Salmonids

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 salmonids 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 Description

The Santa Cruz Mountains study area is home to the Central California Coast (CCC) sub-populations (known as Distinct Population Segments or Evolutionarily Significant Units) of both coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*). These species are anadromous fish that hatch in freshwater rivers and streams, migrate to the ocean to feed and grow to maturity, then return to their natal freshwater habitats to spawn. However, the timing and length of these life stages vary depending on species:

- CCC coho salmon are fall-run fish, entering freshwater streams from the ocean shortly after flows increase in the fall (September through November) and then spawning in November and December. Juvenile coho use parts of their spawning streams and estuary habitats throughout the year, then migrate downstream and into the ocean between April and June. There, they spend 6-18 months before they return to their natal streams to spawn at two or three years old[1].
- CCC steelhead are winter-run fish, with most individuals entering freshwater habitats during annual peak flows that occur between late December and February. Spawning occurs in late spring (between February and April), and juveniles utilize freshwater and estuarine rearing habitats for 1–3 years before migrating out to the ocean[1].

Vulnerability Ranking

High Vulnerability

Low → High

Mod Confidence

Salmonids are sensitive to climate stressors that drive altered flow regimes and warmer water temperatures, which impact habitat availability and quality as well as fish survival, recruitment, and migration. In estuarine habitats, sea level rise may also impact the sandbars and protected lagoons that are utilized by juveniles as rearing habitat. Disturbance regimes, including storm-related flooding and landslides, wildfire, and disease, may also increase the risk of direct mortality in addition to impacting habitat suitability. Non-climate stressors (e.g., development, agriculture, dams/water diversions, environmental contaminants, and timber harvest, among others) further exacerbate the sensitivity of salmonids by directly increasing mortality and/or indirectly by degrading habitat conditions and reducing instream connectivity.

Coho and steelhead are at or near the southern extent of their geographic range in the Santa Cruz Mountains region, and dramatic population declines have occurred in both species due to a combination of habitat fragmentation and degradation as a result of human activity and land use, as well as severe climate events (e.g., heat waves, drought). Salmonids do exhibit high life history, phenotypic, and behavioral diversity, which enhances their ability to adapt to changing conditions. However, decreases in genetic diversity associated with declining populations are likely to limit this potential. Both species receive regulatory support in the form of federal listings under the Endangered Species Act, and their high public and societal value increase support for management. Options that increase the resilience of this species group to climate change include many existing restoration activities, such as improving access to critical spawning areas and coldwater refugia, enhancing habitat complexity and heterogeneity, and restoring natural flow regimes within aquatic systems.

Sensitivity and Exposure

High Impact

Low → High

Mod 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

Salmonids are sensitive to climate stressors that increase physiological stress and mortality, decrease water quality, and/or reduce habitat quality and accessibility.

Climate Stressor	Trend Direction	Projected Future Changes
Water temperature	▲	• 1.1–2.0°C (2.0–3.6°F) increase in mean summer stream temperature by the 2090s[2]
Streamflow	▲ ▼	• Generally, wet season flows are projected to increase and dry season flows are projected to decrease[3]
Precipitation	▲ ▼	• Shorter winters and longer, drier summers likely, with higher interannual variability[4,5]
Drought	▲	• Increased frequency of drought years, including periods of prolonged and/or severe drought[4,6]
Sea level rise	▲	• High likelihood (67% probability) of 0.2–0.3 m (0.6–1.1 ft) sea level rise by 2050[7–9]

- **Warmer water temperatures** can accelerate salmonid development and egg hatching, affect juvenile growth rates, decrease reproductive success, and reduce survival[1,10]. Exposure to high water temperatures can impact physiological processes such as metabolic rate and cardiorespiratory performance[11], and also increase exposure and susceptibility to disease[12,13]. Increasing temperatures reduce dissolved oxygen, which can contribute to juvenile mortality[14,15], and when combined with low flows can contribute to blooms of toxic cyanobacteria (currently rare in the Santa Cruz Mountains but likely to become more common)[16]. In estuarine habitats, warmer water combined with low flows can cause vertical stratification and eutrophication[17]. Altered migration timing may also occur in response to temperature cues[18], and mismatches between migration timing and optimal habitat/prey conditions have the potential to reduce survival[1,19]. Over longer time periods, increasing stream temperatures may increase dependence on coldwater refugia, and climatically suitable habitat may shift northwards in both ocean and freshwater environments[1,10,17].

