



California Red-Legged Frog (*Rana draytonii*) and San Francisco Garter Snake (*Thamnophis sirtalis tetrataenia*)

Climate Change Vulnerability Assessment for the Santa Cruz Mountains Climate Adaptation Project

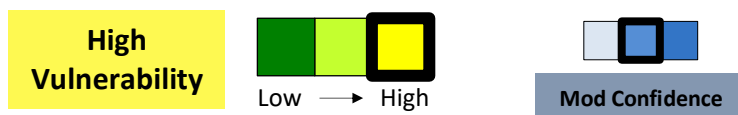
This document represents an initial evaluation of mid-century climate change vulnerability for the California red-legged frog and San Francisco garter snake in the Santa Cruz Mountains region based on expert input during an October 2019 vulnerability assessment workshop as well as information in the scientific literature.

Species Group Description

The California red-legged frog (*Rana draytonii*) is endemic to California and Baja California, and is the largest native frog in western North America¹. It is a highly aquatic species, but adult frogs also utilize terrestrial habitats for estivation during the dry season as well as for movement between aquatic areas^{1,2}. California red-legged frogs are typically found in and around ponds, perennial creeks/streams, wetlands, swales, cattle ponds, retention basins, and drainage ditches^{1,3}.

San Francisco garter snakes (*Thamnophis sirtalis tetrataenia*) are found within a very small coastal range in San Mateo and northern Santa Cruz counties⁴. They forage in freshwater marshes and other aquatic habitats (e.g., ponds, reservoirs, drainage ditches) and use upland habitats for overwintering, reproduction, and movement between aquatic areas⁵.

Vulnerability Ranking

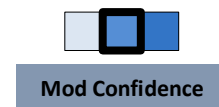
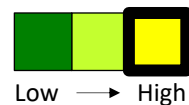


Both California red-legged frogs and San Francisco garter snakes are sensitive to climate stressors and disturbances such as warmer water temperatures, increased disease, more frequent/severe flooding, and altered wildfire regimes, as well as those that impact water availability (e.g., precipitation changes, increased drought, altered stream flows). These changes impact red-legged frogs and garter snakes by increasing physiological stress and mortality rates, reducing reproductive success, and altering habitat availability and quality. Non-climate stressors (e.g., land-use conversion to development and agriculture, invasive species, exposure to pesticides, roads/highways/trails, dams/water diversions, illegal collection) further exacerbate species sensitivity to climate-driven changes by causing direct mortality, reducing food resource availability, and/or impacting habitat availability, quality, and connectivity.

Both species considered within this group have experienced significant population declines, which in the Santa Cruz Mountains region are largely a result of habitat loss as well as the presence of invasive species. Remaining habitats are increasingly fragmented, and isolation of remnant populations reduces genetic diversity and enhances the risk of local extirpation due to stochastic events (e.g., severe drought, wildfire). These two species receive regulatory support in the form of federal and state protection, and public support for management is relatively high. Management strategies designed to reduce the vulnerability of California red-legged frogs and San Francisco garter snakes to climate change may include protection of remnant natural habitat and important movement corridors,

creation of artificial habitat (e.g., stock ponds managed to provide suitable conditions), and management of invasive species.

Sensitivity and Exposure



Sensitivity is a measure of whether and how a species is likely to be affected by a given change in climate and climate-driven factors, changes in disturbance regimes, and non-climate stressors.

Exposure is a measure of how much change in these factors a species is likely to experience.

Sensitivity and future exposure to climate and climate-driven factors



California red-legged frogs and San Francisco garter snakes are sensitive to changes in climate factors that reduce the extent and quality of aquatic habitats, which impact reproduction (for California red-legged frogs) and prey availability (for San Francisco garter snakes).

Climate Stressor	Trend Direction	Projected Future Changes
Precipitation	▲ ▼	<ul style="list-style-type: none"> Shorter winters and longer, drier summers likely, with higher interannual variability^{6,7}
Drought	▲	<ul style="list-style-type: none"> Increased frequency of drought years, including periods of prolonged and/or severe drought^{6,8}
Streamflow	▲ ▼	<ul style="list-style-type: none"> Generally, wet season flows are projected to increase and dry season flows are projected to decrease⁹
Water temperature	▲	<ul style="list-style-type: none"> 1.1–2.0°C (2.0–3.6°F) increase in mean summer stream temperature by the 2090s¹⁰

- Changes in patterns of precipitation (e.g., amount and timing), increased drought, and associated changes in streamflow** alter pond and wetland hydroperiods and can result in drying that reduces available breeding habitat for California red-legged frogs^{5,11}. Lower pond water levels and shorter hydroperiods may increase predation of frogs¹², though these conditions can also limit the presence of invasive aquatic species that negatively affect them¹. Severe and/or prolonged periods of drought are likely to decrease frog recruitment and dispersal, and can lead to increased mortality and population declines^{5,11,12}. By contrast, increases in precipitation may expand habitat availability, allowing increased opportunities for reproduction and dispersal^{5,11}.

