



Coho Salmon (*Oncorhynchus kisutch*) and Steelhead Trout (*Oncorhynchus mykiss*)

Climate Change Vulnerability Assessment for the Golden Gate Biosphere Region

This document represents an evaluation of climate change vulnerability for coho salmon and steelhead trout 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

Coho salmon (*Oncorhynchus kisutch*) are anadromous fish (i.e., they migrate from marine to fresh water for spawning) found along the west coast from central California to Alaska (Quinn 2005). This species begins its 3-year life cycle by emerging from streambed gravel in spring, and spends a year or more in fresh water before migrating into the open ocean to feed and grow for a period of up to 18 months (Quinn 2005). Central California coho typically return to their natal streams or the vicinity in the fall at three years of age, though some males may return a year early (NMFS 2012). Females create redds where eggs are deposited and fertilized by the males, and the adults die soon after spawning (Crisp 1993). Coho salmon in the Golden Gate Biosphere (GGB) region are designated by NOAA Fisheries as part of a distinct genetic population known as the Central California Coastal Evolutionarily Significant Unit (CCC ESU; NMFS 2012), which is listed as endangered under both the federal Endangered Species Act (ESA) and the California Endangered Species Act (CESA; NMFS 2023). CCC coho salmon are currently found in coastal watersheds (Figure 1), including the Garcia River, the Gualala River, the Russian River, Redwood Creek, Pine Creek, Lagunitas Creek, Pescadero Creek, and the San Lorenzo River (Moyle et al. 2017; NMFS 2023), although the last two populations are considered nearly extirpated (NMFS 2023). Coho are also found in Scott Creek in Santa Cruz County, supported by the Southern Coho Salmon Captive Broodstock Hatchery Program (NMFS 2023).

