread of exotics, and increased human use of areas near these roads (Trombulak and Frissell 2000). Impacts of roads are discussed below in terms of their potential direct and indirect effects on frog populations. Also see Andrews et al. (2008) and Beebee (2013) for more recent reviews on the effects of roads on amphibians.

The degree to which roads affect mountain yellow-legged frogs and their habitat depends on many factors such as road density, road type, and traffic intensity. Populations of mountain yellow-legged frogs occurring on private lands are considered the most susceptible to impacts associated with roads because urbanization, including the construction of new, heavily-used roads, may be more likely to occur in those areas. Private lands comprise roughly 13 percent of the mountain yellow-legged frog range in the Sierra Nevada. National Forests generally have many roads, but these are typically dirt-based logging roads as opposed to paved or high-traffic roads. Although vehicular traffic may be lower on these roads, they may still receive substantial foot traffic from recreationists. Recreational use of mountain yellow-legged frog habitat is discussed in the Recreational Activities section. National parks and wilderness areas ordinarily have few roads. However, the presence of even just a few roads may affect frog habitat in a noticeable way. For example, one road has been shown to exhibit edge-effects that can create negative responses in biodiversity extending up to 1-2 km from the road itself (Forman and Deblinger 2000, Findlay and Bourdages 2000).

Several studies have shown amphibian densities to be inversely related to road density and traffic intensity (see Fahrig et al. 1995, Vos and Chardon 1998). This implies that a reduction in road construction and the improvement or decommissioning of both private and public roads may have long-term benefits for frog populations by reducing traffic-related mortality and its corollary impacts on mountain yellow-legged frog habitat. Previously constructed roads may still pose problems for mountain yellow-legged frogs. Because of lags in response to changes, the full effect of road construction on wetland biodiversity may not be detectable in some taxa for decades. Thus, even if no new roads are built, biodiversity may continue to gradually decline in response to historical changes in road density, with local extirpations simply being delayed in time (Findlay and Bourdages 2000).

Direct Effects

Direct impacts to mountain yellow-legged frog populations from roads potentially include road kill and direct loss of habitat or formation of barriers. Traffic mortality can have two effects: 1) reduction in population size; and 2) reduction in movement between resources and conspecific populations (Carr et al. 2000). Studies have concluded that anurans are well known victims of vehicular mortality (Fahrig et al. 1995) because their life histories require them to move between habitats and, consequently, to cross roads (Vos and Chardon 1994). The seasonal life history of mountain yellow-legged frogs may make them susceptible because they move throughout three different habitats, one for each of breeding, feeding, and overwintering. Conversely, the species generally are found near water, which may limit their exposure to vehicle traffic. Mountain yellow-legged frog adults may typically move a few hundred meters (Matthews and Pope 1999) but distances of up to 1 km have been observed (V. Vredenburg, pers. comm., 2002). A study of the northern leopard frog showed that species that are highly vagile are generally more affected by road mortality because they increase their likelihood of encountering roads (Carr and Fahrig 2001). The risks of road mortality are considered relatively minimal for mountain yellow-legged frogs because roads are relatively rare and occupy a relatively small portion of mountain yellow-legged frog habitat, and those that do exist are typically forest roads that have low traffic levels.

Research on habitat fragmentation due to roads is biased towards highly fragmented landscapes, but one study on moor frogs (*Rana arvalis*) in less fragmented habitat revealed that roads increase isolation, and hence contribute to fragmentation (Vos and Chardon 1998). The study also showed that even in a relatively large and stable habitat patch, fragmentation effects were strongly negative, and that the negative fragmentation effects of roads are often underestimated (Vos and Chardon 1998). Mountain yellow-legged frog habitat is primarily found in National Park or National Forest lands, which are relatively far from urban areas, and have fewer roads and lower traffic densities than in moor frog habitat. Specifically, 18 percent of the mountain yellow-legged frog range lies on National Park lands where roads are few (USDA Forest Service GIS ownership layer 2001). For the approximately 66 percent of the range that exists on National Forest land, an average value of about 55 percent of each National Forest's roads occur within the mountain yellow-legged frog's range. In addition, about 89 percent of the total distance covered by roads within the species' range is by dirt or gravel roads (USDA Forest Service GIS transportation layer 2001). These types of roads are primarily used for logging, or access to recreational activities such as hiking, and likely exhibit fairly low traffic density. Still, there may be unrecognized fragmentation effects. Roads may provide a benefit to stream-dwelling mountain yellow-legged frogs if they provide a barrier to fish passage; this has not been studied.

Other impacts to mountain yellow-legged frogs may occur in a variety of forms. Pollution from vehicular emissions and road runoff contains various toxic chemicals that can have negative effects on amphibian populations including reduced survival, deformities in tadpole oral cavities, elevated levels of stress hormones, and inhibited growth and metamorphosis (Mahaney 1994, Lefcort et al. 1997, Welsh and Olivier 1998). Similarly, roads may cause increases in sedimentation and water pollutants (Spellerberg 1998). In a related species, the foothill yellow-legged frog (*R. boylii*), eggs collect sediment (Storer 1925); artificial increases in sedimentation may be detrimental by suffocating eggs (Jennings and Hayes 1994). The amount of sedimentation that foothill or mountain yellow-legged frog eggs or larvae can withstand is not known. Another indirect impact of roads could arise from noise pollution due to increased traffic. Hypotheses for the effects of traffic noise include hearing loss, altered behaviors, and interference with communication during breeding activities (Forman and Alexander 1998). Research indicates that highway noise, as a broad-band noise source, may alter the reproductive behavior of anurans, which depend on acoustic cues for their mating system (Karlstrom 1962, Brattstrom and Bondello 1983, Lovich and Bainbridge 1999). Again, no direct evidence on the negative effects of noise pollution on mountain yellow-legged frogs is available. If there are negative effects, they are most likely slight because mountain yellow-legged frogs appear to call primarily from underwater (Stebbins 1985). Roadside lighting has also been shown to alter nocturnal frog behavior (Buchanan 1993); however, because mountain yellow-legged frogs are chiefly diurnal, the effects of roadside lighting are likely insignificant.

Effects on Habitat

Roads can impact mountain yellow-legged frog populations by affecting their riparian habitat. At least eight physical characteristics of the environment may be altered by roads: soil density, temperature, soil water content, light, dust, surface-water flow, pattern of runoff, and sedimentation (Trombulak and Frissell 2000).

Because the mountain yellow-legged frog depends on aquatic habitat for survival and successful recruitment, changes in the hydrology of Sierran high mountain lake and stream systems can be quite detrimental. 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 both peak flows (floods) and debris flows in stream channels (rapid movements of soil, sediment, and large wood stream channels). These two processes have major influences on riparian vegetation (Jones et al. 2000) and aquatic and riparian patch dynamics critical to stream ecosystems (Pringle et al. 1988). Mountain yellow-legged frogs occasionally breed in the shallows of ponds or in low-gradient stream inlets (Zweifel 1955). These areas can be affected by fluctuations in the frequency or magnitude of peak and debris flows of adjacent streams. Because mountain yellow-legged frogs require breeding sites that are sufficiently deep to avoid drying or freezing of eggs or larvae, fluctuations that ultimately cause a reduction in available water could severely affect recruitment. A drastic increase in flooding or debris flows could dislodge or bury eggs that are attached to rocks, gravel, vegetation, or under banks. Hydrologic effects are likely to persist for as long as the road remains a physical feature altering flow routing, often long after abandonment and revegetation of the road surface (Trombulak and Frissell 2000).

Increased sedimentation is another way roads affect riparian habitat. Although knowledge of the impact of increased sediment load on amphibians is still limited (Gillespie 2002), the negative impacts of increased sediments on stream-dwelling organisms including fish, macroinvertebrates, and periphyton are well documented (Power 1990, Newcombe and MacDonald 1991, Waters 1995). Direct transfer of sediment (and other material) to streams and other water bodies at road crossings is an inevitable consequence of road construction (Richardson et al. 1975). The surfaces of unpaved roads can route fine sediments to streams, lakes, and wetlands, increasing turbidity of the water (Reid and Dunne 1984). This disrupts stream ecosystems by inhibiting aquatic plants, macroinvertebrates, and fish. High concentrations of suspended sediment may directly kill aquatic organisms and impair aquatic productivity (Newcombe and Jensen 1996). The effects are further heightened if the sediments contain toxic materials (Maxell and Hokit 1999). Road construction in Redwood National Park introduced large amounts of sediments into neighboring streams and densities of amphibians were lower in these streams compared to nearby control streams (Welsh and Ollivier 1998). Increased sedimentation may also reduce availability of important food resources for tadpoles like algae (Power 1990). Fine sediment deposits also tend to fill pools and smooth gravel beds, degrading habitats (Forman and Alexander 1998) and possibly reducing the availability of oviposition sites or larval refugia (Welsh and Ollivier 1998). Furthermore, the consequences of past sediment delivery are long-lasting and cumulative, and cannot be effectively mitigated (Hagans et al. 1986).

A third impact of roads on frog habitat occurs via spread of chemicals into the ecosystem. Maintenance and use of roads contribute at least five different general classes of chemicals to the environment: heavy metals, salt, organic molecules, ozone, and nutrients (Trombulak and Frissell 2000). The alteration of the chemical environment by roads may affect living organisms in a number of ways. For instance, organisms may be killed or displaced by contaminants, or plants may accumulate toxins, which can depress their growth.

New road construction often facilitates increased human use of newly roaded areas. An increase in human activity may increase direct and indirect road effects previously discussed. Within National Forests, which have many roads, some degree of conversion of unimproved roads to more developed roads exists; thus, significant opportunity exists for increased human use and vehicular traffic in that landscape. National parks and wilderness areas are unlikely to expand their road networks, so increased human use in these areas, which may result from population growth, would not be facilitated by new road construction or conversion toward more developed roads.

Extent of Risks Related to Roads

The risks of roads to mountain yellow-legged frogs are unknown and to date, unstudied. The substantial road matrix across a portion of the range of mountain yellow-legged frogs and significant science on the negative effects of roads on other amphibians indicate that roads are a potentially significant risk to mountain yellow-legged frogs.

Conservation Options Related to Roads

Agencies should continue to manage road construction, planning, and proliferation. These are activities that are directly within the jurisdiction of agencies participating in this Conservation Assessment. Science is needed to inform how roads may influence mountain yellow-legged frogs, especially where populations are near roads, and to identify where roads may amplify or attenuate the effects of other risk factors.

Vegetation and Fuels Management

Vegetation and fuels management encompasses all management activities that alter vegetation structure and composition, which includes fuels management. The extensive and damaging fires of 2000 and 2002 led to making fuels management a focal part of implementing the National Fire Plan (NFP) (Pilliod et al. 2003). Fuels include standing and downed live and dead vegetation. Vegetation and fuels management activities include thinning, hazard tree removal, salvage logging, mastication, and prescribed fire (including underburning and pile burning). Except for prescribed fire, all these activities can result in significant ground disturbance. Data are lacking on how vegetation and fuels management activities may affect mountain yellow-legged frogs.

Vegetation and fuels management may overlap with mountain yellow-legged frogs more in the northern and lower elevation portions of the taxa's Sierran range than in the higher elevation parts of their central and southern range. In these latter areas, vegetation and fuels management activities are not only less prevalent, but mountain yellow-legged frogs generally use more open lake habitats (see Habitat Requirements in Ecology section). Populations inhabiting forested streams may be most at risk.

Commercial timber harvest occurred historically over the lower elevational range of mountain yellow-legged frogs. However, some forest plans lacked standards and guidelines to provide protection for riparian areas, and timber harvesting occurred to the edges of riparian areas and access roads were constructed across streams and their adjoining aquatic habitats. Commercial logging in this manner affected riparian microclimates and altered water yields that resulted in headcutting, lowering of the water table, and loss of riparian habitat. Habitat alteration legacies of historical harvest practices remain in many areas. Understanding the effects of present-day harvest practices on mountain yellow-legged frogs is difficult because the two major effects of harvest, removal of shading and sedimentation, do not occur to the same degree with each harvest and harvest can affect stream production in a positive manner if sedimentation can be limited (Murphy et al. 1981). The work of Ashton et al. (2006) suggests that sedimentation can be a significant problem for the related species, foothill yellow-legged frogs, in some streams.

Ground-disturbing activities have the potential to directly or indirectly affect mountain yellow-legged frogs. Falling trees, equipment, vehicles, and even personnel can crush mountain yellow-legged frogs; changes in vegetation, shade, and woody debris can alter breeding, active-season, refuge, and overwintering habitat quality; and changes in vegetation can also influence soil stability, erosion, and sediment loading to aquatic habitats. For example, tractor piling occurring near or at the head of drainages removes organic material which can increase streamflow, resulting in erosion and sedimentation. Soil disturbance, erosion, and sediment loading issues were addressed in the section on Livestock Grazing.

The SNFPA (USDA Forest Service 2001a, 2004c) has riparian conservation objectives (RCOs) to conserve riparian and aquatic habitats that supersede all but the Defense Zone fuels treatments. This would limit the direct risk of disturbance to mountain yellow-legged frogs and habitat unless the RCO determined that treatment would be beneficial to the species. The regular and required use of BMPs for soil and water quality also limits the likelihood of upland treatments contributing sediment to streams. The risks described are greater for private lands due to the less restrictive forest practice rules, but they still employ basic stream protections. As opposed to historical times, current NFS vegetation treatment practices in riparian areas are by hand or use very low impact mechanical equipment designed specifically to minimize impacts to riparian and aquatic resources.

Prescribed fire is one method of fuel reduction in the United States, but the effects of such controlled burns on fauna, including mountain yellow-legged frogs, are poorly understood (Pilliod et al. 2003). In 2001, nearly 650,000 ha of federal lands were burned by prescription (USDA Forest Service and USDI 2002). Prescribed fire would have the potential to benefit mountain yellow-legged frogs if it reduced the risk of future high-intensity wildfire, but such conditions are unlikely to occur outside the northern and lower elevation portions of the species' range because of fuel development patterns. Prescribed fire also could damage mountain yellow-legged frog habitat if not properly implemented. Prescribed fire can greatly alter vegetation and soils and may disturb frogs if implemented when fires would not naturally occur or at high-fuel loading, which can lead to high fire intensity. Methods have been developed to reduce effects of prescribed fires on streams. For example, igniting outside a defined buffer and allowing fire to backburn downslope toward the stream channels creates a feathered edge of burned area which usually extinguishes prior to burning riparian growth. Present fuels management on some National Forests uses these no-ignition buffers. Much of the mountain yellow-legged frog range is on granitic soils; improperly implemented prescribed burning could be risky on granitic soils because 1) erosion rates of burned areas on such soils have been shown to be 66 times as great as on undisturbed watersheds, and 2) annual sediment yields is elevated for 10 years or more (Megahan et al. 1995).

Partly due to public concern about allowing prescribed burning near urban areas, the use of mechanical fuel reduction (e.g., brush removal and thinning the tree canopy) has increased in popularity (Pilliod et al. 2003). In 2001, 160,000 ha of federal forestland were thinned to reduce hazardous fuels (USDA Forest Service and USDI 2002) and passage of the Healthy Forests Initiative in 2002 has amplified this effort. No studies have directly examined the effects of thinning understory brush or removing coarse woody debris on amphibians, although an effort has been made to document the effects of timber harvest (e.g., Bury and Corn 1988, Corn and Bury 1989, Dupuis and Steventon 1999). If reducing understory fuels via thinning results in increased air temperatures, decreased soil moistures, and reduced habitat complexity with fewer refuge sites, amphibian populations could decline in thinned forests (Dupuis and Steventon 1999). Studies are lacking to understand whether such habitat alterations would significantly affect mountain yellow-legged frogs.

Extent of Risks Related to Vegetation and Fuels Management

The risk of vegetation and fuels management activities is unknown for the mountain yellow-legged frog. Based on the known effects of vegetation and fuel management activities on riparian habitats, the potential exists for these activities to affect the species; science is needed to inform the issue. This factor poses a higher risk in areas outside wilderness areas where these activities are more prevalent. The potential exposure of mountain yellow-legged frogs, particularly stream dwelling populations, to vegetation and fuels management activities is greater in the northern Sierra and lower elevation portions of its range.

Conservation Options Related to Vegetation and Fuels Management

Agencies should continue to manage for vegetation and fuels management where these activities fall within mountain yellow-legged frog areas. These are major activities that are directly within the jurisdiction of agencies participating in this Conservation Assessment. Research is needed to determine the effects of these activities on the frog and its habitat.

Water Development and Diversion

Water developments, such as dams and diversions, can radically change an aquatic habitat and are a prominent component of the landscape in the Sierra Nevada (Harris et al. 1987, Moyle and Randall 1998). However, the majority of water development, whether assessed based on number, scale, or size, has occurred at lower elevations (Moyle and Randall 1998) and much of it below 1,219 m (4,000 ft) which is below most of the elevation range of mountain yellow-legged frogs (see Status section). Nonetheless, numerous small impoundments and diversions exist at mid-elevations (1,219-2,438 m [4,000-8,000 ft]), a number of which had some mountain yellow-legged frogs present in them at least historically. For example, mountain yellow-legged frogs have been taken at Bear River (MVZ 136236) and Union (MVZ 43076-43077) Reservoirs, located, respectively, on the Eldorado and Stanislaus National Forests. Mountain yellow-legged frogs also have been taken in a number of lakes that have been expanded in size for a water development purpose. For example, mountain yellow-legged frogs were historically known from Hume Lake (MVZ 6215-6228) on the Sequoia National Forest and Shaver Lake (MVZ 223083-223085) on the Sierra National Forest in Fresno County; they no longer exist at either locality (B. Hansen, pers. comm., 2005). Except for one recent (1999) record from Faggs Reservoir (CAS 209370, 209377) on the Plumas National Forest, all of the several dozens of records of mountain yellow-legged frogs from reservoirs or water development-altered lakes are older (pre-1975) and at least half of these pre-date the water development projects at those locations. Because virtually all these sites appear to be no longer occupied by mountain yellow-legged frogs (based on a current check of California Natural Diversity Database, B. Hansen, pers. comm., 2005), this pattern implies that water development or some feature related to water development may have resulted in the disappearance of mountain yellow-legged frogs at these locations. All of the reservoirs and altered lakes mentioned above now harbor several fish species (P. Moyle, B. Hansen, pers. comm., 2005), including selected warmwater taxa, and at least two (Hume and Shaver Lakes) also harbor bullfrogs (Moyle 1973, B. Hansen, pers. comm., 2005). Details regarding fish and bullfrog effects have been discussed elsewhere (see Introduced Fish and Other Predators). Conversely, because creation of ponds and lakes can be beneficial to mountain yellow-legged frogs if these habitats are fishless (see Introduced Fish and Other Predators), one possibility is that mountain yellow-legged frogs continued to occur in these stillwater habitats as long as problematic fish species were either not present or not abundant. Pond or lake creation or augmentation also can increase levels of recreational use, which if not properly managed, can lead to habitat damage or direct negative effects (see Recreational Activities section).

Water diversions or developments also may be detrimental to mountain yellow-legged frogs if they remove water from the frogs' habitat or shorten the length of time a habitat has water. For example, many hydroelectric water developments exhibit short-term (i.e., few hours to diel interval) fluctuations in water level (a few decimeters to several meters) that can discourage oviposition or result in complete stranding of eggs or early developmental life stages. In addition, removal or diversion of water in winter could create artificially low water levels in a pond or lake that can lead to freezing of the entire water body or reduced oxygen levels, resulting in increased frog mortality (Bradford 1982, 1983; see also Ecology section). Unexpected changes in water flow and velocities during frog breeding, egg laying, and development also have the potential to result in injury and mortality to frogs (see Kupferberg 1996).

The only data indicating that water development has negatively affected mountain yellow-legged frogs are anecdotal. Loss of suitable aquatic/riparian habitat through groundwater pumping may have locally extirpated mountain yellow-legged frogs from at least one site on the east slope of the White Mountains. In the 1970s, Giuliani (1994) encountered mountain yellow-legged frogs at Fish Lake, where he found three frogs overwintering under litter (see State of Nevada prior to 1980 in Appendix B). Agricultural groundwater pumps were installed in the area in the late 1980s (D. Giuliani, pers. comm., 2005). In 1994, Giuliani found Fish Lake dry, commenting that the "entire aquatic and riparian habitat now dry desert hardpan"; no frogs were seen (Giuliani 1994).

Extent of Risks Related to Water Development and Diversion

The level of risk posed by water development and diversion to the mountain yellow-legged frog is unknown. Currently, due to the geographic location of existing dams and diversions, they do not appear to pose a widespread risk for the species. Where dams and diversions occur, the impacts can be significant and permanent. Even small projects eliminate or alter aquatic habitat.

Conservation Options Related to Water Development and Diversion

Agencies should continue to manage water development and diversion projects where they overlap with mountain yellow-legged frog habitat. Permitting for water developments and diversion are directly or indirectly within the jurisdiction of agencies participating in this Conservation Assessment. Science is needed to inform how water development or diversion may influence mountain yellow-legged frogs.

Other Risk Factors Beyond Agency Influence

Acid Deposition

Waters of lakes and streams in the Sierra Nevada are often weakly buffered (i.e., have a low acid neutralizing capacity [ANC]; Melack et al. 1985, Landers et al. 1987), so the potential exists to depress pH in a way that might contribute to amphibian declines (Freda 1986). In the eastern United States and Europe, acidic deposition appears to have affected amphibian populations (Freda 1990), so this was viewed as a possibility for mountain yellow-legged frogs in the Sierra Nevada.

Based on a sample of lakes spanning the length of the Sierra Nevada on both sides of the crest, Melack et al. (1985) noted that the low ANC of Sierra waters is striking. They found 70 percent of sampled lakes had summer ANC values below 90 μeq/L, and the few lakes with ANCs above 210 μeq/L were either below 3,000 m elevation or in basins with calcareous rocks. Melack et al. (1985) also recorded summertime pHs between 6.0 and 8.0, and concluded that although Sierran lakes do not seem to show signs of acidification, they would be highly sensitive to only slight increases in the acidity of atmospheric precipitation. During fall 1985, the Western Lake Survey (WLS), conducted to quantify the location and characteristics of sensitive and acidic lakes in the western United States, sampled over 100 lakes in the Sierra Nevada of California and Nevada (Eilers et al. 1987, Landers et al. 1987). The WLS revealed that the California subregion (including California and Nevada) had the highest percentage of lakes (36.7 percent) with a low ANC (≤ 50 μeq/L) and the highest percentage of lakes (86.6 percent) with no more than a moderate ANC (≤ 200 μeq/L) among the 5 subregions sampled. Further, the subregional pattern of low ANC was a consequence of the disproportionately low ANC levels recorded in many lakes in the Sierra Nevada (Eilers et al. 1987, Landers et al. 1987). Of the 719 lakes sampled in the western United States, only 1 had a pH ≤ 5.0, and only 1 percent of western lakes had a pH ≤ 6.0. These findings underscore those of Melack et al. (1985); at the time of the WLS, Sierran lakes had limited acidity despite a generally low buffering capacity.

