California Red-Legged Frog (*Rana draytonii*)

Climate Change Vulnerability Assessment for the Golden Gate Biosphere Region

This document represents an evaluation of climate change vulnerability for California red-legged frog in the Golden Gate Biosphere (GGB) region of California. The following information is based on stakeholder input provided during and following a winter 2022 vulnerability workshop as well as sources from the scientific literature.

Species Description

The California red-legged frog (CRLF; *Rana draytonii*) is the largest native frog in western North America and is a federally threatened species endemic to California and Baja California, Mexico (USFWS 1996). They are distributed along the coast range from Mendocino County, California south to northern Baja, Mexico, with disjunct populations in the Sierra Nevada foothills (Figure 1; USFWS 2002).

CRLFs are highly aquatic, though adult frogs also utilize terrestrial habitats for estivation during the dry season and for movement between aquatic areas (Bulger et al. 2003). CRLFs typically breed during the wet season (December through March) in artificial or natural permanent and ephemeral ponds, lagoons, or in slow-moving waters in streams; however, they require some open water edge habitat with emergent and shoreline vegetation for egg deposition (Jennings & Hayes 1994; USFWS 1996; Bobzien & DiDonato 2007; Fellers & Kleeman 2007; Tatarian 2008; Alvarez et al. 2013; Thomson et al. 2016; Halstead & Kleeman 2017a). The species utilizes a variety of other habitats outside of the breeding season, including slow-moving streams, springs, creeks, tributaries, cattle ponds, retention basins, damp grass areas, and riparian corridors (USFWS 2002; Bobzien & DiDonato 2007; Thomson et al. 2016; Halstead & Kleeman 2017a). While many CLRF observations have been in ponds, they can occur in coastal lagoons and freshwater sloughs and are often observed in coastal dune drainages such as those at Point Reyes National Seashore (Halstead & Kleeman 2017a, 2017b). Adult CRLFs consume terrestrial vertebrates (e.g., mice), aquatic invertebrates, frogs, and fish (Bishop et al. 2014). CRLF tadpoles primarily consume aquatic plants such as algae and detritus, while the primary food source for juveniles is aquatic and terrestrial invertebrates (USFWS 1996; Fellers 2005; Fellers et al. 2017).

