Appendix B: Climate Change

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CLIMATE CHANGE

"Continued research on how salmon will cope with climate change is important and should be emphasized. But we also need to support efforts to control greenhouse gases, do everything we can to help wild salmon adapt to a new, changing environment, and work on adapting to a new way of doing business through proactive, precautionary management and actively promoting wild salmon conservation."

- Pete Rand, IUCN SSC Salmonid Specialist Group

CLIMATES SCENARIOS: CHINOOK SALMON AND STEELHEAD RECOVERY

Reducing the amount of greenhouse gasses in the atmosphere will require national and international actions beyond the scope of this recovery plan. However, identification and mitigation of impacts from global climate change can occur at local geographic scales (Osgood 2008). Management of impacts must consider climate variability. Otherwise, we risk implementing management strategies that are inconsistent with evolving environmental conditions, thereby increasing the probability of recommending ineffectual or irrelevant recovery actions.

Climate is a major driver of the geographic distribution and abundance of salmon and steelhead. Shifts in climate can have a profound socio-economic and ecological impact on fisheries (Osgood 2008). Over 60 percent of California's anadromous salmonids are especially vulnerable to climate change, and future climate change will affect our ability to influence their recovery in most or all of their watersheds (Moyle *et al.* 2008; Moyle *et al.* 2013).

This chapter provides an overview of probable climate change impacts on CC Chinook Salmon, NC Steelhead, and CCC steelhead, examines three climate change scenarios in California, describes which populations may be the most vulnerable, and recommends actions to improve the resiliency of the species.

OVERVIEW

A preponderance of the best available scientific information indicates that the Earth's climate is warming. Global warming is driven by the accumulation of heat-trapping greenhouse gasses in the atmosphere (Oreskes 2004; Battin *et al.* 2007; Lindley *et al.* 2007). Human activities are warming the earth by increasing the concentrations of greenhouse gases, such as carbon dioxide and methane. Activities such as burning coal, oil, and gas for transportation and power generation and removal of trees are largely responsible for the increase in greenhouse gases (IPCC 2007). Concentrations of these gases in the atmosphere affect the amount of incoming solar radiation and outgoing thermal radiation (Forster *et al.* 2007). These gasses absorb some of the outgoing thermal radiation, preventing it from leaving Earth's atmosphere (Forster *et al.* 2007). As the concentrations of greenhouse gasses increase, more heat is trapped, and the Earth's climate continues to warm. This warming affects all aspects of Earth's climate systems: wind patterns; ocean currents; where, when, and how much it rains; how much precipitation falls as rain and how much as snow; soil moisture; sea levels; and the saltiness and acidity of the oceans.

The greenhouse gas of greatest concern to scientists is carbon dioxide (CO_2). The increase in CO_2 since the dawn of the industrial revolution is largely responsible for global warming (IPCC 2007). Concentrations of CO_2 in the atmosphere are increasing rapidly and currently exceed the highest concentrations reached during the last 400,000 years (Feely 2004; IPCC 2007).

The global increase in CO_2 affects both terrestrial and marine environments. These environments absorb about 50% of the CO_2 released by human activities; the remainder persists in the atmosphere (Feely 2004). Oceans absorb approximately 30% of the CO_2 released into the atmosphere due to anthropogenic activities (Feely 2004; Dybas 2007) and terrestrial systems approximately 20% of the CO_2 (Feely 2004).

Changes in seasonal temperature regimes are already affecting fish and wildlife (Quinn and Adams 1996; Schneider and Root 2002; Walther *et al.* 2002; Root *et al.* 2003; Perry *et al.* 2005; Devictor *et al.* 2008; Chen *et al.* 2011; Comte and Grenouillet 2013). These effects manifest themselves as biome and range shifts, changes in the timing of spring activities including earlier arrival of migrants and earlier breeding in birds, butterflies and amphibians, and earlier shooting and flowering of plants (Walther *et al.* 2002; Perry *et al.* 2005; Comte and Grenouillet 2013; Grimm *et al.* 2013). A number of fish have been observed to shift their distributions to higher elevations upstream, deeper water in oceans, or poleward in response to warming waters (Osgood 2008; Comte and Grenouillet 2013). As global temperatures rise, temperatures, winds, and precipitation patterns at smaller geographic scales are expected to change (CEPA 2006; Osgood 2008). In terrestrial environments, freshwater streams important to salmonids may experience increased frequencies of floods, droughts, lower summer flows and higher temperatures (CEPA 2006; Luers *et al.* 2006; Lindley *et al.* 2007; Schneider 2007; Osgood 2008).

In the oceans, climate variability is a key factor controlling the distribution and abundance of marine organisms and ecosystem structure. Changes in physical ecosystem drivers related to climate change may change species distribution and abundance, and community interactions and structures (Harley *et al.* 2006). In marine environments, ecosystems and habitats important to sub adult and adult salmonids are likely to experience changes in temperatures, circulation and chemistry, and food supplies (Diffenbaugh *et al.* 2003; Barth *et al.* 2007; Brewer and Barry 2008; Osgood 2008; Turley 2008; O'Donnell *et al.* 2009). Estuarine and lagoon areas are likely to experience sea level rise and changes in stream flow patterns (Scavia *et al.* 2002).

Because salmon and steelhead depend upon freshwater streams and oceans during different stages of their life history cycle, their populations are likely to be adversely affected by many of the impacts as shown below in Figure 1.

