# Summary

Summary findings of the conservation report.

# Species Background and Ecology

Amphibians are considered one of the most threatened animal groups in the world, with a significant proportion of species considered as a risk for extinction worldwide. Reasons for amphibian declines include anthroprogenic habitat loss, introduction of invasive species, and disease (Skerratt, et al., 2007).

Once a common site amongst the lakes and riparian zones in the Sierra Nevada mountain range, the Sierra Nevada Yellow-legged Frog (*Rana sierrae*) has seen it’s population counts decrease dramatically since the beginning of the 20th century, making it a model species for the overall trend of amphibians worldwide.

The Sierra Nevada Yellow-legged Frog was formerly recognized as part of the same species as the Mountain Yellow-legged Frog (*Rana muscosa*). Research into separate populations of *R. muscosa* has indicated significant genetic differences, indicating that these populations comprised of two distinct species rather than distinct populations of the same species (Vredenburg, et al., 2007). Due to the recent distinction between the two species, and similar morphology and ecology of the two species, data and studies for *Rana muscosa* will often be used to compliment information on the Sierra Nevada Yellow-legged Frog.

## Species Status

The Sierra Nevada Yellow-Legged Frog is a species of great conservation concern in California. Considered endangered by the IUCN Red List of Threatened Species (Hammerson, 2008), the species was formally listed as a federally protected species under the Endangered Species Act as of 4/25/14 (Nafis, 2018). Approximately two years after the listing, the U.S. Fish and Wildlife Service designated 1.8 million acres of protected critical habitat for the Sierra Nevada Yellow-Legged Frog. This protected habitat was also designated to help other threatened and endangered amphibians including the Southern Mountain Yellow-Legged Frog (*Rana muscosa*) and the Yosemite Toad (*Anaxyrus canorus*) (Miller, 2016).

## Morphology

The Sierra Nevada Yellow-Legged Frog is approximately 1.5 to 3.25 inches on average, and is classified as a medium-sized amphibian. Similar to most anurans, the female Yellow-Legged Frog is typically larger than the males (U.S. Fish & Wildlife Service, 2017).

Coloration of the frogs can vary, though adults tend to have a mix of brown and yellow coloration on the dorsal side of the body. The common-name for Rana sierrae comes from the coloration of the underside of the back legs which are a distinctive yellow or light orange. Tadpoles grow up to 2 inches long and are brown with flecks of gold (Nafis, 2018).

## Ecology and Life History

The Yellow-Legged Frog is mostly found near persistent pools of water and does not forage far from their initial breeding lakes. It eats a variety of terrestrial and aquatic invertebrates and tadpoles and may also consume dead frogs and its own eggs (Nafis, 2018).

Unlike other species of frogs found in California, the Yellow-Legged Frog is active mostly during the day. During the height of winter, the species is assumed to live at the bottom of frozen lakes and will not reemerge until shortly after the beginning of snowmelt. It rarely occurs where predatory fishes have been introduced (U.S. Fish & Wildlife Service, 2017).

Reproduction is aquatic and follows a reproductive cycle similar to most other frogs and toads in California. The Yellow-legged frog comes into maturity after approximately 4 years, though food availability can alter the length of the juvenile life-stage. Adult males will produce a mating call after at the beginning of breeding season, which typically occur after April, to attract females.

Fertilization is external, and is done in amplexus, with the male grasping the back of the female and releasing sperm as the female lays her eggs. Females lay eggs in large clusters and are often attached to underwater vegetation. Entire egg clusters have the approximate mass of a tennis ball (Stebbins, 2003).

The eggs hatch into tadpoles which feed in the water and eventually grow four legs, lose their tails and emerge onto land where they disperse into the surrounding territory (Nafis, 2018). Yellow-legged frog tadpoles often overwinter 2-3 times before metamorphosing into juveniles (Vrendenburg, Fellers, & Davidson, 2005).

Juvenile and adult Yellow-legged frogs are considered highly aquatic, rarely found more than a few meters from a source of water (Vrendenburg, Fellers, & Davidson, 2005). These frogs are opportunistic feeders and consume both aquatic and terrestrial invertebrates. Adult Yellow-Legged frogs are expected to live up to 20 years old (Matthews & Miaud, 2007).

Yellow-legged frogs have no natural aquatic predators, other than an occasional cannibalism. Introduced trout species to naturally fish-free lakes and streams in high elevation regions of California are considered the main reason of the species decline (U.S. Fish & Wildlife Service, 2017), followed by the subsequent introduction of a fungal pathogen, *Batrachochytrium dendrobatis*, that has been linked to global declines in amphibian populations (Skerratt L. , et al., 2007).

