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YOSEMITE TOAD CONSERVATION ASSESSMENT

A Collaborative Inter-Agency Project

Forest Service

Pacific Southwest Region

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YOSEMITE TOAD CONSERVATION ASSESSMENT

A Collaborative Inter-Agency Project by:
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EXECUTIVE SUMMARY

The Yosemite toad *(Anaxyrus [Bufo] canorus)* is endemic to the higher-elevation (> 1,980 m [> 6,500 ft]) aquatic habitats of the Sierra Nevada Mountains of California. Once historically abundant, it is estimated that this toad has been extirpated from significant portions of its historical localities, and many of its remaining populations appear depleted. Depletions and extirpations were first recognized during the 1970s, and on 29 April, 2014, the U.S. Fish and Wildlife Service added the Yosemite toad to the Lists of Endangered and Threatened Wildlife and Plants as a threatened species. In the late 1990s, the realization that these declines could rapidly place the species at risk of extinction led to a U.S. Department of Agriculture (USDA) Forest-Service-initiated multi-agency effort to develop a conservation strategy focused on attenuating the risk factors responsible. This conservation assessment is the first step toward the development of this conservation strategy and consists of three parts: (1) a synopsis of Yosemite toad ecology designed to better understand conditions necessary to provide for viable populations; (2) a review of Yosemite toad distribution and abundance over its historical geographic range to describe the risk; and (3) an evaluation of 16 risk factor categories to identify which may contribute the greatest risk to the Yosemite toad and its habitat.

Yosemite toads occupy both aquatic and terrestrial habitats. They breed and rear primarily in shallow still water habitat; use meadows, springs, and terrestrial upland habitats for foraging, refuge, and movements; and overwinter in underground terrestrial sites. Tadpoles develop rapidly in very shallow, typically ephemeral aquatic habitats. Mortality through metamorphosis can be very high, with abiotic factors (desiccation and/or freezing) sometimes causing total or near loss of a year's cohort. Mortality of small post-metamorphic toads also appears high, likely because of high overwinter mortality. The long-lived adults may be key to long-term persistence of populations given the low recruitment in some years. Post-metamorphic life stages (juveniles and adults) occupy habitats some distance from breeding sites seasonally. Little is known about seasonal movements, especially for juveniles, but movements that range several hundred meters from breeding sites are recorded for adults. The population structure and dynamics of Yosemite toads are unclear. Yosemite toads are currently recognized as one taxonomic unit, but genetic data imply that more than one discrete lineage may be concealed within what is now called Yosemite toads. Moreover, the relationship between Yosemite toads as a taxonomic unit and its closest relatives is ambiguous and needs clarification.

Yosemite toads occurred on both sides of the Sierra Nevada mountain divide between the southern portion of the Lake Tahoe Basin and the headwaters of the Kings River between 1,980 m (6,500 ft) and 3,414 m (11,200 ft). Based on pre-1980 information, most (> 99 percent) of the historical range is on federal land including six national forests and two national parks; the remainder of the range is on private and state-owned lands. Historical abundance data are mostly anecdotal, but Yosemite toads were described as being common, and at least one population had several hundred individuals; these data also imply that Yosemite toads were most abundant in the elevation region above 2,438 m (8,000 ft) and below areas of permanent snow and ice. Yosemite toad information obtained since 1990 includes quantitative occurrence and abundance data. Recent occurrence data, based on a USDA Forest Service monitoring program for high elevation amphibians and other survey data, reveal patchy extirpations range wide, with Yosemite toad populations still distributed across their original range. The few data that exist on recent abundances suggest populations may be very small (< 20 adult males) compared to historical levels with relatively few large populations remaining across the geographic range. Whether these populations are persisting in small numbers or on a slow trajectory to extirpation is not known.

For the 16 potential risk factors identified during the Conservation Assessment process, definitive data are generally lacking. Risk factors that affect meadow hydrology or impact the long-lived adults including in their upland nonbreeding habitats may be most significant. Further, small populations may be more vulnerable to risk factors that would be of less concern for larger populations. Given these considerations, observational data of Yosemite toad habitat and circumstantial evidence suggest that climate change, livestock grazing, recreational activity, and the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*, *Bd*) may be important factors. Livestock grazing and recreational activities were identified as important to address because of their widespread occurrence, high overlap with Yosemite toad habitats, potential effects on breeding habitat (e.g., meadow hydrology) and/or adults, and the ability of participating agencies to make meaningful management changes. A Forest-Service-sponsored research project formally addressed livestock grazing. Those results indicated that when livestock grazing use occurred at levels at or below

grazing standards (i.e., 30 through 40 percent use of grass and grass-like plants, depending on meadow seral stage and condition) there were no detectable differences in toad occupancy or density (of various life stages) among areas that were grazed and areas that were not grazed (e.g., fenced meadows). This study occurred over a relatively short time period (5 years) and toad densities were highly variable among meadows. The primary drivers related to toad presence and densities were water year type and meadow wetness. No formal studies have been conducted on recreational activities and the Yosemite toad. Initial studies suggest that *Bd* may be an important factor in Yosemite toad declines, but the results are not conclusive and this is a major information gap. Several other risk factors (fire management; locally-applied pesticides; roads; vegetation and fuels management) are more prevalent at low to mid-elevations of the species range, may affect adults in their nonbreeding habitat, and may be particularly important where they overlap with small populations. These also have the potential to be effectively addressed by management efforts of agencies participating in this conservation assessment. Habitat loss and fragmentation may result from a variety of these risk factors. Four risk factors (acid deposition, airborne contaminants, climate change, 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. Of these, climate change may pose a high risk to Yosemite toads by altering precipitation patterns that may result in significant changes to breeding habitats among other possibilities. Participating agencies may be able to respond indirectly to these global risk factors by instituting land management actions that ameliorate local risk factors and result in higher resiliency of Yosemite toad populations. Experimental and survey data have found no direct effects from introduced fish, acid deposition, and ultraviolet radiation.

Ongoing research address several aspects of the ecology of the Yosemite toad. Studies are examining Yosemite toad habitat relationships, hydrology of breeding meadows, demography, movement ecology, and genetics.

Conservation options for consideration in a conservation strategy for the Yosemite toad include management at multiple scales; identifying and managing within priority basins (watersheds); maintaining and restoring meadow and other habitats; and developing options for effective management of livestock grazing and recreational activities. Further research on Yosemite toad genetics, and the relationships between Yosemite toad populations and habitat and recreational activities, *Bd*, and climate change are proposed.

DEDICATION

Cynthia Kagarise Sherman, PhD (1950-2002)

The Yosemite Toad Working Group very gratefully dedicates this conservation assessment to Cynthia Kagarise Sherman. The pioneering work of Kagarise Sherman on the ecology and behavior of the Yosemite toad near Tioga Pass was pivotal in motivating each of us, especially in the application of our work to conserve this remarkable anuran. Particularly inspirational to our efforts is the dedication with which Kagarise Sherman pursued her work; over 10 years after completing her dissertation, she revisited her study sites to resume careful monitoring of both her study populations and several other sites, work she integrated with family life and the rearing of two children. Collaborating with Martin Morton and D. Earl Green, she documented alarming declines and described the potential role of infectious diseases long before it became the global amphibian conservation issue with which we continue to struggle. We encourage readers of this assessment to take a bit of time to peruse Kagarise Sherman's dissertation and published work, as they provide some of the most detailed and original insights on the natural history of Yosemite toads.

INTRODUCTION

The Purpose of this Conservation Assessment

Information from the mid-twentieth century indicates that the Yosemite toad (*Anaxyrus [Bufo] canorus*) was abundant in high-elevation meadow ecosystems of the Sierra Nevadan Cordillera of North America (Grinnell and Storer 1924, Mullally and Cunningham 1956, Karlstrom 1962). Distributed relatively continuously in aquatic habitats across roughly two-thirds of the longitudinal axis of the California Sierra Nevada from the vicinity of Grass Lake, Lake Tahoe Basin, El Dorado County (Mullally and Powell 1958) to Evolution Valley in Kings Canyon National Park, and Fresno County (Jennings and Hayes 1994), Yosemite toads occurred mostly above 1,980 m elevation (Storer 1925; Stebbins 1951, 2003). Six national forests (Lake Tahoe Basin, Eldorado, Stanislaus, Humboldt-Toiyabe, Inyo, and Sierra) and two national parks (Yosemite and Kings Canyon) encompass the historical range of the Yosemite toad.

Yosemite toads are important components of aquatic ecosystems in the high Sierra Nevada. They likely play important roles in high-elevation food webs. Early developmental stages of Yosemite toads may be seasonally important food for mountain yellow-legged frogs (*Rana muscosa/sierrae*) (Mullally 1953) and garter snakes, tadpoles seem to be dominant aquatic grazers in the typically ephemeral aquatic habitats in which they rear, and post-metamorphic Yosemite toads are among the important predators on terrestrial invertebrates in high-elevation meadow habitats (Wood 1977). Yosemite toads also likely play roles in nutrient cycling between wet meadows, lakes, and adjacent terrestrial systems. Loss of the Yosemite toad from the Sierra Nevada would extirpate this unique endemic, as its entire range is encompassed within the Sierra Nevada. Such a loss may alter food webs and nutrient cycling in ways that have significant, and potentially important, consequences for selected Sierran high-elevation systems, especially aquatic habitats associated with meadows.

The number of localities occupied by the Yosemite toad has decreased over its geographic range (Drost and Fellers 1994, 1996; Jennings and Hayes 1994; Jennings 1996; Brown et al. 2012) and individual populations have undergone significant declines in abundance (Kagarise Sherman and Morton 1993). Rangewide estimates made in the mid-1990s indicated a disappearance from >50 percent of historical localities (Jennings and Hayes 1994, Jennings 1996). More recent monitoring has found that although the species still occurs in a relatively large proportion of areas (84 percent) where it had been found in the 1990s, it has disappeared from the majority (87 percent) of localities recorded prior to the 1990s and populations appear to be very small (Brown et al. 2012). Thus, remaining populations seem more scattered than they were historically and frequently appear to consist of small numbers of breeding adults. Numerous factors, individually and likely in diverse and complex combinations, may have contributed to the species' decline. Pathogens, pesticides, livestock grazing, ultraviolet radiation, introduction of non-native fishes, acidification from atmospheric deposition, nitrate deposition, recreational activities, and drought are among the many risk factors that have been identified as potentially impacting this species and its habitat.

On 28 February 2000, the Center for Biological Diversity and the Pacific Rivers Council petitioned USFWS to list the Yosemite toad under the Endangered Species Act (ESA). On 12 October 2000, the USFWS published a 90-Day Finding indicating that the petition presented substantial scientific or commercial information to indicate that listing the species under the ESA may be warranted, initiating a status review to determine if the petition action was warranted (USFWS 2000). On 10 December 2002, the USFWS published its 12-Month Finding for a petition to list the Yosemite toad, which concluded that the petitioned action was warranted, but precluded by higher-priority actions to amend the Lists of Endangered and Threatened Wildlife and Plants (USFWS 2002). Following publication of this 12-Month Finding, the Yosemite toad was added to the USFWS Candidate Species List (USFWS 2002). On 25 April, 2013, the USFWS proposed to list the species as threatened (USFWS 2013), and subsequently finalized the rule on 29 April, 2014, officially adding the Yosemite toad to the Lists of Endangered and Threatened Wildlife and Plants as a threatened species, meaning it is "likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range" (USFWS 2014).

Prompted by a 2006 lawsuit, the California Superior Court ruled in 2008 that 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*.

The State of California considers the Yosemite toad to be a "Species of Special Concern" (SSC). The Pacific Southwest Region (Region 5) has listed and managed the Yosemite toad as a Sensitive Species since 1998 (USDA Forest Service 1998, 2004a, 2007, 2013). (See discussions below.)

The Sierra Nevada Forest Plan Amendment (SNFPA) Record of Decision (ROD) committed the US Department of Agriculture (USDA) Forest Service to completing a conservation assessment for the Yosemite toad in cooperation with other federal agencies, state agencies, universities, and research scientists (USDA Forest Service 2001a). The conservation assessment is envisioned as the first of a three-phase process that includes a conservation strategy and a Conservation Agreement. The conservation assessment provides the informational foundation for the conservation strategy. The conservation strategy delineates specific conservation actions, and leads to an agreement among various agencies and partners to implement the conservation strategy. Following approval of the SNFPA ROD, a working group of biologists from the USDA Forest Service, National Park Service (NPS), US Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife (CDFW), and academic and independent research scientists was established to develop this assessment and future strategy.

Thus, this conservation assessment was developed as a tool to guide future conservation strategy and recovery planning for the Sierra Nevada populations of the Yosemite toad (Blankenship et al. 2001). Conservation assessments document all available pertinent conservation or management 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 management recommendations based on the best available knowledge. In turn, these management recommendations are incorporated into a conservation strategy designed to benefit the species. Agencies that have contributed to this assessment include the CDFW, the Pacific Southwest and Intermountain Regions of the USDA Forest Service, the National Park Service (represented by Yosemite and Kings Canyon National Parks), and the USFWS.

The majority of work on this Conservation Assessment was accomplished prior to 2007. 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, although some new information has been added to this Conservation Assessment, the Conservation Strategy, when developed, will contain more recent information on topics most pertinent to the species' conservation. Some citations were added to this document to guide readers to new information.

Mission

The mission of this conservation assessment is to provide the information required for developing a conservation strategy that would ensure the self-sustaining, long-term viability and continued evolution of Yosemite toads that represent the historical range of the geographic, genetic, and ecological diversity of the species. Objectives of the strategy supported by this assessment are:

- Maintain viability of existing populations throughout the species' range in the Sierra Nevada.
- Where possible, restore habitat and expand populations within individual basins (watersheds) throughout the historical range of the toad.
- Where possible, recover the species in watersheds where populations were present historically but are absent today.
- Fill information gaps identified by the working team through the conservation assessment process (see Information Gap section).

- Create public understanding of conservation and recovery needs. Encourage 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

1. Summarize current knowledge of conditions necessary to provide for viable populations of the Yosemite toad.
2. Summarize current knowledge about the distribution and abundance of the Yosemite toad.
3. Identify and evaluate importance of key risk factors.
4. 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 Yosemite toads in the Sierra Nevada. As such, the assessment encompasses the entire range of Yosemite toads as currently understood (see Systematics and Taxonomy in Ecology section) which occurs solely within the Sierra Nevada of California (see Status 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 Yosemite toad as a Sensitive Species since 1998 (USDA Forest Service 1998, 2013). The recent listing of the species as Threatened 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 through 33 of the ROD (USDA Forest Service 2004b, 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 native populations.
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 the Yosemite toad. Management direction for carrying out this decision includes S&Gs for project design and implementation. Specifically three standards have been identified for the Yosemite toad:

- Exclude livestock from standing water and saturated soils in wet meadows and associated streams and springs occupied by Yosemite toads or identified as "essential habitat" in the conservation assessment for the Yosemite toad during the breeding and rearing season (through metamorphosis). Wet meadow habitat for Yosemite toads is defined as relatively open meadows with low to moderate amounts of woody vegetation that have standing water on 1 June or for more than two weeks following snowmelt. Specific breeding and rearing season dates will be determined locally. If physical exclusion of livestock is impractical, then exclude grazing from the entire meadow. This standard does not apply to pack and saddle stock (S&G #53).

- Exclusions in standard and guideline #53 above may be waived if an interdisciplinary team has developed a site-specific management plan to minimize impacts to the Yosemite toad and its habitat by managing the movement of stock around wet areas. Such plans are to include a requirement for systematically monitoring a sample of occupied Yosemite toad sites within the meadow to: (1) assess habitat conditions and (2) assess Yosemite toad occupancy and population dynamics. Every 3 years from the date of the plan, evaluate monitoring data. Modify or suspend grazing if Yosemite toad conservation is not being accomplished. Plans must be approved by the authorized officer and incorporated into all allotment plans and/or special use permits governing use within the occupied habitat (S&G #54).
- Complete one survey cycle in suitable habitat for the Yosemite toad within this species' historical range to determine presence of Yosemite toads (S&G #55).

Also, two S&Gs (addressing pesticide application [98] and assessment of habitat [114]) associated with Riparian Conservation Objectives specifically identify Yosemite toads 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

The State of California considers the Yosemite toad to be a "Species of Special Concern" (SSC). This is an administrative designation and carries no formal legal status. The intent of designating SSCs is to:

- focus attention on animals at conservation risk by the Department, other state entities, local and federal governmental entities, regulators, land managers, planners, consulting biologists, and others;
- stimulate research on poorly-known species;
- achieve conservation and recovery of these animals before they meet California Endangered Species Act criteria for listing as threatened or endangered.

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

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

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

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

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

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

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

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

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

Sport take of Yosemite toads with a fishing license is prohibited (Title 14, Section 5.05), and scientific take is regulated by permit (Title 14, Section 650).

National Park Service

The guiding principles for managing biological resources on national park lands includes 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 2006).

To meet its commitments for maintaining native species in parks, the Service will cooperate with states, tribal governments, the U.S. Fish and Wildlife Service, NOAA Fisheries, and other countries, as appropriate, to "encourage the conservation of the populations and habitats of these species outside parks whenever possible," and 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." By extension, these principles encourage the NPS to participate in the Yosemite toad conservation assessment process, and assist in conserving the species in the Sierra Nevada.

The resource management plan for Sequoia and Kings Canyon National Parks (NPS 1999) discusses stressors contributing to the decline of Yosemite toads, but it does not provide management language specific to the toad. The plan provides resource goals for aquatic/water resources that have direct relevance to Yosemite toad conservation issues. The following resource goals have a direct bearing on the toad's 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.

The 2020 Strategic Vision (NPS 2014) incorporates several “Strategic Initiatives” outlining action items for stewardship of natural resources in Yosemite National Park which include:

1. Preserve and Protect Ecosystems
    a. Protect and maintain ecosystems and the species that depend upon them so that restoration is not necessary.
2. Restore Legacy Resources
    b. Restore damaged meadows, taking action where natural recovery is not possible.
3. Implement Species Recovery
    c. Stabilize and increase population and distribution of once common Sierra yellow-legged frog, as well as federally listed and state protected species including Yosemite toad, Great gray owl, bighorn sheep, Pacific fisher, and Sierra Nevada red fox.
4. Mitigate External Threats

Yosemite National Park is also in the process of finalizing a High Elevation Aquatic Ecosystem Recovery and Stewardship Plan Environmental Assessment (Aquatic Plan) in which restoring Yosemite toad populations is outlined.

Broad-based replication of historical surveys was initiated in the 1990s that have provided insights into the status of the amphibian assemblages found in Yosemite National Park (Drost and Fellers 1996, Knapp [N.d.]; see also Status section for Yosemite NP). Further, the parks have ongoing studies on amphibians, including Yosemite toads. Monitoring implemented by the federal Amphibian Research and Monitoring Initiative (ARMI) is occurring in Yosemite National Park. The goal of this initiative was to provide timely, reliable information on the status of amphibians in the United States so that causes of declines could be understood and appropriate management responses initiated (Hall and Langtimm 2001). In 2009, Yosemite park staff began a four-year collaborative study with USGS to improve knowledge regarding the current status and distribution of the Yosemite toad in the park as well as knowledge of some factors that may be contributing to its decline. Specifically, the project (1) determined the current status and distribution of Yosemite toad in the park; (2) assessed temporal trends in toad site occupancy over two time scales: “historical” (pre-1990) vs. current and 1990-2014, and (3) explored what habitat metrics best explain spatial and temporal variation in toad breeding success. This project was initiated, in part, to help inform restoration efforts identified in the Aquatic Plan.

From 2010-2013, the USGS also studied the status and distribution of the Yosemite toad in Kings Canyon National Park, as well habitat attributes between occupied and unoccupied meadows. This project was initiated to (1) help inform planning for a parks wide Wilderness Stewardship Plan and (2) determine the current status of the Yosemite toad in the park.

US Fish and Wildlife Service

The overarching mission of the US 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). The Yosemite toad is listed as Threatened under the Endangered Species Act (USFWS 2014, also see discussion above).

Document Organization

The three main sections of this document address the ecology and status of Yosemite toads as well as 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 its recovery. The status section provides information on Yosemite toad distribution and population abundance within the Sierra Nevada planning area. Appendix 2 discusses how these populations have changed pre- and post-1980 in each of the national forests and national parks. The Risk Factor section identifies, describes, and evaluates the relative importance of key risk factors for Yosemite toads. Risk factors include management activities (e.g., livestock grazing, pesticide use, restoration, vegetation management) and environmental factors (e.g., disease, climate change), which may have played a role in current Yosemite toad population trends in the Sierra Nevada, and are important considerations in future population recovery. Together, these sections provide the conceptual and scientific foundation for the subsequent conservation strategy.

For the Yosemite toad, detailed quantitative data generally are lacking for many key aspects of its ecology and response to various risk factors. Further, little research has been conducted investigating causes of its decline. Recognizing these limitations, the working team viewed this assessment as a compilation of all available information on the Yosemite toad including anecdotal information and professional judgment. This compilation was then used to derive initial conservation options that would serve as the basis for the subsequent Conservation Strategy. As discussed above, pertinent new information on the species will be incorporated into the Conservation Strategy.

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

ECOLOGY

Systematics and Taxonomy

Systematics and taxonomy provide the genetic and geographic foundation for discussing all aspects of Yosemite toad ecology.

Described by Camp (1916), the Yosemite toad was originally given the common name Yosemite Park toad. Later discovery of the species beyond the boundaries of Yosemite National Park led Grinnell and Storer (1924) to begin to refer to it as simply the Yosemite toad.

There is both phenotypic and genetic support for complex relationships among the *Anaxyrus* species in the Sierra Nevada. Camp (1916) noted morphological similarities between the Yosemite toad and the western toad (*Anaxyrus boreas*). Based on general morphology and distribution, the two species were deemed closely related (Myers 1942, Stebbins 1951, Mullally 1956, Savage 1958). Osteological studies (Tihen 1962a, 1962b) also support the close relationship between western toads and Yosemite toads. Using skull characteristics, Camp (1917) concluded that western toads, Yosemite toads, and the extinct form, *Anaxyrus nestor,* are more closely related to each other than to other North American toads, and that these species comprise the most primitive group of North American *Anaxyrus*. Blair (1972) added black toads (*Anaxyrus exsul*) and Amargosa toads (*Anaxyrus nelsoni*) to this taxonomic assemblage, which he labeled the "*boreas* group."

Based on allozymes sampled over a relatively limited geographic range, Feder (1977) found support for regarding Yosemite toads as a distinct species. However, Yosemite toads can be hybridized artificially with western toads (Blair 1959, 1963, 1964), and hybridization with western toads has been observed in the northern part of the Yosemite toad's range (Mullally and Powell 1958, Morton and Sokolski 1978, Martin et al. 1992). Further, mitochondrial DNA analysis suggested that Yosemite toads from the southern part of their range might be more closely related to nearby western toads than they are to Yosemite toads from the northern part of their range (Stephens 2001), a pattern that Stephens (2007) has recently corroborated. Stephens also discovered that Yosemite toads in the northern portion of their range group with geographically more northern western toads. This was also corroborated by Goebel (1996, 2005, Goebel et al. 2009) who, using different mitochondrial DNA sequences, found that western toads from the Oregon Cascades appeared genetically more closely related to Yosemite toads than to other western toad populations. Goebel et al. (2009) have more recently concluded that the Yosemite toad is paraphyletic, and that the two highly divergent groups of Yosemite toads nest within their respective western toad clades. Shaffer et al. (2000) found that black toads always nested within a subgroup of Yosemite toads. However, Goebel et al. (2009) found that black toads formed a sister group to all other toads (including Yosemite toads and western toads) in the southern clade. Whether this means that Oregon populations of western toads belong to a population that should have a separate name or that the taxon we now label the Yosemite toad has been too narrowly defined awaits further evaluation. This same analysis also revealed a close relationship between black toads, Amargosa toads, and Yosemite toads. These data imply that the relationships of black toads, Yosemite toads, and western toads need further evaluation, which is the focus of ongoing research (Stephens 2007).

The analysis of Shaffer et al. (2000) also revealed no shared genetic types between Yosemite toad populations sampled in Yosemite and Kings Canyon National Parks, leading them to conclude that populations occupying these areas represent genetically distinct units. Both Shaffer et al. (2000) and Wang (2012) found an isolation by distance pattern within Yosemite National Park populations, and suggested that breeding sites are relatively isolated with occasional migrations between closely situated areas. These patterns have important consequences for the management of Yosemite toads. More research on the genetics of Yosemite toads and its close congeners is needed for a better understanding of the geographic variation of Yosemite toads.

Description

Yosemite toad adults are moderate-sized (44-84 millimeters [mm] snout-urostyle length [SUL]) with rounded to slightly oval parotoid glands that are less than one gland width apart (Stebbins 1951, Karlstrom 1962, Kagarise Sherman 1980, Stebbins 2003). The iris is dark brown with gold iridophores (Jennings and Hayes 1994). Females average larger than males (Karlstrom 1962); Kagarise Sherman (1980) found that depending on the population, males averaged from 65 to 73 mm SUL (overall adult male range: 48-84 mm SUL), whereas female averaged from 68 to 76 mm SUL (overall adult female range: 53-79 mm SUL). Karlstrom (1962) noted the sample of Yosemite toad adults he obtained from Tioga Pass averaged small for the species (females: $\bar{x} = 52.1$, range: 48-56, $n = 14$; males: $\bar{x} = 49.3$, range: 45-53, $n = 19$). Color dimorphism between adult males and females is more pronounced than in any other North American anuran (Stebbins 1951, 2003). Females have black spots or blotches edged with white or cream that are set against a gray, tan, or brown background color; males have a nearly uniform dorsal coloration of yellow-green to olive drab to darker greenish brown (Karlstrom 1962). This sexual color dimorphism develops from a juvenile pattern of brown, green-brown, or gray background color with black spots, a pattern similar to that found in adult females. Males gradually become yellow-green and less spotted, whereas females retain their background color as their dorsal spots enlarge and darken (Karlstrom 1962, Kagarise Sherman 1980). Juveniles have a thin pale yellow or cream mid-dorsal stripe, which disappears or fades with age, a condition that occurs more rapidly in males (Karlstrom 1962, Jennings and Hayes 1994).

Yosemite toad tadpoles are uniformly black (darker than some western toad tadpoles) such that the coiled intestines are scarcely or not at all visible; the snout in profile is blunt (less pointed than in the western toad) and rounded from above (more truncate than in the western toad). The dorsal fin of Yosemite toad tadpoles is transparent and marked with a few relatively large branched melanophores, and the tail is deepest about midway along its length (in western toad tadpoles the tail is deepest closer to the vent) (Karlstrom and Livezey 1955; Karlstrom 1962; Stebbins 1951, 2003). Tadpoles are 10-37 mm long and develop two upper and three lower rows of labial teeth (or denticles), with a gap in the first upper row (Stebbins 1951, 2003, Karlstrom and Livezey 1955).

Yosemite toad eggs are laid in 2 strings (1 from each ovary); depending on how eggs were laid, the strings can appear as individual strands, a double strand, or may be variously folded forming a radiating network or a cluster of 4-5 eggs deep (Karlstrom and Livezey 1955, Kagarise Sherman 1980). Two jelly envelopes are easily observed surrounding each strand; an outer thinner envelope forms a continuous but scalloped casing because of the way the jelly constricts around each egg, and an inner thicker envelope separately surrounds each egg (Karlstrom and Livezey 1955). Width of the outer envelope is 3.7-4.6 mm ($\bar{x} = 4.1$ mm), width of the inner envelope is 3.4-4.1 mm ($\bar{x} = 3.8$ mm), and diameter of individual eggs is 1.7-2.7 mm ($\bar{x} = 2.1$ mm). Eggs are dark brown to jet black and may be gray to tan-gray over the lower one quarter (Karlstrom and Livezey 1955, Savage and Schuierer 1961).

Habitat Requirements

The Yosemite toad requires aquatic and upland habitats. The species is most associated with wet meadows (Grinnell and Storer 1924, Karlstrom 1962) because they are the habitats most commonly used for breeding. Yosemite toads also have been recorded in a wide range of other high montane and subalpine lentic and lotic habitats including lakes, small ponds, shallow spring channels, side channels, and sloughs (Mullally 1953, Karlstrom and Livezey 1955, Livezey 1955, Karlstrom 1962, Kagarise Sherman 1980, Martin 2008, Figure 1) as well as a variety of upland habitats (see below). The Yosemite toad has been recorded from a few reservoirs (e.g., Upper Blue Lake) that appear to retain appropriate habitat

Figure 1. Meadow breeding habitat at Highland Lakes, Alpine County. (Photo by Katie Kiehl, USFS SNAMPH Monitoring Program.)

(Williams 2006) and Martin (2002) believed that Yosemite toad populations may have been historically more abundant in lake habitats; this cannot be evaluated without historical or experimental data.

Breeding and rearing habitat occurs in shallow warm waters, most commonly in wet meadows, including both standing and flowing water, but also in small permanent and ephemeral ponds, lake edges, and slow-moving streams and sloughs (Karlstrom and Livezey 1955, Karlstrom 1962, Mullally 1953, Kagarise Sherman 1980, Martin 2008; Sadinski 2002, Brown 2006). On the Sierra National Forest, Liang (2010) found that seasonal waters in relatively flat meadows facing a southwesterly direction with warmer water temperatures were most likely to be used by toads for breeding. Breeding sites also were associated with higher elevations, less variable air temperatures, more precipitation in the warmest three months of the year, and less precipitation during the driest three months. Liang (2010) also noted that the species' distribution was related to a number of different factors rather than a small set of variables. In Yosemite National Park, Knapp (2005) found high elevation and meadow shorelines were significantly correlated with occurrence. Roche et al. (2012a) also found annual occupancy to be positively correlated with annual precipitation.

In 14 watersheds monitored across the species' range over an eight year period (2002-2009), Brown et al. (2012) found only 30% of 61 breeding sites to be consistently occupied (occupied every year or every year except one) while the others were occupied in only a few years. Further, most (64%) of the 14 watersheds had 1-2 sites that were consistently occupied with other sites that were occupied in only some years. Within a meadow, toads appeared to select specific breeding areas though, similar to the site (e.g., meadow) scale, some areas were not used every year. Reasons for these patterns are not known but may be due to small population sizes (see Population Dynamics section), or differences in habitat or annual environmental conditions (Brown et al. 2012). Liang and Stohlgren (2011) found that consistently used breeding meadows had low slopes, warm temperatures, and southwesterly aspects whereas intermittently used sites had a broader range of characteristics.

Breeding site characteristics are likely related to the short season available to the species and generally are associated with warm-water environments conducive to rapid development (Karlstrom 1962, Kagarise Sherman and Morton 1984). Mullally (1953) found that breeding ponds were usually less than 30 cm deep. During rangewide surveys for tadpoles, Brown et al. (2014) measured maximum depths of 211 breeding areas and found a median of 0.12 m with a maximum of 0.9 m. Roche et al. (2012a) also found an association between breeding occupancy and shallow, warm water. These conditions, however, pose risks to both eggs and tadpoles. It is not uncommon for eggs to freeze or for eggs and tadpoles to desiccate when shallow waters dry too early (Kagarise Sherman 1980, Kagarise Sherman and Morton 1984, Brown et al. 2012). Thus, suitable aquatic breeding and rearing habitat likely include a mixture of warm shallow water with a hydroperiod long enough to ensure metamorphosis. Water retention sufficient for metamorphosis to occur is likely important.

Eggs generally are laid in very shallow, warm, and often ephemeral water at the edges of small pools or in flooded meadow vegetation, most commonly with no or low flow (Mullally 1953, Kagarise Sherman 1980, Sadinski 2004, Brown et al. 2014). Reported water depths at egg mass sites include < 4 cm (Sadinski 2004), < 5 cm (Kagarise Sherman 1980), < 7.6 cm (Karlstrom 1962) and median of 4 cm (Brown et al. 2014), and water temperatures can reach > 30º C (Sadinski 2004, Brown et al. 2014). Kagarise Sherman (1980) recorded oviposition in water less than 5 cm deep along the edges of 3 tarns, but saw no oviposition or reproductive behavior in another tarn that was almost uniformly 20-30 cm deep and lacked significant shallow margins. Martin (1991c) reported that egg masses deposited in water 2-4 cm in depth had the greatest probability of survival. Brown et al. (2014) have found most egg masses in the shallow margins of potholes and in shallow water flooding vegetation. In preliminary regression analyses, Brown et al. (2014) found water temperature to be highly positively correlated with egg mass deposition locations. Kagarise Sherman (1980) found water temperature at 5 oviposition sites averaged more than 7º C warmer than at 5 structurally similar sites where eggs were never seen. Egg mass placement likely enhances rapid development, but such placement also makes eggs vulnerable to desiccation or freezing (see Mortality section). In six study meadows, eggs laid at the edge of small ponds or in shallow water have desiccated within a few days as water receded from shorelines or dried up (Brown 2009).

Tadpoles also are consistently observed in very warm shallow standing and flowing water in wet meadows, potholes, and pond and lake shallows (Mullally 1953, Karlstrom 1962, Kagarise Sherman and Morton 1984, Brown et al. 2014) where they also likely accrue a developmental advantage (Karlstrom

1962, Kagarise Sherman 1980). Mullally (1953; see also Brattstrom 1962) found tadpoles sensitive to small differences in water temperature, often deserting areas that were only 1-2ºC cooler than the areas they moved to. In September 1952, Mullally recorded mid-day non-margin surface water temperatures in Lower Gaylor and Tioga Pass Lakes at 20-23 ºC, whereas lake margin water temperatures (at 1.3-5.1 cm depths) were 27-33 ºC. Mullally (1953) observed Yosemite toad tadpoles crowded into the warmest water along the shallow margins of pools during the daytime and dispersed into deeper water at sundown. Karlstrom (1962) observed a marked depression in pond temperature (to about 4 ºC) on 6 to 7 July 1955 at his Tioga study site; he noted that "[t]hese low temperatures probably had no adverse effect on the tadpoles, which by this time had access to the deeper parts of the pond where warmer bottom temperatures could prevail." In potholes and small ponds in meadows on the Stanislaus National Forest, tadpoles were found clinging to shore edges (within 0.2 m of the shoreline) during cooler morning hours and were less active. Later in the day, tadpoles became more mobile and dispersed, presumably due to increased water temperatures (Brown 2006). Tadpole rearing sites also need to persist long enough for tadpoles to metamorphose; drought conditions or sites with intrinsically short hydroperiods can result in significant tadpole mortality (Kagarise Sherman 1980, Martin 1991a, Kagarise Sherman and Morton 1993, Brown 2014). Observations of desiccated tadpoles were not uncommon during rangewide Yosemite toad surveys in the Sierra Nevada (Brown 2011; see Mortality section).

The habitat needs of subadult Yosemite toads remain poorly understood. Some metamorphs appear to overwinter their first year in meadow habitat adjacent to their natal pond, often around willows, and to move to more distant terrestrial habitat during mid-summer of their second year (Kagarise Sherman 1980, Kagarise Sherman and Morton 1993, Martin 1997). Metamorphs have been observed moving away from natal breeding pools, and in several cases, toward stream channels (Brown 2011). In meadows, Martin (2008) found an association between metamorphs and yearlings with willows and long sedges and grasses that are often associated with stream channels. Martin (2008) did not commonly see subadults in meadows later in the summer suggesting that subadult toads migrate to upland habitats well away from meadows during their second year (Martin 2008). However, Brown et al. (2014) have found subadults in meadows during summer surveys.

After the breeding period, adult Yosemite toads disperse into meadows, ephemeral streams, seeps and springs, and uplands (Martin 2008, Liang 2010). Because adult are harder to find outside of the breeding season, characterization of their non-breeding season habitat is more difficult. During the non-breeding active season, post-metamorphic Yosemite toads generally have been associated with water. Karlstrom (1962) reported that Yosemite toads had never been found more than 90 m from permanent water. Martin (2008) found that although adult Yosemite toads could travel significant distances from breeding pools to inhabit upslope habitats, they were generally within 7 m of some form of water including seeps, springs and ephemeral streams. Liang (2010), however, found toads in the forest away from water, and while some adults followed drainages, most did not.