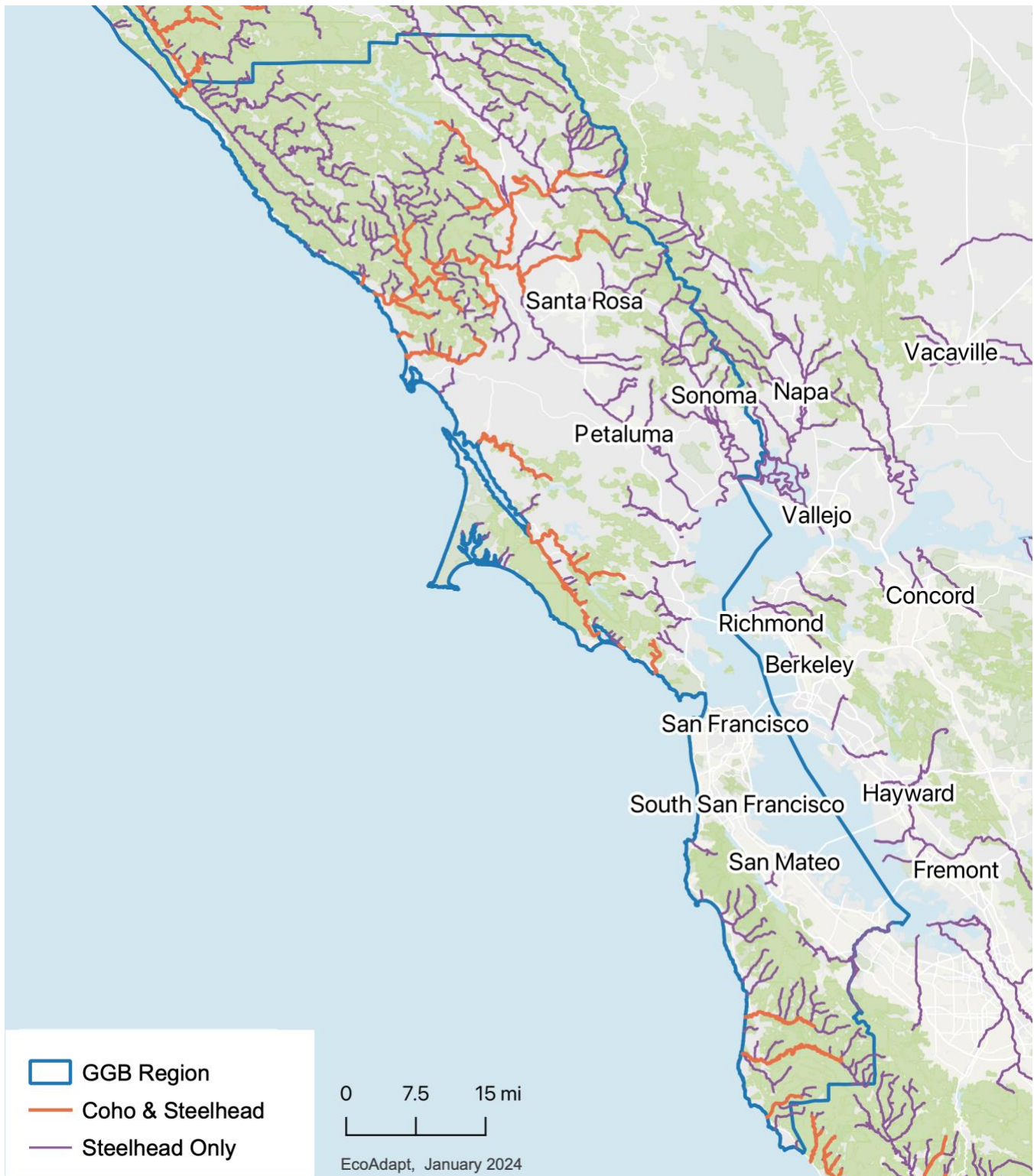


Figure 1. Distribution of coho salmon and steelhead trout within the GGB region, based on datasets published by the California Department of Fish and Wildlife representing observations of coho distribution from 1990–2022 (CDFW 2022) and winter steelhead distribution (CDFW 2012).

Steelhead trout (*Oncorhynchus mykiss*) have an anadromous life history and can be distinguished from rainbow trout, which are the same species but spend their entire life cycle in fresh water (Moyle et al. 2017). Steelhead are iteroparous, meaning they can have more than one breeding cycle, though the rate of iteroparity is highly variable and less common in steelhead than rainbow trout (Quinn 2005). Steelhead hatch after about a month in the gravel and spend up to two years in rivers and estuaries before they move offshore to feed in the north Pacific Ocean (Moyle et al. 2017). Within freshwater systems, steelhead are generally found higher up in the watershed and in higher-gradient streams than coho, which tend to be more abundant in lower gradient and in the middle reaches of streams (Quinn 2005). Because coho generally emerge earlier in the spring, they preferentially occupy lower-energy pools, displacing steelhead into riffle habitat (Young 2004). This differentiation is informed by their physiology and feeding behaviors, as steelhead tend to feed near the substrate, and their body form, which is longer and more cylindrical than laterally-compressed coho, is better suited to holding in higher-velocity habitats (Van Leeuwen et al. 2011).

Steelhead can be “winter” or “summer” maturing; the former are mature when they enter freshwater, typically in late winter or early spring, and breed soon after, while summer steelhead enter fresh water earlier the previous spring or summer but may also spawn in winter or spring (Quinn 2005). The Central California Coast Distinct Population Segment (CCC DPS; similar to the ESU designation as a genetically distinct population) are winter steelhead, and returning adults are generally three to four years old (Moyle et al. 2017). Many streams used by CCC steelhead have dams; populations of trout above those dams were historically anadromous and have been shown to be genetically close to the complementary population below the barrier within a given system, and these are still considered part of this regional population even though they cannot currently complete the anadromous life cycle (Leidy et al. 2005; Leitwein et al. 2017; Vuln. Assessment Worksheets, pers. comm., 2022). However, populations that are currently isolated upstream of barriers are not included in the DPS designation, which focuses on the anadromous form of this species (NMFS 2016a). CCC steelhead are listed federally as threatened (NMFS 2016a). Steelhead in the GGB region are found in the watersheds of the Russian River, Lagunitas Creek, the Petaluma River, Sonoma Creek, Pescadero Creek, and the San Lorenzo River (NMFS 2016a), and are also found in other small coastal watersheds and select San Francisco and San Pablo Bay tributaries (Moyle et al. 2017; Figure 1).

Chinook salmon also occur within the GGB project area, but were not considered in this assessment.