Data addressing levels of acidity in Sierran lakes also provide little evidence of direct effects on mountain yellow-legged frogs. Bradford et al. (1992) examined the tolerance of mountain yellow-legged frogs to low pH in the laboratory and compared the tolerances to the most acidic values recorded in Sierra Nevada lakes (pH = 5.0). Embryos and hatchling larvae were kept for 7 days in reconstituted soft water (RSW) at pHs of 4.0 to 6.0, and subsequently kept for a 4-14 day post-treatment period in RSW at pH 6.0. They found that LC_{50} pH values for post-treatment survival of mountain yellow-legged frog embryos and tadpoles, respectively, averaged 4.4 and < 4.0. Moreover, pH treatments equivalent to the lowest recorded in Sierra Nevada lakes (i.e., pH = 5.0) did not reduce survival significantly for either life stage. However, one sublethal effect was manifest; mountain yellow-legged frog embryos had a reduced body size at pH treatments of 5.0 and 5.25. In another survey of 235 potential breeding sites across 30 randomly selected survey areas, Bradford et al. (1994b) failed to find significant differences in water chemistry parameters (including pH and ANC) between sites with and without mountain yellow-legged frogs. Moreover, water chemistry also did not differ among sites occupied by mountain yellow-legged frogs, Pacific treefrogs, and Yosemite toads in a gradient that might be predicted if their species-specific acid tolerance limits were influencing their distribution. Bradford et al. (1994b) concluded that acidic deposition was not a factor directly contributing to amphibian population declines in the Sierra Nevada at high elevation. In yet another study conducted in Kings Canyon National Park, Bradford et al. (1998) surveyed the biota and water chemistry of 33 lakes with pH values between 5.0 and 9.3, including 8 lakes with a pH < 6.0 (= acidic) associated with geological sources of acidity, and non-acidic lakes with (n = 7) and without (n = 18) trout. Mountain yellow-legged frog larvae, common microcrustaceans (*Daphnia*, *Hesperodiaptomus*, *Diaptomus*), and larvae of a caddisfly (*Hesperophylax*) were rare or absent in acidic lakes but common in non-acidic lakes. The basis of lower numbers of mountain yellow-legged frog larvae in acidic lakes is unclear, but an unrecognized direct effect is possible.

Depressed pH also has the potential to interact with other factors to affect amphibians. One possibility is elevating soluble levels of selected metals, like aluminum. Dissolved aluminum, especially in an inorganic monomeric form, may be a toxic threat to amphibians during episodes of acidification (Freda 1991). The WLS, which also sampled Sierran clearwater lakes for extractable aluminum, revealed that only 5 clearwater lakes in the California subregion had extractable aluminum > 50 µeq/L (Landers et al. 1987). These data imply that if acidification occurred, few lakes might have elevated levels of soluble aluminum. Bradford et al. (1992) also examined the tolerance of mountain yellow-legged frog embryos and larvae to aluminum at different acidic pHs in the laboratory. Aluminum (nominally 75 µg/L) was added as $Al_2(SO_4)_3 \times 18\ H_2O$, which resulted in solutions of pH 4.9, 5.3, and 5.8, and dissolved aluminum levels averaging 80, 70, and 39 µg/L through a 7-day treatment period. This addition of aluminum did not significantly affect the post-treatment survival of either mountain yellow-legged frog embryos or larvae. Further, this treatment did not affect either the body size of embryos or larvae or the length of time to hatching for embryos. Interaction of pH with factors other than soluble metals is possible; a potential interaction with ultraviolet radiation is noted in the UVB Radiation section. Such interactions remain unstudied for mountain yellow-legged frogs.

Extent of Risks Related to Acid Deposition

Acid deposition does not currently appear to be a factor in the rangewide decline of mountain yellow-legged frogs. However, the interaction of acidification with other factors remains poorly understood and entirely unstudied in mountain yellow-legged frogs. Moreover, the continued increase in human population levels in California has some potential to amplify acid deposition, so the generally low ANC of Sierran waters makes this factor a possibility should acidification exceed a threshold that could influence mountain yellow-legged frogs in the future.

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 of agencies outside the jurisdiction of those involved in this assessment. Agencies responsible for mountain yellow-legged frog management should participate in guiding the development of the management and science to inform this issue.

Airborne Contaminants including Pesticides

Decline of amphibians such as mountain yellow-legged frogs in "near pristine" habitats inside National Parks raised the possibility that airborne contaminants might be responsible (Drost and Fellers 1994, Davidson 2004, Davidson and Knapp 2007). Transport and deposition of pesticides from the Great Central Valley of California to the Sierra Nevada is well documented (Aston and Seiber 1997, Datta et al. 1998, McConnell et al. 1998, Lenoir et al. 1999). Cory et al. (1970) showed that airborne pesticides (DDT residues in this case) had accumulated in the tissues of mountain yellow-legged frogs during its heavy use period in the 1960s. New generations of pesticides, now in widespread use in the Central Valley, have renewed the specter of potential negative effects on the biota of the Sierra Nevada resulting from pesticide drift.

Parts of the Sierra Nevada are downwind of one of the most intensely cultivated areas on earth, the San Joaquin and lower Sacramento Valley portions of California's Great Central Valley (Cory et al. 1970). Large-scale pesticide use in this region extends back to the 1950s, but quantitative data on that use are more recent. In the 15 counties that comprise this region (Butte, Colusa, Fresno, Glenn, Kern, Kings, Madera, Merced, Sacramento, San Joaquin, Solano, Stanislaus, Sutter, Tulare, and Yolo), between 48 and 69 million kilograms (106 and 152 million pounds) of pesticide active ingredient were recorded as having been used annually from 1990 to 2002; use generally increased through 1998, declining somewhat thereafter (CDPR 1989-2003). Based on annual data, most (65-72 percent) pesticide use in the state was in this region (CDPR 1989-2003), and pesticide use in California was about 25 percent of all national use (Aspelin 1997, Aspelin and Grube 1999), highlighting the regional concentration. Moreover, recorded use underestimates actual use. Gross levels of use do not reveal the slow change in the composition in the pesticides used over the last 50 years. Bioaccumulating organohalides, in widespread use in the 1960s and early 1970s, gave way to organophosphates and carbamates in the late 1970s and 1980s. In the 1980s, malathion was applied to almost 5 million hectares in the United States (Smith 1987). Increase in use of these second-generation pesticides generally corresponded to the time when declines of mountain yellow-legged frogs were first noted. Since the 1990s, a variety of third-generation agents have emerged, including biocides (e.g., pyrethrins) and biocontrol agents (e.g., *Bacillus thuringensis*), but carbamate and organophosphate use remained elevated until relatively recently.

Pesticides used in the Central Valley are carried on wind currents or as part of eastbound storm systems into the Sierra Nevada (Zabik and Seiber 1993, Cahill et al. 1996, Aston and Seiber 1997, Seiber et al. 1998); varying concentrations can be detected in the ambient air (USGS 1995, Baker et al. 1996). Precipitation strips pesticides from ambient air. Surveys of rain from low elevations and freshly fallen snow at mid-elevations have revealed the presence of chlorothalonil and the toxic organophosphates diazinon, malathion, and chlorpyrifos (Aston and Seiber 1997, McConnell et al. 1998, Seiber et al. 1998). Some of these second-generation pesticides and polychlorinated biphenyls (PCBs) have appeared in fish and the larvae of selected amphibians in the mid-elevation southern Sierra Nevada (Datta et al. 1998), but little is known about their fate in the high-elevation aquatic habitats that mountain yellow-legged frogs use (Boyer and Grue 1995).

Mountain yellow-legged frogs spend a high percentage of their time in water, moving through the interface of water and air, and do a significant proportion of respiration through their skin, so they are at greater risk of exposure to pesticides which are readily absorbed through the skin, respiratory system, or gastrointestinal tract (Gunther et al. 1968). Most pesticides, which are either insoluble or poorly soluble in water, tend to concentrate on the surface, increasing the likelihood that they will come into contact with mountain yellow-legged frogs (Cory et al. 1970).

Some correlative data suggest that pesticides may be linked to mountain yellow-legged frog declines. In 1997, mountain yellow-legged frogs remaining from a reintroduction judged to have failed at Tablelands (Sequoia National Park, Fellers et al. 2007) had concentrations of DDE (a secondary residue of DDT) averaging over 2.5 times those found in frogs from an apparently healthy population at a reference site in the Sixty Lakes Basin (Fellers et al. 2004). Additionally, both γ-chlordane and *trans*-nonachlor were found in greater concentrations in frogs at the Tablelands treatment site than in frogs from the reference site. Further, the organophosphates chlorpyrifos and diazinon, detected primarily in surface waters, were found in greater concentrations at the Tablelands site. Fellers et al. (2007) argued that the failure to repatriate mountain yellow-legged frogs at several Tablelands sites is likely a function of pesticides, disease (chytridiomycosis), or both.

Studies addressing mountain yellow-legged frog developmental and behavioral response to specific pesticides have not been conducted, but numerous studies have shown that a variety of pesticide residues can delay or alter development or reduce breeding or feeding activity in aquatic amphibians in ways likely to reduce fitness or survivorship (Beaties and Tyler-Jones 1992, Corn and Vertucci 1992, Hall and Henry 1992, Berrill et al. 1993, 1994, 1995, 1998, Boyer and Grue 1995). Given that mountain yellow-legged frog larvae require more than one summer to reach metamorphosis, delays in larval development or metamorphosis increases the likelihood of larval losses because of opportunistic predation, or desiccation by drought (especially for larvae that rear in pools that may dry in some years). Furthermore, given the limited active season within which mountain yellow-legged frogs must emerge, successfully breed, and consume enough food to survive up to a 9-month overwintering interval (variation dependent on elevation), the sub-lethal effects of pesticides on adult frogs have the potential to impact local populations.

Of particular concern is the possibility that pesticides act as stressors, rendering mountain yellow-legged frogs more susceptible to aquatic pathogens such as *Aeromonas* bacteria or the amphibian chytrid fungus (Carey 1993, Carey and Bryant 1995, Drost and Fellers 1996, Jennings 1996, Carey et al. 1999). Some of these aquatic pathogens may be opportunistic, infecting only injured or immuno-suppressed amphibians, not healthy animals (Anver and Pond 1984, Cahill 1990, Carey 1993, Carey and Bryant 1995, Carey et al. 1999). Adult Woodhouse toads (*Bufo woodhousei*) experimentally infected with *Aeromonas hydrophila* bacteria and exposed to sub-lethal levels of the organophosphate pesticide malathion sustained higher mortality than infected toads that were not similarly pesticide-dosed; susceptibility to disease appeared linked to suppressed immune responses (Taylor et al. 1999b).DDT or its secondary residue DDE was found in the tissues of mountain yellow-legged frogs (Cory et al. 1970). Of 600 frogs collected from the west side of Mt. Whitney in the 1960s, Cory found not one free of DDT or its secondary residual DDE. The general pattern of DDT distribution in frogs revealed that concentrations were higher in the central and southern Sierra, and that DDT contamination was heavier on the west slope of the Sierra Nevada than on the east slope—a pattern ascribed, respectively, to the regional pattern of application and the directionality of airborne drift. However, the greatest declines in the species were observed after DDT was banned in the 1970s. Further, frogs are virtually gone from the east side while the largest remaining populations are on the west side, so the linkage between pesticide drift and frog declines remains ambiguous. Cory also suggested that chlorpyrifos (Durzban) and Rice Molinate, two currently used pesticides, may be playing a role in the species' decline (Center for Biological Diversity and Pacific River Council 2000).

Data from the Sierra Nevada implicate pesticide drift as a factor for frog declines in general (Sparling et al. 2001) and specifically for mountain yellow-legged frogs (Davidson et al. 2002). Davidson et al. (2002) and Davidson (2004) examined 255 historical locations for the presence of mountain yellow-legged frogs and analyzed the spatial patterns of declines as a function of a series of alternative factors. Declines of mountain yellow-legged frogs were strongly positively correlated with the area of upwind agricultural land use and amount of upwind pesticide use. In a study of 6800 water bodies for habitat characteristics and presence/absence of mountain yellow-legged frogs and fish, Davidson and Knapp (2007) found frog absence to be strongly related to a metric for upwind pesticide use. Using Pacific treefrogs as a sentinel species, Sparling et al. (2001) found cholinesterase (ChE) activity depressed in tadpoles in the Sierra Nevada east of the Central Valley when compared with sites along the coast or north of the valley. Cholinesterase activity is a good bioindicator of exposure to organophosphorus pesticides because those pesticides are formulated specifically to inhibit cholinesterase and very few chemicals have this effect (Ludke et al. 1975).

The Fellers et al. (2004) transplant experiments and the other studies noted previously do not exclude the possibility that other chemicals, also wind-carried in greater concentrations from areas of intensive agriculture or population centers, either contribute to or are independently responsible for mountain yellow-legged frog declines. The possibilities include nitrates, nitrites, and phosphates.

Nitrates (and nitrites) enter the environment through air pollution (largely as a function of vehicle emissions) and the application of agricultural fertilizers, and represent a global problem that has shown signs of becoming increasingly acute in a number of areas (Morris 1991). In the western United States, deposition of atmospheric nitrogen (as nitrates or nitrite) ranges from 1 to 4 kg/ha over most of the region to 30-90 kg/ha downwind of major urban and agricultural areas (Fenn et al. 2003a). Ecological effects of nitrogen deposition are varied, and include effects to aquatic and terrestrial plant and microbial communities that have a suite of secondary effects in local food webs that are just beginning to be understood (Fenn et al. 2003b). One possibility is that particular sources of nitrogen pollution may have contributed to the regional extirpation of frogs in the Sierra Nevada; for example, the pattern of recent frog extinctions in the southern Sierra may correspond to the areas of highest concentrations of exhaust pollutants from automobiles (Jennings 1996).

Nitrate deposition from air pollution can greatly alter lake ecosystems (Baron et al. 2000, Schindler and Cheurell 2002), a condition that is anticipated for lakes in the Sierra Nevada, but the consequences of which remain poorly understood (Fenn et al. 2003b). In the Emerald Lake watershed (2800 m elevation) in Sequoia National Park, mass balance, stream chemistry, and isotopic studies indicate that stream nitrate patterns are the result of flushing from soils and of snowpack nitrate that escapes biological cycling (Sickman et al. 2003a). However, in Emerald Lake, nitrate (both during spring runoff and growing seasons) has declined from 1983 to 1995 (Sickman et al. 2003b). Declining snowmelt nitrate was caused primarily by changes in snow regime induced by the 1987-1992 drought: shallow, early melting snowpacks had lower snowmelt nitrate concentrations owing to less labile nitrogen production in catchment soils and longer growing seasons (Sickman et al. 2003b). Yet, nitrate declines through the growing season continued through wetter years (1993-2000) and are probably the result of increased phosphorus loading to the lake, which released phytoplankton from phosphorus limitation (Sickman et al. 2003b). Sickman et al. (2003b) emphasize that this pattern was not local, because over 70 percent of 28 Sierran lakes sampled from 1985 to 1999 showed a decline in nitrates and an increase in phosphorus. Several possible consequences of nitrogen and phosphorus loading in high-elevation aquatic systems exist for mountain yellow-legged frogs; to date, all are speculative. The more plausible include: 1) a shift away from a favorably nutrient-rich diatom flora could result in food limitation for larvae (see Kupferberg 1997a for a discussion of larval ranid frog diet); 2) slight elevation in respiration among benthic microorganisms (especially bacteria) through a combination of eutrophication (Nydick et al. 2004), and slight elevation of wintertime temperatures could oxygen-deplete overwintering frogs (see Bradford 1982, 1983 for a discussion of overwintering oxygen relations); 3) some unspecified nutrient-linked shift could facilitate the establishment of disease, such as *Bd* (V. Vredenburg, pers. comm., 2002); or 4) embryonic or larval life stages may be killed by slightly elevated nitrite or nitrate concentrations (see Marco et al. 1999 for a discussion on related western North American ranid frogs).

An equally ignored aspect of airborne contaminants is endocrine disruption. Pesticide and non-pesticide chemicals currently used in California and, in particular, the Central Valley can potentially disrupt endocrine systems (Colburn et al. 1996), potentially adversely affecting adult breeding and embryonic larval development in amphibians. Endocrine disruption is of particular concern because: 1) significant effects are manifest at very low concentrations (< 12 ppb), low enough to require special technologies for their measurement (Colburn et al. 1996); and 2) recent work has demonstrated that the very widely used herbicide atrazine displays such an effect by feminizing male northern leopard frogs (Hayes et al. 2002). The possibility that one or more compounds may have endocrine disruptive effects on mountain yellow-legged frogs remains unstudied.

More recent research has not supported a high risk level for airborne contaminants to mountain yellow-legged frogs (see Bradford et al. 2010, USFWS 2013). In their proposed rule for listing the mountain yellow-legged frog as endangered, USFWS (2013) concluded that although "correlative evidence between areas of pesticide (and other) contamination in the Sierra Nevada and areas of amphibian decline support hypotheses that contaminants may present a risk to the mountain yellow-legged frog and could have contributed to the species' decline", "studies confirming exposure in remote locations to ecotoxicologically relevant concentrations of contaminants are not available to support this hypothesis." They cite the following evidence:

"Efforts to date have found fairly low concentrations of many of the primary suspect constituents commonly indicating agricultural and industrial pollution (organochlorines, organophosphates/carbamates, polycyclic hydrocarbons). Bradford et al. (2010, p. 1064) observed a rapid decline in concentrations of endosulfan, chlorpyrifos, and DDE (among others) going out to 42 km (26 mi) linear distance from the valley floor in air, water, and tadpole tissues. These researchers also found relatively minute variation in concentrations among high elevation study sites relative to the differences observed between the San Joaquin Valley and the nearest high elevation sites. Essentially, sites beyond 42 km (26 mi) exhibited very low concentrations of measured compounds, which did not appreciably decrease with distance (Bradford et al. 2010, p. 1064). These observations make the contaminant decline hypotheses less tenable, and so windborne organic contaminants are currently considered minor contributors (if at all) to observed frog declines." (USFWS 2013).

Extent of Risks Related to Airborne Contaminants

Extensive sources of airborne contamination have the potential to influence mountain yellow-legged frogs over a broad geographic range. Although preliminary results from studies on other species indicate that the risk is potentially high, this has not been supported by more recent research on mountain yellow-legged frogs. Substantial science will be needed to define the extent of risk related to this factor.

Conservation Options Related to Airborne Contaminants

Reducing the risk associated with airborne contaminants would require changes in agriculture management in the California Central Valley, the most substantial upwind source, and perhaps also for contaminants originating from more remote sources (e.g., USGS 1995). This would require coordination of agencies outside the jurisdiction of those involved in this assessment. Realistically, this level of regulatory change would require substantially more scientific information attributing agricultural contaminants as a significant contributing factor to observed declines. Agencies responsible for mountain yellow-legged frog management should participate in guiding the development of the management and science to inform this issue.

Climate Change

Many investigators have identified climate change as a potential reason for wildlife population changes (increases, decreases, and extirpations) worldwide (e.g., Inouye et al. 2000, Forchhammer et al. 2001, Thompson and Ollason 2001, McLaughlin et al. 2002, Thomas et al. 2004). Moreover, global climate change has been implicated in the declines of both amphibian assemblages (Pounds et al. 1999) and individual amphibian species (Alexander and Eischeild 2001).

Climate change is not new; analysis of Antarctic ice cores reveals that global temperatures have varied with greenhouse gas (e.g., carbon dioxide and methane) concentrations over the past 160,000 years (Petit et al. 1999). However, the pace of change has been acute since the pre-industrial era; concentrations of atmospheric carbon dioxide have increased about 30 percent, methane has more than doubled, and nitrous oxide (another greenhouse gas) has risen about 15 percent (USEPA 1997). Burning of fossil fuels is the primary source of these increases (USEPA 1997). Moreover, global mean surface temperatures have increased 0.3-0.7 degrees C since the late 19th century (USEPA 1997). The last century has seen some of the most variable climate reversals, at both the annual (extremes and high frequency of El Niño and La Niña events) and near decadal intervals (periods of 5- to 8-year drought and wet periods) (USDA Forest Service 2001a). Climate changes that occur faster than endangered species can adapt may precipitate extirpations that ultimately lead to extinction (Smith and Tirpak 1989).

Climate change has the potential to affect mountain yellow-legged frog populations by increasing the frequency, duration, and magnitude of droughts. Since the 1970s, California has sustained two multi-year intervals of severe drought; mountain yellow-legged frog declines were observed after each interval (Center for Biological Diversity and Pacific Rivers Council 2000). Most researchers believe that deeper permanent aquatic sites historically provided refugia for several species of amphibians in the Sierra Nevada over periods of prolonged drought, allowing peripheral populations to be rescued through re-colonization (Bradford et al. 1993, Knapp 1996, Drost and Fellers 1996). Drought may make water bodies shallower during winter, which increases the likelihood that the entire water body will freeze or become oxygen depleted, both of which can result in mortality that may adversely affect populations (Bradford 1982, 1983).

A study by Lacan et al. (2008) explored the interaction between water availability and the abundance and recruitment of *R. sierrae* in Dusy Basin, Kings Canyon National Park. In the Dusy Basin, lakes were mapped with GPS, water volumes were calculated in a low-snowpack and a high snowpack year (2002, 2003), and mountain yellow-legged frogs were counted. The lakes that dried up in 2002 were repopulated by adults in 2003, without any recruitment of metamorphosed frogs from previous year's tadpoles. The lakes that retained water, even with notable volume decreases (-60%), showed tadpole-to-subadult recruitment in the following year (2003). Similar results were obtained using data for years 1997-2006; there was significantly greater abundance of metamorphs in permanently wet lakes than in lakes that had dried even once during the 10 years. Similarly, those lakes that had retained water during any two preceding years had significantly more metamorphs than lakes that had dried up during that period. These results suggest that any increase in drying of small ponds will reduce frog recruitment. Combined with the introduced fish that prevent frog breeding in larger lakes, lake drying may cause extinction of local frog populations (Lacan et al. 2008).

Drought may also interact with other factors that, to date, are largely unstudied for their additive, multiplicative, or synergistic effects. For example, introduction of non-native fishes can reduce or eliminate the refuge habitat that permanent waters offer (see Section on Introduced Fish and Other Predators), which may render mountain yellow-legged frog populations more vulnerable to extirpation during drought. Likewise, preliminary indications exist that airborne contaminants may have negatively affected mountain yellow-legged frogs and other Sierran amphibians (Fellers et al. 2004; see Section on Airborne Contaminants including Pesticides), a condition that drought may exacerbate and that may have been responsible for the disappearance of the golden toad (*Bufo periglenes*) in Costa Rica (Pounds and Crump 1994). Even more recently, Pounds et al. (2006) have suggested a direct link between extinctions in the speciose Neotropical bufonids genus *Atelopus* to climate change through the promotion of the disease-causing chytrid fungus; this possibility has not been directly addressed for mountain yellow-legged frogs.

Climate change may be a factor in the decline of mountain yellow-legged frog populations in the Sierra Nevada, but its precise contribution remains unclear. One possibility is that climate change effects on mountain yellow-legged frogs may involve a lag effect (see Thompson and Ollason 2001) that will require identifying the correct time interval of influence; another is that the correct spatial scale at which climate change has its impact on mountain yellow-legged frogs may not be identified. It also is possible that climate change may exacerbate the effects of other risk factors on mountain yellow-legged frogs.

Regardless of how climate change contributes to mountain yellow-legged frog declines, unless it somehow involves local (basin-scale) feedbacks that are linked to the management practices of the agencies responsible for developing and implementing this Conservation Assessment, managing anthropogenic sources of climate change are outside their effective jurisdiction. However, these agencies may have the opportunity to engage in and contribute to national protocols that attempt to move toward global management approaches, as even the most conservative climate change scenarios reveal a relatively high risk of extinction for many species (Thomas et al. 2004).

Extent of Risks Related to Climate Change

Climate change may be a factor in the rangewide decline of mountain yellow-legged frogs, but precisely how it might contribute to those declines and its relative importance to this process is not understood. Moreover, climate change has the potential to interact with a suite of other stressors, which remain entirely unstudied in the context of mountain yellow-legged frogs.

Conservation Options Related to Climate Change

Effective management for anthropogenic sources of climate change would require coordination of agencies outside the jurisdiction of those involved in this assessment as well as major societal changes. However, agencies may have the opportunity to contribute to national protocols that attempt to move toward global management approaches. Research is needed to provide a more complete understanding of the effects of climate and interactions of climate with other risk factors on this species.