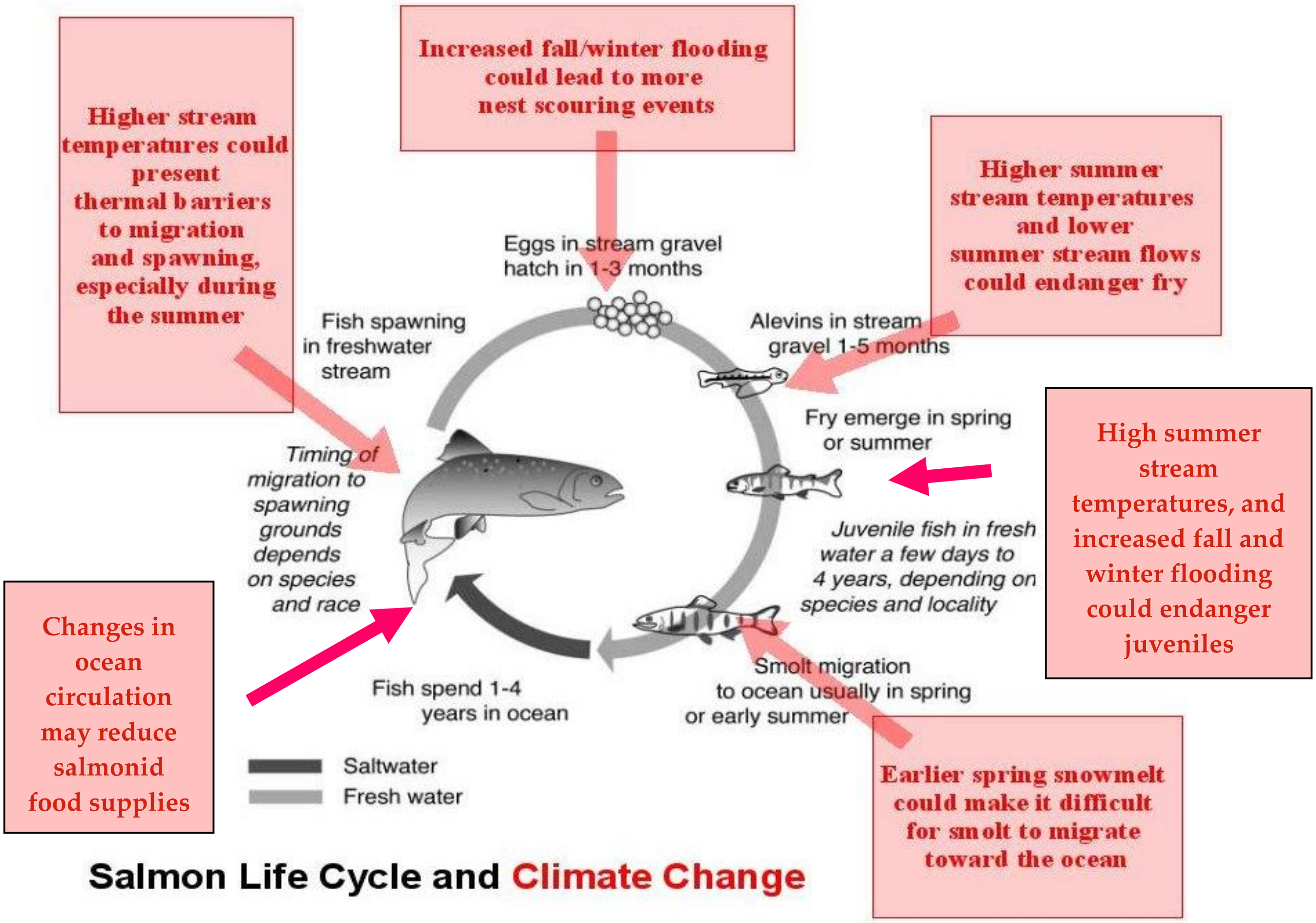

Figure 1: Potential climate change related impacts on salmonids (modified from Casola *et al.* 2005).

CLIMATE CHANGE IN CALIFORNIA

The impacts from a changing climate are already evident in California (Barnett *et al.* 2008; Bonfils *et al.* 2008), and these impacts have the potential to significantly alter aquatic habitats. The annual amount of runoff from spring snowmelt to the Sacramento River declined in the 20th Century by about 9 percent, extreme heat events have increased, average annual temperatures have increased by 0.83 degrees Celsius, seas have risen approximately 7 inches, and sea surface temperatures have increased (Kadir *et al.* 2013). Scientists expect climate change trends in California are likely to include further increases in average air temperatures, rising sea levels, changes in precipitation, and change in the frequency and/or severity of extreme events such as heat waves, droughts, and catastrophic fires (Hanak *et al.* 2011; Mastrandrea and Luers 2012).

IMPACTS ON FRESHWATER STREAMS

Modeling of climate change impacts by the end of the Century in California suggests average summer air temperatures are expected to increase (Lindley *et al.* 2007). Heat waves are expected to occur more often, and heat wave temperatures are likely to be higher (Hayhoe *et al.* 2004). Total precipitation in California may decline; the frequency of critically dry years may increase (Lindley *et al.* 2007; Schneider 2007; Moser *et al.* 2012). Wildfires are expected to increase in frequency and magnitude, by as much as 55 percent under the medium emissions scenarios modeled (Luers *et al.* 2006; Westerling *et al.* 2011; Moser *et al.* 2012). Vegetative cover may also change, with decreases in evergreen conifer forest and increases in grasslands and mixed evergreen forests. Impacts on forest productivity are less clear. Tree growth may increase under higher CO_2 emissions, but as temperatures increase, the risk of fires and pathogens also increases (CEPA 2006). NMFS anticipates these changes will affect freshwater streams in California used by CCC steelhead, NC steelhead, and CC Chinook salmon as described below.

AIR TEMPERATURE

Changes in air temperature significantly impact stream temperature (Poole and Berman 2001). Increasing air temperatures have the potential to limit the quality and availability of summer rearing habitat for salmonids. For example, modeling results reported by (Lindley *et al.* 2007) show that as warming increases from low greenhouse gas emission scenarios to very high emissions scenarios, the geographic area experiencing mean August air temperature exceeding 25 degrees by 2100 moves further into coastal drainages and closer to the Pacific Ocean. Stream temperatures will likely increase in these areas. Many stream temperatures in the CCC steelhead NC steelhead DPSs, and CC Chinook ESU areas are at or near the high temperature limit of these species and increasing water temperatures may limit habitat suitability in many stream reaches.

PRECIPITATION

The likely direction of change in amount of rainfall in Northern and Central Coastal streams under various warming scenarios is less certain, although as noted above, total rainfall across the state is expected to decline. For the California North Coast (including the northern part of the NCCC Domain), some models show large increases (75 to 200 percent) while other models show decreases of 15 to 30 percent (Hayhoe *et al.* 2004) by the end of this Century. Increases in rainfall during the winter have the potential to increase the loss of salmon redds via streambed scour from more frequent high stream flows. Reductions in precipitation will likely lower flows in streams during the spring and summer, reducing the availability of flows to support smolt migration to the ocean and the availability of summer rearing habitat.