Species Vulnerability → High (*high 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

Salmonids such as coho and steelhead are dependent on clear, cool stream temperatures and adequate habitat complexity to ensure success in the spawning and juvenile life stages, and on ocean conditions that support growth and survival. As a result, coho and steelhead are sensitive to climate stressors that alter streamflow regimes and increase water temperatures, which can impact habitat availability and quality as well as fish recruitment, migration and survival. Changes in disturbance regimes, including more extreme wildfires, flooding, drought, and pathogen outbreaks, may also affect habitat availability and quality in addition to causing direct mortality. Non-climate stressors, such as urban development, agriculture, dams and water diversions, flood control structures, pollutants, and timber harvest, further stress these populations by degrading habitat conditions, reducing habitat connectivity, and directly increasing fish mortality.

Central California Coast coho salmon are at the southern extent of their geographic range, where climate change is expected to have particularly significant impacts on salmonids. Populations of both coho and steelhead have declined dramatically as a result of habitat loss, historical overfishing, and changing ocean conditions. Steelhead trout, and to a much lesser extent coho salmon, exhibit life history and genetic diversity that may enhance their ability to adapt to changing conditions; however, this diversity is threatened by very small population sizes. Both species receive significant regulatory support and resources for protection and habitat restoration under the Endangered Species Act. The general public highly values these species, and they are of significant importance to area tribes. Many existing restoration activities are likely to increase the resilience of this species group to climate change, including efforts to address land stewardship and pollutant discharges, improve connectivity and access to cold water refugia and critical spawning habitat, increase habitat complexity, and restore natural flow regimes.

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 (*high confidence*)

- **Warmer air temperatures and more frequent and intense heat waves** can drive **increases in freshwater temperatures**. Salmon require relatively cold water temperatures throughout their life cycle (Quinn 2005; NMFS 2012). An average maximum temperature of 9–12°C is

recommended for pre-emergent coho (Richter & Kolmes 2005) and 12–14°C is considered ideal for juvenile development (NMFS 2012). For steelhead, optimal incubation temperatures are below 12°C with a single daily maximum not higher than 14.5°C, and temperatures protective of steelhead juveniles are generally considered to be below 17°C (Richter & Kolmes 2005). However, during juvenile growth periods prior to outmigration, steelhead may be able to tolerate and even benefit from warmer temperatures that can drive high food productivity. For example, juvenile steelhead in Scott Creek were shown to have the highest rates of growth in the warmer waters (15–24°C) of the lagoon (Hayes et al. 2008).

As stream temperature increases, less oxygen is dissolved in water, due to both direct effects of temperature on oxygen capacity as well as increased oxygen demand from higher rates of growth and subsequent decay of organic matter (Hauer & Hill 1996). Low levels of dissolved oxygen can stress and even kill salmon (Quinn 2005). Higher temperatures can also increase salmonid pathogens, including bacteria and parasites (Schaaf et al. 2017). Water temperature can be highly variable within a stream system depending on shading, stream depth, gradient, and groundwater connectivity, among other factors. In general, more complex stream channels provide greater variability and opportunity for thermal refugia (Hauer & Hill 1996). High water temperatures are particularly problematic in modified streams with little to no heterogeneity (e.g., flood control channels and urbanized streams), and smaller streams tend to have less buffering capacity against temperature changes (Woltemade & Hawkins 2016; Vuln. Assessment Worksheets, pers. comm., 2022). Increases in harmful algal blooms (HABs) that can poison or suffocate fish and other aquatic organisms have been linked to increasing water temperatures (Gobler et al. 2017; Coffey et al. 2019). Algal blooms and their subsequent decay can drive declines in dissolved oxygen that can be stressful and even lethal to fish, particularly in semi-enclosed habitats such as lagoons where rates of water flushing are low (Bricker et al. 2008; Turner et al. 2015).

- **Changes in the amount and timing of precipitation** have important repercussions for salmon and steelhead, primarily because of their role in **altering streamflow**. High flows in the winter season are important for sediment redistribution and flushing organic materials and silt. However, extreme high flows can lead to scouring of the stream bed that can disturb or destroy incubating eggs (Wald 2009; Czuba et al. 2018), and lack of refugia for fish during extreme flows has been linked to reduced overwintering survival and is recognized as a threat to salmon recovery (Quinn & Peterson 1996; NMFS 2016a, 2023). The timing of precipitation is exceedingly important, particularly for coho which enter the streams in fall and early winter and depend on sufficient base flow to enter and migrate up streams. Lack of sufficient rain in fall and early winter can create a barrier to spawning migration, particularly in smaller streams (Quinn 2005; Vuln. Assessment Worksheets, pers. comm., 2022). Earlier onset of the dry summer season could have significant impacts on juvenile growth for both coho and steelhead, as they need sufficient cool, oxygenated waters during their development within freshwater

habitats (NMFS 2012). Decreases in spring streamflow have also been shown to be associated with a contraction in the period of outmigration for juvenile coho, which could lead to mismatches with the timing of oceanic upwelling that supports the marine life stage (Kastl et al. 2022).