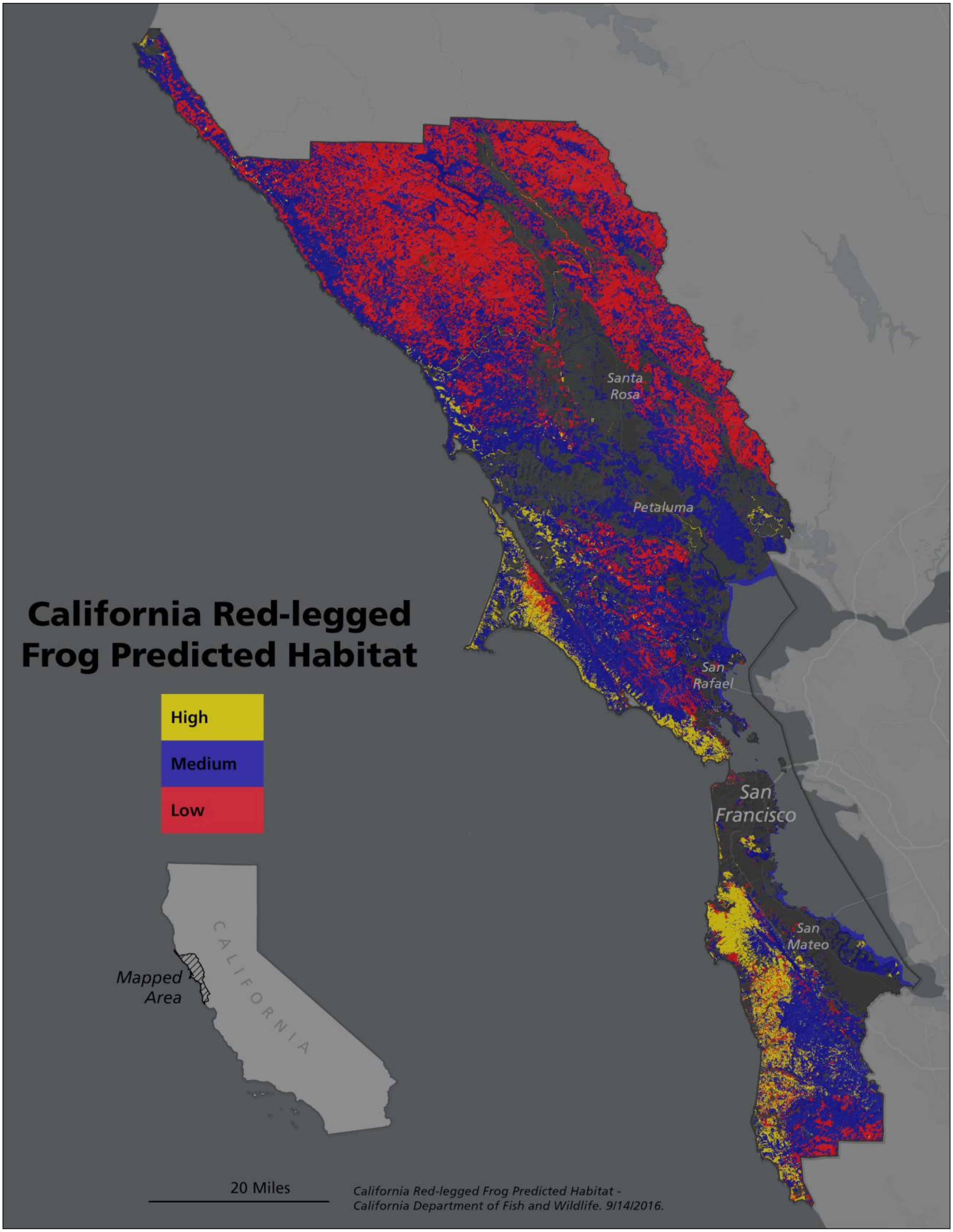

Figure 1. California red-legged frog predicted habitat within the GGB region (map provided by the National Park Service).

Species Vulnerability → Moderate *(moderate confidence)*

Vulnerability is evaluated by considering the species' sensitivity and exposure to various climate and non-climate stressors as well as the species' adaptive capacity (i.e., ability to cope with these stressors), and is given a ranking of low, moderate, or high. The confidence ranking represents confidence in the accuracy of the ranking based on available scientific knowledge, and is similarly ranked on a scale from low to high.

Summary of species vulnerability

The CRLF is highly susceptible to climate stressors and disturbances that influence water availability, including changes in precipitation patterns, increased drought, and altered stream flows. Moreover, elevated water temperatures, disease (e.g., *Batrachochytrium dendrobatidis*), storms, flooding, and the presence of invasive species (e.g., invasive American bullfrog, *Lithobates catesbeianus*) can significantly contribute to physiological stress and mortality among CRLF populations. As the climate becomes warmer and drier, the extent of critical aquatic habitats such as freshwater wetlands may be reduced, impacting habitat availability for the breeding and the early life stages of CRLF. Disturbances that displace CRLF may alter the prevalence of diseases and threaten the survival of egg masses, and reduced reproductive success as a result of these factors is likely to impact the species significantly. Eggs and larvae are particularly vulnerable to physical disruption, pollution, and chemicals.

The adaptive capacity of CRLF to climate change impacts is constrained by the extensive loss of their historical range, fragmented populations, limited connectivity, and various barriers to dispersal. Conservation efforts prioritizing habitat protection and restoration (including breeding and non-breeding habitat and migration corridors), habitat creation (e.g., construction of artificial stock ponds), connectivity enhancement, and invasive species control will be crucial for supporting the species' resilience to climate change. However, continued habitat loss as a result of human expansion remains a significant threat to the CRLF, and efforts to balance development with conservation and adaptation measures are necessary to ensure the species' long-term survival.