In upslope habitats in one alpine watershed, toads were associated with seeps and springs with lush vegetation and with areas with large granitic boulders (Martin 2008). Martin (2008) found that subadults more commonly used meadows whereas adults more often used upland areas. In meadows, toads, including subadults and metamorphs, were associated with willows and long sedges and grasses. In contrast, in a more forested watershed on the Sierra National Forest, Liang (2010) found adults associated with forest clearings with fewer trees and shrubs and less canopy cover than unoccupied areas. Morton and Pereyra (2010) found adult females utilize different habitat than adult males during the non-breeding season. During late July and August, over 60% of toads in upland rocky hillside habitat were adult females and less than 10% were adult males. In lowland meadow habitat near the breeding pond, 54% of toads observed were adult males and about 19% were adult females. Juvenile toads were evenly spread across the surveyed area. Rodent burrows are important components of cover for adults and subadults, and willows, logs, rocks, tree roots, and stumps also are used (Mullally 1953, Karlstrom 1962, Kagarise Sherman 1980, Martin 2008, Liang 2010). Martin (2008) found that subadult and adult Yosemite toads are usually found within 1 m of a burrow of some kind.

In his alpine study watershed, Martin (2008) examined the structural features of postreproductive terrestrial habitats utilized by subadult and adult Yosemite toads, comparing the characteristics of meadow foraging habitats, upslope foraging habitats, and overwintering habitats used by toads. He found that areas where toads were found in meadows were significantly different from areas where toads were found in upslope habitats. Meadow areas with toads were characterized by sedges and willows with relatively tall vegetation. Toads were generally found within ~6 m of willows and the mean vegetation height within sample plots was ~25 cm. These areas also were characterized as having a minimal amount of rock and gravel ground coverage and being located relatively far away from rocks (~25 m) and forested areas (~33 m). In upslope habitats, on the other hand, the areas where toads were found were characterized as being closely associated with rocks (< 1 m) and herbaceous vegetation (most notably lupines) rather than woody vegetation with shorter vegetation (~11 cm). In upslope habitats, toads were generally found close to forested areas (within ~8 m) but far from willow stands (within ~48 m).

Overwintering habitat has not been well characterized. It has been suggested that adult and juvenile Yosemite toads overwinter in the root tangles at the bases of willows, in crevices beneath rocks and stumps, and in the burrows of mountain voles (*Microtus montanus*), pocket gophers (*Thomomys* spp.), Belding's ground squirrels (*Spermophilus beldingi*), and yellow-bellied marmots (*Marmota flaviventris*; Kagarise Sherman 1980, Davidson and Fellers 2005, also see Karlstrom 1962). In Tioga Pass Meadow, Kagarise Sherman (1980) found many small toadlets early in the season, concluding that first-year juveniles appear to spend the winter near the pools from which they emerged. Brown et al. (2014) has observed young from the previous year at snowmelt in several meadows. Early in the active season, Morton (1981) reported finding several adult female Yosemite toads, which had presumably just emerged from their hibernacula, at the edge of a talus slope that was predominantly covered with snow at the time. Martin (2008) radio-tracked three Yosemite toads (1 female and 2 males) that entered abandoned rodent burrows between mid-September and mid-October, and continued monitoring their lack of movement in the burrows until after the first winter snows fell. The toads all overwintered in rodent burrows located in rocky soil along the margins of lodgepole pine forests surrounding the meadow where the breeding pools were located. One of these overwintering burrows was excavated and found to be a 6-7 cm diameter, 130 cm long tunnel through lodgepole pine roots with a moist chamber, 35 cm beneath the ground surface, at the end of the tunnel (Martin 2008). Martin (2008) suggested that the forest soils in which these overwintering burrows were located probably provide moist soil conditions that would prevent desiccation of toads in burrows but not wet conditions that would act to conduct cold temperatures. Quality of overwintering sites has not been examined, but large deep burrows, such as those of Belding's ground squirrels, may provide high-quality overwintering sites (see Kagarise Sherman 1980). Likewise, the range of habitats that may serve as suitable overwintering sites remains poorly understood.

The least-understood aspect of Yosemite toad habitat requirements is the spatial scale at which breeding, active-season, and overwintering habitats need to be juxtaposed in order to support the toad's seasonal life cycle. Further, the spatial scale of seasonal habitat use may differ from year to year if unusually wet years or, conversely, drought years change local habitat conditions (e.g., selected ponds or springs become ephemeral in a season where they were perennial in other years) (Kagarise Sherman and Morton 1993; see Mortality section). Such conditions are likely to occur with some regularity due to the high between-year variation in snowpack (Morton 1978) and predicted climate change scenarios for the Sierra Nevada (Jeton et al. 1996, Johnson et al. 1999a) have the potential to increase this variation. Because Yosemite toads are thought to be relatively long-lived (see Life History section), adults have the potential to experience and respond to years where habitat conditions may differ substantially. A better understanding of how Yosemite toads respond to habitat changes under different seasonal and inter-seasonal conditions and at different spatial scales is needed.

Life History

The Yosemite toad is an explosive breeder that lays eggs at snowmelt. Toads emerge from overwintering as nearby breeding pools form from snowmelt (Karlstrom 1962, Kagarise Sherman 1980). Depending on elevation and year, emergence of adults for breeding ranges from late April to late June (Kagarise Sherman 1980, Brown et al. 2012). Males appear at breeding pools first and tend to arrive synchronously (Karlstrom 1962, Kagarise Sherman 1980). Grinnell and Storer (1924) found many males present at Peregoy Meadow in Yosemite National Park on 20 May 1919, while the only females they observed at this early date were small non-breeding individuals. Males form variable-sized breeding choruses and call during the day and evening

(Grinnell and Storer 1924, Storer 1925, Wright Kagarise Sherman 1980; Brown et al. 2007)

The male breeding call is a long sustained mellow trill with 26-51 evenly spaced notes (Karlstrom 1962). The duration of 42 trills given by one male averaged 2.6 seconds (range: 0.8-3.8 seconds). Males tend to space themselves out in the breeding area even though oviposition sites are not defended, and they move around over short distances. Silent (non-calling) males may be positioned near calling males to potentially intercept incoming females (Kagarise Sherman 1980). Males have been observed to clasp other males preventing them from calling, to amplex conspecifics in trial-and-error searches for females, and to attempt to displace an amplexed male (Kagarise Sherman 1980). Successfully mated males were more likely to be larger, to have arrived at breeding sites earlier, and to have stayed at breeding sites longer (Kagarise Sherman 1980). In three years of study by Kagarise Sherman (1980), males remained at breeding sites an average of 11, 6, and 10 days, and most eggs were laid within a 5-day interval.

Figure 2. Adult male Yosemite toad calling at snowmelt, Bull Creek watershed, Fresno County. (Photo by Lucas Wilkinson, USFS SNAMPH Monitoring Program.)

Females arrive at breeding sites later and leave earlier than the males (Kagarise Sherman 1980), and their secretive behavior and cryptic coloration contribute to making them difficult to observe unless in amplexus. Only 19 percent of females that Kagarise Sherman (1980) recorded were never observed in amplexus, and these tended to be smaller animals. Females deposit one clutch annually. Karlstrom (1962) estimated the number of eggs per clutch at 1500-2000 (n = 2) based on the number of pigmented ovarian eggs in two preserved females collected in prebreeding condition. Kagarise Sherman (1980) found a mean of 1,113 eggs per clutch (se = 275.5; range: about 700-1,800; n = 29 clutches). Egg mass strings are often intertwined (but not attached) among low emergent vegetation and may, to varying degrees, be buried in silt (Stebbins 1951, Karlstrom and Livezey 1955, Karlstrom 1962), presumably as a result of disturbance by toads, other aquatic organisms, or wind (Figures 3 and 4). Females may lay single clutches of eggs in multiple units and may lay egg masses separately or communally (Kagarise Sherman 1980, Kagarise Sherman and Morton 1993, Brown et al. 2012). Kagarise Sherman (1980) found that 23 of 128 (18 percent) pairs split their clutches, depositing eggs more than 1 m apart. For these pairs, the mean distance between parts of clutches was 11.2 m (range: 1 to 41 m). A few females deposited eggs in three locations in the same pool, and a few even split clutches between two different pools.

Two long-term Yosemite toad demographic studies suggest that males generally breed consecutive years whereas females often skip years. Of 522 males marked from 1976–1979 in Tioga Pass Meadow, Kagarise Sherman (1980) found that 66 percent were captured in only one year with the remaining 34% captured in 2-4 years. Of the 177 males captured more than one year, 35 (20 percent) skipped one or more years. Of 216 females marked during the same period, 84 percent were captured only one year,

Figure 3. Amplexed Yosemite toad pair laying eggs, Highland Lakes, Alpine County. (Photo by Cathy Brown, USFS SNAMPH Monitoring Program.)

and of the 34 females captured more than one year, 20 (59 percent) skipped at least one year. For both sexes, most of the toads skipped only one year. Similar results were found over a longer period (2006-2012) in six meadows in two watersheds (Stanislaus and Sierra National Forests). Of 216 unique males captured in the two watersheds, 49 percent were captured in only one year and of the 110 males captured more than one year, 17 (15 percent) were captured in nonconsecutive years. Of 137 unique females captured, 63 percent were captured in only one year, and of the 51 females captured more than one year, 25 (49 percent) were captured in nonconsecutive years (Brown et al. 2014, also see Brown et al. 2012). Eggs typically hatch in 4-6 days; more than 15 days may be needed with cooler water temperatures (Kagarise Sherman 1980, Brown 2011). In the laboratory, Karlstrom (1962) found eggs hatched in 4-5 days at 16-17 ºC and 3-4 days at 20-23ºC temperatures. Under the often > 20 ºC diel temperature fluctuations in the field during the breeding interval, Kagarise Sherman (1980) found longer developmental intervals, an average of 11-12 days to hatching; she also found that eggs that were laid later in the breeding period hatched almost twice as fast ($\bar{x}$ = 7-8 days) as those laid earlier ($\bar{x}$ = 14 days). Eggs laid earlier in the season were under conditions that were cooler on average (Kagarise Sherman 1980). In 6 meadows on the Stanislaus and Sierra National Forests, eggs generally hatch within 5-6 days of being laid (Brown 2014).

Figure 4. Newly laid Yosemite toad egg strand, Highland Lakes, Alpine County. (Photo by Cathy Brown, USFS SNAMPH Monitoring Program.)

After hatching, tadpoles require 4-6 weeks to reach metamorphosis (Karlstrom 1962, Kagarise Sherman 1980, Martin 2002, Sadinski 2002). Karlstrom (1962) recorded metamorphosis 48-56 days after breeding (encompassing embryonic and tadpole development), whereas Kagarise Sherman (1980) estimated 52-63 days for the same interval; the difference between the two studies likely represents the confounded effects of elevation, annual weather pattern differences, and local tadpole food resources. Immature tadpoles have been observed well into September (Mullally 1956), but the fate of those tadpoles is unknown. Tadpoles are not known to overwinter (Stebbins 1951, Karlstrom 1962, Kagarise Sherman 1980, Jennings and Hayes 1994).

Newly metamorphosed juveniles, which typically appear July to September, are very small (about 10 mm SUL; Karlstrom 1962, Kagarise Sherman 1980, Martin 2002, Figure 5). Metamorphs found during rangewide monitoring surveys were generally 9 to 14 mm SVL, but some were as small as 7 mm (Brown et al. 2014). With the more rapid growth rates that Kagarise Sherman (1980) measured, some males have the potential to attain reproductive size at 2 years of age, but most individuals likely require longer to reach maturity. Males have been observed to first breed at 3-5 years of age and females at 4-6 years (Kagarise Sherman 1980, Kagarise Sherman and Morton 1984). Yosemite toads are thought to be relatively long-lived, with females documented to reach 15 years of age and males 12 years (Kagarise Sherman and Morton 1984).

Figure 5. Researcher taking data on a recently metamorphosed juvenile, Highland Lakes, Alpine County. (Photo by Katie Kiehl, USFS SNAMPH Monitoring Program.)

After breeding, adults move into meadow (Kagarise Sherman 1980) and/or upslope habitats (e.g., ephemeral streams, headwater springs and seeps; see Habitat Requirements), which can be hundreds of meters away from breeding areas (Martin 2008, Liang 2010, see Movement). Knowledge of adult post-breeding behavior is limited, because adults become more difficult to detect as they become more dispersed across habitats away from breeding sites. However, they are thought to occupy meadow or non-breeding aquatic habitats for the remainder of the active season prior to entry into overwintering sites (Karlstrom 1962, Kagarise Sherman 1980, Martin 2008).

Most studies have considered Yosemite toads to be diurnal (Karlstrom 1962, Kagarise Sherman 1980), but recent data suggest they are more nocturnal than has previously been reported. Yosemite toads actively breed during the day, but one study found them to be equally active at night. Initial observations of toads calling after 2130 hours were observed in 2 locations in 2006 (Stanislaus and Sierra National Forests). These observations led to more intensive surveys between 2130 and 0030 hours in 2007 at 3 meadows at the Stanislaus National Forest location. Toads were found to be equally as active during these hours as during the day (Brown et al. 2007). Further, during tracking studies, both Martin (2008) and Liang (2010) found that adults regularly traveled both diurnally and nocturnally. No significant difference could be found in the median distance traveled between nocturnal and diurnal periods (Martin 2008) and the majority of longer distance movements took place at night (Martin 2008, Liang 2010). A few adults were found during a night survey on the Stanislaus National Forest in 2005 (Brown 2007).

Entry into overwintering sites (see Habitat Requirements section) is probably coincident with the decline in seasonal temperatures (Mullally 1953, Karlstrom 1962, Kagarise Sherman 1980), and there is some evidence that the cue for toads to enter overwintering burrows may be the occurrence of the first nighttime freezing temperatures at the end of the season in mid-September to mid-October (Martin 2008). However, overwintering behavior is largely unstudied. If the pattern parallels that for other anurans, the decline in nighttime temperatures, which may precede a decline in daytime temperatures, may be the important cue (Rome et al. 1992).

The multi-year studies of Kagarise Sherman (1980), Martin (2008), Liang (2010), and Brown et al. (2012) using marked animals reveal that adults show high site fidelity to breeding and adult habitats. In Tioga Pass Meadows, adults bred at the same ponds and, after breeding, tended to use the same one or two locations for daytime refuges (Kagarise Sherman 1980). During four years of a mark-recapture study in six meadows in two locations (Stanislaus and Sierra National Forests), only three of 37 males moved to different meadows to breed, though males did move among breeding areas within meadows (Brown et al. 2012). Brown et al. (2012) also notes that toads appear to select specific breeding areas within meadows though some are not used every year, a pattern similar to that observed at the meadow scale. Liang (2010) reported that some radio-tracked toads were found in the same upland areas and sometimes the same exact site multiple years, which suggests that toads also show fidelity in their use of terrestrial sites. Movement data from radio-tracked toads suggests that adult toads could easily move between breeding pools over 1 km apart in a single season (Martin 2008, Liang 2010, see Movement). Adults not recaptured in these studies could represent individuals either more likely to move beyond the study area or mortalities, so Barrowclough's (1978) caution about underestimating dispersers in studies with a restricted finite area likely applies.

Population Dynamics

Little is known about the demography and population dynamics of Yosemite toads, but three relatively long-term studies provide insights. Kagarise Sherman (1980) conducted a four-year study on the Yosemite toad's natural history and mating system in Tioga Pass Meadows. Brown et al. (2012) present results from the multi-scale bioregional USDA Forest Service Sierra Nevada Amphibian Monitoring Program (SNAMPH) which includes demography data for six meadows on the Stanislaus and Sierra National Forests. D. Martin studied multiple populations over several years in the north-central Sierra Nevada, particularly at a site on the Stanislaus National Forest (these data are not summarized here).

Relatively long-term data is available for the Yosemite toad from Tioga Pass Meadows (Karlstrom 1962, Kagarise Sherman 1980, Kagarise Sherman and Morton 1993). Karlstrom (1962) provided natural history, size distribution, and sex ratio data for samples from this meadow during the mid-1950s, whereas Kagarise Sherman and Morton (Kagarise Sherman 1980, Kagarise Sherman and Morton 1993) developed more detailed demographic data over a twelve-year interval, 1971-1982. Of the 2,270 Yosemite toads studied during the interval 1971-1982, 1,259 were males, 779 were females, and the rest were immatures. In the interval 1974-1978 when Kagarise Sherman was conducting intensive behavioral and ecological work, annual counts of adult males varied from 162 to 342, whereas those of females varied from 45 to 100 individuals. Sex ratios observed for adults seem strongly male-biased, but the difficulty observing the more cryptic females makes it difficult to assess actual sex ratios (Kagarise Sherman 1980). This population declined in the 1980s (see Status section); observations made in 1990 indicate that the Tioga Pass Meadows population had persisted, but at low levels with apparently limited reproduction (Kagarise Sherman and Morton 1993, Martin 2008). Males appeared to decline first; the number of males counted in 1982 was a nine-fold drop from the 1974-1978 average. Female numbers varied among years with no apparent trend through 1982 and then declined by 1990. Kagarise Sherman and Morton (1993) attributed this asymmetry in decline to differences in behavior between males and females. Males spend more time in breeding pools within a breeding period, attempt to breed in more years, and tended to inhabit different habitats during the nonbreeding season than females. The decline in this study population was interpreted to be a function of drought and disease (Green and Kagarise Sherman 2001), but the relative contribution of these factors and whether they interacted is not understood (Kagarise Sherman and Morton 1993).

Some data on historical population sizes are also available from 6 other locations near Tioga Pass Meadow (Kagarise Sherman and Morton 1993, also see Status section). The maximum number of toads found per survey during 1976 and 1977 ranged from 60-216 at 3 sites, and 2-38 at 3 other sites. Populations at all 6 sites declined by 1990.

Population abundances and survival of adult males were estimated for the six SNAMPH meadows (Brown et al. 2012). From 2006 to 2009 the number of males present at the spring breeding chorus was estimated from mark-recapture data and the number of egg masses was counted. Annual breeding male population estimates were relatively small with the largest population within each watershed having only 16-21 (Sierra National Forest) and 18-19 (Stanislaus National Forest) individuals per year. One meadow in each watershed had very few individuals present each year (2-4 males and 3-7 males, respectively). Egg mass counts were also relatively low with a maximum within a meadow of 48 (Sierra National Forest) and 30 (Stanislaus National Forest) counted in a single year. Annual survival estimates of adult males ranged from 0.49-0.72. Monitoring has continued in these meadows and as of 2012, with similar results (Brown et al. 2014).

Survivorship of eggs to hatching and tadpoles to metamorphosis is variable and probably associated with weather, precipitation, and local hydrology. This has only been quantified recently, so whether these patterns reflect what was historically typical is unclear (see Mortality section). Desiccation of breeding and rearing habitats can be an important source of mortality for both eggs and tadpoles (see Mortality section). Slow growth of juveniles (see Life History section) likely reflects the short active season available in high elevation habitats. The apparently long lifespan (see Life History section) is likely a response to the unpredictability of year-to-year recruitment, and may also be a function of the harsh high-elevation habitat conditions. One hypothesis is that the Yosemite toad may have a population dynamic where there is little to no recruitment in many years, but because adults are long-lived, only an occasional high recruitment year is needed for long-term population persistence (Kagarise Sherman and Morton 1993; also Olson 1992, Daszak et al. 2005, Brown et al. 2012).

Montane amphibians with life history traits similar to the Yosemite toad may exhibit characteristics typical of metapopulation dynamics (e.g., Bradford 1991). Metapopulation theory states that the persistence of a species depends on the extinction-colonization balance among interconnected populations (Smith and Green 2005). Individual local populations may go extinct due to a variety of chance events (e.g., severe winters, prolonged drought), but they are eventually recolonized by animals from nearby populations (Levins 1970; see review in Hanski and Gilpin 1991). The extent to which Yosemite toad populations actually function as metapopulations is not known, though recent species distribution modeling work indicated that that the likelihood of a site being occupied was strongly influenced by proximity to nearby occupied sites (Liang 2010). Local extirpation is known to have occurred and populations are subject to mass mortality resulting from natural factors such as drought and prolonged cold periods (Kagarise Sherman and Morton 1993, Milano 2002, Brown 2014), but study of the dynamics among local populations is lacking. The fact that populations currently appear to be small (Sadinski 2002, Martin 2008, Brown et al. 2012) may make them more vulnerable to random events that could extirpate them (Pimm 1991, Noss and Cooperrider 1994, Martin

2008). A better understanding of the interactions among local populations, the degree that toad populations function as metapopulations, and the "rescue" capability, the ability of a nearby population to contribute immigrants to a reproductive population pool (Brown and Kodric-Brown 1977), would inform management strategies (Smith and Green 2005).

Movement

Movement patterns of Yosemite toads are not fully understood, but recent telemetry studies suggest that toads move greater distances than were initially reported. Kagarise Sherman (1980) provided data on movements between overwintering sites and breeding habitats from Tioga Pass Meadows. At this site, toads moved 150-230 m each spring between overwintering and breeding sites. Morton (1981) reported finding several female Yosemite toads early in the active season, presumably just having emerged from their overwintering burrows, about 750 m from the closest major breeding site. Martin (2008) found that the mean distance from overwintering sites to the nearest breeding pool was ~123 m and that travel was through dry rocky sage and lodgepole pine forests. Martin (2008) radio-tracked three toads into their overwintering burrows. Two adult male Yosemite toads were tracked from meadow foraging habitat located near breeding pools to overwintering burrows located over 100 m away in the margin of lodgepole pine forest. One adult female was tracked from upslope foraging habitat that was nearly 300 m from the nearest breeding pool to an overwintering burrow that was 71 m closer to the breeding pools in the margin of a lodgepole pine forest.

During a brief time interval in late summer (4 days), Mullally (1953) observed that toads moved very little and estimated the home ranges of several adult toads to be 1.9 m^2. More recently, significant post-breeding active season movements have been observed from aquatic breeding sites to meadows and other terrestrial or sometimes aquatic habitats. At Tioga Pass Meadows, males appeared to live in the central meadow closer to the breeding pools, whereas females often moved farther away between spawnings, especially to a willow thicket located on the east slope of the meadow system (Kagarise Sherman 1980). For a random sample of 20 males and females, the mean distance from the fenced study ponds to each toad's most distant recapture location averaged greater for females ($\bar{x}$ = 207 m) than for males ($\bar{x}$ = 162 m). Further, Kagarise Sherman (1980) and Morton and Pereyra (2010) periodically searched for toads along a 100 m x 850 m transect from the top of the aforementioned east slope down to the central meadow. Nearly all the males (93 percent [208 of 225 males found]), but fewer than one-third of the females (29.9 percent [71 of 237 females found]) occurred near the central meadow (closer to the breeding ponds), whereas only 3.1 percent (n = 7) of males and nearly half the females (45.6 percent [n = 108]) were found just below the talus at the top of the willow slope. Hence, females may typically move further from breeding ponds than males, a pattern also found in western toads (Muths 2003, Bartelt et al. 2004). Distances between incidental terrestrial observations of adult Yosemite toads during the post-breeding season and the closest occupied meadow in the Sierra National Forest varied from 40 m to 462 m ($\bar{x}$ = 209 m, SD = 149 m, n = 14; Grasso 2006) and appear to agree with patterns observed by Kagarise Sherman and Morton.

Martin (2008) radio and/or string tracked a total of 21 Yosemite toads (7 females and 14 males) and found that after spawning, adult Yosemite toads left the breeding pools and either foraged in the meadows surrounding the breeding pools or traveled in a fairly straight line to upslope habitats along ephemeral streams, seeps, or springs with lush vegetation. Some adult toads foraged in the meadow habitat for a few weeks after breeding and then migrated to upslope habitats for the remainder of the active season, but others remained in the meadow habitat until they migrated upslope to overwintering habitats. It is also possible that nonbreeding adult toads remain in or near upslope foraging habitats during the entire active season including the breeding period (Martin 2008). Martin (2008) reported a maximum dispersal distance of 657 m from breeding pools to upslope habitat.

In a pilot study on toad movements in the Sierra National Forest, Liang followed two adults (one male and one female) from each of two breeding sites at Kaiser Peak Meadow in June (Liang 2007). The two females moved straight-line distances of 359 m and 417 m in 3.5 and 2.5 weeks, respectively; the two males moved distances of 301 m and 1.36 km in 11 and 3.5 weeks, respectively. Subsequent work on 42 radio-tracked toads at another set of meadows indicated that individuals traveled as far as 1.26 km from meadows into upland habitats, but average travel distance was 275 m from the breeding meadow (Liang 2010). Females appeared to move further than males; the average distance travelled by females was twice that of males, and females moved a maximum of 1261 m compared with a maximum of 865 m for males. Most long distance travel occurred within the first 60 days after breeding. Toads often stayed in the same locations for several days or weeks.

Dispersal capabilities of Yosemite toads are also poorly understood. Martin (2008) found two adult males sharing the same burrow in upland foraging habitat after having participated in breeding congregations in separate meadows. In contrast to older animals, at least some young-of-the-year toadlets appear to remain relatively close (dozens of meters) to their breeding ponds and appear to overwinter the first time in that vicinity (Kagarise Sherman 1980; see Habitat Requirements section). Although a few older juveniles have been found at various distances from their presumptive natal pond (Karlstrom 1962, Kagarise Sherman 1980), we know the least about this life stage.

Stebbins (1951) suggested that isolation or semi-isolation of subpopulations of Yosemite toads is likely, because they are unlikely to cross large dry forested areas between meadows. Although this idea has never been tested, the finding of Kagarise Sherman (1980) that only 2.1 percent (6 of 282) of the toads marked in southern Tioga Pass Meadows between 1971 and 1979 were recaptured in northern Tioga Pass Meadows (approximately 400 m distant) may imply that exchange between regionally proximate populations may be limited. During the SNAMPH mark-recapture surveys, only three animals moved among meadows for breeding, suggesting the toads have high site fidelity at the scale of individual meadows (Brown et al. 2012). Further, genetic studies (Shaffer et al. 2000, Wang 2012) showed an isolation by distance pattern among regionally proximate population systems, implying that gene flow may be low on a local scale.

Feeding

Post-metamorphic Yosemite toads are thought to be largely ambush predators. They generally remain motionless until a prey item approaches, then strike and capture their prey at close range with their sticky tongues (Kagarise Sherman and Morton 1984). Feeding occurs primarily during the non-breeding active season, and only rarely during the breeding season, when most adults do not seem to feed at all (Wood 1977, Kagarise Sherman 1980). The pattern of feeding during the non-breeding active season is correlated with deposition of gonadal and liver fat, which typically increases throughout this period and is particularly pronounced in females (Morton 1981).

Relatively few diet data exist. Grinnell and Storer (1924) described stomach contents for one adult Yosemite toad from Porcupine Flat, which contained two tenebrionid beetles (Coleoptera: Tenebrionidae), several different weevil species (Coleoptera: Curculionidae), numerous large ants (Hymenoptera: Formicidae), one centipede (Chilopoda), and some red fir (*Abies magnifica*) needles; the latter were interpreted as having been taken incidentally. Mullally (1953) examined the stomachs of an unspecified number of Yosemite toads from the Gaylor Lakes area near Tioga Pass, which contained spiders (Arachinda: Aranea) and an assortment of insects, including ladybird beetles (Coleoptera: Coccinellidae), dragonfly (Odonata: Anisoptera) naiads, mosquitoes (Diptera: Culicidae), and Lepidoptera larvae. Wood (1977) provided the most substantial and quantified data on the diet of adult Yosemite toads; he reported an invertebrate diet dominated by terrestrial invertebrates. Bees and wasps (Hymenoptera) represented nearly 80 percent of all food items, followed by beetles and julid millipedes (Diplopoda: Julida).

Martin (1991a) analyzed the stomach contents of 10 Yosemite toads, including three newly metamorphosed toadlets, three individuals taken two months after metamorphosis, two one-year olds, and one each of an adult male and female. He reported 10 families from six insect orders and two arachnid groups, including five previously unreported taxa: spider mites (Arachnida: Tetranychidae), craneflies (Diptera: Tipulidae), springtails (Collembola), owl flies (Neuroptera: Ascalaphidae) and damsel flies (Odonata: Zygoptera). Although few, the data of Martin are of interest because they suggest a dietary shift in prey size with body size that influences which taxa are eaten. Notably, newly metamorphosed toads consumed mostly spider mites (70 percent) and owl flies (10 percent). In contrast, two-month old metamorphs also took spider mites (20 percent) and owl flies (5 percent), but contained mostly small spiders (45 percent) and chalid wasps (20 percent). One-year olds that contained mostly ants (75 percent) had not eaten spider mites or owl flies. The two adults had eaten mostly craneflies, beetles, and large spiders; the female ate mostly craneflies (75 percent), the male ate mostly beetles (40 percent). Predominance of terrestrial prey in the diet was in agreement with Wood (1977).

Yosemite toad tadpoles are grazers (Grinnell and Storer 1924). Cannibalism has been recorded in Yosemite toad tadpoles (Chan 2001), but this single observation is ambiguous as to whether the cannibalized tadpole was actually killed by conspecifics or was eaten opportunistically after dying of some other cause. Tadpoles can be highly opportunistic, as illustrated in the Martin (1991a) photograph of many tadpoles swarming on a dead ground squirrel (species not identified). Martin (1991a) also describes Yosemite toads feeding on the tadpoles of Pacific chorus frogs (*Pseudacris* [*Hyla*] *regilla/sierrae*) and predaceous diving beetle larvae, but it is unclear whether this is opportunistic feeding on dead individuals.

Mortality

Several biotic and abiotic sources of mortality affect Yosemite toads. Sources of mortality vary from easily observed (e.g., for immobile egg masses) to elusive (e.g., for relatively mobile adults where observing mortality events such as predation is often difficult). Further, changing conditions attributable to factors such as climate change or exposure to new diseases make it difficult to gauge historically typical patterns of mortality.

Mortality during embryonic development seems relatively high, and freezing and desiccation seem to be important causes. Nearly all the eggs in masses laid in shallow oviposition sites at Tioga Pass Meadows in each study year died, presumably because of freezing before hatching (Kagarise Sherman 1980, Kagarise Sherman and Morton 1984). These eggs turned white when they died and became covered with what appeared to be a white, fuzzy fungus. Whether this fungus actually accounted for any mortality or simply grew on the eggs after death is unclear. In 1996-2001, Sadinski (2004) monitored 17 Yosemite toad breeding sites (mostly in Yosemite National Park) and found embryonic mortality at individual breeding sites averaged about one-third of eggs laid annually (range: about 1-96 percent); much of this mortality was attributable to freezing. Mortality attributable to freezing occurred more often at sites where breeding occurred earlier in the year (typically lower in elevation). It was inversely related to median minimum air temperatures during breeding, which was positively associated with elevation, and it appeared to be associated with exposure to ice, since egg masses at least partially encased in ice typically had high mortality. Sadinski (2004) also observed a fungus rapidly invade freeze-killed embryos; based on samples obtained from egg masses in 2004, it was identified as the water mold, *Saprolegnia diclina*. Fungal load on egg masses was positively correlated with numbers of dead embryos, and Sadinski also noted that once the fungus was established, it would spread over the entire egg mass, also killing presumably live embryos if these were not close to hatching. During breeding surveys from 2006-2013, Brown (2014) routinely observed high mortality of egg masses attributable to freezing and desiccation. In some cases, entire egg masses were stranded as water receded from shorelines or dried up.

Besides the water mold, Sadinski (2004) observed an unidentified flatworm (Turbelleria) feeding on Yosemite toad eggs. Though not quantified, flatworm numbers were described as relatively high on some egg masses. Flatworm numbers were also greater on egg masses where the water mold was present and with more dead embryos, and flatworms were often seen killing developing embryos. In 2001, when minimum air temperature during the Yosemite toad breeding interval increased, presence of flatworms in egg masses was observed to decrease. Mortality during tadpole development also seems relatively high, and desiccation seems to be an important cause. Kagarise Sherman (1980) viewed desiccation of breeding habitat before tadpoles could metamorphose as a particularly important cause of mortality (see also Kagarise Sherman and Morton 1993, Brown 2014). At Tioga Pass meadows, the drought winter of 1975-76 resulted in such shallow snow depths that the shallow tarns dried up by 12 July, killing almost all tadpoles present. Only 20-30 tadpoles, located in the deepest tarn, survived this event (Kagarise Sherman 1980). Sadinski (2004) also found that all or portions of breeding sites often dried before Yosemite toad tadpoles were able to metamorphose. The hydroperiod length of breeding sites affected metamorphic success and resulted from summer storms as well as snow melt. During rangewide surveys of Yosemite toad breeding sites, crews commonly found desiccated tadpoles (Brown 2011). For example, in a meadow on the Stanislaus National Forest, tadpoles were desiccating as early as mid-July despite the fact that 2005 was a wetter year than normal (Brown 2006). Later in the summer, hundreds of desiccating and dead tadpoles were found in these meadows. A similar pattern was observed in 2006 which also was a wet year.

A SNAMPH crew recorded a seemingly unusual instance of predation on 31 July 2005 (Brown 2006). Numerous (1000s) of Yosemite toad tadpoles were initially seen in a meadow pool. On a subsequent visit, only 50-100 tadpoles (most with four limbs) remained, along with several metamorphs. No metamorphs were found away from the water or in the surrounding meadow, and a large number were dead at the site. A large carpenter ant (*Camponotus modoc*) colony was present, and ants were observed attacking metamorphs along the water's edge. In several instances, a carpenter ant was seen to chase down, bite, and kill a metamorph and clusters of ants were observed feeding on dead metamorphs. A revisit the next day found the pool to be completely dry. No tadpoles, metamorphs, or even desiccated remains were found, but hundreds of ants were seen at the site. The importance of this kind of predation is unclear.

Although Kagarise Sherman (1980) generally viewed predation of Yosemite toad tadpoles by passerine birds and invertebrates a minor source of mortality relative to desiccation of breeding sites, anecdotal and experimental observations of predation on Yosemite toad tadpoles exist, and the relative importance is unknown. In 1976-77, Kagarise Sherman (1980) saw American robins (*Turdus migratorius*) eat Yosemite toad tadpoles from breeding pools on five occasions. On three occasions in July 1977, Kagarise Sherman (1980) noticed predaceous diving beetles (*Dytiscus* spp.) with a Yosemite toad tadpole in its mandibles. Grasso (2005) found that diving beetles ate Yosemite toad tadpoles; however, in experimental choice tests in which two tadpoles (one Yosemite toad and one Pacific treefrog) were offered to individual beetles, the beetles always switched to eating the Pacific treefrog larva. Mullally (1953) saw a dragonfly naiad capture and kill a Yosemite toad tadpole, an observation that Kagarise Sherman (1980) never made despite the fact that she recorded dragonfly naiads as common in her study tarns. Stomach contents analysis of four mountain yellow-legged frogs led Mullally (1953) to suggest that some frogs fed largely on Yosemite toad tadpoles; each contained 1-9 Yosemite toad tadpoles among a few other prey. Oregon spotted frogs (*Rana pretiosa*) also prey on the early life stages of toads for food (Pearl and Hayes 2002). One presumed instance of cannibalism in Yosemite toad tadpoles has been recorded (Chan 2001); however, it was unclear whether the tadpole being cannibalized was actually killed by conspecifics or if it was eaten opportunistically after dying of some other cause.

Several species of garter snakes occur within the Yosemite toad range and can be common in Yosemite toad breeding sites. These include the western/mountain garter snake (*Thamnophis elegans*), the Valley form of the common garter snake (*T. sirtalis fitchi*), and the Sierran garter snake (*T. couchi*). Grasso (2005) noted seeing western/mountain garter snakes consume all life stages of the Yosemite toad except eggs during field surveys and Nelson (2008) documented this in a study of western/mountain terrestrial garter snake diet in six meadows on the Sierra National Forest in 2007. In that study, garter snakes were found to be opportunistic foragers; they preyed on all life stages of Yosemite toads, but if Pacific treefrogs were present that species appeared to be preferred and snakes were more abundant and had higher body condition index when feeding on Pacific treefrogs. Karlstrom (1962) thought that western terrestrial garter snakes might be particularly important predators of Yosemite toads because they occur at high elevations in the Sierra and are known to prey on co-occurring anuran species (Matthews et al. 2002; see also Fitch 1940). Fitch (1940) reported toads as prey of the common garter snake and the Sierran garter snake, but toads were infrequently identified to species, and the Yosemite toad was not among those identified.