- **Increases in the severity and length of future droughts**, which are closely associated with changes in temperature and precipitation described above, can impact all freshwater life stages of coho and steelhead. Drought leads to reduction or cessation of water volume and amount of wetted stream channel, reducing or eliminating habitat for juvenile fish and contributing to declining oxygen concentrations and reduced water quality (Deitch et al. 2018). Smaller streams are particularly vulnerable to drought as they have less water to lose before stream function and connectivity is compromised or lost. In 2015, severe drought was responsible for early sandbar formation on Scott Creek that delayed outmigration of coho and steelhead for several months, and studies found that growth rates of juvenile coho were lower than co-occurring steelhead (Hayes et al. 2011; Osterback et al. 2018). Drought conditions is also associated with increased surface and groundwater withdrawals that can impact stream flow and water quality for salmonids, particularly during summer months when stream flows are already low (Deitch et al. 2009).
- **Sea level rise** is likely to push saline waters inland, where a combination of anthropogenic land uses, shoreline modifications, and steeper topography is projected to drive loss of estuary habitat (Galbraith et al. 2002; Thorne et al. 2018) that is vitally important to juvenile coho and steelhead which rear in and migrate through these estuaries (Quinn 2005).

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

- **Changes in wildfire regimes**, particularly increases in fire intensity and frequency, are likely to impact coho salmon and steelhead. High-intensity wildfires are most common during heat waves and periods of drought when extreme fire behavior is more likely (Westerling 2018; Wahl et al. 2019), and high-intensity fires that burn in riparian areas and/or those that burn a large proportion of the catchment area can have particularly severe negative impacts on streams and their aquatic biota (Minshall 2003). Loss of riparian vegetation following high-severity fires can increase stream temperatures (Isaak et al. 2012; Chen & Chang 2023), and mortality events are especially likely where streams are already warming or where fish are near their thermal limits (Isaak et al. 2010). Loss of riparian vegetation can also decrease organic matter inputs and primary productivity, which can drive decreases in insect populations that support juvenile salmon (Cooper et al. 2015; Justice et al. 2017; Chen & Chang 2023). Burned areas are more susceptible to erosion, delivering ash and sediment to streams and increasing the risk of post-fire landslides and debris flows that impact spawning habitat and smother redds (Ice et al. 2004). The Lockheed fire in 2009 burned the headwaters of Scott Creek and impacted

riparian canopy cover and stream conditions, which increased risks to the coho population in this stream (NMFS 2012). The CZU fire in 2020 also led to significant losses of watershed canopy cover and consequently increased stream temperatures, erosion, and sedimentation that are likely to impact salmonid egg and fry survival, particularly for coho that prefer cooler temperatures (Crockett 2022; Smith 2022a, 2022b). Recent fires in major components of the Russian River system burned across multiple headwaters of tributaries, causing significant damage to riparian habitat and instream wood shelter and increasing landslides and sediment input to these streams (NMFS 2023). Roads and fire breaks created to provide access to firefighters can also impact salmonids by removing vegetation and increasing sediment delivery to streams (NMFS 2023).