Sensitivity and Exposure → High *(moderate confidence)*

Sensitivity *is a measure of whether and how a species is likely to be affected by a given change in climate factors, climate-driven changes in disturbance regimes, and non-climate stressors. By contrast,* ***exposure*** *is a measure of how much change in these factors a species is likely to experience. Sensitivity and exposure are combined here into one score representing both components of vulnerability, with high scores corresponding to increased vulnerability and low scores suggesting a species is less vulnerable.*

Sensitivity and future exposure to climate factors → High *(moderate confidence)*

- **Increased temperatures** may impact the CRLF by causing the degradation and loss of suitable habitat. For instance, higher air temperatures increase evaporation and transpiration rates, shortening aquatic habitat hydroperiods and potentially initiating and quickening the drying out of breeding sites (Blaustein et al. 2010; Vuln. Assessment Worksheets, pers. comm., 2022). This may severely impact CRLF larvae survival, particularly if it has drought-related impacts on vertebrate and invertebrate prey availability (Sappington et al. 2009; Blaustein et al. 2010). If thermal tolerances are exceeded for larval CRLF, it may reduce metamorphosis completion for individuals, affecting the overall survival of that population (Semlitsch 2000). Increased temperatures can also lead to a reduction in the larval period and increased growth rates as well as metamorphosis at smaller sizes, suggesting that there may be a trade-off between the growth and developmental period for the CRLF under certain environmental pressures (Blaustein et al. 2010; Vuln. Assessment Worksheets, pers. comm., 2022).
- **Changes in the amount and timing of precipitation**, including shorter winters and drier summers, may limit breeding habitat availability, impacting CRLF reproductive ability, output, and breeding success. In particular, the persistence and availability of breeding ponds with sufficient depth to support the complete breeding cycle of CRLF will be crucial for the species' long-term survival during climate change (Vuln. Assessment Worksheets, pers. comm., 2022). In coastal California, CRLFs tend to be winter/early spring breeders, typically laying their eggs during or after rainfall events during these months (USFWS 1996; Cook & Jennings 2007). Decreased or more variable precipitation during the wet season in winter and early spring may hinder the use of some seasonal sites by shortening pond and wetland hydroperiods, threatening the ability of these sites to retain enough water (at least 0.6m in depth) to be successful breeding habitats (Fellers & Kleeman 2007). Analysis of long-term hydrologic data in the Golden Gate National Recreation Area indicates that February precipitation in Redwood Creek has significantly decreased in the last 20 years (Kondolf et al. 2022). Decreased soil moisture due to drought periods and decreased precipitation events could also limit upland refugia and access to potential new breeding sites (Vuln. Assessment Worksheets, pers. comm., 2022). Additionally, frogs must have sufficient moisture to allow their persistence during the months when they are not breeding, which can be the majority of the year (up to 11 months; Fellers & Kleeman 2007). Alternately, increased precipitation events could inundate drying ponds or shallow potential breeding sites, enabling reproduction for CRLF in areas that may have previously had less favorable sites (Bobzien & DiDonato 2007).
- **Changes in water temperature** can alter CRLF development, survival, and reproduction (Bobzien & DiDonato 2007). Increased water temperatures in the spring could accelerate CRLF larval growth and development and lead to earlier emergence from breeding ponds (Jennings & Hayes 1994; USFWS 1996). However, any advantage gained from this may be overshadowed by the risk of breeding sites drying up or exceeding the thermal tolerances of larvae due to