Habitat drying is also likely to impact the San Francisco garter snake³, which forages for amphibians in aquatic environments⁴. Some researchers have observed decreased survival of juveniles during years when frog reproduction declined due to drought¹³, suggesting that climate-driven changes in frog populations could play a role in San Francisco garter snake population dynamics as well.

- Warmer water temperatures** may accelerate frog larval development rates^{5,14}, potentially benefitting California red-legged frogs. However, effects on tadpole development are

unknown³. Water temperature also influences pathogen potential and the growth of vegetation that impacts habitat quality for both species (e.g., locations for egg deposition, cover from predators, anoxic conditions)³.

Sensitivity and future exposure to climate-driven changes in disturbance regimes



California red-legged frogs and San Francisco garter snakes are sensitive to changes in disturbance regimes that directly impact survival as well as those that alter habitat quality and availability.

Disturbance Regimes	Trend Direction	Projected Future Changes
Disease	▲	<ul style="list-style-type: none"> Expansion of the projected future climate niche for <i>Bd</i> in northern temperate ecosystems¹⁵
Storms & flooding	▲	<ul style="list-style-type: none"> Increased storm intensity and duration, resulting in more frequent extreme precipitation events and flooding^{6,16,17}
Wildfire	▲	<ul style="list-style-type: none"> Slight to moderate increase in wildfire risk, particularly in areas of higher rainfall^{18,19}

- The **introduced chytrid fungus** *Batrachochytrium dendrobatidis* (*Bd*) originated in Asia and has spread globally²⁰. Although it has not been well-studied in California red-legged frogs, *Bd* has been implicated in population declines for many other amphibian species^{20,21}. A recent study of 4 ranid frog species in the western U.S found that *Bd* reduced frog survival by 6–15%, with lower survival rates occurring within California red-legged frogs compared to the other 3 species²². Studies of other frog species suggest that *Bd* may increase mortality to a greater degree in populations that are already experiencing stress due to factors such as unusually warm temperatures, altered hydrology, and the presence of American bullfrogs (*Rana catesbeiana*)^{21,23}. Because they are disease-tolerant, American bullfrogs can also play a role in spreading the chytrid fungi²⁴.
- **Increased storms and associated flooding** could impact California red-legged frog recruitment, as seasonal flooding is known to wash away or strand and desiccate eggs and tadpoles in affected stream reaches¹. However, winter flooding has greater negative impacts on bullfrog populations than it does on California red-legged frogs²⁵, suggesting that climate-driven increases in flooding may benefit red-legged frogs by reducing the presence of invasive bullfrogs. Flooding could also benefit both California red-legged frogs and San Francisco garter snakes by increasing overall wetland habitat³.
- **Altered wildfire regimes** may increase California red-legged frog mortality when they occur during migration or estivation in upland habitats¹. However, frogs may survive wildfire by taking cover in wetlands³. Indirectly, California red-legged frogs may be impacted by changes in water quality due to increased sedimentation from runoff³.

Dependency on habitat and/or other species



Both California red-legged frogs and San Francisco garter snakes depend on aquatic (e.g., ponds, wetlands, perennial streams) and upland habitats^{2,4}. California red-legged frogs breed in aquatic habitats, and adult frogs also require access to cool, moist microsites in riparian and upland habitat for aestivation during dry periods^{1,2}. San Francisco garter snakes utilize grassy upland areas for both

breeding and overwintering^{4,13}, but forage on the edges of ponds and shallow marshes where habitat conditions are suitable for frogs that make up their primary food source⁵.

California red-legged frogs are prey generalists, consuming a wide variety of aquatic macroinvertebrates⁵. San Francisco garter snakes are more specialized and prey almost exclusively on co-occurring amphibians such as Pacific tree frogs (*Pseudacris regilla*) and California red-legged frogs^{3,4,13,26}.

