Salamanders

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 salamanders 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

Salamanders within the Santa Cruz Mountains region include species such as the California slender salamander (*Batrachoseps attenuatus*), ensatina (*Ensatina eschscholtzii*), arboreal salamander (*Aneides lugubris*), black salamander (*A. flavipunctatus*), California newt (*Taricha torosa*), rough-skinned newt (*T. granulosa*), red-bellied newt (*T. rivularis*), California giant salamander (*Dicamptodon ensatus*), California tiger salamander (*Ambystoma californiense*), and Santa Cruz black salamander (*A. flavipunctatus niger*). They occur within a variety of terrestrial and aquatic habitats, and range from widespread, locally abundant species (e.g., California slender salamander) to extreme habitat specialists that inhabit very restricted ranges[1,2].

Vulnerability Ranking

High Vulnerability

Low ⟶ High

High Confidence

Salamanders are sensitive to climate stressors and disturbances such as warmer air and water temperatures, changes in precipitation, increased drought, altered wildfire regimes, and disease. These changes impact salamanders directly by increasing physiological stress and mortality rates and indirectly by altering habitat availability and quality. Salamanders are particularly sensitive to factors that result in the loss of cool, moist microclimates within terrestrial habitats as well as those that alter stream and pond hydroperiods. Non-climate stressors (e.g., development, roads/highways, timber harvest, invasive species) further exacerbate salamander sensitivity to changes in climate factors and disturbance regimes by contributing to habitat loss and fragmentation. Additionally, salamanders are highly sensitive to contaminants, which can cause physiological impacts and mortality as well as reductions in prey availability.

Salamander distributions in the Santa Cruz Mountains region vary, as some species are widely but patchily distributed and others are found only in very restricted locations. Species with limited ranges and/or isolated populations are particularly vulnerable to habitat fragmentation/loss and environmental changes that increase the risk of desiccation. Small, isolated populations also generally have lower genetic diversity than more widespread species. However, salamanders display some behavioral plasticity in that they are able to exploit microhabitats that may offer thermal and/or hydrological refugia from climate change. Within the Santa Cruz Mountains region, several salamander species receive regulatory protection through state- or federal-listings. Management strategies designed to increase the resilience of salamanders to climate change are likely to focus on maintaining or increasing the availability of cool, moist forest microsites and restoring connectivity between habitat patches, as well as reducing the impacts of non-climate stressors.

Sensitivity and Exposure

High Impact

Low → High

High Confidence

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

Salamanders are sensitive to climate stressors that alter cool, moist microclimates within terrestrial habitat and water levels/hydroperiods within aquatic habitat, as well as those that increase physiological stress and mortality rates.

Climate Stressor	Trend Direction	Projected Future Changes
Precipitation	▲ ▼	• Shorter winters and longer, drier summers likely, with higher interannual variability[3,4]
Drought	▲	• Increased frequency of drought years, including periods of prolonged and/or severe drought[3,5]
Air temperature	▲	• 1.5–3.1°C (2.7–5.6°F) increase in annual mean temperature[6,7]
Water temperature	▲	• 1.1–2.0°C (2.0–3.6°F) increase in mean summer stream temperature by the 2090s[8]

- **Changes in precipitation patterns (e.g., amount and timing)** and **increased drought** are likely to impact salamanders directly by increasing physiological stress and mortality rates, and indirectly by affecting habitat quality in both terrestrial and aquatic systems[2,9–12]. Most lungless terrestrial salamanders (e.g., slender salamander, ensatina) must maintain moist skin that facilitates gas exchange, so they utilize moist forest microsites such as decaying logs when not actively foraging[1]. Periods of low precipitation and/or drought force terrestrial salamanders to spend more time underground or within moist microsites in order to avoid desiccation, limiting opportunities for foraging and courtship activity[11,12]. Loss of canopy cover and changes in vegetation as a result of drought can also alter microclimatic factors (e.g., light, temperature, moisture) as well as the accumulation, quality, and decomposition of leaf litter that salamanders depend on to retain soil moisture and provide cover from predators[1].

  Semi-aquatic salamanders are vulnerable to drier overall conditions associated with reduced streamflow and wetland/pond water level and hydroperiod[9,13,14]. Severe drought may cause streams and wetlands to become ephemeral/intermittent or dry completely, with the greatest impacts on breeding salamanders and larval stages[9,12,13].
- **Warmer air and water temperatures** are likely to affect salamanders directly through increased physiological stress, reduced reproductive success, and altered larval development as well as indirectly through decreased food availability[2,12]. Reduced levels of dissolved oxygen in aquatic habitats, which are associated with warmer water temperatures, may also delay development

and/or hatching of salamanders, or could cause premature hatching[12]. Increased water temperatures are likely to affect the availability of spring macroinvertebrates, an important salamander food source[15].