projected hotter and drier spring and summer seasons before the larvae can complete metamorphosis and find suitable habitats (Blaustein et al. 2010; Vuln. Assessment Worksheets, pers. comm., 2022). As water temperatures rise, dissolved oxygen concentrations decrease in aquatic habitats. These lowered oxygen levels have been found to delay development and reduce the growth rates of amphibian larvae (Blaustein et al. 2010; Nolan et al. 2023). In *Rana* species, lowered dissolved oxygen levels have been linked to accelerated hatching, but the tadpole size tends to be much smaller (Blaustein et al. 2010). Changing temperatures could also allow the expansion of pathogens, such as the amphibian chytrid fungus *Batrachochytrium dendrobatisis* (Bd), by creating more favorable conditions for their reproduction and dispersal, which may lead to a higher prevalence of pathogens and a greater risk of disease transmission among CRLF populations (Turner et al. 2021).

- **Altered stream flows** can impact the survival of egg masses and larvae and the CRLF's distribution and reproductive success. Slow-moving portions of streams are generally the preferred breeding habitats for stream-breeding CRLF (Bobzien & DiDonato 2007; Ford et al. 2013), and changes in flow volume or variability can affect the availability of shallow, slow-moving water necessary for successful egg deposition and tadpole development (Kupferberg et al. 2012; Furey et al. 2014; Hayes et al. 2016). Projected flow increases during the wet season (Grantham et al. 2018) when CRLFs typically breed can negatively impact egg masses by dislodging and damaging them, potentially leading to egg mass and larvae desiccation (Bobzien & DiDonato 2007; Kupferberg et al. 2012). By contrast, intermittent or reduced flows could hinder movement, restrict habitat access, fragment populations, and potentially eliminate aquatic habitats for frogs (Thomson et al. 2016). Alterations in streamflow can also affect the quantity and types of aquatic invertebrates available as a food source for CRLF (Furey et al. 2014; Grantham et al. 2018), which can impact the population’s development, growth, and overall viability (Furey et al. 2014; Grantham et al. 2018). Streambank erosion as a result of fast flows can influence the presence/absence of shoreline vegetation, which is critical as a potential food source for CRLF tadpoles, and also cools stream temperatures and serves as a refuge from predators (Tatarian 2008). Altered stream flow patterns, such as reduced flows during drought or increased flows during extreme rainfall events, can impact water oxygen levels, nutrient transport, and waste removal in CRLF habitats, leading to higher mortality rates and impaired growth of CRLFs (Vuln. Assessment Worksheets, pers. comm., 2022).
- **Sea level rise** threatens coastal wetland areas utilized by CRLFs, primarily by inundating these crucial habitats. Adult frogs tend to avoid locations with high salinity and target freshwater areas (e.g., pools and ponds) for breeding and egg deposition (Jennings & Hayes 1989). Increased salinity levels as a result of sea level rise may diminish the suitability of coastal habitats for breeding and negatively affect egg mass, larval, and tadpole survival (USFWS 1996; Bobzien & DiDonato 2007; Chuang et al. 2022). For instance, studies have shown that in the pre-hatching stage, high salinity levels can lead to embryonic mortality or morphological

abnormalities for CRLFs (Jennings & Hayes 1989; USFWS 1996, 1996; Bobzien & DiDonato 2007). In the Laguna Salada at Sharp Park, south of San Francisco, extirpation of the CRLF has been noted, primarily attributed to the adverse effects of saltwater intrusion and storm surge overwash on critical habitats (Vuln. Assessment Worksheets, pers. comm., 2022).

Sensitivity and future exposure to climate-driven changes in disturbances → High *(moderate confidence)*