WILDFIRE

The frequency and magnitude of wildfires are expected to increase in California (Luers *et al.* 2006; Westerling and Bryant 2006; Westerling *et al.* 2011; Moser *et al.* 2012). The link between fires and sediment delivery to streams is well known (Wells 1987; Spittler 2005). Fires can increase the incidence of erosion by removing vegetative cover from steep slopes. Subsequent rainstorms produce debris flows that carry sediments to streams. Increases in stream sediment can reduce egg to emergence survival and can reduce stream invertebrate production -- an important food source for rearing salmon and steelhead juveniles (Bjornn and Reiser 1991; Waters 1995).

VEGETATIVE COVER

Changes in vegetative cover can impact salmon and steelhead habitat in California by reducing stream shade (thereby promoting higher stream temperatures), and changing the amount and characteristics of woody debris in streams. High quality habitat for most salmonid streams with extant populations is dependent upon the recruitment of large conifer trees to streams. Once these trees fall into streams, their trunks and root balls provide hiding cover for adult and juvenile salmonids. In streams, large conifer trees can also interact with stream flows and stream beds and banks, sorting sediments to create areas with appropriately sized gravels for spawning, and creating deep stream pools needed by steelhead to escape high summer water temperatures.

Impacts on the Marine Environment

Oceans are also warming, with considerable interannual and inter-decadal variability superimposed on the longer-term trend (Bindoff and Willebrand 2007). Current changes in the North Pacific include changes in surface wind patterns that impact the timing and intensity of upwelling of nutrient-rich subsurface water, and rising sea surface temperatures (SST) that increase the stratification of the upper ocean and increasing ocean acidification which may change plankton community compositions with bottom-up impacts on marine food webs (ISAB 2007). Scientists studying the impacts of global warming on the marine environment predict the coastal waters, estuaries, and lagoons of the West Coast of the United will experience continued 1) increases in climate variability, 2) changes in the timing and strength of upwelling (the spring transition), 3) warming, stratification, and changes in ocean circulation, and 4) changes in ocean chemistry (Scavia *et al.* 2002; Diffenbaugh *et al.* 2003; Feely 2004; Harley *et al.* 2006; Osgood 2008). Estuaries and lagoons will also likely undergo changes in environmental conditions due to sea level rise (Scavia *et al.* 2002).

Climate Variability and Upwelling (the Spring Transition)

Global warming is likely to change the frequency and magnitude of natural climate events that affect the Pacific Ocean (Harley *et al.* 2006; Osgood 2008). For instance, winter storms may become frequent and severe. El Nino events may occur more often or be more severe. The Pacific Decadal Oscillation (PDO) is expected to remain in a positive value condition (resulting in warmer ocean conditions in the California Current), which may result in reduced marine productivity and salmonid numbers off the coast of California (Mantua *et al.* 1997; Osgood 2008). In addition, the plankton production fueled by coastal upwelling may become more variable than in the past, both in magnitude and timing. While the winds that drive upwelling are likely to increase in magnitude, greater ocean stratification may reduce their effect (Osgood 2008). The strongest upwelling conditions may also occur later in the year (Diffenbaugh *et al.*

2003; Osgood 2008). The length of the winter storm season may also affect coastal upwelling. For example, if the storm season decreases in length, upwelling may start earlier and last longer (Osgood 2008).

Weak early season upwelling can have serious consequences for the marine food web, affecting invertebrates, birds, and potentially other biota (Barth *et al.* 2007). Weak upwelling results in low plankton production early in the spring, when salmonid smolts enter the ocean. Plankton is the base of the food web off the California Coast, and low levels of plankton reduce food levels throughout the coastal environment. Variations in Chinook salmon and coho salmon survival and growth in the ocean are similar to copepod (a salmonid food item) biomass fluctuations, which are also linked to climate variations (Hooff and Peterson 2006; Mackas *et al.* 2007; Peterson 2009; Burke *et al.* 2013; Daly *et al.* 2013). Salmon smolts entering California coastal waters could be impacted by reduced food supplies, which lower marine survival rates (Osgood 2008).

OCEAN WARMING

Ocean warming has the potential to shift salmonid ranges northward. Warming of the atmosphere is anticipated to warm the surface layers of the oceans, leading to increased stratification. Many species may move toward the Earth's poles, seeking waters that better meet their temperature preferences (Osgood 2008; Cheung *et al.* 2009). Salmonid distribution in the ocean is defined by thermal limits and salmonids may move their range in response to changes in temperatures and prey availability (Welch *et al.* 1998). The precise magnitude of species response to ocean warming is unknown, although recent modeling suggests that by mid-Century high latitude regions are likely to experience the most species invasions, while local extinctions may be the most common in the tropics; Southern Ocean, North Atlantic, the Northeast Pacific Coast, and enclosed seas (such as the Mediterranean) (Cheung *et al.* 2009).

OCEAN CIRCULATION

The California Current brings prey items for salmonids south along the coast. This current, driven by the North Pacific subtropical gyre, starts near the northern tip of Vancouver Island, Canada and flows south near the coast of North America to southern Baja, Mexico (Osgood 2008). Coastal upwelling and the PDO influence both the strength of this current and the types of marine plankton it contains. If upwelling is weakened by climate change, and the PDO tends toward a warm condition, the quantity and quality of salmonid food supplies brought south by the current could decrease (Osgood 2008). However, if rising global temperatures increase the strength of coastal upwelling, cold water fish like salmonids may do well regardless of the PDO phase (Osgood 2008).

Ocean Acidification

Although impacts to salmon and steelhead are difficult to predict, increases in ocean acidity are of concern because they may affect the Pacific Ocean's food web. The increase in atmospheric CO_2 is changing the acidity of the oceans (Feely 2004; Turley 2008; O'Donnell *et al.* 2009). The world's oceans absorb CO_2 from the atmosphere, and rising levels of atmospheric CO_2 are increasing the amount of CO_2 in seawater (Feely 2004; Turley 2008; Hönisch *et al.* 2012). Chemical reactions fueled by this CO_2 are increasing ocean acidity and the speed by which acidity is increasing is similar only to rates during some ancient planet-wide extinction events (Sponberg 2007; Brewer and Barry 2008; Turley 2008; Hönisch *et al.* 2012). Shelled organisms in the ocean (some species of phytoplankton and zooplankton, and snails, urchins, clams, *etc*.) are likely to have difficulty maintaining and even forming shell material as CO_2 concentrations in the ocean increase (Feely 2004; The Royal Society 2005; Brewer and Barry 2008; O'Donnell *et al.* 2009). Under worst case scenarios, some shell forming organisms may experience serious impacts by the end of this century (The Royal Society 2005; Sponberg 2007; Turley 2008). In addition, increased CO_2 in the oceans is likely to impact the growth, egg and larval development, nutrient generation, photosynthesis, and other physiological processes of a wide range of ocean life (Turley 2008; O'Donnell *et al.* 2009). However, the magnitude and timing of these impacts on ocean ecosystems from these effects remains uncertain (Turley 2008).