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

Salamanders are sensitive to changes in disturbance regimes that directly impact survival as well as those that reduce habitat availability and quality.

Disturbance Regimes	Trend Direction	Projected Future Changes
Disease	▲	• Increased disease risk[16,17] and expansion of the projected climate niche for *Bd* in northern temperate ecosystems[18]
Wildfire	▲	• Slight to moderate increase in wildfire risk, particularly in areas of higher rainfall[6,7]

- Like other amphibians, salamanders in California are affected by the **introduced disease chytridiomycosis** (caused by the chytrid fungus *Batrachochytrium dendrobatidis;* Bd)[17,19], which originated in Asia and has spread globally[20]. A newly described chytrid species (*B. salamandrivorans*; Bsal) from Asia also appears to cause disease in some salamander species, warranting additional concern in California[21–25]. *Batrachochytrium* pathogens can cause effects ranging from disease tolerance to death of infected salamanders depending on factors such as host susceptibility, fungal virulence, and environmental conditions[26]. Aquatic species are particularly vulnerable to infection because fungal zoospores are transmitted readily in water but become desiccated rapidly on land[27]. Terrestrial species with a higher degree of sociality also appear to be more vulnerable due to increased disease transmission[17]. As air temperatures continue to rise, research suggests that salamander species adapted to cooler environments are likely to become increasingly vulnerable to the disease[28], likely because environmental stressors compromise the immune system[29]. Altered precipitation patterns are also likely to impact patterns of fungal reproduction and transmission[19].
- **Altered wildfire regimes** (e.g., changes in the size or frequency of high-intensity fires) may increase salamander mortality due to the direct impacts of fire and post-fire events (e.g., flooding, landslides, debris flows) within both terrestrial and aquatic habitats[30]. Indirectly, these factors also affect salamanders by altering habitat structure and function, though the degree of impact varies across habitats and spatial scales[30]. For instance, fires can eliminate or alter cover through burning of understory vegetation and woody debris or deposit ash and sediment in aquatic substrates[30]. At larger scales, fires may increase solar radiation and water temperatures, alter forest microclimates and hydroperiods in aquatic habitat, and impact aquatic food webs[30]. Post-fire debris flows may also reduce breeding habitat by filling pools and stream channels with sediment and debris[30]. In general, species with a limited distribution, dependence on restricted microclimate associations, and limited capacity for recolonization are likely to be most affected by altered wildfire regimes[30,31].

Dependency on habitat and/or other species

Salamanders are dependent on a variety of habitats and microhabitat conditions for survival and reproduction[1,2]. Terrestrial species, in particular, require cool, moist microhabitats (e.g., deep leaf litter, downed logs, rock crevices) for cover, foraging, and to prevent desiccation[1,12]. All species are dependent on habitats that provide abundant macroinvertebrates as prey, though some salamanders also prey on small mammals[2,32].

Sensitivity and current exposure to non-climate stressors

Non-climate stressors can exacerbate species group sensitivity to changes in climate factors and disturbance regimes by increasing salamander mortality and/or contributing to the loss or fragmentation of aquatic and terrestrial habitats.

- **Land-use conversion to residential/commercial development** results in habitat loss for salamanders following reductions in forest canopy cover and elimination or degradation of aquatic habitats[12]. Development also limits salamander movement and dispersal, reducing population connectivity and juvenile survival[33].
- **Roads and highways** increase habitat fragmentation and represent a significant source of direct mortality for salamanders, particularly when they are moving between aquatic and terrestrial habitats[34].
- Because of their permeable skin, salamanders are highly sensitive to **contaminants** such as pesticides[35], herbicides[36], and chemical applications commonly used for fire suppression[31] or road maintenance[37]. Pollutants enter salamander habitats through both overland and aquatic pathways, affecting salamanders directly by disrupting embryo development, increasing motor activity, and enhancing susceptibility to other stressors (e.g., disease)[35,36]. Pesticides may also affect salamanders indirectly by reducing invertebrate prey availability[35].
- **Historical timber harvest** practices (e.g., clearcutting, plantation forestry) have had significant adverse impacts on salamander survival and population connectivity[1,2,33,38,39]. Practices such as historical clear-cutting killed salamanders by crushing them with heavy equipment; they also eliminated shading and leaf litter, increased soil surface temperature, and reduced litter moisture[38,40,41]. In riparian areas, the loss of the tree canopy after clear-cutting increases water temperatures, potentially reducing habitat for cold-adapted salamanders[2].
- Aquatic-breeding salamanders are negatively impacted by **invasive species** such as non-native fish and American bullfrogs (*Lithobates catesbeianus*), which increase egg and larval predation rates and/or compete with salamanders for resources[42–44]. American bullfrogs can also be a vector for the fungal pathogen *Bd*[17,45].