UV-B Radiation

Increases in mid-range ultraviolet radiation (UV-B; 290-320 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). Increased UV-B seems an attractive hypothesis to explain amphibian declines that have taken place in "pristine" high mountain habitats where, except for introduced fish, human intrusion has been generally limited. However, experimental and field studies addressing UV-B are controversial and have produced mixed results (Licht and Grant 1997). This fact suggests that the actual effects of increased UV-B on amphibian growth and survivorship vary across a variety of conditions (e.g., species, life stages, and habitats) and that this factor is, at best, limited in its ability to explain declines (Licht 2003).

Much of the work on UV-B has involved experiments that address the vulnerability of the embryos and newly laid eggs of several amphibian species found in western North America. This work has shown that the direct effects of exposure to elevated UV-B resulted in reduced hatching success, reduced larval growth rates, or sometimes increased physical abnormalities in Cascades frogs (Blaustein et al. 1994), western toads (Blaustein et al. 1994), and long-toed salamanders (Belden et al. 2000) in western Oregon, and California newts (*Taricha torosa*) in California (Anzalone et al. 1998), but not in Pacific treefrogs (Blaustein et al. 1994, Ovaska et al. 1997, Anzalone et al. 1998), Columbia spotted frogs (Blaustein et al. 1998), northern red-legged frogs (Blaustein et al. 1996, Ovaska et al. 1997), and Oregon spotted frogs (Blaustein et al. 1998), all from the Pacific region of North America, and western toads from the Rocky Mountains (Corn 1998). 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); for example, Pacific treefrogs, Columbia spotted frogs, northern red-legged frogs, and Oregon spotted frogs possess two to five times as much of the UV-B damage repair enzyme photolyase as Cascades frogs, western toads, and long-toed salamanders from western Oregon (Blaustein et al. 1998). Differences between western toads in Oregon and in the Rocky Mountains may be in part due to the fact that toads from these disparate locations are now thought to represent different species (Goebel 2005).

Most studies of UV-B effects on amphibians have focused on the egg stage, but some studies have shown that the effects of exposure can extend beyond the egg stage (e.g., Ankley et al. 2000, 2002). In particular, some ranid frog species appear most susceptible to UV-B exposure between hatching and late larval stages of development (Tietge et al. 2001, Ankley et al. 2002). Further, the possibility that UV-B exposure of embryos may have more subtle effects than direct mortality remains poorly studied. In studies where embryos and tadpoles of the northern red-legged frog were exposed to sublethal UV-B levels, exposed animals had depressed growth rates when compared to a control group (Belden and Blaustein 2002). Little has been done to address UV-B effects on the post-metamorphic stages of anurans, although Fite et al. (1998) described retinal damage found in adult wild-collected Cascades frogs as similar to UV-B-induced retinal damage in adult northern leopard frogs as evidence that Cascades frogs are exposed to increased UV-B radiation; unexposed Cascades frogs were not available for controls.

Although field and laboratory experiments suggest that embryos and larvae of some ranid frogs can either be killed or sustain sub-lethal damage from UV-B exposure, information from the environments in which these life stages exist suggest that habitat conditions for large geographic areas in western North America limit UV-B exposure (Licht 1996, 2003). Notably, the realization that dissolved organic material (DOM) or dissolved organic carbon (DOC) can effectively absorb UV-B (Scully and Lean 1994, Morris et al. 1995) has refocused attention on the levels of these solutes in the aquatic habitats amphibians use. Levels of DOM/DOC in 85 percent of 136 western toad breeding sites in the Cascades Mountains of Oregon and Washington were sufficient to reduce UV-B to levels below those that Blaustein et al. (1994) had found to affect embryos (Palen et al. 2002). Further, the percentage of these breeding sites over which UV-B radiation did not reach the potentially harmful levels that Blaustein et al. (1994) described were similar for three other montane species: Cascades frog, northwestern salamander (*Ambystoma gracile*), and long-toed salamander (Palen et al. 2002). In addition, Adams et al. (2001) examined the distribution of three amphibians in the montane Pacific Northwest and found that Cascades frog was most likely to breed in fishless shallow ponds with relatively low transmission of UV-B radiation. This pattern agrees with the hypothesis that UV-B influences the distribution of this species (Nagl and Hofer 1997), but their study did not incorporate some major factors that can contribute to the variation among ponds. However, even if the reduction in hatching success observed by Blaustein et al. (1994) was found to occur over a larger spatial range, it is unclear whether or not this reduction would be sufficient to cause population declines of the levels suggested given the high fecundity of the species involved (see Palen et al. 2002).

In the Sierra Nevada, Davidson et al. (2002) examined the spatial pattern of population declines of mountain yellow-legged frogs, as well as six other anuran species to see if patterns were consistent with those that might be expected with 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 that the likelihood of occupancy increased with elevation, just the opposite of what would be expected if declines were the result of UV-B; they also found no relationship between declines and latitude. Adams et al. (2005) compared amphibian presence to site-specific estimates of UV-B levels in 683 ponds and lakes across a broad geographic range in western North America that included sites in Kings Canyon National Park in the southern Sierra Nevada. Of eight amphibian species examined, including mountain yellow-legged frogs, only three species (long-toed salamanders, Pacific treefrogs, and roughskin newts [*Taricha granulosa*]) showed relationships with UV-B that were potentially attributable to negative effects. Finally, although embryos of mountain yellow-legged frogs were negatively affected by exposure to artificially increased levels of UV-B in laboratory experiments, ambient UV-B levels experienced under current field conditions did not appear to affect them (V. Vredenburg, pers. comm., 2002).

Failure to reveal a convincing link between amphibian declines and UV-B may result from the fact that significant effects are more likely if UV-B interacts 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 non-lethal when each was individually applied produced significant mortality when the same levels of each 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 exposing boreal toad and Cascades frog embryos to UV-B increased mortality from the pathogenic water mold *Saprolegnia ferax* over embryos treated by the same levels of each alone. Other additive or synergistic effects are possible; none have been studied in mountain yellow-legged frogs.

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 mountain yellow-legged frogs. However, the synergistic relationships between UV-B, other stressors, and frog declines is poorly understood, so UV-B has the potential to contribute to declines in ways that remain unidentified. Moreover, levels of ambient UV-B appear to be still on the increase (Middleton et al. 2001) so effects of increased UV-B on mountain 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 mountain yellow-legged frog management should participate in guiding the development of the management and science to inform this issue.

Relative Importance of Risk Factors

Weighing the relative importance of each risk factor provides the rationale for the conservation actions to be developed in the Conservation Strategy. Hence, this section identifies criteria used to prioritize risk factors. Seven criteria were used for this evaluation:

- Spatial extent of the risk
- Duration and persistence of the risk
- Intensity of the risk
- Ecological permanence of the risk
- Potential for management to reverse or reduce the risk
- Quantifiable weight of evidence
- Agency jurisdiction

Table 1 defines the evaluation criteria, whereas Tables 2 and 3 summarize the results of applying these criteria using the risk factor summaries in the previous section for the focal and other risk factors, respectively.

Three risk factors have substantial data linking them to mountain yellow-legged frog declines, or evidence suggestive of a link that warrants further investigation. These three focal risk factors are:

- Introduced Fish
- Disease
- Habitat Loss and Fragmentation

Introduced fish and disease are the most important risk factors to address for conservation of mountain yellow-legged frogs. Fish stocking is widespread throughout the range of the species, and unequivocal data show that fish have eliminated or greatly reduced mountain yellow-legged frog distribution and abundance. Fish currently occur in most large lakes in the frogs' range, limiting or eliminating frog populations where they co-occur. Further, fish removal experiments have resulted in re-colonization and increases in abundance of frogs. Regulation of fish introductions and fish removal are within the jurisdiction of agencies participating in this assessment.

Chytridiomycosis has resulted in dramatic declines of mountain yellow-legged frog populations and is now found throughout almost all of the species' ranges. Management actions that would eliminate or reduce the impacts of this risk factor are currently unknown, though potential mitigation measures are an area of active research (see Mountain Yellow-legged Frog Conservation Strategy). Further management options may become clearer as the disease becomes better understood.

Mountain yellow-legged frog habitat has become increasingly unavailable and fragmented from the widespread introduction of predatory fish, and as frog populations have declined from this and other risk factors (e.g., disease), they have become increasingly isolated. Isolation coupled with small population sizes place this species at further risk of decline. Management to avoid further habitat fragmentation and population isolation would benefit the species.

Most or all aspects of the following additional 10 risk factors are within the jurisdiction of the agencies participating in this Conservation Assessment, and participating agencies can influence land and resource management that directly or indirectly reduces the risk these factors pose to mountain yellow-legged frog populations and habitat:

- Fire Management
- Habitat Restoration
- Locally Applied Pesticides
- Livestock Grazing
- Mining
- Recreational Activities (incl. Packstock)
- Research Activities
- Roads
- Vegetation and Fuels Management
- Water Development and Diversions

These 10 risk factors deserve inclusion in the Conservation Strategy for the mountain yellow-legged frog because participant agencies can engage in actions addressing these risk factors that have a high probability of successful implementation.

Understanding the relative importance of these factors based only on available data is not possible because they have little or no information directly pertaining to mountain yellow-legged frogs or their habitat (see Quantifiable/Weight of Evidence column in Tables 2 and 3). However, these risk factors either have at least some studies for related (or other) species indicating the risk factor may be an issue for mountain yellow-legged frogs, or studies involving habitats somewhat similar to those that mountain yellow-legged frogs use indicating the risk factor has an impact. Hence, assessing the geographic extent, the duration and persistence, the intensity, and the reversibility of these risk factors (columns two through five from left in Tables 2 and 3) is the best basis for evaluating their relative importance.

That assessment reveals that Livestock Grazing and Recreational Activities may be important because their effects are widespread, frequent, persistent, appear at least locally intense across the mountain yellow-legged frog's range, and are potentially reversible. Even though its prevalence is decreasing (over past decades), Livestock Grazing occurs frequently in a number of aquatic or riparian habitats used by mountain yellow-legged frogs. Recreational Activities, which represent an expanding risk factor, have high overlap potential with all segments of mountain yellow-legged frog habitat. The importance of the second tier of manageable risk factors (Fire Management, Habitat Loss, Locally Applied Pesticides, Research Activities, Restoration, Roads, Vegetation and Fuels Management, Water Development and Diversion) is difficult to evaluate given current knowledge. Some of these risk factors have importance for the mountain yellow-legged frog over specific parts of its range, and for some, their effects are either less frequent or more localized. However, all potentially impact mountain yellow-legged frog populations and/or habitats, and given the current prevalence of small isolated populations, all are important for agency management consideration. Thus, these risk factors should be addressed at some level in the Conservation Strategy.

The four remaining risk factors fall largely outside the purview of the agencies participating in this Conservation Assessment and as such, participating agencies have few or no options to reduce the risk these factors pose to mountain yellow-legged frogs and their habitat. These four risk factors are:

- Acid Deposition
- Airborne Contaminants (incl. pesticides)
- Climate Change
- UV-B Radiation

Preliminary research suggested that the impact to the frog from airborne contamination may be potentially high. Much of the mountain yellow-legged frog range is downwind from the Central Valley, the most substantial upwind source of contaminants. Thus, the working team initially identified the risk from airborne contamination as potentially high. However, more recent research not summarized in this assessment does not support this hypothesis, and instead suggests this risk factor may be of low importance.

All these four latter risk factors have a regional or global atmospheric vehicle. Although these risk factors lie largely outside the purview of agencies participating in this Conservation Assessment, agencies may have opportunities to participate in and guide the development of management strategies to address the risk factors. Further, understanding how these risk factors affect the mountain yellow-legged frog will facilitate the development of a Conservation Strategy that can effectively address the risk factors previously discussed. The reasons are twofold. First, if one of these risk factors results in a local condition in which mountain yellow-legged frogs cannot survive, but that condition is unrecognized, addressing another risk factor (e.g., management of recreation) may be less effective. Second, additive, multiplicative, or synergistic effects may exist between one (or more) of these risk factors and the 13 risk factors previously discussed. Not recognizing such interactions may impede management actions focused on only those factors that management can address. High priority information gaps are listed below in Key Information Gaps.

In summary, introduced fish and disease are highest priority risk factors to address for conservation of mountain yellow-legged frogs. The other risk factors under agency jurisdiction should be addressed in the Conservation Strategy by identifying potential management actions that could reduce their possible impacts. For most of the risk factors, major information gaps exist on how they affect these species.

Table 1 – 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 can be applied to reduce or reverse the effects of the Risk Factor. For example, management can alter fish stocking levels, but management may have limited capability to address disease epidemics. The more management can be effective, 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.
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.

Table 2—Evaluation summary of focal risk factors for mountain yellow-legged frogs (MYLF).

Risk Factor	Spatial extent of the risk	Duration & Persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/ Degree of management effectiveness	Quantifiable/ weight of evidence	Jurisdiction of participating agencies
Disease	Chytrid widespread regionally; documentation good for chytrid; poor for other types.	Probably long-term and persistent.	High over the short-term; unclear over the long-term.	Unknown, depends on potential for recovery and interaction with other factors.	Unknown, depends on development of mitigation measures and transmission mode.	Direct and significant evidence of chytrid on MYLF, some iridovirus data.	Uncertain because focal modes of transmission not characterized.
Introduced Fish and Other Predators	Regionally widespread; fewer data for flowing-water habitat.	Long-term and persistent in many habitats; persistence depends on stocking in some.	High with both direct and indirect effects.	Yes, if self-sustaining trout populations exist and in absence of active fish-removal.	Yes and high, fish removal has proven very successful in frog restoration.	Extensively studied in stillwater, less in streams. Fish impact all life stages and postmetamorphic food. Observational and experimental local and landscape data extensive.	For fish, yes. Various codes and mission statement give the responsibility for action to CDFW. USFS has the SNFPA, CARs, etc.
Habitat Loss and Fragmentation	Fragmentation is widespread, an interaction of other RFs; habitat loss is localized, risk of habitat loss from urbanization more likely at lower elevations.	Both habitat loss and fragmentation potentially long-term; dependent on interacting RF.	High where habitat is lost; losses often magnify fragmentation.	Variable, potential to recover depends on type of habitat loss and pattern of losses over time.	Yes; effectiveness depends on the basis of losses.	Extensive observational data on fragmentation due to other RFs, specifically fish and disease; no data exist for habitat loss *per se* to MYLF, though a few altered sites now unoccupied; evidence from other species extensive.	Yes for habitat loss, management within jurisdiction of participating agencies; but fragmentation depends on causal RF category.

Table 3—Evaluation summary of other risk factors for mountain yellow-legged frogs (MYLF).

Risk Factor	Spatial extent of the risk	Duration & Persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/Degree of management effectiveness	Quantifiable/ weight of evidence	Jurisdiction of participating agencies
Acid Deposition	Limited regionally, but vulnerable due to low ANC.	Unknown; if conditions change, may be persistent and long-term.	Low for direct effects, but may be high for interactions with other RFs.	Probably not, but little basis for evaluation.	No, management effectiveness probably limited.	Solid evidence for limited deposition; MYLF threshold tolerance levels to pH lower than most field-measured values; interactive effects unstudied.	No, would require broad societal changes and coordination among multiple regulatory agencies.
Airborne Contaminants (including Pesticides)	Widespread, regional and extra-regional contributions; variable due to composition and loading patterns.	Long-term with seasonal pulses; persistence depends on chemical and use pattern.	Possibly high; interactive effects possible; details unknown.	Unknown; may accumulate or flush; effect chemical-dependent.	No for NFS and NPS, management effectiveness probably limited but agency may influence public awareness. CDFW and USFWS can influence use and regulation.	Evidence all indirect; air- born transport, release from snow, in amphibian tissue; higher occupancy in areas not upwind of agriculture; and suggestive failed MYLF transplant experiments.	No, requires broad societal changes and coordination among multiple regulatory agencies.
Climate Change	Global with regional effects documented.	Long-term and persistent; likely to change hydrology.	High if eliminates or reduces quality of breeding sites.	Permanent on a practical time scale (human lifetimes).	No, management effectiveness probably limited.	Well-documented, but effect on MYLF unestablished though several mechanisms suspected; interactive effects likely, but unstudied.	No, would require broad societal changes and coordination among multiple regulatory agencies.
Fire Suppression	Rangewide, but effects are limited to aquatic and riparian habitat frogs use.	Long-term, but sporadic; frequency elevation dependent.	High if animals killed or habitat impacted.	No, but recovery varies with local conditions and other factors.	Yes; effectiveness depends on approach implemented.	No data on MYLF; studies of effects on riparian and aquatic habitat characteristics exist.	Yes for USDA Forest Service and National Park Service, many management tools available.
Habitat Restoration	Localized at restoration sites; activity expected to increase.	Depends on type; removal of fish barriers long-term.	Unknown; potentially high for fish barrier removal.	No, but recovery depends on type of effect.	Yes, through regional planning process; potentially highly effective. Important to distinguish between barrier removal that facilitate restoration of native vs. non-native fish stocks.	Much data for MYLF on fish removal; other types unstudied for MYLF; effects inferred from changes to habitat.	Yes, NPS and USFS jurisdiction, but science needed to refine conservation options.

Risk Factor	Spatial extent of the risk	Duration & Persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/Degree of management effectiveness	Quantifiable/ weight of evidence	Jurisdiction of participating agencies
Livestock Grazing	Widespread, more at lower elevations; localized to grazed areas.	Seasonal in some areas; long-term persistence management-dependent.	Variable dependent on grazing level; can be severe if habitat compromised.	Different grazing levels result in different rates of recovery.	Yes and high, but appropriate approach for high effectiveness not well understood.	No data on MYLF, but lots of data on habitat effects; interactive effects unstudied.	Yes, NPS and USFS jurisdiction, but science needed to refine conservation options.
Locally applied Pesticides	Local; variable due to pesticide composition and loading levels.	Short-term for most in current use; persistence use and chemical type dependent.	Little data exists.	Probably not, but poorly known; effect chemical-dependent.	Yes, potentially effective; reduce impacts through regulation of application (amount, timing, and constituent).	No field data on MYLF; toxicity data indicates surfactants more toxic than pesticides themselves; toxicity chemical-dependent.	Yes, for pesticide application on public lands; on private lands, coordination with other agencies needed.
Mining	Widespread, but primarily at lower elevations; sites localized.	Persistent and long term.	Unknown, but potential to be locally high.	Potentially, but depends on effect and magnitude of affected area.	Yes, potentially effective through mining regulations.	No field data on MYLF; potential for toxicity through acid mine drainage; suction dredge mining unstudied; interactive effects possible, but unstudied.	Yes, through USFS application of 1872 mining law and associate statutes; CDFW for suction dredging.
Recreational Activities (including Packstock)	Widespread regionally, but localized to use sites.	Long-term persistence in local areas depends on use patterns and management.	Variable, depends on use levels; likely to increase w/o management.	No, but recovery may depend on amount of time sites have been impacted.	Yes, management effectiveness potentially high depending on implementation approach.	Anecdotal field data on MYLF; effects of most activities inferred largely from impacts to habitat; interactive effects unstudied.	Yes, NPS and USFS jurisdiction; public demand for amenities may conflict with species management objectives.
Research Activities	Localized at research sites; extent depends on extent of research.	Seasonal, may be long-term and persistent depending on research objectives.	Probably low, but specifics unknown.	No, but pattern of recovery depends on type of effect.	Yes, through permitting, requiring treatment of equipment; likely effective, but unexamined.	No data on MYLF; researchers acting as disease vectors important unexamined possibility.	Yes, CDFW jurisdiction, but science needed to refine conservation options.
Roads	Widespread, but primarily at lower and mid-elevations.	Persistent and long-term.	Potentially high; depends on road density, and traffic intensity.	Yes, unless roads decommissioned.	Yes, through regional planning process; potentially highly effective.	Unstudied for MYLF, but effects inferred from patterns in other species; interactive effects possible, but unstudied.	Yes, NPS and USFS jurisdiction, but science needed to identify conservation options.

Risk Factor	Spatial extent of the risk	Duration & Persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/Degree of management effectiveness	Quantifiable/ weight of evidence	Jurisdiction of participating agencies
UV-B Radiation	Global; locally and regionally mitigated by elevation, DOC, latitude.	Persistent and long-term; depends on anthropogenic influence on atmosphere.	Low for direct effects, but possibly high for unidentified interactions with other RFs.	Yes, in the short-term; long-term depends on human actions for remediation.	No, beyond agency jurisdictional scope; agency-influenced public awareness may promote change.	Direct effect on MYLF contraindicated; indirect effects or interactions with other factors unstudied.	No, would require broad societal changes and coordination among multiple regulatory agencies.
Vegetation and Fuels Management	More prevalent in northern and lower elevation geographic range; effects limited to riparian and aquatic areas used by frogs.	Potentially long-term, but sporadic; repeat of treatments several times over a decade.	Unknown, may be high if animals killed or habitat is impacted.	No, but recovery may vary with location and impact complexity.	Yes; effectiveness depends on implementation approach.	Unstudied for MYLF; studies on vegetation management in riparian and aquatic habitat numerous.	Yes, direct management responsibility of USFS and NPS.
Water Development and Diversion	Rangewide at middle to lower elevations across geographic range, but effects are localized.	Local long-term and persistent effects: effects numerous in type.	Variable, but may be high depending on level of habitat modification.	Variable, type dependent; reservoirs usually permanent; fish enhancement dams and spring development potentially reversible.	Yes; where projects dismantled effectiveness probably high.	Unstudied on MYLF; but effects of water development on other species and habitat well-documented and quantifiable.	FERC permitting or re-licensing of hydrological projects has NPS and USFS link; linkages to water rights also directly within agency jurisdiction.

EXISTING MANAGEMENT & RESEARCH TO ADDRESS RISK FACTORS

Existing management and research currently addressing mountain yellow-legged frog conservation include:

Restoration and Fish Removal

- California Department of Fish and Wildlife (CDFW) high mountain lake management involves developing Aquatic Biodiversity Management Plans (ABMP) that outline opportunities for native fauna restoration as well as recreational fisheries management based on assessments of existent fish and amphibian populations, recreational values and other public uses, and physical habitat characteristics. Contact: Mitch Lockhardt, Sarah Mussulman, Dawne Becker, Curtis Milliron, California Department of Fish and Wildlife.
- In the mid-late 1990s, experimental fish removal was conducted during several studies in the southern Sierra (Vredenburg 2004, Knapp et al. 2007, see Introduced Fish and Other Exotic Predators for more information). Based on the success of these experiments, mountain yellow-legged frog restoration involving fish removal and re-introductions has been conducted in several regions of the mountain yellow-legged frog's range. Multiple agencies and researchers have been involved in these efforts. Details on these restoration projects are described in the Mountain Yellow-legged Frog Conservation Strategy.

Chytrid Research

- Since 2001, research has been conducted on the spread of the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*, referred to as Bd) in the Sierra Nevada (Sequoia, Kings Canyon, and Yosemite National Parks, John Muir Wilderness) and its effects on mountain yellow-legged frogs. Much has been learned about the spread, impacts, and epidemiology of the disease relative to mountain yellow-legged frogs. Current research is focused on treatments and mitigation measures. Details are described in the Mountain Yellow-legged Frog Conservation Strategy. Contact: Roland Knapp, Sierra Nevada Aquatic Research Lab; C. Briggs, University of California Santa Barbara; V. Vredenburg, San Francisco State University.

Monitoring

- From 2002-2009, the USDA Forest Service implemented the first cycle of a long-term bioregional monitoring program (Sierra Nevada Amphibian Monitoring Program) for the mountain yellow-legged frog and Yosemite toad that assesses the status and trend of populations and habitat on National Forest lands within the species' ranges in the Sierra Nevada and provides information for the 10-year Forest Service planning cycle. The monitoring combines extensive and intensive components. Extensively, small watersheds (2-4 km^2) are surveyed throughout the range of the species over a 5-year cycle, with 20% revisited annually. Population trends are measured by breeding occupancy (number of occupied watersheds, number of occupied sites per watershed) and habitat by attributes that assess hydrologic condition, habitat matrix, cover, water temperature, disturbance, and general characterization. The intensive component for the mountain yellow-legged frog, which has not yet been implemented, is intended to provide more detailed abundance, life history, and habitat data in selected watersheds. Contact: Cathy Brown, USDA Forest Service.