Grasso (2005) and Grasso et al. (2010) experimentally demonstrated that the eggs and tadpoles of Yosemite toads were unpalatable to brook trout (*Salvelinus fontinalis*), and that even the mouthing or sampling of tadpoles by potentially naïve brook trout rarely injured them. These experiments indicate that brook trout predation on Yosemite toads is unlikely (see Introduced Fish and Other Predators section).

Sources of adult Yosemite toad mortality are difficult to determine because they are rarely observed directly. Nearly all reports originate with Kagarise Sherman (1980; see also Kagarise Sherman and Morton 1993). From 1976 to 1979, she observed 12 successful and four unsuccessful attacks by Clark's nutcracker (*Nucifraga columbiana*; see also Mulder et al. 1978). Clark's nutcrackers were believed responsible for 1-6 Yosemite toad deaths annually and just over one-quarter (26.7 percent) of all known mortality of adult toads over the four-year study. Nine of these toads were attacked while crossing snow, five were in the vicinity of breeding pools, and two were near willow overwintering sites when a nutcracker found them. In 1978, she twice observed a California gull (*Larus californicus*), a potential predator, attack but not kill an adult Yosemite toad. Kagarise Sherman (1980) also documented the death of one female that may have drowned or been asphyxiated when multiple males attempted to amplex her, and found three additional females and two males that may also have died during such mass amplectic behavior. Kagarise Sherman (1980) believed that toads could die of exposure when crossing snow or ice if they were caught in late-season storm events. In 1977, a series of closely spaced storms between 30 April and 26 May brought high winds, intermittent snow, and low temperatures. These storms began after Yosemite toads had emerged from hibernation and delayed breeding for nearly a month (Kagarise Sherman 1980). The influence of the storms was especially pronounced on the early-emerging males. In 1977, males lost more weight, a greater percentage of their emergence weight, and at a faster rate/day than males in 1976 and 1978 that were not exposed to such a lengthy interval of unfavorable conditions. Further, Yosemite toads with insufficient reserves to survive an overwintering period may simply die inside their hibernacula, where they would not be observed.

Bird predation on adults, particularly by corvids, may be underestimated because actual predation events may often be unobserved and if toads were carried off, no evidence of the event might remain. Common ravens (*Corvus corax*) have been observed preying on western toad adults (Olson 1989) and may eat adult Yosemite toads. Based on the Breeding Bird Survey (Sauer et al. 2011), the number of common ravens in the Sierra Nevada has increased by 9.5 percent annually over the 24-year period 1966-1989 (Davidson and Fellers 2005), a pattern that may be related to human activities (Kagarise Sherman and Morton 1993).

Emergent diseases have recently been identified as a possible source of mortality for Yosemite toads. Chytridiomycosis, caused by the amphibian chytrid fungus (*Batrachochytrium dendrobatidis, Bd*), bacillary bacterial septicemia, or a combination were detected in histological examinations of four of 12 toads that were salvaged or collected during a die-off in 1976-1979 that immediately preceded a population decline (Green and Kagarise Sherman 2001). The importance of chytridiomycosis in recent declines of mountain yellow-legged frogs in the Sierra Nevada is well established (Rachowicz et al. 2006, Vredenburg et al. 2010), but the importance of this disease in declines of Yosemite toads remains unclear. Details of the risk of this disease are addressed in the Risk Factors section. Green and Kagarise Sherman (2001) also found infectious diseases of uncertain significance in five additional adult Yosemite toads from this same sample. These included a systemic fungal infection by an unidentified species of *Dermosporidium* in one toad; an infection of the kidney by the myxozoan, *Leptotheca ohlmacheri*, in another toad; and a systemic infection by larval nematodes of an unidentified species of *Rhabdias* in three adults.

Key Ecological Factors to Consider for Species Conservation

Many factors contribute to the long-term viability of the Yosemite toad, but the following components of its natural history are considered important for its conservation:

Resource needs of each life history stage (eggs, tadpoles, subadults, adults) vary and are important for population persistence. Successful breeding, metamorphosis, recruitment of new individuals into the adult population, and survival of the long-lived adults are required for long-term viability. In particular, mortality rates of eggs and tadpoles appear to be high naturally resulting in low recruitment in many years. Thus, factors that increase survival of these stages are important. In the unpredictable and often extreme conditions of Yosemite toad environments (e.g., prolonged drought, extreme cold periods), the long lifespan of adults may sustain populations over the long-term. Thus, conservation measures that reduce mortality of early life stages and increase the survival of adults are important.

- Required habitat components for all life stages are important. Data are lacking on habitat requirements, particularly for nonbreeding and overwintering habitats. However, based on our current knowledge, Yosemite toads need access to several habitat types to complete their life history. These include:
    - Aquatic habitat for egg, larvae, and tadpole rearing through metamorphosis. These habitats most commonly are very shallow, warm water found in wet meadows, ponds, lake edges, slow-flowing streams, and backwaters. Warm water facilitates rapid development and the hydroperiods of the shallow ephemeral breeding habitat must be long enough for tadpoles to metamorphose;

  - Nonbreeding habitat for post-metamorphic toads including meadows, headwater springs, and uplands. These habitats may be relatively dispersed;
  - Suitable overwintering habitat which may include rodent burrows, large hollow logs, and complex talus debris.
- Although studies are limited, Yosemite toads appear to display regional, and perhaps even local genetic differences. It is important to take this variation into account when developing the conservation strategy. Genetics must also be considered if translocation becomes an option. The spatial scales over which populations function remain largely unknown; genetic data are needed to effectively and precisely define that scale and its variation.

  Conservation goals include preserving the genetic variability that remains throughout the species' range and re-establishing and preserving the gene flow that was historically present. This may be accomplished by conserving populations (both numbers of populations and abundances) throughout the species' historical range and preserving intervening habitat that provides avenues for dispersal and colonization.
- To accomplish the above goals, conservation of the species may be best accomplished by integrating strategies at multiple scales.

In summary, approaches for conserving the Yosemite toad should provide mechanisms to manage for the species throughout its entire range, for all life history stages, and for all required habitats. The species should be managed at multiple scales and conservation should seek to stabilize and increase abundances of existing populations by protecting them from known risks and by increasing connectivity.

STATUS

This section provides a summary of the status of the Yosemite toad. Comparisons are between recent (post-1980) and historical (pre-1980) population distribution and abundance. The year 1980 was chosen to partition recent and historical data because the first quantified declines in the Yosemite toad were evident just prior to 1980 (Kagarise Sherman and Morton 1993). Hence, it was thought such a break would provide the best contrast between the intervals when Yosemite toad populations were presumably still largely intact and when their declines became evident.

In 2001, information was compiled from USDA Forest Service, National Park Service, and California Department of Fish and Wildlife biologists working in the Sierra Nevada, from academic researchers, and from literature and museum sources. A substantial amount of data has been collected after 2001; these data have been compiled to a limited extent and are described in this assessment to varying degrees.

Documentation from museum collections is listed according to the standard symbolic codes for each institution (Appendix 1) and the pertinent specimen number(s) in the status discussion. Appendix 2 provides distribution and abundance information for individual national forests and national parks.

Prior to 1980

Historical data on the Yosemite toad extend back to 8 June 1915, when Tracy Irwin Storer collected the first individual of this species at Porcupine Flat in Yosemite National Park (MVZ 5759), the year prior to the species description (Camp 1916). Records prior to 1980 exist for Yosemite toads in the Sierra Nevada from a meadow area between Heather and Grass Lakes (El Dorado County; LACM 11885-11886) and the Blue Lakes, upper Mokelumne River Basin (Alpine County; MVZ 64877-64878, CAS-SU 6420) in the north to Evolution Lake, Kings Canyon National Park (Fresno County; MVZ 38633) and Rock Meadow, 8 km south of Kaiser Pass (Fresno County; CAS-SU 10998-10999) in the south (Stanton 1940, Wiggins 1943, Livezey 1955, Mullally and Powell 1958, Karlstrom 1962, Jennings and Hayes 1994). The historical range appears to have been exclusively in California (Figure 6).

The species' historical elevational range was from about 1,980 m at Aspen Valley in Yosemite National Park (Tuolumne County; MVZ 16061) to over 3,400 m in lakes north of Mount Dana (Mono County; CAS 65926; SDNHM 30034, 30436) and in Pine Creek Pass (Inyo County; MVZ 41293-41294; see also Zweifel 1955, Mullally and Cunningham 1956, Karlstrom 1962). Well over 90 percent of historical locations are at or over 2,600 m. Morton and Sokolski (1978) stated that the Yosemite toad is seldom found below 2,134 m.

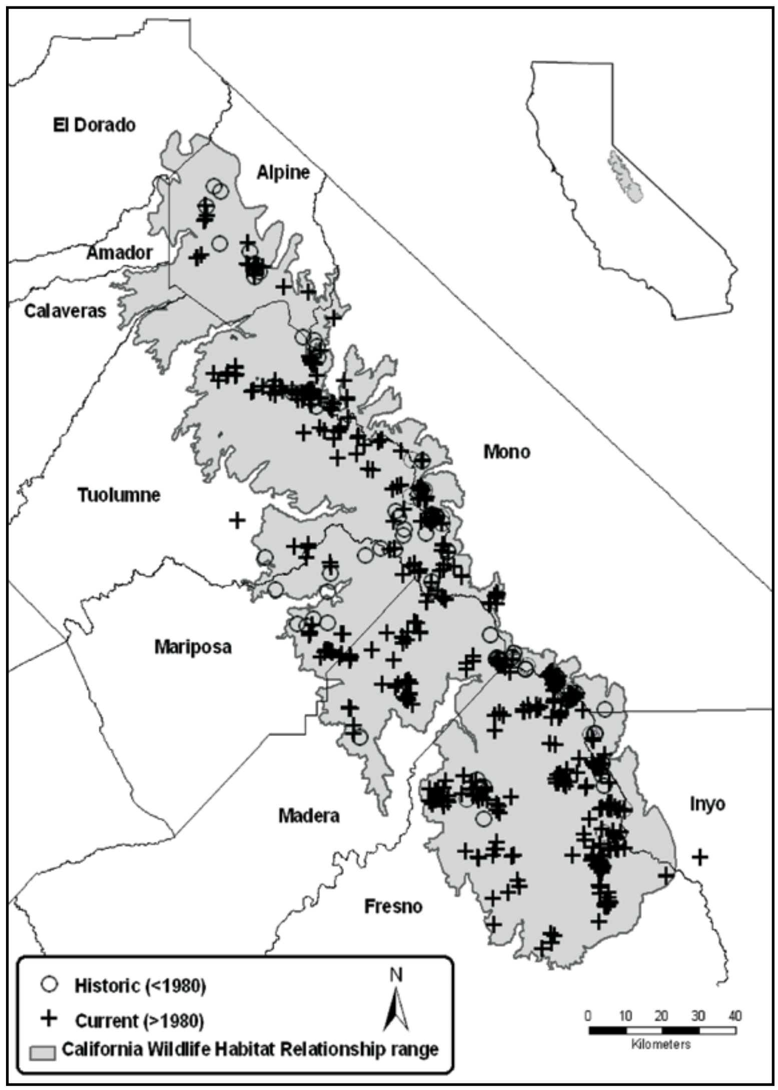

Figure 6. Historical and recent localities for the Yosemite toad (*Anaxyrus canorus*) in the Sierra Nevada, California. This map contains most known localities up to 2002, and a few localities up to 2003.

Few data exist describing Yosemite toad abundance prior to 1980. Grinnell and Storer (1924) noted that Yosemite toads were a "common resident in Canadian and Hudsonian zones" and used terms such as "many males present" and "numbers of [toads or males] found" to describe abundances in several locations. In 1952, Mullally (1953) visited Tioga Pass and the lakes and stream in the adjacent Gaylor Lakes Basin (on 14-17 September 1952). He noted that:

> Yosemite] Toads were numerous about the lakes on the crest of Tioga Pass and at a lake located at 10,100 ft [3,078 m] on the northwestern side of the Gaylor Lakes Basin. They were also common along the stream flowing from Upper to Middle Gaylor Lake and along the stream flowing into the lake located at 10,100 ft.

Mullally (1953) also described other locations where toads were few or not found, making comparisons among habitats. Nonetheless, these quotes imply that toads were numerous, at least in some locations. In addition, the fact that more than 93 percent of the roughly 1,200 specimens of Yosemite toads that exist in museum collections were taken prior to 1980, and the numbers of toads collected by various investigators over this period implies that they were historically common. For example, John Van Denburgh and Joseph Slevin collected 118 Yosemite toads from Tuolumne Meadows in 1922 (CAS 55524-55619, 55645-55663; MCZ A9003-A9005; UMMZ 57498); Kenneth Stanton and Douglas Motley collected 46 Yosemite toads from Mildred Lake in 1940 (CAS-SU 5878-5834, UIMNH 34728); and Ernest Karlstrom collected 100 Yosemite toads from near Tioga Pass in 1954-1955 (MVZ 61790-61794, 62543, 62545-62638). All three are localities at which later workers recorded Yosemite toads as common during the 1960s and 1970s (Kagarise Sherman 1980, Kagarise Sherman and Morton 1993, MVZ field notes from various workers, e.g., David Wake).

The only investigators providing systematically collected abundance data prior to 1980 were Morton and Sokolski (1978), Kagarise Sherman (1980), and Kagarise Sherman and Morton (1993). They provided some data on seven localities: Frog Lakes, Hoover Lake, Mildred Lake, two sites on Saddlebag Lake, Sylvester Meadow, and Tioga Pass Meadows. The most systematic demographic data were collected at Tioga Pass Meadows where toads were marked. From 1971-1979, a total of 2,165 toads were marked including 1,252 males, 665 females, and 248 immatures (Kagarise Sherman 1980). From 1974 to 1978, annual counts of adult males ranged from 162 to 342, declining to 75 in 1979, and counts of females ranged from 45 to 100 (Kagarise Sherman and Morton 1993). Counts of females are typically lower because they are more cryptic and harder to find. Over the more extended period, 1971-1982, a total of 2,270 animals were observed (Kagarise Sherman and Morton 1993). Note that the majority of the animals were recorded prior to 1980.

At Frog Lakes, Morton and Sokolski (1978) marked 70 individuals from 10 to 13 July 1976, and an additional 81 were found in August of that year (life stage was unspecified). Kagarise Sherman and Morton (1993) reported the range of numbers of toads (≥ 2 year old) found per survey at that site to be 4-67 in 1976 and 43-143 in 1977. At Hoover Lake, the range of numbers of toads found per survey was 25-85 in 1976 and 16-60 in 1977. The range of numbers of toads found per survey at Mildred Lake was 13-216 in 1976 and 37-97 in 1977. Abundances at Saddlebag Lake NW and SE, and Sylvester Meadow during 1976 and 1977 were less. See the accounts for the national forest or park units in Appendix 2 for more information on these sites. These data suggest that at least some toad populations were reasonably large historically.

Post-1980

Most data from 1980 to the present are based on survey information (broad scale surveys that report both positive and negative data) targeting occupancy (presence/not found) rather than abundance. Further, a considerable amount of new toad survey data have been collected since the original 2002 data compilation. Table 1 summarizes these survey efforts.

Only 60 of the roughly 1,200 specimens of Yosemite toads that exist in museum collections were taken since 1980. This disparity partly reflects a decrease in collection frequency relative to field efforts for a variety of reasons: (1) the toad was listed as a Species of Special Concern in 1989, which restricted collecting; (2) Yosemite toads have been increasingly perceived as having been well-vouchered across their geographic range; and (3) negative views toward collecting. This disparity may also reflect declines and disappearances of the species over portions of its geographic range. The 60 specimens represent 18 different localities, 7 of which were also historically collected; information on these specimens is provided in the respective administrative units in which they occur in Appendix 2.

Systematic survey efforts in the Sierra Nevada did not begin until the early 1990s. In 1990, surveys were conducted at 75 sites for which historical records of species presence existed (cut-off date was pre-1975 for these surveys) throughout the range of the Yosemite toad using 2 one-hour time-constrained searches at each site. These surveys did not detect Yosemite toads at 47 percent (n = 35) of those sites (Martin 1991b, 1991c). During the course of these surveys, Yosemite toad life stages were also incidentally encountered at 9 sites that were not part of the historical record.

Between 1 June and 28 August 1992, field crews conducted general amphibian surveys throughout the national forests of the Sierra Nevada (Martin et al. 1992). These surveys included 24 sites within the known geographic and elevational range of the Yosemite toad (this includes all of the Eldorado National Forest; additional surveys were conducted outside of the toad›s range), of which 58 percent (n = 14) included habitat with a high probability of toad occupancy (meadows). Yosemite toads or possible western/Yosemite toad hybrids were found at half (n = 7) of the higher probability sites (meadow habitat) and none of the lower probability sites (no meadow habitat). Except for one breeding site in the Eldorado National Forest, surveys found almost exclusively adult rather than toad tadpoles and never more than 40 individuals per site.

Based on data from a variety of sources (e.g., Martin 1991b, 1991c; Martin et al. 1992; Drost and Fellers 1996, their own fieldwork), Jennings and Hayes (1994) estimated that the Yosemite toad had declined or disappeared from over 50 percent of the sites where it had been historically recorded across its geographic range. Jennings and Hayes (1994) provided a distribution map showing which sites were extant and which were likely extirpated. Davidson et al. (2002), using the data from Jennings and Hayes (1994) which was based on 55 locations treated independently, reported the value of disappearance at 52 percent of sites across the geographic range. Davidson et al. (2002) also found the Yosemite toad to be disproportionately absent at lower elevations, with that pattern explaining about two-thirds of the variation in occupancy.

In its 12-Month finding to list the Yosemite toad, the USFWS (2002) reported that of 292 sites surveyed across its historical range, 78 percent (n = 229) had been recorded as occupied since 1990. The dataset upon which the USFWS based their analysis was compiled by the USDA Forest Service to support development of this conservation assessment (sources are described at the beginning of this Status section, see above). In their analysis, localities that were currently occupied were assumed to also have been occupied historically.

From 2000-2002, Knapp (2005) surveyed 2,655 mapped and unmapped water bodies in Yosemite National Park. Yosemite toads were detected at 2.8 percent of the sites (n = 74). Surveys for this effort were single-pass visual encounter surveys during the summer season.

Between 2002 and 2005, systematic surveys of potential habitat for Yosemite toads were undertaken on the Sierran national forests within the Yosemite toad›s geographic range (only Forest Service lands were surveyed). The purpose of these surveys was to provide an inventory of Yosemite toad occupancy (presence/not found) in suitable habitat across its historical range to provide guidance for range management (see Appendix 3). Because tadpoles are the life-stage most reliably found, they were the focal life stage for these surveys (protocol in Appendix 3). Although the habitats with first priority for surveys were meadows in range allotments, many meadows and lakes both within and outside of allotments were surveyed. Thus, these surveys encompassed a large proportion of potential Yosemite toad habitat available on national forests; these surveys uniformly collected data at more sites and recorded more Yosemite toad localities than any previous survey. These surveys indicate that Yosemite toads occur at approximately 470 localities (lakes, meadows, stream sections) collectively on five Sierra Nevada national forests (Table 1). The majority of these localities (approximately 70 percent) are on the Sierra National Forest. Interpretation of these data relative to the species' status is difficult given the lack of historical information.

Table 1—Summary of Yosemite toad survey data collected in the Sierra Nevada since 2000

Program	Years	No. units surveyed[a]	No. occupied units[b]	Extent of surveys	Description
USDA Forest Service (Region 5) Inventories:	2002-2005				Surveys of potential Yosemite toad habitat to support Range Management. Surveys were prioritized for meadows in allotments and timed to coincide with the tadpole life stage to document breeding. In addition, many surveys were conducted in other habitat types and outside allotments. Surveys obtained present/not found data.
Eldorado National Forest	----	77 Sites	7 (*A. canorus*, *A. boreas*, or hybrid)	Forestwide	
Stanislaus National Forest	---	290 Sites	36 with 26 having evidence of breeding	Forestwide	
Sierra National Forest	---	>2230 Sites	323 with 256 having evidence of breeding	Forestwide	
Inyo National Forest	---	>300 Sites	86	Forestwide	
Toiyabe National Forest	---	>50 Sites	17	SN[c] portion of Forest	
USDA Forest Service (Region 5) Sierra Nevada Amphibian Monitoring Program	2002-2009	134 basins	72 (with 65 having evidence of breeding	Rangewide	Long-term bioregional monitoring program designed to assess status and trend of Yosemite toad populations and habitat. Randomized, unequal probability, rotating panel design. Surveys obtain presence/not found data. Summary of data sample is provided here; see text for more detailed explanation and rangewide estimation.
		>2200 sites	274 (with 96 having evidence of breeding)		
California Department of Fish and Wildlife High Mountain Lakes Surveys	2001-2010	8692 sites	270 sites (with 151 having evidence of breeding)	4 National Forests (INF, SNF, STF, TOI)	Surveys designed for mountain yellow-legged frogs and targeted lentic water bodies found on 7.5 minute topographic maps, or discovered during field surveys. Surveys obtained presence/not found data. Surveys were not timed to coincide with life stages indicative of toad breeding and may have occurred after metamorphosis.
Yosemite National Park	2000-2002	2655 water bodies	74 sites	National Park	Surveys conducted in mapped and unmapped water bodies using single-pass visual encounter surveys.

[a]Sites generally refer to lakes, meadows, or stream segments, but definitions may differ among the studies. Sites do not imply populations.

[b]For Stanislaus NF surveys, "evidence of breeding" is defined as presence of eggs or tadpoles. For Sierra NF and Amphibian Monitoring Program surveys, it is defined as presence of eggs, tadpoles, or metamorphs.

[c]SN = Sierra Nevada

In addition to the inventories mentioned above, in 2002, the USDA Forest Service implemented the Sierra Nevada Amphibian Monitoring Program (SNAMPH), a bioregional monitoring program designed to assess the status and trend of Yosemite toad breeding populations on national forest lands across the species' range (Brown et al. 2012, Brown and Olsen 2013). Small watersheds (2-4 km^2) are surveyed throughout the range of the species over a proposed 5-year cycle, with 20 percent revisited annually. An unequal probability sample of watersheds was selected based on historical occupancy using three mutually exclusive categories. In recently occupied watersheds, Yosemite toads were last observed between 1990 and 2001, in historically occupied watersheds they were last observed prior to 1990, and in the remaining watersheds occupancy was unknown or toads had 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, 134 watersheds were surveyed across the Yosemite toad's range containing > 2200 meadows, lakes, ponds or stream reaches. Yosemite toad breeding was found in an estimated 22 percent (se = 1.2) of watersheds rangewide (Figure 7). The species was found to be fairly widespread relative to recent distributions but has declined from historical levels. Breeding was found in an estimated 84 percent (se = 3.2) of watersheds with known presence of toads 1990-2001 and in only about 13 percent (se = 3.8) of watersheds with locality data only prior to 1990. Few additional watersheds were occupied by adults or subadults with no signs of breeding (Brown et al. 2012). Numbers of occupied sites by forest are summarized in Appendix 2.

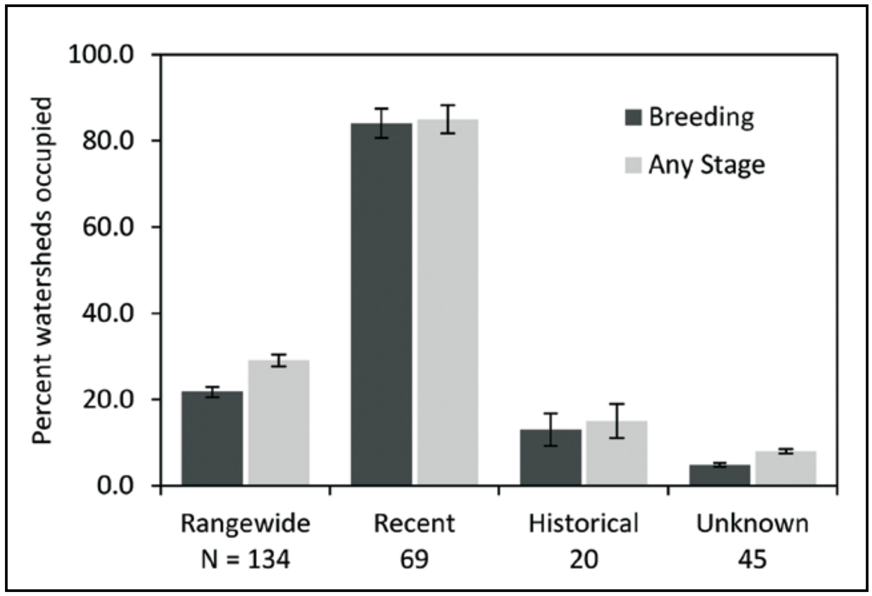

Figure 7. Estimated percent of watersheds occupied by Yosemite toad breeding (dark bars) and any life stage (light bars) by historical occupancy category from USFS SNAMPH monitoring of 134 watersheds on national forest lands throughout the Yosemite toad range from 2002 through 2009. See Brown et al. (2012).

During surveys for mountain yellow-legged frogs, CDFW also detected Yosemite toads at a small number of sites. Over the period 2001-2010, CDFW surveyed 8,692 sites on the four national forests encompassing some of the Yosemite toad's historical range. A site was defined as any lentic water body roughly within the mountain yellow-legged frog range 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. Yosemite toads were detected at just over 3 percent of sites (n = 270) on four national forests (Humboldt-Toiyabe, n = 42; Inyo, n = 87; Sierra, n = 93; Stanislaus, n = 48). These data provide additional information on Yosemite toad presence, but surveys were designed to detect mountain yellow-legged frogs rather than Yosemite toads and the predominant habitat surveyed was lakes rather than the typical wet meadows used by Yosemite toads.

It is difficult to assess changes in Yosemite toad population abundances. There are no range-wide estimates for historical abundance, and only one systematic study that estimated population sizes prior to 1980. Further, little information is available about current population sizes. Nevertheless, all sources available suggest that current population abundances are generally less than historical levels. Kagarise Sherman and Morton (1993) indicated either a five-to-ten-fold decline in numbers, or extirpation by 1990 for 7 different Yosemite toad populations; no populations increased. They resurveyed Tioga Pass Meadows in various ways during the interval 1981-1991. They provided data on adult numbers in their study breeding pools for the years 1981 and 1982; on the mean number of adults found at breeding pools on each survey day for 1981, 1982, and 1990; and on periodic surveys for selected other years during the interval 1983-1991. In the study pools in Tioga Pass meadow, the number of males had dropped to 28 by 1982, and only 2 males were found in 1990. Although the number of females remained similar in the 1970s through 1982, a decline was noted by the 1990s. In 1990, only one female and 4-6 egg masses were found, and in 1991, no females and one egg mass were found. At the 6 other sites described by Kagarise Sherman and Morton (1993), the numbers of toads found per person-hour had declined by 1990.

From 2006 to the present, the USDA Forest Service monitoring program, SNAMPH, has conducted mark-recapture of adult males and counts of egg masses during the spring breeding chorus in 6 meadows in 2 watersheds (Stanislaus and Sierra National Forests). Populations in the six meadows appear to be very small relative to the historical numbers reported by Kagarise Sherman (1980) and Kagarise Sherman and Morton (1993). From 2006-2009, annual estimates of adult males per meadow were generally less than 20 individuals and some meadows had only a few toads. Numbers of egg masses also were low (Brown et al. 2012; see Population Dynamics in Ecology section) (Figure 8). A longer time series of these data (through 2014), show similar results. In a six year study of 19 meadows in the central and southern Sierra Nevada, similarly small population sizes were found at the majority of the meadows (A. Lind 2010).

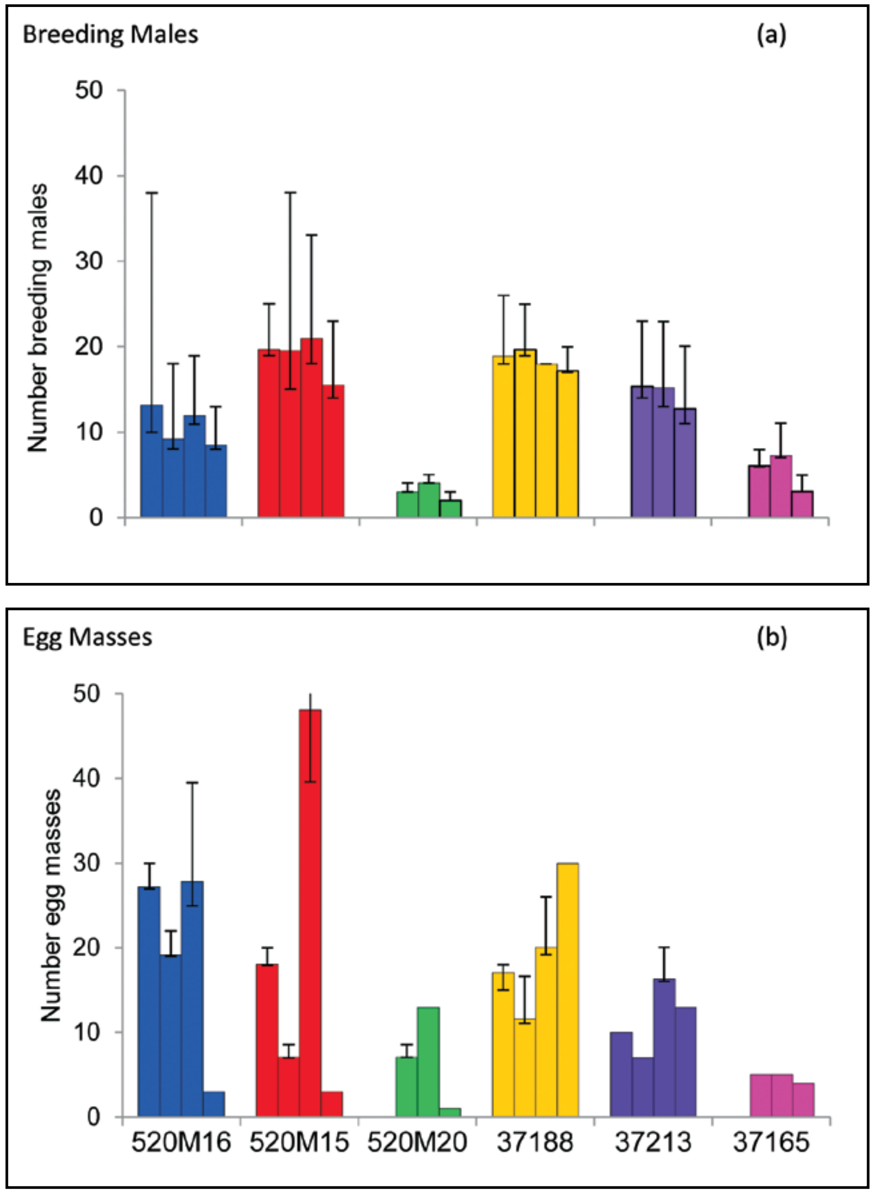

Figure 8. Estimated number of (a) breeding males and (b) egg masses from 2006 through 2009 from USFS SNAMPH monitoring of six meadows in the Bull Creek Watershed on the Sierra National Forest (520M16, 520M15, 520M20) and the Highland Lakes Watershed on the Stanislaus National Forest (37188, 37213, 37165). Each cluster of bars is one meadow and each bar is a year. See Brown et al. (2012).

Finally, most of the recent surveys described above (Martin 1991b, 1991c; Martin et al. 1992; Drost and Fellers 1996, Brown et al. 2012) consistently reported low numbers in contrast to the large collections historically made within a single day. This supports the view that current abundances are low. However, several caveats should be made in interpreting these survey data. Given current knowledge of toad ecology, estimates of abundances cannot reliably be made from one-time surveys (but note that SNAMPH intensive abundance estimates are based on mark-recapture methods). Large numbers of animals are indicative of larger populations, but small counts may be attributable more to the timing of surveys rather than true abundances. Adult toads are not reliably found outside of breeding, a time that is not practical to survey in most locations. Yosemite toad tadpoles develop quickly and their habitats often are ephemeral; thus surveys conducted after the majority of tadpoles have metamorphosed or desiccated will underestimate tadpole abundance (Brown et al. 2012).

Finally, assessments of occupancy may depend on annual precipitation patterns; toads may be more active or tadpoles available longer during the season during wet years than dry years. Despite these caveats, historical accounts suggest that toads were relatively common and easy to find, which does not appear to be the case today.

Conclusions about Status

The Yosemite toad, once a common amphibian in high-elevation aquatic ecosystems of the Sierra Nevada, appears to have declined over the last 20 years. However, assessing status is difficult because so few historical data exist. Depending on the scale and definitions of current and historical occupancy, analyses from the 1990s estimated that toads had declined from approximately 50 percent of historical locations (e.g., Martin 1991b, 1991c; Jennings and Hayes 1994; Drost and Fellers 1996; Jennings 1996). The more recent rangewide assessment conducted by SNAMPH found that toads still occupied the majority of watersheds (84 percent) where they have been found more recently (1990-2001), but have declined from most of the watersheds where they were last observed prior to 1990 (only 13 percent still occupied). Forest Service surveys conducted during the early 2000s have found toads in approximately 470 localities on five national forests, but the majority of these were from one national forest (Sierra NF); the lack of historical data collected with the same level of effort precludes interpretation of these numbers.

Importantly, indications are that remaining Yosemite toad populations may have declined from their historical abundance levels and some populations appear very small. It is not known whether these populations are persisting at low numbers or whether they are on a slow trajectory to extirpation.

The decline in occupancy and abundances suggest fragmentation may be an increasing problem for this species. If the species typically functions as metapopulations, opportunities for these dynamics to exist have become more limited. Small, isolated populations are more susceptible to local extirpation and loss of genetic diversity, while fragmentation reduces the chances of recolonization following extirpation events.

Although the numbers and abundances of Yosemite toad populations have been reduced, populations remain in many parts of the toad's historical range. Thus, the opportunity exists for pro-active conservation to prevent further declines. Proposed goals of the forthcoming conservation strategy include:

- Protection of remaining populations to retain the toads in these areas;
- Increasing the size of these populations to better buffer them from stochastic events such as weather extremes and disease;
- Maintenance of current connectivity and providing additional colonization opportunities to facilitate dispersal to new sites and recolonization of unoccupied sites.

RISK FACTORS AFFECTING THE STATUS OF THE SPECIES

Risk factors include environmental conditions and human activities that may adversely affect individuals, populations, or their habitat. These include anthropogenic and other factors. The following are the 16 risk factors identified and evaluated for this Yosemite toad Conservation Assessment:

- Acid deposition
- Airborne contaminants, including pesticides
- Climate change
- Disease
- Fire management, including fire suppression
- Habitat loss and fragmentation
- Introduced fish and other predators
- Livestock grazing
- Locally applied pesticides
- Recreational activities, including packstock
- Research activity
- Restoration
- Roads
- UV-B radiation
- Vegetation and fuels management
- Water development and diversion

For the narratives that follow, risk factors are intentionally listed alphabetically to avoid implying an importance gradient. Each risk factor is described in detail, including its potential impacts, and this provides information for evaluating its relative importance. This evaluation, which provides the rationale for the conservation actions to be developed in the conservation strategy, is provided in a summary following these narratives.

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). Thus, 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 has affected amphibian populations (Freda 1990), so this was considered a possibility for Yosemite toads in the Sierra Nevada.

Based on sampling from 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 3000 m elevation or in basins with calcareous rocks. Melack et al. (1985) also recorded circumneutral summertime pHs (i.e., between 6 and 8), and concluded that although Sierran lakes do not 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 more than 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 five subregions sampled. Further, the subregional pattern of low ANC was a consequence of the disproportionately low ANC levels recorded in many Sierra Nevada lakes (Eilers et al. 1987, Landers et al. 1987). Despite the low buffering capacity, Sierran lakes had limited acidity at the time of the WLS, underscoring the results of Melack et al. (1985). Of the 719 lakes sampled in the western United States, only one had a pH ≤ 5.0, and only 1 percent of western lakes had a pH ≤ 6.0. This pattern notwithstanding, precipitation acidity at some local stations in the Sierra Nevada (e.g., at about 2,100 m elevation near Lake Tahoe) has increased (Byron et al. 1991), a condition also reflected in snow samples (pH 5.1-5.9; Laird et al. 1986); how these local increases in acidity in precipitation translate to acidity in water bodies is unclear.