In general, coho occupy cooler waters and exhibit greater sensitivity to increasing stream temperatures compared to steelhead. This is due, in part, to the longer period of time that juvenile coho reside in freshwater habitats where they are exposed to higher summer water temperatures[10]. Coho are also at their southern distribution limit in the central California region, suggesting that they are at or near their thermal limits and so are at increased risk of extirpation as a result of temperature increases[17].

- **Altered flow regimes** are likely to occur as a result of **changes in precipitation amount/timing** and **increased drought**, resulting in overall declines in habitat quality and availability that are associated with reduced spawning and survival and altered timing of fish migration[1,10,15,20]. For example, lower summer flows increase the number of days that stream reaches are disconnected, which may prevent fish from migrating and can strand them within isolated pools[15]. Low flows also limit suitable spawning and rearing habitat, alter aquatic food webs, and increase the occurrence of cyanobacteria blooms[1,10,16,17]. The most extreme low flow conditions generally occur during periods of drought, which can expose eggs, larvae, and rearing juveniles to lethal water temperatures and/or desiccation[17].

  Changes in the timing, magnitude, and duration of high flows are also likely to impact recruitment, survival, and habitat quality in salmonids. They are particularly sensitive to changes in the timing and magnitude of late-season high flows (February/March), which may scour redds, wash away larvae or juveniles, and deposit sediment within gravel spawning habitats[10].
- **Sea level rise** is likely to cause significant changes in estuarine habitats utilized by juveniles as they prepare to enter the open ocean, potentially breaching sandbars and protected lagoons[10]. Coho are particularly dependent on estuarine habitats, increasing their vulnerability to sea level rise[10].

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

Salmonids are sensitive to changes in disturbance regimes that alter habitat quality, heterogeneity, and connectivity, as well as those that directly increase illness or mortality.

Disturbance Regimes	Trend Direction	Projected Future Changes
Storms & flooding	▲	• Increased storm intensity and duration, resulting in more frequent extreme precipitation events and flooding[4,21,22]
Wildfire	▲	• Slight to moderate increase in wildfire risk, particularly in areas of higher rainfall[23,24]
Disease	▲	• Enhanced disease spread due to increasing water temperatures, declining flows, and degraded water quality[12,25]

- Salmonids in the Santa Cruz Mountains region are highly vulnerable to **increases in storms and associated impacts (e.g., flooding, landslides)**, particularly in highly-altered landscapes (e.g., where flood control structures are present)[10,26]. While periodic flooding plays an important role in maintaining suitable habitat conditions[25–27], changes in the magnitude, frequency, and timing of floods could increase fish mortality. For example, uncharacteristically frequent and/or severe floods can reduce salmonid recruitment and survival by scouring redds and washing away eggs[25]. Late-season floods, in particular, reduce egg and larvae survival and wash juvenile fish out of overwintering habitat in side channels and estuaries[1]. Floods and landslides/debris flows associated with storms also physically alter habitat by increasing turbidity, filling pools with sediment and debris, and reducing refugia and stream connectivity[25,28].
- Although wildfires can have positive impacts by maintaining stream habitat complexity over long time scales[25,28,29], climate-driven changes in **wildfire regimes (e.g., more frequent high-severity fires)** can reduce riparian vegetation and associated shading, increasing direct fish mortality by causing lethal stream temperatures[30–33]. Fish in smaller streams, streams already exhibiting warming trends, or areas already near their thermal limits are most vulnerable[25,34]. Wildfires also reduce instream wood availability and extreme precipitation events following fires can kill fish or bury spawning and rearing habitats in headwater reaches[1,25].
- Salmonids are sensitive to climate-driven increases in **disease**, which enhances mortality and can result in large fish kills under some circumstances[25]. Increasing water temperatures may increase susceptibility to disease[12], and spread is also increased where fish are trapped in remnant pools as a result of low flows[17,25].

