

intensive and focused effort to restore fishless conditions (Knapp and Matthews 1998, 2000; Knapp *et al.* 2001). Removing fish from lakes with an adjacent source population of mountain yellow-legged frogs can result in the rapid recolonization of the lake by the species and, over time, may result in recovery to conditions similar to lakes that had never been stocked (Knapp *et al.* 2001; Briggs *et al.* 2002; R. Knapp, *in litt.* 2002). Trout removal from several lakes has been successfully accomplished in the Sierra National Forest's John Muir Wilderness. This has resulted in the natural recolonization and initial recovery of mountain yellow-legged frogs in one of the lakes where trout were removed (R. Knapp, *in litt.* 2002). In the other two lakes within this basin where trout were removed, mountain yellow-legged frogs were successfully reintroduced, and there is evidence of reproduction in these translocated populations (R. Knapp, *in litt.* 2002). Sequoia and Kings Canyon National Parks have initiated a mountain yellow-legged frog restoration project which employs gill nets and electrofishing to remove fish from select lakes and adjacent stream segments at sites with little to no human visitation (NPS 2001). However, because of the cumulative effect of past mountain yellow-legged frog population declines (upwards of 80 percent in the 20th century), and ongoing population declines caused by disease or other factors, the recolonization of lakes restored to fishless conditions will grow less likely as the number of viable source populations of mountain yellow-legged frogs dwindles (Knapp *et al.* 2001).

The best-documented cause of the decline of the mountain yellow-legged frog is the introduction of non-native fish (Bradford 1989; Bradford *et al.* 1993; Knapp and Matthews 2000). In summarizing the effects of non-native fish on the mountain yellow-legged frog, it is important to recognize that: (1) The vast majority of the range of the mountain yellow-legged frog did not evolve with any species of fish as this frog predominantly occurs in water bodies above natural fish barriers; (2) water bodies throughout the range of the mountain yellow-legged frog have been intensively stocked with non-native fish, and where stocking has terminated, self-sustaining fish populations continue to persist; (3) the multiple year larval stage of the mountain yellow-legged frog prevents successful recruitment to populations that co-occur with non-native fish because when water bodies ice over in winter, larvae

are forced from shallow margins of lakes and ponds into deeper unfrozen water where they are vulnerable to predation by non-native fish; (4) adult mountain yellow-legged frogs that co-occur with non-native fish are vulnerable to predation when they are exposed to these fish, such as when adult mountain-yellow legged frogs overwinter at the bottom of deep water bodies; and (5) the introduction of non-native fish has fragmented mountain yellow-legged frog habitat, isolated populations from each other, and generally restricted remaining mountain yellow-legged frog populations to marginal habitats, thereby increasing the likelihood of localized extinctions without the possibility of recolonization.

#### Disease

There have been recent reports from around the globe of disease- and pathogen-related population declines and mass die offs of amphibians (Bradford 1991; Blaustein *et al.* 1994b; Alford and Richards 1999). Mountain yellow-legged frogs are susceptible to diseases such as red-leg disease, caused by the bacterial pathogen *Aeromonas hydrophila*. This pathogen can cause localized population crashes (Bradford 1991). Bradford (1991) suggested that one such outbreak was a result of overcrowding within the mountain yellow-legged frog population. Though it is opportunistic and successfully attacks the immunosuppressed individuals, this pathogen appears to be highly contagious, affecting the epidermis and digestive tract of otherwise healthy amphibians (Shotts 1984; Carey 1993; Carey and Bryant 1995). Grinnell and Storer (1924) reported red-legged disease had infected some mountain yellow-legged frog populations in Yosemite National Park.

In California, chytridiomycosis (*Batrachochytrium dendrobatidis*), more commonly known as chytrid fungus, has been detected in nine amphibian species, including the mountain yellow-legged frog (Fellers and Green, pers. comm., as cited in Briggs *et al.* 2002; R. Knapp, Sierra Nevada Aquatic Research Laboratory, University of California at Santa Barbara, pers. comm. 2002). Fellers *et al.* (2001) report the presence of several bacteria and chytrid fungus in larval and recently metamorphosed mountain yellow-legged frogs from sites within the Sierra Nevada. Chytrid fungus affects the keratinized (horny epidermal tissue) mouth parts and epidermal tissue of larvae and metamorphosed mountain yellow-legged frogs (Fellers *et al.* 2001). Though little is known about its life history in

the Sierra Nevada, chytrid fungus has a simple asexual life cycle, and chytrids can generally withstand adverse conditions such as freezing or drought (Briggs *et al.* 2002). A research effort is underway to study the dynamics of this pathogen and the mountain yellow-legged frog within the Sierra Nevada (Briggs *et al.* 2002). Whether adult frogs acquire this fungus from tadpoles or whether the fungus is retained through metamorphosis is unknown. However, the mountain yellow-legged frog may be especially vulnerable to infections of chytrid fungus as all life stages of the mountain yellow-legged frog share the same habitat nearly year round, facilitating the transmission of this fungus to individuals at different life stages within a population (Fellers *et al.* 2001). Survey results from 2000 in Yosemite and Sequoia-Kings Canyon National Parks indicate 24 percent of the mountain yellow-legged frog populations show signs of chytrid infection (Briggs *et al.* 2002). In mountain yellow-legged frogs, chytrid fungus has been observed to result in overwinter mortality and mortality during metamorphosis (Briggs *et al.* 2002). Effects of chytrid fungus on host populations of the mountain yellow-legged frog are variable, ranging from extinction, persistence with a high level of infection, to persistence with low levels of infection (Briggs *et al.* 2002). Studies of the microscopic structure of tissue and other evidence suggests chytrid fungus caused many of the recent extinctions in the Sierra National Forest's John Muir Wilderness Area and in Kings Canyon National Park, where 41 percent of the populations went extinct between 1995 and 2002 (R. Knapp, *in litt.* 2002).

Chytrid fungus affecting wild frog populations was not documented until the late 1990s. Since then, it has been reported in amphibian populations worldwide (Fellers *et al.* 2001). We do not know how long the mountain yellow-legged frog populations have been exposed to chytrid fungus. Red-leg disease is typically a secondary infection following a chytrid infection. If this was also the case in the early 1990s, then it would suggest that what Grinnell and Storer (1924) actually were seeing was chytrid infections (R. Knapp, *in litt.* 2002). During a visual examination of mountain yellow-legged frog tadpoles preserved between 1993 and 1999, abnormalities attributed to the chytrid fungus were detected on 14 of 36 specimens and no abnormalities were detected on any of the 43 tadpole specimens collected between 1955 and 1976 (Fellers *et al.* 2001). This indicates