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GEL 136
6/8/18

Predation of the Endangered Sierra Yellow-Legged Frog by Introduced Trout in the Tuolumne River Watershed

Introduction

Historically, the Sierra yellow-legged frog (SYLF) inhabited a broad range extending throughout the Sierra to montane regions of Oregon and Nevada (Fellers, et al., 2013). Current populations, however, have been reduced to small, fragmented sections only in the Sierra Nevada (IUCN, 2008). The species (*Rana sierrae/muscosa*) is currently listed as 'Endangered' under the IUCN Red List due to consistently declining populations. A study between 1995-2005 showed a 92% extirpation rate of SYLF from 146 known historic sites within the Sierra region (Vredenburg, 2004). While there are many stressors currently limiting the survival of the SYLF, predation by introduced trout has proven to be a major factor. This study looks to understand the impacts of trout presence on the SYLF within the Tuolumne River watershed.

The Tuolumne watershed provides prime examples of fragmented habitats in which SYLF populations are in decline and where experimental management strategies have been implemented. The main factors currently affecting the success of SYLF populations within this region are anthropogenically influenced, including altered climate patterns, the spread of pathogens like chytrid fungus (*Batrachochytrium dendrobatidis*), and predation by introduced trout (USFS, 2014). In addition to a highly fragmented habitat, predation by trout is often the most consistent factor limiting the success of a SYLF population (Matthews and Knapp, 1999). Stress from trout predation is also one of the easiest factors to control and manipulate through management practices.

Trout Invasion

The SYLF is only found in higher elevations streams and ponds of the Sierra Nevada, usually above 4,000 ft (USFS, 2014). These regions have been historically fishless due to the underlying geology, characterized by large, granitic batholiths that create steep-sloping streambeds which fish have been unable to migrate through (Mount, et al., 2010). Since the 1850's, however, multiple species of trout have been introduced into these upper reaches of the Sierra for subsistence and recreational fishing (Matthews and Knapp, 1999). Fish have been hauled by burro, by truck, and dropped out of planes to stock even the most remote lakes of this once fishless region. Larger lakes are still regularly stocked by the state (Matthews and Knapp, 1999). Introduced trout now occupy roughly 90% of SYLF habitat, including the Tuolumne River watershed (Vredenburg, 2004). This has major implications for the future survival of the species and as well as the management of the watershed.

There is not an exact demographic record of SYLF range or population sizes predating these widespread fish releases. However, there are anecdotal and investigative descriptions of the species throughout the 20th century (Fellers, et al., 2013). SYLF were often noted as among the most prominent species along the banks of lakes and rivers throughout the Sierra Nevada (USFS, 2014); (Finlay and Vredenburg, 2007). There are also extensive museum records of the species which confirm their past abundance in these high-elevation meadows and streams (Vredenburg, 2004). Part of the widespread decline of the species has been correlated to trout introductions, with greatly reduced SYLF populations in lakes and streams that contain trout (Matthews and Knapp, 1999).

Effects of Predation

While there are many environmental stresses on this species, the direct predation of non-native trout on SYLF eggs and tadpoles is a consistent cause for population declines in the Tuolumne watershed (Vredenburg, 2004). The Rainbow trout (*Oncorhynchus mykiss*) and the Brook trout (*Salvelinus fontinalis*) have the greatest impact on the species (Vredenburg, 2004). These trout effect the survival of larval SYLF through direct predation, as well as their growth through competition for resources.

The presence of large, predatory fish prevents the SYLF from reproducing in larger lakes, limiting populations to smaller lakes and tributaries (Vredenburg, 2004). Due to their 2-3 year larval period, however, the species also requires perennial aquatic habitats that are not completely frozen over during winter nor completely dry during summer (USFS, 2014). These habitats often become prime territories for non-native trout species who can easily migrate throughout the watershed during winter freeze and summer drought. Studies have shown up to 100% mortality of SYLF eggs and tadpoles within certain reaches due to trout predation (Lacan, et al., 2008). This massive loss results in gaps in the food web and limits the potential success of the natural predators of adult frogs within the ecosystem, like garter snakes, egrets, herons, and hawks (IUCN, 2008).