Studies have found little evidence of direct effects of acidity on Yosemite toads using levels similar to those recorded in Sierran lakes. Bradford et al. (1992; see also Bradford and Gordon 1992) examined the tolerance of Yosemite toads to low pH in the laboratory and compared the tolerances to the most acid values recorded in Sierra Nevada lakes (pH = 5.0). Embryos and hatchling tadpoles 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 LC50 pH values for post-treatment survival of Yosemite toad embryos and tadpoles, respectively, averaged 4.7 and 4.3. 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 non-lethal effect was observed; Yosemite toad embryos hatched earlier at pH treatments of 5.0. In another survey of 235 potential breeding sites across 30 randomly selected survey areas, Bradford et al. (1994) failed to find significant differences in water chemistry parameters (including pH and ANC) between sites with and without Yosemite toads. Water chemistry also did not differ among sites occupied by Yosemite toads, mountain yellow-legged frogs, and Pacific treefrogs over a gradient that might be predicted if their species-specific acid tolerance limits were influencing their distribution. Bradford et al. (1994) concluded that acidic deposition was not a factor directly contributing to amphibian population declines in the Sierra Nevada at high elevation. In a retrospective analysis among 14 breeding ponds in Yosemite National Park, Sadinski (2004) found no relationship between pH and hatching success; pH values measured ranged from 5.5 to 7.2.

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 five clearwater[1] 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 Yosemite toad embryos and tadpoles 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 seven-day treatment period. The addition of aluminum did not significantly affect the post-treatment survival of Yosemite toad embryos or tadpoles. However, there were sublethal effects; there was a reduction of body size of tadpoles and earlier hatching time for embryos. Aluminum concentrations were greater than those recorded in the field, although concentrations during snowmelt are unknown (Bradford et al. 1992). Interaction of pH with factors other than soluble metals is possible; for example, a potential interaction with ultraviolet radiation is discussed in the Increased UV-B Radiation section. Such interactions remain unstudied for Yosemite toads.

Extent of risks related to acid deposition

Acid deposition does not currently appear to be a factor in the rangewide decline of Yosemite toads. However, the interaction of acidification with other factors is unstudied in this species. The risk level may change with the continuing increase in human populations in California.

Conservation options related to acid deposition

At this time, acid deposition does not warrant management consideration in this conservation assessment. Should the risk level for this risk factor increase, effective management would require coordination of agencies outside the jurisdiction of those involved in this assessment. Agencies responsible for Yosemite toad management should participate in guiding the development of the management and science to inform this issue.

[1] Population estimates for extractable aluminum in the WLS were given only for clearwater lakes, which comprised 96.1 percent of the lake population. Clearwater lakes were defined as having true color < 30 PCU; darkwater lakes (> 30 PCU) were assumed to have adequate concentrations of dissolved organic material to produce organic complexes of aluminum, which can ameliorate the toxic effects of aluminum (Landers et al. 1987).

Airborne Contaminants, Including Pesticides

Declines of amphibians such as Yosemite toads in apparently "pristine" habitats inside national parks raised the possibility that airborne contaminants might be responsible (Drost and Fellers 1996, 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 (in this case DDT residues) had accumulated in the tissues of the sympatric mountain yellow-legged frog, and accumulation in Yosemite toad tissues is possible. New generations of pesticides now in widespread use in the Central Valley renew the potential for negative effects on biota in the Sierra Nevada resulting from 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 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 this region comprises (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 national use (Aspelin 1997, Aspelin and Grube 1999), highlighting the regional concentration. Moreover, recorded use underestimates actual use. However, gross levels of use do not reveal the slow change in the composition in pesticides used over time. 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®[2] 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 some Sierran amphibians were first recognized. 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), and 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 Sieber 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 Yosemite toads use (e.g., Boyer and Grue 1995). 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 anurans while in the water (Cory et al. 1970). Amphibians, such as Yosemite toads which are exposed to both water and air, may be at greater risk of exposure to pesticides which are readily absorbed through the skin, respiratory system, or gastrointestinal tract (Gunther et al. 1968).

Pesticide linkage to Yosemite toad declines is, for the most part, unstudied. The only study that specifically addressed the Yosemite toad was by Davidson et al. (2002) and Davidson (2004) who examined 55 historical locations for presence of Yosemite toads and analyzed the spatial patterns of declines as a function of a series of alternative factors. Numbers of sites where Yosemite toads were absent were not strongly associated with the area of upwind agricultural land use. However, Davidson et al. (2002) found fewer occupied sites at lower elevations, which may reflect in part the proximity of Central Valley pesticides.

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Other data from the Sierra Nevada implicate pesticide drift as a possible factor for amphibian declines in general. Correlative data suggest that pesticides may be linked to mountain yellow-legged frog declines. In 1997, mountain yellow-legged frogs remaining from a reintroduction effort judged to have failed at Tablelands (Sequoia National Park, Fellers et al. 2007) had dichlorodiphenyldichloroethylene (DDE) concentrations that averaged more than 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 the Tablelands sites is likely a function of pesticides, disease (chytridiomycosis), or both.

DDT has been found in the tissues of mountain yellow-legged frogs (Cory et al. 1970). Of 600 mountain yellow-legged frogs collected from the west side of Mount Whitney in the 1960s, Cory found not one free of DDT or its secondary residual DDE. The general pattern of DDT distribution in the 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. These patterns were ascribed to the regional pattern of application and the directionality of airborne drift.

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).

No studies similar to these have been conducted for Yosemite toads. Further, studies addressing Yosemite toad developmental and behavioral response to specific pesticides also have not been conducted. However, 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 Yosemite toads must often metamorphose from ephemeral breeding sites rapidly (see Ecology section), delays in tadpole development or metamorphosis increase the likelihood of tadpole losses resulting from desiccation of rearing sites. Furthermore, given the limited active season within which Yosemite toads must emerge, successfully breed, and consume enough food to survive up to a nine-month overwintering interval, sub-lethal effects of pesticides on adult toads have the potential to impact local populations.

Of particular concern is the possibility that pesticides act as stressors, rendering Yosemite toads 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 (Anver and Pond 1984, Cahill 1990, Carey 1993, Carey and Bryant 1995, Carey et al. 1999). Adult woodhouse toads (*Anaxyrus [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).Studies noted previously do not exclude the possibility that other chemicals are also wind-carried in greater concentrations from areas of intensive agriculture or population centers and either contribute to or are independently responsible for Yosemite toad 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 kilograms/hectare/year over most of the region to 30-90 kilograms/hectare/year 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). It is possible 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 anuran 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 possible condition for lakes in the Sierra Nevada. Consequences of nitrogen and phosphorus loading in high-elevation aquatic systems for Yosemite toads are poorly understood (Fenn et al. 2003b), but possibilities, all speculative to date, include: (1) a shift away from a favorably nutrient-rich diatom flora could result in food limitation for tadpoles (see Kupferberg 1997 for a discussion of ranid frog tadpole diet); (2) some unspecified nutrient-linked shift could facilitate disease establishment; or (3) embryonic or tadpole life stages may be killed by slightly elevated nitrite or nitrate concentrations (see Marco et al. 1999 for a discussion on western North American anurans). Data suggest there have been declines in nitrogen and increases in phosphorus loading. 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 the 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) emphasized that this pattern was not just local, because more than 70 percent of 28 Sierran lakes sampled from 1985 to 1999 showed a decline in nitrates and an increase in phosphorus.

An equally ignored aspect related to airborne contaminants is endocrine disruption. Pesticide and non-pesticide chemicals currently used in California, and the Central Valley in particular, 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 significant effects are manifest at very low concentrations (< 12 parts per billion), low enough to require special technologies for their measurement (Colburn et al. 1996). Also, research has demonstrated that the 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 Yosemite toads remains unstudied.

Although research has not been conducted for the Yosemite toad, more recent research for the mountain yellow-legged frog has not supported a high risk level for airborne contaminants (see Bradford et al. 2010, USFWS 2013). In their proposed rule for listing the Yosemite toad as threatened, USFWS (2013) concluded that contaminants did not pose a significant threat to this species citing evidence used for the mountain yellow-legged frog. They found that "studies confirming exposure in remote locations to ecotoxicologically relevant concentrations of contaminants are not available" to support the hypothesis that contaminants contributed to mountain yellow-legged frog declines and cited 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 Yosemite toads over a broad geographic range. Although preliminary results from studies on other species indicated that the risk is potentially high, this has not been supported by more recent research in the Sierra Nevada. Substantial science will be needed to define the extent of risk associated with this factor. No data exist specifically addressing the risk for Yosemite toads, nor addressing synergistic effects between airborne contaminants and other risk factors.

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 showing agricultural contaminants to be a significant contributing factor to observed declines. Agencies responsible for Yosemite toad 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 declines of both amphibian assemblages (Pounds et al. 1999, 2006) and individual amphibian species (Alexander and Eischeid 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 five- to eight-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).

Yosemite toads breed and rear in extremely shallow, ephemeral water (see Habitat Requirements in Ecology section). Thus, alterations to annual and seasonal hydrologic cycles that reduce the amount or retention of water in breeding areas have the potential to impact Yosemite toad populations. Greater short-term oscillations in annual and near decadal climate variability may alter the frequency, duration, and magnitude of either droughts or severe winters. Since the 1970s, California has sustained two multi-year intervals of severe drought (Center for Biological Diversity and Pacific Rivers Council 2000). Moreover, modeling suggests that the overall effect of global warming on California climate will include higher average temperatures in all seasons, higher total annual precipitation, and decreased spring and summer runoff due to decreases in snowpacks (Smith and Tirpak 1989, USEPA 1997). Reduction in snowpacks, especially in the Sierra where snow loads represent the dominant surface water source to fill breeding pools, can lead to increased stranding and death of Yosemite toad eggs and tadpoles, a major documented source of mortality (Kagarise Sherman 1980, Kagarise Sherman and Morton 1993; see Mortality in Ecology section). Sadinski (2004) observed that summer storms often extended the hydroperiods of breeding sites allowing successful metamorphosis in Yosemite National Park. If this is a common dynamic, climate change, by altering summer storm frequency, could influence metamorphic recruitment success in Yosemite toads. Decreases in summer runoff also have the potential to lead to the loss of foraging and refuge habitat for adults and juveniles. Severe winters may force extended overwintering, thereby stressing toads by reducing time available for feeding outside the breeding interval. Severe winters may kill toads with inadequate reserves to survive a lengthy overwintering period. Morton (1981) thought that fluctuations in energy storage from year to year might explain why many female Yosemite toads do not breed every year; climate scenarios are possible where female Yosemite toads might accumulate only enough energy to typically reproduce biennially, triennially or even quadrennially, which likely has significant demographic consequences.

Drought may also interact with other factors that, to date, are largely unstudied for their additive, multiplicative, synergistic, or secondary effects. If airborne contaminants have negatively affected some Sierran amphibians (Fellers et al. 2004), drought may exacerbate these effects and may have been responsible for the disappearance of the golden toad (*Bufo periglenes*) in Costa Rica (Pounds and Crump 1994). Changes in temperature may affect both amphibian immune systems and pathogen virulence; this may occur to different degrees, making amphibians such as the Yosemite toads more susceptible to disease (Carey et al. 1999). 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 amphibian chytrid fungus, *Bd*. Hogg and Williams (1996) found an experimental increase in stream water temperature decreased density and biomass in invertebrates; thus global warming may have a negative impact on the Yosemite toad prey base. It is possible that climate change effects on Yosemite toads may involve a lag effect (see Thompson and Ollason 2001) that will require identifying the correct time interval of influence; also the correct spatial scale at which climate change has its impact on Yosemite toads may not be identified. Finally, it is possible that climate change may exacerbate the effects of other risk factors on Yosemite toads.

Extent of risks related to climate change

The risk to the ephemeral water breeding Yosemite toads from climate change is potentially high, particularly given the species reliance on shallow water ephemeral breeding sites. Any changes to the hydroperiods of breeding sites may have a large effect on recruitment. However, it unknown to what degree and how climate change may be influencing Yosemite toads.

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 climate effects on this species including how climate-change linked habitat alteration may affect Yosemite toad population dynamics, how climate change may compromise toad energetics, and how climate changes may interact with other risk factors (e.g., emerging pathogens).

Disease

Amphibian diseases, particularly chytridiomycosis and its effects on the sympatric mountain yellow-legged frog, are currently an area of active research and there is substantial new information since this section was updated in 2007. Updates on new disease research pertinent to the conservation of Yosemite toads will be included in a conservation strategy.

Since 1993, new aquatic pathogens have been observed killing amphibians in the Sierra Nevada and worldwide (Carey et al. 1999). Mass die-offs of amphibians have been attributed to the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*, *Bd*, Longcore et al. 1999), which has seriously affecting many amphibians globally (Berger et al. 1999, Daszak et al. 1999, Fellers et al. 2001, Bradley et al. 2002, Bell et al. 2004). Locally, other diseases have been identified as potentially important factors in anuran declines including *Saprolegnia* fungal infections (Blaustein et al. 1994a), iridovirus and bacterial infections (Carey et al. 1999), and trematode infections (Johnson et al. 1999b).

Tissue samples of Yosemite toads were collected from dead or dying adults and from healthy tadpoles during a die off of adult Yosemite toads at Tioga Pass Meadow and Saddlebag Lake in the 1970s (Green and Kagarise Sherman 2001). These samples (12 adults, 11 from Tioga Pass Meadow and 1 from Saddlebag Lake) were later analyzed for disease. Several infections were found in adults including chytridiomycosis, *Dermosporidium* (a fungal infection), myxozoan infection (parasitic cnidarians), *Rhabdias* spp. (a parasitic nematode) infection, and several species of trematode (parasitic flatworm) infection. However, no single infectious disease was found in more than 25 percent of individuals, and some dead toads showed no infection that would explain their death. No evidence of infection was found in tadpoles. The authors hypothesized that the die-off may have been caused by immunosuppression caused by an undiagnosed viral infection or chemical intoxication that made the toads susceptible to the diagnosed infections.

Perhaps of greatest concern is *Bd*, the amphibian chytrid fungus, which is the pathogen most consistently linked with anuran declines (Green et al. 2002, Daszak et al. 2003). The extent and impacts of this disease on the Yosemite toad are not well-understood though there is much active research on the effects of this disease on amphibian species worldwide (Berger et al. 1998), including mountain yellow-legged frogs (Rachowicz et al. 2006, Rachowicz and Briggs 2007, Briggs et al. 2010, Vredenburg et al. 2010), a species that is sympatric with the Yosemite toad over much of its range (Stebbins 2003). Chytrid fungi are ubiquitous in soil, but the aquatic *Bd* 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). *Bd* often alters the keratin-rich mouthparts of tadpoles (Vredenburg and Summers 2001, Rachowicz 2002), but has only been recorded to produce morbidity, not mortality, in this life stage (Berger et al. 1999, Green et al. 2002, Rachowicz and Vredenburg 2004). However, as the tadpoles undergo metamorphosis, *Bd* establishes in their keratin-rich skin, where it often eventually kills them (Berger et al. 1999, Rachowicz and Vredenburg 2004). Many *Bd* epizootics may have gone undetected because observing field casualties is rare, (Green et al. 2002). Sobering data from the tropics have shown that the progression of a *Bd* epizootic can be extremely sudden, with populations crashing in one season (Lips et al. 2006). *Bd* 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), and *Bd* is a major cause of declines in mountain yellow-legged frogs (Rachowicz et al. 2006, Vredenburg et al. 2010). *Bd* epizootics are the only infectious disease currently associated with population declines of multiple amphibian species (Green et al. 2002).

It is not known whether *Bd* has contributed to declines in Yosemite toads. In their examination of toads collected during a die-off in the 1970s (see above), Green and Kagarise Sherman (2001) found epidermal chytridiomycosis in one adult and a combination of chytridiomycosis and bacillary bacterial septicemia in a second (Green and Kagarise Sherman 2001). Although the rapid decline of Yosemite toads in Tioga Pass Meadows (Kagarise Sherman and Morton 1993) is characteristic of declines associated with chytridiomycosis (Rachowicz et al. 2006, Skerratt et al. 2007), Green and Kagarise Sherman (2001) concluded that *Bd* was not responsible for these declines because the low infection rates found in their specimens could not easily be reconciled with the high rates reported for *Bd*-associated declines in other species (e.g., Berger et al. 1998) and there was no evidence of infection in their tadpoles specimens. Further, *Bd* and other pathogens were not found in the skins of 14 Yosemite toads salvaged from the remains of 22 toads that were killed in 1990 during a corvid predation event at Mildred Lake (Green and Kagarise Sherman 2001). More recently, based on samples collected from 2006-2011 in collaboration with two USDA Forest Service programs (SNAMPH and a livestock grazing study, see Livestock Grazing), Dodge et al. (in prep) found that prevalence of *Bd* was low in adults (<10%) and moderate in juveniles (23%). Infection intensities were low for all life stages. Dodge et al. (in prep) also found that *Bd* can kill toads when infection levels are high enough. Finally, Dodge and Vredenburg (2012 in USFWS 2013) reported that high prevalence of *Bd* in museum specimens coincided with the recorded declines at Tioga Pass Meadow in the late 1970s. Also see Fellers et al. (2011).

Several factors may make Yosemite toads vulnerable to *Bd* infection. Yosemite toads may be exposed to sympatric infected mountain yellow-legged frogs. *Bd* prefers cooler temperatures (Longcore et al. 1999, Piotrowski et al. 2004) and the Yosemite toad's geographic range occupies the climatically coolest regions of the Sierra Nevada (Stebbins 2003), possibly predisposing the toad to successful attack (Longcore et al. 1999, Piotrowski et al. 2004). On the other hand, other factors may make this species less susceptible. Yosemite toads breed in ephemeral shallow water where water temperatures can exceed the thermal optimum temperatures for *Bd* (e.g., >25 C^{o}; Brown 2009; Piotrowski et al. 2004). Further, because tadpoles metamorphose quickly within a year and post-metamorphic toads spend much of their time out of water and presumably fairly dispersed, exposure to *Bd* may be limited reducing the potential period for infection and allowing adults and subadults to shed the infection.

Thus, the epidemiology of *Bd* for the Yosemite toad remains poorly understood. Research is needed on the vulnerability of different Yosemite toad life stages to the fungus, the modes of transmission (e.g., transport by recreational human activities like fishing; see Recreation Activities section), and the abilities of stocked fishes (see Introduced Fish and Other Predators section), native waterfowl, and other amphibian species to act either as reservoirs or transport vectors. 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 appears to be unaffected by *Bd* and may be a reservoir species. Mazzoni et al. (2003) revealed that bullfrogs [*Lithobates [Rana] catesbeiana*] farmed for food can serve as a vector for *Bd*, a condition that has been experimentally verified (Daszak et al. 2004); bullfrogs, though, are not typically sympatric with Yosemite toads (Stebbins 2003). Finally, complex predator-by-pathogen interactions are possible (Parris and Beaudoin 2004). Gray treefrogs (*Hyla chrysoscelis*) developed more slowly when reared with the *Bd*, but only when eastern newts (*Notophthalmus viridescens*) were present.

An important area under investigation is resistance to *Bd* infection. Species in the western United States like the Yosemite toad, in which *Bd* epizootics have been identified, have been characterized as lacking innate resistance (Green et al. 2002). However, demographic trends among selected Australian frogs, in which declines associated with *Bd* 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, 2002b, 2003). For reasons that are unclear, chytridiomycosis activates little or no cellular immune response (neutrophils or macrophages) to infection (Carey 2000). Ten peptides in eight peptide families derived from five species of ranid frogs (northern leopard frog [*Lithobates [Rana] pipiens*], American bullfrog, crawfish frog [*Lithobates [Rana] areolata*], Columbia spotted frog [*Rana luteiventris*], and montane brown frog [*Rana ornativentris*]), four of which occur in North America, have been shown to inhibit *Bd* growth. In laboratory studies, these peptides appeared effective at low concentrations (2-25 μM) and more effective at lower temperatures (10 C vs. 22 C; Rollins-Smith et al. 2002a). Further, a four-year mark-recapture study of the Australian frog *Taudactylus eungellensis* conducted from 1994-1998 revealed a stable level of *Bd* 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 *Bd* 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 exactly what comprises this defense may not yet be 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, but none of these have been linked to Yosemite toads. The pathogenic water mold, *Saprolegnia ferax*, is a fungus that attacks living amphibian embryos and has been documented to cause massive die-offs of eggs in Cascades frogs (*Rana cascadae*) and western toads in Oregon (Blaustein et al. 1994a, Kiesecker and Blaustein 1997). 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), raising the specter of stocked fish as vectors (see Introduced Fish and Other Predators section). The possibility also exists that this disease could be spread from infected populations of frogs to healthy ones through human transport of infected animals or field gear. To date, *Saprolegnia ferax* has not been implicated in declines of Yosemite toads, but Sadinski (2004) recorded *Saprolegnia diclina* on dead embryos that once established, spread throughout egg masses, apparently killing healthy embryos (see Mortality in Ecology section). However, whether *Saprolegnia diclina* can behave like *Saprolegnia ferax*, and attack living embryos *de novo*, i.e., in the absence of having dead embryos present, is unclear. Kagarise Sherman (1980) also recorded fungi on embryos, but was not certain whether they were the cause of mortality or became established on embryos that were already dead; those fungi, also presumably water molds, were not identified. Water molds are a potential problem that needs study.

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 in the U.S., iridoviruses were the cause of 25 of 44 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, Knapp [N.d.]). However, iridovirus-caused mortality has been reported for adults of some European ranid frogs (Fijan et al. 1991, Cunningham et al. 1996). In the western U.S., iridovirus-caused mortality may be much more common in salamanders than in frogs and toads (Green et al. 2002). However, Knapp (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 Sierra Nevada yellow-legged frog tadpoles infected in the laboratory. Thus, Yosemite toads may come in contact with species carrying iridoviruses. Iridoviruses may move between fish and amphibians under natural conditions (Mao et al. 1999), raising the possibility that stocked fish species act as vectors for iridoviruses (see Introduced Fish and Other Predators).

A condition termed "red-leg disease" has also been recorded in Yosemite toads. However, this "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. Emaciation and sluggishness also characterize most individuals found with this ventral reddening (Bradford 1991). Red-leg symptoms were noted in declines of populations of both the Yosemite toad in the Sierra Nevada (Kagarise Sherman and Morton 1993) and the boreal toad (*Anaxyrus boreas boreas*) in the Rockies (Carey 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 simply be a secondary manifestation (Green et al. 2002).

In their meta-analysis of amphibian mortality events, besides *Bd* and iridoviruses, Green et al. (2002) identified a third important pathogen, a previously undescribed Mesomycetozoan fungus closely related to *Dermocystidium*. This fungus was associated with mortality of larvae in four species of amphibians, two of which were ranid frogs and one of which was the American bullfrog. This pathogen has not been reported from the Yosemite toad and is currently too poorly understood to make predictions 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 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 stage 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 treefrog populations in California. Johnson et al. (1999b) 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). Green and Kagarise Sherman (2001) found trematodes in the urinary bladder (either *Gorgodera*, *Gorgoderina*, or *Megalodiscus* spp.) and lungs (probably *Haematoloechus* spp.) of adult Yosemite toads collected during a die-off, but considered these parasites neither responsible for the observed mortality nor to have significantly compromised these toads. If trematode infections causing deformities are common, they may contribute to anuran decline by rendering individuals more susceptible to predation (Johnson et al. 1999b).

Significant questions remain regarding the taxonomy and identity of aquatic pathogens (especially viruses), their epidemiology, and their relationship to the ecology of montane amphibian species, including the Yosemite toad. If pathogens of interest are native to the Sierra Nevada, they may take advantage of environmental stressors that make 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 Bryant 1995, Drost and Fellers 1996, Jennings 1996, Carey et al. 1999, Taylor et al. 1999a). Finally, caution is 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

Based on current knowledge, whether disease contributes to Yosemite toad declines is unknown. Knowledge of *Bd* impacts to other species, such as the co-occurring mountain yellow-legged frogs, suggests that the risk of this disease to the Yosemite toad may be high. Further research is needed on the virulence and epidemiology of *Bd* for this species. Whether other diseases or pathogens contribute to Yosemite toad declines also is unknown. Finally, whether other factors modulate the effects of diseases and pathogens (e.g., movements of humans or fish) is also unstudied in the Yosemite toad.

Conservation options related to disease

Research on the extent, impact, and epidemiology of *Bd* for the Yosemite toad is a high priority. Research on *Bd* as a primary factor in declines of mountain yellow-legged frogs may contribute to an understanding of what to expect for Yosemite toads, but toad-focused research is needed to understand the risk of the disease and potential management options for this species. Management options may be limited depending on the vectors of the disease. Given a better understanding of the disease, actions could be taken to reduce manageable environmental stressors that facilitate or augment the effects of disease and pathogens.

Fire Management, Including 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, and their potential effect on wildlife (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). Issues related to fire management are diverse, but this section focuses specifically on direct fire suppression activities that may affect Yosemite toads. Fire management may have both positive and negative impacts, depending on the circumstances (Russell et al. 1999). In some cases, fire management activities may have short-term negative impacts that lead to long-term benefits.

During prescribed fires or wildfires, crews and other fire personnel attempt to minimize impacts to aquatic and semi-aquatic species and their habitats, but inadvertent impacts may occur. Direct fire suppression activities that could affect Yosemite toads include water drafting from ponds and streams, water application, retardant application, construction of hand lines, construction of dozer lines, and increased human presence including the location of fire camps in riparian zones. Mechanical fuels treatments to establish and maintain strategically placed area treatments (SPLATs) and defensible fuels profile zones (DFPZs), direct burning and backburning in riparian areas, fire salvage activities, and prescribed fires in the uplands can all affect toads. Indirectly, these activities produce changes in aquatic and riparian habitats via sedimentation changes, alteration in down woody debris, and reduction in amounts of vegetation associated with the habitat (with potentially both positive and negative effects). Pile burning may directly trap and kill toads, while underburning may indirectly reduce habitat. No data are available specific to Yosemite toads 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 have 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 concentrated. Large removals of water from those locations had the potential to stress the occupant species present by further reducing available aquatic refuge habitat and/or making it accessible to aquatic-edge foraging predators (Holland 2005). In one particular instance, a variety of aquatic amphibians and reptiles were concentrated in a pond from which water was being drafted for fire suppression in 1994, and many animals were taken up by the helicopter water bucket and subsequently rained onto the fire site when it was emptied (Holland 2005).

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). More than 240 km of 1-10 m wide fire line were 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), but such features are not consistently implemented. Sedimentation may be the most detrimental road-like effect of firelining 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). 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. Formulations for retardant include ammonium phosphate and ammonium sulfate plus various plant-derived binders in a water solution. Retardant compounds are not easily dissolved and therefore do not move readily into ground water or into surface water from runoff. Some fire-suppressant cocktails are toxic or hazardous to aquatic organisms (Gaikowski et al. 1996, McDonald 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 Bucks 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 (Hopkins 2007). Although there is evidence of retardant and suppressant toxicity to aquatic organisms, few studies address 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) may pose a greater problem. This is an ingredient of fire retardants and suppressants used as a corrosion inhibitor for equipment, and has been shown to be highly toxic to fish and amphibians, especially on exposure to sunlight (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). Further research 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 Yosemite toads.

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.

Kattelmann (1996) identifies that catastrophic fire can produce some of the most intensive and extensive changes in watershed condition of any disturbance. Effects on water yield, peak flows, and sediment yield are translated to alteration of aquatic habitat. Kattelmann notes that changes in forest density related to wildfire suppression policies that began early in the last century may have reduced water yields. Suppression of fire may secondarily contribute to meadow encroachment by lodgepole pine (*Pinus contorta*), leading to loss of critical meadow habitat (see Habitat Requirements in Ecology section).

The USDA Forest Service is initiating a program of active pre-suppression to reduce fuel loading in an effort to reduce the intensity and extent of wildfires. Most of these actions will occur within the wildland-urban interface, which generally occurs in close proximity to human habitations and is below the elevational range of the Yosemite toad. One component of the pre-suppression strategy is the defense zone, which extends out about 0.4 kilometers from man-made structures. Pack stations, resorts, and summer homes occur within the lowest portion of the elevational range for the Yosemite toad and are accorded a 0.4-kilometer defense zone. Treatments within these areas are currently lower priority, but fuels reduction projects will likely be proposed in the future.

The higher-elevation forests generally have a longer fire return interval than lower-elevation mixed-conifer stands. When fires do occur at higher elevations, suppression action depends on whether the fire is located within a wilderness area or not. Wilderness suppression involves more work by hand crews due to exclusion of mechanized equipment.

Post-fire effects depend on the location and intensity of the burn in relation to Yosemite toad habitat, along with post-burn activities. Such activities generally focus on stabilizing slopes to reduce off-site erosion to stream channels, but may also include salvage logging. Salvage logging may have effects similar to those of vegetation management, but has the potential for accelerating erosion, further diminishing habitat if adjacent to meadows, or upstream of meadows.

Prescribed fire can benefit the Yosemite toad by reducing the risk of future high-intensity wildfire. However prescribed fire can also damage Yosemite toad populations if not properly implemented. Prescribed fire can dramatically alter vegetation and soils and disturb toads if implemented when fires would not naturally occur and at high fuel loading, which can lead to high fire intensity.

Hossack and Corn (2007) examined occupancy patterns of three amphibian species before and after a large, stand-replacing wildfire in Glacier National Park. No evidence was found that the fire negatively affected occupancy or vital rates of the three species. Hossack and Corn (2007) found a temporary increase in breeding by western toads after the wildfire; western toads colonized several wetlands after the fire, and then occupancy declined in subsequent years.

Extent of risks related to fire management

So few data exist on the impact of fire management and suppression activities on amphibians that the risk to Yosemite toads remains difficult to evaluate. However, because much of the habitat for the Yosemite toad occurs in wilderness and high-elevation areas with sparse vegetation where fire suppression activities are rarely conducted or mechanized equipment is not used (e.g., mechanized equipment generally is not allowed in wilderness areas), risk from fire suppression activities to Yosemite toads is largely a lower elevation phenomenon within the Yosemite toad's range.

Conservation options related to fire management

Agencies should continue to manage fire-related activities, suppression, and modes of application for the Yosemite toad. Management can influence the degree that these activities affect the toad and are within the jurisdiction of agencies participating in the assessment. This will be most important in the lower-elevation portion of the Yosemite toad geographic range, where fire is significant and frequent. Science is needed to inform how fire suppression techniques may influence Yosemite toads, including how their application may amplify or attenuate the effects of other risk factors. Until significant science becomes available to inform this issue, minimum-impact fire suppression techniques may be the best alternative to protecting Yosemite toads and their habitat.

Habitat Loss, Urbanization, 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). However, except in limited areas along the lower-elevation portion of the Yosemite toad range, opportunities for urbanization are lacking. Most of the range of the species is on federal lands at higher elevations, much 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 roads, that may explain habitat losses at those sites. No studies have attempted to disentangle the factors potentially confounded with habitat losses attributable to urbanization for Yosemite toads; it is difficult to address this question given the disappearance of Yosemite toads from most of their lowest-elevation sites. As a result, whether declines of the Yosemite toad are attributable to urbanization per se is unknown, and even if some are, this factor addresses but a very small part of the Yosemite toad range. However, increased population growth and development in the Sierra Nevada may put Yosemite toad populations at risk from this kind of habitat loss in the future.

Other opportunities for habitat loss or fragmentation are a function of other risk factors discussed in their respective sections (for example see sections on Roads, Water Development and Diversion). These include opportunities for habitat loss via agricultural use, which may have occurred through livestock grazing (see 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 Yosemite toad range. Similar to urbanization, the few opportunities that may have existed would have been restricted to lower elevations; this issue is unstudied.

Yosemite toads may be losing little habitat per se through anthropogenic factors, but many of the risk factors discussed in this document may be increasingly isolating its populations. These populations appear smaller today than historically (see Status section), and are therefore more vulnerable to extirpation from random events (Pimm 1991, Noss and Cooperrider 1994) such as prolonged drought, exceptionally heavy winter snowpack, extreme cold periods, or disease outbreaks. As declines continue to isolate populations, the toad becomes more vulnerable to extirpation of the species in entire regions. Because Yosemite toads are fairly long-lived (10-15 years in high elevation sites) the negative effects of disturbance and isolation may take several decades before population declines are apparent.

The degree to which such fragmentation occurs has never been studied in Yosemite toads. However, the few genetic data available imply that the genetic neighborhood of local Yosemite toad populations appears to be rather small, i.e., on the scale of a few kilometers or less (Shaffer et al. 2000), so how much Yosemite toads might be affected by fragmentation is unclear.

Extent of risks related to habitat loss, urbanization, and fragmentation

Direct habitat loss per se appears to be an unlikely cause of Yosemite toad declines except in context of habitat losses discussed under other risk factors. Habitat loss via urbanization and development is not currently considered to be significant, but may have some unknown level of local importance in the lower-elevation portion of the Yosemite toad's geographic range; development in the mid-elevation Sierra Nevada may increase the importance of this factor in the future. However, alterations of habitat and population impacts via other risk factors discussed in this document (e.g., livestock grazing) may fragment Yosemite toad populations. This isolation of existing populations may be a high risk to the species.

Conservation options related to habitat loss, urbanization, 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 Yosemite toad. In addition, the cumulative impacts of the various risk factors that lead to increased fragmentation should also be considered. Species conservation approaches should not only protect existing populations, but also provide mechanisms for re-establishing Yosemite toads in nearby areas, eventually leading to robust metapopulations of toads.

Introduced Fish and Other Predators

Prior to the stocking of high Sierra Nevada lakes with salmonid fishes, begun over a century ago, fish were entirely absent from most stillwater habitats in this region (Bradford 1989). Species that are stocked include rainbow trout (*Oncorhynchus mykiss* ssp.), golden trout (*O. aguabonita*), brown trout (*Salmo trutta)*, and brook trout. Predation by introduced fishes has been shown to have a negative impact on native populations of other Sierra Nevada amphibians, most notably the mountain yellow-legged frog (Bradford 1989, Knapp and Matthews 2000, Vredenburg 2004) and Pacific treefrog (Matthews et al. 2001).

The impact of introduced fish on Yosemite toads is only partly understood, but data collected to date suggest that impact via predation is unlikely. Knapp (2005), examining all lentic bodies of water in Yosemite National Park ($n = 2{,}655$) found the presence of Yosemite toad, which was detected at 74 (3 percent) of the water bodies, was unrelated to the presence of trout. Grasso (2005) and Grasso et al. (2010) clearly demonstrated that Yosemite toad eggs and tadpoles are unpalatable to brook trout, whether or not the toad life stages or the trout were obtained from sites where they co-occurred. He showed that brook trout would sample Yosemite toad eggs or tadpoles, but consistently rejected them, and that mouthing or sampling rarely resulted in injury. Grasso (2005) and Grasso et al. (2010) also had limited evidence for unpalatability of metamorphs. Further, Grasso (2005) and Grasso et al. (2010) found that Yosemite toad tadpoles showed no differences in activity or refuge use in the presence of brook trout; decreases in activity or increase in refuge use are behaviors often displayed by tadpoles of anuran species vulnerable to aquatic predators. Whether this means that Yosemite toad tadpoles recognize the non-native brook trout as non-lethal or simply do not recognize brook trout as a predator is unclear. Response of Yosemite toad life stages to other introduced salmonid fishes has not been tested, but as some other toad species seem unpalatable to co-occurring salmonids (e.g., western toad to rainbow trout; Licht 1968), the typical *Anaxyrus* [*Bufo*] pattern where tadpoles are unpalatable to at least some fish predator groups (Manteifel and Reshetnikov 2002) is likely for the suite of salmonid fishes introduced to the high elevation Sierra Nevada.