- **Changes in flooding** can impact coho salmon and steelhead, which have evolved in tandem with the seasonal patterns and magnitude of stream flow in their natal streams (Quinn 2005). Seasonal flooding is important for reconnecting off-channel habitat used by juvenile salmon and steelhead (Beechie et al. 2013; Baldock et al. 2016; NMFS 2023), and in distributing organic matter and nutrients that support riparian food webs (Tabacchi et al. 1998). Flooding also redistributes salmon carcasses into floodplains, which historically provided an important source of marine-derived nutrients into terrestrial ecosystems (Ben-David et al. 1998), though this has been lessened by diminishing salmon returns (Merz & Moyle 2006). Loss of flooding due to drought, delayed onset of rains, or human-built structures can lead to loss of these important ecological services. Conversely, more frequent and/or severe flooding can impact salmon and their habitat through scouring of the streams and loss or disturbance of nesting gravel redds. Salmon redds can be destroyed if severe flooding intersects with the period of spawning and egg development (Wald 2009; Czuba et al. 2018).
- Salmonids are known to be affected by several **pathogens and parasites**. Low flows and high water temperatures have been linked to outbreaks of some pathogens within adult salmon populations (Belchik et al. 2004) and in juvenile steelhead (Schaaf et al. 2017). Though wild fish tend to be less susceptible to these pathogens than hatchery-reared fish, episodic outbreaks of disease can be significant, particularly for small populations (NMFS 2012). The widespread use of hatchery fish has introduced new exotic organisms that can threaten native fish (NMFS 2016b).

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

Central California Coast coho salmon and steelhead trout are highly dependent on a wide range of habitats, including streams, floodplains, estuaries, and marine waters. All of these habitats are considered sensitive to climate-driven changes that may result in altered habitat structure and function (NMFS 2012, 2016a; Crozier et al. 2019; Vuln. Assessment Worksheets, pers. comm., 2022). Landscape-level shifts in conditions, such as projected reductions in coastal fog that support maritime temperature and moisture conditions and/or shifts in vegetation communities towards species that

provide less stream shading and fog capture have the potential to impact salmonids significantly over the long term (Johnstone & Dawson 2010; DellaSala et al. 2018).

Coho and steelhead populations depend on unimpeded access to stream habitat for up to two years during their juvenile life stage, and then for outmigration to the ocean. Adults need access to spawning gravel to successfully reproduce, and the developing eggs need consistent, cool temperatures and ample flowing water to oxygenate the eggs and flush away waste products (Crisp 1993; Richter & Kolmes 2005). Coho, in particular, are affiliated with narrower temperature range preferences for emergence and development than are steelhead (Richter & Kolmes 2005; NMFS 2012). Coho are also more closely associated with lower-gradient streams that tend to be proximate to urban development, and also suffer the accumulated impacts of upstream land uses and warming temperatures across the watershed (Spanjer et al. 2018; Crozier et al. 2019). In their diet, both species consume a diverse range of zooplankton and aquatic macroinvertebrates during their juvenile life stages in freshwater and estuarine habitats (Quinn 2005).

Salmonids are additionally dependent on marine habitats, and transition to a diet of fish and crustaceans in the marine environment, though less is known about the role of their food supply as a potentially limiting factor in their marine life stage (Vuln. Assessment Worksheets, pers. comm., 2022). They are vulnerable to changes in ocean conditions (e.g., ocean temperatures, acidification, currents) that impact prey availability and the distribution of competitors and predators (Katz et al. 2013; Koenigstein et al. 2016). Warm temperatures and weak upwellings in the California Current System have been shown to reduce ocean productivity and impact marine food webs, reducing salmonid survival (Katz et al. 2013; Wells et al. 2017).

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.

- **Dams and diversions** exist throughout the entire distribution of Central California Coast coho and steelhead, and are considered significant impediments to recovery of these populations (NMFS 2012, 2016b). Over the past century and accelerating in the second half of the 20th century, numerous dams were built on coho and steelhead streams throughout the GGB region (NMFS 2012; Moyle et al. 2017). In some cases, dams were built in the upper watershed above coho spawning areas, such as those on the Russian River (NMFS 2012). Dams impede access for salmonids, and some have separated steelhead into anadromous (below barriers) and resident rainbow trout populations above barriers (NMFS 2016b; Vuln. Assessment Worksheets, pers. comm., 2022). In addition to presenting a physical barrier to migration, dams also alter stream thermal regimes, flow volume and timing, and sediment transport processes (Collier et al. 1996; Slagel & Griggs 2008). These changes impact spawning and rearing habitat by disconnecting floodplains and altering natural flow regimes and streambed composition (Power et al. 1996; NMFS 2012; Yarnell et al. 2015). Outmigration of salmonid juveniles and adult in-migration to

spawning grounds are cued by variability in flow regimes, and regulation of these flows can narrow or curtail these cues, leading to measurable declines in successful outmigration and spawning (Sturrock et al. 2020). River regulation below dams can reduce base flows, and they may also increase summer flows above baseline levels, which can result in mixing of warm waters with the cooler waters of deeper pools that leads to loss of thermal refugia for juvenile salmonids (NMFS 2012).