Adaptive Capacity

Moderate Adaptive Capacity

Low → High

High Confidence

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

Some salamander species are widely but patchily spread across the landscape, while others are restricted to very small ranges[1,2]. Many species found within the region have experienced severe population declines and extirpation from large portions of their range, primarily due to habitat loss and fragmentation[2,12]. Climate change and disease are expected to drive further population declines and range losses of salamanders within California as well as globally[2,46].

Salamanders are unable to migrate long distances, and most species do not disperse any appreciable distance across non-forested habitat[33,47]. Thus, salamander movement and dispersal is affected by geologic barriers (e.g., topography), forest clear-cuts, land-use conversion to residential/commercial development or agriculture, and high-intensity wildfires, and they have little ability to recolonize areas from which they have previously been extirpated[2,47].

Intraspecific/life history diversity

Across the species group, salamanders demonstrate some behavioral/phenotypic plasticity and diversity in life history strategies, which likely evolved as adaptations to the wide range of habitats and climates they occupy[1,2,48]. For instance, salamanders are able to move between habitat niches in response to local environmental stressors, providing them with some ability to mitigate the impacts of increasing stressors or disturbances[11,48]. Lungless terrestrial salamanders can also delay egg-laying by several months in response to unfavorable environmental conditions[1]. Over the longer-term, salamanders may adjust to warmer temperatures or shorter active seasons by decreasing body size, either through plasticity in growth response or changes in physiological response (i.e., energy allocation)[11,49]. Some changes in terrestrial salamander body size have already been observed over the past several decades[49].

Salamander genetic diversity varies[2,47], and can be extremely high for some species complexes (e.g., black salamanders)[50]. Habitat elevation and topography strongly influence genetic diversity within species by limiting dispersal across high ridges and other barriers, resulting in high rates of genetic differentiation among some species[47,51]. However, lack of habitat connectivity also results in very low genetic diversity in small, isolated populations[1,47], increasing their vulnerability to stressors and disturbances in a changing climate[47].

Resistance and recovery

Adaptations to habitat variability and environmental changes may increase resistance to climate change and disturbances among some salamander species and/or in certain life stages[1,2,31]. For example, species with biphasic life cycles may be somewhat insulated from significant losses following wildfire in one habitat type (i.e., aquatic larvae may die but terrestrial adults survive)[30]. Salamanders are also known to retreat underground or into cool aquatic refugia to avoid the impacts of high temperatures or short-term drought[11,52,53]. However, the limited ability of salamanders to disperse overland to new habitats reduces their ability to recover from disturbances that are likely to increase with climate change, including high-intensity wildfire and habitat drying from increased air temperatures and hydrological changes[1,2]. Species with small and/or isolated populations and narrow ranges are particularly at risk of declines or even extirpation following severe environmental stress or extreme disturbances[2,30,31].

Management potential

Despite their widespread distribution, salamanders are one of the least understood North American vertebrates[1]. However, several species found within the Santa Cruz Mountains region receive regulatory support through federal- or state-listing as threatened or endangered species, including the California tiger salamander[54].

The scientific literature suggests multiple approaches that may increase the resilience of salamanders to climate stressors and disturbances, often focused on reducing habitat degradation and loss associated with non-climate stressors[14]. The protection of habitat within mature forests is also critical, including riparian zones that serve as dispersal corridors and may act as climate refugia[38,55–58]. Other salamander habitats that should be prioritized for protection include ponds, seeps/springs, and headwater stream reaches[1]. Within terrestrial habitats, managers may consider leaving downed wood on the forest floor and preserving canopy cover to prevent soil drying and the alteration of understory vegetation[14,59–61]. Timber harvest practices can be improved by utilizing partial harvest techniques and long-term rotation cycles[38]. Other strategies that could minimize stress include minimizing disease spread by limiting pathogen introduction and promoting early detection through surveillance of high-risk areas[25].

Recommended Citation

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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).

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