Estuarine Habitat

Impacts to estuaries and lagoons from global climate change may affect CCC steelhead, NC steelhead, and CC Chinook because many populations of these species depend on coastal estuaries and lagoons for extended juvenile rearing. Significant portions of juvenile steelhead populations in some coastal streams utilize lagoons for rearing (Smith 1990; Zedonis 1992; Cannata 1998; Hayes *et al.* 2008). Research indicates that steelhead in some coastal streams may be dependent on lagoon rearing for high numbers of adult returns (Bond 2006; Hayes *et al.* 2008). Both steelhead and Chinook salmon smolts need high quality estuaries and lagoons for rearing and to transition to salt water. Time spent feeding in estuaries and lagoons is important as smolt size at ocean entry greatly enhances marine survival (Ward and Slaney 1988; Holtby *et al.* 1990; Bond *et al.* 2008). As the steelhead and salmon return to their natal stream to spawn, they move once again from saltwater to freshwater; they depend on the near shore and estuarine environments to assist with this transition.

Estuaries are likely to become increasingly vulnerable to eutrophication (excessive nutrient loading and subsequent depletion of oxygen) due to changes in precipitation and freshwater runoff patterns, temperatures, and sea level (Scavia *et al.* 2002). These changes can affect water residence time, dilution, vertical stratification, water temperature ranges, and salinity. For example, salinities in San Francisco Bay have already increased because increasing air temperatures have led to earlier snow melt, reducing freshwater flows in the spring. If this trend continues and strengthens, salinities in the Bay during the dry season will increase, contributing additional stress to an already altered and highly degraded ecosystem (Scavia *et al.* 2002). If these impacts occur elsewhere, the result may be reduced food supplies for steelhead and Chinook salmon that use estuaries for rearing before going to sea. Fewer salmonids would be expected to survive to complete their life cycle.

SPECIES VULNERABILITY TO CLIMATE CHANGE

We considered species vulnerability assessments for climate change described or reviewed by Fussel and Klien (2006), Klausmeyer *et al.* (2011), Thomas *et al.* (2011), and Snover et al. 2013.

Given that much of the data (as Klausmeyer *et al.* 2011 indicate) are not available to fully conduct these assessments, we choose to develop our own approach that is somewhat similar to what we reviewed. We used the information generated through the CAP process as the foundation for our vulnerability assessment. Our approach evaluated the vulnerability of each recovery focus population for each species relative to the other populations of that species in the NCCRD. Vulnerability was evaluated by: 1) using the available information on climate change to select ecological attributes, indicators and threats from the CAP process most likely affected by climate change, 2) examining how these indicators, attributes, and threats may be affected by climate change using climate change emissions scenarios, 3) weighting the results of CAP threat and current condition vulnerability assessments for those ecological attributes, indicators and threats identified for each focus population, 4) summing the weights for each focus population, and 5) using the sums to rank the focus populations relative to each other for each species. Our approach will need to be improved upon as more information becomes available. For example, we did not attempt to assess whether or not specific populations of each species would be more or less vulnerable to climate change impacts in the marine environment.

After we evaluated ecological attributes, indicators, and threats under the scenarios, and ranked the vulnerability of focus populations or focus areas for each species, we considered changes that may be needed to recovery priorities and strategies for CCC steelhead, NC steelhead and CC Chinook salmon.

CLIMATE CHANGE SCENARIOS

As described above, climate change is likely to further degrade salmonid habitats, regardless of other impacts to streams, rivers, estuaries, and oceans. However, scientists are currently unable to make precise predictions of impacts. To overcome this difficulty, scientists have projected future scenarios based on reasonable assumptions from available information. These projected scenarios describe how climate change may affect various aspects of the environment. NMFS used these climate change scenarios to help evaluate the impacts of climate change on CCC steelhead, NC steelhead, CC Chinook salmon and their habitats using the CAP ecological attributes, indicators, and threats most likely affected by climate change.

NMFS has relied mainly on the scenario analyses done for the California Climate Change Center, part of the California Energy Commission (Cayan *et al.* 2012), and the California Environmental Protection Agency (CEPA 2006). We also looked at temperature and precipitation projections from climatewizard.org as well as Cal-Adapt.org for comparison. Each set of projected scenarios relies on averaging the results of several climate models (16 for climatewizard and 4 for Cal-Adapt). This multi-model approach is "the state of the science" (Mote and Salathe 2010) and recommended by climate change researchers (Littell *et al.* 2011; Mote *et al.* 2011; Wenger *et al.* 2011). The results for California, including the multi-species plan area, are similar, as can be seen in Figure 2, Figure 3, below, which show temperature and rainfall projections from climatewizard.org and Cal-Adapt.org under the same emission scenario (Figure 4, Figure 5). All projections examined by NMFS show air temperatures on the California Coast are expected to increase, perhaps as much as 4-6 degrees C under the A2 emission scenario[1]. As discussed briefly above, precipitation projections are more ambiguous. For example, of the 16 GCMs in climate wizard.org, less than 80% were in agreement regarding the direction of precipitation change (more or less rainfall) for much of the United States, including the multi-species recovery plan area. The averaging of the precipitation projections done by climate wizard and Cal-Adapt shows less rainfall may occur in the multi-species recovery plan area.

[1] The A2 emissions scenario is a common high CO_2 emissions scenario used by climate modelers. See, for example, IPCC 2000. We have briefly described the A2 emissions scenario, and two others later in this chapter.

