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**An Analysis of Non-Native Fish Removal**
**in Yosemite National Park**

Given the widespread distribution of non-native fish species throughout Yosemite National Park (YNP), efforts to completely restore the high alpine meadow and lake ecosystems to their pre-European settlement condition would be extremely costly, time consuming, and likely ineffective regardless of effort. In addition to logistical problems associated with removal programs, large scale restoration efforts will likely face opposition from anglers who have enjoyed over a century of fishing in YNP. Despite these constraints, YNP has undergone a modest fish removal project in an attempt to restore lake and meadow ecosystems for native species such as the Endangered Species Act (ESA) listed Sierra Nevada yellow legged frog *(Rana sierrae)*, the Mountain Giant Garter Snake (*Thamnophis elegans elegans)*, and other threatened species of birds, bats, mammals, zooplankton, and invertebrates. (Brown et al. 2014, Vredenburg 2004, Matthews and Knapp 2002, Latta IV et al. 2010, Herbst et al. 2009). The habitat degradation and decline of Yosemite's native species over the last century is a direct result of anthropogenic changes to the landscape including non-native species introductions, livestock over-grazing, and alteration of successional patterns (Mount et al. 2002). In this research paper, I will evaluate current non-native fish management efforts used by YNP, as well as potential alternatives, in order to assess the ability of various management techniques in achieving the national parks goals of recovering native amphibians and the native ecosystem as a whole.

Due to natural barriers such as Preston Falls on the Tuolumne River and Vernal Falls on the Merced River, most of the waterways in high alpine Sierran environments were historically fishless (Moyle et al. 1973). This changed shortly after Europeans settled in California following the Gold Rush, when non-native fishes were transferred to the High Sierra for a food supply and recreational activity. From the 1880's to the 1950's, transfers were limited to simple techniques such as carrying fish in barrels up the mountain, but by the mid 1950's California Department of Fish and Game began using planes to drop millions of juvenile trout into alpine lakes every year (Knapp 1996). However by the 1970's, the stocking programs ceased in National Parks in response to 'Leopoldian' ideals that brought to light the severe negative effects introduced species could have on natural ecosystems (Vredenburg 2004). Even though termination of stocking programs has allowed some lakes to return to a fishless state, surveys continue to reveal the presence of nine non-native self-sustaining fish species in the park to this day (five species of salmonids, two hybrid salmonids, bluegill, and smallmouth bass) (Knapp and Matthews 1998). Recent predictive models have estimated that the park still has non-native fish species in 60% of its 1,205 miles of streams and in 250 of the 2700 ponds and lakes (Knapp and Matthews 1998). The long history, technological improvements of stocking programs throughout the 1950's, and the quality trout habitat within YNP are likely drivers behind these self-sustaining non-native fish populations in the park. It is these self- sustaining populations that directly affect amphibian and zooplankton populations, and indirectly affect many more species. (Matthews et al. 2002, Knapp et al. 2005). Despite documented declines and even eradication of multiple native species that have been directly influenced by non-natives fishes, fish removal programs did not begin until 2007 (Brown et al. 2014). The modest recovery plan to eradicate fish from 10 lakes following the 2000 ESA listing of the Mountain yellow legged frog (*Rana muscosa)*, (now the Sierra Nevada- yellow legged frog (*Rana sierrae*)) and concern over the effects of these non-native species on the overall health of YNP's ecosystem warranted the efforts.

Currently restoration efforts in the park center on gillnetting and electrofishing techniques in order to remove invasive fish. The project is focusing on removing non-native fishes from 10 lakes designated as important for native amphibian habitat recovery. While YNP has not published peer reviewed data on the success of their efforts, a similar removal effort took place in Sequoia and Kings National Park (SEKI) from 2001-2007 resulting in successes. Not only were fish removed from six of the seven lakes, but Sierra Nevada yellow legged frogs had 19-60 fold increases in abundances (Brown et al. 2014, Knapp et al. 2007). However, there are still some concerns with gillnetting and electrofishing for employing large scale restoration efforts. For example, gillnetting is ineffective at capturing young-of-the-year fish, which are able survive and sustain populations for a number of years after initial removal (Knapp and Matthews 1998). Gillnetting and electrofishing are also limited by the lake bathometry as the technologies have not been developed for use in deeper than 10 m of water. To avoid future re-introductions, restoration efforts should focus on lakes without inlets, and barriers at the outlets (Knapp and Matthews 1998). These techniques have been applied in the Upper Truckee River Lahontan Trout Restoration Project, where they have spent 25 million dollars and eight years restoring 10 miles of river and 85 acres of lake habitat. While Cutthroat trout are doing well in the upper reaches of the river, efforts are on-going to complete restoration for a lower 10-mile stretch of river (Lemmers et al. 2011).

Given the large scale costs of physically removing non-native fish for restoration efforts, it is prudent to explore alternative adaptive management techniques. Though controversial, one of the most effective techniques in fisheries management has been the application of the piscicides rotenone and antimycin. Finlayson et al. (2010) found that these were "the only 100% effective tool for removing invasive fish", and some papers have claimed that the application of rotenone has had no detrimental effects on non-target species assemblages following application (Britton and Brazier 2006). Despite this claim there have been many studies which have shown rotenone does have lethal and sub-lethal effects on phytoplankton and zooplankton communities, amphibians with gill breathing tadpoles, and sensitive invertebrate species (Finlayson et al. 2010, Billman et al. 2012, Dalu at al. 2015). Because of these findings, and likely detrimental effect to amphibian populations, there has been no application of piscicides on trout species in Sierran National Parks. SEKI and YNP have denied even the consideration of these techniques at this time (Brown 2014). Similar concerns would likely be raised about an innovative biocide the Tiger Muskellunge (Northern Pike *Esox lucius* × Muskellunge *E. masquinongy*). This sterile hybrid has been used with success at reducing brook trout (*Salvelinus fontinalis*) populations in 7

Northern Idaho lakes, reducing fish densities from an average of 25 fish/net-night to 2 fish/net-night in 5 years (Koenig et al. 2015). While this is not 100 percent effective, the methodology has its relative benefits. Raising and stocking programs could be more cost effective if more widely employed, and stocking programs would require much less physical effort than the other methods. Also tiger muskellunge are able to capture brook trout, and the method could be employed in larger lakes where gillnetting and electrofishing are difficult (Koenig et al. 2015). However, there are obvious concerns with the extent that tiger muskellunge would exhibit a predatory relationship on non-target native species, such as the endangered Sierra Nevada yellow legged frog. More research would need to be done before the hybrid is introduced to YNP to avoid unintended consequences on native species. However, based on the effectiveness of this study, tiger muskellenge could be a viable option in currently amphibian-free lakes; some of which may be important for increasing the connectivity of amphibian populations.

Current invasive fish management strategies are often limited by effectiveness per unit effort, or have possible negative effects on native species when the effort is minimal. Given this dilemma, it has been difficult to determine the best strategies moving forward, but with native amphibians and other species facing the threats of extinction from a multitude of factors (fungal diseases, poor air quality, and global warming), the time to act is now (Brown et al. 2014). Whether increasing physical removal efforts through increased funding, researching the viability of implementing one of the more controversial controls in a park setting, or even a combination of the two; continued restoration efforts must be made to try and preserve the meadow and lake ecosystems and their inhabitants. This will be absolutely necessary if the park is going to achieve its goals of protecting native species and preserving the natural state of the ecosystem.

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