CONSERVATION OPTIONS

This Conservation Assessment identified the following management considerations as focal in structuring a Conservation Strategy for mountain yellow-legged frogs in the Sierra Nevada. These considerations are:

- Use of a multi-scale management approach that addresses at least three scales:
  - The highest level is a species scale that recognizes the geographic distribution of the two new species, *R. sierrae* and *R. muscosa,* in the Sierra Nevada. Significant genetic partitioning within the two species may need attention for selected conservation actions. This includes 3 major clades within *R. sierrae* and 2 major clades within *R. muscosa* (Vredenburg et al. 2007).
  - An intermediate scale which covers management at the level of administrative units (individual National Forests or National Parks).
  - The smallest scale is management at the level of local basins, which encompasses population-level units. This scale incorporates the priority basin approach similar to that currently used by CDFW (Aquatic Biodiversity Management Plans; see Existing Management and Research section).
- Use of a priority basin approach will require development of criteria for selecting priority basins based on habitat suitability, complexity and uniqueness, chytrid issues, fish issues, source frog populations, and perhaps other criteria which may be important for comprehensive conservation and management of the species.
- Addressing issues related to fish and fish management, most notably:
  - Restoring fishless habitat where local population recovery is feasible
  - Identification of fishless habitat not occupied by mountain yellow-legged frogs
  - Examination of the influence of local barriers to fish movement
  - Use of the existing (CDFW) ABMP approach to integrate fish management issues into conservation efforts for mountain yellow-legged frogs.
- Develop a Translocation Feasibility Study, which:
  - Should be based on genetics at the basin scale and the larger landscape scale with special attention to the major clades within the two recognized mountain yellow-legged frog species.
  - Consider using a Criteria Decision Tree similar to the one developed by A. Lind for foothill yellow-legged frog.
- Investigate mountain yellow-legged frog populations in habitat types not represented by the majority of studies, especially stream and meadow populations and lower elevation areas.
- Continue research on epidemiology of the amphibian chytrid fungus.
- Investigate the effects of airborne contaminants on mountain yellow-legged frog populations.

Other management considerations may arise during development of the Conservation Strategy.

KEY INFORMATION GAPS

This Conservation Assessment identified several important gaps for which it will be critical to develop information in order to effectively implement conservation actions proposed in the Conservation Strategy. High priority research areas addressed in Conservation Options are not repeated here. Information gaps include:

- Better understanding of water quality and pathogen risks that may be linked to fish stocking.
- A comprehensive understanding of risks associated with recreational activities; includes the potential for anglers and recreationists to move pathogens, degrade mountain yellow-legged frog habitat, and directly place mountain yellow-legged frog life stages at risk.
- The relationship between mountain yellow-legged frog occupancy, abundance, and meadow habitat condition.
- The effects of vegetation management on mountain yellow-legged frogs.

GLOSSARY

allozymes - proteins in the first generation of molecular systematic studies

antimicrobial - a condition or a compound that has activity against microbes (bacteria) or other micropathogens

bioaccumulating - the accumulation of compounds to a greater degree in the tissues of organisms the higher in the food web the organism is; typically used with reference to pesticides

centrarchids - freshwater fish group; includes basses, crappies and sunfishes

chytrid (*Batrachochytrium dendrobatidis)* - a common, widespread group of soil-inhabiting fungi, many of which consume keratin; a recently discovered form is a severe pathogen of amphibians, especially frogs and toads

clade - general term for a phylogenetic or systematic grouping of related populations or taxa

corvids - bird group; includes crows, jays, magpies, and ravens

electroshocking - sampling technique where an electric field is applied to a water body to attract and capture fish

carbamates - carbamic acid-derived insecticides that inhibit the enzyme cholinesterase; unlike organophosphates, their activity is reversible

charr - common name applied to salmonid fishes of the genus *Salvelinus*

cholinesterase - an enzyme critical to normal nerve function; organophosphate pesticides were developed specifically to compromise its activity

control - a reference group or condition in an experiment to which treatment conditions or groups are compared

DDE - dichloro-diphenyl-dichloroethylene; a residual breakdown product of DDT

DDT - dichloro-diphenyl-trichloroethane; the best known of the bioaccumulating organohalide insectides; developed during World War II; widely used in agriculture during the 1960s

dorsolateral folds - glandular skin folds along each side of the back in some frogs that begin at the back of the eyes and extend partly or completely down the back

epibenthic - adjective used to describe the area on the surface of the bottom of aquatic habitats

epidemiology - the study of disease; in this document, the life history of a pathogen; includes its transmission mode, reservoir hosts, etc.

fibulotibia - the long bone of the lower leg of frogs; analogous to the fibula and tibia bones found in humans, but in frogs, these two bones are fused into one.

fireline - a linear area excavated to the inorganic soil layer (organic litter removed) to limit the movement of fire in a direction typically perpendicular to the line

immuno-suppressive - adjective used to describe conditions in which the immune (defensive) system of vertebrates is compromised or suppressed

impoundments - human-constructed or altered lakes

iridoviruses - group of viruses originally described from fishes; many of the same viruses are now also known from amphibians

limnetic - adjective describing the region of the water column in aquatic habitats

macrophages - white blood cells that consume pathogens; important defense against pathogens in the immune system of vertebrates

microcrustaceans - aquatic crustaceans (e.g., water fleas) typically abundant in stillwater habitats; the largest typically just big enough to be visible to the unaided human eye

monophyletic - group of organisms sharing the same recent common ancestor

neutrophils - white blood cells important in immune system response against pathogens in vertebrates

oligotrophic - a low-nutrient system; often use to describe lakes; opposite of eutrophic

organohalides - organic (carbon-containing) compounds with one or more halogen elements (bromine, chlorine, etc.); term often used generically to refer to pesticides with that makeup

organophosphates - organic (carbon-containing) compounds with the element phosphorus; term often used generically to refer to pesticides with that chemical makeup that are irreversible cholinesterase inhibitors

osteological - having to do with or pertaining to bone

packstock - pack animals (e.g., horses, llamas) used for recreational camping

PCBs - polychlorinated biphenyls;

peptides - small protein-like molecules made up of a few amino acids

photolyase - an enzyme important in the repair of UVB-damaged DNA in vertebrate cells

POEA - polyethoxylated tallowamine; a surfactant that is mixed with certain herbicides to enhance herbicide absorption into plant tissues

pyrethrins - plant-derived pesticides obtained from chrysanthemums and their related species

reticulum - a relatively fine color pattern of repeatedly interlinked lines

rodenticides - pesticides applied to control rodents (mice, rats, and their relatives)

***sensu lato* -** a phrase (Latin) meaning "in the broader sense"; used to indicate the former group referred to by a scientific species names (e.g., a broader geographic area or more populations). *Sensu stricto,* or "in the narrower sense", refers to the group for which the name currently applies.

seral stage - a stage in succession of vegetation that can be identified from its structure, such as the grassland stage or mature forest stage

skeletochronology - an approach to aging by examining annual lines of arrested growth (LAG lines) in vertebrate bone; requires clipping a toe to examine bone cross-sections in amphibians.

systematics - the field that addresses the classification of organisms

tadpole(s) - the term often applied to the larval stage of frogs and toads

tarn - a high-elevation, low production (oligotrophic) lake of glacial origin

thermocline - zone of rapid temperature change between surface and deeper waters in a lake

toadlets - juvenile toads; often refers to young-of-the-year or recently metamorphosed individuals

tympana - eardrums

underburning - fire management approach where vegetation understory is burnt to reduce fuel that could ultimately risk a severe fire

vitelline capsule - a clear jelly capsule, the innermost membrane surrounding freshly deposited aquatic amphibian eggs

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APPENDIX A – 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 and Gibbs 1988). Institutions lacking a standard symbolic code for which one was created are indicated by an asterisk.

Institution	Symbolic Code
American Museum of Natural History	AMNH
Auburn University Museum	AUM
California Academy of Sciences	CAS
California Academy of Sciences – Stanford University Collection	CAS-SU
California State University Chico – Vertebrate Museum	CSUC*
Los Angeles County Natural History Museum	LACM
Louisiana State University – Museum of Zoology	LSUMZ
Museum of Comparative Zoology (Harvard)	MCZ
Museum of Vertebrate Zoology (University of California at Berkeley)	MVZ
San Diego Natural History Museum	SDNHM
Texas Cooperative Wildlife Collection	TCWC
United States National Museum (Smithsonian Institution)	USNM
University of Kansas Natural History Museum	KUNHM

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APPENDIX B – STATUS – ADMINISTRATIVE AND POLITICAL UNITS

This appendix provides information on the status of the mountain yellow-legged frog for individual administrative and political units within the historical range of the taxa in the Sierra Nevada. This includes all Forest Service and National Park administrative units and the State of Nevada. Much of the information in this Appendix was initially compiled by the Center for Biological Diversity and Pacific Rivers Council for the petition to the US Fish and Wildlife Service to list the mountain yellow-legged frog (2000) (J. Miller, pers. comm., 2001, permitted use of this information from the Center for Biological Diversity). Additional information is from USDA Forest Service, National Park Service, and California Department of Fish and Wildlife biologists, from academic researchers, and from literature and museum sources. Where documentation from museum collections is mentioned, records are listed in parentheses with the standard symbolic codes for each institution (Appendix A) followed by the pertinent specimen number. This appendix was last updated in 2007. The mountain yellow-legged frog Conservation Strategy contains updated information on the species current distribution and abundance.

State of Nevada

Prior to 1980

Sparse documentation exists for the historical occurrence of mountain yellow-legged frogs in Nevada, so the data probably underestimate their historical distribution. Based on the analysis of Vredenburg et al. (2007), only *Rana sierrae* is thought to have historically occurred in the small area of Nevada occupied by the mountain yellow-legged frog. Data exist for two disjunct areas: verifiable data exist for the vicinity of Lake Tahoe (Linsdale 1940, Zweifel 1955) and one reliable, but unverifiable (no specimen or photograph) record exists for Fish Lake Valley (Giuliani 1994). Most records are between 1,920 m (6,300 ft) and 2,835 m (9,300 ft) elevation along small streams and in shallow lakes in meadows (Linsdale 1940). The Fish Lake Valley record, also in a historically shallow lake within a meadow, represents an elevational outlier (1,458 m); if valid, this record represents the lowest elevation at which mountain yellow-legged frogs have been recorded anywhere east of the Sierra Nevada by well over 305 m (1,000 ft).

The oldest Nevada record is one specimen taken October 1876 near the mouth of Edgewood Creek at Lake Tahoe, Douglas County, during the early explorations for railroad routes (USNM 8665; Jennings 1984). Cope (1899) originally identified this frog as *Rana temporaria pretiosa* (= *R. pretiosa*), and Linsdale (1940) re-identified it as *Rana boylii sierrae* [= *R. muscosa*], but investigators ignored it until the work of Jennings (1984). No additional mountain yellow-legged frogs were collected from Nevada for over 50 years.

Most historical data are from near Lake Tahoe. The earliest observations from this area, dating from the 1930s, are from near Incline Lake (Linsdale 1940). In 1931, Jean Linsdale collected 1 mountain yellow-legged frog at Incline at the north end of Lake Tahoe (MVZ 12790); in 1932, he also collected 10 mountain yellow-legged frogs 8.8 km north of Incline, at 2,835 m (MVZ 14643-14652); in 1934, John R. Arnold collected 6 mountain yellow-legged frogs from Galena Creek in Tahoe Meadows (MVZ 17588-17593); in 1935, John Mohr collected 2 mountain yellow-legged frogs at an unspecified location on the Nevada side of Lake Tahoe (MVZ 32390-32391); and in 1936, Emmet T. Hooper collected 1 mountain yellow-legged frog 4.8 km south of Mount Rose (MVZ 21423).

A World War II-influenced collection hiatus occurred in the 1940s, but collection resumed during the 1950s. In 1955, Jay M. Savage and Charles F. Walker collected 8 mountain yellow-legged frogs 0.8 km south of Mount Rose summit at 2,590 m (UMMZ 112359; see also Panik 1995). T.C. Frantz and T. Kerstetter (Nevada Game and Fish Commission) collected 3 mountain yellow-legged frogs along Franktown Creek in Little Valley in the Carson Mountains (CAS-SU 17536-17538). Panik (1995) mentions the latter locality as the Whittell Tract based on information Fred Ryser (pers. comm.) provided. Ryser stated that 1 frog was collected, but whether this animal differs from one of the Frantz and Kerstetter collections is unclear. Also in the same year, Frantz and Kerstetter made a single mountain yellow-legged frog collection along Galena Creek (CAS-SU 17539) very near the 1934 collection location.

From the 1960s up to the 1980s, historical data from Nevada are based exclusively on sightings. Fred Ryser (1966, unpublished manuscript and pers. comm., as cited in Panik 1995) stated that he saw "many mountain yellow-legged frogs in Tahoe Meadows from about 1965 to about 1984."

The Fish Lake Valley record from Fish Lake is based on the following single sentence from Giuliani (1994): "In the early 1970s, I found Yellow-Legged Frogs at Fish Lake (part of the eastside drainage system in Fish Lake Valley)." As no collections of mountain yellow-legged frogs exist for either Fish Lake Valley or its near vicinity and potential existed for confusion with northern leopard frogs (*Rana pipiens*), Giuliani was queried about this record. Giuliani (pers. comm., 2005) indicated that this record was based on his finding 3 overwintering mountain yellow-legged frogs under submerged leaf litter in the shallows of Fish Lake near a beaver dam. Giuliani (pers. comm., 2005) was unequivocal about mountain yellow-legged frog being the identified species when he was asked whether they could have been northern leopard frogs.

Post-1980

In 1994 and 1995, the Nevada Division of Wildlife conducted mountain yellow-legged frog surveys at 45 sites (at least 7 of which were historical) in the Carson Range of the Sierra Nevada. Mountain yellow-legged frogs were not found at any of the surveyed sites (Panik 1995). Recent (1995) surveys of 10 creeks in the Carson Range, including electroshock surveys in 6 of the creeks, failed to detect the species (Panik 1995). The few sightings of mountain yellow-legged frogs reported in Nevada have represented only 1 or a few frogs (R. Panik, pers. comm.).

In 1994, Giuliani (1994) revisited Fish Lake; at that time, he recorded no frogs because he found Fish Lake "totally dry due to recent agricultural activity."

No systematic surveys of mountain yellow-legged frog localities in Nevada have been conducted since the mid-1990s (D. Bradford, pers. comm., 2006).

Lassen National Forest

Prior to 1980

Mountain yellow-legged frogs were historically present in the southern portion of the Lassen National Forest and vicinity. Records are distributed in the Butte Creek watershed, tributaries to the West Branch Feather River system (Zweifel 1955, Hayes and Cliff 1982), and a tributary to the North Fork Feather River. These historical occurrences appear to comprise an isolate separated by the Feather River Canyon from mountain yellow-legged frogs in the Sierra Nevada to the south (Zweifel 1955).

In the Butte Creek watershed, mountain yellow-legged frogs were historically recorded from three general localities, the earliest of which dates from 1923, when Frank Bassett collected 2 frogs at Butte Meadows (MVZ 9109-9110) and another at nearby Jonesville (MVZ 10356; Zweifel 1955). In 1965, Chris Dokos collected 2 frogs on Bull Hill Creek, 4.8 km northeast of Inskip (CSUC 1242-1243). Over the years 1974-1978, Marc Hayes (pers. comm., 2005) devoted over 1,200 hours of survey effort for ranid frogs at the Butte Meadows and Jonesville historical mountain yellow-legged frog localities, but he found no mountain yellow-legged frogs.

In tributaries to the West Branch of the Feather River watershed, mountain yellow-legged frogs were recorded from 5 general historical localities. The earliest record is from 1952, when 5 frogs were collected in Coon Hollow Creek (Zweifel 1955). In 1961, D. Collett collected 17 more frogs at Coon Hollow Creek (CSUC 907-919, 1249-1252) and 1 frog near Philbrook Lake (CSUC 1105); and in 1966, Chris Dokos collected 5 frogs near Snag Lake (CSUC 1244-1248).

The mountain yellow-legged frog also occurred historically in Butt Creek (a tributary to the North Fork Feather River system), 12.8 km (8 mi) east of Jonesville; in 1961, 2 frogs were collected in this tributary (CSUC 1132-1133).

No records of collections or sightings exist from the Lassen National Forest during the 1970s.

Post-1980

Over 200 hours of systematic surveys addressing ranid frogs conducted at the Butte Meadows and Jonesville historical localities in 1981 and 1983 failed to detect any mountain yellow-legged frogs (M. Hayes, pers. comm., 2005).

During both informal (such as LNF 1993) and formal (Fellers 1995, 1998; EAEST 1995, 1996) surveys conducted between 1993 and 2002 to assess the relative distribution and abundance of amphibian species (including the mountain yellow-legged frog) on the Lassen National Forest, no mountain yellow-legged frogs were found (M. MacFarlane, *in litt*., 2002 in USFWS 2003). This effort included drainages with historical records. More comprehensive surveys are needed to locally verify status of the mountain yellow-legged frog on the Lassen National Forest.

From 2003 to 2006, the USDA Forest Service Sierra Nevada Amphibian Monitoring Program (SNAMPH) surveyed 1 watershed on the Lassen National Forest containing 11 sites. Evidence of mountain yellow-legged frog breeding was found at 1 of these 11 sites, with no frogs found in the remaining 10 sites. Only a few frogs were found, but surveys were not designed to obtain accurate abundance information. Also over the interval 2003-2006, CDFG conducted 91 surveys (see detail of survey approach in Status section) of 89 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were detected at 1 percent (n = 1) of surveyed sites.

Lassen Volcanic National Park

Prior to 1980

Only one historical record exists from within Lassen Volcanic National Park (Lassen Volcanic National Park). R. Russell collected 2 adult male mountain yellow-legged frogs 1.6 km east of Drakesbad (Tehama County) in 1954 (UMMZ 200265-200266); these records are the northernmost across the geographic range of *R. sierrae*. Previous investigators have not recognized this record, and information regarding this record is in preparation (M. Hayes, M. Jennings, V. Vredenburg, unpubl. data).

Post-1980

Extensive surveys within Lassen Volcanic National Park have revealed only a few Cascade frogs (*Rana cascadae*; Fellers and Drost 1993). No records of mountain yellow-legged frogs have been found in Lassen Volcanic National Park (NPS 1999, Stead et al. 2005) since the two 1954 Russell collections.

Plumas National Forest

Prior to 1980

Historical mountain yellow-legged frog data for the Plumas National Forest and vicinity are sparse. Prior to 1980, mountain yellow-legged frogs have been recorded from 6 general localities.

No data exist prior to the 1940s. In 1943, Margaret Storey collected mountain yellow-legged frogs from 3 localities in Sierra County: At the bridge over Slate Creek [CAS-SU 8602-8604]; 1 km north of Scales [CAS-SU 8611]; and Howland's Flat [CAS-SU 8612]). In 1947, D. V. Brown collected a juvenile mountain yellow-legged frog at Camp La Porte, the Boy Scouts of America camp at La Porte (CAS-SU 9528).

One collection dates from the 1950s; Walter Howard and Ed Jameson, Jr. collected a juvenile mountain yellow-legged frog 11.2 km north of Quincy in 1950 (CAS 218482).

The only other pre-1980 records from the vicinity of the Plumas National Forest date from the 1960s. In 1960, 8 mountain yellow-legged frogs were collected from near La Porte (CSUC 1115, 1253-1259). In 1961, 5 mountain yellow-legged frogs were collected from Big Grizzly Creek (CSUC 1107-1111; Koo and Vindum 1999).

Post-1980

There are multiple recent records of mountain yellow-legged frogs throughout the Plumas National Forest (Koo and Vindum 1999). Generally, they exist within two broad geographic areas, a southern population centered around the Slate Creek watershed, and a northern population occurring between the Middle and North Fork Feather Rivers (Koo and Vindum 1999). Mountain yellow-legged frog sightings on the Plumas National Forest have been documented from reservoirs, small ponds, and streams; the classic Sierra Nevada alpine lake habitat generally associated with this species is not commonly available.

A California Academy of Sciences review of collection holdings at major American museums documented the lower elevation limit of mountain yellow-legged frogs as 1372 m (4,500 feet) at San Antonio Creek, Calaveras County (Koo and Vindum 1999). However, a telemetry study of mountain yellow-legged frog movements in Bean Creek in the Mount Hough Ranger District of the Plumas National Forest revealed that some individuals seasonally migrated downstream to elevations as low as 1189 m (3,900 feet) (MGW Biological 2008). (Note that some telemetered frogs in this study may have been *R. boylii*.) It is not unusual to find mountain yellow-legged frogs populations at relatively lower elevations (< 1219 m [4,000 feet]) in the northern portion of the species range, such as on the Plumas National Forest (K. Matthews, pers. comm.).

Based on re-surveys of historically occupied sites, Jennings and Hayes (1994) indicated that the species appeared extirpated from several localities. Plumas National Forest surveys conducted from 1990 through 2004 have generally followed the Fellers and Freel (1995) protocol, but significant variation in survey effort has been applied. A handful of these surveys have recorded mountain yellow-legged frogs at 1-3 locations, and most observations have been of individual frogs; sites with even 2 or 3 individuals are rare (Twedt and Evans 1993; USDA Forest Service 1994, 2000a; Fellers and Freel 1995; Fellers 1997; Koo and Vindum 1999, 2002; Foster Wheeler 2001; Williams 2004). A number of surveys within the appropriate elevation range and habitat have failed to detect mountain yellow-legged frogs (Fellers 1996; Ganda 2001a, 2001b, 2001c, 2001d, 2001e; Ecosystems West 2001, NSR 2001, Klamath WR 2003, M&A 2004, Brown et al. 2014).

Based on surveys during the 1990s, analysis of amphibian survey data, and collected positive sightings from the Plumas National Forest, 54 known sites had mountain yellow-legged frogs, but data on numbers of individuals were largely lacking (C. Davidson, pers. comm., 2001). More recent surveys have found population sizes to be very small (Foote et al. 2013, Brown et al. 2014, CDFW unpublished data Sarah Mussulman, pers. comm., 2013). Nine of these sites, all in Plumas County, are specimen-documented: meadow on Pinkard Creek (CAS 203170); tributary to Rock Creek (CAS 206093); small pond north of Pine Grove Cemetery (CAS 209668); Faggs Reservoir (CAS 209370-209377); Silver Lake (CAS 209386); Rock Lake (209404) and its effluent (CAS 227668); outlet of Gold Lake (CAS 227259); upper Lone Rock Creek (CAS 227639); and Boulder Creek at Lowe Flat (CAS 227640). During surveys using the Anuran Survey Protocol for the Sierra Nevada of California (Martin et al. 1993), mountain yellow-legged frogs were detected in Lower Bucks Lake, Upper Boulder Creek, Elysian Valley Creek, and Rock Lake. Finally, an independent study conducted through the local community college found high densities (100+ each) of mountain yellow-legged frogs in the three lakes, Rock Lake, Bushwack Lake, and "no-name" lake, and moderate densities at Silver Lake (M. Grover, pers. comm., 2002).

Based on the most recent entries into the Plumas National Forest Amphibian Database, between 2000 and 2003, of over 80 surveys conducted that included mountain yellow-legged frog as a target species, 34 surveys across 26 different sites recorded the species. At most sites, 1 to 12 mountain yellow-legged frogs (various life stages) were recorded; at 1 site, Cattle Springs at the head waters of Rock Creek, ca. 100 mountain yellow-legged frog larvae were found (T. Hopkins, pers. comm., 2006).

