APPENDIX C: EFFECTS OF NONNATIVE FISH SPECIES

Impacts of Nonnative Fish on High Elevation Ecosystems
Nonnative fish have been widely introduced to naturally fishless, mountain ecosystems throughout western North America, commonly resulting in negative ecological effects to these systems (Anderson 1971, Bahls 1992, Knapp 1996). In SEKI, high elevation waterbodies were naturally inhabited by a diverse assemblage of aquatic species that developed over thousands of years in a fishless environment. Fish were naturally restricted in distribution by waterfalls and cascades to low or middle elevation waterbodies depending on the drainage (Christenson 1977). Stocking of nonnative fish (various trout species) into SEKI's fishless high elevation waterbodies began in the 1860s (Knapp 1996) before Sequoia National Park was established.

Many studies have been conducted on the impacts of introduced trout on native biota in the high Sierra Nevada including in SEKI. Important contributions to our understanding of this issue come from landscape analyses with large sample sizes that correlate the presence of introduced trout with the absence or near-absence of native biota such as amphibians and large invertebrates (Knapp 1996, Knapp and Matthews 2000, Matthews et al. 2001, Matthews et al. 2002, Knapp 2005A).

In the Sierra Nevada, studies show that nonnative trout negatively impact entire food webs, including native fish, amphibians, aquatic invertebrates, zooplankton, algae and birds. The impacts of nonnative trout on high-elevation aquatic and adjacent terrestrial ecosystems are well documented and occur at all levels of the food web (Bradford et al. 1998, Matthews et al. 2002, Knapp and Sarnelle 2008, Pope et al. 2008, Herbst et al. 2009, Epanchin et al. 2010). Nonnative fish impact native species directly through predation and indirectly through competition for food resources. Nonnative fish can disrupt the type and distribution of species, and the natural function of aquatic ecosystems. For example, researchers found that the distribution and abundance of MYLFs, conspicuous aquatic invertebrates (e.g. mayflies) and zooplankton (e.g., *Daphnia*) were dramatically reduced by the introduction of fish (Knapp et al. 2011). There is no hard boundary between aquatic and terrestrial ecosystems. For example, leaves may drop into a lake and provide food for aquatic insect larvae. When the insects emerge as adults, they may be eaten by frogs, birds, or bats. When nonnative fish consume the insect larvae or frogs, they in turn impact snakes, birds, and bats. Consequently, the impacts of nonnative fish disrupt the flow of energy and nutrients within and between aquatic and terrestrial ecosystems (Knapp and Matthews 1996, Finlay and Vredenburg 2007).

Nonnative trout directly impact native amphibians by preying on eggs, tadpoles and frogs and competing with frogs for food, thereby reducing or eliminating reproduction (Vredenburg 2004). MYLFs are especially vulnerable to the impacts from nonnative trout (Bradford et al. 1993, Knapp and Matthews 2000, Vredenburg 2004, Knapp 2005A, Knapp et al. 2007. Trout and MYLFs both require deep, permanent lakes because they do not freeze solid in the winter, nor do they dry out even in drought years (Grinnell and Storer 1924, Hayes and Jennings 1986, Bradford 1989, Bradford et al. 1993, Bradford et al. 1994B, Knapp 1996, Knapp and Matthews 1996, Knapp and Matthews 2000, Knapp 2005A). Nonnative trout typically cause large reductions in distribution and abundance of local MYLF populations (Knapp et al. 2001), ultimately resulting in extinction in many locations (Bradford et al. 1994B; Knapp 1996, Knapp and Matthews 2000, Knapp 2005A). In turn, the presence of nonnative trout in lakes and streams across SEKI's landscape has fragmented the remaining MYLF populations and drastically reduced their ability to re-establish populations that go extinct (Bradford et al. 1993). The remaining isolated frog populations are at much greater risk for extinction (Bradford et al. 1993; Lacan et al. 2008).

The widespread introduction of nonnative trout is therefore a major factor in the disappearance of MYLF populations from approximately 92% of historic localities in the Sierra Nevada (Vredenburg et al. 2007).

Due to this steep decline, the populations of both species of MYLFs in the Sierra Nevada are currently proposed for federal listing as endangered under the Endangered Species Act (FWS 2013). A listing decision for both species is expected in 2014. In 2012, the Sierra Nevada population of the southern species (*Rana muscosa*) was state-listed as endangered and the northern population (*Rana sierrae*) was state listed as threatened under the California Endangered Species Act (CFGC 2012).