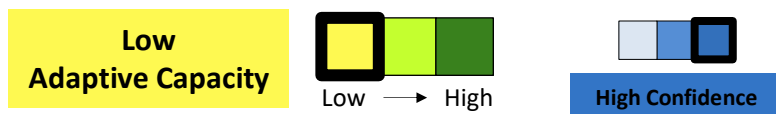
Sensitivity and current exposure to non-climate stressors



Non-climate stressors can exacerbate California red-legged frog and San Francisco garter snake sensitivity to changes in climate factors and disturbance regimes by directly increasing mortality and/or indirectly by impacting habitat availability and connectivity.

- **Land-use conversion for residential/commercial development and agriculture** in the Santa Cruz Mountains region has resulted in significant modification and loss of freshwater aquatic habitats over the past century, severely impacting California red-legged frog and San Francisco garter snake populations^{1,4,5}. However, artificial ponds in agricultural areas can provide habitat for these species^{4,11}, and may become increasingly important under warmer, drier future conditions.
- **Invasive American bullfrogs** compete for shared resources and prey upon larval and juvenile California red-legged frogs^{5,27}, reducing frog recruitment and causing extirpation of the species from heavily-impacted areas^{1,5}. Bullfrogs are typically associated with larger, deeper ponds that hold water year-round²⁸, and their expansion has been implicated in the decline of California red-legged frogs⁵.
- Anecdotal evidence suggests that **invasive water fern** may reduce habitat quality for California red-legged frogs by creating anoxic conditions²⁹. This may become more of a concern in the future as climate change tends to favor the growth of invasive vegetation³⁰.
- **Roads, highways, and recreational trails** are associated with increased risk of direct mortality (e.g., vehicle strikes) and habitat fragmentation for California red-legged frogs and San Francisco garter snakes^{1,30}. Within the Santa Cruz Mountains region, high road densities are associated with significantly increased risk of extirpation for San Francisco garter snakes³⁰, and proximity to roads and trails reduces the likelihood of California red-legged frog presence in ponds²⁸.
- **Agricultural pesticides** are known to increase frog larval mortality in aquatic communities, even at very low concentrations³¹. Studies also suggest that wind-borne transport of chemicals from surrounding agricultural areas may be associated with declines in several amphibian species³², including California red-legged frog populations in other portions of their range^{32,33}.
- **Dams and water diversions** alter stream hydrology, impacting habitat availability and quality for California red-legged frogs⁵. For example, water diversions used to irrigate spring and summer crops can expose and desiccate frog egg masses and/or increase predation risk¹. Dams can also aid the spread of invasive species into downstream reaches where formerly intermittent streams shift towards regulated perennial flows¹.
- **Illegal collection** of San Francisco garter snakes represents an ongoing threat to the species, and it thought to have contributed to their decline at some sites⁴.

Adaptive Capacity



Adaptive capacity is the ability of a species to accommodate or cope with climate change impacts with minimal disruption.

Species extent, integrity, connectivity, and dispersal ability



California red-legged frogs have been reduced to 30% of their historical range in California, largely due to habitat loss, degradation, and fragmentation⁵. Although this species is more abundant in the Santa Cruz Mountains region compared to some other portions of its range¹, continued land-use conversion threatens remaining habitat areas and isolates remnant populations where human infrastructure limits movement across the landscape³. Although they usually migrate short distances between breeding and upland non-breeding sites, California red-legged frogs do have the potential to move relatively long distances (as much as 2.8 km [1.7 mi])^{1,2}, increasing the ability of this species to colonize newly suitable habitat and/or respond to environmental stressors.

San Francisco garter snakes have been extirpated from many locations where they were historically found, although the overall size of their range has changed little⁴. Although little data exists about population trends in this species, remnant populations are likely declining or are at risk of decline⁴. San Francisco garter snake populations are also increasingly isolated due to habitat loss and fragmentation as well as natural barriers that restrict movement and gene flow^{4,34}. Additionally, this species disperses very short distances, usually staying within 100-200 m (330–660 ft) of pond foraging habitat and winter upland habitat⁴. Low dispersal distances and increasing isolation of remaining populations enhance the risk of local extirpation due to stochastic events such as severe drought or wildfire³⁴.

Intraspecific/life history diversity



San Francisco garter snakes have low genetic diversity, and studies suggest the species is at risk of inbreeding depression, particularly in the northern portion of their range³⁴. Diversity within life history strategies is relatively unknown for this species, but they do display some flexibility in habitat use⁴.

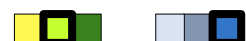
Genetic diversity for California red-legged frogs is currently unknown, though it is thought to be high³. The species does possess a variety of behavioral adaptations (e.g., reduced swimming activity in early stages of development) in response to the presence of invasive bullfrogs, likely as a result of predation and competitive pressure²⁷.