Contracted consultants conducted amphibian surveys in the Sugarberry Project area on 192 miles of streams with a total of 26 MYLF sitings (M&A 2001, Galloway Consulting, Inc. 2005, and Klamath Wildlife Resources/MGW Biological 2006). Tadpoles were documented within Slate Creek.

From 2003 to 2006, the USDA Forest Service SNAMPH surveyed 9 watersheds containing 50 sites on the Plumas National Forest. No evidence of mountain yellow-legged frog breeding was observed in any of the 9 watersheds, though adults or subadults were located at 2 (4 percent) of the sites in one watershed. Only 1-2 mountain yellow-legged frogs were found on any given survey, but surveys were not designed to obtain accurate abundance information.

Based on capture-mark-recapture techniques, Foote et al. (2013) documented small populations (< 20 adults) in three stream reaches.

Also over the interval 2003-2006, CDFG conducted 86 surveys (see detail of survey approach in Status section) of 78 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were detected at 16.7 percent (n = 13) of surveyed sites.

Tahoe National Forest

Prior to 1980

Mountain yellow-legged frogs were historically present throughout the Tahoe National Forest and surrounding areas in Nevada, Placer, and Sierra Counties. Collections record 31 different localities for the mountain yellow-legged frog made prior to 1980 with at least 3 additional localities based on high confidence observations; 19 of these collections and observations are from stream habitats.

The oldest mountain yellow-legged frog records from the Tahoe National Forest consists of 7 specimens that Cloudsley Rutter and William Atkinson collected in 1899 from the Little Truckee River (CAS-SU 1813) and the vicinity of Sierraville, Sierra County (CAS-SU 1817-1822; Tahoe National Forest Amphibian Database). No further collections or sightings were recorded until 1928, when Charles Burt collected 1 frog at an unspecified locality 64 km west of Lake Tahoe (UMMZ 67498). In 1929, Tracy and Ruth Storer collected 7 mountain yellow-legged frogs south of Gold Lake (CAS 218349-218355).

A few collections were made in the 1930s. In 1932, Storer collected 1 frog in Ennor Pass Creek, 4.8 km west of Webber Lake (CAS 218348). In 1933, 2 localities in Placer County were collected: Soda Springs (KUNHM 18131-18133) and 16 km southeast of Soda Springs summit (SDHNM 20424-20431). In 1935, Henry Fitch collected 1 mountain yellow-legged frog 0.8 km above the mouth of Gray Creek, Nevada County (MVZ 18603). In 1939, A. J. Calhoun collected 12 mountain yellow-legged frogs from 4 Tahoe National Forest localities: Prosser Creek, Nevada County (CAS-SU 4866-4871), Five Lakes (CAS-SU 4889), Martis Creek on Brockway Road (CAS-SU 4890-4894), and Squaw Valley (CAS-SU 4888), Placer County. In 1939, Charles Miller also collected 3 mountain yellow-legged frogs from 2 localities in the vicinity of the South Fork of the Yuba River, Placer County (MVZ 34704-34706), and Thomas Rodgers collected 1 frog north of Sierra City, Sierra County (MVZ 35554).

Two records exist for the 1940s. In 1942, Robert Rush Miller collected 5 mountain yellow-legged frogs 7.2 km (4.5 mi) north of Truckee, Nevada County (UMMZ 91678) and he collected an additional frog along the Little Truckee River, 22.4 km (14 mi) north of Truckee, Sierra County (UMMZ 91680).

More records were added in the 1950s. In 1950, J. C. Marr collected 1 adult frog in the stream that flows out of Sand Pond, just east of Lower Sardine Lake, Sierra County (CAS-SU 11060) and in 1958, John Applegarth noted 9 adult frogs in the South Yuba River above Lake Van Norden, Nevada County. The most collected Tahoe National Forest site in the 1950s was Sagehen Creek, due to the presence of the University of California field station located there. Between 1951 and 1956, 5 different investigators collected 28 mountain yellow-legged frogs from the vicinity of Sagehen Creek (MVZ 53968-53971, 57049-57050, 58257, 59661-59664, 60100-60114, 60238, 66217).

In the 1960s and 1970s, at least 170 collections and observations of many additional mountain yellow-legged frogs were made in the Tahoe National Forest:

- In 1960, Paul De Benedictis collected 26 mountain yellow-legged frog at 8 locations near Squaw Valley (MVZ 71830-71848) and re-collected the Five Lakes locality (MVZ 71850-71855).
- In 1961, Darrell Torgerson collected 8 frogs from 3 different localities in the vicinity of Prosser Creek, Nevada County (CSUC 1538-1544, 1598); C. Williams collected 2 frogs from Lincoln Creek, Sierra County (CSUC 1116-1117); and Alan Ziegler collected 25 mountain yellow-legged frogs (13 adults, 12 larvae) from a revisit to the Sagehen Creek locality (MVZ 72493-72497, 72499-72512, 72514-72519) and observed mountain yellow-legged frogs at 8 other Tahoe National Forest locations in Nevada County.
- Between 1961 and 1969, Harold Houser collected 90 mountain yellow-legged frogs from 8 different sites in Nevada County (Houser and Sutton 1969): Paradise Lake (CSUC 848-849), 3 in the vicinity of

Magonigal Summit (CSUC 850-882, 1112-1115, 1119-1131), on Rattlesnake Creek (CSUC 883-906), on Castle Creek in Round Valley (CSUC 1262-1263), and 2 localities on Poorman Creek (CSUC 1599-1608, 1816-1818).

- In 1964, H. Leech collected 1 frog from Cold Creek, 28.9 km north of Truckee (CAS 113526).
- Half a dozen times during July-August in 1964 and 1965, Hal Michael (Washington Department of Fish and Wildlife, Fish Program, pers. comm., 2005) caught 3-4 mountain yellow-legged frogs on a baited line while sport-fishing on a reach of Summit Creek about 0.8 km above the western end of Donner Lake. Michael noted that the particular reach of Summit Creek in which he caught mountain yellow-legged frogs consistently appeared to lack trout, which he caught with some frequency both above and below this reach.
- In 1965, F. Mine collected 3 frogs in another revisit of Sagehen Creek (MVZ 79563-79565).
- During 1968, Jeffrey Briggs collected 1 frog at Tollmonese Lake, east of Jackson Meadows Reservoir (AUM 35727); and with John Haertel, Briggs also collected 2 mountain yellow-legged frog larvae from Tollhouse Lake (UMMZ 151817).
- From 1968 through 1974, M. Graf (pers. comm., 2002) described mountain yellow-legged frogs as abundant "everywhere" in Alpine Meadows, Squaw Valley, and the Five Lakes area of the Granite Chief Wilderness. Graf had observed a large population of mountain yellow-legged frogs at Lake Estelle, which "typically had over 1,000 frogs each summer."
- In 1973 and 1974, Susan M. Case collected 13 frogs from 3 previously collected localities, Poorman Creek (MVZ 136159-136168), Rattlesnake Creek (MVZ 136158), and Sagehen Creek (MVZ 136170, 136221; Case 1978).

A distributional map of mountain yellow-legged frogs (Jennings and Hayes 1994) indicates that the species was historically well-distributed throughout higher elevations of the Tahoe National Forest. Moreover, the many frogs collected in the 1960s and 1970s suggest that the species continued to be abundant through at least 1974 (Tahoe National Forest Amphibian Database).

Post-1980

Since 1980, mountain yellow-legged frogs have been recorded at approximately 50 locations in both stream and pond habitats in the Tahoe National Forest, but most observations have been of single frogs (Tahoe National Forest Amphibian Database). By the mid-1980s, the species had apparently disappeared from the Squaw Valley/Alpine Meadows area southward in the Tahoe basin where it had been observed in abundance a few years earlier (see M. Graf comments in previous section). By 1992, the species was extinct in a number of locations, based on re-surveys of historical locations (Jennings and Hayes 1994).

The Tahoe National Forest has conducted amphibian surveys from 1993 to the present. Survey thoroughness varies among years and locations. Surveys of mountain yellow-legged frog habitat during the past 8 years have generally been consistent and thorough, following the Fellers and Freel (1995) protocol. Among these records are 2 collections: in 1997, J. Kools collected a juvenile mountain yellow-legged frog along Independence Lake Road 1.9 km south of Jackson Meadows Road, Sierra County (CAS 203394); and in 1999, J. Wilkinson also collected another juvenile mountain yellow-legged frog in "Rattlesnake Pond", 8.8 km northeast of Cisco, Nevada County (CAS 210033). The largest numbers observed in recent surveys (1993 to 2005) were at 3 sites (Lyon Bog, Rattlesnake Creek, and Poorman Creek), at each of which only 5 adults were observed. Mountain yellow-legged frogs have also been observed consistently between 1996 and 2006 within a 1000-meter stream reach on Independence Creek; individual surveys have recorded up to 4 adults and 20 larvae (also see Foote et al. 2013 for more recent information). In 2004, a single adult was recorded in a relatively high gradient (11 percent) tributary to Fordyce Lake, a previously unknown site. After extensive surveys in the Sagehen Creek watershed between 2002 and 2005, a single adult was observed in 2005 in a small tributary of Sagehen Creek.

From 2003 to 2006, the USDA Forest Service SNAMPH surveyed 6 watersheds containing 67 sites on the Tahoe National Forest. Mountain yellow-legged frogs were found in one of the watersheds. This watershed had 1 site (1 percent) with evidence of breeding and 8 (12 percent) additional sites where only adult or subadult frogs were recorded. Numbers of adults and larvae observed were less than 10, but it needs emphasis that these surveys were not designed to obtain accurate abundance information.

Also over the interval 2003-2006, CDFG conducted 492 surveys (see detail of survey approach in Status section) of 474 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were detected at 6.1 percent (n = 29) of surveyed sites.

Lake Tahoe Basin Management Unit

Prior to 1980

Many historical sightings and collections of mountain yellow-legged frogs exist from the Lake Tahoe Basin Management Unit (LTBMU), and anecdotal accounts indicate that the species was relatively abundant in the Lake Tahoe area (M. Schlesinger, pers. comm.).

The oldest record from the LTBMU consists of 4 mountain yellow-legged frogs taken October 1876 near the mouth of Edgewood Creek (Lake Tahoe), Douglas County, Nevada (USNM 8665, 334997-334999; Jennings 1984).

No additional records were obtained until 35 years later. In 1911, James Otterbien Snyder (Stanford University) and C. H. Richardson collected 6 mountain yellow-legged frogs in the vicinity of Tallac on Emerald Bay, Lake Tahoe (CAS-SU 3529-3534) and 1 additional frog at Tahoe City, along the northwest shore of Lake Tahoe (CAS-SU 2042). In 1913, Joseph Slevin made what remains the largest collection of mountain yellow-legged frogs ever made at a single locality; he took 262 frogs at Fallen Leaf on Fallen Leaf Lake (CAS 36454-36711; UMMZ 49951-49952, 50137, 53909). Additionally, 3 undated collections exist suspected of also having been made in the 1910s; these were also collections from near Fallen Leaf Lake (CAS-SU 1545-1546, 1548).

No records exist for the 1920s, but a few exist for the 1930s. Most of the 1930s records are from Washoe County, Nevada. In 1931, Jean Linsdale collected 1 mountain yellow-legged frog at Incline (MVZ 12790), on the Nevada side of Lake Tahoe; the following year, he collected 10 more frogs 8.8 km north of Incline at an elevation of 2,835 m (MVZ 14643-14652). In 1934, John Arnold collected 6 mountain yellow-legged frogs at Tahoe Meadows on Galena Creek (MVZ 17588-17593); in 1935, John Mohr collected 2 frogs at an unspecified locality on Lake Tahoe (MVZ 32390-32391), and R. E. Smith collected 1 mountain yellow-legged frog 0.8 km northeast of Star Lake, El Dorado County (MVZ 18192). In 1936, Emmet Hooper collected 1 frog 4.8 km south of Mt. Rose (MVZ 21423).

One record exists from the 1940s; in 1942, Robert Rush Miller collected 1 mountain yellow-legged frog at Cascade Creek on the southwest side of Lake Tahoe (UMMZ 91681).

Records from the 1950s are sightings and collections. During CDFG lake surveys, adult and larval mountain yellow-legged frogs were recorded at Kalmia Lake and at unnamed Lake No. 3 above Fontinallis Lake in 1953 (CDFG 1953). In 1955, T. Frantz and T. Kerstetter (Nevada Game and Fish Commission) collected 3 mountain yellow-legged frogs along Franktown Creek in Little Valley (CAS-SU 17536-17538), and 1 additional frog on Galena Creek (CAS-SU 17539); both localities are in the Carson Mountains, Washoe County, Nevada. In the same year, Jay Savage and Charles Walker collected 8 frogs 0.8 km southwest of Mt. Rose summit (UMMZ 112359).

Few historical records exist for the 1960s and 1970s. Fred Ryser (1966, unpubl. MS, and pers. comm., as cited in Panik 1995) stated that he saw "many mountain yellow-legged frogs in Tahoe Meadows from about 1965 to about 1984." In 1975, Susan Case collected 5 mountain yellow-legged frogs at Tamarack Lake (MVZ 136231-136235) in the course of gathering information for her systematic revision of western North American ranid frogs (Case 1978a, 1978b).

Post-1980

From 1997 to date, the USDA Forest Service has conducted extensive surveys of over 138 sites and 2 entire drainages in LTBMU-administered lands. Only 1 known reproducing population of mountain yellow-legged frogs has been found; in 1997, 3 frogs were observed in Hell Hole Swamp, El Dorado County (M. Schlesinger, pers. comm.; J. Reiner, pers. comm.). Some adults were seen in 1999, but no adults were detected during 2002 surveys, although larvae were observed (M. Schlesinger, pers. comm.). In 2004, 2 metamorphs were found in extensive surveys that included historical sites in the vicinity of Echo and Cagwin Lakes. The USDA Forest Service SNAMPH did not survey any watersheds on the LTBMU.

Also over the interval 2003-2006, CDFG conducted 256 surveys (see detail of survey approach in Status section) of 256 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were not detected at any of surveyed sites.

Humboldt-Toiyabe National Forest

Prior to 1980

About 20 historical sightings and collections of mountain yellow-legged frogs exist from the Humboldt-Toiyabe National Forest and vicinity; Jennings and Hayes (1994) provide a distribution map of the mountain yellow-legged frog records on the Humboldt-Toiyabe National Forest in California.

The earliest historical collections on what is now the Humboldt-Toiyabe National Forest are ambiguous because an undated Stanford University collection exists from Tamarack Lake, Alpine County (CAS-SU 1544, 1547) that, based on the collector, C. V. Burke, is pre-1935 vintage. However, the earliest dated records are from the 1930s when in 1930, Tracy Storer collected 8 mountain yellow-legged frogs from Alpine Lake, Alpine County (CAS 218381-218386, CU 1934-1935). In 1934, 2 frogs were collected near Carson Pass, Alpine County (SDNHM 22789-22790). In 1935, Henry Fitch collected 1 frog 0.8 km above the mouth of Gray Creek, a tributary to the Truckee River, Nevada County (MVZ 18603). In 1939, David Johnson collected 8 frogs along the West Fork of Silver Creek and 3.2 km north of Ebbett's Pass (MVZ 28577-28584), and R. E. Smith collected 4 mountain yellow-legged frogs at Faith Valley (MVZ 32614-32617); both localities are in Alpine County.

Records from the 1950s are a mix of sightings and collections. In 1956, Ernest Karlstrom re-collected the Faith Valley locality (MVZ 68056-68057); in 1958, Thomas McIntyre collected 1 frog from Red Lake (MVZ 67330); both localities are in Alpine County.

In 1964, Frederick Schuierer collected 3 mountain yellow-legged frogs near Ebbett's Pass (CAS 97670-97672). In the 1960s, biologist Lawrence Cory found a "thriving population with an unusually dense larval population" of mountain yellow-legged frogs in a pond connected to Koenig Lake in the Leavitt Lake basin east of Sonora Pass, Mono County (Cory 1989).

Two records exist for the 1970s. In 1974, Richard Sage collected 3 mountain yellow-legged frogs in the meadows below Leavitt Lake (MVZ 149006-149008) and in 1976, Sage also collected 1 frog 2.1 km east of Sonora Pass, Mono County (MVZ 137606).

Post-1980

Only 1 record exists for the early 1980s. In 1981, Richard Sage collected 6 mountain yellow-legged frogs from Nobel Lake, 3.9 km southeast of Ebbett's Pass (MVZ 180142-180143, 180160-180163).

By 1988, the large mountain yellow-legged frog population in the Leavitt Lake basin had disappeared. Lawrence Cory carefully searched all parts of the pond in a revisit of this site in 1988 and showed "convincingly" that the species was no longer present (Cory 1989). According to Jennings and Hayes (1994), based on the Cory resurvey and resurveys of selected locations where it was historically extant, the species had been extirpated at a number of sites on the Humboldt-Toiyabe National Forest by 1992. In a resurvey of Koenig Lake and its peripheral ponds in 1996, Jamie Reaser (Stanford University) also found no frogs (USDA Forest Service 2000b); Vance Vredenburg (pers. comm., 2002) also independently visited this location in 1996 and 1998 and likewise found no frogs.

Humboldt-Toiyabe National Forest personnel have surveyed and searched for frogs informally from 1995 through 1999 (P. Shanley, pers. comm., 2002). Observations at White Cliff Lake in the Silver King Creek drainage of the Carson/Iceberg Wilderness found "thousands of frogs hopping around" in 1990, but only 3 tadpoles and 1 one sub-adult were located when the lake was revisited in 1999 (P. Shanley, pers. comm., S. Lehr, pers. comm., 2002). In 1999, the Bridgeport Ranger District of the Humboldt-Toiyabe National Forest surveyed 5 lakes, 3 springs, and a seasonal pond and detected no mountain yellow-legged frogs (USDA Forest Service 2000b).

Of 17 sites surveyed in 1996, and 14 areas (containing single or multiple sites, covering 308 ha [760 ac] of aquatic habitat) surveyed in 1999, only 2 areas were found to have mountain yellow-legged frogs: the Rainbow Meadow area and locations at Chango Lake. "Numerous" larvae and 10-20 adults were found in 1995 in 3 adjacent ponds in the Rainbow Canyon drainage, and an unspecified number of adults and tadpoles were found in pools along the creek through Rainbow Canyon. Frogs were again seen in 1999 at 7 sites in 6 lakes at Rainbow Meadow, but only 3 adults, over 800 subadults, and over 1,000 larvae were found. In 2002, CDFG (C. Milliron, pers. comm., 2002) resurveyed the Rainbow Meadow area (including Tower Lake); few adults (~12) were observed. Larvae in the Rainbow Meadow area showed signs of chytrid infection in 2002.

In 1996, mountain yellow-legged frogs were found at 2 sites at Chango Lake (2 adults, 107 sub-adults, and 749 tadpoles). In the 1999 survey, about 200 adults and 300 larvae were seen at Chango Lake (USDA Forest Service 2000b). In 2001, CDFG observed mountain yellow-legged frogs in the Walker Basin in a pond near Grizzly Lake (C. Milliron, pers. comm., 2002). As of 2002, approximately 4 populations (all in California) existed on the Humboldt-Toiyabe National Forest (C. Milliron, pers. comm., 2002 in USFWS 2003).

From 2003 to 2006, the USDA Forest Service SNAMPH surveyed 8 watersheds containing 164 sites on the Humboldt-Toiyabe National Forest. Two watersheds had evidence of breeding by mountain yellow-legged frogs and one additional watershed had observations of adult or subadult frogs. In these watersheds, evidence of breeding was found at 9 sites (5 percent) and an additional 17 sites (10 percent) had observations of adults or subadults. The Rainbow meadow area mentioned above had large populations multiple years with more than 1000 larvae in 4 sites and more than 50 adults in 2 sites. However, it needs emphasis that these surveys were not designed to obtain accurate abundance information.

Also over the interval 2003-2006, CDFG conducted 249 surveys (see detail of survey approach in Status section) of 161 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were detected at 35.4 percent (n = 57) of surveyed sites.

Eldorado National Forest

Prior to 1980

Sightings and specimen collections of mountain yellow-legged frogs exist for over 20 different localities in the Eldorado National Forest prior to 1980; most are from above 1,500 m of elevation.

The oldest record from the Eldorado National Forest consists of 4 frogs collected by William Ritter in Heather Lake, El Dorado County in 1900 (MVZ 43337-43340) in what is now the Desolation Wilderness Area. Subsequently in 1925, Tracy Storer collected mountain yellow-legged frogs in the vicinity of Silver Lake, Amador County; these collections were from Mudspring (CAS 218358), Tragedy Creek (CAS 218359-218360), and a few small lakes and ponds just east of Silver Lake (CAS 218356-218357, 218390; see also Storer field notes for 12-21 July 1925 on file at MVZ).

In the 1930s, Earl Herald collected 1 mountain yellow-legged frog near Riverton (CAS-SU 4329). In 1939, David Johnson collected 5 frogs in a pond near Blue Lakes (MVZ 32618-32622) in Alpine County.

In 1940, A. J. Calhoun collected 6 frogs from upper Blue Lake, Alpine County (CAS-SU 6084-6089). In 1941, Storer collected 1 frog at Blue Lakes, Alpine County (CAS 218387).

In 1942, Robert Rush Miller collected along a tributary to the North Fork of the Mokelumne River, Alpine County (UMMZ 91682); in 1945, Alden Miller collected 2 frogs from each of Lake of the Woods (MVZ 41180-41181) and 1.6 km east of Phillips (MVZ 41182-41183), both in El Dorado County; and in 1949, John Hendrickson collected 1 frog in a meadow 0.4 km west of Audrian Lake, El Dorado County (MVZ 75917).

During the 1950s, Richard Zweifel made 1 mountain yellow-legged frog collection 5.6 km east-southeast of Phillips, El Dorado County (MVZ 58086); and Gene Christman collected 3 frogs in a small pond northeast of Lake Winnemucca, Alpine County (MVZ 66188-66190). In 1951, a CDFG lake survey found mountain yellow-legged frogs and tadpoles "plentiful" in Summit Meadow Lake, Alpine County (CDFG 2000). Also during the 1950s, CDFG lake surveys revealed an abundance of frogs and larvae in Frata and Upper Leland

Lakes, El Dorado County; and Summit Meadow Lake, Alpine County. Frogs were identified as mountain yellow-legged frogs only at Upper Leland Lake, but the abundance of frogs reported implies that mountain yellow-legged frogs were regionally common at that time.

During the 1960s, data exist for 5 localities, all in El Dorado County. In 1960, Ed Kessel collected a total of 14 mountain yellow-legged frogs from Alder Creek Camp (CAS 87862-87867) and 3.2 km south of Wrights Lake (CAS 87854-87861). In 1963, Tracy Storer collected 1 frog at Johnson's Pass near Echo Summit (MVZ 8263). In 1966, James Lynch re-collected the Lake of the Woods locality (MVZ 81262); and P. Fodor collected 1 frog along the South Fork of Silver Creek (LACM 91269).

Collections continued during the 1970s, largely due to the systematic work of Case (1978a, 1978b) on western North American ranid frogs. On the Eldorado National Forest, she collected 9 mountain yellow-legged frogs total from Grouse (MVZ 136211-136214) and Smith (MVZ 136215, 136237-136238) Lakes, El Dorado County; Upper Lake on the trail to Lake Winnemucca, Alpine County (MVZ 136220); and Bear River Reservoir, Amador County (MVZ 136236). Also during the 1970s, Kristine Tollestrup collected 1 mountain yellow-legged frog from Hemlock Lake, El Dorado County, in the Desolation Wilderness (MVZ 128855). In addition, L. Wilson and G. Forni (pers. comm., 2002), 2 local ranchers/grazing permittees, reported that frogs matching the description of mountain yellow-legged frogs were numerous before the 1976-1977 drought. Both recalled observing the frogs throughout the Jones Fork of Silver Creek, the South Fork of Silver Creek, and Lyons Creek drainages from headwater lakes downstream to as low as 1,950 m on the South Fork of Silver Creek. Craig Thomas and Lonnell Wilson of Wilson Ranch (pers. comm., 2002), 2 more local residents, also reported that 2 unnamed headwater tarns in the Lyons Creek drainage contained high densities of frogs thought to be mountain yellow-legged frogs prior to 1980.