- **Increases in storm intensity/duration** and associated flooding can impact CRLF recruitment and breeding site availability. Seasonal flooding may wash away or strand egg masses or tadpoles, and flooding occurring at unusual times in late spring or early summer can lead to mortality of egg masses laid in streams (Kupferberg 1996; Kupferberg et al. 2012; Vuln. Assessment Worksheets, pers. comm., 2022). Heavy winter rains may initiate breeding, but if storms cease for an extended period, larvae may be exposed to drying ponds, leading to mortality before precipitation returns (USFWS 1996; Fellers & Kleeman 2007; Cook & Jennings 2007). However, flooding that increases available wetland habitat could benefit the CRLF (USFWS 2002). Additionally, winter flooding may increase mortality events for bullfrogs to a greater degree than for CRLFs (Doubledee et al. 2003).
- The aquatic **chytrid fungus pathogen**, *Batrachochytrium dendrobatidis* (*Bd*), is a parasitic fungus that causes chytridiomycosis and is recognized to be a driver of amphibian population declines globally (Stuart et al. 2004; Garner et al. 2009). In a study looking at the impact of *Bd* on amphibian populations in the western US, Russell et al. (2019) found a 6-15% reduction in the survival of ranid frogs, including the CRLF. In California's greater Bay Area, the fungus has been observed in locations such as Point Reyes National Seashore (Marin County), Pepperwood Creek (Sonoma County), Capell Creek (Napa County), Lake Lagunitas (Marin County), and the San Francisco Bay Islands (e.g., Alcatraz Island; Fellers et al. 2011; Huss et al. 2013; Yap et al. 2016).

  Temperature can have a significant influence on the effects of *Bd* on frog species. For instance, frogs tend to be less affected by *Bd* when temperatures are high in terrestrial habitats, potentially mitigating the effects of *Bd* on frogs during summer months (Piovia-Scott et al. 2011; Adams et al. 2017). Infection rates are higher at colder temperatures when *Bd* has a greater capacity to penetrate the skin of the CRLF (Bradley et al. 2019). Mortality from *Bd* infection is predominately seen in the post-metamorphic stages, while infected larvae tend to experience less lethal effects (Bradley et al. 2019). Furthermore, research indicates that *Bd* can significantly increase mortality rates in frog populations already facing stressors like higher temperatures, changes in hydrology, and the presence of American bullfrogs. In addition to predation pressure, the American bullfrog, known for their tolerance to certain diseases (including *Bd)*, could play a role in spreading the chytrid fungus to other frog species (Huss et al. 2013; Kupferberg et al. 2022).

Dependency on habitat and/or other species → Moderate *(moderate confidence)*

In coastal California, the breeding success of CRLF depends on the availability of suitable sites, including permanent and seasonal bodies of water such as freshwater seeps, springs, ponds, lagoons, wetlands, slow-moving shaded ponds, pools, streams with a tall vegetative cover (e.g., cattails and grasses), and wet meadows (USFWS 2002; Vuln. Assessment Worksheets, pers. comm., 2022). These sites need to retain water sufficiently to allow the egg masses and larvae of CRLF to complete their metamorphosis, which takes several months (USFWS 2002; Fellers & Kleeman 2007). Breeding failure occurs in areas that do not hold water long enough, and CRLF will not breed in shallow ponds. However, deeper permanent ponds do not necessarily guarantee successful breeding for CRLF because the predacious American bullfrogs can also thrive in such sites (Anderson 2019).

Sensitivity and current exposure to non-climate stressors → High *(high confidence)*

Non-climate stressors can exacerbate ecosystem sensitivity to changes in climate factors and disturbance regimes, and/or can be exacerbated by these changes.