Typical Yosemite toad habitat use patterns in the absence of fish remain poorly understood (see Habitat Requirements section) limiting an assessment of other potential fish effects. For example, the frequency that Yosemite toads might use permanent water bodies in the absence of fish has not been evaluated, especially given their high thermal requirements for oviposition and rearing (see Habitat Requirements section). Also, because drought years can modify local habitat conditions and toads are apparently long-lived (see Ecology section), how flexible Yosemite toads are in switching aquatic habitats under adverse conditions is unclear. Kagarise Sherman and Morton (1993) observed Yosemite toads move to larger, more permanent water bodies under drought conditions; similarly, Strand (2002) observed Yosemite toads successfully switch breeding activities to fish-occupied stream habitat during years of low water. Under such conditions, Yosemite toads may compete with fish for food (but see below).

A possible indirect introduced fish effect on Yosemite toads may be via the food web. Finlay and Vredenburg (2007) described a fish effect on mountain yellow-legged frogs; however both the mountain yellow-legged frog and fish feed on aquatic insects and thus their diets heavily overlap. In the case of the Yosemite toad, the limited data suggests that terrestrial rather than aquatic invertebrates dominate the diet of post-metamorphic stages. Based on studies of the tadpoles of ranid frogs (Seale 1980, Kupferberg 1997), Yosemite toad tadpoles (along with co-occurring anurans [Pacific treefrogs and mountain yellow-legged frogs]), undoubtedly play an important role in cycling nutrients within and between water bodies. Both the removal of anuran tadpoles (Ranvestel et al. 2004) and the addition of fish (Schindler et al. 2001), have the potential to alter aquatic system nutrient cycles in unobvious ways. No data exist on these and other possible fish-induced changes in Yosemite toad-occupied systems.

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). Fish stocking also may have the indirect effect of drawing increased recreational activity to toad breeding areas (see Recreation Activities including Packstock section).

Some native predators may be abundant enough, at least seasonally, to impact recruitment and survival of Yosemite toads (see Mortality in Ecology section), especially where toad populations may be depleted. In particular, corvid predators, the distribution and abundance of which may be increasing due to human activity (see Mortality in Ecology section), may require study.

Extent of risks related to introduced fish and other predators

The risk of introduced fish to Yosemite toads appears low, but indirect effects such as changes to food web links, system nutrient cycling patterns, and pathogen transmission patterns are unknown. If a risk exists, these indirect effects are among the more likely possibilities.

Conservation options related to introduced fish and other predators

Based on our current knowledge, direct effects of introduced fish is not a high priority for conservation options. However, given the extent of introduced fish in the high Sierra, further research is needed on potentially significant indirect effects on Yosemite toad ecology. Fish management is within the jurisdiction of the partner agencies in this assessment. Finally, science is needed to inform the issue of whether other predators (e.g., corvids) warrant attention.

Livestock Grazing

In the Sierra Nevada Ecosystem Project's *Final Report to Congress* (SNEP Report), Kattelmann (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 Yosemite toads from breeding until they move into terrestrial overwintering sites in the fall. Some managed grazing practices can negatively affect riparian and aquatic systems through changes in hydrologic functioning, nutrient cycling, and herbaceous biomass productivity, soil compaction, vegetation removal, and nutrient redistribution (Kauffman and Krueger 1984, Flenniken et al. 2001). These hydrologic and vegetation changes can have effects on sensitive wildlife and their habitat. Because Yosemite toads breed in wet meadows in shallow ephemeral water that must remain long enough for metamorphosis, there is considerable concern regarding potential livestock impact on Yosemite toads and their habitat. Results from studies of livestock grazing effects on Yosemite toads are clarifying and narrowing the scope of this concern. Changes in livestock grazing management on Forest Service lands over the last decade are intended to mitigate and even reverse previous habitat degradation in some areas.

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 vegetation, 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 (Menke et al. 1996). By 1930, degraded forage conditions due to overstocking became apparent.

Between 1950 and 1970, livestock numbers were reduced due to allotment closures and uneconomical operations. Cattle replaced sheep and became the dominant livestock on most allotments. Between 1970 and 1990, the emphasis on resource protection increased, and riparian enhancement 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 to about 97,000 head (USDA Forest Service 2001a). Factors contributing to this decline included 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, beginning in 2001, imposed standards that further modified grazing management and led to reduced livestock numbers. Data from the USDA Forest Service show that, as of 2009, current authorized numbers were approximately 89,000, a 9 percent reduction since 2001 (Holland 2011, Yost 2011). These more moderate livestock grazing practices have the potential to increase native plant species diversity in wet and mesic meadows by decreasing litter accumulations, especially in *Carex* spp.-dominated communities, and allowing live native plant cover to increase on the site (Menke et al. 1996, USDA Forest Service 2004c, Weixelman [N.d.]). Forest Service grazing Standards and Guidelines for herbaceous and woody vegetation use by livestock are based on research, consider soil stability and desired plant communities, and are designed to improve or maintain rangeland ecological conditions (USDA Forest Service 2004 b, 2004c). Implementation of allowable use standards can significantly improve the health of riparian areas (Clary and Webster 1989). Maintaining a minimum stubble height (or otherwise defining a maximum level of utilization) helps to maintain forage vigor, retain sufficient forage to reduce cattle browsing of willows, and stabilize sediments (Clary and Leninger 2000). A 10-cm residual stubble height is recommended by Clary and Leninger (2000) as a standard for improved riparian grazing management, and this standard was implemented through the SNFPA (USDA Forest Service 2004c). Under current management, livestock are permitted on allotments based on range readiness guidelines, and active grazing is not allowed until soil and vegetation conditions can support it. Livestock seasonal turn out dates vary 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. Animals turned out on the range should not reach portions of an allotment prior to range readiness and enforcement of grazing permit terms and conditions are intended to prevent this from occurring.

Effects on habitat: Wet and mesic meadow and riparian ecosystems

The impacts of certain livestock grazing practices on high-elevation mesic and wetland ecosystems are well documented (Menke et al. 1996). Because they tend to concentrate in these areas (Belsky et al. 1999), livestock 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 affect meadow hydrology, increase bare ground, and decrease site productivity; this pattern 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. Overuse by livestock results in a change in vegetation species composition which in some cases has led to stream incision and lowered water tables in the Sierra Nevada and other montane regions of the western U.S. (Clary and Webster 1989, Armour et al. 1991, 1994). 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). Livestock can also alter the physical characteristics of wetlands, ponds, potholes, stream margins, flooded areas, and springs in meadows. The typically high soil moisture along stream banks, other aquatic edge habitats, and wetlands make these areas easier to trample (Marlow and Pogacnik 1985). Trampling may increase 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, under some regimes, 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). For these reasons, cumulative effects of overgrazing may have historically impacted Yosemite toad populations in multiple ways including alteration of system hydrology, shortening the period of water availability for toad breeding and rearing (see Life History section), and reduction of residual vegetation and vegetative cover that may affect food resources, increase xeric habitats, and increase predation risk for tadpole and juvenile Yosemite toad life stages. Alterations to meadow hydrology in ways that reduce recruitment are likely of particular importance to the species (see Habitat Requirements in Ecology, and discussion under Recreation section).

Removal of successional aquatic margin vegetation in ponds has been identified as a potentially positive effect of grazing for Columbia spotted frogs (Bull and Hayes 2000), and reintroduction of grazing has been used to reverse succession in selected coastal meadows in Europe for the natterjack toad (*Bufo calamita*), a species that requires open ponds for breeding habitat (Rannap 2004) with some similarity to those Yosemite toads use. Use of livestock grazing management as a habitat maintenance or restoration tool has not been evaluated for Sierra Nevada montane meadows in general or Yosemite toads in particular.

Development of springs for stock water can impact native plant and terrestrial species habitat by altering or de-watering riparian areas. Such alteration may impact Yosemite toad tadpoles if this diverts water from breeding areas, or adults who forage in such habitats during the non-breeding active season (see Habitat Requirements in Ecology section). Springs could also be used for overwintering. Knowledge of non-breeding habitat use patterns remains incomplete.

Data on meadow conditions from the USDA Forest Service Region 5 long-term range meadow monitoring collected from 1999 to 2001 (Weixelman 2011) indicated that most meadow plots (62 percent) were in a moderate quality condition class. Slightly over one-quarter of meadow plots (28 percent) were in a high quality condition class, and 10 percent were in a low condition class. This analysis is based on 261 plots across five of the six Sierran national forests where the Yosemite toad occurs (all except the Humboldt-Toiyabe National Forest). Data on trends in meadow condition class, which are collected in a five-year staggered rotation, were available for 160 plots on four of these national forests (too few resampled plots exist on the Lake Tahoe Basin Management Unit). These data revealed that a significant change in condition class occurred on meadow plots on the Sierra National Forest, which displayed an upward trend (i.e., more meadows with improving trend conditions); the remaining three national forests (Eldorado, Inyo, and Stanislaus) showed statistically equal numbers of plots increasing versus decreasing in condition class and the remainder not changing in condition class. Hence, most meadows were in an intermediate quality condition class, and a significant change in condition class had occurred on the Sierra National Forest within the first ten years of monitoring.

A collaborative research project on the relationship of grazing and Yosemite toads and their habitat, funded by the USDA Forest Service Region 5, was recently conducted by the USDA Forest Service Pacific Southwest Research Station and the Universities of California, Berkeley and Davis. Two primary questions were addressed: (1) Does livestock grazing under Forest/Sierra Nevada Forest Plan Amendment Riparian Standards and Guidelines have a measurable effect on Yosemite toad populations, and (2) What are the effects of livestock grazing intensity on key habitat components that affect survival and recruitment of Yosemite toad populations? The study included both an experimental component and a longitudinal survey across gradients of meadow hydrologies and livestock use (Tate et al. 2010, Lind et al. 2011, Roche et al. 2012a, 2012b, McIlroy et al. 2013).

In the experimental component, three livestock grazing treatments were implemented and responses of Yosemite toad populations and habitat characteristics were assessed over time. Treatments were: (1) grazing in accordance with riparian standards and guidelines across whole meadows, (2) fencing of Yosemite toad breeding areas only (partial fence), and (3) complete fencing of meadows. There were five replicates of each treatment distributed across the Stanislaus and Sierra National Forests (n = 15 meadows). Pilot field work began in 2005 and fences were constructed in early 2006. Data were collected on Yosemite toads and habitat through 2010 and were analyzed using generalized linear mixed models accounting for meadow area, allotment, meadow wetness, and bivariate correlations. Over the period of the study no differences were detected in tadpole and young of the year (metamorphs) Yosemite toad densities or breeding pool occupancy rates among the three livestock grazing/fencing treatments (Tate et al. 2010, Lind et al. 2011, McIlroy et al. 2013). Variation in densities was high and was apparently strongly influenced by water year type and meadow wetness. On grazed (unfenced) meadows, livestock use was higher on dryer meadows than wet meadows and Yosemite toad densities were negatively correlated with depth to water table (indicating dryness) and livestock use (especially tadpoles). Analysis of habitat conditions indicated that Yosemite toad eggs and tadpoles were associated with the warm, shallow, relatively nitrogen-enriched pools within meadows. Both breeding and non-breeding pool conditions did not differ in relation to livestock grazing/fencing treatments, over time (Tate et al. 2010, Lind et al. 2011, Roche et al. 2012a). Partial fencing of meadows resulted in high livestock use of areas outside of fences but within the meadow and thus is not recommended as a grazing management measure to protect Yosemite toads.

A larger set of meadows ($n = 24$) was included in the longitudinal survey of gradients of livestock use, meadow wetness and Yosemite toad occupancy on the Sierra National Forest. Each meadow was typed based on a meadow wetness index and data was collected on both livestock use and Yosemite toad presence (all life stages) from 2006 through 2008. Bayesian structural equation modeling was used to evaluate relationships among meadow wetness, vegetative biomass and forage quality, livestock use, and Yosemite toad occupancy. Based on modeling results, Tate et al. (2010, Roche et al. 2012b) concluded that Yosemite toad occupancy was more related to meadow wetness than to livestock use.

Effects on individuals: Trampling

There is little research on direct impacts (e.g., trampling) of cattle grazing on Yosemite toads or other amphibians. The limited information that does exist is based on field observations and some natural history records. Livestock trampling has the potential to directly impact all life stages of Yosemite toads. Mortality risk from livestock trampling may be greatest for early life stages with no or low mobility and in situations where livestock are concentrated when toad densities are high. Breeding adults aggregate and lay eggs early in the season, but cattle typically are not present during this time (Figure 9). In shallow water habitats, tadpoles also may be vulnerable to trampling. Perhaps the life stage most at risk are the small metamorphosing and recently metamorphosed juvenile toads (often ≤ 10 mm in size), which aggregate, en masse, in wetland habitats often at the time when cattle are present (Kagarise Sherman 1980, see Ecology section). In Idaho, numerous recently metamorphosed juvenile western toads were trampled within a few days of sheep moving into the riparian area of a montane meadow (Bartelt 1998). Quantitative information on the effects of trampling on Yosemite toad individuals and populations is incomplete; research is needed to inform this issue.

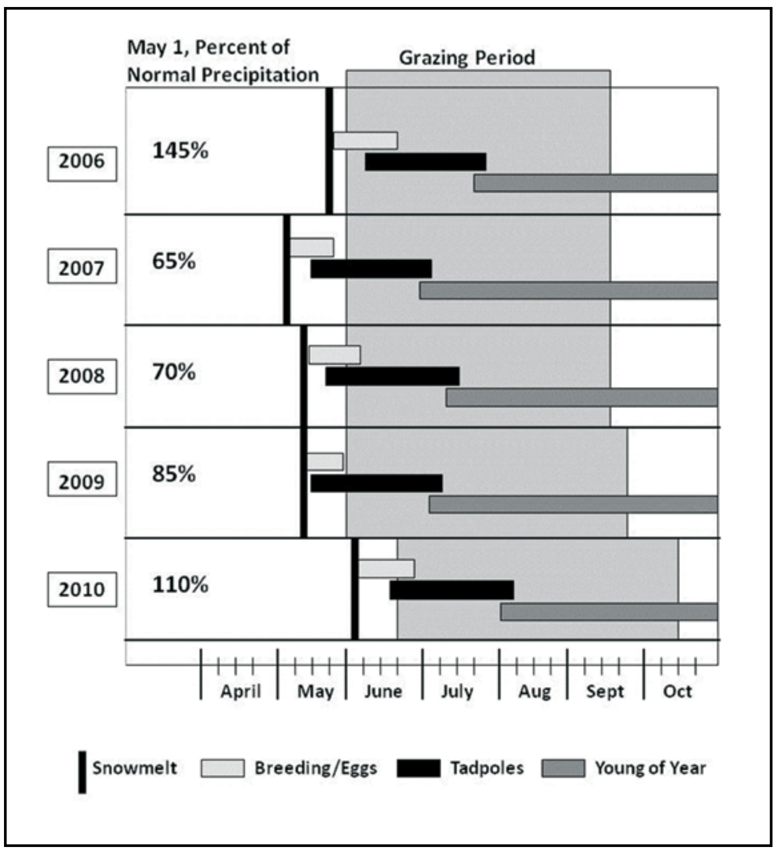

Figure 9. Yosemite toad life-stage timing and livestock grazing timing for meadows on the Sierra National Forest (2006-2010). Adapted from Tate et al. 2010.

Trampling risk depends largely on the timing and duration of cattle in the allotment. Guthery and Bingham (1996) developed a theoretical model based on concerns for threatened, endangered, and sensitive plant and animal species (primarily focused on ground nests and trampling of animals, but not specifically anurans), to predict 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. The Yosemite toad›s life history suggests that the risk of trampling may be higher than levels indicated in this study because the study used randomly placed inanimate objects to test the model whereas some toad life stages aggregate in large numbers. Conversely, larger toads have the ability to move out of the way, though this may not be their typical escape response. To minimize trampling risk, livestock could be actively managed to avoid areas of meadows occupied by the less mobile Yosemite toad life stages (tadpoles and new metamorphs).

Effects on populations: Disease transfer and water pollution

Some concern exists regarding livestock transport of pathogens (e.g., fecal coliforms, other bacteria, *Bd*) between water bodies, and nutrient inputs which may promote algal growth in heavily used streams and water sources (Stephenson and Street 1978, Kattelmann 1996). Potential concerns regarding disease transfer within montane meadow ecosystems include: risks of pathogen transmission from livestock fecal material, or when livestock move or are moved between ponds; and risk of pathogen transport between low-elevation winter ranges and high-elevation summer ranges. Specifically, the potential for livestock to transport *Bd* zoospores on their hooves is a concern, but this has not been studied, and there is currently no other evidence linking livestock to the transmission of disease-causing pathogens that could affect Yosemite toads.

Bacteria and nutrients from feces can reach a water source by direct deposit or overland flow from upland runoff. Fecal material can accumulate in streambed sediments and be dislocated by flow changes or cattle trampling. Amount of manure and its dilution ratio may determine the potential degree of risk to Yosemite toads. Cold, snowmelt mountain streams, and oligotrophic mountain lakes may support few bacteria in their sediments in the absence of significant nutrient inputs. In nutrient limited systems, these inputs may not be negative. Tate et al. (2010) and Roche et al. (2012a) found that nutrient levels were low in their study meadows and that nutrient levels did not exhibit a response to livestock grazing treatments. In addition, it appears that Yosemite toad egg/tadpole rearing pools may typically have higher nutrient levels than non-breeding pools. The USDA Forest Service Region 5 is funding a collaborative study with the University of California focused on water quality and grazing across several national forests.

Extent of risks related to livestock grazing

Risks related to grazing for the Yosemite toad are potentially high because riparian and meadow systems are critical habitat for Yosemite toads and are also key livestock forage areas. Practices that lead to meadow drying and reduced hydroperiods of shallow water breeding habitats may pose the greatest risk. Grazing is widespread throughout the historical range of the Yosemite toad, although its prevalence varies geographically. Grazing is more widespread at elevations below 2,438 m (8,000 ft). As of 2002, grazing occurred on about 75 percent of the range of the Yosemite toad within five national forests (Eldorado, Stanislaus, Sierra, Inyo, Humboldt-Toiyabe) (adapted from Sierra Nevada Forest Plan Amendment [SNFPA] FEIS GIS data 2002). The 1996 SNEP Report indicated 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. Current livestock management practices on national forest lands, resulting from SNFPA, such as appropriate timing, intensity, and duration, are intended to result in improved hydrologic and vegetation function and ultimately in restored ecosystems in wet and mesic meadows. Standards for managing habitat for threatened, endangered, and sensitive species such as the Yosemite toad were also incorporated in SNFPA (USDA Forest Service 2004c).

Conservation options related to livestock grazing

Potential effects of livestock grazing should be included in management considerations for the Yosemite toad. Management can influence the degree that this activity affects the toad and it is within the jurisdiction of agencies participating in the assessment. Timing of Yosemite toad and livestock grazing use of meadows and conservation of meadow hydrology are key factors to consider in development of meadow and grazing allotment management strategies (Figure 9). At a minimum, agencies should continue to manage this activity to reduce its potential impact to this species and its habitat. More research is needed to identify and mitigate potential effects of livestock grazing on Yosemite toads, including incorporating adaptive livestock management.

Locally Applied Pesticides

National forests in the Sierra Nevada occasionally use pesticides to control rodents, insects, fungi, noxious weeds, and brush. 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 (Bakke 2004). Most of the conifer plantations where herbicides are used lie below the elevational range of the Yosemite toad, although there are some plantations that intersect with the lower elevation Yosemite toad populations. Plantations established after stand-replacing fires may occur within the Yosemite toad range (Strand 2009). 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 herbicide 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 to the full Roundup® formulation of Glyphosate than juveniles or adults (Bidwell and Gorrie 1995, Mann and Bidwell 1999). A study showing high toxicity of Roundup® to tadpoles and post-metamorphic life stages of northern leopard frogs 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 (Bakke 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 2001b). Persistence and impacts of glyphosate formulations in shallow-water pools, which constitute breeding habitat for toads 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 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 (Bakke 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 three 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 also 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 Yosemite toads. Both Chen et al. (2004) and Edginton et al. (2004) found the Vision® formulation of glyphosate increased in toxicity to the embryonic and tadpole stages of green frogs (*Lithobates[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 tadpoles of three anuran species (gray treefrog [*Hyla versicolor*], American toad [*Anaxyrus [Bufo] americanus*], northern leopard frog), zooplankton, and algae, where combinations of predators (no predators, red-spotted newts [*Notophthalmus viridescens*], larval diving beetles [*Dytiscus* spp.]) and pesticides (no pesticides, the insecticide Malathion®, 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 Yosemite toads are not known. Some risk to Yosemite toads is suggested from data on other amphibians, but no data currently exist evaluating level of risk of these pesticides to Yosemite toads per se. Aerial application potentially poses a threat because of the unpredictability of pesticide drift and the likelihood that it may reach aquatic habitats. Adults and subadults may be at risk in their terrestrial habitats. Because most application of various pesticides occurs below the elevational range over which Yosemite toads are known to occur, the risk of locally applied pesticides to Yosemite toads generally appears limited. However, there may be local situations where the risk is high.

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 Yosemite toads. Management should continue to regulate this activity to reduce its impact to this species.

Recreational Activities Including Packstock Grazing

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 (including those that involve packstock grazing), to hiking, fishing, off-highway vehicle use, suction dredging, and mountain biking. Yosemite toad 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, or the misguided release of rehabilitated wildlife into non-native habitats.

Yosemite toads occur away from major population centers with roughly 99 percent of their geographic range on public lands. Of the range on public lands, roughly 70 and 30 percent, respectively, occur on national forest and national park lands. Of the range on national forest lands, much occurs in wilderness areas (USDA Forest Service 2001c). 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. Only 1 percent of the Yosemite toad 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).

High overlap exists between Yosemite toad habitats and areas often used for recreation. Yosemite toads inhabit high mountain meadows and ponds and their near vicinities (see Habitat Requirements in Ecology section). These areas are also attractive for human recreation and receive a disproportionate amount of recreational use through trail networks and campsites located through and near meadows, ponds, and lakes (Vinson 1998). Recreational packstock grazing, which can occur in meadows used by Yosemite toads, has the potential to affect Yosemite toads and their habitat. Packstock includes horses, llamas, and goats, and tends to be a high-elevation phenomenon associated with access to more remote locations for often longer dispersed camping forays. Packstock tend to graze close to lakes, meadows, ponds, and trails, where suitable forage often exists. Off-highway vehicle (OHV) and snowmobile (OSV) use also may affect Yosemite toads and their habitat. Grasso (2006) has twice observed fresh off-highway vehicle (OHV) tracks intersecting a rearing pond that contained mid-stage Yosemite toad tadpoles on the Sierra National Forest. The first observation, made at Kaiser Pass Meadow in 2003, involved a 4-6 m diameter breeding pool in which roughly 200 Yosemite toad tadpoles were observed; the second, which occurred at an unnamed meadow near Hot Springs Pass (Dinkey Wilderness) along the Dusy-Ershim OHV route in 2004, involved a 10 m by 20 m breeding pool containing roughly 2,500 Yosemite toad tadpoles. In both cases, neither dead tadpoles nor the offending vehicle was observed. OHVs are often the first vehicles to pass through roads blocked by winter snow, occasionally driving off the roads to bypass snowdrifts (Holdeman 2007, Brown 2009). OSVs are increasingly reaching more remote areas and several Yosemite toad meadows receive heavy use by snow machines (Holdeman 2007). The effect of OSVs on Yosemite toads and their habitats are unknown. Such habitat-disturbing recreational activities have the potential to cause Yosemite toad mortality.

To date, no studies have examined the impacts of recreational activities on Yosemite toads. Moreover, few studies have examined recreational impacts on amphibians with similar life histories. However, some information exists on the effects which selected recreational activities may have on the aquatic habitats that Yosemite toads use. This literature together with knowledge of the ecology of the species allows a preliminary assessment on the effects of recreation. Because various recreational activities have similar effects on toads and their habitat, they are addressed based on their impacts.

Direct effects

Recreational activities may disturb or kill all life history stages of Yosemite toads. All life history stages, but especially the less mobile eggs, tadpoles, and juveniles, may be injured or killed through crushing, trampling, or other means by recreational hikers (Milano 2002), bikers, anglers, pets, and off-highway vehicles (OHV). Packstock, like livestock, have the potential to kill all life stages (Milano 2002; see Bartelt 1998). Anglers, hikers, and their pets have been observed trampling and disturbing western toad egg masses, tadpoles, and metamorphosing froglets at a site in Oregon (Brown 2001). The abundance of Iberian frogs (*Rana 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). Toads have been observed on OHV and other types of roads. For example, one female Yosemite toad was observed walking along a popular OHV road on the Sierra National Forest, and crushed Yosemite toad adults have been found on the road into a popular campground on the Stanislaus National Forest (Brown 2006). 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 at levels that caused hearing loss in some of the desert herpetofauna (Brattstrom and Bondello 1983). Moreover, the noise caused aseasonal 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 suggested 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). At the Oregon site mentioned above, Brown (2001) observed children placing western toad tadpoles (almost the entire population one day) and metamorphs into buckets to carry them around the site.

Although introduced fish may be less of a concern for Yosemite toads (see Introduced Fish and Other Predators section), recreational fishing common in high-elevation habitats may be a source of introduced parasites and pathogens via fishing lines, lures, and clothing of fishermen (see Disease section). The introduced fish also may serve as disease vectors. Finally, anglers have been observed using toads and tadpoles as bait (Milano 2002).

State statutes prohibit collection of Yosemite toads, but one observation indicates that some Yosemite toads may be collected for sale in the pet trade. In spring 2005, a student at California State University, Sacramento showed Grasso (2006) a toad she thought to be a Yosemite toad. Upon examination of the toad, Grasso confirmed that it was a Yosemite toad, a subadult that he estimated was 3-4 years old. When asked how the toad was acquired, she indicated that she had purchased it two years prior from a Los Angeles pet store no longer in business.

Effects on habitat

Recreation also can indirectly affect Yosemite toad 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 impact 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, it was concluded that the impacts on campsites used only a few nights per year (less than 10) had already reached a threshold beyond which further increases in use had little effect on the severity of impacts. 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. Packstock camps in the Bob Marshall Wilderness of Montana exhibited large areas of bare ground, increased soil compaction, and slower rates of water infiltration (Cole and Fichtler 1983). 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 between productivity and grazing intensity. This could then be used to anticipate levels of 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 Yosemite toads is unstudied.

Relatively little is known about the natural resilience of high-elevation ecosystems in the Sierra Nevada following disturbance from recreation (Stohlgren and Parsons 1986). However, at high elevations, riparian habitats may be more sensitive to disturbance because of the short growing season. The effects of different recreational activities to Yosemite toad habitat can be categorized into four main types: (1) hydrology; (2) breeding area morphology; (3) water quality; and (4) terrestrial cover.

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 Yosemite toads. Toads prefer to breed in very shallow water such as small ephemeral or permanent ponds or shallow water in flooded meadows (Mullally 1953). Both water depth and water temperature appear to be important limiting factors in the survival of eggs and tadpoles (Kagarise Sherman and Morton 1993). Consequently, any activities which alter the hydrology and bring drying trends to these already susceptible water sources could have major impacts to the species' breeding success. Desiccation of breeding habitat before tadpoles metamorphose is a major cause of mortality (Kagarise Sherman 1980; see Habitat Requirements and Mortality in Ecology section). Springs also may be an important element of non-breeding active season habitat. Hence, any changes in hydrology that induce premature drying or shallowing of water bodies, reduction of shallow shoreline habitat, or reduction or loss of springs are likely to have a significant impact on the species.

Recreational activities that occur near meadows, ponds, lakes, and streams can affect hydrology and available water in several ways. These activities can 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 breeding ponds. These in turn have effects on hydrology including diversion of water, downcutting, and eventually lowering of water tables, leaving formerly suitable habitat susceptible to desiccation. Effects to habitat from disruption of hydrology are particularly likely in the shallow water systems used for oviposition or rearing, or low-volume springs that may be important non-breeding habitat.

Breeding area morphology

Yosemite toads typically breed in shallow ephemeral pools or the shallows of larger water bodies. These shallows are especially prone to damage from trampling by hikers, packstock, or OHVs. Trampling by packstock can be particularly detrimental in sensitive shallow 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 Yosemite toad breeding habitat.

Water quality

Besides the physical effects related to riparian soil and vegetation, localized water pollution resulting from camp use may also 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 Yosemite toads at risk. 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 remains limited (Gillespie 2002). Increases in sedimentation may reduce the availability or quality of oviposition sites, or tadpole refugia or rearing sites (Welsh and Ollivier 1998). Increased sedimentation may also reduce availability of important food resources for larval amphibians (e.g., algae; Power 1990). Still, Yosemite toads typically inhabit silty environments.

Terrestrial cover

Yosemite toads can often be observed sheltering in low vegetation, often where mammal burrows providing refuge are present. Metamorphs and yearlings are often associated with willow, long sedges, and grasses (Martin [N.d.]), which likely provide cover from predators as well as protection from desiccation (see Habitat Requirements in Ecology section). Because vegetation cover is reduced by trampling (Dale and Weaver 1974), various recreational activities can destroy meadow vegetation that toads 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, cause soil compaction, and reduce organic litter material (Weaver and Dale 1978). Yosemite toads typically do not move quickly when disturbed and take refuge under meadow vegetation hummocks, in mammals' burrows, or under rocks or woody debris (see Habitat Requirements under Ecology section).

Extent of risks related to recreational activities

The risk level of recreational impacts to the Yosemite toad is unknown. The nature of many recreational activities places them in direct contact with Yosemite toads 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 may add to cumulative impacts on already stressed small populations. Developed camping and fish stocking for recreational fishing (largely because this promotes increased human use), pose the greatest risk from recreational activities to the Yosemite toad. 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 exist for this risk factor relative to the Yosemite toad.

Conservation options related to recreational activities

Agencies should continue to manage recreational activities to reduce and mitigate potential impacts to the Yosemite toad. Recreational activities are within the direct purview of agencies participating in this assessment. Studies on the extent and scope of recreational impacts to Yosemite toads are needed. There is also a need to educate the public on activities that protect and harm the species.

Research Activity

Researchers have the potential to negatively affect anuran 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, evidence is lacking to suggest that research activities have negatively affected Yosemite toad populations. Cynthia Kagarise Sherman, Ernest Karlstrom, David Martin, Martin Morton, and Walter Sadinski studied Yosemite toads intensively at several sites over several-year periods (Karlstrom 1962, Kagarise Sherman 1980, Kagarise Sherman and Morton 1993, Sadinski et al. 1997, Sadinski 2004; Martin 2002). The populations that Kagarise Sherman and Morton studied declined during their study interval, but it is not possible to ascribe declines to their study activities without examining unstudied controls, an impossible condition. Intensive study in these populations included marking individual animals using different modes, handling animals for measurement, and monitoring specific locations with high (daily or every few day) frequency. If handling and marking is viewed as an issue, the radioactive cobalt tags that Karlstrom used were probably more damagingly invasive than any other method (see Karlstrom 1957 for details), but his study population did not decline until Kagarise Sherman and Morton (1993) had studied the same site during the 1970s for several years. Effects due to these investigators are unlikely, but cannot be unequivocally excluded.

Historically, handling and marking of animals has been viewed as innocuous, but 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 found 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 of the use of PIT tags on survival or body condition have been found, but comparisons to unmarked reference animals have been restricted to laboratory analyses (Perret and Joly 2002), leaving open the question of how well such analyses translate to field conditions.

The poorly understood epidemiology of aquatic pathogens (e.g., *Bd*, water molds; see Section on Disease) has focused attention on their transmission between water bodies, and between carrier or 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 (Knapp 2002, Padgett-Flohr 2002, Vredenburg 2002); these provisions are 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 Yosemite toads. Some predators, particularly 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 humans carry (Lawrence 1973); whether such attraction would pose a significant threat to local Yosemite toad populations is unknown (see Mortality in Ecology section).

Extent of risks related to research activity

Researchers typically have their study species' best interest in mind when designing their studies, so research activity is not likely to be a significant factor in Yosemite toad declines. Still, precisely how research activity might contribute to declines and the extent of risk is unstudied.

Conservation options related to research activity

Given that field research activity represents the most fundamental way that scientific information can be gathered on Yosemite toads, 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 a high risk to the Yosemite toad. Agencies should promote prophylactic measures against potential disease transmission.

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 Yosemite toads. 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 two categories of restoration are likely to be especially important to Yosemite toads; both involve aspects of meadow restoration that are connected to varying degrees. These include meadow restoration efforts designed to set back succession, particularly encroachment of lodgepole pine into meadow systems (see Sharsmith 1961); and efforts designed to restore meadow hydrology. Restoration efforts designed to restore meadow hydrology are diverse and beyond the scope of this document, but are intended to reverse the secondary effects of excessive historical livestock grazing.

One example of a successful meadow restoration project is the Lower Three Meadows on the Stanislaus National Forest. In 1976-1977, the project installed grade stabilizers and reconnected the water table to the meadow. Resulting benefits were (1) the pond in the meadow became larger and has had greater persistence than prior to restoration; (2) the stream flow has persisted longer than prior to restoration; and (3) the headcut in Upper Three Meadows was restored. This restoration has had apparent benefits for the Yosemite toad population that breeds in these meadows. Both the pond and stream persist until metamorphosis nearly every year, thus supporting successful breeding through metamorphosis (Frazier 2007, Holdeman 2007).

Science is needed to evaluate both the positive and negative effects of meadow hydrology restoration on Yosemite toads, as no systematic data currently exist. Selected other types of restoration, such as fish passage and stream enhancement projects, may also have the potential to influence Yosemite toads; science is also needed to inform how and the degree to which these types of restoration may affect Yosemite toads.

Extent of risks related to restoration

The level of risk of restoration depends on the type and implementation of the specific restoration activity. Restoration efforts are expected to take on even greater importance in the future. Implementing restoration activities may have short-term negative effects on Yosemite toads, but these are likely counterbalanced by the proposed positive effects of restoration on Yosemite toad habitat. The precise effects, both positive and negative, and the degree to which they influence Yosemite toads and their habitat are unknown.

Conservation options related to restoration

Agencies should continue to guide and manage restoration efforts for the Yosemite toad. 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 Yosemite toads and their habitat, from both short- and long-term perspectives.

Roads

Roads have become an increasingly common feature of most landscapes and have the potential to have several negative effects on Yosemite toads. Roads have been constructed over parts of the Yosemite toad range, especially the lower elevations. Five important trans-Sierran highways (State Highways 120, 108, 4, and 88; and U.S. Highway 50) bisect at least some of the Yosemite toad's geographic range; all five are located in the northern three-fifths of the range. The state highways have seasonally high traffic; Highway 50 has high traffic levels essentially year-round. Other roads that may affect Yosemite toads include non-trans-Sierran primary, secondary, and logging roads. Yosemite toads are generally viewed as occurring in more remote areas, but populations proximate to roads can face negotiating seasonally high traffic, primarily during the non-breeding active season, when movements away from breeding sites may be significant (see Habitat Requirements and Life History in Ecology section).

The degree to which roads affect Yosemite toads and their habitat depends on many factors such as road density, road type, and traffic intensity. Populations of Yosemite toads occurring on private lands are viewed as 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. However, private lands comprise only a small fraction (roughly 1 percent) of the Yosemite toad range. The roughly 70 percent of the Yosemite toad range on national forest lands generally has many roads, but more than half are dirt-based logging roads rather than paved or high-traffic roads. National forest lands in the range of the Yosemite toad contain approximately 400 km of paved roads (primary/secondary highways and improved paved roads), 725 km of gravel roads, 1,988 km of dirt roads (dirt and unimproved dirt roads), and 2,807 km of trails (USDA Forest Service 2001c). Vehicular traffic may be lower on these roads, but they may still receive substantial traffic from recreationists. (see Recreational Activities). Portions of the Yosemite toad range are also in wilderness areas and national park lands, where generally few roads exist but information on road coverage is limited or lacking. However, the presence of even just a few roads may impact amphibian habitat in a noticeable way. For example, roads have been shown to exhibit edge effects that can create negative responses in biodiversity extending up to 1-2 km from the road itself (Findlay and Bourdages 2000, Forman and Deblinger 2000).