Post-1980

The only mountain yellow-legged frog data from the 1980s are sighting information. Wilson and Thomas, the local residents who had reported frogs from the unnamed tarns in the Lyons Creek drainage (see previous section), continued to observe high densities of frogs until 1988. By 1990, Thomas reported that the frog population had nearly disappeared. USDA Forest Service surveys in 1995, 2000, 2001, and 2002 have recorded low numbers of frogs including adults, metamorphs, and larvae, albeit with a slightly increasing trend since 2000. Trout had been stocked 8 times in the upper tarn at irregular intervals from 1965 to 1988; these tarns were subsequently removed from the fish-stocking program. By 1995, gill net fish removal efforts revealed that both tarns now seemed to be fishless.

From 1991 onwards, the USDA Forest Service, CDFG, and several contractors conducted numerous surveys for mountain yellow-legged frogs on the Eldorado National Forest. Reproducing populations have been found at scattered localities above 1,500 m. Mountain yellow-legged frogs appear to remain widely distributed across the Forest, but numbers reported are low compared to historical reports of sites teeming with frogs.

During 1992 and 1993, Dave Martin (Martin 1992, 1993) conducted surveys for amphibians that included the Eldorado National Forest. The 1992 surveys encompassed 26.2 km of streams, meadows, and lakes at 11 sites at elevation above 1,525 m; no mountain yellow-legged frogs were found. The 1993 surveys addressed 38.9 km of streams, meadows, and lakes at 12 sites above 1,525 m; 4 mountain yellow-legged frogs were detected at 5 sites, 4 of which had been surveyed in 1992. During both years, moderate-to-high gradient streams, which represented 90 percent of the survey distance, appeared to provide only marginal breeding habitat. Lake surveys were conducted at 3 trout-stocked reservoirs, which would be unlikely to support reproducing populations of mountain yellow-legged frogs.

Beginning in 1993, most USDA Forest Service and CDFG searches were full-perimeter visual encounter searches of lakes and ponds. Perennial inlet and outlet streams were also surveyed for distances up to 100 m as part of the lake surveys.

In 1993 and 1994, George Elliott (Eldorado National Forest) and his field crews recorded mountain yellow-legged frogs at over 20 Eldorado National Forest sites (Panik 1995; H. Panik, pers. comm.), 7 of which are documented by specimens: an unnamed lake east of American Lake (CAS 197622), unnamed tributary to Cole Creek (CAS 197618-197619), Forni Lake (CAS 197623), Ladeux Meadow (CAS 197624), Lake Zitella (CAS 197621), ponds in Highland Lake outlet (CAS 197625), and Pyramid Lake (CAS 197620). Mountain yellow-legged frogs that may represent local populations were also identified from several streams not closely associated with any lakes.

Since the early 1990s, sighting data from the Eldorado National Forest indicate that mountain yellow-legged frogs have been observed at 118 localities that are thought to represent at least 18 populations. Many localities had a few or single individuals that appeared to be part of a larger population; mountain yellow-legged frogs observed at these localities are thought to be largely tadpoles or seasonally dispersing adults. During 2000, surveys of 9 key localities recorded 64 adults, 362 juveniles, and about 2,200 larvae. In 2002, more than 25 adult frogs were observed in 5 of these populations, with 50 adults in 1 population being the greatest number observed. Six other populations surveyed in 2002 had 10-25 adults. Adults have been the most difficult life stage to observe in the field likely because of crypsis and dispersal patterns, so adult counts likely underestimate actual numbers of adults (G. Elliott and J. Williams, pers. comm., 2009).

Surveys have been repeated at fewer than 20 sites. Trends from repetitive surveys have been variable, ranging from non-detection in several ponds, lakes, and streams; to maintenance of similar numbers in several streams and lakes; to small increases in several streams and lakes. In a tributary to Cole Creek, mountain yellow-legged frogs appear to have responded positively to reductions in trout density through electroshocking. Numbers of juvenile frogs and larvae appear to have increased following fish removals (Appendix Table B1*)*.

In 2001 and 2002, 26 historical frog locations in lakes were resurveyed; mountain yellow-legged frogs were not observed in any of the 15 lakes that contain trout. Trout stocking began in these lakes from 33 to 71 years prior to the historical specimen collections. Notably, among localities with a longer timeline of historical data, the three Storer localities from 1925 currently support apparently reproducing populations of mountain yellow-legged frogs.

In 2004, a few adult and juvenile mountain yellow-legged frogs were observed at the historical locality just east of Silver Lake, and moderate to high numbers of diverse life stages were observed around Lake Aloha. However, no frogs were observed during surveys of Caples Lake, and only 2 metamorphs were found in extensive surveys that included historical sites in the vicinity of Echo and Cagwin Lakes.

Appendix Table B1 – Mountain yellow-legged frog survey numbers from a tributary to Cole Creek where rainbow trout were removed beginning in 1998. Levels of effort (number of electroshockers and surveyor days) varied among years; 2002 was a drought year.

	Sample Year				
Life Stage	**1998**	**1999**	**2000**	**2001**	**2002**
Adults	4	8	11	6	3
Juveniles	1	2	7	15	10
Larvae	0	9	62	164	97
Totals	**5**	**19**	**80**	**185**	**110**

Recent surveys have found a large population in Lake Aloha, and frogs have been found adjacent to and below Lake Aloha, Waca Lake, and Pyramid Lake.

From 2003 to 2006, the USDA Forest Service SNAMPH surveyed 11 watersheds containing 145 sites on the Eldorado National Forest. Two watersheds had evidence of breeding by mountain yellow-legged frogs and two additional watersheds had observations of adult or subadults. In these watersheds, evidence of breeding was found at 3 sites (2 percent) and an additional 3 sites (2 percent) had adults or juveniles. Populations were generally small with a maximum number of 30 tadpoles found at a given site and the numbers of adults and juveniles being less than 10. However, it needs emphasis that these surveys were not designed to obtain accurate abundance information.

Also over the interval 2003-2006, CDFG conducted 434 surveys (see detail of survey approach in Status section) of 370 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were detected at 26.5 percent (n = 98) of surveyed sites.

Based on Eldorado NF surveys (or records, or compilations), as of September 7, 2008, MYLF have been recorded in a total of nineteen watershed areas. Between 10 and 25 adult frogs have been observed in 5 populations, more than 25 adult frogs have been observed in 5 populations, more than 50 adult frogs have been observed in one population and more than 75 have been observed in one. These data include the California Department of Fish and Wildlife surveys of the species' entire range between 2001-2008 (see above). Overall, known populations seem to be stable, with increases a result of more extensive surveying (George Elliott and Jann Williams, pers. comm., 2009).

Stanislaus National Forest

Prior to 1980

Historical sightings and specimen collections of mountain yellow-legged frogs exist for over 30 different localities on the Stanislaus National Forest prior to 1980. A distributional map of mountain yellow-legged frogs shows some of the historical sightings and collections of this species on the Stanislaus National Forest (Jennings and Hayes 1994).

The earliest historical record of mountain yellow-legged frogs on the Stanislaus National Forest dates from the 1920s. In 1928, O. J. Millard collected 2 frogs at Big Meadow, Calaveras County (UMMZ 67497).

Three additional sites were collected in the 1930s. In 1930, Tracy Storer collected a series of 8 frogs from Leland Meadow, Tuolumne County (CAS 218373-218380). In 1931, A. C. Taft collected 1 frog near Chipmunk Flat close to Sonora Pass, Alpine County (CAS-SU 2679), and in 1932, A. E. Daugherty collected 13 mountain yellow-legged frogs from Eagle Meadows, Tuolumne County (CAS-SU 3993-4005).

Five localities were collected in the 1940s. In 1942, Margaret Storey collected 2 mountain yellow-legged frogs 6.4 km west of Niagara Creek, Tuolumne County (CAS-SU 8609-8610); in 1943, Alden Miller collected a series of 14 frogs 6.4 km west of Lookout Peak, Alpine County (MVZ 39429-39442); and in 1946, L. Talbot collected 7 frogs total from 3 localities: Dardanelles Cone (MVZ 43080-43081) and Union Reservoir (MVZ 43076-43077) in Alpine County, and Gabbett Meadow in Tuolumne County (MVZ 43078-43079, 43082).

With Richard Zweifel's efforts to systematically revise the yellow-legged frog group (Zweifel 1955), collections increased in the 1950s, during which time 14 different localities were collected on the Stanislaus National Forest. In 1952, Richard Zweifel re-collected Big Meadow, where he took 2 frogs (MVZ 58087-58088), and also collected 7 frogs at Camp Connell (MVZ 58089-58095), both sites in Calaveras County; in the same year, Joseph Gorman, Jr. collected 10 frogs 2.4 km southwest of Sonora Pass, Tuolumne County (MVZ 58304-58310, 59525-59527). In 1953, Zweifel collected a total of 10 frogs over 2 visits in the vicinity of Dorrington, Calaveras County (MVZ 59576-59580, 64177-64181), and commented on the abundance of frogs there (see Population Dynamics under Ecology section). In the same year, Ernest Karlstrom collected a total of 6 frogs from 3 localities: Elephant Lake, Alpine County (MVZ 60191-60192), and 1.1 km northwest and 4.8 km west of Sonora Pass, Tuolumne County (MVZ 60210-60212, 60209). In 1954, Robert Stebbins collected a total of 3 frogs from Camp Wolfeboro (MVZ 61573) and Ebbett's Pass (MVZ 61571-61572). In 1955, Jay Savage and Charles Walker collected 8 frogs and 1 larva 3.2 km west of Sonora Pass, Tuolumne County (UMMZ 112356, 145825). In 1956, James Anderson collected 8 mountain yellow-legged frogs at Lake Alpine, Alpine County (MVZ 65644-65651). In 1958, both Anderson and Richard Banks collected the Mosquito Lakes (MVZ 67494-67495, 70383), and Gene Christman collected the vicinity of Iceberg Meadow (MVZ 67921), both in Alpine County.

Collection continued in the 1960s, when at least 7 different localities were recorded; at least 2 of these sites represented localities that were re-collected as a result of 1950s visits. In 1960, D. Rentz collected 10 frogs near Sonora Pass, Tuolumne County (CAS 86829-86838) and Ed Kessel collected 2 frogs in Pacific Valley, Alpine County (CAS 87814-87815). In 1961, Alan Ziegler collected 1 frog 2.7 km west of Sonora Pass, Tuolumne County (MVZ 72513), the same locality at which Steve Anderson collected 3 frogs in 1968 (CAS 121142-121144). In 1966, Raymond Huey re-collected the Mosquito Lakes site, where he collected 4 frogs (MVZ 80830-80833). In 1968, Alexander Johnson re-collected both Alpine Lake (MVZ 84981) and Mosquito Lakes (MVZ 84982), and Steve Anderson re-collected the locality 2.7 km west of Sonora Pass, where he collected 3 frogs (CAS 121142-121144). In 1969, Sam Sweet collected 8 frogs 1.6 km west of Sonora Pass (CU 8928-8935).

With Susan Case's systematic revision of western North American ranid frogs (Case 1978a, 1978b), collection continued in the 1970s; 6 different localities were collected, of which 3 represented recollections of sites collected either in the 1950s or 1960s. In 1973, Case collected 1 frog 0.8 km west of Sonora Pass, Tuolumne County (MVZ 136169); and in 1974, she re-collected Mosquito Lakes, where 21 frogs were taken (MVZ 136171-136190, 136399). Also in 1974, R. A. Wilson collected 1 frog from each of Little Frog Lake No. 1 and No. 2, Alpine County (MVZ 136218, 136219). In 1976, Richard Sage collected 1 frog from the meadow between the Highland Lakes, Alpine County (MVZ 137435). In 1979, Robert Seib re-collected the 1960s-collected locality, 2.7 km west of Sonora Pass, where he took 10 frogs (MVZ 170912-170921).

Post-1980

Collections of mountain yellow-legged frogs from the Stanislaus National Forest continued into the mid-1980s. In 1982, David Green re-collected the Mosquito Lakes locality, where 1 frog was taken (MVZ 178550), and in 1983, he re-collected the 1950s and 1960s localities, 2.7 km and 4.8 km west of Sonora Pass, where he collected 9 and 5 frogs, respectively (MVZ 227662-227670, 186410-186414). He also collected 12 mountain yellow-legged frogs at a locality not previously collected, 6.4 km west of Sonora Pass, Tuolumne County (MVZ 186415, 186384-186394). In 1985, Robert Macey, Thomas Wake, and Charles Brown re-collected the locality 2.7 km west of Sonora Pass, where they collectively took 14 frogs (MVZ 197553-197557, 227662-227270).

Similar to the Eldorado National Forest, surveys that the USDA Forest Service and CDFG began in the 1990s on the Stanislaus National Forest were full-perimeter visual encounter searches of lakes and ponds.

The earliest systematic survey on the Stanislaus National Forest is that of Martin (1992), who surveyed over 42 km of streams, meadows, and lakes, but found mountain yellow-legged frogs at only 2 of the 16 locations examined, 12 of which represented historical sites. Three adult frogs and 223 larvae were found at 1 historical site, and a lone adult was detected at the other (non-historical) site. Based on this survey and a few others, Jennings and Hayes (1994) indicated that mountain yellow-legged frogs were no longer present at a number of historical locations, which included at least 12 sites on the Stanislaus National Forest (M. Hayes, pers. comm., 2005).

From 1994 to date, the Stanislaus National Forest has conducted amphibian surveys, but the extent and thoroughness of these surveys has been uneven (USDA Forest Service 2009). Mountain yellow-legged frogs were located at more than 70 sites during this time period, but the majority of sightings were of scattered small populations. Only 10 relatively large populations were recorded (>15 adults) with the largest recorded from Coolidge Meadow in 1994 (20 adults, 43 sub-adults, and 475 larvae); Pruitt Lake (18 adults) and Blackbird Lake (15 adults, 20 sub-adults, and 2,500 larvae) in 1995; Wilson Meadow Lake (21 adults, 130 sub-adults, 109 larvae) and Moore Creek (25 adults, 5 larvae, 3 egg masses with about 75 eggs per mass) in 1996; and Stanislaus Meadow (16 adults, 9 subadults, 296 larvae) in 2008. Stanislaus Meadow and Moore Creek have been resurveyed multiple times since 1994 and population sizes have been variable through time.

Analysis of amphibian survey data and collected sightings from the Stanislaus National Forest through 2002 indicate that 82 known sites existed with mountain yellow-legged frogs, of which adults have been recorded from 51. Of sites with adults, 8 sites have more than 10 adults, 2 sites have 25 or more adults, and none of the sites have more than 30 adults (C. Davidson, pers. comm., 2002; USFWS 2003).

From 2003 to 2006, the USDA Forest Service SNAMPH surveyed 16 watersheds containing 327 sites on the Stanislaus National Forest. Five of these watersheds had evidence of mountain yellow-legged frog breeding and two additional watersheds had observations of adult or subadult frogs. In these watersheds, evidence of breeding was found at 16 sites (5 percent) and an additional 30 sites (9 percent) had adults or subadults. One watershed had a large population with more than 1000 tadpoles at one site and more than 100 adults in the watershed. In other areas, numbers were generally low. These surveys were not designed to obtain accurate abundance information.

Also over the interval 2003-2006, CDFG conducted 273 surveys (see detail of survey approach in Status section) of 271 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were detected at 16.2 percent (n = 44) of surveyed sites.

Yosemite National Park

Prior to 1980

Specimen collections and observations of mountain yellow-legged frogs exist for no fewer than 60 different localities within Yosemite National Park prior to 1980. Largely because of special interest in this National Park, historical information for mountain yellow-legged frogs is better documented here than perhaps anywhere else in the Sierra Nevada.

The earliest records are those made during the transect across the Yosemite portion of the Sierra Nevada conducted from 1914 through 1920 by field teams from the Museum of Vertebrate Zoology at Berkeley (Grinnell and Storer 1924). Most of the collections of mountain yellow-legged frogs made in the course of this transect were collected in 1915; 2 additional collections were made in 1922. They recorded mountain yellow-legged frogs at 14 sites within Yosemite National Park, 13 of which are vouchered by specimens. Eight of these specimen-vouchered localities are in Mariposa County: McGurk Meadow (MVZ 5781-5788), Mono Meadow (MVZ 5800), Porcupine Flat (MVZ 5774-5775, 5789, 5803-5804), Sunrise Trail at Cathedral Pass (MVZ 211786), Sunrise Trail at Sunrise Creek (MVZ 5987), Tenaya Lake (MVZ 5790), an unnamed lake north of Mt. Clark (MVZ 8570), and Vogelsang Lake (MVZ 5962-6016). The remaining 5 are in Tuolumne County: Evelyn Lake (MVZ 6017-6027), head of Lyell Canyon (MVZ 5797-5799, 5802, 28062), south side of Ragged Peak (MVZ 5778), Tuolumne Meadows (MVZ 5801), and Young Lakes (MVZ 5776-5777, 5791-5796, 211797-211798). The mountain yellow-legged frog was noted as “the most abundant amphibian” along the Yosemite Section of their survey (Grinnell and Storer 1924). Numerous frogs were found in lakes and streams throughout the high-elevation portion of the Yosemite transect, from Westfall Meadow and Porcupine Flat east to the head of Lyell Canyon and Tioga Pass. “Hundreds of frogs” were found at Young Lakes, and frogs were “very numerous” at Westfall Meadow (Camp field notes 1915, as cited in Drost and Fellers 1996). Eighty-nine mountain yellow-legged frogs were collected from the aforementioned localities, including 54 animals at Vogelsang Lake (Grinnell field notes 1915, partly cited in Drost and Fellers 1994). Following the publication of Grinnell and Storer (1924), investigators from the MVZ made 1 additional collection from Yosemite National Park during the 1920s; 1 frog was collected at Tamarck Flat in 1929 (MVZ 16007). Additionally, Camp (1917) noted that “...in some of the lakes, it was found in great numbers…”, which referred at least in part to his observations at Tenaya Lake (Charles Camp field notes at MVZ).

John Van Denburgh and Joseph Slevin from the California Academy of Sciences made the vast majority of collections from the 1920s. In 1922, they collected 152 mountain yellow-legged frogs from 10 sites, 7 of which had not been previously recorded. The new localities were: Dana Meadows at the Tioga Road crossing (CAS 55636-55642, 55768-5584) 9.6 km east of the west entrance of Yosemite National Park (CAS 55374-55378), 1.6 km north of Lyell Glacier (MVZ 55455-55479, 55766-55767), at the head of Rafferty Creek (CAS 55480-55483), and a small unnamed lake between Tuolumne Pass and Evelyn Lake (CAS 55484-55517), all in Tuolumne County. Additionally, 2 of the new localities were from Mariposa County: 2.4 km and 3.2 km below Wawona (CAS 55740, 55741-55742). Van Denburgh and Slevin also re-collected Tenaya Lake (CAS 55664-55666), Tuolumne Meadows (CAS 55620), and Vogelsang Lake (CAS 55384-55435). The 52 frogs taken at Vogelsang Lake combined with the 54 collected by MVZ investigators in 1915 (see previous paragraph) make it the second most heavily collected locality across the mountain yellow-legged frog range (behind Fallen Leaf Lake; see LTBMU). Three additional mountain yellow-legged frog localities in Yosemite National Park were collected during the 1920s: Herbert Mason collected 13 frogs at Tioga Pass in 1923 (CAS 65927-65939); Stanford University investigators collected 1 frog at each of 2 localities in Mariposa County in 1928: Mariposa Big Trees (CAS-SU 2934) and Tamarack Creek (CAS-SU 2925); and Rudolph Stohler collected 1 frog at Tamarack Flat in 1929 (MVZ 16007). At the close of the 1920s, mountain yellow-legged frogs had been documented at 26 different localities within Yosemite National Park.

Collection of mountain yellow-legged frog in Yosemite National Park continued through the 1930s, but at lower levels. During the 1930s, frogs were collected from 8 different localities, 6 of which had not been previously recorded: 2.4 km east of Chinquapin Junction (CAS 218598), near Mono Meadow (CAS 218596), Peregoy Meadow (CAS-SU 3559-3561, UMMZ 84838), and from a stream flowing west from the ridge from Tenaya Lake (CAS-SU 3716-3724), all in Mariposa County; and Dana Meadow (CU 2821) and Elizabeth Lake (MVZ 31959-31976), both in Tuolumne County. Tenaya Lake (MVZ 31977-31982) and Tioga Pass (CU 2898, MVZ 31955-31958) were re-collected (Martin 1940). Additionally, Albert Wright describes C. Van Deman finding egg masses of this species at Peregoy Meadows in 1930 and himself finding mountain yellow-legged frogs at Aspen Valley, White Wolf, and the Middle Fork crossing of the Tuolumne River in 1934 (Wright and Wright 1949). During 1939, the Park Service initiated their own series of collections and observations (NPS 1999); most sites for which the Park Service obtained information overlapped with previous collection locations, but a few sites were new. The real value of this new information was that a few assessments of relative abundance were provided. In particular, frogs were described as "especially numerous" at Upper McCabe Meadows and "thousands" were counted near Middle McCabe Lake. The species was also described as "abundant" in lakes and streams in Virginia Canyon from 3,290-3,415 m, and "very numerous" in Upper Virginia Canyon's lakes, ponds, and streams. Larvae were also said to be "swarming" along the edge of a lake just north of Isberg Peak (NPS 1999). By the close of the 1930s, mountain yellow-legged frogs had been documented from nearly 40 different localities within Yosemite National Park.

World War II resulted in a decrease in collections during the 1940s; only 5 sites were recorded; 1 was new: Wallace Wood collected 3 frogs at the foot of Donohue Pass in 1946 (CAS 81553-81555). The remaining 4 sites involved revisits of previously recorded sites; in 1940, C. D. Hemphill collected 1 frog at the unnamed lake north of Mt. Clark (CU 3971); and in 1946, a total of 4 frogs were collected from 3 sites: at the head of Lyell Canyon (MVZ 46811), 1.6 km north of Mt. Lyell (MVZ 42843-42844), and Mono Meadow (MVZ 42845).

Collection increased during the 1950s. Mountain yellow-legged frogs were collected at 8 localities, 5 of which were new: 3.2 km northeast and 4.8 km east-northeast of Chinquapin (MVZ 62914, 62888-62890, 62893, 63956-63967), 4.0 km east of Crone Flat (MVZ 62873-62874), Erratic Dome (MVZ 62876), and Potholes Meadows (MVZ 60904). Recollections were made at Porcupine Flat (LACM 13599-13615, MVZ 62910), Tioga Pass (MVZ 62875), and Tuolumne Meadows (LACM 26718). The mountain yellow-legged frog was documented at 6 additional locations by Park Service personnel within Yosemite National Park from 1957 to 1960 (Heller 1960, NPS 1999). Investigators that spent time in Yosemite National Park during the 1950s provided important observations on mountain yellow-legged frog abundance. Mullally and Cunningham (1956) remarked that some of the "densest aggregations of frogs ever noted" were within lakes close to Ostrander Lake just south of Glacier Point; but they also pointed out that in 1950, no frogs could be found in Ostrander Lake *per se* (possibly due to trout being planted). In 1955, Mullally and Cunningham also observed frogs at Johnson Lake, Gaylor Lakes, Tuolumne Meadows, and "abundant" numbers at Elizabeth Lake, Porcupine Flat, and Tioga Pass. David Wake, senior research herpetologist at the University of California at Berkeley Museum of Vertebrate Zoology, reported that while hiking near Tioga Pass during the summer of 1959, he saw so many mountain yellow-legged frogs that "it was difficult to walk without stepping on them" (Parker 1994). By the close of the 1950s, nearly 50 different locations had been documented to have mountain yellow-legged frogs.