- **The American bullfrog** was introduced to California in the late 1800s and has since been associated with the decline of several native ranid species, including the CRLF (D'Amore et al. 2009). The bullfrog is a highly adaptable species, and due to the impacts its predatorial and territorial behaviors have on the CRLF, it poses a significant threat to its survival. Bullfrogs compete with CRLFs for shared resources, such as algal food sources relied upon by both bullfrog and CRLF larvae (Doubledee et al. 2003; Anderson & Lawler 2016). However, the severity of this competition may depend on how food resources are distributed throughout the habitat. In areas where resources are clumped together, there can be a higher level of competition between bullfrogs and other frog species compared to places where resources are more evenly distributed (Kiesecker et al. 2001). Adult bullfrogs also directly prey on multiple life stages of the CRLF (USFWS 2002; Thomson et al. 2016). The presence of the bullfrog can contribute to a reduction in CRLF recruitment as well as restrict CRLF dispersal, endangering population persistence by impeding their movement to new suitable habitats for breeding, foraging, and shelter (Lawler et al. 1999; Anderson & Lawler 2016). It may also undermine their ability to cope with the effects of climate change, potentially contributing to the further decline of the CRLF (Lawler et al. 1999). The American bullfrog can also be a carrier host for the chytrid fungus *Bd* and can spread it to other amphibians, such as the CRLF, negatively impacting native populations (Huss et al. 2013; Piovia-Scott et al. 2015, 2015; Adams et al. 2017; Kupferberg et al. 2022).
- **Residential, commercial, and agricultural development** can render CRLF habitats unusable for breeding and non-breeding purposes. Alterations in land use can contribute to habitat fragmentation and the isolation of breeding ponds, impacting individuals' dispersal and metapopulation dynamics (Semlitsch 2000; Thomson et al. 2016; Anderson 2019). These activities can also result in habitats lacking sufficient vegetation cover, increasing the

vulnerability of frogs to predation during dispersal attempts (Vuln. Assessment Worksheets, pers. comm., 2022). The use of pesticides and herbicides in agriculture directly harms CRLF populations and affects the abundance of the species (Davidson et al. 2001; Davidson 2004; Blaustein et al. 2010; Anderson 2019). Pesticide use can also indirectly affect the CRLF by reducing their prey base (Sappington et al. 2009). Land-use changes could benefit introduced species, such as the invasive American bullfrog, known to travel easily through human-altered landscapes (Thomson et al. 2016; Anderson 2019). However, agricultural habitats harboring ponds or the creation of new artificial ponds in these areas can provide suitable breeding grounds for CRLF (Bobzien & DiDonato 2007; USFWS 2010).

- **Dams and water diversions** generally negatively impact CRLF habitat availability and quality due to alterations in stream hydrology, which are linked to the survival and distribution of CRLF egg masses and larvae (USFWS 1996). Irregular flows and stream reaches with consistently high discharge from nearby reservoirs may result in stream habitat with poor reproductive conditions (Bobzien & DiDonato 2007). Reservoirs also often contain non-native fish species (e.g., bass) and bullfrogs that prey on CRLF and their larvae (Alvarez et al. 2003; Vuln. Assessment Worksheets, pers. comm., 2022).
- **Roads, highways, and trails** can act as barriers to dispersal and lead to habitat fragmentation for the CRLF (Semlitsch 2000; Glista et al. 2009). These features disrupt movement between sites and are considered a significant threat to species survival as urbanization spreads (USFWS 2002; Brehme et al. 2018). The presence of CRLF is negatively correlated with the number of roads and impervious surfaces within a given area (Anderson 2019). Areas characterized by high foot and vehicle traffic are also significant factors associated with the absence of CRLFs in ponds (Anderson 2019). Additionally, roads and highways can increase the risk of direct mortality events for the CRLF via vehicle strikes (USFWS 2002; Glista et al. 2009; Anderson 2019).

Adaptive Capacity → Moderate *(moderate confidence)*

Adaptive capacity *is the ability of a species to respond to or cope with climate change impacts with minimal disruption. High adaptive capacity corresponds to lower overall climate change vulnerability, while low adaptive capacity means that the species will be less likely to cope with the adverse effects of climate change, thus increasing the vulnerability of the species.*

Species extent, status, connectivity, and dispersal ability → Moderate (high confidence)

