Impacts of Altered Flow Regimes on the Foothill Yellow-Legged Frog (*Rana boylii)*

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Resource Needs of the Foothill Yellow-Legged Frog

Synchrony Needs and Importance of Timing in Life History Events

Synchrony between an organism's life history events with seasonality of resources and physical conditions is critical for the reproductive success. Synchrony is especially important for the foothill yellow-legged frog living in highly variable river environments where the recruitment of offspring into adulthood depends on the ability to avoid flood mortality in the egg and larval stages. However, regulation of rivers by dams has caused a mismatch between the timing, magnitude, duration, and frequency of floods and natural history of many native species. (Kupferberg et al. 2011). Resource and habitat requirements will be assessed for the foothill yellow-legged frog to identify how to better manage flow releases for the conservation of this species of concern.

Natural History and Habitat Requirements

The foothill yellow-legged frog (*Rana boylii)* occurs from Baja California, Mexico to central Oregon, West of the Sierra Nevada and Cascade crests (Lind et al. 1996) and has an adapted life cycle to the lotic waters in a Mediterranean climate with wet winters and dry summers. Unregulated rivers within California typically experience a slow decline in discharge over the course of the larval period. Juvenile and adult frogs are much more mobile, traveling throughout the drainage network often found to be associated with stream riffles that have rocky substrates with partly shaded banks. During the rainy season frogs will seek refuge in tributaries, springs, and seeps to avoid flood mortality. Frogs attach their egg clutches to rocks in slow, shallow channels during peak spring runoff. As the discharge declines in the early summer, the tadpoles hatch and will metamorphose by the next rainy season (Kupferberg et al. 2011). Juvenile frogs will often remain in the margins of the river or in nearby riparian tributaries until the following spring (Bondi et al. 2013). However, foothill yellow-legged frog populations are threatened by regulation of stream flows in dammed river systems through direct (detachment and stranding of egg masses) and indirect consequences (elimination of suitable breeding habitat) which ultimately lowering the population's reproductive output (Wheeler and Welsh 2008).

Issues with Altered Flows and Foothill Yellow-Legged Frogs

Foothill yellow-legged frogs have reproductive cycles adapted to natural flow regimes which make them particularly vulnerable to the altered flow in managed rivers (Bondi et al. 2013). Currently, there are over 800 dams within the historic range of *R. boylii* and the species has disappeared from over 50% of known historic sites. Adult animals are reacting to an environment with limited predictive values (water temperature, depth, and velocity) on conditions for offspring weeks or months later we are seeing for tadpoles.

Summer pulsed flows released by dams elevate velocities of nearshore environments, displacing tadpoles as well as exerts artificial selective pressures toward small body size which ultimately negatively affects population growth rate (Kupferberg et al. 2011). Additionally, dams can cause limitation of interstitial flow refugia used as habitat for amphibians downstream with high inputs of fine sediments from human activities which the spaces amount larger rocks. Furthermore, fine sediment loading can have negative impacts on benthic macroinvertebrate diversity growth and abundance which can in turn negatively impact on the amphibians that consume them (Kupferberg et al. 2011). Elimination of these manufactured pulsed flows, once breeding begins for *R. boylii* in the spring through early fall, will enhance recruitment (Kupferberg et al. 2011).

Exotic species are also dam-related factors that may influence breeding ecology of the foothill yellow-legged frog. Suitable habitat for bullfrogs (*Rana catesbeiana)*, a notable predator of native western ranids, increase with controlled flows and lack of winter flooding as they provide stable pool areas with established aquatic vegetation (Lind et al. 1996).

