Science Foundation Chapter 5 Appendix 5.1 – Case Study California Red-Legged Frog (*Rana draytonii*)

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DESCRIPTION OF THE SPECIES

This case study considers the California red-legged frog (*Rana draytonii*) that is endemic to California and northwestern Baja California, ranging from central California, south to the mountains of southern California and east to the Sierra Nevada up to an elevation of 1,500 m (5,200 ft) (USFWS 2002). Molecular studies by Shaffer et al. (2004) demonstrated that *Rana aurora* and *Rana draytonii* are separate species with a small range overlap in northern California along the coast in Mendocino County. The California red-legged frog (CRLF) was historically more wide-spread than the current distribution, occupying greater portions of the western slope of the Sierra foothills and the Central Valley, the north Coast Range foothills, and the Southern Transverse Range and Peninsular Ranges of California. Current populations, though, are now fragmented, and the species has been extirpated from 70% of the former range, though reasonable numbers of frogs still occupy the north-central coast, around San Francisco Bay, and the central coast of California The species presently is associated with all of the counties surrounding San Francisco Bay estuary, occupying many of the freshwater marshes that fringe, and tributaries that flow, into the bay: in Suisun Bay (i.e., near Suisun Marsh); in San Pablo Bay (i.e., near Sears Point at junction of Highway 37 and Lakeville Road); in South San Francisco Bay (i.e., near SF International Airport); central San Francisco Bay; and Contra Costa and Alameda counties (i.e., East Bay Regional Park lands; USFWS 2002). Specific locations identified in the North Bay include Point Reyes National Seashore, Suisun Valley, Green Valley, northwest of Fairfield, and the triangle or tri-city/county open space roughly defined by Interstate Highways 80, 680 and 780 between Vallejo, Cordelia, and Benicia. From the tri-city/county open space area and the hills north of I-80 (identified as the Jameson Canyon-Lower Napa River core recovery area) and in the Stebbins Cold Canyon Preserve in the northwest corner of the county (LSA 2009). As a consequence of the range contraction and population decline, the species was listed as Federally Threatened under the Endangered Species Act in 1996 and Critical Habitat was designated in 2010. The California Department of Fish and Wildlife lists California red-legged frogs as a Species of Special Concern.

California red-legged frogs are a large native frog (females up to 138 mm, 5.4 in), considered one of the largest native frogs of the western US. They are distinguished from sympatric congeners by exhibiting pronounced dorsal-lateral folds. Coloration is highly variable and not a diagnostic characteristic of the species, but can range from nearly brick red dorsum with dark spots to a brownish background color; hind leg and lower abdomen coloration is variable as well. Frogs are sexually mature at 3-4 years and egg-laying occurs from late November to April. In cooler climates near the coast, larvae (tadpoles) are able to over-winter, with metamorphosis typically occurring from 3-7 months after hatching (Fellers et al. 2001). Little is known of the juvenile life stage. Adults are reported to live 8 to 10 years (USFWS 2002). The adult diet consists mostly of terrestrial and aquatic invertebrates (Tennant 1985), but they will also eat Pacific chorus frogs (*Pseudacris regilla*), California mice (*Peromyscus californicus*) and even smaller life stages of their own species (P. Kleeman, USGS, per obs.). Larvae likely eat algae.

CRLF occur in very diverse habitats which may differ among life stages and across the range. Adults are resident in dense, shrubby or emergent riparian vegetation near ponds or streams. Breeding habitat is associated with distinct water depth and hydroperiod habitat characteristics such that the water must be "shallow enough (and the hydroperiod must be long enough) to support submergent and/or emergent vegetation as oviposition substrate during egg-laying, and as a refuge from predation" (Collins and Collins 2007). They also can use deep ponds as long as there are shallow margins for vegetation to grow in (P. Kleeman, USGS, pers. comm.).

Physical characteristics that limit their distribution and habitat use include water temperatures higher than 29^0C and salinity levels greater than 7.0 ppt for adults (Jennings and Hayes 1990). CRLF are freshwater species and have only slight tolerances to salinity. Adults and subadults avoid brackish waters, however, they will use freshwater habitats that are adjacent to brackish waters and sometimes become inundated with salt water during exceptional high tides or storm surges, at which time, frogs will retreat to refugia in adjacent upland habitat (P. Kleeman, USGS, pers. comm.). At Point Reyes National Seashore, eggs surviving to hatching have not been observed in water with a salinity > 2.0 ppt (P. Kleeman, USGS, pers. comm). Critical habitat is defined by USFWS to include essential aquatic habitat, associated uplands, and dispersal habitat that connects essential aquatic habitat (USFWS 2002).