## Range and Habitat

The historical range of the Sierra Nevada Yellow-Legged Frog (R. sierra) extended throughout California and parts of Nevada. The historical range is bounded by the Diamond Mountains in Plumas County at the Northwest; Mount Rose, located in Washoe County, Nevada, to the Northeast; the Middle and South Fork of the Kings River, located in Fresno County, California, to the Southwest; and the Glass Mountains, located in Mono County, California, to the Southeast. Rana sierrae is now extirpated from Nevada and from large portions of the historical range in the Sierra Nevada of California (Hammerson, 2008).

## Population Data

The population of this species that I will be looking at is located within Yosemite National Park and includes studies of species across several geographically distinct lakes found within that park (Knapp, et al., 2016). Surveys were conducted for 2,154 distinct water bodies within Yosemite National Park over a period of 20 years. Not all water bodies were surveyed every year, and some sites were surveyed multiple times within a same year. In total 7,678 frog population count surveys were conducted for this population (Knapp, et al., 2016).

# Conservation Problem

The decline in population counts for the Sierra Nevada Yellow-legged frog is due to many stressors. Initial declines began due to the introduction of nonnative fish to formerly fishless lakes in the early 20th century. Fish introductions have ceased within Yosemite National Park, though are still common outside of the park. Additionally, while the artificial stocking of fish have ceased within Yosemite National Park, populations of fish still exist in most of the lakes from which they were introduced to.

Efforts to remove non-native fish have been tested using sinking monofilament gill nets. Initial efforts have shown some success in eradicating non-native fish populations from oligotrophic lakes in the Sierra Nevada region (Knapp & Kathleen, 1998), though remain a time intensive and expensive endeavor.

Expirements conducted on populations of Mountain Yellow-legged Frogs in the Humphreys Basin and LeConte Basin, both located in the southern Sierra Nevada region (Sierra National Forest and Kings Canyon National Park respectively) have shown drastic increases in population sizes immediately following the removal of non-native trout species (Knapp, Boiano, & Vredenburg, Removal of nonnative fish results in population expansion of a declining amphibian mountain yellow-legged frog, Rana muscosa, 2007).

In addition to population pressures that are the result of introduced, and persisting, populations of non-native fish, the spread of the chytrid fungus into Yosemite National Park starting in the 1970s has caused additional declines in frog populations. The presense of chytrid is considered ubiqioutous within Yosemite National Park, with infected frogs likely to exist at all surveyed populations, however, data containing information on infection loads were not collected during the surveys used for this project. Lab research done in conjunction with these population surveys, however, indicate that mortality due to chytrid, measured via infection intensities, is lower for frogs from populations that have persisted with chytrid in the environment (Knapp, et al., 2016).

Analyses of this data have shown an overall positive intrinsic growth rate for the Yosemite National Park (Figure 1) ( (Knapp, et al., 2016) population of Yellow-legged Frogs, though recovery of the species is far from complete. Part of this is that despite population counts of frogs at a single lake are growing, there is little movement towards reestablishing areas where the species was extripated from. Using the population survey count data, along with recorded environmental characteristics of each of the survey sites, can identify key indicators for places to artificially reestablish native populations.

# Population Trend Analysis

# Demographic Analysis

A demographic stage analysis was conducted using literature reviewed information to assume life stage survivorship rates for the Sierra Nevada Yellow-legged Frog. Due to the Sierra Nevada Yellow-legged Frog’s fairly recent designation as a distinct species from the Mountain Yellow-legged Frog, a lot of the details about life stage survivorship was derived from research conducted on the latter species. Additional asusmptions based on generalized amphibian studies were also used to estimate the survivorship for each of the life cycle stages.

For this analysis five distinct age classes were used. An individual remains in each age class for one year, though certain age classes can by skipped entirely due to the life history of this species. These a classes are defined as below:

* Tadpole1. The Tapole1 stage refers to tadpoles that have survived one overwintering. These are tadpoles which have hatched from eggs in the previous year (spring to early fall), and survived through the winter.
* Tadpole2. The tadpole2 stage refers to tadpoles who overwinter for a second time, while remaining as tadpoles.
* Subadult1. This life stage refers to any individual who has metamorphed but is not yet to breeding size (40 mm snout/vent length)
* Subadult2. This life stage occurs if an individual remains too small to breed for a second consecutive year.
* Adult. Adults are individuals that have reached breeding size and are assumed to be breeding annually thereafter.

A life stage demographic table (Table 1) displays the survival probabilities for an individual. These probabilities were determined using best estimates from literature review. This analysis is based upon a pre-breeding assumption.

## Reproduction Rates

Reproduction only occurs in the adult stage (snout/vent length > 40mm). Breeding occurs within a distinct seasonal time period and female frogs only lay one egg mass per year. Egg masses on average contain 150 to 300 eggs (Nafis, 2018). For this assessment I have assumed that 300 eggs on average are laid.