- **Timber harvesting** within riparian areas can increase water temperatures, affecting the growth, development, and survival of fish and invertebrate food sources (Stone & Wallace 1998; Johnson & Jones 2000). Increased channel erosion, debris slides, and mass wasting are associated with logged slopes and the presence of logging roads, leading to declines in water quality and increases in siltation where sediment and debris enters streams (Beschta 1978; Amaranthus et al. 1985; Bottorff & Knight 1996). Logging roads can also create impassible barriers for fish when they are not properly culverted (Harper & Quigley 2000). Although standards of practice and regulations are improving for timber management, the legacy of centuries of timber harvest on riparian cover include loss of large trees for recruitment of large woody debris into streams and negative impacts on instream wood, hydrology, soil structure and fish passage, all of which contribute to ongoing impacts on these fish populations (NMFS 2012, 2016b; Moyle et al. 2017).
- More than a century of **residential and commercial development** has fundamentally reshaped the watersheds of the GGB region and has had profound impacts on the ecology of its streams and rivers and the fish species they support. Development has fragmented and eliminated wetlands and reduced floodplain connectivity critical for regulation of instream flow and water quality (Duffy et al. 2016). Urbanization and the growth of associated **roads and highways** has also led to more impervious surfaces, which increase runoff and delivery of sediment and pollutants into streams. Greater flow volume and velocity as a result of this runoff increases channel erosion and scouring, which can eliminate salmon redds, habitat, and macroinvertebrate food sources (Moscrip & Montgomery 1997; Vuln. Assessment Worksheets, pers. comm., 2022). Roads and associated culverts can also contribute to channel incision and floodplain disconnection, and undersized or improperly-engineered culverts can directly impede fish passage (Goodrich et al. 2018; Vuln. Assessment Worksheets, pers. comm., 2022).
- **Flood control activities, structures, and drainages** used to protect human lives and development can eliminate salmon habitat by removing channel complexity, riparian vegetation, floodplain connectivity, and spawning and rearing habitat, and by exacerbating flashy hydrology already driven by impervious surfaces (Scouras et al. 1996; Scott et al. 2016; Vuln. Assessment Worksheets, pers. comm., 2022). Where increased flooding and scouring occurs, modified channels provide fewer velocity refugia for salmonids at multiple life stages, and fish in these modified habitats can be vulnerable to extreme precipitation events through scouring of redds and direct mortality of eggs and fry (Peters 1978).

- Livestock grazing and agriculture** has been extensive throughout watersheds of the GGB region for more than a century (Baumgarten et al. 2018, 2021). Agricultural activities increase water demand for irrigation and livestock, contributing to water withdrawals that reduce instream flow, impacting fish habitat (Bauer et al. 2015; Moyle et al. 2017); intensive agricultural land uses have been linked to declines in juvenile steelhead survival (Grantham et al. 2012). Where livestock congregate along stream banks and in riparian areas, trampling and loss of riparian vegetation can increase bank erosion and channel incision, degrading instream habitat (CDFW & NOAA Fisheries 2022). Agriculture can also increase inputs of nutrients and pesticides to streams and rivers that can both poison fish and contribute to growth in primary productivity that can reduce or impair spawning and rearing habitat (NMFS 2016b).
- Pollution and poisons** in salmon-bearing streams largely result from the agricultural and urbanization activities described above. Many pesticides are applied in coho and steelhead watersheds in association with agricultural crops, home pest control, commercial and industrial facilities, transportation corridors, parks, golf courses, and timber lands (NMFS 2012). Stormwater runoff from urbanized areas also contributes pollutants including nutrients, metals, pesticides, PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls), and emerging chemicals whose toxicity is still poorly understood (McKee et al. 2003; NMFS 2023). Additionally, recent evidence has tied a chemically-transformed product of car tire wear runoff to direct toxicity and pre-spawn mortality of coho salmon (Greer et al. 2023). Increased water temperatures can enhance the toxicity of metals in aquatic systems, so climate change is likely to exacerbate impacts to salmonids and their food web (Kazmi et al. 2022).
- Many **invasive species** impact CCC coho and steelhead populations. The New Zealand mud snail (NZMS; *Potamopyrgus antipodarum*) is a globally-distributed invasive species found in many river and lake systems in California, including the Russian River (CDFW 2023). NZMS can achieve very high densities (up to 750,000 per m²) and can outcompete other macroinvertebrates for food and habitat (Geist et al. 2022; CDFW 2023). Mud snails have been shown to have poor nutritive value for fish, and studies show that rainbow trout feeding on NZMS lose weight and have poorer body condition compared to fish not feeding on this invasive snail (Vinson & Baker 2008).