Dependency on habitat and/or other species

Salmonids in the Santa Cruz Mountains region utilize a wide range of habitats, including riparian areas, floodplains, estuaries, and streams within redwood forests. Many of these habitats are considered sensitive to climate-driven changes that may result in altered habitat structure and functioning that reduce their availability and suitability for salmonids[35]. Both coho and steelhead primarily consume insect prey within freshwater environments, increasing their sensitivity to climate factors that impact their aquatic macroinvertebrate prey[35]. However, CCC steelhead are relatively opportunistic and take advantage of a diverse range of aquatic and terrestrial invertebrates[36].

Because salmonids are additionally dependent on marine habitats, they are vulnerable to changes in ocean conditions (e.g., sea surface temperature, acidification, currents) that impact prey availability as well as the distribution of competitors and potential predators[1,10,20,37]. For instance, warm temperatures and weak upwellings within the California Current System reduce ocean productivity, impacting marine food webs which, in turn, reduces salmonid survival[1,38].

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 reducing habitat availability and complexity, creating artificial barriers to movement, and impacting water quality.

- **Land-use conversion to residential/commercial development** and **agriculture** has significantly altered habitat availability and complexity for salmonids[20]. In coastal areas, channel straightening and the diking and filling of floodplains and wetlands have reduced the suitability of both freshwater and estuarine habitats for salmonids by impacting hydrology, water quality, and connectivity[25]. Urban and agricultural water demand also exacerbates the impacts of climate change on rivers and streams, reducing water availability during the dry season when rivers and streams are already experiencing low flows[25].

- **Dams and water diversions** disconnect mainstem rivers from their upstream reaches as well as from side channels and floodplains, limiting salmonid access to spawning grounds, high-quality rearing areas, and potential climate refugia[1,20,39,40]. Dams and water diversions also alter downstream water temperature regimes and sediment dynamics (including gravel recruitment), disrupting physical processes in streams and decreasing the quality of spawning habitat[1,25,39,40]. Changes in hydrologic regimes (e.g., the magnitude and timing of seasonal high flows) can disrupt the life cycle of salmonids by causing a mismatch between seasonal cycles of runoff and the timing of spawning, egg hatching, juvenile rearing, and migration[1,39,41].
- **Contaminants** associated with runoff from **urban and agricultural areas**, **roads and highways,** and **legacy mining operations** reduce salmonid health and survival[1,25,42]. For example, pesticide runoff from agricultural areas has contributed to regional fish kills, including of juvenile coho salmon[25]. A common chemical used in tire rubber has also been recently linked to acute mortality in coho salmon in the Pacific Northwest following exposure to stormwater runoff[42].
- **Roads, highways, and trails** increase runoff, altering stream hydrology and sediment delivery processes[43,44]. Increased erosion near roads can elevate stream sedimentation and turbidity, which reduces habitat availability and negatively affects juvenile recruitment and instream feeding[17,25,44]. Many culverts associated with road crossings also block the passage of salmonids, severing the connection between floodplains and mainstem rivers and acting as a significant barrier to migration and dispersal[1,45,46].
- **Timber harvest** and **mining** are associated with damming, channel incision, and increased sediment and contaminant loads that flow downstream, resulting in stream degradation and loss of habitat extent and complexity[1,25,47]. Vegetation removal due to logging temporarily increases surface runoff, groundwater recharge, and peak flows experienced during storm events[47–49]. Tree removal also reduces inputs of large wood into streams, reducing habitat complexity and opportunities for fish shelter from high flows[25,47]. Even for areas not currently experiencing timber harvest, the legacy impacts of logging on riparian cover, hydrology, and sediment regimes contributes to low contemporary fish production[1].
- **Livestock grazing** increases stream sedimentation and can cause streambanks to collapse, reducing habitat quality for salmonids[1,25]. Grazing in riparian areas can also reduce stream shading by impacting riparian vegetation composition[1,50].
- **Hatcheries** can have a negative effect on wild fish as a result of increased competition for resources in both freshwater and marine environments[20]. They also have the potential to introduce maladaptive genotypes that could impact wild populations[10]. However, hatchery practices have improved over the past two decades, and they could provide some benefits by reducing the short-term risk of extinction[10].
- **Recreational fishing** in both ocean and riverine environments contribute to salmonid population declines, particularly where they are subject to multiple other stressors that contribute to isolation and reduced abundance[1].