Breeding is constrained by the number of available females, so therefore this demographic analysis will only be looking at female population numbers. The sex ratio for this frog has been observed as 1:1 (Bonham, 2011), and I have found no indication that environmental factors contribute to whether or not an egg is female or not, so therefore I have assumed that half of the laid eggs will be female (150). A personal conversation with a herpatologist confirmed that for this species that would be a decent enough estimation (E., Wilson, Personal Conversation on February 26, 2018).

Fecundintry rates for this model takes into account survivorship from an egg being laid, to egg hatching, and the tadpole surviving the first year. Studies have shown that a significantly large portion (99-98%) of fertilized eggs hatch into tadpoles after 18-20 days and survive the first winter (Vrendenburg, Fellers, & Davidson, 2005).

Since this is a pre-breeding model, three life stages can possible contribute to the next generation of tadpoles: Surviving adults, Subadult1’s that survive and transition directly to the adult stage, and Subadult2 that survive and transition directly to the adult stage. As indicated by Table 1, the number of expected tadpoles that survive from egg to the first year of survey from each life stage are 105 for adults, 15 from subadult2, and 28.5 from subadult1.

## Tadpole Survivorship

Tadpole metamorphosis occurs between 1-2.5 years, or 2-3 overwinters (Vrendenburg, Fellers, & Davidson, 2005). Information is lacking regarding the probability that a tadpole metamorphisizes after the second or third overwinter. Literature for higher elevation Mountain Yellow Legged Frogs, which would include the population of Sierra Nevada Yellow-legged Frogs located in Yosemite National Park, suggest that they tend to take overwinter 3 times.

Studies also indicate that survivorship of tadpoles into subadults is relatively low. I could not find specific numbers for the Mountain Yellow-Legged Frogs, however found studies indicating that approximately 1-5% of tadpoles survive metamorphisis and become subadults across a variety of frog species (Calef, 1973). For this analysis, I am assuming the lowest survivalship rate of 1% for all tadpoles to reach the subadult life stage.

Using this information, I have assumed that the cumulative probability of tadpole1 and tadpole2 stages reaching the subadult1 stage is equal to 0.1. This cumulative probability is the probability of surviving a year multiplied by the probability of transitioning to the next lifestage, either tadpole2 or subadult1 plus the probability that a tadpole2 survives multiplied by it’s probability of transitioning to a subadult1. Figure 2 details the exact equation used. This assumption presumes that annual survivorship for tadpole1 and tadpole2 is equal. This may not be the case in reality, as it is possible that a larger tadpole2 may have greater survivorship compared to a more recently born tadpole1, however since that data is lacking I feel that this assumption is relevant. Any demographic related managerial decisions based upon either tadpole1 or tadpole2 survivorship rates will likely affect all tadpoles equally.

Observations of the species have observed that higher elevation Mountain Yellow Legged Frogs typically spend 2 years as tadpoles (3 overwinters), I am presuming that only 0.1% of 1 year old tadpoles become subadults in year 2 and survive. The probability for a tadpole1 in year 1 to survive and become a year 2 tadpole2 is presumed to be 9.5%. This creates a cumulative survivorship for tadpoles to subadults to be the probability of Tadpole1 becoming Subadult1 (0.001) plus the probability of a tadpole in year 1 remaining a tadpole in year 2 (0.095) multiplied by the probability of a tadpole in year 2 survining and becoming a subadult (0.095) which equals 0.01, or 1% of tadpoles reach the lifestage of a subadult (Figure).

## Subadult Survivorship

Subadult individuals are any individuals which have metamorphisized from a tadpole, but are still too small to breed. Typically an individual will progress into breeding adults after 1 year, however some may remain as subadults for a second year, likely due to environmental effects. Similar to tadpoles, studies are not conclusive regarding the proportion of subadults that reach breeding size after one year or not, so some assumptions were made based upon the overall survivorship of all subadults into adults.

Mortallity of subadults is observed to be high, with only approximately 20% reaching the adult stage (Bonham, 2011), this is likely due to how metabollically expensive it is for the tadpole to complete metamorphisis, and the risk associated with being a smaller frog.

Literature suggest that usually subadults become breeding adults after one year, so I have assumed a very small (10%) proportion of subadult1 transition into subadult2, while a relatively larger proportion go straight to the adult stage (19%).

Adults, in comparison, have been found to have fairly high estimates. One assessment claims that over 90% of adults survive year to year, with other estimates suggesting between 56% and 86% (Bonham, 2011) (Briggs, Knapp, & Vredenburg, 2010). For this project I took an estimated median value of 70%.