The extent to which predation by introduced fish impacts native salmon and steelhead is poorly understood, but predaceous introduced fish species including striped (*Morone saxatilis*), largemouth (*Micropterus salmoides*), and smallmouth (*Micropterus dolomieu*) bass are widely distributed through the same streams and estuaries used by these salmonids (NMFS 2016b). Predatory impacts by these invasive fish are exacerbated where habitat is simplified, leaving fewer places for fish to hide, and where low flows, spillways, and other flood control structures crowd or disorient native fish (NMFS 2016b; Vuln. Assessment Worksheets, pers. comm., 2022). Introduced bullfrogs (*Lithobates catesbeianus*) can also both prey on and compete for resources with juvenile salmonids (Moyle et al. 2017). Within riparian systems, invasive giant

reed (*Arundo donax*) and eucalyptus (*Eucalyptus* spp.) can take up significant amounts of water, leading to declines in in-stream water available to salmon and trout (Katz et al. 2013; Moyle et al. 2017).

- **Fire exclusion and suppression** can impact coho and steelhead by creating shifts in vegetative communities that impact the stream habitats on which these fish rely. Fire exclusion can create a build-up of fuel materials (Keeley 2006) that, when fire does eventually come, leads to high-intensity fires that can burn riparian vegetation and eliminate functions that regulate stream water quality, including shading and erosion control (Minshall 2003; Ice et al. 2004, 2004; Chen & Chang 2023). Aerially-applied fire retardants that are inaccurately applied during fire suppression can also cause lethal and non-lethal effects in aquatic organisms, including fish kills (NMFS 2008; Dietrich et al. 2013, 2014).
- **Hatchery production** can impact coho and steelhead by increasing competition for resources within both freshwater and marine environments, and introducing maladaptive genotypes that could have negative impacts on fitness and genetic diversity within wild fish populations (Katz et al. 2013; Moyle et al. 2017; Herbold et al. 2018). Hatcheries are also associated with disease outbreaks, and their presence can mask the magnitude of declines of wild stocks (Katz et al. 2013; Moyle et al. 2017; Herbold et al. 2018). However, conservation hatcheries that follow carefully-planned spawning rules play a critical role in reducing the short-term risks of extinction for endangered salmon in the region (Pregler et al. 2023). Federal management is clear on the need to limit hatchery efforts to programs that emphasize closely related broodstocks that are managed as conservation facilities and not for fisheries supplementation (NMFS 2012, 2016b).

Adaptive Capacity → Low (*high 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 → Low (*high confidence*)

Coho salmon in the Central California Coast ESU are state- and federally-listed as endangered (i.e., at imminent risk of extinction), while the Central California Coast steelhead DPS is federally listed as threatened. CCC coho and steelhead are considered demographically-independent populations within a larger mosaic of populations distributed from California to Alaska. Although steelhead are found further south in California, coho in this ESU are at the very southern limit of coho distribution and so are expected to be particularly vulnerable to climate change (NMFS 2012; Vuln. Assessment Worksheets, pers. comm., 2022). CCC coho salmon in the GGB region have declined from hundreds of thousands of fish half a century ago to hundreds today (NMFS 2012; Katz et al. 2013) and are considered extirpated from all rivers flowing into the San Francisco Bay (NMFS 2012). The current viability of coho salmon is considered progressively worse moving north to south in the ESU (NMFS

2023). Reduced distributions of coho and steelhead in the GGB region is due to multiple anthropogenic and climatic factors that reduce flood plain connectivity, simplify, degrade and contract salmonid habitat, and create barriers to fish passage that restrict distribution and genetic connectivity (Leidy et al. 2005; NMFS 2016b, 2023; Crozier et al. 2019).