Surveys conducted between 1997 and 2002 of all lakes, ponds, and marshes (waterbodies) in SEKI showed that frogs and fish rarely coexist (Knapp 2003). These surveys detected nonnative trout at 575 waterbodies. Although nonnative trout were present in 18% of all waterbodies surveyed (575 of 3,244), they were present in 33% of lakes [2.5 acres (1 hectare) or larger], which are crucial for the long-term survival of MYLFs. MYLFs were also present in 18% of all waterbodies surveyed (569 of 3,244), but they were only detected with nonnative trout in 4% of waterbodies (135 of 3,244). Of these 135 waterbodies, MYLF adults and/or subadults were present in 122 waterbodies (4% of 3,244), whereas MYLF tadpoles and/or egg masses (evidence of breeding) were only present in 67 waterbodies (2% of 3,244). These results show that although adult and/or subadult MYLFs may occasionally be observed with trout, MYLF tadpoles and egg masses are more susceptible to fish predation and thus are rarely observed with trout.

Nonnative trout occupy an estimated hundreds of miles of high elevation (6,000 to 12,000 ft / 1,800 to 3,700 m) stream and river habitat in SEKI, and only small portions of headwater stream habitats are in a naturally fishless state (Knapp 2003). The presence of trout reduces the chance that MYLFs will occupy these streams, and precludes movement by this species between most remaining populations. Given the current distribution of trout and the scarcity of extant frog populations, it is difficult for MYLFs to move between existing populations, and the remaining isolated populations (Bradford et al. 1993) are consequently more vulnerable to extirpation from random events such as prolonged drought, severe winters (Bradford 1983) or disease outbreaks. Continued loss of MYLF populations will further isolate populations and make MYLFs more vulnerable to extirpation from entire watersheds (Bradford 1989, Bradford et al. 1993, Lacan et al. 2008).

Nonnative fish indirectly impact native predators such as the mountain garter snake (*Thamnophis elegans elegans*), which primarily preys on amphibians including MYLFs. These snakes are now less common at fish-containing versus fishless lakes in the high Sierra, likely because amphibians are rarely available as food at fish-containing lakes (Matthews et al. 2002). In addition, nonnative fish directly impact large aquatic invertebrates (Bradford et al. 1998, Knapp et al. 2001) and zooplankton (Stoddard 1987, Knapp et al. 2001) by severely reducing or eliminating them in lakes, and thus indirectly impact wildlife that rely on these organisms for food. This causes trophic cascades in aquatic food webs that extend into terrestrial environments (Finlay and Vredenburg 2007). For example, the gray-crowned rosy finch (*Leucosticte tephrocotis*), a high elevation Sierran bird that feeds extensively on adult mayflies emerging from lakes during the breeding season, is now less common at fish-containing lakes than fishless lakes (Epanchin et al. 2009). This difference is the result of nonnative fish feeding on mayfly larvae which severely reduces or eliminates mayfly emergence from lakes, resulting in a substantial loss of food for rosy finches.

Nonnative fish impact native fish in low-to-mid elevation Sierran streams through hybridization, predation and competition (Moyle 2002). Because nonnative fish have been introduced to all of the Sierran streams containing native fish, the entire native fish assemblage has declined, including several subspecies of trout and several non-trout species. Some of these fish have declined throughout their range and the following have been given protected status by the FWS. Listed as threatened under the Endangered Species Act are the Little Kern golden trout (*Oncorhynchus mykiss whitei*; FWS 1978), Paiute cutthroat trout (*Oncorhynchus clarki seleneris*; FWS 1975) and Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*; FWS 1975). The California golden trout (*Oncorhynchus mykiss* *aguabonita*) has been petitioned for listing (FWS 2002A), and the pure form of Kern River rainbow trout (*Oncorhynchus mykiss gilberti*) has become extremely rare (Erickson et al. 2010).