No studies have yet identified the impacts of road construction or road use on Yosemite toads. However, roads have been shown to have several negative ecological effects (Forman and Alexander 1998), especially within aquatic or riparian ecosystems (Trombulak and Frissell 2000) and forested landscapes (De Maynadier and Hunter 2000), and some studies have addressed road effects on other species of anurans and amphibians. Other studies have also 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 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 Yosemite toads. Also see Andrews et al. (2008) and Beebee (2013) for more recent reviews on the effects of roads on amphibians.

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). Hence, reduction in road construction and the improvement or decommissioning of both private and public roads may have long-term benefits for toad populations by reducing traffic-related mortality and road impacts on Yosemite toad habitat. Previously constructed roads may still pose problems for Yosemite toads. 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 Yosemite toad 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 and Fahrig 2001). 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 1998). The seasonal life history of Yosemite toads may make them susceptible because they move among three different habitats, one for each of breeding, the non-breeding active season, and overwintering. Adult Yosemite toads may typically move at least a few hundred meters seasonally, but movement over 1 kilometer has been recorded (Liang 2007; see Movements in Ecology section). Species that are highly vagile are generally more affected by road mortality because their likelihood of encountering roads is increased (Carr and Fahrig 2001). Three squashed adult Yosemite toads, presumably killed by vehicles, have been found on the road to a popular national forest campground. Also, live toads are occasionally found on OHV and other roads (Brown 2006). In general, relatively few roads are near Yosemite toad populations, roads occupy a relatively small portion of Yosemite toad habitat, and those that exist are typically forest roads with low traffic levels. Nonetheless, road-related mortality has occurred and this risk merits more investigation.

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). Yosemite toad habitat has fewer roads and lower traffic densities than in moor frog habitat; however, there may be unrecognized fragmentation effects. Roads as potential barriers may have an effect at a population level in part because Yosemite toads may exhibit characteristics typical of metapopulation dynamics (Bradford 1991) (see Ecology section), but roads may also impede gene flow at larger scales, particularly where high-traffic trans-Sierra highways and other major west-slope access roads exist.

Other impacts to Yosemite toads may occur in several 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 Ollivier 1998). Similarly, roads may cause increases in sedimentation and water pollutants (Spellerberg 1998).Yosemite toad eggs collect sediment and artificial increases in sedimentation may be detrimental by suffocating eggs (Jennings and

Hayes 1994). The amount of sedimentation that Yosemite toad eggs or tadpoles can withstand is unknown. Another indirect impact of roads may 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 on two anuran genera (*Anaxyrus* and *Pseudacris*) that depend on acoustic cues for mating suggests that highway noise (as a broad-band source) could alter reproductive behavior. Karlstrom (1962) speculated that noise pollution might interfere with Yosemite toad breeding at his Tioga Pass Meadow study site. If a negative noise effect exists, it is currently probably slight over the species' range because most Yosemite toad breeding sites are some distance from roads. Roadside lighting has also been shown to alter nocturnal frog behavior (Buchanan 1993); however, roadside lighting is rare in Yosemite toad habitat, so roadside lighting effects are unlikely to be significant.

Effects on habitat

Roads affecting riparian habitat can impact Yosemite toads. Roads may alter at least eight physical characteristics of the environment: soil density, temperature, soil water content, light, dust, surface-water flow, pattern of runoff, and sedimentation (Trombulak and Frissell 2000). Road effects to streams are more studied than effects to the meadows Yosemite toads typically inhabit.

Because Yosemite toads depend on aquatic habitat for survival of early life stages and successful recruitment, changes in the hydrology of the high mountain meadows, lakes, and stream systems they inhabit may be detrimental. 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), two processes that have major influences on riparian vegetation (Jones et al. 2000) and aquatic and riparian patch dynamics critical to stream ecosystems (Pringle et al. 1988). Effects from these fluctuations in the frequency or magnitude of peak and debris flows may be more of a risk in watersheds where the combination of sufficient debris, fluvial power, and confinement of the upstream channel have the potential to affect the hydrology of the breeding meadow system. Although Yosemite toads rarely breed in shallows pools adjacent to streams, when they do they may be affected by these dynamics. For example, a drastic increase in flow could dislodge, bury, or destroy eggs deposited in shallows adjacent to streams. Changes in peak flows or debris flows that affect meadow hydrology have the potential to greatly impact Yosemite toads. Because Yosemite toads use shallow breeding sites vulnerable to drying of eggs or tadpoles (see Mortality in Ecology section), fluctuations that ultimately cause a reduction in available water may severely affect recruitment. 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 impact riparian habitat. Most literature on this topic addresses stream systems, which are not commonly used by Yosemite toads. Yosemite toad habitats typically are lentic with silty substrates used for cover, and thus, the effects of increased sedimentation to this species are unknown. Although knowledge of the impact of increased sediment load on amphibians generally remains limited (Gillespie 2002), the negative impacts of increased sediments on stream-dwelling organisms including fish, macroinvertebrates, and periphyton, are well known (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/or impair aquatic productivity (Newcombe and Jensen 1996). The effects are further heightened if the sediments contain toxics (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 reference 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 for some species, possibly reducing the availability of oviposition sites or tadpole refugia (Welsh and Ollivier 1998). Moreover, the consequences of past sediment delivery are long-lasting and cumulative, and cannot be effectively mitigated (Hagans et al. 1986). The degree of impact to Yosemite toads likely depends on the levels of increased sedimentation.

A third impact of roads on toad habitat occurs via spread of chemicals. 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). Road alteration of the chemical environment may affect organisms in a number of ways. For example, organisms may be killed or displaced by contaminants, or plants may accumulate toxins, which can depress their growth. Some Sierran national forests use red cinders or alternative materials as a traction aid on mountain roads in winter and during periods of ice accumulation; some of these materials can have negative effects on nearby aquatic systems (e.g., Staples et al. 2004, Shi et al. 2005), but their effects on Yosemite toads are unstudied.

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, will not be facilitated by new road construction or conversion toward more developed roads.

Extent of risks related to roads

The effects of roads on Yosemite toads and the level of risk are unknown and, to date, unstudied. The substantial road matrix across a portion of the Yosemite toad range and significant science on the negative effects of roads on other amphibians indicate that roads are a potentially significant risk to Yosemite toads, at least in some local situations.

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, and will be particularly important in the lower elevation portion of the Yosemite toad's geographic range, where human use levels are greater. Science is needed to inform how roads may influence Yosemite toads, especially in meadow systems, and to identify where roads may amplify or attenuate the effects of other risk factors.

UV-B Radiation

Increases in mid-range ultraviolet radiation (UV-B; 290-320 nanometers) resulting from depletion of atmospheric ozone has been hypothesized to contribute to amphibian declines, a pattern consistent with their apparent global nature (Blaustein and Wake 1990, Wake 1991). Increased UV-B appeared an attractive hypothesis to explain amphibian declines that have taken place in near "pristine" high mountain habitats, where except for introduced fish, direct human intrusion has been generally limited. However, experimental and field studies addressing UV-B have produced mixed results (Licht and Grant 1997), suggesting 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; Licht 2003).

To date, much 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 tadpole growth rates, or sometimes increased physical abnormalities in Cascades frogs (Blaustein et al. 1994b), western toads (Blaustein et al. 1994b), 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. 1994b, 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 tadpole 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 tadpoles 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, dissolved organic material (DOM) or dissolved organic carbon (DOC) can effectively absorb UV-B (Scully and Lean 1994, Morris et al. 1995). 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. (1994b) 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. (1994b) 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 the 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). However, even if the reduction in hatching success observed by Blaustein et al. (1994b) 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, Sadinski et al. (1997) observed a high (26-59 percent) proportion of embryo mortality in Yosemite toads at 6 breeding sites in Yosemite National Park, but a preliminary field experiment found this mortality unrelated to UV-B. However, experiments using Yosemite toad embryos have since shown the species to be highly tolerant of all experimental doses, including those that are almost twice the ambient exposures (Hansen 1999). Definitive field experiments also on Yosemite toad embryos likewise found no relationship between either mortality or DNA damage (evaluated as the formation of pyrimidine dimers) and exposure to ambient UV-B (Sadinski 2004). The increase in UV-B at high elevations in the Sierra Nevada has not been more than 5 percent in the past several decades (Jennings 1996). These data imply that UV-B has not contributed directly to the decline of Yosemite toads and may be currently a low risk to the species. However, changes in UV-B levels are not static, but were anticipated to reach a maximum in association with maximal levels of ozone-depleting substances before 2000 (UNEP 1998). More recent data indicate that this maximum has not been reached and UV-B levels are still on the increase (Middleton et al. 2001); moreover, indirect effects of UV-B at current ambient levels are unexamined.

Davidson et al. (2002) examined the spatial pattern of population declines in Yosemite toads to see if patterns were consistent with what 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. 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 Sequoia-Kings Canyon National Park in the southern Sierra Nevada. Of eight amphibian species examined, 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. This analysis did not include Yosemite toads.

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 parallel pattern has been reported in embryos of the common frog, *Rana temporaria* (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. Many other additive or synergistic effects are possible; none have been studied in Yosemite toads.

Extent of risks related to UV-B radiation

Increased UV-B radiation does not appear to be a primary factor directly responsible for the rangewide decline of Yosemite toads. However, the synergistic relationship between UV-B, other stressors, and toad 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 so effects of increased UV-B on Yosemite toads 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 in this conservation assessment. Should the risk level for this risk factor increase, effective management would require coordination of agencies outside the jurisdiction of those involved in this assessment. Agencies responsible for Yosemite toad management should participate in guiding the development of the management and science to inform this issue.

Vegetation and Fuels Management

Vegetation and fuels management encompasses all management activities that alter vegetation structure and composition. These include commercial logging, lodgepole pine removal for meadow enhancement, fuels management, and firewood cutting. The extensive and damaging fires of 2000 and 2002 led to making fuels management a focal part of National Fire Plan (NFP) implementation (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. As data are lacking on how vegetation and fuels management activities may impact Yosemite toads, this discussion addresses potential effects. Vegetation and fuels management overlap with Yosemite toads primarily in the lower elevation portions of the species' range. Lodgepole pine or red fir generally surround the high-elevation meadows that provide habitat for the Yosemite toad; neither of these conifers has the commercial value of the lower-elevation mixed-conifer assemblage (Douglas-fir, incense cedar, ponderosa pine, sugar pine, and western white pine). Thus, in general, the high elevation meadow habitats typically used by Yosemite toads are less affected by these activities.

Commercial timber harvest occurred historically over the lower elevational range of Yosemite toads. However, some forest plans lacked standards and guidelines to provide protection for riparian areas (including meadows), so that timber harvesting occurred to the edges of riparian areas and access roads were constructed across streams, their adjoining aquatic habitats, and in the vicinity of meadows. Commercial logging in this manner affected microclimates surrounding meadows and altered water yields resulting in headcutting, lowering of the water table, and loss of riparian habitat. Roads constructed across meadows also affected water transport and meadow function. Although illegal on national forest lands, some visitors drive on to meadows and cut green lodgepole pine for firewood. Driving on meadows results in compaction and rutting, which can affect meadow function and initiate down-cutting of channels. Habitat alteration legacies of historical harvest practices remain in many areas.

Ground-disturbing activities have the potential to directly or indirectly affect Yosemite toads. Falling trees, equipment, vehicles, and even personnel can crush Yosemite toads; 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 a drainage removes organic material which can increase streamflow resulting in erosion and sedimentation. Erosion and sediment loading issues were addressed in the section on Roads.

Prescribed fire is one method of fuel reduction in the United States, but the effects of such controlled burns on fauna, including Yosemite toads, 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 Yosemite toads if it reduced the risk of future high-intensity wildfire, but such conditions are unlikely to occur outside the lower elevation portion of the species' range because of fuel development patterns. Prescribed burning in lodgepole stands has the potential to restrict meadow invasion by lodgepole. A reduction of the stand density may increase the water table in the short-term (until the remaining stems increase growth and water consumption). The short-term increase may be enough to drown lodgepole pine invading the meadow perimeter. The effectiveness of this treatment for Yosemite toad habitat is unknown. Prescribed fire could also damage Yosemite toad habitat if not properly implemented. Prescribed fire can greatly alter vegetation and soils and may disturb toads 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 use these no ignition buffers. Much of the Yosemite toad range is on granitic soils; some prescribed burning could be risky on granitic soils because (1) erosion rates of burned areas on such soils have been shown to be up to 66 times as great as on undisturbed watersheds, and (2) annual sediment yields are 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 amplified this effort. No studies have directly examined the effects of thinning understory brush or removing coarse woody debris on amphibians, although 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 altered air temperatures, decreased soil moistures, and reduced habitat complexity with fewer refuge sites, amphibian populations could decline in thinned forests (Dupuis and Steventon 1999). How these factors affect Yosemite toads is unknown.

On a smaller scale, selected actions are intended to prevent lodgepole encroachment on meadows through removal of small trees, which are piled and burned along the meadow edge. In these cases, the harvest can benefit habitat for the Yosemite toad, assuming that vehicle and disturbance activity from the restoration itself does not negatively affect Yosemite toad breeding and refuge habitat. It is possible that Yosemite toads may take cover under the wood piles placing them at risk of burning.

Extent of risks related to vegetation and fuels management

Much of the habitat for the Yosemite toad occurs in wilderness and high-elevation areas with sparse vegetation, where vegetation and fuels management activities are infrequently conducted. Thus, risk from these activities to Yosemite toads is primarily a lower-elevation phenomenon within the Yosemite toad range. The potential exists for these activities to affect Yosemite toads where they occur. Data are lacking on the impact of vegetation and fuel management activities on Yosemite toads.

Conservation options related to vegetation and fuels management

Agencies should continue to manage for vegetation and fuels management where these activities fall within Yosemite toad areas. These are major activities that are directly within the jurisdiction of agencies participating in this conservation assessment, and will be most important in the lower-elevation portion of the Yosemite toad geographic range, where vegetation is more substantial and fire is an important factor. Science is needed to inform how vegetation and fuels management may influence Yosemite toads and their habitats.

Water Development and Diversion

Water developments, such as dams and diversions, can radically change an aquatic habitat, including potentially that of Yosemite toads, and are a prominent component of the landscape in the Sierra Nevada of California (Harris et al. 1987, Moyle and Randall 1998). However, the vast majority of water developments and diversions, whether assessed based on number, scale, or size, have occurred at lower elevations (Moyle and Randall 1998), and much of it below 1,219 meters (4,000 feet) which is below nearly all the elevational range over which Yosemite toads are known to occur (see Status section). Nonetheless, over the mid-elevations (1,219-2,438 meters [4,000-8,000 feet]), many small impoundments and diversions exist, of which roughly several dozen structures are within the range of the Yosemite toad. Further, several high elevation reservoirs flooded what was probably Yosemite toad habitat (e.g., Lake Thomas Edison and Florence Lake; Strand 2007). About a half-dozen locality records exist for Yosemite toads from water development-altered sites, and most are pre-1975. Yosemite toads currently exist at Upper Blue Lake reservoir and a few other sites where alteration of aquatic habitat is limited. Because most of these sites with significant alteration or development of aquatic habitat appear to no longer be occupied by Yosemite toads (based on 2005 California Natural Diversity Database; Hansen 2005), this pattern implies that water development or some feature corollary to water development may have resulted in the disappearance of Yosemite toads at these locations. Yosemite toads have, however, also disappeared at other lower elevation sites so other factors also may explain these patterns.

Water development and diversions can be detrimental to Yosemite toads if they eliminate shallow-water habitat, remove water from toad breeding habitat, or shorten the water retention time of breeding habitat. For example, hydroelectric development generally includes reservoir construction which may eliminate meadow habitat; a few of these have been built on meadows above 2,134 m (7,000 ft). Sometimes reservoir volume is enhanced through diversion of small streams from adjacent basins, reducing water available to meadows in these systems. Some water developments also exhibit short-term (i.e., few hour to diel interval) fluctuations in water level (a few decimeters to several meters) that can either discourage oviposition outright or result in stranding of eggs or early developmental life stages. Aseasonal 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). On a smaller, more local scale, spring development for livestock and other uses can reduce available water within meadows. Finally, some small high-elevation lakes have been enlarged using small dams to improve the fishery of the lake, while releasing the water over a longer period of time through the summer to improve the downstream fishery. Construction of these small dams has flooded adjacent habitats, including some meadows. Some of these fishery-enhancement dams have not been maintained and are no longer functioning. Water development 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).

Extent of risks related to water development and diversion

The level of risk posed by water development and diversion to Yosemite toads is unknown. Anecdotal evidence exists indicating that water development and diversion may present a risk to the species, particularly when wet meadow habitat is flooded under reservoirs. Risks that water development and diversion may present to Yosemite toads may be confounded with other factors, so water development and diversion per se may not be the factor effecting declines. Most of the Yosemite toad range is at high elevations, where water diversion projects have generally been small (e.g., small-scale dams to enlarge impoundment size), so risks may be localized. Nonetheless, risks can be significant within basins where water developments occur.

Conservation options related to water development and diversion

Agencies should continue to manage water development and diversion projects where they overlap with Yosemite toad 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 Yosemite toads, particularly to distinguish where water diversion or development may affect the species.

Relative Importance of Risk Factors

The relative importance of each risk factor was assessed to prioritize conservation actions to be developed in the conservation strategy. The following 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
- Quantifiability / weight of evidence
- Agency jurisdiction

These evaluation criteria are defined in Table 2, and are summarized for each of the 16 risk factors in Table 3.

The primary causes for declines of Yosemite toads are still unknown, and with a few exceptions, little direct information is available on the effects of most of the risk factors on the species. Further, although studies do exist on the effects of the various risk factors on riparian systems, these are often focused on streams and riparian zones, and less on the breeding meadows and upland habitats used by Yosemite toads. Thus, assessing the relative importance of the risk factors based on available data is challenging, and to some extent relies on professional judgment.

Risk factors that affect the following components of the Yosemite toad's ecology may be of most importance. Because Yosemite toads breed in very shallow, often ephemeral water with sufficient hydroperiods for successful metamorphosis, factors that affect meadow hydrology pose high risks. There is increasing understanding of the importance of protecting the long-lived adults given the high rates of mortality in the early life stages, and we are learning more about their upland habitat usage. Thus, although we lack sufficient information about how best to manage these dispersed habitats, given the apparent prevalence of small populations, risk factors that impact individual adults may be important. As a corollary, if the majority of populations are small, loss of even a few individuals may matter. Thus, small populations may be vulnerable to risk factors that would have less impact on larger populations. Given the high elevations of much of the Yosemite toad's range, some factors may pose a high risk locally, but are not a widespread threat. A final consideration was the ability of participating agencies to address the risk factors.

Table 2—Evaluation criteria for assessing relative importance of Risk Factors

Criteria	Definition
Spatial extent of Risk Factor	Geographic area affected by the Risk Factor. The larger the affected area, the greater the importance of the Risk Factor.
Duration/persistence of Risk Factor	The time period and periodicity over which the species is affected by the Risk Factor. The longer the time period and the shorter the periodicity between impacts, the greater the importance of the Risk Factor.
Intensity of Risk Factor	The impact severity. The likelihood that the Risk Factor will result in a rapid decline in the species or its habitat. The higher the intensity, the greater the importance.
Ecological permanence of Risk Factor	The degree to which a system can recover ecologically and the length of time it would require. The more permanent the impact, the greater the importance.
Potential for management to reverse or reduce Risk Factor and degree of management effectiveness	The degree to which management is needed or can be applied to reduce or reverse the effects of the Risk Factor. For example, management is needed to and can alter fish stocking levels, but management may have limited capability to address disease epidemics. The more management is needed and 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.

Most or all aspects of 11 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 Yosemite toads and their habitat. These are Fire Management, Habitat Loss, Urbanization, and Fragmentation, Introduced fish and other predators, Livestock Grazing, Locally Applied Pesticides, Recreational Activities including Packstock, Research Activities, Restoration, Roads, Vegetation and Fuels Management, and Water Development and Diversion. Legacy effects from some of these risk factors (e.g., livestock grazing) may have contributed to Yosemite toad declines, particularly those that resulted in meadow drying, shortened hydroperiods of breeding habitats, and potentially, lowered breeding success. Many of these effects remain today, and although improved management may have lessened the impacts of some of these risk factors, their extensive overlap with Yosemite toad habitats and the high potential for further effects on the species and its habitats (e.g., meadow hydrology) merit continued attention.

Livestock grazing has been and potentially still is a significant risk factor for Yosemite toads because it is widespread across the species' range and has high overlap with Yosemite toad habitats. Effects from past grazing practices are still present in many Yosemite toad meadows, with alterations to meadow hydrology of primary importance. The extent of impacts to Yosemite toads of these legacy effects cannot be evaluated since no historical data addressing this exists and there are very few ungrazed meadows in the Sierra Nevada. Current management is intended to minimize these impacts, lead to restored meadow conditions, and may result in increases in greater connectivity among high elevation meadow systems.

Recreation also is widespread across the range of the Yosemite toad, and potentially has high overlap with the species and its habitats. The impacts of this risk factor to the species are unknown. Effects to the species may occur locally affecting meadow hydrology or potentially to the toads themselves, including in nonbreeding habitats. In general, the level of risk is probably low at the broader range scale because of the dispersed nature of many recreational activities.

Several risk factors may be locally significant at low to mid elevation ranges with greatest risk to adults in nonbreeding habitats. These factors currently are not likely to be major causes of rangewide declines but may be important in specific situations, particularly where toad populations are small. Roads are relatively common at these elevations, and mortality of toads from vehicle traffic has been documented. Other risk factors in this category include fire management, locally applied pesticides, vegetation management, and water dams and diversions. The extent of risk of these activities to meadows and other breeding habitats is unknown, but there is high potential for these activities to affect individuals in their upland habitats. Potential benefits of these activities to Yosemite toad habitat are unstudied.

Although Introduced Fish is a primary risk factor for some amphibian species, a recent study suggested that the direct impact on Yosemite toads via predation may be minimal. However, indirect impacts of introduced fish on aquatic systems in general (e.g., food webs, nutrient cycling, vectors of disease) may pose a risk to the species.

Disease potentially is a significant risk factor for the Yosemite toad but currently there is insufficient data to fully evaluate its importance. Initial studies suggest that *Bd* may have played a role in the species' decline and may continue to impact the species. The pattern of some Yosemite toad declines is similar to *Bd*-related declines in other species. Further, data for other species worldwide, in the Sierra, and for similar taxa, implicate *Bd* as a potentially primary risk factor. However, high *Bd* infection rates and large mortality events have not been observed for the Yosemite toad. Thus, this is a crucial information gap.

Although urbanization or development for agriculture are not of concern for the Yosemite toad, many of these risk factors may cause habitat loss and/or fragmentation, leading to increased isolation of remaining populations. Small isolated populations increase the risk of further declines for this species.

Four risk factors fall largely outside the purview of the agencies participating in this conservation assessment and have the potential to impact populations on a regional or global scale. These include Acid deposition, Airborne contaminants, including pesticides, Climate change, and UV-B radiation. Participating agencies have few options to reduce the risk these factors pose to Yosemite toads and their habitat. However, they may be able to respond indirectly to these global risk factors by instituting land management actions that ameliorate local risk factors and result in higher resiliency of Yosemite toad populations. Of these, climate change likely poses the most risk to the species given the Yosemite toad's reliance on very shallow ephemeral water for reproduction. Reduced snowpacks may result in less available surface water, fewer breeding pools, and faster drying of breeding sites, all of which may lead to less successful reproduction. Early snowmelt and warmer temperatures may affect the Yosemite toad's behavior, the timing of reproduction and other phenological events, the duration of tadpole development, and resulting effects on survivorship.

Although these four risk factors lie largely outside the purview of agencies participating in this conservation assessment, these agencies may have opportunities to participate in and guide the development of management strategies to address them. In addition, participating agencies may have opportunities to support research on how these risk factors affect the Yosemite toad and interact with other risk factors. Knowledge gained will facilitate the development of a successful conservation strategy by better understanding the various factors which may impede or increase the success of a proposed management action. For example, if one of these risk factors results in a local condition in which Yosemite toads cannot survive (e.g., presence of *Bd*), but that condition is unrecognized, addressing another risk factor (e.g., re-routing hiking trails) may be less effective.

Table 3—Evaluation summary of focal risk factors for the Yosemite toad

Risk factor	Spatial extent of the risk	Duration and persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/Degree of management effectiveness	Quantifiable/ weight of evidence	Jurisdiction of participating agencies
Acid deposition	Currently low; low buffering capacity of Sierran waters make this a risk if acid deposition ever increases.	Unknown; if conditions change, may be persistent and long-term.	Currently low; if interaction with another factor may be higher.	Unknown, only answerable if becomes a problem.	Unlikely and unknown, actions that could address likely limited.	Limited and localized in Sierras, Yosemite toad seems tolerant of existing levels.	No, would require broad societal changes and coordination among multiple agencies; agencies can guide the development of management and science and promote awareness.
Airborne contaminants	Widespread, regional and extra-regional contributions; variable due to composition and loading patterns. .	Long-term effect; seasonal pulses; persistence depends on chemical and use pattern.	Unclear, but interactive effects possible such as increased susceptibility to disease key; potentially high.	Not clear, depends on contaminants, and interaction with other factors.	Unclear, but likely no; management promoting public awareness may be more effective than anything else.	Evidence of aerial transport, deposition, and loading in tissues of amphibians, but Yosemite toads not examined; needs focused study.	No, would require broad societal changes; but agencies can guide the development of management and science.
Climate change	Global with regional effects documented.	Impact long-term and persistent; especially if meadow successional changes promoted; likely to change hydrology. .	High if eliminates or reduces quality of breeding sites.	Permanent over practical time scales (next many decades).	Actions that could address likely limited.	Climate change well-documented; effects on Yosemite toad not known, life history data imply multiple effects and interaction with other risk factors.	No, would require broad societal changes and coordination among multiple agencies; agencies can guide the development of management and science.
Disease	Unknown; chytrid widespread in aquatic habitats regionally; extent of risk needs study.	Unknown, but based on other species, likely persistent.	For chytrid, high over the short term, unclear over the long term; unknown for other diseases.	Unknown, depends on potential for recovery and interaction with other factors.	Unknown, depends on transmission mode, whether humans, fish, or other organisms act as vectors.	Chytrid present in Yosemite toads and in co-occurring species, but distribution, effect on species, and other mitigating factors unknown for chytrid; limited data on other diseases.	Possibilities depend on better understanding of modes of transmission and epidemiology.
Fire management	Effects mostly lower elevation; episodes largely local.	Potential to be long term and persistent.	Variable, but potentially severe.	Non-permanent, but long-term if meadow recovery needed.	Yes, effectiveness depends on approach implemented. .	No data for Yosemite toad; limited observational data on habitat based on vegetation project effects.	Yes for USDA Forest Service and National Park Service .

Risk factor	Spatial extent of the risk	Duration and persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/Degree of management effectiveness	Quantifiable/ weight of evidence	Jurisdiction of participating agencies
Habitat loss, urbanization and fragmentation	Widespread but localized, other Risk Factors contribute (see Livestock Grazing, Recreation, and Roads); urbanization not currently significant.	Variable, depends on what promotes habitat loss or fragmentation.	Variable, can be locally severe, degree of loss and fragmentation dependent on cause.	Yes, where elimination of Yosemite toad habitat or "ancient" peat meadow soils occurs.	Yes where loss and fragmentation will likely occur.	No data for Yosemite toad; see also Livestock Grazing, Recreational Activities, and Roads; lots of data on other amphibians suggest negative effects.	Yes for habitat loss due to RF within jurisdiction of participating agencies; fragmentation depends on causal RF category.
Introduced fish and other predators	Fish widespread across species' range, but habitat overlap probably limited; corvids widespread and increasing in range.	Fish presence is long-term and persistent; corvid predation is sporadic but may be on the increase.	Low for fishes; unpalatability makes direct threat unlikely; indirect effects unknown: for corvids now low but monitoring needed.	No, known to be reversible for fish; likely also reversible for other predators.	For fish, high effectiveness assuming no other confounding factors; unclear for other predators.	Experimental evidence for fish unpalatability; one disease transfer study from fish to toad eggs for a related species; observational study on related species for corvid predators.	Yes for fish and linked human activities; other predators unclear.
Livestock grazing	Widespread, but varies over range; common on westside below 2438 m, and on eastside.	Potentially long-term persistent impact; depends on livestock and allotment management plan.	Varies depending on livestock grazing management; changes in habitat quality potentially biggest effect.	Unclear, level of grazing and historical conditions will influence recovery time; not all results may be negative.	Yes, management probably effective, but requires permittee co-operation and local enforcement.	Numerous studies on impact to meadow habitat; but few linked to Yosemite toad; recent study addresses this information gap and showed no differences among livestock grazing treatments, but high variability in toad density dependent on water year type and meadow wetness.	Yes, NPS and USFS jurisdiction.
Locally applied pesticides	Local; variable due to pesticide composition and use.	Short-term for most pesticides in current use; but depends on chemical and use.	Unknown.	Probably not, but poorly known; effect chemical-dependent.	Yes, potentially effective; through regulation of application (amount, timing, and constituent).	No field data for Yosemite toad; toxicity data on other and related species suggest surfactants more toxic than pesticides; toxicity chemical-dependent.	Yes, management can affect application on public lands; change on private lands requires coordination with other agencies.
Recreational activities (including packstock grazing)	Widespread across range, but localized to use sites; higher in less remote locations; packstock an issue in less accessible wilderness areas.	Seasonal and variable, particularly depending on use of meadows; potential for long-term impact. Depends on use patterns and management.	Unknown but probably depends on use level; high if promotes persistent habitat decline.	Probably not, but patterns not understood, recovery timelines may depend on amount of time sites have been impacted.	Yes, through managed use, education.	Studies exist on impact to meadow habitat, but none linked to Yosemite toad; selected observational data suggest an impact.	Yes, NPS and USFS jurisdiction

Risk factor	Spatial extent of the risk	Duration and persistence	Intensity of the threat	Ecological permanence	Potential for management to reverse or reduce impacts/Degree of management effectiveness	Quantifiable/ weight of evidence	Jurisdiction of participating agencies
Research activities	Localized at research sites; extent depends on extent of research. Broadscale surveys are now more common.	Seasonal, long-term potential persistence depending on research objectives.	Unknown, but probably limited.	Probably not but pattern of recovery depends on type of effect.	Yes, through permitting; protocol for minimally invasive research and disease prophylaxis.	No data, one investigator reported potential for direct mortality.	Yes, through permitted protocols for minimally invasive research and disease prophylaxis.
Restoration	Localized at restoration sites; currently limited, but growing.	Seasonal short-term for activity, long-term positive effect anticipated.	Low for actual activity, likely none for long-term effect.	No because presumably permanent positive effect.	Yes, through planning process; potentially highly effective.	No data on effectiveness for Yosemite toads; few data from other systems.	Yes, NPS and USFS jurisdiction .
Roads	Widespread at lower elevations, localized; limited at higher elevations.	Long-term and persistent for all elements linked to road matrices except decommissioning.	Unknown, expected to be locally severe; degree of loss fragmentation dependent.	Yes, where elimination of habitat occurs; potentially less severe for fragmentation.	Yes, through planning process; potentially effective to minimize loss to Yosemite toad habitat and reduce roadkill..	No quantification for Yosemite toad; limited observational data including documented roadkills; lots of data on other amphibians indicate many negative effects.	Yes, NPS and USFS jurisdiction .
UV-B radiation	Global, but any potential problem more likely with increased elevation.	Persistent and long-term until maintaining factors removed; may still be increasing.	Currently low; possibly higher if interaction with another risk factor.	Probably, depends on whether current elevated UV-B levels reversible.	No, beyond agency jurisdictional scope; agency-influenced public awareness may promote change.	Extant distribution of Yosemite toad and experimental evidence shows no effects with this factor; but interactive effects with other factors unstudied.	No, would require broad societal changes but agencies can guide the development of management and science.
Vegetation and fuels management	More prevalent in low to mid elevation range, now localized. May affect Yosemite toads in nonbreeding upland habitats.	Lowering water table, habitat loss effects from harvest potentially long-term; succession changes long-term and persistent.	Timber harvest legacy and succession in meadow habitat locally severe. May be high if animals killed or habitat is impacted, particularly in upland nonbreeding habitat.	No, but recovery may be long-term depending on location and impact.	Yes, to restore hydrological impacts; effectiveness likely degree of damage dependent.	Unstudied for Yosemite toads.	Yes, direct management responsibility of USFS and NPS.
Water development and diversion	Widespread, but localized effects; primarily across lower and mid elevation portion of the range.	Long-term and persistent where effects exist.	Probably severe if results in loss of habitat.	May depend on scale of change; more likely to be yes if large-scale habitat loss.	Yes, management can be effective if habitat restoration occurs.	Studies exist on effects of water development on aquatic species, but none addressing Yosemite toad.	Yes, through state and federal relicensing process for hydroelectric projects; restoration activities.

EXISTING MANAGEMENT AND RESEARCH

Existing management and research currently addressing Yosemite toad conservation include:

Ecology and Status

Sierra Nevada Amphibian Monitoring Program, USDA Forest Service

From 2002-2009, the USDA Forest Service implemented the first cycle of a long-term bioregional monitoring program (Sierra Nevada Amphibian Monitoring Program, SNAMPH) for the Yosemite toad and mountain yellow-legged frog 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 (Brown et al. 2012, Brown and Olsen 2013). The monitoring combines extensive and intensive components. Extensively, small watersheds (2-4 km^2), selected using an unequal probability design based on historical occupancy, 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. Intensively, more detailed abundance, life history, and microhabitat data are collected in two small watersheds for the Yosemite toad. Analyses of multi-scale Yosemite toad habitat relationships are currently underway. Contact: Cathy Brown, USDA Forest Service.

Genetic analysis of Yosemite toads

Molly Stephens (University of California at Davis/U.C. Merced) is continuing to work on an analysis of population genetic structure in the Yosemite toad and its genetic relationship to its sister species, the western toad (summarized in part in Systematics and Taxonomy in the Ecology section). Her findings that Yosemite toads in the southern and central portion of their range appear to group genetically with western toads from southern California, which was obtained with mitochondrial DNA markers, is now being examined with nuclear DNA markers to determine whether this pattern is unique to mitochondrial DNA or indicative of a truly polytypic species. She is currently conducting a study using RAD-Seq markers to examine rangewide relationships of Yosemite Toads to western toads.

Paul Maier (San Diego State University) is conducting phylogenetic and population structure analyses of Yosemite Toad populations in Yosemite National Park using ddRAD-seq analyses.

Management

Bull Creek/Kings River Experimental Watersheds Collaborative Study on Yosemite toad demography, movement, habitat, and response to disturbance

A collaborative study between SNAMPH, Pacific Southwest Research Station (PSW), and the Sierra National Forest (SNF) has built upon existing programs to investigate Yosemite toad ecology, meadow conditions, and the response to common management activities such as timber harvest and prescribed fire. SNAMPH monitors Yosemite toad abundances and demography using mark-recapture methods, PSW investigates adult movements and habitat use through radio-tracking, and PSW/SNF monitors meadow hydrology (water table depths, surface water area and depth) and water chemistry using piezometers and surface grids. In addition to providing data on demography and movement ecology (see Ecology section), results will describe relationships between meadow surface water retention and depth, water table depths, water chemistry, and Yosemite toad breeding occupancy, timing, and successful metamorphosis. Contacts: Cathy Brown, Stephanie Barnes USDA Forest Service, Carolyn Hunsaker, Christina Liang PSW Research Station.

Packstock grazing research completed in Yosemite National Park (Moore et al. 2000; Cole et al. 2004)

Yosemite National Park initiated a meadow monitoring program that continues to be ongoing within the Park. The program involves 14 meadows in 12 areas ranging from 1,300 to 3,050 m in elevation (Moore et al. 2000). Monitoring is meant to provide feedback adaptively to adjust allowable levels of packstock grazing with evaluation intended to occur at regular intervals.