Downstream distance from the dam was found to be a better predictor of occupancy and abundance than upstream suggesting that downstream habitat changes from reservoir creation has a much stronger effect on anuran occupancy and abundance than did upstream changes. (Eskew et al. 2012). Additionally, it was found that the foothill yellow-legged frog has populations 5 times smaller on average in regulated rivers compared to unregulated rivers (Kupferberg et al. 2012). Organisms may be changing their reproductive behaviors downstream of dams as a result of the decoupling of seasonal cues (day length, temperature) that trigger migration and instream cues (depth and velocity) that ultimately influence the ovipositional sites of the adult foothill yellow-legged frog (Kupferberg et al. 2012). Furthermore, significantly higher dam height in watershed where foothill yellow-legged frogs were absent suggests an association between extensive hydrologic modification and loss of population persistence (Kupferberg et al. 2012).

Water temperature is another factor known to influence the breeding ecology of the foothill yellow-legged frog. Notably, Rana boylii oviposition appears to occur when water temperatures reach least 10 °C (Wheeler et al. 2015). Retention of water behind a dam can cause artificially low summer base flows as well as warm downstream temperatures. One study performed a census of adult frogs breeding density within a drainage network and combined studies of short term individual thermoregulatory behavior with field manipulation of water temperatures and food resources. Ultimately, researchers found that populations of frogs were most dense where the mid-summer water temperature matched temperatures most favorable for survival and metamorphosis of tadpoles (19.60+/- .58℃) (Catenazzi and Kupferberg 2013). Operating at temperatures near an organism’s thermal preferences may benefit many physiological and biological processes, especially in the rapidly developing tadpole phase (Catenazzi and Kupferberg 2013). Furthermore, it was found that colder, regulated mainstem habitats had breeding activities, hatching success, and metamorphosis occur later, compared to unregulated tributaries (Wheeler et al. 2015). Metamorphs were also noted to be smaller and leaner (Wheeler et al. 2015). Without lateral warming in the shallows, tadpoles may not be able to find warm water refuges during their development and may not be able to mediate thermal preference through behavioral responses if conditions persist. Ultimately, larger size may increase the probability and could have long term effects on post-metamorphic growth rates, size at maturity, and reproductive success (Wheeler et al. 2015).

Potential Management Actions to Improve Flows

Modeling exercises have been used to help species managers predict temporal breeding patterns of the foothill yellow-legged frog (Wheeler and Welsh 2008). While studies have been showing the detrimental effects of dams on amphibians, there are potential benefits of water release from dams through restoration of downstream amphibian breeding habitats. When water is released in pulsed flows to mimic natural flooding events we are more likely to provide anurans with riparian zone habitats during the appropriate season (Eskew et al. 2012). When river managers and dam operators consider alternate flow proposals, the impacts of thermal changes should be evaluated to insure suitable habitat for species like the foothill yellow-legged frog. To identify suitable habitat, Bondi et al. (2013) created a model with habitat suitability criteria, however this was found to be better at predicting suitability of breeding habitat in larger rivers in the Sierra Nevada than smaller tributary streams. Acknowledging repeated use of the same gravel bar or mesohabitat units will also be critical in effective management to protect breeding hotspots (Lind et al. 2016). By mimicking natural patterns of daily, seasonal, and annual variations in river flow, geomorphic process, and riverine species, and food webs are more likely to be sustained (Kupferberg et al 2012).

Projects That have Improved Flow for Frogs

As mentioned previously, two-dimensional hydrodynamic modeling, such as those incorporating habitat suitability criteria from data on habitat conditions allow us to better understand availability of breeding habitat on various temporal scales. Two-dimensional models can more accurately predict water velocities and depths at local scales which can be useful to know in management scenarios (Yarnell et al. 2012). When such methods are implemented in management, we are better able to identify areas in need of protection and restoration. Additionally, managers can use these habitat suitability criteria to make flow recommendations beneficial to the foothill yellow-legged frog during the hydropower relicensing process (Eskew et al. 2012). Relicensing of hydropower allows the opportunity to change flow regimes such as those that have had negative impacts on the foothill yellow-legged frog. Conservation of foothill yellow-legged frogs in regulated rivers will depend on management that minimizes atypical flows during the particularly sensitive breeding and tadpole rearing seasons.

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