The SYLF also shows a high degree of site fidelity (Matthews and Preisler, 2010). This is limiting for the success of the species because it means individuals are more likely to return to their initial habitat for breeding or wintering than to choose the nearest suitable habitat. Predicted climate change patterns for the region suggest the drying of small lakes becoming more frequent and winter freezes becoming more extreme (Lacan, et al., 2008). This implies reduced reproductive habitat for many SYLF populations, leading to overall reductions in potential reproductive success for the species. This also implies reduction in habitat for invasive trout species, leading to greater overlap of habitat and higher rates of larval predation.

Trout presence has also been shown to have a negative influence on benthic macroinvertebrate communities, the primary food source of both juvenile and adult SYLF (Herbst, et al., 2009). These same macroinvertebrates are also the primary food source for juvenile trout within these regions (Finlay and Vredenburg, 2007). Matthews and Knapp's (1999) comprehensive survey of the headwater streams and lakes of the Sierra Nevada showed a reduction in 20% of the common native taxa in habitats containing trout when compared to fishless regions, leading to a doubling of algal biomass. Average macroinvertebrate species diversity, abundance, and size have also been observed to be reduced in lakes containing trout (Matthews and Knapp, 1999); (Finlay and Vredenburg, 2007). This means that the presence of trout is not only a threat to the SYLF through predation, but also through trophic effects and competition food resources.

Management

Past management attempts have focused on the experimental removal of trout from high-elevation lakes of the Sierra. One study showed that the removal of non-native trout species allowed populations of SYLF to rapidly recover from near extirpation (Vredenburg, 2004). After 1-year, experimental lakes in this study with trout removed showed massive growth in both tadpoles and adult frogs. After 3 years, SYLF populations in these lakes were identical to those in control lakes that were never inhabited by trout (Vredenburg, 2004). The success of SYLF in this study demonstrated how trout predation was a major cause for frog declines, and that the negative effects of this predation could be reversed.

Similarly, the cessation of fish stocking throughout Yosemite National Park has resulted in an increase of SYLF abundance through draining portions of the upper Tuolumne watershed (Knapp, et al., 2016). A 20-year study of frog abundance throughout this region showed that despite ongoing stress from chytrid fungus, agricultural pollution, and climate change, the reduction in trout allowed for significant SYLF population recoveries (Knapp, et al., 2016). This shows that the species' resilience towards other limiting factors can be improved through reduced stress from predation by invasive trout. To restore the natural food webs of these ecosystems, the introduced predators must be removed.

Unfortunately, the removal of all non-native trout from lakes and streams of the Sierra Nevada is not a feasible management strategy due to the high demand for recreational fishing in the region. For the best likelihood of success, removal of trout for SYLF conservation must then focus on select habitats. Many studies have suggested that small, isolated populations of SYLF are more vulnerable than large populations (Fellers, et al., 2013); (Lacan, et al., 2008), and that the species' persistence is highly dependent on metapopulations (USFS, 2014). As small populations go locally extinct from predation, individuals from surrounding populations eventually recolonize the area. This means that the connectivity of SYLF populations is vital to their future success. Directed removal of trout from these connecting habitats will likely be necessary to reestablish healthy metapopulations of SYLF that can continue to persist through localized extirpations.

Conclusion

As with many amphibian species across the globe, the Sierra yellow-legged frog is currently in decline. A once common species throughout the Sierra Nevada has been reduced only to small, fragmented populations, vulnerable to local extirpation. Direct predation on SYLF eggs and tadpoles by non-native trout has proven to be a major cause of this decline and has become a subject of management concern. However, experimental fish removals like those in parts of the Tuolumne watershed (Knapp, et al., 2016) have shown that the reduction of stress from these invasive trout can allow for increased reproductive success for the SYLF.

The removal of non-native trout species will not guarantee the success of any population of SYLF since there are many other factors limiting their survival. A combination of changing climate conditions, pollution, habitat loss/fragmentation, and the spread of chytrid fungus also contributes to the current decline of this species. The underlying catalyst to these factors, however, is anthropogenic activity, indicating that mitigation actions will likely be required to restore ecological health and resilience. Future research should focus on the reconnection of isolated populations and the re-establishment of healthy metapopulations to enhance the resiliency of the imperiled SYLF to further stress.

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