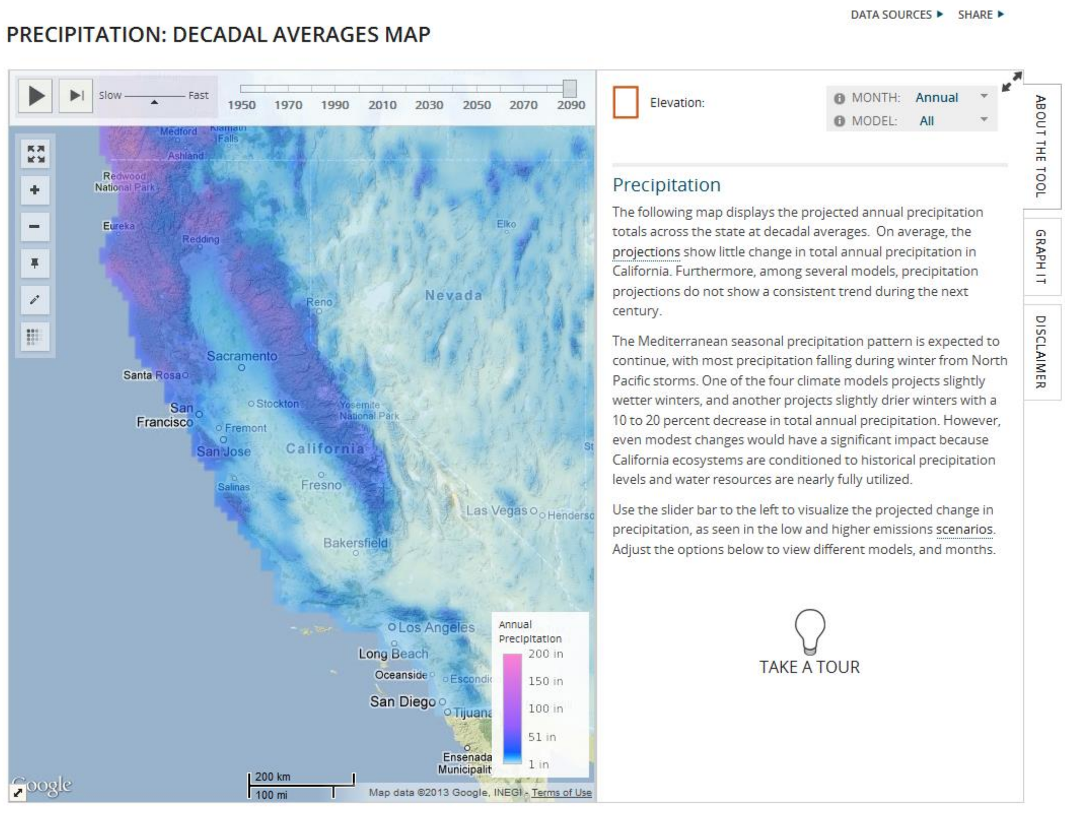

Figure 2: Cal-Adapt.org high emissions scenario for precipitation in 2090.

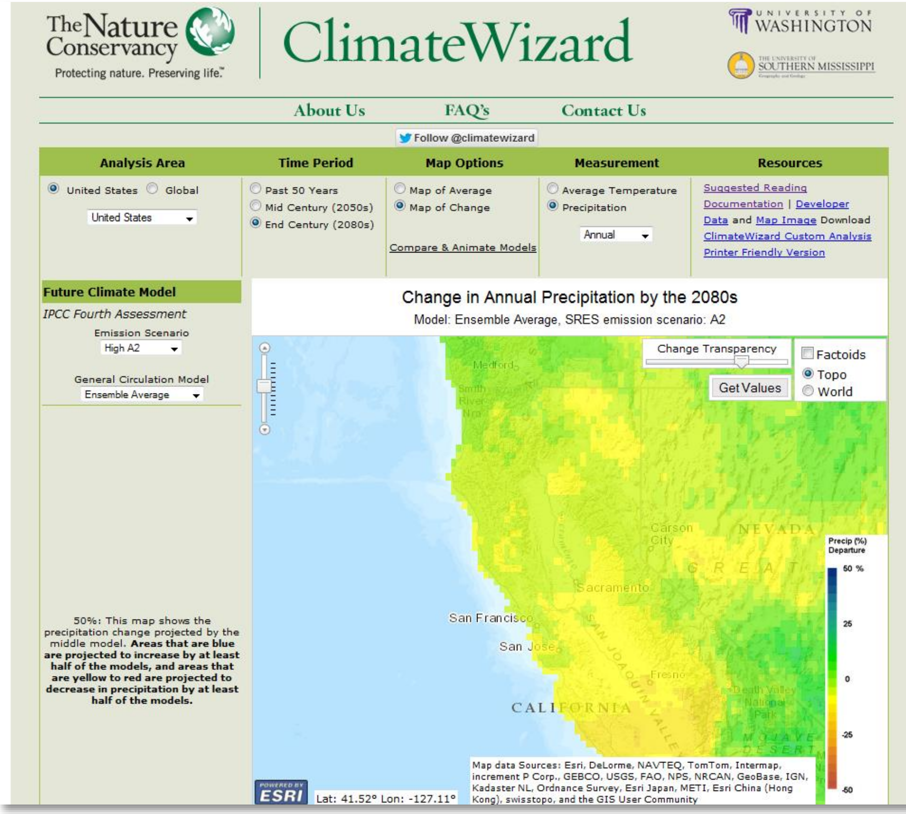

Figure 3: Climate-wizard.org model ensemble average of: precipitation change by 2080s for much of California.