Resistance and recovery



Both California red-legged frogs and San Francisco garter snakes have low resistance to environmental stressors and disturbances, and recovery from impacts is slow due to the isolation of remnant populations³.

Management potential



Public support for management of these species is relatively strong, and is aided by organizations such as the Midpeninsula Regional Open Space District that provide constituency support for their management and conservation³. California red-legged frogs receive regulatory support from their

listing as a threatened species under the U.S. Endangered Species Act⁵ and as a Species of Special Concern in California³⁵, while the San Francisco garter snake is federally- and state-listed as an endangered species .

The impacts of climate change may be managed for these species to some degree, though it is unlikely that they can be completely alleviated³. Management options focused on reducing climate change vulnerability may include engaging private landowners to provide artificial habitat on agricultural land (e.g., stock ponds), which could then be managed to maintain suitable conditions (e.g., hydroperiod, vegetation structure/type)¹. One study also found that restored habitat for San Francisco garter snakes within urbanized areas can support healthy populations, suggesting that these areas can be used to supplement larger tracts of natural habitat³⁸. Overall, protection of small ponds and wetlands from development and increased human activity (e.g., roads and hiking trails)²⁸ and preventing the spread of invasive bullfrogs^{25,27} are likely to be critical. Upland habitat and migration corridors are also important to consider in protection efforts², as both species utilize a variety of habitat types for breeding, foraging, and estivation^{2,4}.

Recommended Citation

EcoAdapt. 2021. California Red-Legged Frog (*Rana draytonii*) and San Francisco Garter Snake (*Thamnophis sirtalis tetrataenia*): Climate Change Vulnerability Assessment Summary for the Santa Cruz Mountains Climate Adaptation Project. Version 1.0. EcoAdapt, Bainbridge Island, WA.

Further information on the Santa Cruz Mountains Climate Adaptation Project is available on the project page (<http://ecoadapt.org/programs/awareness-to-action/santa-cruz-mountains>).

Literature Cited

1. USFWS. *Recovery plan for the California red-legged frog (Rana aurora draytonii)*. (2002).
2. Fellers, G. M. & Kleeman, P. M. California red-legged frog (*Rana draytonii*) movement and habitat use: implications for conservation. *Journal of Herpetology* **41**, 276–286 (2007).
3. Vuln. Assessment Workshop. Personal communication. (2019).
4. USFWS. *San Francisco Garter Snake (Thamnophis sirtalis tetrataenia) 5-Year Review: Summary and Evaluation*. (2006).
5. USFWS. Endangered and threatened wildlife and plants: determination of threatened status for the California red-legged frog. *Federal Register* **61**, 25813–25833 (1996).
6. Pierce, D. W., Kalansky, J. F. & Cayan, D. R. *Climate, drought, and sea level rise scenarios for the Fourth California Climate Assessment*. (2018).
7. Swain, D. L., Langenbrunner, B., Neelin, J. D. & Hall, A. Increasing precipitation volatility in twenty-first-century California. *Nature Climate Change* **8**, 427 (2018).
8. Cook, B. I., Ault, T. R. & Smerdon, J. E. Unprecedented 21st century drought risk in the American Southwest and Central Plains. *Science Advances* **1**, e1400082 (2015).
9. Grantham, T. E. W., Carlisle, D. M., McCabe, G. J. & Howard, J. K. Sensitivity of streamflow to climate change in California. *Climatic Change* **149**, 427–441 (2018).
10. Hill, R. A., Hawkins, C. P. & Jin, J. Predicting thermal vulnerability of stream and river ecosystems to climate change. *Climatic Change* **125**, 399–412 (2014).
11. USFWS. Endangered and threatened wildlife and plants: revised designation of critical habitat for California red-legged frog; final rule. *Federal Register* **75**, 12816–12959 (2010).
12. Jennings, M. R., Hayes, M. P. & Holland, D. C. *A petition to the U.S. Fish and Wildlife Service to place the California red-legged frog (Rana aurora draytonii) and the western pond turtle (Clemmys marmorata) on the list of endangered and threatened wildlife and plants*. (1992).