Relatively few collections were made during the 1960s; collectors from the MVZ obtained frogs from 4 sites. Mountain yellow-legged frogs had not been previously recorded at any of these sites: 4.8 km southwest of Glacier Peak (MVZ 83675-83676), the May Lake Road, 1.6 km northeast of Highway 120 (MVZ 146342-146346), Siesta Lake (MVZ 146339-136341), and White Wolf (MVZ 187311). Lawrence Cory (research biologist, St. Mary's College), who collected mountain yellow-legged frogs extensively in the Sierra through the 1960s in the course of examining DDT and DDT by-product burdens, had qualitative relative abundance information from having sampled sites within Yosemite National Park (Cory et al. 1970). In particular, Cory noted dense populations of the species, in some cases from "several dozen to hundreds of adults and with swarms of tadpoles" (Cory 1989). In Yosemite National Park, Cory saw a population at Mono Pass with "certainly hundreds of adults and swarms of hundreds of tadpoles"; a "very abundant" population in a small lake north of Mt. Hoffman; a "moderate population (estimated at dozens)" east of Ostrander Lake; and a population west of the May Lake basin.

The systematic revision of western North American ranid frogs (Case 1978a, 1978b) was the basis of all collections made during the 1970s. From 1972 to 1975, Case collected 8 sites, all in Tuolumne County, and 4 of which were new: Cathedral Creek (MVZ 136156-136157), Dog Lake (MVZ 136202-136210, 136227), Lukens Lake (MVZ 136338-136229), and the creek at the fork in the trail to Lukens Lake and the 10 Lakes Area (MVZ 136230). The remaining 4 sites were recollections of the Dana Fork of the Tuolumne River (MVZ 136151-136152), Elizabeth Lake (MVZ 136192-136300), Siesta Lake (MVZ 136153-136155), and Tuolumne Meadows

(MVZ 136150). Susan Case (pers. comm., 2002) found that mountain yellow-legged frogs were still common in Yosemite National Park in the course of making these collections. However, in 1979, when David Wake (pers. comm., 2002) revisited the same spot at Tioga Pass 20 years after he had reported large numbers of mountain yellow-legged frogs, he found frogs still present, but they were fewer and harder to find (Phillips 1994). Thus, the first indication of decline may have occurred by the end of the 1970s.

Post-1980

Indications of mountain yellow-legged frog declines began to emerge in the 1980's. In the late 1980s, David Wake returned to the Tioga Pass locality and found no mountain yellow-legged frogs. He emphasized that "not even determined hunting could turn any up, and this in a National Park, a protected area" (Phillips 1994).

In 1988, Lawrence Cory revisited sites in Yosemite National Park where he had observed dense frog populations in the 1960s (Cory 1989). Cory found that most of these formerly thriving populations had been extirpated. He could find neither larvae nor frogs at the site of a former population of "certainly hundreds of adults and swarms of hundreds of tadpoles" in a pond at Mono Pass. Similarly, no frogs or larvae were found during a "very careful search" of a small lake north of Mt. Hoffman and west of the May Lake basin that formerly contained a "very abundant" population. A pond 0.8 km east of Ostrander Lake, formerly containing a "moderate population (estimated at dozens)," also lacked frogs (Cory 1989).

A distribution map of mountain yellow-legged frogs produced by Jennings and Hayes (1994) based on data through 1992 indicated that the species was thought to be extinct in a number of locations in Yosemite National Park, based on the collective resurveys of locations where it was historically extant. Disappearances of local mountain yellow-legged frog populations in the past 20 to 30 years at Medlicott Dome, Young Lakes (G. Fellers, unpublished data, as cited in Drost and Fellers 1996), and Westfall Meadows (Yoon 1977) also have been documented.

In 1992 and 1993, Drost and Fellers (1996) revisited 38 of the original 40 sites that Grinnell and Storer surveyed from 1914 through 1920 and intensively searched for the frog species known from the area. Drost and Fellers found that mountain yellow-legged frogs had disappeared from most of the transect sites; they were able to find mountain yellow-legged frogs at only 2 (14 percent) of the 14 sites in Yosemite National Park where they were originally documented. Moreover, at the two sites, they found only 1 tadpole (Mono Meadow) and 1 adult (Evelyn Lake). They did encounter small but apparently viable populations at Summit Meadow and Mount Hoffman, off the original Grinnell and Storer Yosemite transect. In reporting the large declines across Yosemite National Park, Drost and Fellers concluded that the species had suffered serious losses in the heart of its geographic range.

In 1992 and 1993, researchers from Humboldt State University (M. Colwell, pers. comm., 2005) surveyed 35 lakes within the Tuolumne and Merced River drainages of Yosemite National Park. Only 3 (9 percent of lakes) had mountain yellow-legged frogs.

Between 1995 and 2001, Sadinski (2004) conducted surveys for anurans along Highway 120 between near Lembert Dome and east of Tioga Pass. This area encompasses a large segment of Moraine Flat north of Highway 120, the Gaylor and Granite Lakes areas, all of Dana Meadows, Parker Pass Creek upstream to the vicinity of Spillway Lake, all of Tioga Meadows, the Tioga Lake basin, and the southern end of Saddlebag Lake. During these surveys, which examined over 60 sites (most repeatedly surveyed), no mountain yellow-legged frogs were found.

In 1997, 260 sites with suitable habitat were surveyed for aquatic amphibians within Yosemite National Park (Fellers 1997); mountain yellow-legged frogs were found at 43 locations. Most of these locations had small populations (i.e., < 20 adults). Only 4 relatively large (≥ 20 adults) populations were found: Big Island Lake (29 adults, 315 larvae); southeast of lower Twin Lake (20 adults); north of Haystack Peak (34 adults, 65 larvae); and west of Richardson Peak (24 adults, 449 larvae). Fellers revisited the Drost and Fellers (1996) surveyed sites. The Summit Meadow population had 38 adults and 12 larvae (in September), but, of 18 sites surveyed around Mt. Hoffman, only 10 larvae were found in 1 pond. The documented disappearance (Drost and Fellers 1996) of mountain yellow-legged frogs from Westfall Meadows was reconfirmed. At Mono Meadows, where Drost and Fellers found 1 larva in 1992-1993, 7 larvae were found (Fellers 1997).

Survey data and the report of Fellers (1999) indicated that 203 of 1,659 surveyed sites had mountain yellow-legged frogs in Yosemite National Park. Only 5 of the occupied sites had 25 or more adults (C. Davidson, pers. comm.).

Since 2000, mountain yellow-legged frogs collections have been made at 3 sites: an unnamed lake 1 km east of Evelyn Lake (MVZ 245551), the creek below Monroe Meadow (MVZ 240826-240-828), and Summit Meadow (MVZ 240829-240833). In their re-analysis of red-legged frogs, Shaffer et al. (2004) obtained tissue from mountain yellow-legged frog life stages from 3 localities within Yosemite National Park: an unnamed pond 0.8 km (by air) west of Roosevelt Lake, Tuolumne Co. (HBS 30608-30610); Mono Meadow, Mariposa County (HBS 12823); and an unnamed lake and stream draining from it, 2.3 km (by air) southwest of Merced Peak, Madera County (HBS 30606-30607). These collections are presumably recent, but dates of collection were not provided.

In a comprehensive survey of all mapped and unmapped stillwater habitats in Yosemite National Park (n = 2655) in 2000-2001, Knapp (2005) recorded mountain yellow-legged frogs at 10.6% (n = 282) surveyed sites.

As of 2003, 285 populations of Sierra Nevada yellow-legged frogs were thought to occur in Yosemite National Park, of which 3 have populations over 100 adults (snout-vent length >= 40 mm) and another 10 have populations between 10 and 100 adults (R. Knapp, pers. comm., 2009). Fewer than 10 adults have been recorded at the remaining 272 sites. Of the 285 occupied sites, evidence of breeding has been recorded at 135 sites (R. Knapp, pers. comm., 2009). Based on resurveys of these 285 sites conducted 4-7 years after the original survey (resurveys conducted in 2005, 2006, and 2007), Sierra Nevada yellow-legged frogs (of any life stage) were detected at only 62% of the sites where they were detected during the original survey (R. Knapp, unpublished data). If the absence of *R. sierrae* during the resurvey is indicative of population extinction (and not simply a failure to detect animals that were in fact present), this would suggest a population extinction rate of approximately 5-10% per year.

Inyo National Forest

Prior to 1980

Historical data on mountain yellow-legged frogs for the Inyo National Forest extend back to 1891, when 2 mountain yellow-legged frogs were collected at Mulkey Meadows, Tulare County (USNM 18929-18930) during the United States Biological Survey (USBS) Death Valley-Mt. Whitney Expedition. From 1891 through 1979, mountain yellow-legged frogs have been collected or observed at over 30 locations in and adjacent to the Inyo National Forest (Parker 1994, CDFG 1998), including McGee Creek, Mono County (SDNHM 47223), a locality for which the record date is lacking.

In 1904, the USBS collected 5 mountain yellow-legged frogs at Tunnel Meadow on the South Fork of the Kern River (USNM 34658-34662).

During the 1910s, mountain yellow-legged frogs were collected at 6 more sites on or close to the Inyo National Forest. In 1911, 4 localities were in Tulare County: N. Stern and Walter P. Taylor collected 14 frogs from Monache Meadow (MVZ 3020-3033); Tracy Storer collected 1 frog in each of Ramshaw Meadows (MVZ 3035) and 1.6 km west of Templeton Mountain near Ramshaw Meadows (MVZ 3034); and 18 mountain yellow-legged frogs from upper Golden Trout Creek in Big Whitney Meadow (MVZ 3036-3053). In 1912, mountain yellow-legged frogs were also recorded from Matlock Lake, Inyo County (Storer field notes at MVZ). In 1915, J. C. Bradley collected 3 frogs from a pond in upper Crabtree Meadow (CU 7081). In 1916, Joseph Dixon collected 10 mountain yellow-legged frogs at Farrington's on Mono Lake, Mono County (MVZ 6062-6071). In 1917, G. Allen collected 2 frogs in the vicinity of Lone Pine (MCZ A3774-A3775).

Two records exist for the 1920s. In 1922, Joseph Grinnell collected 1 frog at Mammoth Lakes (MVZ 8643) and another at Pine City near Mammoth (MVZ 8644), each in Mono County.

Seven localities were documented in the 1930s. In 1932, Seth Benson collected 3 mountain yellow-legged frogs at Tioga Lake (MVZ 14919-14921) and 2 more frogs at Camp Tioga (MVZ 14922-14923), both in Mono County. In 1933, Klyver collected 1 frog from Little Lakes Valley (CAS 71307); and 1 sight record exists for Hot Creek. In 1934, Carl Hubbs collected 6 frogs along Cottonwood Creek, a tributary to Owens Lake, Inyo

County (UMMZ 77938), and Paul Needham collected 1 frog at Darwin Lake (CU 4367). In 1937, H. J. Rayner collected 3 frogs in Convict Creek, Mono County (CAS 2688-2689, 2709). Two sites in Inyo County were documented in 1939; John Mohr collected 1 frog in Long Lake (MVZ 32389); A. J. Calhoun collected 2 frogs in the Hot Creek trout rearing ponds (CAS-SU 4355-4356); and a sight record exists for Tioga Pass.

Nine records are available from the 1940s. In 1945, Larry Talbot collected 2 frogs in a lake near Pine Creek Pass (MVZ 41298-41299) and 3 additional frogs in a lake above Pine Lake in the headwaters of Pine Creek (MVZ 41300-41303), both in Inyo County. In 1946, Wallace Wood collected 1 frog at Mono Lake, Mono County (CAS 81558); 2 Madera County locations were also collected in 1946: Crater Creek Meadow and Donohue Pass. In 1948, J.C. Couffer collected 1 frog in each of a stream near Saddlebag Lake (LACM 1741) and Rock Creek (LACM 1742); and John Davis collected 3 frogs in Reds Meadow (MVZ 45992, 46622-46623). In 1949, Ray Porter collected 3 mountain yellow-legged frogs 1.9 km east of Tioga Pass (UMMZ 100992).

At least 10 mountain yellow-legged frog localities are documented from the 1950s. In 1950, William Duellman and Ray Porter collected 2 frogs 3.2 km east of Tioga Pass (UMMZ 102409). In 1951, 3 localities in Madera County were documented: Ediza Lake (LACM 1968-1973), Shadow Lake (1963-1964), and Vivian Lake (1965-1967). In 1953, 4 new sites were collected: Emerald (LACM 13569-13573), Emily (LACM 13574), and Thousand Island (LACM 13575) Lakes, Madera County; and Kenneth Lake (LACM 13565-13567), Inyo County. Also in 1953, Vivian Lake was re-collected (LACM 13568, 74420) and frogs were found during a revisit of Tioga Lake (CDFG 1953). In 1954, Ernest Karlstrom collected 11 frogs 200 yards northeast of Tioga Pass Ranger Station (MVZ 62877-62887) and F. Durham collected 1 frog in Rosalie Lake (LACM 1962). In 1955, Karlstrom re-collected the Reds Meadow locality, where he took 7 frogs (MVZ 62403-62405, 63952-63955). Douglas Powell reported frogs in 1955 in Cottonwood Basin in the White Mountains, southeast of White Mountain Peak (Giuliani 1996). In 1958, 1 frog was collected from the southwestern part of Lake Crowley (SDNHM 43873), and M. Lieberman collected 10 frogs from the Moon Lake area at Pine Creek Pass (MVZ 67578-67587). In work done between 1950 and 1955, Mullally and Cunningham (1956) found "a great many" on the Inyo County side of Pine Creek Pass. Mountain yellow-legged frogs were also described as being "common" on the Kern River within the Inyo National Forest through the 1950s (R. Knapp, pers. comm., as cited in Parker 1994).

In 1961, Norman Scott revisited the Big Whitney Meadow locality and collected 2 frogs (LACM 26704-26705), and Raymond Hock collected 1 frog 12.8 km west of Bishop (MVZ 73780). In 1963, J. E. Brooks collected 12 frogs from Reds Meadow (LACM 26706-26717) and 3 additional frogs in a creek 0.4 km east of Minarets Lookout (LACM 67391-67393). In 1966, J. Gerst collected 18 frogs along the Bennettville Trail, Mono County (CSUC 1645-1662). Lake survey locations (and year) documented in CDFG files are: in Inyo County—Little Lakes Valley (1967); in Mono County—northeast of Tioga Pass (1964), Clark Lakes (1966), and Greenstone Lake (1968); and in Madera County—Pumice Flat (1966) and Nydiver Lakes (1968). Scattered sightings of 1 to 2 adults were reported from 6 locations in the Inyo National Forest from 1966 through 1968. Many local populations of yellow-legged frogs were documented from the Hall Research Natural Area, including Maul Lake, in the 1960s and 1970s (R. Knapp, pers. comm., as cited in Drost and Fellers 1996)

Reports from local ranchers (T. Noland, pers. comm., cited in Parker 1994) and herpetologist Bob Hansen (Hansen 1980) indicate that mountain yellow-legged frogs were abundant in the Inyo National Forest during the 1970s. An early 1970s survey on the east slope of the White Mountains in the state of Nevada revealed mountain yellow-legged frogs in Fish Lake (Giuliani 1994). In 1972, V. Bleich collected 3 frogs from (west) Twin Lake, Madera County (LACM 91271-91273); in 1975, Susan Case collected 5 frogs in Pine Creek west of Bishop, Inyo County (MVZ 136222-136226); in 1976, 3 frogs were taken from Lee Vining Creek, 1.6 km below Saddlebag Lake, Mono County (LSU 85500-85502); and 1 frog was taken from Tioga Pass (LSU 85499).

Post-1980

Most 1980s data consist of sighting information. In 1982, Robert Hansen (pers. comm., 2005) and Ron Tremper recorded 1 of the 2 largest recently documented populations of mountain yellow-legged frogs in the Sierra Nevada at the Crooked Meadows (Dexter Creek), a tributary to Mono Lake, Mono County. During that visit, ca. 900 frogs were found in a 3-hour search and Hansen found frogs so abundant that in many places it was difficult to avoid stepping on them. Hansen (pers. comm.) returned to this site with Dan Holland in 1983, at which time frogs were still abundant and 2 transformed frogs and 2 larvae were collected. Mountain yellow-legged frogs were apparently still abundant at this site in 1988, as Giuliani reported seeing "many" adult frogs (Parker 1994).

In 1982, Hansen (pers. comm., 2005) and Tremper recorded a second large population of mountain yellow-legged frogs on Dry Creek at Big Sand Flat, Mono County. During that visit, hundreds of frogs were observed. Hansen returned to this site with Dan Holland in 1983 and found frogs still abundant. The only other record available for the 1980s dates from 1985, when Robert Macey collected 1 frog in the South Fork of Bishop Creek, 20.9 km (by air) southwest of Bishop (MVZ 227661).

Recent re-surveys of historical sites, begun in the 1990s, have documented the disappearance of mountain yellow-legged frogs from many sites in the Inyo National Forest. In 1992, Knapp reported a large population of frogs at Upper Wonder Lakes (Parker 1994), which was also recorded during 1993 lake surveys (CDFG 1998). Re-surveys in 1995 and 1996 indicated that the population had apparently either become extinct or been severely reduced (R. Knapp, pers. comm.).

Mountain yellow-legged frogs disappeared from Maul Lake in the Hall Research Natural Area (R. Knapp, pers. comm., as cited in Drost and Fellers 1996). A small population was noted in 1992 (CDFG 1998), and Knapp began a frog reintroduction project in the lake in 1993. In 1994, the project was abandoned when fingerling trout were air dropped into the lake (Parker 1994). By 1997, the Maul Lake population had been extirpated, as was another frog population in a small nearby pond in the Lee Vining Creek drainage (R. Knapp, pers. comm.).

In 1993, the Crooked Meadows (Dexter Creek) site was revisited by Knapp (1993), who counted only 25 adults and eggs, and tadpoles of 2 year-classes. This represented an apparent substantial decrease in frog abundance from the Hansen-Giuliani observations during the 1980s.

In 1993, the Dry Creek site was also revisited by Knapp (1993), who reported a very large population (over 1,000 adults counted, excluding tadpoles) that encompassed the area above and below Highway 120. In 1995, CDFG estimated the Dry Creek population at 2,300 adults, 1,000 sub-adults, and 2,500 larvae (CDFG 1998). In 1996, the Dry Creek population contained upwards of 1,000 adults and many hundreds of larvae and egg masses (R. Knapp, pers. comm.). The population has since crashed, apparently due to a chytrid fungus infection; many tadpoles had deformed mouthparts (R. Knapp, pers. comm.). In 1997, Fellers (1997) found only 10 adults at the Dry Creek location; in 1998, Vance Vredenburg and Roland Knapp observed ca. 20 adults, 10 tadpoles, and 5 egg masses (R. Knapp, pers. comm.). In summer 1999, Ron Panik (Western Nevada Community College, pers. comm., 2002) found only 2 adult frogs on both sides of the Dry Creek system; he believes this population near extirpation. Shaffer et al. (2004) collected tissue from 1 mountain yellow-legged frog from Dry Creek (HBS 12823), but they did not specify a date of collection.

In 1994, Monache Meadows was revisited (Christopher 1994); no frogs were found. A 1994 survey of Fish Lake found the lake was dry and without frogs (Giuliani 1994). Giuliani (1996) also was unable to detect frogs at 2 other historical sites: Cottonwood Basin southeast of White Peak and Middle Creek below Boundary Peak.

Based on his surveys or the previous surveys of others, Knapp re-surveyed several localities in 1997 that were known to be occupied in the early 1990s. Sites near Edith Lake in the Convict Creek drainage, upper Chalfant Lake in the Pine Creek drainage, and Slim Lake in the Independence Creek drainage no longer contained mountain yellow-legged frogs (R. Knapp, pers. comm.). Further, a population of 20 adults seen in Mildred Lake/Convict Canyon in 1994 (Parker 1994) was also extinct as of 1999 (R. Knapp, pers. comm., 2002).

Surveys from 1990 through 1996 revealed few additional mountain yellow-legged frog sites in the Inyo National Forest and most sightings consisted of small populations. On the east side of the Sierra, Giuliani (1995) surveyed about 600 ha of the Hot Creek area in 1990 and found no frogs. Giuliani also surveyed 20 watersheds of the eastern White Mountains, including at 3 historical locations, from 1994 through 1996, and found no mountain yellow-legged frogs (Giuliani 1996). Review of Inyo National Forest amphibian surveys for grazing allotments and timber sales in 1994 indicates that, of over 150 locations surveyed incidentally, mountain yellow-legged frogs were reported at 9 sites, and no large populations were found (USDA Forest Service 1999b).

In 1993, the Inyo National Forest began a comprehensive amphibian survey on the Kern Plateau, covering 13 drainages (some only partially), but found only 1 small population of mountain yellow-legged frogs (Parker 1994). Surveys in 1994 of the 12 drainages in the southern Kern Plateau located only 2 small populations (Christopher 1994). Inyo National Forest personnel visited more than 115 locations during the 1994 surveys; frogs were found at only 3.5 percent (n = 4) of sites (CDFG 1998).

From 1995 through 1996, Knapp and Mathews extensively surveyed 669 lakes, ponds, and other water bodies in the John Muir Wilderness in the Sierra and Inyo National Forests. Mountain yellow-legged frog adults were found in only 4 percent of these water bodies, and frog larvae in 3 percent. More than 20 frogs were found at only 1 percent of the sites (Knapp and Matthews, 2000a, 2000b).

Besides the formerly large populations at Crooked Meadows and Dry Creek, mountain yellow-legged frogs have been found to exist in large numbers at several sites in 2 other areas: the Baker Creek and Cow Creek drainages. In 1994, 54 adult frogs were found at Baker Creek (Parker 1994). Frogs were again located in the area in 1995 in an unnamed pond near Baker Lake (1 adult, 50 sub-adults, and 100 tadpoles) and in three reaches of Baker Creek (27 adults; 90 adults; and 54 adults, 5 sub-adults, and 20 larvae). In 1996, frogs were present throughout Baker Canyon: large populations were found in ponds and marshes above Gable Lake No. 2, in a pond south of Sixth Lake on the North Fork of Big Pine Creek, and in marshes around Seventh Lake in the same drainage. Frogs were found at 2 locations on Cow Creek in 1995: 158 adults, 5 sub-adults, and 10 tadpoles in Cow Creek, and 75 adults, 5 sub-adults, and 140 larvae at Sanger Meadow on Cow Creek (USDA Forest Service 1999b).

Four mountain yellow-legged frog populations were present within the North Fork of the Big Pine Creek drainage in 1998 (Milliron 2000). Two populations (Eighth Lake and Sam Mack Meadow) appeared in good condition, with 700-1,000 individuals (adults and larvae combined) observed in each. The 2 other populations (a pond near Seventh Lake and a meadow south of Summit Lake) appeared to have populations of less than 70 individuals (likewise adults and larvae combined). The Seventh Lake population inhabited several shallow ponds (<1 m deep) located just 2 m away from the lake, which was teeming with brook charr. This population was extirpated in 1999, when brook charr invaded the ponds.

As of 2002, 7 basins within the Inyo National Forest were known to have mountain yellow-legged frog populations or presumptive metapopulation units (USFWS 2003). Some were stable and represented by several hundred individuals of all age classes (L. Sims, *in litt*., 2002 in USFWS 2003). However, chytrid fungus was documented at an additional population that is now extinct (C. Milliron, *in litt*., 2002 in USFWS 2003).