Across their range adult frogs vary in their habitat use; some may remain resident for an entire annual cycle, where as others may disperse to multiple habitats depending upon the reproductive status. Generally, though, they are limited to within 0.5 km of water. The species is slightly more tolerant of higher salinities than most frog species, and adult frogs have been observed in emergent vegetation in brackish ponds and streams adjacent to coastal beaches in Drakes Bay (Fellers and Guscio 2002).

Breeding occurs in many different aquatic habitats such as streams, deep pools, backwater areas, ponds, marshes, sag ponds, dune ponds and lagoons (USFWS 2002). Eggs masses are usually deposited on emergent vegetation, such as bulrushes (*Scirpus* spp.), cattails (*Typha* spp.), roots or twigs, but in ponds, they have been observed unattached (LSA 2009). At Point Reyes National Seashore, made-made stock ponds are used by breeding frogs, if there is sufficient emergent vegetation for cover and egg masses. Habitat required for breeding is limited to deep (> 0.7 m; 2.3 ft) still or slow moving freshwater (GOGA Draft management plan 2011), and Fellers (2007) noted that most breeding sites are deeper than 25 cm (0.8 ft). However, ponds that harbor predators such as non-native fish, crayfish or bullfrogs may limit the presence of CRLF. Frogs avoid terrestrial mammal and avian predators such as raccoons (*Procyon lotor*), river otters (*Lutra canadensis*), and wading birds when associated with dense cover, including dense emergent vegetation and also upland coastal scrub habitat (Collins and Collins 2007). Mortality is highest for the larvae to metamorphs with an estimated < 1-2% survivorship. This lifestage also has the largest variation in survivorship, and consequently are likely an important cause of natural variation in the population growth rate of the species (Biek et al. 2002).

Radio telemetry studies have found that CRLF can move up to 2.8 km (Bulger et al, 2003, Fellers and Kleeman, 2007). CRLF move towards breeding sites (ponds, marshes, slow moving parts of some streams) during the heavy winter rains. Some CRLF remain at breeding sites year round if habitat is suitable, while others will leave after breeding and spend much of the year in non-breeding habitat (riparian corridors, very small streams, marshes that may be too shallow to breed in).

CRITERIA FOR SELECTION OF THE SPECIES

CRLF have been well studied over the last century (Storer 1925, Stebbins 1985, Fellers 2005), and more recently, in the San Francisco Bay Area there are several studies (i.e., Bobzien et al. 2000, Fellers and Kleeman 2007, Tatarian 2008). Recent studies have focused on mitigation associated with wetland restoration work, and others on potential impacts of climate change on wetlands due to sea level rise (NPS 2007). Because they are a federally listed threatened species, land managers have developed strategies for preserving and enhancing habitat for frogs, and frogs often serve as an umbrella species for fresh water habitats. The San Francisco Bay Area Network of National Parks selected the CRLF as an indicator species of these habitats and Golden Gate National Recreation Area is monitoring the species' distribution in some areas around the SF Bay Estuary (Fong, National Park Service, pers. comm.).

The species are of high conservation concern and considered highly vulnerable to climate change due to (i) anticipated impacts on their habitat (fresh water habitats near the ocean that may become too saline) and (ii) direct effects of tidal flooding and sea level rise on reproduction, as elaborated below.

OTHER RELEVANT INFORMATION

CRLF populations function as a metapopulation, a collection of sub-populations that exchange genetic information through individual dispersal events (LSA 2009). Subpopulations in breeding ponds may blink in and out of existence, with extinction and colonization being a function of the distances between ponds or aquatic breeding habitat, and the probability of a pond being occupied may be positively correlated with the distance to the nearest occupied pond (Marsh et al. 1999). Consequently, dispersal habitat corridors and distances are important for the species' survival. Frogs are year round residents, and though, they may disperse to forage in other habitats during the non-breeding season, dispersal has not been found to be greater than 2.8 km (Bulger et al, 2003, Fellers and Kleeman, 2007). Most frogs disperse less than 1.2 km (1 mi), and the median distance along the Redwood Creek corridor in Muir Woods NM was 150 m (Fellers and Kleeman, 2007). Dispersal is often from breeding sites to riparian corridors, and frogs may travel direct routes, even crossing open pasture land and roads.

In the San Francisco Bay Area, some populations are fragmented and isolated. The causes for population declines are many, and may include historical over-harvest for food, predation by non-native species, habitat alteration, pathogens and pollutants. Populations continue to decline in many regions; though in some areas, populations are stable.

While bullfrogs have frequently been called a threat, or even a primary cause of the declines, there is almost no direct evidence that this is the case (Fellers and Guscio 2002), and it is at least as likely that non-native fish (e.g., striped bass, green sunfish, catfish, mosquitofish) play a significant role in the decline of native ranid frogs (Hayes and Jennings 1986).