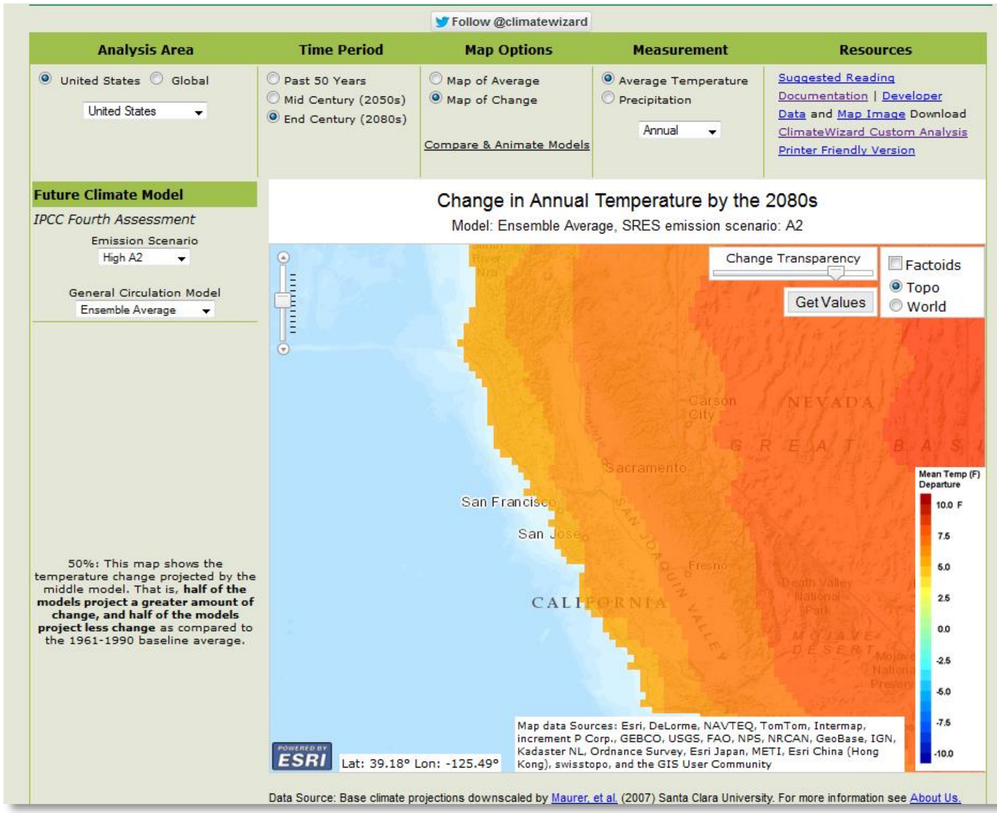

Figure 4: Climate-wizard.org model ensemble average of temperature change by 2080s for much of California:

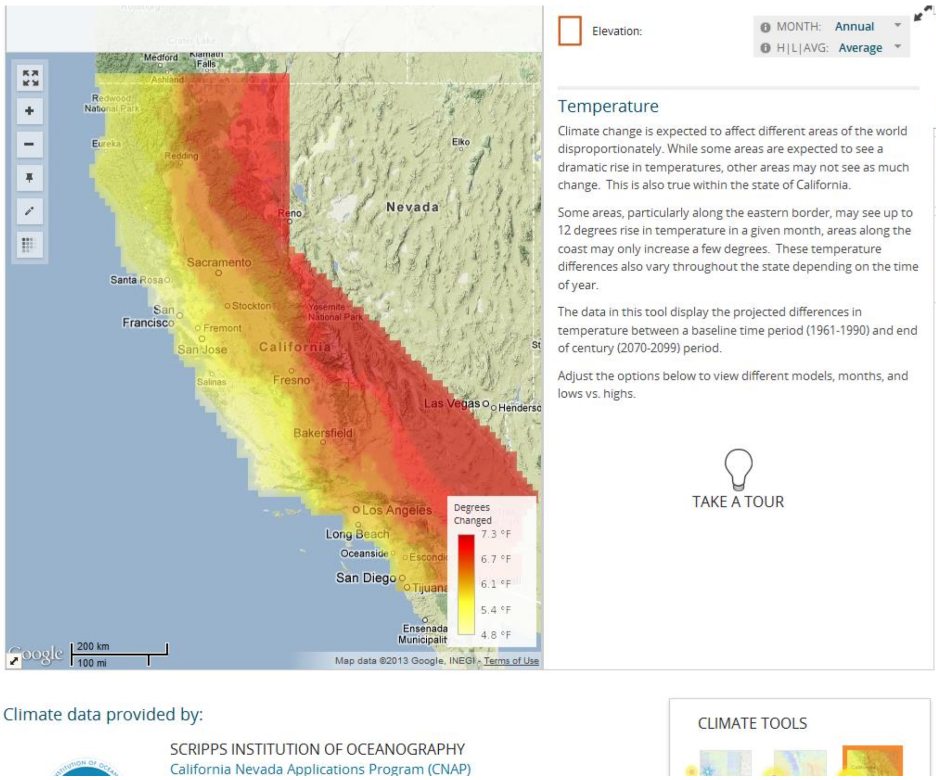

Figure 5: Cal-Adapt.org high emissions scenario for temperature in 2090

CEC considered two CO_2 emissions scenarios in 2012 (moderately high and lower emissions) These scenarios, A2 and B1, came from the Forth International Panel on Climate Change (IPCC) assessments (Cayan *et al*. 2012). CEPA considered 3 scenarios, the two considered by CEC above and a high emissions scenario from the IPCC, A1Fi, (CEPA 2006). Details of the environmental, population, economic, resource use, and technological assumptions behind these scenarios are briefly described in Cayan *et al*. (2012), CEPA (2006), and IPCC (2000). Readers wishing more information on these emissions scenarios can find the 4th IPCC assessment reports at www.ipcc.ch. Although CEC in 2012 decided not to use the high emissions scenario CEPA used in 2006, we decided to keep it as we believe it represents a reasonable worst case scenario of the highest CO_2 emissions possible during this century[2]. These scenarios (like those of the other projections we reviewed) are not precise predictions of how California will be affected by climate change. Rather, they are projections of changes that

[2] The high emissions scenario assumes rapid world-wide growth via reliance on fossil fuels. The moderately high emissions scenario assumes that the magnitude of economic growth and technological change depends on location. The low emissions scenario assumes slower growth, local differences, and more sustainable economies and technologies (IPCC 2000).

could occur by the end of this century in temperature, rainfall, vegetation, *etc*., at a Statewide, West Coast wide, or larger eco-region scales[3] due to different emission levels

Climatic changes during shorter time scales are difficult to detect. For example, natural climate variability within ten year periods currently overwhelms scientists' ability to identify changes from global warming at such short time scales (Cox and Stephenson 2007). Progress is being made on forecasting changes from climate change within short time periods at global and large regional scales (Smith and Murphy 2007; Keenlyside and Ba 2010). Unfortunately, predicting impacts on more local geographic areas in short time frames, such as the first decade of multi-species recovery plan implementation, remain elusive. Given California's complex topography and variety of micro climates, particular local areas in the CCC steelhead, NC steelhead and CC Chinook salmon ESU and DPSs may respond differently to climate changes[4].

In this recovery plan, NMFS considered the potential effects of the A1Fi high emissions scenario, A2 moderately high emissions scenario, and B1 low emissions scenario on future habitat conditions and threats for CCC steelhead, NC steelhead, and CC Chinook salmon in the freshwater and estuarine environments[5]. We identified the habitat attributes, indicators, and threats used in this multi-species Recovery Plan that are likely the most directly vulnerable to climate change by comparing these variables to those discussed in the climate change literature summarized above. We included attributes and indicators directly related to changes in temperature, precipitation, fire, vegetative cover and estuaries (passage flows, passage at river

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[3] Where CEC 2012 and Cayan et al. 2012 have provided updated information on the moderately high and lower emissions scenarios for California, we have used that information along with CEPA 2006.