From 2003 to 2006, the USDA Forest Service SNAMPH surveyed 21 watersheds containing 368 sites on the Inyo National Forest. Two watersheds had evidence of breeding by mountain yellow-legged frogs. In these watersheds, evidence of breeding was found at 9 sites (2 percent) and an additional 9 sites (2 percent) had only adults or subadults. Numbers were generally low, but these surveys were not designed to obtain accurate abundance information.

Also over the interval 2003-2006, CDFG conducted 797 surveys (see detail of survey approach in Status section) of 566 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were detected at 20.3 percent (n = 115) of surveyed sites.

Sierra National Forest

Prior to 1980

Historical collections and sightings of mountain yellow-legged frogs exist for over 20 sites on the Sierra National Forest. The earliest record from the Sierra National Forest is a series of 20 frogs J. Gaut collected on 22 August 1901 at Summit Lake near Mono Pass (USNM 45479-45498).

Two additional records are from the 1910s. In 1915, Tracy Storer collected 1 mountain yellow-legged frog along Sweetwater Creek, 3.2 km east of Feliciana Mountain (MVZ 5961) and Joseph Dixon collected 4 frogs at Bullfrog Lake (MVZ 6212-6214, 211796).

Two Sierra National Forest collections were made during the 1920s. In 1922, Sarah Atsatt collected 5 mountain yellow-legged frogs from Huntington Lake (MVZ 8652-8656) and in 1926 Jean Linsdale collected 1 frog from Shaver Lake (MVZ 10138).

In 1942, G. Auguston collected 1 mountain yellow-legged frog on Fish Creek near Duck Lake (LACM 1714). In 1945, Otto Sokol re-collected Huntington Lake, where he took 1 frog (CAS-SU 8573). In 1946, 7 frogs were collected from Manse Meadow (LACM 1715-1721). In 1949, J. Lamont and Jay Savage collected 1 mountain yellow-legged frog from meadows 8 km south of Kaiser Pass (CAS-SU 11057) and Giles Mead collected 2 frogs from the top of Kaiser Pass (CAS-SU 11058-11059).

In 1953, Ernest Karlstrom collected 3 frogs along Highway 168, 2.1 km north of Big Creek (MVZ 60193-60195) and 12 frogs 1 km northwest of Kaiser Pass (MVZ 60197-60208); and John Cunningham collected 2 frogs from String Meadows (LACM 13576-13577). In 1954, Cunningham also collected 18 frogs from the lake on the Fresno County side of Pine Creek Pass (LACM 13581-13598) and Karlstrom collected 1 frog from Kaiser Peak Meadow, 4.0 km northwest of Kaiser Pass (MVZ 62870), and 2 frogs from 0.3 km northwest of Kaiser Peak summit (MVZ 62871-62872). In 1955, Karlstrom re-collected the Huntington Lake and Kaiser Peak Meadow localities, where he took 1 and 3 frogs, respectively (MVZ 62891-62892, 62894, 62915). In 1955, Mullally and Cunningham (1956) reported finding mountain yellow-legged frogs along Piute Creek "very sparingly" at 2,350 m elevation, with frogs becoming more abundant at higher elevation. The "densest populations" were found above 3,050 m in the Humphrey's Basin area and a "great many, including tadpoles" were noted at and near Pine Creek Pass, with frogs also seen at Golden Trout and Desolation Lakes (Mullally and Cunningham 1956). In 1958, M. Lieberman collected 10 mountain yellow-legged frogs at Moon Lake above French Canyon, Fresno County (MVZ 67568-67577).

In 1964, Frederick Schuierer re-collected Kaiser Pass Meadow, where 9 mountain yellow-legged frogs were taken (CAS 97643-97649, MCZ A48725-A48726). In 1966, Oliver Johnson collected 3 frogs 3.2 km northeast of Shaver Lake (UMMZ 223083-223085) and in 1967, he collected 2 frogs on Henderson Creek, 0.8 km east-northeast of Shaver Lake (UMMZ 223086-223087). In the 1960s, Lawrence Cory (1989) reported seeing a "thriving" population of mountain yellow-legged frogs in a pond 0.8 km (0.5 mi) south of Corbett Lake, Kaiser Wilderness Area, Fresno County.

One mountain yellow-legged frog collection was made during the 1970s. In 1974, the Kaiser Pass locality was re-collected, where Susan Case took 2 frogs (MVZ 136216-136217).

Post-1980

No mountain yellow-legged frog data are available for the early 1980s on the Sierra National Forest. In 1988, Cory (1989) revisited a pond south of Corbett Lake, but found no frogs. Re-surveys by Jennings and Hayes (1994) indicated that the mountain yellow-legged frog was extirpated at a number of historical locations in the Sierra National Forest by 1992.

A 1992 survey of over 26 km of potential habitat at 15 sites turned up only 2 adult mountain yellow-legged frogs at 2 locations (Martin 1992). A handful of small frog populations were found in 1994, but the level of survey effort was not specified (USDA Forest Service 1999c). During 1995 amphibian surveys of over 260 sites (Buck 1995), no mountain yellow-legged frogs were found in the Mariposa, Minarets, or Pineridge Ranger Districts, and only 1 small population was found in the Kings River District (USDA Forest Service 1999c). Vinsen (Montana State University masters thesis) surveyed 56 additional lakes during 1995 and found small populations at 2 sites and large populations at 3 others (USDA Forest Service 1999d). Incidental surveys of a grazing allotment in 1995 revealed small populations of mountain yellow-legged frogs in 2 of 40 meadows surveyed (USDA Forest Service 1999d, Center for Biological Diversity and Pacific Rivers Council 2000).

As noted earlier, Knapp and Matthews extensively surveyed 669 lakes, ponds, and other water bodies in the John Muir Wilderness in the Sierra and Inyo National Forests in 1995-1996. Mountain yellow-legged frog adults were found in 4 percent of these water bodies, and frog larvae in 3 percent (Knapp and Matthews 2000a).

Through 1996, only 3 large mountain yellow-legged frog populations had been found in the Sierra National Forest: in 1995, mountain yellow-legged frogs were found in Upper Mills Creek Lakes (181 adults/juveniles and 300 tadpoles), Snow Lakes (1,047 adult/juveniles, 1,020 tadpoles, and 200 eggs), and Golden Lake (18 adult/juveniles, 25 tadpoles, and 1,100 eggs). Adult and juvenile frogs were not distinguished in these population counts (USDA Forest Service 1999c). Except for these 3 populations, the mountain yellow-legged frog appears to be scattered in isolated small populations in the Sierra National Forest. In 1997, Knapp re-surveyed a large pond in Humphrey's Basin in the Piute Creek drainage that was known to be occupied in the early 1990s and found that the site no longer contained mountain yellow-legged frogs (R. Knapp, pers. comm., 2002).

Based on data collected July 2002-August 2004, mountain yellow-legged frogs were recorded at 32 different localities in the Sierra National Forest (H. Eddinger, pers. comm., 2006). However, only 23 adults were found at the population where the largest number of adults was recorded, only 3 of the 32 sites had 10 or more adults, and only non-adult life stages were observed at 15 of the 32 sites. These site records occur in eleven HUC 6 subwatersheds, primarily concentrated in the East Mono Creek subwatershed near Mono Pass, Snow Lakes, and Upper Mill Creek. Two individually isolated populations exist on the west side of the forest. These are Snow Corral Meadow within general forest in the Lower Dinkey Creek subwatershed of the North Fork Kings River and Hoggem Lake, located on private land within Sierra NF in the White Chief subwatershed of the South Fork Merced River.

The Upper Mill Creek Lake population, where the greatest number of adults and juveniles were found (n = 126), had 30 percent fewer adult and juveniles than in the 1995 survey. The Snow Lakes, from which >1,000 adults and juveniles were recorded in 1995, appears to have declined even more precipitously; only 9 adults and juveniles were observed in 2003. In 2003, 44 percent fewer adults and juveniles (n = 10) were recorded in Golden Lake. At least two-thirds of the sites at which mountain yellow-legged frogs are thought to still exist on the Sierra National Forest can be considered precarious from a demographic perspective alone. The Snow Corral Meadow population is within a Critical Aquatic Refuge (USDA Forest Service 2001). The population has been observed annually since 1999 and appears to be declining. A meadow restoration project is proposed for 2009.

During 2007, two sites occupied by mountain yellow-legged frogs were located within the North Fork Willow Creek drainage at Soquel Meadow and a small pond near Texas Flat. Approximately two dozen adult and juvenile frogs were observed at Soquel Meadow, along with 10 tadpoles. Fourteen juvenile frogs were observed at the pond near Texas Flat (tadpoles were observed in the pond during 2008), with an additional 6 juveniles along a nearby tributary stream. During 2008, several adult frogs and 6 tadpoles were located at Long Meadow in the Chiquito Creek basin. Two additional localities were found in the headwaters of Lost Lake Creek in Chiquito Creek basin. The sites at Soquel Meadow, Texas Flat, and Long Meadow are all located less than 5500 feet in elevation and represent the lowest known sites on the Sierra National Forest.

From 2003 to 2006, the USDA Forest Service SNAMPH surveyed 26 watersheds containing 501 sites on the Sierra National Forest. Three of these watersheds had evidence of breeding by mountain yellow-legged frogs and adults or subadults were recorded from an additional 2 watersheds. In these watersheds, evidence of breeding was found at 7 sites (1 percent) and an additional 11 sites (2 percent) had only adults or subadults. Numbers were generally low, but these surveys were not designed to obtain accurate abundance information.

Also over the interval 2003-2006, CDFG conducted 466 surveys (see detail of survey approach in Status section) of 397 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were detected at 8.8 percent (n = 35) of surveyed sites.

Sequoia and Kings Canyon National Parks

Prior to 1980

Many historical records exist for Sequoia and Kings Canyon National Parks. As indicated from museum records, literature, park records, and personal communications, mountain yellow-legged frogs were recorded from at least 25 sites scattered throughout Sequoia and Kings Canyon National Parks between 1891 and 1979. Because of access, a disproportionate number of historical sites are in Sequoia National Park. A distribution map for the mountain yellow-legged frog encompassing most historical sightings and collections of the species in Sequoia and Kings Canyon National Parks was provided in Jennings and Hayes (1994).

The earliest records of mountain yellow-legged frogs in Sequoia and Kings Canyon National Parks date from the 1891 as a result of collections made by the USBS during the Mt. Whitney-Death Valley Expedition. Twelve frogs were taken from at least 5 localities, including Mineral King (USNM 18944), Halstead Meadows (USNM 18948-18949), 2 sites along the east Fork of the Kaweah River in the vicinity of Little Lake (USNM 18735-18737, 18940-18943), and along Whitney Creek (USNM 18939). All these localities are in Sequoia National Park.

In 1904, the USBS re-collected at Whitney Creek, specifically in Crabtree Meadows, where 13 frogs were obtained (USNM 34688-34700). The USBS also collected 2 frogs at Summit Lake, south of Hockett Meadows (USNM 34654-34655), and 1 frog from Volcano Creek (USNM 34671). In 1907, J. C. Bradley collected 7 frogs at Giant Forest (CU 1614). Again, all records for these periods are for Sequoia National Park.

The earliest records from Kings Canyon National Park date from 1910, when E. C. Van Dyke collected 14 frogs along Bubbs Creek (CAS 17929-17942). In 1911, Tracy Storer revisited Whitney Creek and collected 1 frog (MVZ 3055). In 1915, J. C. Bradley collected 1 frog along Whitman Creek, Sequoia National Park (CU 7087). In 1916, Halstead White collected 1 frog along the Kings River in Kings Canyon National Park (MVZ 6229). In 1917, Albert Hazen Wright collected 16 frogs and 1 larva at Alta Meadow, Sequoia National Park (CU 7840, 7845). He noted that "plenty" of this species was encountered in the pools at Alta Meadow (Wright and Wright 1949).

In 1921, Barton Evermann collected along the Kaweah River, Sequoia National Park (CAS 50483).

In 1933, Joseph Dixon collected 6 frogs at Giant Forest in Round Meadow, Sequoia National Park (MVZ 16473-16478). In 1934, Joseph Dixon collected 3 frogs at each of Emerald Lake (MVZ 33997-33998, 21824), Junction Meadow (MVZ 33988-33990), Lake South America (MVZ 33991-33993), and Kaweah Gap (MVZ 33994-33996), all in Sequoia National Park. In 1935, Theodore Eaton collected 2 frogs in Evelyn Lake (MVZ 21821-21822) and 1 frog in Hockett Lake (MVZ 21823), both in Sequoia National Park. In 1937, John Applegarth collected 2 frogs at Giant Forest at the church of Sequoia Meadow, Sequoia National Park (CAS-SU 3662-3663), and 1 frog at Ranger Lake, Kings Canyon National Park (CAS-SU 3661).

In 1940, Earl Herald re-collected at Giant Forest, obtaining 13 frogs (LACM 1744, CAS-SU 6513-6524). In 1941, Herald also collected at Grant Grove (CAS-SU 6508-6510) and at 9.6 km from Grant Grove (CAS-SU 6511), both in Kings Canyon National Park.

In 1951, A. Small collected 1 frog in Crescent Meadow, Sequoia National Park (LACM 1743). In 1952, Joe Gorman collected 1 frog 2.4 km (by trail) northwest of Lodgepole Camp 3980, Sequoia National Park (MVZ 58303). In 1955, Bayard Brattstrom re-collected Crescent Meadow, where he obtained 4 frogs (LACM 13637-13640); and Ernest Karlstrom collected 6 frogs from Summit Meadow, Kings Canyon National Park (MVZ 62901-62906). In 1956, B. Osborne collected 1 frog from Heather Lake (LACM 91111); and D. Harvey collected 2 frogs from Wolverton at Long Meadow (LACM 91582-91583), both in Sequoia National Park.

In 1968, Martin Ruggles collected 2 frogs from Pinto Lake, Sequoia National Park (LACM 115490-115491).

In 1972, 3 frogs were collected in Paradise Valley (SDNHM 47223, 47662-47663). In 1978 and 1979, the headwaters of 7 creek systems in the parks were surveyed for mountain yellow-legged frogs. Surveys found that mountain yellow-legged frogs occupied 27 sites greater than 200 m apart (Bradford et al. 1994); frog abundance data were not obtained.

Cory et al. (1970) reported MYLF at numerous localities throughout the Sierra, including Sequoia/Kings Canyon.

Post-1980

A map meant to approximate mountain yellow-legged frog distribution through 1992 showed the species was extinct at a number of sites across Sequoia and Kings Canyon National Parks (Jennings and Hayes 1994). Based on resurveys of historical locations (Bradford et al. 1994), the species had already disappeared from many areas of Sequoia and Kings Canyon Parks by the late 1980s. In 1997, Knapp re-surveyed an unnamed lake in the Cartridge Creek drainage that was occupied in the early 1990s and did not find mountain yellow-legged frogs (R. Knapp, pers. comm.).

The headwaters of 7 creek systems in Sequoia and Kings Canyon National Parks were resurveyed for mountain yellow-legged frogs in 1989 to compare with original surveys completed in 1978-1979 (Bradford et al. 1994). Frogs were found at 27 different sites (i.e., greater than 200 m apart) in the 1978 and 1979 surveys, but at only 1 of those sites in 1989; by 1991, the population at this site had also disappeared. Elsewhere in Sequoia and Kings Canyon National Parks, historical records (1955 through 1979) were compared with recent records (1989 through 1990) for 22 sites; this comparison revealed that mountain yellow-legged frogs had persisted at only 11 sites. Bradford et al. (1994) concluded that in three decades, the mountain yellow-legged frog had been eliminated from at least half of the sites where it was historically present in Sequoia and Kings Canyon National Parks, and that it was completely extirpated from some drainages.

In 1989 and 1990, Bradford et al. (1993) searched 312 lakes in 95 survey basins in both Kings Canyon and Sequoia National Parks. Mountain yellow-legged frogs were found in 35 percent (n = 109) of surveyed lakes, with tadpoles occurring in 66 of the occupied lakes. In 1992, Bradford et al. (1998) surveyed 104 lakes in the South Fork Kings River and Woods Creek drainages in Kings Canyon National Park. Adult mountain yellow-legged frogs were found in 32 percent of the lakes (n = 33) and tadpoles in 21 percent (n = 22).

Fellers (1994) was unable to locate mountain yellow-legged frogs at any of the sites examined across the entire Kaweah drainage within Sequoia and Kings Canyon National Parks. In 1994, field crews checked 651 sites within the range of the species, and located mountain yellow-legged frogs at only 21 percent (n = 138) of these sites. No mountain yellow-legged frogs were seen in the South, East, Middle, or Marble forks of the Kaweah River. Some of these drainages historically supported large populations of mountain yellow-legged frogs, among them the study sites at which Bradford (1982) did his doctoral work on the species. Fellers and Bradford re-visited a number of historical sites, including Bradford's focal study site in the Tablelands area of the Marble Fork, but were unable to find mountain yellow-legged frogs at either the historical sites or elsewhere within the drainage (Fellers 1994). In 1994, during a study in which frogs were translocated to the Tablelands, collections were made at 2 sites in Tablelands; Kathleen Freel took 2 frogs from Full Moon Pond (CAS 201795-201796), and Leslie Long took 1 frog from Frog Lake (CAS 201797).

In 1997, Robert Stebbins collected 1 frog from the Sixty Lakes Basin, Kings Canyon National Park (MVZ 226112); and in 1999, Vance Vredenburg collected another frog from 1 km east of Mt. Cotter, also within the Sixty Lakes Basin (MVZ 230960).

Knapp and Matthews (2000a) extensively surveyed lakes, ponds, and other water bodies in the northern portion of Kings Canyon National Park during 1996 and 1997. Mountain yellow-legged frog adults were found in 31 percent of 1,059 water bodies, and frog larvae in 20 percent (Knapp and Matthews 2000a). Some large populations were found; 10 percent of the sites had more than 20 adults, 6 percent had more than 50 adults, and 4 percent had more than 100 adult frogs (Knapp and Matthews 2000a).

As of 2002, 507 sites where mountain yellow-legged frogs were extant were known from Sequoia and Kings Canyon National Parks (USFWS 2003). More than 100 adults have been recorded from 54 of these sites, between 10 and 100 adults have been recorded from 157 sites, and 296 sites had fewer than 10 adults. Breeding has been recorded at roughly half (n = 259) of the sites (USFWS 2003). Some frog populations remain in Sequoia and Kings Canyon National Parks; however, extensive declines have been described.

In their re-analysis of red-legged frogs, Shaffer et al. (2004) obtained tissue from mountain yellow-legged frog life stages from three localities within Sequoia and Kings Canyon National Parks: pools north of Golden Bear Lake, Center Basin, Kings Canyon National Park (HBS 30585); unnamed ponds 2.2 km (by air) east-southeast of Mt. Jordan (HBS 30565, 30572) and an unnamed pond 4.8 km (by air) east-northeast of Table Mountain (HBS 30553), both in Sequoia National Park. Collection dates were not specified.

Sequoia National Forest

Prior to 1980

Between 1875 and 1979, mountain yellow-legged frogs were collected from at least 16 locations on the Sequoia National Forest (Hansen 1980, USDA Forest Service 1999a). Hansen (1980) has a distribution map for mountain yellow-legged frogs in the Kern and South Fork of the Kern River drainages that showed 11 of these localities.

The oldest collection from the Sequoia National Forest is from 1875, when Henry Weatherbee Henshaw collected 4 frogs from along the Kern River in the mountains east of Old Kernville (USNM 8687).

No additional records were obtained until after the turn of the century when in 1911, Joseph Grinnell, Tracy Storer, and Walter Taylor collected 19 mountain yellow-legged frogs at Jackass (MVZ 3014-3019), Manter (MVZ 3012-3013), and Taylor (MVZ 3000-3010) Meadows. In 1916, Harry Swarth collected 14 mountain yellow-legged frogs at Hume (MVZ 6215-6228). No records exist from the 1920s.

In 1934, William Richardson collected 30 mountain yellow-legged frogs in Quaking Aspen Meadow (MVZ 33999-34016, 34018-34027, 34075-34076), and Joseph Dixon collected 3 frogs at Emerald Lake (MVZ 33997-33998, 21824). In 1938, Ira Wiggins collected 3 frogs in a small stream near Camp Lena, ca. 2 mi from Balch Park (CAS-SU 4061-4063).

In 1942, 3 mountain yellow-legged frogs were collected at Wheel Meadow (LACM 141884-141886).

Several records exist for the 1950s. Early 1950s collections on the Sequoia National Forest include the southernmost isolated location of this species in the Sierra Nevada: the Mill Creek headwaters on the north slope of Breckenridge Mountain, a location where Wade Fox collected one frog in 1952 (MVZ 63389). In 1953, Richard Zweifel collected 15 mountain yellow-legged frogs at French Joe Meadow (MVZ 59606-59620) and 2 frogs from Sequoia Lake (MVZ 59626-59627). In 1955, Karlstrom collected Horse Corral Meadow, where 7 frogs were taken (MVZ 62895-62900, 62913) (USDA Forest Service 1999a).

In 1966, S. H. Kamler collected an additional mountain yellow-legged frog in Quaking Aspen Meadow (LACM 91758).

In 1970, J.M. Sheppard collected 3 mountain yellow-legged frogs in Dunlap Meadow (LACM 106059-106061); in 1971, Richard Zweifel collected 24 mountain yellow-legged frogs 3.2 km (2 mi) north-northwest of Johnsondale (AMNH 86590-86613); in 1979, Robert Hansen and Dan Holland encountered 1 mountain yellow-legged frog at Beach Meadow (Hansen 1980; B. Hansen, pers. comm.).

Post-1980

Since the 1980s, frogs have been observed at fewer than 10 locations on the Sequoia National Forest. All sightings have involved very small numbers (< 10) of frogs, often single individuals, implying remnants of populations that had been “decimated in recent years” (Hansen 1980). By 1980, mountain yellow-legged frogs had become rare even in streams with suitable habitat on the Kern Plateau (Hansen 1980). Keeler-Wolf (1989) recorded a few mountain yellow-legged frogs (Keeler-Wolf, pers. comm., 2006) along the North Fork of the Middle Fork of the Tule River during a 1988 survey of the Moses Mountain candidate Research Natural Area; he also noted that mountain yellow-legged frogs were “occasional” during a 19-22 June 1990 survey of Mountaineer Creek (Keeler-Wolf 1991). A 1992 survey of 17 Sequoia National Forest localities involving over 66 km of streams, lakes, and meadows revealed no mountain yellow-legged frogs (Martin 1992). Over 80 percent of recent sightings are located in the headwaters of the Little Kern River (USDA Forest Service 1999e, 1999f).

As of 2002, only 2 extant populations of mountain yellow-legged frogs were known from the Sequoia National Forest (S. Anderson, *in litt*., 2002 in USFWS 2003).

During 2007 many of the historical sites on the Sequoia National Forest were surveyed for presence/absence of mountain yellow-legged frogs. The species was not detected at Taylor, Jackass, Quaking Aspen, French Joe, Horse Corral, Redwoods, Smith and Failing, or Lloyd Meadows. Surveys in 2008 identified an adult mountain yellow-legged frog along a branch of Alpine Creek in the Little Kern River drainage. Additionally during 2008, bullfrogs were reportedly located at Little Kern Lake and a pond south of the lake which had been identified by the California Department of Fish and Wildlife in 1999 as being occupied by the mountain yellow-legged frog. The three sites believed occupied by the mountain yellow-legged frog within the Sequoia National Forest occur within the Little Kern River drainage.

From 2003 to 2006, the USDA Forest Service SNAMPH surveyed 4 watersheds containing 24 sites on the Sequoia National Forest. No mountain yellow-legged frogs were recorded during any of the surveys in these watersheds.

Also over the interval 2003-2006, CDFG conducted 4 surveys (see detail of survey approach in Status section) of 4 different sites with potential mountain yellow-legged frog habitat. Mountain yellow-legged frogs were detected at 75 percent (n = 3) of surveyed sites.

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