Despite their widespread distribution, CRLFs have experienced significant range contraction, with 70% of their historical range extirpated, leaving sparse and fragmented populations (USFWS 1996; Thomson et al. 2016). However, some studies have observed populations on the central California coast to be in stable condition with instances of population growth (e.g., Cemetery Pond, an artificial stock pond in the Olema Valley in Point Reyes National Seashore; Fellers 2005; Fellers et al. 2017). Fragmentation of CRLF populations, which occurs when habitats are isolated by land-use conversion, may restrict dispersal and their ability to exchange genetic material (Spear & Storfer 2008). Within the GGB region, coastal CRLF populations appear more abundant and show signs of persistence; however, even in coastal areas, connectivity could decrease where land use activities pose additional barriers to dispersal and threats to survival (Semlitsch 2000; Fellers et al. 2017). The loss of wetland habitat, primarily caused by land conversion, diversion, or impoundment, further exacerbates the fragmentation of CRLF populations and causes additional stress to the species on top of the impacts of climate change. For instance, limited habitat availability for CRLFs means that, under changing climate conditions, areas that can serve as climate refugia may be minimal (Vuln. Assessment Worksheets, pers. comm., 2022).

CRLFs typically undertake short migrations between breeding and upland non-breeding sites, but they can travel longer distances across both aquatic and terrestrial habitats, reaching up to 2.8 km (1.7 mi; USFWS 2002; Fellers & Kleeman 2007; Brehme et al. 2018). This ability may enhance their capacity to colonize new suitable habitats and adapt to environmental stressors. Safeguarding habitat components, such as vegetated migration corridors, could facilitate movement and allow for the successful dispersal of CRLF (Fellers & Kleeman 2007; Anderson 2019).

Intraspecific/life history diversity → Moderate (moderate confidence)

Behavioral diversity in CRLF, particularly in relation to their response to environmental cues and breeding patterns, could contribute to their ability to adapt to changes in precipitation regimes (Vuln. Assessment Worksheets, pers. comm., 2022). The species demonstrates a range of timing for breeding and egg-laying, which can be triggered by rainfall or other events that influence streamflow, water depth, and water temperature (Kupferberg 1996; Wheeler et al. 2015, 2018). This flexibility suggests they may have the capacity to adjust their breeding behavior in response to changing precipitation patterns. The CRLF also possesses the behavioral adaptation of reducing swimming activity during the early stages of development in response to the presence of the American bullfrog (Anderson & Lawler 2016).

Although there is little known regarding the genetic diversity of the CRLF, some studies shed light on the genetic structure and diversity of CRLF populations in California. Researchers found that populations in the northern Sierra Nevada (northeast of the GGB region) had lower genetic diversity than those in the San Francisco Bay Area (Richmond et al. 2014), and that both populations have lower genetic diversity compared to those in southern California (Richmond et al. 2014). Low genetic diversity has been linked to decreased resilience to environmental changes (Frankham 2005; Markert et al. 2010). This may pose a challenge to CRLF populations in the San Francisco Bay Area as they experience increased climate change.

Resistance and recovery → Moderate (high confidence)

Despite significant land use change and habitat loss in its native range, CRLF has persisted over time, albeit experiencing considerable population declines (USFWS 1996, 2002). The species is generally recognized to have a low resistance to environmental stressors and disturbances, particularly significant changes in hydroperiod or thermal regimes that may lead to the loss of critical habitats such as wetlands (Wheeler et al. 2015). This could hinder the species' recovery from climate impacts, as once critical wetland habitat is lost, the remaining isolated populations of CRLF have limited ability to maintain stasis and recovery (Vuln. Assessment Worksheets, pers. comm., 2022). Conversely, the CRLFs' ability to survive in various habitats (e.g., natural ponds and pools, artificial stock ponds, retention basins, coastal dune drainages, and slow-moving streams) could enhance their adaptive capacity by providing them with multiple options for refugia from climate impacts (USFWS 2002; Bobzien & DiDonato 2007; Thomson et al. 2016; Halstead & Kleeman 2017a). Additionally, amphibians, as a group, can adapt and utilize new habitats for breeding when they become accessible (such as areas that become flooded due to above-average rainfall (Semlitsch 2000). This could increase the chances of CRLF's continued reproduction and survival in the face of a changing climate (Semlitsch 2000). However, habitats must contain certain characteristics to be suitable for CRLFs (e.g., access to permanent or semi-permanent water bodies for breeding, adequate aquatic vegetation for egg-laying sites and shelter, and availability of food sources; Jennings & Hayes 1994; USFWS 1996; Bobzien & DiDonato 2007; Fellers & Kleeman 2007; Tatarian 2008; Thomson et al. 2016; Halstead & Kleeman 2017a).