[4] For example, an article in the Santa Rosa Press Democrat reports the incidence of high temperatures in the Ukiah Valley (which includes a large portion of the mainstem Russian River) has decreased during the last 50 years, while the incidence of high temperatures in Napa Valley have increased (Geniella 2008). This information suggests that climate change may actually be decreasing the incidence of high temperatures in the vicinity of the Russian River. Due to the absence of peer reviewed climate change models linking global temperature changes to the Russian River watershed, we cannot project cooler temperatures in the Ukiah Valley forward into the future without developing a series of additional scenarios. Ukiah Valley temperatures could continue to drop at the same rate or a different rate, stabilize at some point in time, stabilize and then begin to go up, *etc*.

[5] We focused on the freshwater and estuarine environments because more is known about habitat conditions, underlying processes that create and maintain habitat, and there is more information about what may happen due to climate change.

mouths, redd scour, temperature, *etc*). We also chose different attributes and indicators based on differences in species life history. For example, we chose indicators for the juvenile life history stage for steelhead because of this species juvenile life history stage spends more time in freshwater streams than juvenile Chinook salmon. After we selected attributes, indicators and threats, we attempted to identify how those attributes, indicators and threats are likely to change based on the emissions scenarios we selected. In many cases, the scenarios available for California are not specific enough for us to project changes in habitat attributes, indicators or threats with much confidence. We do conclude that greater detrimental changes are likely under higher CO_2 emissions.

<u>Indicators, and threats most likely affected by climate change.</u>

Our analysis focused on the following habitat indicators and threats:

- Precipitation (droughts, storms, flooding)
    - Passage flows (all life stages)
    - Passage at River Mouths (adults and smolts)
    - Baseflow*
    - Velocity refuge
    - Redd Scour*
- Temperature
- Riparian Species composition, and canopy cover
- Disease, Predation, and Competition
- Fire and Fuel Management
- Estuary/lagoon
        - *For this analysis, these habitat attributes/indicators, or threats, are primarily influenced by either Droughts, Storms or Flooding.

We did not address other indicators and threats identified for CCC steelhead, NC steelhead, or CC Chinook salmon in this Recovery Plan because: (1) they can be easily linked to changes in the above indicators or threats, or (2) we cannot make reasonable projections regarding the impacts of global climate change on these indicators or threats based on the available information. For example, agricultural practices (identified as a threat in the Multi-Species

Recovery Plan) can result in sedimentation and turbidity. It is unclear how farmers will respond to changes in precipitation and temperature, and what resulting impacts on sediment and turbidity would be. Farmers may respond by (1) using more water, (2) stopping farming and allowing the land to go fallow, (3) stopping farming and selling the land for residential or urban development, (4) changing crops or modifying crop rotations, (5) building additional reservoirs and/or, (6) conserving water resources, *etc*. Similarly, we did not include the number of diversions or impoundments because while they often indicate watersheds with streamflow issues, the presence of dams may also provide a more assured cold water supply for some populations in the face of climate change.

We also did not include NMFS pool habitat indices, LWD, cover and shelter data because these parameters may fluctuate based on climate change impacts. In some areas pool habitats may improve if large floods remove sediment that accumulates and fill in pool habitats. Large floods may also trigger landslides that supply LWD to streams. Conversely, large floods may remove LWD and deposit large amounts of sediment into streams further degrading salmonid habitat.

We did consider summer-run steelhead in the NC steelhead DPS somewhat separately. Because juvenile summer run steelhead emerge from redds in the winter, and then usually rear in streams for 1-3 years, they share similar vulnerabilities to climate change as juvenile winter-run steelhead (although in some cases they may be more susceptible to redd scour). However, because summer-run adults enter streams in late spring/early summer, and hold in mainstems until early fall to spawn, summer-run steelhead adults are likely more vulnerable to climate change impacts than winter-run adults in most (if not nearly all) cases.

EMISSION AND TEMPERATURE SCENARIO OVERVIEW

The CEPA and CEC modeling approaches consist of three emissions scenarios, high (970ppm), medium-high (830 ppm), and low emissions (550 ppm) and their predicted condition outcomes CEPA (2006), Moser *et al.* (2012), Cayan *et al.* (2012). Modeling results indicate unclear or minor differences among the environmental impacts for these different emissions scenarios until beyond mid-century. Past these years, the environmental impacts of high emissions scenarios begin to show marked differences from lower emissions scenarios (IPCC 2000; CEPA 2006; Burgett 2009; Cayan *et al.* 2012). The following emissions and air temperature scenarios (Figure 6 and Figure 7) from Mastrandrea and Luers (2012), and Lindley *et al*. (2007) were used to examine how the ecological attributes, indicators, and threats identified above may be affected by climate change. The temperature modeling effort by Lindley et al. (2007) focused on Central Valley salmonids but their analysis was illustrative because their temperature scenario maps include projections for coastal areas used by NC steelhead, CCC steelhead, and CC Chinook salmon. NMFS recognizes such projections do not provide the level of precision and accuracy needed to determine when air temperatures may reach certain levels in particular streams. Similarly, actual future temperatures in particular streams may be influenced by other factors and the results presented here will need to be updated as more information becomes available.