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

CCC populations of coho salmon are at the southernmost edge of the species' range, suggesting that this species may already be near its thermal tolerance limit within the Santa Cruz Mountains region[10]. By contrast, steelhead are more widely distributed, occurring down to southern California, and are generally assumed to have higher adaptive capacity and lower vulnerability to climate change compared to coho[10]. Both species are declining across their geographic range, largely as a result of habitat fragmentation and degradation associated with human activity as well as severe climate events (e.g., drought, heat waves)[1,17,25]. As a result, the CCC steelhead and coho sub-populations have been federally-listed as threatened and endangered, respectively[17]. CCC coho are also state-listed as endangered, and are at high risk of extirpation within the next 50 years[1].

Large dams and culverts associated with roads act as significant barriers for salmonid migration and dispersal, preventing fish from accessing large portions of their historical range[1,10,17,51]. These areas may include higher-elevation headwaters, tributary streams, and other areas that may provide climate refugia[51]. Natural geologic features may also limit movement of fish between streams, contributing to the development of genetically distinct populations[14].

Intraspecific/life history diversity

Salmonids generally exhibit high levels of local adaptation to particular regions or even watersheds as a result of adult migration to their natal streams over many generations[10]. Local populations of Pacific salmonids can display variations in morphology, behavior, life history, and genetics in response to differences in stream temperature, hydrology, and disturbance regimes[1,10,20]. These variable responses to environmental factors suggest high innate capacity in salmonids to adapt to increasingly variable climate conditions[20]. However, extreme population declines and decreased availability of diverse, high-quality habitats strongly limits genetic and phenotypic diversity within salmonid populations, reducing the potential for adaptation to climate change and increasing vulnerability to extirpation or extinction[1,10,20,41,46].

Coho salmon currently exhibit lower life history and genetic variation compared to steelhead[10].

Resistance and recovery

Although salmonids are generally well-adapted to variable environmental conditions in both freshwater and marine habitats, resistance to stressful conditions and disturbance regimes is highly dependent on the availability of diverse thermal and hydrological conditions within a given watershed[10,20]. Habitat fragmentation and simplification as a result of human land uses and activity reduces their resistance to extreme events (e.g., floods, droughts) by decreasing the availability of refugia and/or exacerbating the impacts of these events on the habitat itself[10,20,46]. For instance, floodplain disconnection reduces the availability of flow refugia for salmonids, but also causes greater changes in river and stream channels (e.g., increased erosion) due to a loss of floodwater storage that increases water velocity and magnitude within the channel.

Recovery from disturbances in salmonids is undermined by declining population sizes and low genetic diversity[17,20]. Stressors that limit recruitment and survival may further slow population recovery. For instance, reproductive potential of coho salmon is dependent, in part, on body size, which is tied to factors such as ocean productivity and competition with hatchery fish[25].

Management potential

Salmonids are charismatic species that have high public value and are critically important for Indigenous people, which significantly increases societal support for conservation and management[35]. For instance, bond funds have been allocated to support salmonids in California, indicating strong support for recovery of populations[35]. A large amount of research attention is also devoted to salmonids, which are often viewed as indicator species[35]. However, salmonid management will likely be challenged by continued land-use conversion to development and agriculture as well as increasing competition for water, particularly under drier climate scenarios[35].

There are many known management options that support salmonid survival and reproduction and increase their resilience to climate change[17,20,52]. For instance, addressing artificial barriers to fish passage (e.g., culverts, dams) allows improved access to freshwater habitat upstream, including critical spawning areas and coldwater refugia[20,52]. Increasing habitat availability and heterogeneity through restoration of both freshwater and estuarine habitats (e.g., by increasing streamflow, reconnecting floodplains and tidal flow, re-aggrading incised channels) increases food supplies and creates spatial and temporal refugia from flow and temperature extremes[20,26,52,53]. Enhancing habitat complexity and heterogeneity also allows the expression of intrinsic life history diversity, which is tied to greater resilience to stress[10,20,39,41]. Management strategies may also focus on directly ameliorating the impact of flow and temperature extremes on salmonids through climate-informed dam releases and riparian restoration that increases shading[52,54]. Overall, strategies that maintain genetic diversity within Distinct Population Segments are critical in order to allow the potential for genetic adaptation to changing environmental conditions over longer time scales[10].

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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