Management potential → Moderate (high confidence)

The CRLF has relatively strong public support in north-central California, where it is a focal species for conservation groups such as the National Wildlife Federation and Save the Frogs (Vuln. Assessment Worksheets, pers. comm., 2022). It also gained recognition through Mark Twain's "The Celebrated Jumping Frog of Calaveras County" (Vuln. Assessment Worksheets, pers. comm., 2022). Societal support for the CRLF is bolstered by regulatory recognition, as the species is listed as threatened by the US Fish and Wildlife Service (USFWS) and designated as a "Species of Special Concern" by the California Department of Fish and Wildlife (Jennings & Hayes 1994; USFWS 1996). The USFWS has allocated significant funding towards the listing and recovery of the species, contributing to habitat restoration endeavors (Vuln. Assessment Worksheets, pers. comm., 2022). There are also legal obligations, regulatory measures (e.g., Clean Water Act Sections 401 and 404; California Department of Fish and Wildlife Lake and Streambed Alteration Agreement Section 1600), and financial resources that encourage management efforts and guide conservation and adaptation action to protect wetland habitats against the impacts of climate change. For example, within the Golden Gate National Recreation Area, the National Park Service facilitates recovery efforts by ensuring that projects located within areas inhabited by the CRLF must undergo a meticulous assessment to evaluate their potential impacts before receiving a permit Vuln. Assessment Reviewer, pers. comm. 2023). CRLF is also a focal indicator species for non-governmental organizations such as One Tam, a collaborative consortium comprising various interest groups concerned with areas encompassing Mount Tamalpais (Vuln. Assessment Reviewer, pers. comm. 2023). Leveraging these obligations and resources can help managers improve their ability to implement adaptation strategies (Vuln. Assessment Worksheets, pers. comm., 2022).

The impacts of climate change can likely be managed for the CRLF, at least to some extent (Vuln. Assessment Worksheets, pers. comm., 2022). While the loss of critical wetland habitat poses a significant challenge for their long-term persistence, restoring prioritized wetlands and removing invasive bullfrogs are feasible management strategies that could contribute to the recovery of CRLF populations and help ensure suitable conditions (e.g., hydroperiod, vegetation, structure) in breeding and non-breeding habitats (USFWS 2002; Doubledee et al. 2003; Anderson & Lawler 2016). Additionally, agricultural stock ponds could offer viable habitats and enhance connectivity among currently fragmented CRLF sub-populations (USFWS 2010). However, ongoing habitat conversion and human activity has the potential to impede management and adaptation strategy implementation efforts in the future (Vuln. Assessment Worksheets, pers. comm., 2022). Additionally, it is important to note that while wetland restoration projects and other management strategies (e.g., culling invasive bullfrogs) may be effective, they can also be complex and require significant time and resources for successful implementation (Vuln. Assessment Worksheets, pers. comm., 2022). The processes must involve careful planning, public support, continuous monitoring, coordination between stakeholders (e.g., scientists and managers), and a sustained effort to be successful (Semlitsch 2000). Some monitoring efforts are already in place within the region, such as the San Francisco Area Inventory and Monitoring Network's efforts at Pinnacles National Park to oversee the state of CRLF populations and better understand how factors such as water quality and changing drought patterns influence the species (San Francisco Bay Area Inventory & Monitoring Network & National Park Service 2014). The data obtained from these and similar monitoring efforts can be used to inform future management and adaptation strategies.

Recommended Citation

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Further information on the Golden Gate Biosphere Region Climate Adaptation Project is available on the project page (www.ecoadapt.org/goto/GGBRClimateProject).

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