Restoration that targets creating freshwater ponds with dense emergent vegetation upslope from brackish water has been successful in attracting breeding frogs; however, creating new ponds next to brackish habitat may become brackish themselves due to SLR and this would not benefit frogs in the long-term (P. Kleeman, USGS, pers. com). Restoration sites in the San Francisco Bay Area include Giacomini wetland in Tomales Bay, Big Lagoon in Muir Beach, and Mori Point ponds in San Mateo County (NPS 2007).

REVIEW OF CLIMATE CHANGE EFFECTS ON THE SPECIES

Amphibians generally, and frogs specifically, are sensitive to changes in temperature, moisture and salinity. Any change in these physical states may alter habitat, and in turn, further affect frogs. Changes in weather patterns (including predicted increased intensity and frequency of El Niño events) may change breeding habitat and behavior. And too, the phenology of breeding may change with climate changes. The timing of amphibian breeding is correlated to temperature and moisture cues, and studies in other areas have shown a trend towards earlier breeding with changes in climate (LSA 2009).

Winter rain seasons that begin normally and then stop prematurely, put egg masses at risk because CRLF often put their egg masses in shallower parts of ponds (presumably to take advantage of warmer water temperatures that allow the egg mass to develop more quickly), and if the rains do not continue, many egg masses can become stranded above the receding water line and perish. In tributaries that flow into the bay, egg masses could be at risk to increased flash stream flows that could dislodge and destroy egg masses during brief, high intensity storms. Larvae in smaller, more shallow ponds will be at increased risk due to rising temperatures and perhaps less precipitation overall that could cause ponds to dry out before the larvae can metamorphose and leave the pond.

As noted for other species, the availability of freshwater marsh habitat adjacent to tidal marsh habitat, and specific characteristics of tidal marsh habitat, including salinity, is expected to change in the short term (2030), mid-term (2050) and long-term (2100). Although tolerant of salinity, tadpoles are sensitive to salinity levels exceeding 4.5 ppt and egg masses exceeding 2.0 ppt (see above).

Salinity levels may be altered with either SLR or changes in the amount and timing of freshwater runoff. Ambient temperatures are predicted to increase with climate change which would lead to desiccation, alteration and fragmentation of wetland breeding and foraging habitat. Loss of freshwater marsh, ponds and riparian corridor habitat will fragment and depress populations.

Climate change models predict warmer, drier conditions, but also predict more intense and more frequent El Niño events: such conditions are likely to decrease survival of egg masses and tadpoles and increase uncertainty in breeding from year to year. Warmer, drier conditions may shorten the breeding season, and eliminate breeding sites due to desiccation and vegetation loss. Exposure to predators would be more likely if frogs have to disperse across less hospitable habitat and preferred aquatic habitat decreases in size and is fragmented. More intense El Niño events may produce more moisture intermittently to the benefit of frogs, but also may result in elevated sea levels and large storm surges, which would inundate tidal areas into brackish and freshwater marshes, resulting in breeding habitat change and fragmentation. Habitat fragmentation may also result from alteration of dispersal habitat between foraging and essential aquatic habitat.

Whether current freshwater marshes adjacent to tidal marshes will be able to survive increasing regional SLR, depends on whether accretion (organic and non-organic) can keep up with or outpace increasing sea levels. As water levels increase, can tidal marshes migrate to areas that are currently supratidal? That will depend on the availability of such areas, as well as on the ability for tidal marsh plant species to migrate as well (i.e., establish themselves in new sites). [Sentences above apply to all tidal marsh habitat, so may be moved to a more appropriate section.] Additionally, the ability of plants to tolerate higher ambient temperatures and desiccation will influence the ability of frogs to seek cooler areas under cover.

Elevated water levels due to extreme tides or storms events may damage egg masses in adjacent freshwater habitat and limit freshwater habitat. Timing of extreme water levels is also important: the complete egg cycle requires about 21 days and metamorphis occurs in a minimum of 3.5 months. One inundation event of a freshwater marsh habitat because of major storms and extreme tides could raise the salinity enough to destroy an entire year of CRLF breeding effort by killing the eggs or larvae.

OTHER STRESSORS

Several factors may have a synergistic effect on and may confound 'normal' stressors to frogs, including development (urbanization, intensive agriculture, and excessive livestock grazing), UV-B exposure, predation, pathogens and pollutants. Any one stressor alone may not have a negative effect but synergistically may become significant when combined with other stressors. For example, pathogens may have minimal effects on a healthy population, but in the presence sub-lethal concentrations of pesticides, they may cause declines in populations in (LSA 2009).

Other synergistic effects include elevated pollutant concentrations or pathogen exposure in aquatic habitat where water evaporates with elevated temperatures. Tadpoles exposed to high concentrations of nitrite and nitrate fed less, swam less vigorously, and developed malformations of the body (LSA 2009). Other researchers noted strong correlations between frog declines and being down-wind of agricultural areas where large amounts of agrochemicals were applied (Davidson 2004).