Intraspecific/life history diversity → Moderate (high confidence)

Both coho salmon and steelhead trout are well-studied species, and diversity in their life history has been well documented (Quinn 2005; Vuln. Assessment Worksheets, pers. comm., 2022). Steelhead exhibit a wide array of life history patterns in terms of migration timing, freshwater residence, age at migration, use of varied habitats including estuaries and lagoons, and iteroparity (Quinn 2005; Hayes et al. 2011; Moyle et al. 2017). Steelhead can also persist above barriers as resident trout and then resume anadromy if the barrier is removed (Leidy et al. 2005). Coho are less flexible in their life history patterns, usually demonstrating a single-spawning, 3-year life cycle. However, some fraction of the coho population may return as two-year-old males, or jacks, and some juveniles may spend an extra year in freshwater, which allows for genetic exchange between the 3-year classes (Quinn 2005; Vuln. Assessment Worksheets, pers. comm., 2022).

Resistance and recovery → Low (high confidence)

Coho have been extirpated from watersheds throughout the Pacific Northwest as well as many within the GGB region (Vuln. Assessment Worksheets, pers. comm., 2022). Steelhead show comparatively greater life history variability that may make the population more flexible with respect to changing conditions, and they can also tolerate a wider range of environmental conditions, including the ability to exhibit semelparity or iteroparity depending on whether they have access to marine waters for the completion of their life cycle (Leidy et al. 2005; NMFS 2016b; Vuln. Assessment Worksheets, pers. comm., 2022).

Management potential → Moderate (high confidence)

Salmonids are charismatic species that have high public value, provide valuable sports fisheries (though coho harvest is currently prohibited), and are critically important for area tribes (Moyle et al. 2017; Vuln. Assessment Worksheets, pers. comm., 2022). Because of their federally-listed status, CCC coho and steelhead are afforded regulatory protection and significant investments have been made in their protection and recovery. These funds may be expected to grow substantially with recent federal passage of policies such as the Inflation Reduction Act (NMFS 2016b, 2023; USFWS 2023; Vuln. Assessment Worksheets, pers. comm., 2022). There is a large amount of research attention devoted to salmon biology, conservation, and recovery, and also significant public involvement in education and restoration activities to support these threatened and endangered populations (NMFS 2016b, 2023; Vuln. Assessment Worksheets, pers. comm., 2022). However, salmon face steep challenges including climate change, dams and diversions, and ongoing habitat degradation and loss that is extremely

expensive and politically challenging to address (Vinson & Baker 2008; Moyle et al. 2017; Crozier et al. 2019; Vuln. Assessment Worksheets, pers. comm., 2022).

There are many management options that support salmonid survival and reproduction and are likely to increase their resilience to climate change (Beechie et al. 2013). These include removing artificial barriers to fish passage, including culverts and dams, which allows salmon to access upstream habitat, including critical spawning areas and thermal refugia (Beechie et al. 2013; Moyle et al. 2017).

Increasing habitat availability and heterogeneity of both freshwater and estuarine habitats (e.g., by reconnecting floodplains and tidal connectivity, adding in-stream complexity through wood placement and removal of simplifying or constricting structures, or re-aggrading incised channels) increases food supply and enhances thermal and flow refugia critical to spawning and rearing (Herbold et al. 2018; NMFS 2023). Efforts to restore natural flow regimes including protecting in-stream flow, groundwater connectivity, and natural seasonal flooding can support in- and out-migration as well as protect habitat availability and cold-water refugia (Beechie et al. 2013; Null et al. 2013, 2023; Moyle et al. 2017).

Cooperative agreements and regulations that support better forest practices such as California's Forest Practice rules address the legacy and ongoing impacts of commercial forestry (NMFS 2012, 2023).

Enhancing habitat complexity and natural flow regimes supports salmonid life history diversity, which can enhance resilience to stressors (Beechie et al. 2006; Swales 2010; Herbold et al. 2018; Crozier et al. 2019). Overall, strategies that maintain genetic diversity within these populations are critical in order to allow for the potential for genetic adaptation to changing environmental conditions over longer time scales (Moyle et al. 2017; Crozier et al. 2019).

Recommended Citation

EcoAdapt. 2024. Coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*): Climate change vulnerability assessment summary for the Golden Gate Biosphere region. EcoAdapt, Bainbridge Island, WA.

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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