Collectively, these processes result in a negative effect by nonnative fish on native species and high elevation aquatic and terrestrial ecosystems in the Sierra Nevada. However, these negative effects appear to largely disappear after nonnative fish either naturally die out or are actively eradicated from these systems (Knapp et al. 2001, Vredenburg 2004, Knapp et al. 2005, 2007). Although nonnative fish (trout) stocking was terminated in SEKI in 1988, recent research indicates that approximately 70% of previously-stocked lakes in SEKI have sufficient habitat to sustain trout populations in the absence of stocking (Zardus et al. 1977, Armstrong and Knapp 2004). Since trout typically live 6 to 7 years (Behnke 2002), and have been aged to 24 years in one high Sierra lake (Reimers 1979), all natural disappearances of nonnative trout in SEKI's high elevation waterbodies have likely already occurred. The remaining trout-containing waterbodies in SEKI's high elevations therefore contain self-sustaining fish populations that will continue to cause negative effects to these ecosystems unless they are eradicated by human intervention.

Past Aquatic Management in High Elevation Waterbodies in SEKI

Nonnative fish stocking into high Sierra waterbodies was largely conducted by various sporting groups (Knapp 1996). After 1890 and the establishment of Sequoia National Park, U.S. Army staff was dispatched to manage the new park lands and they conducted extensive fish stocking (Christenson 1977). Easily accessible waterbodies were stocked with fish using packstock. After the NPS was created in 1916, NPS staff continued to conduct fish stocking in park waterbodies, and the California Fish and Game Commission began coordinating these efforts. By the 1940s, fish stocking in park waterbodies was almost entirely managed by the California Department of Fish and Game (CDFW) (Knapp 1996), with permission from the NPS. Under CDFW management, nonnative fish were systematically stocked using aircraft to plant fish in remote lakes. From the 1940s to the 1970s, most large waterbodies in SEKI were stocked at least once; many were stocked repeatedly with nonnative fish.

In the 1960s, the NPS began to apply a Servicewide policy of science-based management. The "Leopold Report" (Leopold et al. 1963) assessed various NPS resources management policies and among many findings concluded that 1) fish stocking into naturally fishless habitat was not congruent with NPS management policies and 2) indiscriminate stocking of nonnative fish into naturally fishless waterbodies may be causing negative ecological effects. The report recommended that the NPS should reevaluate its fish stocking policy and investigate whether nonnative fish stocking was impacting native species.

In the 1970s, SEKI began phasing out nonnative fish stocking while conducting a study of nonnative trout in 137 SEKI lakes (Zardus et al. 1977) to determine how those populations might respond to an absence of stocking. The study found that fish in 97 (72%) of the 137 lakes were likely able to sustain their populations in the absence of stocking. The study also recorded observations of other biota, reporting MYLFs swimming in open water in two (1.5%) of the 137 lakes, and stating: "In lakes with large populations of fish, tadpoles are observed only in shallow or protected waters, or are not present at all." In addition, in 1975 the NPS adopted a policy in which naturally fishless waters will no longer be stocked with fish (NPS 1975). As a result, the NPS proposed to terminate the authorization for CDFW to continue stocking nonnative fish in SEKI lakes. Instead, a compromise was reached in which CDFW was allowed to continue stocking fish in no more than seven lakes per year in SEKI, intermittently selected from a total of 16 high use lakes. This practice continued until 1988 when the NPS terminated all fish stocking in SEKI lakes. Although stocking no longer occurs in SEKI, nonnative fish had established self-sustaining populations in approximately 575 waterbodies (Knapp 2003) and in hundreds of miles of stream.

In the 1980s and 1990s, while additional studies were investigating landscape-scale effects of nonnative fish introductions in SEKI and the high Sierra Nevada (Bradford 1989, Bradford et al. 1993, 1998), researchers and NPS staff observed that amphibians, particularly MYLFs, appeared to be declining. Several studies ensued to quantify the MYLF decline and attempted to determine its causal factors. The primary conclusions from these studies were that 1) lake acidity levels were not elevated and thus did not appear to be a contributing factor to MYLF decline (Bradford et al. 1994A), and 2) MYLFs were much less likely to occur in lakes with nonnative fish versus fishless lakes (Bradford et al. 1994B, Knapp and Matthews 2000). To further investigate the effects of nonnative fish, researchers studied the response of MYLFs and other native species (e.g., aquatic invertebrates and zooplankton) when nonnative fish disappeared from historically fishless lakes due to stocking termination or experimental eradication. Results showed that native species quickly recovered toward pre-disturbance levels following the return of lakes to a fishless condition (Knapp et al. 2001, 2005, 2007; Vredenburg 2004; Knapp and Sarnelle 2008).