LIFE CYCLE CONSIDERATIONS AND POPULATION DYNAMICS

Tadpoles and egg masses are vulnerable life stage for the species because they are more sensitive to changes in habitat, water quantity and salinity. However, an ecological sensitivity analysis on red-legged frogs noted that post-metamorphic vital rates and highly variable vital rates both have a strong influence on population dynamics (Biek et al. 2002).

FACTORS THAT MAY AFFECT SPECIES RESILIENCE

Population resilience will be enhanced if reproductive success, especially breeding habitat and survival of larvae are increased (see below for specific suggestions). Since the variability in the survival rates of larvae is so high, reducing mortality due to predation, desiccation especially during extreme temperatures and tides/water levels, and salinity will enhance population growth rates and thereby resilience.

Maintaining connectivity of habitat will help maintain resilience for dispersal and retreat. Particularly effective may be the establishment of restored freshwater marshes upslope of extant tidal marsh, especially marshes that are likely to be "sources" rather than "sinks" and not likely to be affected by SLR.

LIKELY CLIMATE CHANGE IMPACTS AND RISKS

Freshwater marshes adjacent to tidal marshes will change between now and 2100, but the magnitude of change is uncertain. The total amount of freshwater and tidal marsh habitat likely will shrink and current tidal marshes will migrate inland into areas that are currently upland (above Extreme High Water levels). A management approach would be to maximize production of young and their successful recruitment into the breeding population as adults. Thus, maintaining essential habitats and connectivity for CRLF is essential.

Current levels of breeding success need to be increased despite future pressures from climate change (mediated through flooding of habitat) and predators (specifically, non-native aquatic species). The range of the species has contracted significantly over the past 50 years leading to the species federal listing. Any further decline in the habitat will jeopardize the survival of the species.

MANAGEMENT ACTIONS TO BE CONSIDERED

Management should focus on two key demographic rates: survival rates of tadpoles and over-winter survival. A priority for management is to increase reproductive success by reducing loss of freshwater habitat and reducing predation rates. Increased survival rates could be accomplished by reducing predator access or exposure to predators. This will be a challenge because numerous species are documented to prey upon frogs, including a variety of mammals, birds, and snakes. Reducing predation may serve to offset egg mass failure due to flooding of salt water. Removal of non-native aquatic predators such as bull frogs and mosquitofish might increase survivorship of egg masses and juveniles.

Habitat restoration may increase survival rates and reduce predation rates. Restoration could include providing or enhancing inland and upslope habitat where frogs may currently reside adjacent to brackish water habitat. Such inland refugia may reduce the effects of flooding and provide refugia for adult and juvenile CRLF from extreme water levels during winter storms. Adults are tolerant of higher levels of salinity but may require more transition habitat to freshwater marsh. Planting native vegetation around marshes including coyote bush and berries also will increase the potential cover for CRLF to avoid terrestrial and avian predators such as raccoons and wading birds.

However, it is important to note that freshwater habitat adjacent to salt water marshes are marginal for frogs since they act as population sinks in the years that saltwater intrudes and destroys egg masses. Creating CRLF habitat in places where expected sea level rise could intrude into the created habitat is not a long term solution. Instead, creating ponds in inland habitat with corridors from brackish water areas in the same drainage would be a better long-term solution.

UNCERTAINTY AND ITS SOURCES

The future of tidal and adjacent freshwater marsh habitat is uncertain with regard to its location, extent, and specific characteristics. This uncertainty is due to uncertainty regarding climate change projections and decisions regarding land-use (maintenance of levees, conversion of current diked baylands to tidal marsh, maintenance of managed ponds, etc.) The magnitude, frequency, and timing of extreme water levels is difficult to predict but will have severe consequences for frogs. The demographic response of CRLF to climate change is not well known, especially with regard to survival rates since so little is known about the survival rates of various life stages.

IMPORTANT DATA GAPS/NEEDS

Potential impacts of climate change on survival of egg masses, tadpoles and adults are not known. Small changes in survival rates can have substantial consequences for population growth (or decline) and population resilience. An important gap to address is information on environmental influences on survival of egg masses, tadpoles and juveniles. Since one ecological sensitivity analysis on red-legged frogs showed that post-metamorphic vital rates and highly variable vital rates strongly influence population dynamics, more research in this area would likely yield important information for management (Biek et al. 2002). The ability of CRLF to colonize newly restored habitat, or re-occupy habitat, is well documented; however, barriers to dispersal need to be identified and better understood. An inventory of the distribution of frogs in ponds adjacent to tidal marshes in the San Francisco Bay Area could guide management to identify potential restoration sites. Upland habitat in the same drainages where frogs currently exist in ponds (adjacent to tidal marshes likely to be inundated with SLR) could provide refugia and breeding habitat for frogs in the long-term future.

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