Fish Management

Several efforts addressing fish management may indirectly help Yosemite toad populations. Fish presence may not directly affect Yosemite toads, but fish have the potential to influence Yosemite toads indirectly such as through food web elements that may link aquatic and terrestrial pathways (see Introduced Fish and Other Predators in Risk Factor section). If such linkages are found to have some influence on Yosemite toads, ongoing fish management efforts that may benefit them include:

> 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 (CDFW [N.d.]). 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). 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.

CONSERVATION OPTIONS AND KEY INFORMATION GAPS

This conservation assessment has revealed a number of conservation options for structuring the forthcoming conservation strategy for Yosemite toads. These options tie together current knowledge of Yosemite toad ecology, current distribution and abundance, and potential sensitivity to various risk factors and include identification of key ecological requirements for the species, approaches that are likely to be successful given the toad's ecology, specific risk factors that may be of importance to the species, and selected research to provide information that would enhance our ability to conserve the species.

- Provide for the ecological requirements of Yosemite Toads. Maintaining a diversity of habitats for all life stages of Yosemite toads. This means maintaining or restoring the hydrological and habitat functions of meadows and other breeding habitat, maintaining upland nonbreeding habitat, and maintaining or restoring landscape configurations between meadow and non-meadow habitats so that all habitats used by different Yosemite toad life stages are encompassed.
- Use a multi-scale management approach that identifies and manages within priority basins. Focus on three scales:
  - The most extensive scale is the geographic range of the Yosemite toad as currently understood. Significant genetic partitioning has been found (see Ecology section) and data from pending studies should provide guidance for prioritizing the different portions of the species' range.
  - An intermediate scale covers management at the level of individual national forests or national parks, representing administrative units with the ability to guide conservation-oriented actions over significant geographic areas.
  - The local scale encompasses management of small basins (watersheds) which represent population-level units. This scale incorporates a priority basin management approach similar to that used by CDFW (CDFW [N.d.]).
- Develop criteria for selecting priority basins based on habitat complexity and suitability, source toad populations, potential disease issues, and other criteria that may be important for comprehensive toad management and conservation. For example, high elevation areas which could provide refugia during projected climate warming may be prioritized for protection and/or restoration.
- Continue current management and develop further options for high priority risk factors.
  - Develop further management options for livestock grazing in priority basins.
  - Develop further management options for recreation in priority basins.
  - Continue existing levels of management for the other nine risk factors under the participating agencies' jurisdiction.
- Develop strategies for addressing key information gaps and applying results of recent studies.
  - Continue programs or develop new studies as appropriate that provide a basic understanding of the demographic and genetic structure of Yosemite toad populations and how these vary, especially with variation in habitat structure. These data will provide a better understanding of the appropriate scales for management of the species. For example, if toads generally function as metapopulations, conservation efforts would address broader scales than individual breeding meadows. Programs that address this to varying degrees include SNAMPH (demographic structure) and Genetic Analysis of Yosemite toads (genetic structure). See Existing Management and Research Section for more details.
  - Continue programs or develop new studies as appropriate that further investigate nonbreeding habitat requirements for adults, subadults, and metamorphs. Programs that address this to varying degrees include SNAMPH and the Bull Creek/Kings River Experimental Watersheds Collaborative Study.

- Address the two high priority risk factors (livestock grazing and recreation).
    - Continued monitoring and adaptive livestock management to reduce and mitigate potential adverse effects of livestock grazing on Yosemite toad populations and their habitats following the results of a cooperative study by the USDA Forest Service and the University of California (see Livestock Grazing risk factor)
    - Develop research that will inform extent of risk and management options for addressing impacts of recreational activities on Yosemite toads. Of particular importance are identifying which activities are most likely to negatively affect Yosemite toad populations including packstock use, activities that involve use, construction, or maintenance of roads or trails near Yosemite toad habitat, and activities that have the potential to move pathogens or diseases, particularly among aquatic water bodies.
- Investigate the impact and epidemiology of *Bd* infection for Yosemite toad populations. If *Bd* proves to be a significant factor in toad declines, develop a more comprehensive research program that addresses the epidemiology and vectors of the disease.
- Investigate the impacts of climate change and potential management options. This risk factor is outside of the jurisdiction of participating agencies but may play a significant role in Yosemite toad declines and may influence the ultimate success of conservation efforts.

Other conservation options may become important during conservation strategy development. These should be considered for incorporation into the conservation strategy at that time.

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ENGLISH EQUIVALENTS

When you know:	Multiply by:	To find:
Millimeters (mm)	0.0394	Inches
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Meters	1.094	Yards
Kilometers (km)	0.621	Miles
Hectares (ha)	2.47	Acres
Square kilometers (km^2)	0.386	Square miles
Liters (L)	0.265	Gallons
Liters (L)	33.78	Ounces (fluid)
Kilograms (kg)	2.205	Pounds
Milligrams (mg)	0.00035	Ounces
Degrees Celsius (C)	1.8 C + 32	Degrees Fahrenheit

METRIC EQUIVALENTS

When you know:	Multiply by:	To find:
Feet (ft)	0.305	Meters
Pounds (lb)	454.0	Grams
Pounds (lb)	0.454	Kilograms

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

anurans - the collective name for the amphibian group that includes frogs and toads

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

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

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

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

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

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

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

corvids - birds in the family Corvidae; includes crows, jays, magpies, and ravens

***Dermosporidium* -** genus of poorly known protistan parasites, some of which have been found in frogs and toads

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

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

embryonic development - for anurans, the time interval from when eggs are laid to when embryos hatch out of their jelly mass, at which point they are called tadpoles

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

epidemiology - life history of a pathogen, including its transmission mode, reservoir hosts, and other factors affecting the rate and pattern of spread.

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

forb - a non-grass herbaceous plant

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

labial teeth (= denticles) - the small tooth-like structures in the mouthparts of frog or toad tadpoles (= larvae); not true teeth, but rather keratinized structures aligned in rows that tadpoles use to scrape algae or biofilms off surfaces in aquatic habitats

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

livestock - production grazing animals, i.e.; cattle and sheep

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

meltout - melting of snow and ice at spring thaw

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

myxozoans - a group of single-celled parasitic animals

nanometer - one billionth of a meter; unit of measurement used at micro scales like to describe wavelengths of light

nematodes - large group of related worms with both free-living and parasitic forms; some parasitize anurans

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, mules, goats) used for recreational camping

parotoid glands - large poison or toxin glands located behind each eye on the head of a toad

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

photolyase - an enzyme important in the repair of UV-B-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

pyrimidine dimer - parts (pairs of bases) of DNA in an organism that become abnormally fused together because of exposure to damaging UV radiation

range readiness - term used to indicate that production grazing habitat (e.g. meadows) are in a condition that will permit grazing; range that is unready places habitat quality at risk

reticulum - a relatively fine color pattern of repeatedly interlinked lines

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

***sensu lato* -** a Latin phrase meaning "in the broader sense"; used to indicate the former species group referred to by a scientific species name (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 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 of recently metamorphosed individuals

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 1: MUSEUM STANDARD SYMBOLIC CODES

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

Institution	Symbolic Code
California Academy of Sciences	CAS
California Academy of Sciences – Stanford University Collection	CAS-SU
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
University of Colorado Museum	UCM
United States National Museum (Smithsonian Institution)	USNM
University of Illinois Museum Natural History	UIMNH

APPENDIX 1 LITERATURE CITED

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APPENDIX 2: STATUS – ADMINISTRATIVE UNITS

This appendix provides information on the status of the Yosemite toad for individual administrative units within the species' range, including national forest and national park units. The information in this appendix was compiled 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 1) followed by the pertinent specimen number. This appendix was last updated in 2009.

Lake Tahoe Basin Management Unit

Prior to 1980

The only presumptively verifiable historical records from the Lake Tahoe Basin Management Unit (LTBMU) consists of two Yosemite toads that David H. Powell collected from a meadow at 2,286 m between Heather and Grass Lakes in 1956 (LACM 11885-11886; Mullally and Powell 1958). David Martin (as cited in Jennings and Hayes 1994) believed that these animals were misidentified high-elevation isolates of the western toad with Yosemite toad-like color dimorphism, but this supposition has never been formally evaluated.

Mullally and Powell (1958) also discussed a second location, Upper Angora Lake, that may have had Yosemite toads. Upper Angora, at 2,274 m elevation, is 4 km east-southeast of Grass Lake and 2 km south of Fallen Leaf Lake. Their comments were:

> In 1953 many toads were observed by the junior author [Powell] at the northeast end of Upper Angora Lake….None was collected, but animals are remembered as being small. This impression in conjunction with the high elevation of the lake [in a local context] make it probable that the toads were *canorus* rather than *boreas*, but search during July, 1956, failed to yield specimens at upper Angora Lake. Apparently some event or condition had greatly reduced the population. The record heavy snowfall of the previous winter may have been a factor. An unusually large reside of snow persisted as patches at least into September. A lingering snowpack effectively lengthens the period of dormancy for ground-inhabiting poikilotherms and may have resulted in the destruction or thinning of this population.

Mullally and Powell (1958) then further commented on additional searches in the region:

> …a search in late August 1957 of the shores of lakes and streams in Desolation Valley near Fallen Leaf Lake failed to reveal any toads, whereas similar environment in Yosemite National Park almost certainly would have yielded specimens. They are definitely rare in the northern part of the Sierra Nevada.

Post-1980

Surveys that George Elliott (Eldorado National Forest) conducted during the 1990s in areas within the Lake Tahoe Basin Management Unit failed to reveal Yosemite toads. Similarly, more recent surveys conducted by CDFW between 2000 and 2004 have not revealed Yosemite toads within the Lake Tahoe Basin Management Unit.

Eldorado National Forest

Prior to 1980

Two historical localities exist for the Eldorado National Forest. One, at Upper Blue Lake, was collected by A. J. Calhoun in 1941 (CAS-SU 6420); in 1956, Ernest Karlstrom collected two Yosemite toads at this same locality (MVZ 64877-64878). In 1955, Karlstrom also collected one Yosemite toad 9.6 km west of Ebbetts Pass on the trail to Deer Valley [= Deer Creek] (MVZ 64900).

Post-1980

The 1990 survey addressing 75 historical sites across the range of the Yosemite toad included both the Deer Creek and Upper Blue Lake historical localities (Martin 1991a, 1991b). No Yosemite toad life stages were detected at either site.

Of the 16 sites that the survey crews of Martin et al. (1992) examined on the Eldorado National Forest, 4 were considered to be high probability (had meadow habitat) for Yosemite toads (see Status section of main document for sampling details). Of these 4 high-probability sites, two were actually occupied by what was considered to be western/Yosemite toad hybrids; no Yosemite toads proper were recorded. On 28-29 July 1992, crews working for David Martin surveyed creek and meadows areas along Meadow Lake Creek in the upper Mokelumne River basin (Alpine County) where they recorded one adult of what they labeled a western/Yosemite toad hybrid and about 1,000 tadpoles that, based on the presence of the adult, were also recorded as western/Yosemite toad hybrids. On 30-31 July 1992, they also surveyed the creek and meadows areas along Upper Blue Lake Creek above Upper Blue Lake and recorded 40 adults, all of which were deemed to be western/Yosemite toad hybrids. None of the 12 low-probability sites (did not have meadow habitat) on the Eldorado National Forest had either Yosemite toads or putative western/Yosemite toad hybrids.

Surveys that George Elliott conducted during the 1990s on the Eldorado National Forest failed to reveal Yosemite toads. In 2002, Jones & Stokes conducted surveys for PG&E at Upper Blue Lake and recorded 19 adult, 1 juvenile, and 7,685 Yosemite toad tadpoles (Williams 2006).

The USFWS (2002) reported that Yosemite toads were known from three sites in the Eldorado National Forest where it borders with the Toiyabe and Stanislaus National Forests, but they erroneously placed the Hermit Valley (Alpine County) locality that Livezey (1955) reported in the Eldorado National Forest; this record is on the Stanislaus National Forest and is discussed in that summary. The two sites they discuss as occupied since 1990 are the records from Martin et al. (1992) for Upper Blue Lake and Meadow Lake Creek discussed above.

Assessment of western/Yosemite toad hybrids from the Upper Blue Lake and Meadow Lake Creek sites should be viewed with both caution and concern. Definitive assessment of hybrids requires genetic analysis. If the hybrid assessment of Martin et al. (1992) is correct for these two sites, genetic swamping of Yosemite toads by western toads may be occurring. This notion was historically not viewed as a problem (Jennings and Hayes 1994), but may have to be re-evaluated. This may be particularly pertinent if habitat modification induced by climate change increases the upper elevation limit of the distribution for western toads.

Between 2002 and 2005, systematic surveys for Yosemite toads in potential meadow habitat were undertaken on the six Sierran national forests within the Yosemite toad's geographic range, including the Eldorado National Forest. In 2002 and 2003, Forest Service crews surveyed 77 potential Yosemite toad sites on the Eldorado National Forest (Williams 2006). Fifty-four (70 percent) of these sites were within existing range allotments. Of these 54 sites, toad life stages were detected at one site in Summit City Creek. A follow-up survey in 2005 did not find Yosemite toads at that site (Williams 2007). Of the remaining 23 sites outside of range allotments, toads were seen at seven locations including an ephemeral pond northeast of Twin Lake, south end of Upper Blue Lake, Blue Creek, a marsh off Granite Lake Trail (18E08), Snow Canyon, Indian Valley, and Hope Valley (at a pond at the intersection of Hwy 88 and Blue Lakes road.) Toads found at six of these sites were identified as western toads (identification was based on the space between the parotoid glands, see Morton and Sokolski 1978), although there were other characteristics present which made species identification confounding. Adults were diurnal and with calls like Yosemite toads. They were sexually dimorphic, much larger than other toads in the Sierras to the south, and tadpoles were jet black in color, similar to Yosemite toad tadpoles (Grasso 2009). Tissue samples were taken at most toad-occupied locations and given to Molly Stephens for genetic analysis (see Existing Management and Research to Address Risk Factors section). Results have yet to determine a consistent pattern of speciation or hybridization in this region (see Goebel et al. 2009 for more information); additional further testing using nuclear genetic markers will be needed to make definitive conclusions.

As part of the USDA Forest Service Sierra Nevada Amphibian Monitoring program, crews surveyed four watersheds on the Eldorado National Forest containing 42 sites from 2002 to 2009. One watershed contained one site with evidence of reproduction (presence of eggs, tadpoles, metamorphs) and one additional site with only adults or subadults. These were found in the upper Blue Lake area and were probable hybrids between Yosemite toads and western toads. More than 1,000 tadpoles were found in one meadow.

Stanislaus National Forest

Prior to 1980

Yosemite toad data exist for 11 localities on the Stanislaus National Forest prior to 1980. Records extend back to 16 July 1930, when Tracy Storer collected one toad 3.2 km southwest of Sonora Pass along upper Deadman Creek (CAS 218446). Two additional sites were recorded during the 1930s: in 1937, Earl Herald collected two Yosemite toads at Bond Pass, (CAS-SU 4327-4328), a locality just opposite the head of Jack Main Canyon, which is in Yosemite National Park; in 1938, Robert E. Smith collected two more from Emigrant Meadows (MVZ 32623-36624). All three localities are in Tuolumne County.

One Stanislaus National Forest locality was recorded in the 1940s. In 1947, Wallace Wood collected five Yosemite toads 1.2 km west of Sonora Pass from the meadows at the extreme upper end of the Deadman Creek drainage (Alpine County; CAS 81659-81663). This locality is about 2 km distant from the 1930 collection location of Storer.

In the course of their work in the Sierra Nevada, Robert Livezey (1955) and Ernest Karlstrom (1962) together recorded five new localities for Yosemite toads during the 1950s; all were in the vicinity of Ebbetts Pass and the Highland Lakes. On 11 August 1952, he and Robert Livezey collected one toad 2.4 km airline miles south of Ebbetts Pass (MVZ 61796)[1]. At this site, 12 toad tadpoles were collected from a small stream 5 cm deep by 30 cm wide and a pond 1.8 m wide by 4.6 m long by 30 cm deep; 15 juvenile toads were also collected from damp cattle hoof prints in the meadow 8-45 m from the stream. Livezey (1955) observed tadpoles at this site again on 27 June 1954, and collected two more juvenile toads from this location on 11 July 1954. On 26 June 1955, Karlstrom collected three Yosemite toads at this same locality (MVZ 62670-62671, 64903), which he described as 3.9 km south of Highway 4 along Highland Lakes Road (see Livezey 1955). On 11 July 1954, Livezey (1955) found one adult male, one adult female, and one juvenile Yosemite toad near a small snowmelt pond at the south edge of South Highland Lake. On 26 June 1955, Karlstrom collected 14 Yosemite toads on the northeast side of the northernmost of the two Highland Lakes (MVZ 62672-62684, 64899) and another 3 individuals on its southeast side above the same lake (MVZ 62685-62687). These three localities, treated here separately, are 0.5 to 0.8 km apart. On 20 July 1955, Karlstrom also collected one Yosemite toad at Tryon Meadow (MVZ 64901), which is 1.6 km north of the northernmost of the two Highland Lakes. All localities are in Alpine County and the localities in the vicinity of Highland Lakes are in the headwaters of the North Fork Mokelumne River.

The only records during the 1960s were six more Yosemite toads collected by Ted Papenfuss at the Highland Lakes (MVZ 77057, 79185-79189), and one toad that Steven C. Anderson collected 2.7 km west of Sonora Pass (CAS 121141). The latter location differs from the Storer collection site in 1930 because they are 0.5 km apart.

During the 1970s, one new Stanislaus National Forest locality was recorded. In 1975, James F. Lynch collected two Yosemite toads in a meadow 1.6 km south of the Highland Lakes (MVZ 116520-166521). Additionally, Yosemite toads were recollected at one site west of Sonora Pass in 1975 (MVZ 128984-128987; $n = 4$), and in the meadow between the two Highland Lakes in 1976 (MVZ 142948-142972; $n = 25$). The latter collections were incorporated in the genetic analysis of Feder (1977) on western North American toads. If declines occurred prior to 1980 on the Stanislaus National Forest, they are not identifiable from available information.

Post-1980

Most data collected on Yosemite toads on the Stanislaus National Forest since 1980 are survey data. The only Stanislaus National Forest collections made after 1980 consisted of the recollection of Highland Lakes in 1983 (MVZ 186454-186455; $n = 2$) and 1994 (MVZ 223334-223339; $n = 6$). The latter were incorporated into the analysis of Goebel (1996, 2005) on North American toads.

The first systematic surveys addressing Yosemite toads on the Stanislaus National Forest began in the 1990s. During his Sierran-wide survey of 75 Yosemite toad historical sites in 1990, Martin (1991a, 1991b) included at least nine sites on the Stanislaus National Forest; 67 percent ($n = 6$) of the nine sites were occupied. These occupied sites included: Tryon Meadow, the meadow between Highland Lakes, the meadow north of

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[1] Livezey (1955), providing details of this site, stated that it was in a small meadow in the upper end of Hermit Valley. Hermit Valley proper is located about 10 km west of Ebbetts Pass, but has a long extension that could be construed as the upper end of Hermit Valley; this extension has a meadow area that extends to the collection locality.

North Highland Lake, the meadow southeast of South Highland Lake, the meadow 3.9 km south of Highway 4 [= upper Hermit Valley], and 1.2 km west of Sonora Pass. The unoccupied sites were: Upper Blue Lake, 0.3 km west of Ebbetts Pass, and 2.7 km west of Sonora Pass.

In 1992, Martin et al. (1992) surveyed 16 sites on the Stanislaus National Forest for amphibians (see Status section of main document for sampling details). Three of the sites sampled were high probability (had meadow habitat) for Yosemite toad occupancy, whereas the 13 remaining sites had a low probability (no meadow habitat) of being occupied by Yosemite toads. Yosemite toads were not found at either the high- or low-probability sites.

Based on the compilation for the USFWS (2002) 12-Month Finding, Yosemite toads had been recorded on 28 sites on the Stanislaus National Forest, of which 79 percent (n = 22) were occupied based on survey information collected between 1990 and 2002. For this analysis, localities that were currently occupied were assumed to also have been occupied historically.

Between 2002 and 2005, the Stanislaus National Forest conducted systematic surveys for Yosemite toads in approximately 290 sites with potential habitat. Of these sites, Yosemite toad life stages were detected at 36, with 26 having evidence of reproduction. Survey data imply that most reproductive populations were small.

As part of the USDA Forest Service Sierra Nevada Amphibian Monitoring program, crews surveyed 36 watersheds containing 662 sites from 2002 to 2009 on the Stanislaus National Forest. Sixteen of these watersheds contained evidence of reproduction (presence of eggs, tadpoles, metamorphs). Within these 16 watersheds, evidence of reproduction was recorded at 49 (7 percent) of the lake, meadow, or stream sites, and adults or subadults only at an additional 18 (3 percent) of sites. Eighteen of the 49 sites with early life stages had more than 1,000 tadpoles and 7 had more than 5000. In general, few adults and subadults are found. From 2006-2009, in one watershed in the Highland Lakes vicinity, mark-recapture surveys for males were conducted in three meadows during the spring breeding chorus. Annual breeding male population estimates were relatively small with the largest population having only 18 to 20 individuals per year. Egg mass counts were also relatively small with an annual maximum within a meadow of 30.

Yosemite National Park

Prior to 1980

Yosemite National Park has the earliest and most extensive historical records for Yosemite toads across its geographic range. Prior to 1980, Yosemite toads were recorded at more than 30 sites within the park.

The earliest collections are based on the extensive trans-Sierra Yosemite transect that Grinnell and Storer (1924) began in 1915. During that year, Charles Camp, Joseph Grinnell, Charles Hollinger, Tracy Storer, and Walter Taylor documented Yosemite toads at 10 sites: the head of Dingley Creek (MVZ 5738), the East Fork of Indian Canyon (MVZ 5728-5730; n = 3), the head of Lyell Canyon (MVZ 5733, 5739-5741, 5745, 5748-5758, 5760; n = 17), McGurk Meadow (1.6 km north of Peregoy Meadow; MVZ 5742), near Mono Meadow (MVZ 5747), at or near Porcupine Flat (MVZ 5736, 5743-5744, 5759; n = 4), 1.6 km west of Ragged Peak (MVZ 5721, 5731-5732, 5734-5735, 5737; n = 6), south side of Ragged Peak (MVZ 5722-5727; n = 6), and Vogelsang Lake (MVZ 6035, 6044; n = 2). In 1919, MVZ field teams recollected Yosemite toads at McGurk Meadow (MVZ 7179-7180) and added a new site near Tamarack Flat (MVZ 7182-7185). Based on information collected in the 1910s, Grinnell and Storer (1924) described Yosemite toads as a “common resident in Canadian and Hudsonian [life] zones from near Chinquapin and Tamarack Flat eastward to Tioga Pass.” Grinnell and Storer (1924) also provide a few qualitative comments on a few sites:

> …at Peregoy Meadow there were many males present on May 20, 1919….at the head of Lyell Canyon on July 16, 1915, numbers of Yosemite toads were found in a small pond….On May 20, 1919, numbers of male Yosemite toads were congregated in the wet meadows on either side of the ridge east of Chinquapin.

The most extensive collections of Yosemite toads were made in the 1920s, when Yosemite toads were recorded at seven new sites. These included five sites collected in 1922: Aspen Valley (USNM 311297), Dana Meadows at the crossing of Tioga Road (CAS 55643-55644; *n* = 2), Lake Tenaya (CAS 55667), Tioga Pass [Yosemite National Park side of pass in Tuolumne County] (USNM 311298-311300; *n* = 3), and Tuolumne Meadows (CAS 55524-55619, 55645-55663; MCZ A9003-A9005; UMMZ 57498; *n* = 118). The Tuolumne Meadows collection, made by John Van Denburgh and Joseph Slevin during the California Academy of Sciences Mount Lyell expedition, is the most extensive collection of Yosemite toads from any single location. One additional location, Peregoy Meadow (CAS-SU 2936), was collected in 1928; a last new location, the Dana Fork of the Tuolumne River (MVZ 11273-11277; *n* = 5), was collected in 1929. Yosemite toads were collected at as many as three additional locations within Yosemite National Park in 1928 and 1929 (i.e.; CAS-SU 2881; CU 1764, 1926), but lack of specific data for these Park collections prevents determining whether they represent different localities. By the end of the 1920s, Yosemite toads had been recorded from at least 18 sites within Yosemite National Park.

Extensive collection continued in the 1930s, when Yosemite toads were found at 15 different localities; they had not been previously recorded at eight of these sites. The eight new localities were: Upper Grouse Creek near Peregoy Meadow in 1931 (CAS-SU 2132); Cathedral Lakes (MVZ 15968-15970; *n* = 3) and on the southwest slope of Mount Dana (USNM 94988) in 1932; Tamarack Flat near Big Oak Flat Road (MCZ A19431-19432; *n* = 2) and Tioga Road between White Wolf and Porcupine Flat (MCZ A19434; MVZ 16062; *n* = 2) in 1933; Elizabeth Lake (UCM 1975, MVZ 31949-31950, 32000-32001; *n* = 5), 3.2 km east of Tuolumne Meadows Camp north of Tioga Pass Road (MVZ 206917-206920), and Tuolumne Meadows on the north side of Mammoth Mountain (MVZ 40930-40939) in 1939. Recollected localities included: Peregoy Meadow in 1930 (CU 2452, 2507, 2509; *n* = 3), 1931 (CAS 218444-218445; *n* = 2), and 1936 (SDNHM 25868-25869; *n* = 2); near Mono Meadow in 1931 (CAS 218421); Dana Meadows in 1932 (MVZ 15971-15973; USNM 94989-94990; *n* = 5) and 1934 (CU 2823); Tuolumne Meadows in 1932 (MVZ 15966-15967; *n* = 2) and 1934 (CU 2828, 2899; *n* = 2); Aspen Valley (MCZ A19433, MVZ 16061; *n* = 2), Tamarack Flat [in Mariposa County] (MVZ 16060), and Tioga Pass (MVZ 31946-31948; *n* = 3) in 1939. Three additional collections were made from at least two localities within the Park that were unspecified (CAS 71321-71322; UMMZ 73412). By the close of the 1930s, Yosemite toads had been recorded from at least 26 sites within Yosemite National Park.

Collection declined somewhat during the 1940s. Nevertheless, Yosemite toads were recorded from four localities, two of which were new. The new localities included: the meadow between Lunch Meadow and Emigrant Lake in 1942 (CAS-SU 7750-7751; *n* = 2); 1.6 km north of Mount Lyell in 1946 (MVZ 42842). The previously collected localities were: Tioga Pass in 1946 (CAS 86162) and 1948 (LACM 1047); Tuolumne Meadows in 1940 (CU 4076; MVZ 206921; *n* = 2), 1941 (USNM 118611-118614; *n* = 4), and 1948 (LACM 1041-1042; *n* = 2). Additionally, 14 collections were made from at least one unspecified locality within the Park (SDNHM 33361-33374). By the end of the 1940s, Yosemite toads had been recorded from at least 28 sites within Yosemite National Park.

Collection efforts increased slightly during the 1950s. Yosemite toads were recorded from six localities, four of which were new. The new localities included: Dog Lake in 1951 (CAS-SU 10866), 3.2 km east of Tuolumne Meadows in 1954 (MVZ 62544), 0.8 km south or southeast of Tioga Pass Ranger Station in 1955 (MVZ 62641-62642, 62661-62668, 62704, 62693-62697, 62814, 64211; *n* = 18), and 1.6 km west of Tenaya Lake in 1957 (MVZ 19927-19928). The previously collected localities were: Peregoy Meadow (MVZ 60880) and Tioga Pass (MVZ 62543, 62553-62556; *n* = 5) in 1954. Additionally, one collection was made from one unspecified locality in 1957 (UIMNH 41661). At the end of the 1950s, Yosemite toads had been recorded from at least 32 sites within Yosemite National Park.

Qualitative information on historical abundances is available from the 1950s, particularly in the context of habitat. In 1950 and 1952, Mullally (1953) observed Yosemite toads at several sites in Yosemite National Park. On 19-20 August 1950, he visited Elizabeth and Johnson Lakes; on 14-17 September 1952, he visited Tioga Pass and the lakes and stream in the adjacent Gaylor Lakes Basin. He noted the following:

> [Yosemite] Toads were numerous about the lakes on the crest of Tioga Pass and at a lake located at 10,100 ft [3,078 m] on the northwestern side of the Gaylor Lakes Basin. They were also common along the stream flowing from Upper to Middle Gaylor Lake and along the stream flowing into the lake located at 10,100 ft. The toads became less common upstream, and the source lake of this stream, at 10,700 ft [3,261 m], had only one toad observed in its vicinity. Upper Gaylor Lake, at 10,800 ft [3,291

> m], a timberline lake ringed by snow banks, also had only one observed toad. Middle Gaylor Lake, 10,500 ft [3,200 m], had few toads in its vicinity; the apparent scarcity of toads here may be due to the elevation or to the effect of numerous fishermen.

Mullally continued:

> The above areas are on southern and western exposures. Toads were also present at nearby Elizabeth Lake [9,500 ft (2,896 m)], but none was observed in the vicinity of Johnson Lake [10,300 ft (3,139 m)]. These lakes are on northern and eastern exposures. Slope exposure seems to affect the elevational distribution of the toads. Conditions become too rigorous, apparently, for the existence of the toads in normal numbers at elevations between 10,200 and 10,700 ft [3,109 and 3,261 m] on warm exposures, and between 9,500 ft and 10,300 ft on cold exposures.

Only one locality was recorded to have Yosemite toads during the 1960s. Two toads were collected 3.2 km south of the summit of Mount Dana in 1968 (MVZ 204278-204279).

All Yosemite toads recorded during the 1970s were from locations where they have been previously recorded within Yosemite National Park. Three toads were collected from the Yosemite National Park side of Tioga Pass in 1976 (UMMZ 144321-144323). Most of the work of Kagarise Sherman (1980) and Kagarise Sherman and Morton (1993) occurred on the Inyo National Forest side of Tioga Pass, and their substantial data are summarized in the Inyo national forest status section. Lastly, three undated collections also exist for Tioga Pass that, based on their accession numbers, are pre-1980 vintage (LACM 97433, 137768-137769). If any declines in Yosemite toads occurred prior to 1980 in Yosemite National Park, they are not evident from available data.

Post-1980

Most data collected on Yosemite toads in Yosemite National Park since 1980 are survey data. The only collections of Yosemite toads from Yosemite National Park made since 1980 were made in 2003 and 2004. They include two historically collected sites: upper Lyell Canyon in 2003 (MVZ 240737-240749; $n = 13$) and Vogelsang Lake in 2004 (MVZ 245448); six sites from which the species had not be previously recorded, all collected in 2004: unnamed lake 1 km east by trail of Evelyn Lake (MVZ 245454-245463; $n = 10$), Fletcher Creek southeast of Emeric Lake (MVZ 245449), McSwain Meadow (MVZ 245464), Tamarack Creek (MVZ 245452), the southwest end of Townsley Lake (MVZ 245450-245451; $n = 2$), and 0.5 km north of Tuolumne Pass (MVZ 245453).

The first systematic surveys addressing Yosemite toads, at least in part, in Yosemite National Park began in the 1990s. During his Sierran-wide survey of 75 Yosemite toad historical sites in 1990, Martin (1991a, 1991b) included 22 historical sites within Yosemite NP; of these 22 sites, only 36 percent ($n = 8$) were occupied. Martin (1991b) did not report all occupied sites, but the three occupied ones he did report included: Elizabeth Lake, southwest of Mount Dana, and Dana Meadows. These three occupied sites had only five Yosemite toads combined: one adult male, one adult female, and three metamorphosing individuals. The three unoccupied sites he reported were: Dog Lake, 1.6 km north of Highway 120, and Tuolumne Meadows.

In 1991, Drost and Fellers (1994, 1996) conducted systematic surveys at 38 of the 40 sites in Yosemite National Park where Grinnell and Storer (1924) had recorded amphibians historically. Of those 38 sites, 13 were locations where Grinnell and Storer (1924) had recorded Yosemite toads. Surveys of those 13 sites revealed Yosemite toads at 46 percent ($n = 6$). Moreover, Yosemite toads were observed in low numbers at all sites; only 15 individuals (all adults and juveniles) were observed at all six occupied sites combined (USFWS 2002).

Between 1995 and 2001, Sadinski (2004) conducted surveys for anurans, including Yosemite toads, along Highway 120 between near Lembert Dome and east of Tioga Pass. The surveyed area, well over 90 percent of which was in Yosemite National Park, encompassed 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, Sadinski examined an unspecified number of stillwater sites and found 63 Yosemite toad breeding sites. Few adult Yosemite toads were recorded at most breeding sites. At 19 sites at which breeding was monitored, 20 adults males were recorded at only one site, 11 additional sites had 1-10 males, and no males were recorded at 7 additional sites at which 1-20 egg masses were found. The number of egg masses found at these 19 sites varied from 1 to 29. Moreover, at seven sites monitored for recruitment of metamorphs, only three sites had > 100 metamorphs, and only one site (at which 15 egg masses had been laid) had between 500 and 600 metamorphs.

In a comprehensive survey of all 2,655 mapped and unmapped water bodies in Yosemite National Park conducted over the interval 2000-2002, Knapp (2005) detected Yosemite toads at 2.8 percent of sites ($n = 74$). Surveys for this effort were single-pass visual encounter surveys during the summer season. Because of the survey method applied and some unknown level of false-negative error rate especially in detecting post-metamorphic life stage, these data may underestimate actual occupancy. Nonetheless, even if it were to represent a twofold to threefold underestimate, which is unlikely, Yosemite toads would still occupy a relative small proportion of water bodies in Yosemite National Park.

Based on the compilation for the USFWS (2002) 12-Month Finding, Yosemite toads were known from 78 sites in Yosemite National Park, most of which were based on the Knapp (2005) survey data. Seventy-three ($n = 57$) percent of these sites had been confirmed as occupied since 1990. For this analysis, localities that were currently occupied were assumed to also have been occupied historically.

Sierra National Forest

Prior to 1980

Yosemite toad data exist for 11 localities on the Sierra National Forest prior to 1980. Records extend back to 18 August 1930, when Berry Campbell collected 4 toads from the northeast slope of Isberg Pass, Madera County (USNM 89847-89850). One additional collection was made during the 1930s; Thomas Rodgers collected four Yosemite toads from Kaiser Pass, Fresno County (MVZ 26964-26967).

Two new Sierra National Forest localities were documented for Yosemite toads during the 1940s: Chilkoot Lake, Madera County in 1946 (CAS 86164); Rock Meadow [8 km south of Kaiser Pass], Fresno County in 1949 (CAS-SU 10998-10999).

Collection increased significantly during the 1950s with Karlstrom's Sierran-wide work on Yosemite toad. In 1953, Karlstrom collected 1 km northwest of Kaiser Pass (MVZ 60159-60175; $n = 17$); also in 1953, John Cunningham collected a large series of Yosemite toads from String Meadow (LACM 11864-11884, 74566-74568; $n = 24$). In 1954, Karlstrom collected two new sites: 0.3 km northwest of Kaiser Pass summit (MVZ 61789, 64498-64507, 81730-81731; $n = 13$) and Kaiser Pass Meadow (MVZ 61786-61788, 64496-64497; $n = 5$). In 1955, Karlstrom collected two new sites near Kaiser Pass: 0.3 km north of Kaiser Pass (MVZ 62649-62652, 62654-62659; $n = 10$) and 0.3 km northeast of Kaiser Pass (MVZ 62389, 62639-62640, 62660, 62700, 62702; $n = 6$); he recollected Kaiser Pass Meadow (MVZ 62643-62648, 62653, 62701, 62703; $n = 9$). In 1958, M. Leiberman collected three toads at Moon Lake above French Canyon (MVZ 67588-67590). All sites collected in the 1950s are in Fresno County.

During the 1960s, Kaiser Pass Meadow was recollected in 1961 (CAS 98074-98075; $n = 2$), 1964 (CAS 97650-97662, 97679-97683, MCZ A48727-A48729; $n = 21$), and 1965 (CAS 102596-102605; $n = 10$).

No records for Yosemite toads exist from the Sierra National Forest during the 1970s. Seven additional undated collections of Yosemite toads also exist from Kaiser Pass that, based on their accession number, are pre-1980 vintage (CAS-SU 10819-10825).