13. Larsen, S. S. Life history aspects of the San Francisco garter snake at the Millbrae habitat site. (California State University, Hayward, 1994).
14. Jennings, M. R. & Hayes, M. P. *Amphibian and reptile species of special concern in California*. (1994).
15. Xie, G. Y., Olson, D. H. & Blaustein, A. R. Projecting the global distribution of the emerging amphibian fungal pathogen, *Batrachochytrium dendrobatidis*, based on IPCC climate futures. *PLoS ONE* **11**, e0160746 (2016).
16. Dettinger, M. Climate change, atmospheric rivers, and floods in California – a multimodel analysis of storm frequency and magnitude changes. *Journal of the American Water Resources Association* **47**, 514–523 (2011).
17. Shields, C. A. & Kiehl, J. T. Simulating the Pineapple Express in the half degree Community Climate System Model, CCSM4. *Geophysical Research Letters* **43**, 7767–7773 (2016).
18. Flint, L. E. & Flint, A. L. *California Basin Characterization Model: a dataset of historical and future hydrologic response to climate change (Ver. 1.1, May 2017)*. <https://doi.org/10.5066/F76T0JPB> (2014).
19. Flint, L. E., Flint, A. L., Thorne, J. H. & Boynton, R. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. *Ecological Processes* **2**, 25 (2013).
20. O’Hanlon, S. J. *et al.* Recent Asian origin of chytrid fungi causing global amphibian declines. *Science* **360**, 621–627 (2018).
21. Cohen, J. M., Civitello, D. J., Venesky, M. D., McMahon, T. A. & Rohr, J. R. An interaction between climate change and infectious disease drove widespread amphibian declines. *Global Change Biology* **25**, 927–937 (2019).
22. Russell, R. E. *et al.* Effect of amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) on apparent survival of frogs and toads in the western USA. *Biological Conservation* **236**, 296–304 (2019).
23. Adams, A. J. *et al.* Extreme drought, host density, sex, and bullfrogs influence fungal pathogen infection in a declining lotic amphibian. *Ecosphere* **8**, e01740 (2017).
24. Huss, M., Huntley, L., Vredenburg, V., Johns, J. & Green, S. Prevalence of *Batrachochytrium dendrobatidis* in 120 archived specimens of *Lithobates catesbeianus* (American bullfrog) collected in California, 1924–2007. *EcoHealth* **10**, 339–343 (2013).
25. Doubledee, R. A., Muller, E. B. & Nisbet, R. M. Bullfrogs, disturbance regimes, and the persistence of California red-legged frogs. *Journal of Wildlife Management* **67**, 424–438 (2003).
26. Kim, R. When frogs violate trophic hierarchy: conservation of the endangered San Francisco gartersnake. (San Francisco State University, 2017).
27. Anderson, R. B. & Lawler, S. P. Behavioral changes in tadpoles after multigenerational exposure to an invasive intraguild predator. *Behav Ecol* **27**, 1790–1796 (2016).
28. Anderson, R. B. Human traffic and habitat complexity are strong predictors for the distribution of a declining amphibian. *PLOS ONE* **14**, e0213426 (2019).
29. J. Andersen. Personal communication. (2021).
30. Liu, Y. *et al.* Do invasive alien plants benefit more from global environmental change than native plants? *Global Change Biology* **23**, 3363–3370 (2017).
31. Brehme, C. S., Hathaway, S. A. & Fisher, R. N. An objective road risk assessment method for multiple species: ranking 166 reptiles and amphibians in California. *Landscape Ecol* **33**, 911–935 (2018).
32. Relyea, R. A. A cocktail of contaminants: how mixtures of pesticides at low concentrations affect aquatic communities. *Oecologia* **159**, 363–376 (2009).
33. Davidson, C., Shaffer, H. B. & Jennings, M. R. Spatial tests of the pesticide drift, habitat destruction, UV-B, and climate-change hypotheses for California amphibian declines. *Conservation Biology* **16**, 1588–1601 (2002).
34. Davidson, C., Bradley Shaffer, H. & Jennings, M. R. Declines of the California red-legged frog: climate, UV-B, habitat, and pesticides hypotheses. *Ecological Applications* **11**, 464–479 (2001).
35. Wood, D. A. *et al.* Combining genetic and demographic monitoring better informs conservation of an endangered urban snake. *PLOS ONE* **15**, e0231744 (2020).
36. Thomson, R. C., Wright, A. N. & Shaffer, H. B. *California amphibian and reptile species of special concern*. (University of California Press, 2016).
37. CNDDDB. *State and federally listed endangered and threatened animals of California*. (2020).
38. Reeder, N. M. M., Byrnes, R. M., Stoelting, R. E. & Swaim, K. E. An endangered snake thrives in a highly urbanized environment. *Endangered Species Research* **28**, 77–86 (2015).