Recent Aquatic Management Actions in SEKI

From 1997 to 1999, researchers used gill nets to experimentally eradicate nonnative fish from two park waterbodies, which showed that fish eradication was feasible (Vredenburg 2004). In 2001, SEKI began to implement preliminary (experimental) restoration of MYLFs (NPS 2001). The primary goal was to assess the feasibility of SEKI staff using gill nets and electrofishers to eradicate nonnative fish from low- to moderate-use individual lakes having short associated streams. The purpose of the program was to restore aquatic habitat for native species, with an emphasis on improving the status of imperiled MYLFs. From 2001 to 2012, SEKI removed nearly 48,000 fish from targeted lakes and streams (Figure 2; NPS 2012A, NPS unpublished data). By 2012, fish were fully eradicated from 10 lakes and nearly eradicated from nine lakes. The final 5 waterbodies previously approved for nonnative fish eradication (NPS 2001, 2009A) were initiated in 2012.

In nine of the lakes eradicated of fish, MYLFs remained disease-free three years after trout removal. Average tadpole density in these nine lakes increased by 13-fold (from 0.8 to 10.1 per 10 m of shoreline; $P = 0.008$), while average frog density increased by 14-fold (from 0.8 to 11.1 per 10 m of shoreline; ; $P = 0.004$) (Figure 3). One lake showed an overall 49-fold increase from 0.9 to 43.9 individuals per 10 m of shoreline (NPS 2011A). Several of these MYLF populations are now among the largest in the entire range of MYLFs.

To test the mechanism driving the increases in restored MYLF populations, a study compared the change in MYLF density between 1997 and 2005 in 22 fishless control lakes in SEKI and three trout removal lakes, including two of the SEKI restoration lakes and one lake adjacent to the SEKI boundary in the Inyo National Forest (Knapp et al. 2007). The average change in *tadpole* density in the control lakes and trout removal lakes was +2.3-fold and +35.2-fold, respectively ($P = 0.025$), while the average change in *frog* density in the control lakes and trout removal lakes was +0.4-fold and +24.9-fold, respectively ($P = 0.0004$). Thus, increases in MYLF frog numbers in trout removal lakes result from fish eradication rather than regionally favorable conditions for population growth. These results show that eradicating nonnative trout is highly beneficial to MYLFs.

In addition, monitoring efforts have detected significantly more garter snakes per survey in trout removal lakes (0.15) versus fish-containing lakes (0.02; P=0.014; Figure 4; 2012A). Garter snakes were thus 10 times more likely to be found in fish removal lakes versus fish-containing control lakes where no removal was conducted. Snake detections also increased over time, exhibiting a positive linear relationship with the number of years since trout removal began (Upper Bubbs Creek, R^2=0.55, P=0.09 and Upper LeConte Canyon, R^2= 0.49, P=0.02) (NPS 2011A). These differences are likely attributable to the presence of increased numbers of MYLFs, which are a primary prey of garter snakes, in fishless lakes versus fish-containing lakes (Knapp et al. 2007).

Clark's nutcrackers, Brewer's blackbirds and American robins are now seen opportunistically feeding on MYLFs in restored populations (NPS unpublished data). In addition, abundant mayfly hatches are now a common annual occurrence at most trout removal lakes, providing improved forage for gray-crowned rosy finches and several bat species (NPS unpublished data).

These results show that nonnative trout eradication provides ecological benefits extending beyond frog restoration. Nonnative trout eradication in high Sierra aquatic ecosystems is feasible and beneficial to MYLFs and other native species at the local scale of individual or small groups of waterbodies. Nonnative trout eradications in SEKI are complete in 12 waterbodies, nearly complete in 9 waterbodies, and in-progress in 5 waterbodies (initiated in 2012). Restoration at the landscape scale focusing on entire basins or larger groups of waterbodies and connecting streams, however, would provide even greater benefit to native species and ecosystems. Nonnative fish eradication in multiple waterbodies and the streams that connect them would enable MYLFs and other native aquatic organisms to disperse between these waters naturally, improving ecosystem health and resistance and resilience to other stressors and uncertain future conditions.

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