Post-1980

Most data collected on the Sierra National Forest since 1980 are survey data. To date, only four sites have been collected for Yosemite toads on the Sierra National Forest since 1980. All four represent previously undocumented localities in Madera County from single collections made in 1999: 0.16 km east of Bowler Campground (CAS 209233), Jackass Meadow near Forest Road 5S88 (CAS 209209), Polk Salt Log Meadow near Forest Road 5S20Y (CAS 209231), and a pond on the west side of Forest Road 5S39 (CAS 209232).

During his Sierran-wide survey of 75 Yosemite toad historical sites in 1990, Martin (1991a, 1991b) included several sites at which Yosemite toads had been recorded historically on the Sierra National Forest; he did not report what proportion of Sierra National Forest sites were occupied, but he did indicate that 60 percent of historical Yosemite toad sites examined in westside Sierra Nevada national forests were occupied, which included information for the Sierra National Forest.

In 1992, Martin et al. (1992) surveyed 16 sites on the Sierra National Forest for amphibians (see Status section of main document for sampling details). Seven of the sites sampled were high probability (meadow habitat present) for Yosemite toad occupancy, whereas the nine remaining sites had a low probability (no meadow habitat) of being occupied by Yosemite toads. Yosemite toads were found at 71 percent (n = 5) of the high-probability sites, but none of the low-probability sites.

Based on the compilation in the USFWS 12-Month Finding (2002), Yosemite toads had been recorded on 91 sites on the Sierra National Forest, of which 92 percent (n = 84) were occupied based on survey information collected between 1990 and 2002. For this analysis, localities that were currently occupied were assumed to also have been occupied historically.

Between 2002 and 2005, the Sierra National Forest conducted systematic surveys for Yosemite toads in more than 2,230 sites with potential habitat (Eddinger 2006). Of these 2,230-plus sites, Yosemite toad life stages were detected at 323, and 256 had life stages indicating reproduction (i.e. eggs, tadpoles, metamorphs). Only 8 percent (n = 21) of the sites had > 10 egg masses, > 5,000 tadpoles or both, which may imply that most reproductive populations are small.

As part of the USDA Forest Service Sierra Nevada Amphibian Monitoring program, crews surveyed 49 watersheds on the Sierra National Forest containing 856 sites from 2002 to 2009. Twenty-seven of the watersheds had evidence of reproduction (presence of eggs, tadpoles, metamorphs) and an additional four had only adults or subadults. Within these watersheds, 73 (9 percent) sites contained evidence of reproduction and an additional 36 (4 percent) sites contained adults or subadults. Eleven of the 55 breeding sites had more than 1,000 tadpoles and two had more than 5,000. In general, few adults and subadults were found. In the Bull Creek Watershed from 2006-2009, mark-recapture surveys for males were conducted in three meadows during the spring breeding chorus. Annual breeding male population estimates were relatively small with the largest population having only 16 to 21 individuals per year. Egg mass counts were also relatively small with an annual maximum within a meadow of 48.

Inyo National Forest

Prior to 1980

Yosemite toad data exist for 29 localities on the Inyo National Forest prior to 1980. Records extend back to 12 July 1915, when Charles Camp and Tracy Storer collected one toad from Tioga Lake, Mono County (MVZ 5746).

No additional records of Yosemite toads were obtained for sites on the Inyo National Forest until the 1930s, when five new localities were recorded: Camp Tioga [= Tioga Campground] (MVZ 14916-14918) and Alpine Lake on the east slope of Mount Conness (USNM 94986-94987) in 1932, Valley of the Little Lakes in 1933 (CAS 71308), 0.8 km east of Edith Lake in 1938 (CU 3545), and McGee Creek in 1939 (CAS-SU 4358-4359).

Seven new Inyo National Forest localities for Yosemite toads were recorded in the 1940s. These included: a large series of toads from Mildred Lake in 1940 (CAS-SU 5834-5878, UIMNH 34728; n = 46); the lake above Pine Lake in the headwaters of Pine Creek (MVZ 41295-41297; n = 3) and the lake in Pine Creek Pass (MVZ 41293-41294; n = 2) in 1945; Crater Creek Meadow in 1946 (LACM 1060-1083; n = 24) and again in 1948 (MVZ 45994-45999; n = 6); 23 m north of Tioga Ranger Station in 1948 (MVZ 46795-46810; n = 16); Upper Crater Meadow [4.8 km south-southeast of Reds Meadow] (MVZ 45993) and Rock Creek (LACM 1043-1045) in 1948.

Collection increased during the 1950s with the work of Karlstrom (1962) on the species, and seven new localities were recorded. In 1952, one Yosemite toad was collected on the eastern base of Mount Conness in the Harvey Monroe Hall Research Area (MVZ 61795). Karlstrom collected a very large series 183 m northeast of the Tioga Ranger Station in 1954 (MVZ 62545-62552, 62557-62638, 61790-61794, n = 94) and 1955 (MVZ 62669, 62688-62690, 64890-64891; n = 6); an additional toad was collected 91 m northeast of the Tioga Ranger Station in 1955 (MVZ 64887); other series were taken 274 m northeast of the Tioga Range Station in 1955 (MVZ 62698-62699, 64881-64885, 64888-64889; n = 9), in 1956 (MVZ 64893, 64907, 64912-64916, 68046-68053; n = 15), and in 1958 (MVZ 67749-67753; n = 5); Glacier Canyon, 1.6 km north-northeast of Tioga Pass (MVZ 62691-62692; n = 2) and Tioga (MVZ 64886, 64892; n = 2) were collected in 1955; a point 137 m northeast of Tioga Pass Ranger Station was collected in 1958 (MVZ 67749-67753; n = 5).

Collection in the 1960s added six more new localities. Collections included: Rock Creek Lake in 1960 (CAS 87414); the meadow between Grass and TJ Lakes (LACM 26291-26313; n = 23), Mammoth Mountain (LACM

26314-26327; $n = 14$) and Pumice Flat, 4.8 km northwest of Mammoth Mountain (LACM 76486-76489; $n = 4$) in 1962; TJ Lake in 1963 (LACM 1046); the west end of Saddlebag Lake in 1967 (LACM 87432). Additionally, Tioga Pass Meadow was recollected in 1967 (UMMZ 151570).

Information from the 1970s is a combination of collections and systematic demographic work on selected populations. New locality collections from the 1970s included: Barney Lake on Duck Pass Trail (MVZ 137735-137736; $n = 2$) and Lake Mary in the Mammoth Lakes Group (MVZ 142991-143002; $n = 12$) in 1976; the southeast end of Saddlebag Lake in 1977 (UMMZ 156682-156684, 156687; $n = 4$). Sites recollected include: Tioga Pass Meadow in 1974 (UMMZ 133865), 1977 (UMMZ 156674-156681; $n = 8$), and 1978 (UMMZ 156688-156690, 156714-156718; USNM 209446-209450, 209460; $n = 14$); the west end of Saddlebag Lake in 1977 (UMMZ 156685-156686; $n = 2$).

It was during the 1970s that Kagarise Sherman (1980) and Kagarise Sherman and Morton (1993) began their Yosemite toad study on the Inyo National Forest portion of Tioga Pass Meadows. They provided data on adult numbers entering their study breeding pools for the years 1974 and 1976 through 1979. In 1974 and 1976, more than 300 adult males were recorded in the study pools. The number of adult males dropped to 162 in 1977, increased to about 215 in 1978, and then dropped again to 75 in 1979. Over the same period, the number of adult females varied between 45 in 1974 to 100 in 1978 with no trend between 1974 and 1979 (females are harder to find than males). Data were also provided on the mean number of males and females observed per survey in the Tioga Pass Meadow study pools from 1971 to 1979 (see Figure 4 in Kagarise Sherman and Morton 1993). These data show that the mean number of males at study pools increased through 1975-1976 to more than 60 males per survey, dropped in 1977 to around 20 males per survey, increased to 30 males per survey in 1978, and dropped back down to around 20 males per survey in 1979. In contrast, the mean number of females per survey fluctuated between one and four during this same period without any indication of a trend. Based on data collected at Tioga Pass Meadows in 1981 and 1982, this population may have been beginning to undergo a decline in 1977 first indicated by the drop in the number of adult males and shift in the adult sex ratio (also see Population Dynamics section).

Kagarise Sherman and Morton (1993) provided some abundance data for four additional sites on the Inyo National Forest during the 1970s. These include: Mildred Lake, two locations on Saddlebag Lake (NW and SE), and Sylvester Meadow. Comparative data are available for at least two years among 1973, 1976, and 1977 for all sites except Saddlebag SE, which was surveyed only once in 1977. Saddlebag Lake NW has data for all three years, whereas Mildred Lake and Sylvester Meadow have data for only 1976 and 1977. The number of surveys at these three sites in each year varied from 2 to 8. Data available are the number of adults observed per person hour. In general, fewer toads were found in these locations than in the Tioga Pass Meadows study pools (see data listed below). For example, the maximum number of toads found during one survey in 1976 was 18 toads in Saddlebag Lakes SE and 216 toads at Mildred Lakes. However, these data suggest that no significant change occurred in the populations during the 1970s (mean ± standard deviation of the number of adults per person hour, number of surveys [n =], and range = number of toads caught per survey in parentheses for each year): Mildred Lake 1976 (20.4 ± 20.7, $n = 5$, range = 13-216) and 1977 (17.3 ± 7.4, $n = 3$, range = 37-97), Saddlebag Lake NW 1976 (6.4 ± 5.1, $n = 8$, range = 5-38) and 1977 (9.7 ± 6.2, $n = 2$, range = 28-33), and Sylvester Meadow 1976 (12.0 ± 11.3, $n = 2$, range = 2-20) and 1977 (4.5 ± 3.9, $n = 3$, range = 2-9).

Post-1980

Kagarise Sherman and Morton (1993) resurveyed Tioga Pass Meadows in various ways during the interval 1981-1991. They provided data on adult numbers in their study breeding pools for the years 1981 and 1982, on the mean number of males and females found at breeding pools on each survey day for 1981-1982 and 1990, and on periodic checks for selected other years in the interval 1983-1991. In 1981 and 1982, the total number of adult males in the study pools had dropped to below 40, around half the already low number at the tail of the 1970s, and a nine-fold decline from the average number from 1974-1978 (257.8 ± 83.1). In contrast, the number of adult females entering study pools was more than 60 for both 1981 and 1982, which was in the same range it had been during the 1970s. The mean number of males at the breeding pools on any survey date also declined in 1981 and 1982 and in 1991, only one was found calling. In contrast, the mean number of females found per survey date in 1981 and 1982 was equal to or higher than it had been during any year during the 1970s. However, by 1990, only one female and 4-6 egg masses were found, and in 1991, no females and one egg mass was found. Based on data collected at Tioga Pass Meadows during the 1970s, males in this population had unquestionably declined by the early 1980s, and the drop in 1977 (see pre-1980 data) with the shift in adult sex ratio may have been the first manifestation of this decline. The 1990-1991 data, albeit more limited, suggest that the females subsequently followed in this decline.

Kagarise Sherman and Morton (1993) revisited Mildred Lake, the two locations on Saddlebag Lake, and Sylvester Meadow at least once in 1981, 1982, or 1990. Comparative data are available for all three years for Saddlebag NW, 1981 and 1990 for Sylvester Meadow, and only 1990 for Saddlebag SE and Mildred Lake. Data available are the number of adults observed per person hour. Number of surveys at these sites in each year varied from one to three. These data suggest that by 1990, all four of these populations had sustained a marked drop in numbers (three- to over ten-fold) when contrasted with the pre-1980 data (mean ± standard deviation [where appropriate] of the number of adults per person hour, number of surveys [n =], and range = number of toads caught per survey in parentheses for each year): Mildred Lake 1990 (1.7, n = 1, range = 10); Saddlebag Lake NW 1981 (6.8 ± 1.2, n = 3, range = 15-32), 1982 (11.0 ± 4.2, n = 2, range = 4-14) and 1990 (2.9 ± 0.8, n = 2, range = 6-7); Saddlebag Lake SE 1990 (1, n = 1, range = 1); Sylvester Meadow 1981 (2, n = 1, range = 2) and 1990 (0, n = 1, range = 0).

During his Sierran-wide survey of 75 Yosemite toad historical sites in 1990, Martin (1991a, 1991b) included at least five sites where Yosemite toads had been historically recorded on the Inyo national forest; 80 percent (n = 4) of these five sites were occupied (Martin 1991b). The occupied sites included: northwest Saddlebag Lake, southeast Saddlebag Lake, northeast Tioga Pass, and north Tioga Meadow. The unoccupied site was the Harvey Monroe Hall Research Area east of Mount Conness.

Based on the compilation for the 12-Month Finding by the USFWS (2002), Yosemite toads had been recorded at 49 sites on the Inyo national forest, of which 71 percent (n = 35) were occupied based on survey information collected between 1990 and 2002. For this analysis, localities that were currently occupied were assumed to also have been occupied historically.

Between 2002 and 2005, the Inyo National Forest conducted systematic surveys for Yosemite toads in more than 300 potential meadow sites, which include nearly all potential Yosemite toad habitats on the Inyo national forest (Milano 2005). Of these 300+ sites, Yosemite toad life stages were detected at 86 (around 30 percent). Survey data imply that most reproductive populations were small.

As part of the USDA Forest Service Sierra Nevada Amphibian Monitoring program, crews surveyed 33 watersheds on the Inyo national forest containing 572 sites from 2002 to 2009. Seventeen of these watersheds contained evidence of reproduction (presence of eggs, tadpoles, metamorphs) and none contained only adults or subadults. Within these watersheds, 48 (8 percent) sites contained evidence of reproduction and an additional 32 (6 percent) sites contained only adults or subadults. Ten of the breeding sites had more than 1,000 tadpoles, and two sites had more than 5,000 tadpoles. In general, few adults and subadults were found.

Humboldt-Toiyabe National Forest

Prior to 1980

Eleven localities with records for the Yosemite toad exist for the Humboldt-Toiyabe national forest prior to 1980. Historical information dates back to 11 August 1923, when Herbert Mason collected Yosemite toads on the Mono County side of Mount Dana, probably from near Dana Lake (CAS 65926). The next oldest records for the Humboldt-Toiyabe National Forest represent a recollection of this site in 1938 (SDNHM 30034, 30436).

No further records were obtained on the Humboldt-Toiyabe National Forest until the 1950s, when 3 new localities were documented. Six Yosemite toads were collected in the upper Sardine Creek system just east of Sonora Pass in 1952 (USNM 542164-542169), and Ernest Karlstrom collected one toad in each of Charity Valley (MVZ 64897) and Faith Valley (MVZ 64904) in 1955. Faith Valley was also the site where Mullally obtained a 62 mm female toad (LACM 11887) in the 1950s that he believed to be a western/Yosemite toad hybrid (Mullally and Powell 1958). Karlstrom (1962) believed this animal was an immature western toad. However, Morton and Solokski (1978) showed it to be intermediate morphologically between western and Yosemite toads and in agreement with animals they believed were western/Yosemite toad hybrids from Frog Lakes. Genetic data must verify hybridization, but the Morton and Sokolski analysis is currently the best support for the Faith Valley toad being a hybrid.

One new locality was added during the 1960s when Alan Ziegler collected 11 Yosemite toads in upper Sardine Creek Meadow 2.25 km east of Sonora Pass in 1961 (MVZ 72522-72532).

During the 1970s, Richard Sage collected three Yosemite toads in the meadows near Leavitt in 1974 (MVZ 164900-164902) and Julia Feder recollected the upper Sardine Creek Meadow locality in 1976, but at a point 0.19 km west of the Ziegler 1960s collection location (MVZ 142973-142985; $n = 13$). Feder also collected Yosemite toads at two additional sites: one farther east of Sonora Pass in the Sardine Creek system in 1976 (MVZ 142986-142990; $n = 5$) and Frog Lakes, a site where she collected 36 toads with Martin Morton in 1977 (MVZ 145273-145308). The relatively large collections that Feder made were used in her analysis of western North American toads (Feder 1977). Frog Lakes is also the site of analysis of natural hybridization between western and Yosemite toads (Morton and Sokolski 1978). Morton and Sokolski first visited the site on 10-13 July 1976, when they toe-clipped and released 70 toads; all were judged to be Yosemite toads. Sokolski returned on 25 July 1976 and during the course of this visit found one male western toad. Frog Lakes was then revisited on 3, 9, and 23 August. Of the 81 toads captured during the latter visits, 52 were marked and released and 29 were retained and preserved (later catalogued into the Moore Laboratory of Zoology collection at Occidental College, Los Angeles, California). A plot of ratios generated by dividing parotoid gland width and web length by body length (measured as snout-vent length) separated the western and Yosemite toads into clearly discernable groups based on animals of both species from other locations where the two species are known not to occur together. Parallel analysis with the Frog Lake specimens revealed that 12 could be identified as western toads, 13 could be identified as Yosemite toads, and the remaining 4 had intermediate measurements. The Faith Valley specimen of Mullally and Powell (1958; LACM 11887) was included in this analysis and fell out with the 4 toads having intermediate measurements.

Frog Lakes was also one of the two sites for which Kagarise Sherman and Morton (1993) provided some abundance data, the second being Hoover Lakes. Comparative data are available for 1976 and 1977. Data available are the number of adults observed per person hour. Number of surveys at these sites varied from two to six in each year. The data suggest that there was no significant change in the populations over the two years compared (mean ± standard deviation of the number of adults per person hour, number of surveys [n =], and range = number of toads caught per survey in parentheses for each year): Frog Lakes 1976 (6.7 ± 4.0, $n = 6$, range = 4-67) and 1977 (11.5 ± 4.0, $n = 2$, range = 43-143), and Hoover Lakes 1976 (9.5 ± 4.6, $n = 2$, range = 25-85) and 1977 (10.2 ± 6.9, $n = 2$, range = 16-60).

Post-1980

Most data collected on the Humboldt-Toiyabe National Forest since 1980 are survey data. To date, only two Yosemite toad collections have been made on the Humboldt-Toiyabe National Forest; both represent previously undocumented localities: the meadow south of Kettle Peak collected in 1985 (CAS 188351-188352; n = 2); 2.7 km east of Sonora Pass collected in 1994 (MVZ 223340-223344; n = 5). The latter five animals were incorporated into the systematic analysis of Anna Goebel (formerly Graybeal) addressing North American toads (Goebel 1996, 2005).

Kagarise Sherman and Morton (1993) provided some abundance data for the Frog and Hoover Lakes[2] sites that had been surveyed during the 1970s. Comparative data are available for 1981, 1982 and 1990, but data are lacking for Hoover Lakes in 1982. Data available are the number of adults observed per person hour. Only one or two surveys were conducted at these sites in each year. Although the effort reduced compared to the pre-1980 information[3], the data suggest that by 1990, these populations had declined to about one-fifth the level observed in 1977 (mean ± standard deviation [where appropriate] of the number of adults per person hour, number of surveys [n =], and range = number of toads caught per survey in parentheses for each year): Frog Lakes 1981 (1, n = 1, range = 5), 1982 (0, n = 1, range = 0) and 1990 (1.8 ± 2.5, n = 2, range = 0-7), and Hoover Lakes 1981 (2.8, n = 1, range = 21) and 1990 (2.3 ± 1.0, n = 2, range = 4-6).

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[2] Kagarise Sherman and Morton (1993) term the map locality Hoover Lakes as Hoover Lake, whereas they correctly use the map label Frog Lakes. Regardless of the labeling, it remains unclear from their description whether one or the assemblage of lakes was surveyed for either the Hoover Lakes or the Frog Lakes locality.

[3] The greatest risk with reduced effort is that timing of surveys relative to snow melt can affect the numbers of animals found. Thus, timing in a given year may have missed the similar seasonal interval in a different survey year.

During his Sierran-wide survey of 75 Yosemite toad historical sites in 1990, Martin (1991a, 1991b) included at least 10 sites on the Humboldt-Toiyabe National Forest where Yosemite toads had been historically recorded; of these 10 sites, 80 percent (n = 8) were occupied (Martin 1991b). Occupied sites included: Frog Lakes, Hoover Lakes, Leavitt Lake, Sardine Meadow, east Sardine Meadow, west Sardine Meadow, 2.2 km east of Sonora Pass, and 4.8 km east of Sonora Pass. Unoccupied sites were Charity and Faith Valleys.

Based on the compilation for the USFWS (2002) 12-Month Finding, Yosemite toads were known from 25 sites on the Humboldt-Toiyabe National Forest. Sixty (n = 15) percent of these sites had been confirmed as occupied since 1990. For this analysis, localities that were currently occupied were assumed to also have been occupied historically.

Between 2002 and 2005, the Humboldt-Toiyabe National Forest conducted systematic surveys for Yosemite toads in over 50 sites with potential habitat. Yosemite toad life stages were detected at 17 of these 50 sites.

As part of the USDA Forest Service Sierra Nevada Amphibian Monitoring program, from 2002 to 2009, crews surveyed 12 watersheds on the Humboldt-Toiyabe national forest containing 170 sites. Of the 12 watersheds, 4 contained evidence of reproduction (presence of eggs, tadpoles, metamorphs) and 2 had only adults or subadults. Within these watersheds, 7 (4 percent) sites contained evidence of reproduction and an additional 9 (5 percent) sites contained adults or subadults. Three of the breeding sites had more than 1,000 tadpoles and 1 had more than 5,000. In general, few adults and subadults are found.

Sequoia and Kings Canyon National Parks

Prior to 1980

One historical record exists for Yosemite toad in Sequoia and Kings Canyon National Parks: Evolution Lake on the South Fork of the San Joaquin River in Kings Canyon National Park (MVZ 38633). This record consists of one toad that Joseph Dixon collected in 1942. An undated observation by Carl Sharsmith from Evolution Valley would most likely precede 1980.

Post-1980

Most records are from the northern half of Kings Canyon National Park in the South Fork San Joaquin River drainage. Two disjunct sites in the Middle Fork of the Kings River are located in Blue Canyon on the west side of the park and one isolated report from Knapsack Pass on the east side of the park. The park wildlife observation database shows 10 records after 1980. Surveys by professional herpetologists found additional sites. Gary Fellers found 18 sites during surveys in 1993-1994. These are likely the sites reported in the USFWS (2002) 12-Month Finding. Seventy-eight (n = 14) percent of these sites had been confirmed as occupied since 1990. For this analysis, localities that were currently occupied were assumed to also have been occupied historically. Between 1997 and 2004, Roland Knapp reported 88 observations from 46 sites. In 2009, a botanist, Jenifer Jones, photographed Yosemite toads in a meadow north of Martha Lake.

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APPENDIX 3: STUDY PLAN FOR SNFPA ROD SURVEY REQUIREMENTS

The 2001 Sierra Nevada Forest Plan Amendment Record of Decision required one cycle of inventory surveys for Yosemite toads in suitable habitats within the species historical range to determine Yosemite toad (*Anaxyrus canorus*) presence (Standard and Guideline [S&G] 55). The purpose of this inventory was to provide the needed information for the livestock grazing/range permit process and implementation of S&G 53. S&G 53 excludes livestock from standing water and saturated soils in wet meadows and associated streams and springs occupied by Yosemite toads (USDA Forest Service 2001a). This appendix contains a study plan for these inventory surveys. The surveys were conducted in the early 2000s by national forest personnel (El Dorado, Stanislaus, Sierra, Inyo, Humboldt-Toiyabe). The specific protocols are available from Cathy Brown (cathybrown@fs.fed.us).

Note: All elements of the Proposed Study Plan have been left as originally presented to the national forests except for minor editing for clarity; the meaning of the original document has been retained.

Project identification

Project title— Assessment of Yosemite toad occupancy in suitable habitats within its historical range.

Author— Cathy Brown.

Date— 2001.

Problem reference and literature

Aspects of Yosemite toad natural history that may impact survey success are:

- Yosemite toads occur in a wide variety of high montane and subalpine lentic habitats including lakes, wet meadows, small ponds, as well as shallow spring channels, side channels, and sloughs. However, they are most commonly found in shallow, warm water areas including wet meadows, small permanent and ephemeral ponds, and flooded, shallow, grassy areas and meadows adjacent to lakes. Some evidence suggests that Yosemite toad populations may have been more abundant in pond and lake environments than currently.
- Adults are encountered infrequently after breeding (snowmelt), many sites are inaccessible when breeding occurs, and tadpoles (tadpoles) are relatively easy to detect and are found over a relatively long interval during summer. Hence, the life-history stage targeted to determine occurrence will be the larval (tadpole) stage.
- Timing is crucial to species detection. Timing of surveys will be scheduled relative to snowmelt rather than a fixed calendar date. Dry years may require earlier surveys to allow for sampling of sites before they dry out.
- The probabilistic nature of assessing absence makes it difficult to document, but the nature of Yosemite toad populations may make it particularly difficult. Because many Yosemite toad populations appear marginal and/or have low numbers and because adults may not lay eggs every year, a survey may not coincide with an egg-laying year. Further, no tadpoles may be found during a survey due to severe weather conditions or other factors that resulted in complete egg or tadpole mortality. These factors may result in failure to detect Yosemite toads during surveys despite their presence (false negative). Thus, repeat visits in consecutive years may be optimal. Non-detection may also result from observer error or poor survey conditions (e.g.; cold or rainy weather). Repeat visits within a season would minimize the likelihood of false negatives due to these factors. In general, because tadpoles are relatively easy to detect, the likelihood of the latter categories of false negatives appear to be less of a problem than annual differences in tadpole presence.

Objective

To provide an inventory of Yosemite toad occupancy (presence/not found) in suitable habitat within the historical range of the toad to provide necessary information for the range permit process

Focal question— Which meadows and other suitable habitat within its historical range does the Yosemite toad currently occupy?

Study area

The study area consists of the historical range of the Yosemite toad. The historical range of the Yosemite toad is entirely within the Sierra Nevada between about 1,950 m and about 3,450 m (6,435 to 11,385 ft) in elevation from El Dorado County south to Fresno County. This range encompasses six national forests: the Eldorado, Lake Tahoe Basin Management Unit, Stanislaus, Sierra, Inyo, and Humboldt-Toiyabe.

Methods

The ROD survey will assess occupancy of all suitable habitat within the historical range of the Yosemite toad in the Sierra Nevada, providing a baseline data set for known locations of the Yosemite toad. Information on each meadow will be used in the range permitting process. For logistical and other reasons (e.g. lack of knowledge, uncertainties), certain decisions and assumptions were made for the ROD survey.

Area of inference— Historical range of the Yosemite toad.

Sample units— Individual sites (e.g. ponds, meadows) or individual livestock allotments.

Strata— Prioritization may be made to sample active allotments and high use recreational and commercial packstock use areas first, then inactive allotments, and finally sites outside of allotments. A spatially representative sample will be completed each of the three years to prevent geographic biases in assessment of occupancy.

Definition of suitable habitat— For the purposes of the ROD survey, suitable habitat will include wet meadows with potholes, ponding, or any standing water, wet meadows adjacent to lakes, and small permanent and ephemeral ponds. Ponds are defined as water bodies that are < 0.5 ha. Shallow, side channels and sloughs will be included when near wet meadows. While it is recognized that the toad may use lake margins and shallow slow-moving streams and sloughs (Milano [N.d.]), these will not be included in the ROD survey for logistical reasons unless they are adjacent to the above habitat types. First, such areas are not thought to be the primary breeding habitat of the Yosemite toad, and second, over 6,500 wet meadows and ponds are estimated to exist within the Yosemite toad geographic range. Adding lakes and streams would greatly increase the survey effort needed over the three-year period.

Toads may not always be found at a given site even though they are present for reasons described above, so the following definition of suitable habitat will be used. The purpose of this definition is to separate sites that dry within a few weeks and are never suitable for breeding, from those where water is present for sufficient duration during average water years. Additional surveys may be made in suitable sites to verify occupancy. Also, range management may differ depending on the suitability of the site and the confidence in the occupancy assessment.

A conceptual definition of suitable habitat is the retention of water for sufficient time after snowmelt to allow tadpoles to metamorphose during enough years to sustain a population. Estimates of time from egg laying to metamorphosis are 5-6 weeks (Sadinski 2000), 7-8 weeks (Kagarise Sherman 1980), and 6-7 weeks (Karlstrom 1962). Suitable habitat will include those sites that retain water for at least 4-5 weeks after snowmelt (to allow for development of tadpoles into metamorphs) during water years that are slightly less than average. This definition is intended to be conservative in favor of the toad in that it includes sites that may produce metamorphs only during wetter years. It is anticipated to include sites that retain water during most years (high quality sites) and sites that may dry in some years but may provide important habitat during wetter years, but exclude sites that dry during most years.

Because the persistence of water throughout the summer varies among years depending on annual precipitation, the presence or absence of water during site visits is insufficient to determine the duration that a site retains water. Suitable sites may dry during drought years and unsuitable sites may have water during wet years. For a one-time survey, presence or absence of water during one site visit is inadequate to determine suitability. Therefore, during field surveys, attributes will be measured that reflect the general hydrology at the site providing an indicator of average water conditions among years. Methods for such an assessment are not yet developed, so this will not be done during year one of the survey. Methods will be developed during initial years of survey and applied during years two and three of the survey.

Overall, this definition covers the most important elements of Yosemite toad breeding habitats. Assessment of suitability in dry years can miss sites that are wet in normal years and assessment of suitability in wet years can add sites that would be dry in normal years. Proposed habitat attributes can provide an adequate indicator of suitability. Yosemite toads have been found in other lentic and lotic habitats that will not be searched at this time.

Temporal survey considerations— The ROD specifies that the surveys be completed within three years. As discussed above under suitable habitat, timing of surveys is problematic due to the climatic variability in the Sierra Nevada. Indicators for assessing suitability will be developed during the initial years of surveys.

Toads may not be found in a given year even though they are present due to a variety of reasons. As a result, a single survey in one year may not be adequate to document the presence of the toad. If a site is determined to be suitable and no toads are found during the survey, the site will be resurveyed the following year.

Methodological Details

Occupancy status— This will be based on presence/not found data collected at each site. An occupied site is defined as the presence of any life history stage of the Yosemite toad. Presence of one adult or even one metamorph would indicate a potential breeding population for the purposes of the ROD survey. This seems appropriate given the current status of the Yosemite toad, and the fact that potentially only one survey may be conducted per site. This approach may overestimate occupancy. Presence of one or more adults, juveniles, or metamorphs does not necessarily indicate a breeding site. On the other hand, the site may provide important non-breeding habitat.

Verification of suitable habitat— This will be based on hydrologic indicators that will be developed during the summer of 2001. The definition proposed above is adequate to identify primary breeding habitat. This approach may underestimate suitable habitat, in particular potentially non-breeding habitat used the non-breeding active season.

Site selection— All suitable habitat will be surveyed; this is a census rather than a sample. However, sites will be prioritized based on administrative considerations. First, sites located within active allotments and high use recreational and commercial packstock use areas will receive highest priority. Second, sites will be selected to represent east-west, north-south, and elevation gradients across the Sierras so that some information Sierra-wide will be available each year. Lastly, for logistic reasons, all suitable sites within topographic basins will be surveyed simultaneously, meaning within the same survey interval. Tables 4 and 5 provide estimates of the number of sites of different habitat types, by different allotment status and national forest. These are likely underestimates due to the quality of the data and because the California Wildlife Habitat Relationships (CWHR) range map used for the Yosemite toad needs to be expanded to include additional known sites.

Identifying sites may be problematic, given that a complete survey is required. Ideally, locations of all wet meadows and ponds within the Yosemite toad range would be known and compiled into current GIS geodatabases. However, quality of data among the six national forests within the Yosemite toad range is unknown and inconsistent. Because of these limitations, potential lentic habitat within each basin should be identified from aerial photographs, compared against the existing lake and meadow geodatabases, and as appropriate, digitized using Digital Orthophotoquads (DOQs). Aerial photographs have been successfully used to identify these types of habitats in other studies (Brown 1997, Milano [N.d.]). Very small sites or those in heavily forested environments may be missed.

Field surveys— During field surveys, data will be collected to verify whether each site contains suitable habitat and to determine presence/not found for the toad by life stage. Visual Encounter Surveys (VES) will be used to search for the toad. Protocols for collecting habitat data to verify suitable sites are described in the full document. Surveys will be timed to maximize detection. Surveys will target the tadpole stage when tadpoles are large enough to identify easily. Surveys will start three weeks after snowmelt and continue approximately six to eight weeks into the summer, as long as tadpoles are still present at sites. Lower elevations will be surveyed first, with the crews working their way up in elevation as sites open up. Only one survey at each site will be conducted per year because tadpoles are relatively easy to detect.

Yosemite toad data collected will include the number of animals per life history stage: eggs, tadpoles, adult, juvenile, and metamorph. When possible, all animals will be counted individually. Egg masses will be counted individually. For tadpoles and in some cases for adults, it may be difficult to do this. In these cases, numbers will be estimated using the following protocols. Adults will be counted individually for numbers up to 50, and rounded to the nearest 10 for numbers greater than 50. For other life history stages, they will be counted individually for numbers up to 20, rounded to the nearest 10 for numbers up to 100, rounded to the nearest 100 for numbers up to 1000, and rounded to the nearest 1000 for numbers greater than 1000. Incidental data on all amphibians and reptiles found will be collected.

Other data collected include the presence and extent of disease (*Saprolegnia*, chytrid) and other evidence of mortality (e.g. predation), and weather conditions at the time of the survey.

Appendix Table 1—Estimates of the number of wet meadows and ponds by allotment status across the Yosemite toad historical range. Data are based on the Framework meadow and lake geodatabases and the CWHR distribution map for Yosemite toad available in 2001. Numbers are likely underestimates. Unknown meadows are exclusively in the Humboldt-Toiyabe National Forest.

	Allotment				
Unit category	Active	Inactive	Total	Non-allotment	Total
Wet meadows	1047	330	1377	1102	2479
Unknown meadows	29	1	30	24	54
Ponds (< 0.5 ha)	926	1202	2128	1890	4018
All meadows & ponds	2002	1533	3535	3016	6551
Lakes (≥ 1 ha)	277	447	724	581	1305
All ponds & lakes	1203	1649	2852	2471	5323
Total all meadows, ponds & lakes	2279	1980	4259	3597	7856

Appendix Table 2—Estimates of the number of wet meadows and ponds by allotment status within each national forest across the Yosemite toad historical range. This data is based on the Framework meadow and lake GIS datasets and the CWHR distribution map for the Yosemite toad available in 2001. Numbers are probably underestimates. Allotment categories are active (AC), inactive (IN), non-allotment (NA), and total represents the sum of these three categories per national forest; note that the Lake Tahoe Basin Management Unit has no inactive allotments.

a. Eldorado and Inyo National Forests and Lake Tahoe BMU.

	National Forest										
	Eldorado				Inyo				Lake Tahoe BMU		
Habitat	AC	IN	NA	Total	AC	IN	NA	Total	AC	NA	Total
Wet Meadows	116	163	225	504	20	19	495	534	164	125	289
Unknown Meadows	—	—	—	—	—	—	—	—	—	—	—
Ponds (< 0.5 ha)	20	28	109	157	2	68	869	939	28	13	41
All Meadows/Ponds	136	191	334	661	22	87	1364	1473	192	138	330
Lakes (≥ 1 ha)	4	3	25	32	5	39	372	416	12	8	20
All Ponds/Lakes	24	31	134	189	7	107	1241	1355	40	21	61

b. Sierra, Stanislaus, and Humboldt-Toiyabe National Forests.

	National Forest											
	Sierra				Stanislaus				Humboldt-Toiyabe			
Habitat	AC	IN	NA	Total	AC	IN	NA	Total	AC	IN	NA	Total
Wet Meadows	170	125	—	295	577	23	257	857	—	—	—	—
Unknown Meadows	—	—	—	—	—	—	—	—	29	1	24	54
Ponds (< 0.5 ha)	373	1090	2	1465	347	2	782	1131	156	14	115	285
All Meadows/Ponds	543	1215	2	1760	924	25	1039	1988	185	15	139	339
Lakes (≥ 1 ha)	162	402	—	564	42	—	135	177	52	3	41	96
All Ponds/Lakes	535	1492	2	2029	389	2	917	1308	208	17	156	381

— = no habitats of this type found in the Forest

Appendix 3 Literature Associated with Protocols

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