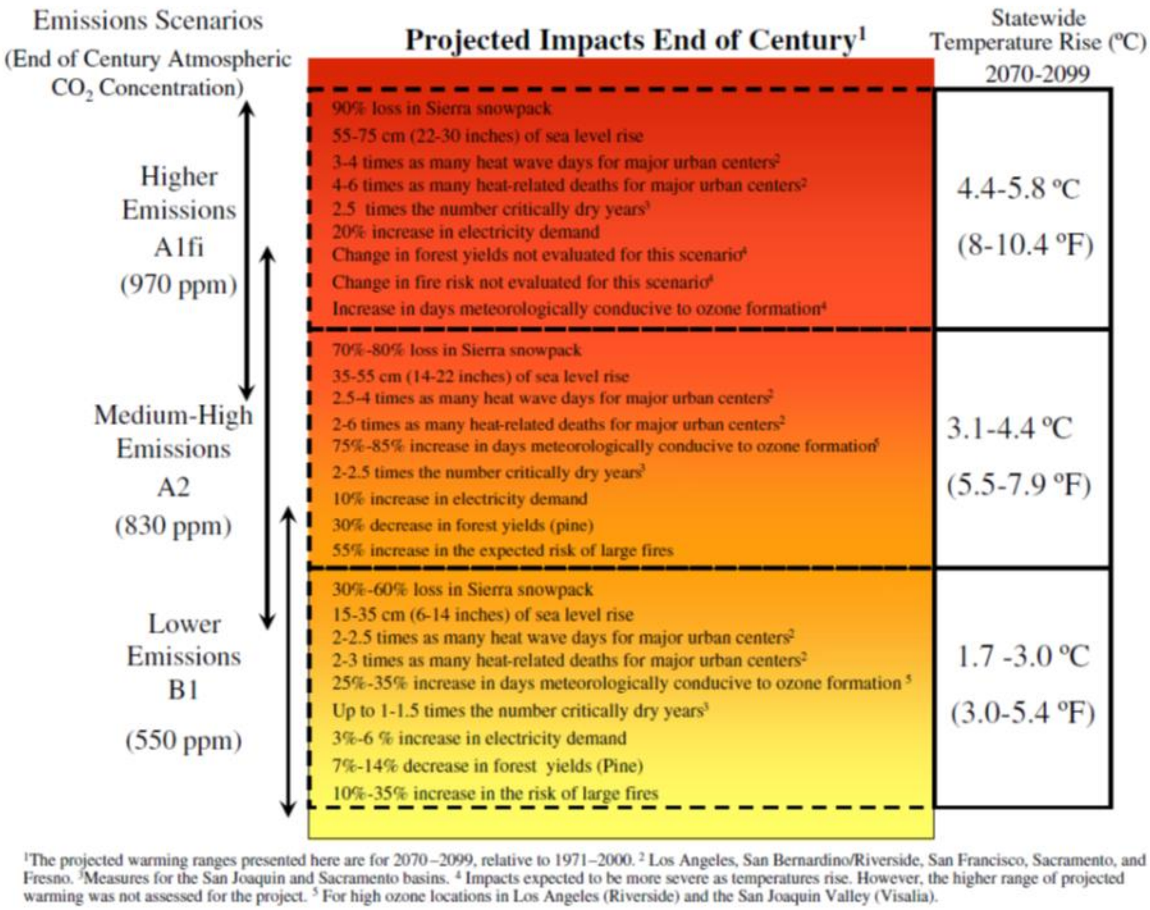

Figure 6: Emission scenarios for California for a 30-year period at the end of the 21st century, identifying increased threats associated with average annual air temperature (from Mastrandrea and Luers 2012).

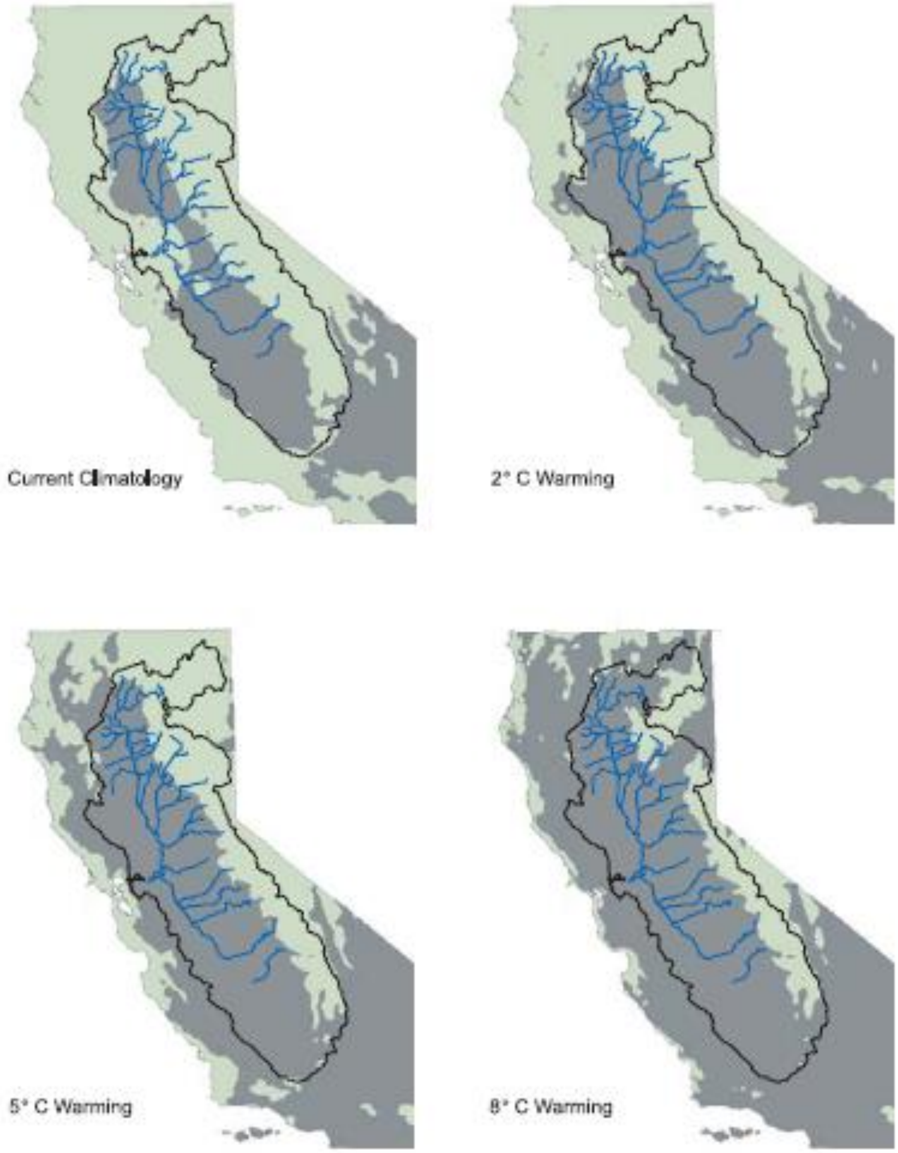

Figure 7: Geographic areas in California experiencing a mean August air temperature >25 C by year 2100 under different warming scenarios (Lindley *et al.* 2007).

HIGH EMISSIONS SCENARIO

Under this emissions scenario, statewide average annual temperature is expected to rise between 4.4 and 5.8 C (CEPA 2006; Luers *et al.* 2006). This temperature rise is predicted to cause loss of nearly all of the Sierra snowpack, increase in droughts and heat waves, increased fire risk, and changes in vegetation. The North Coast is expected to experience similar effects, although the models appear to differ regarding precipitation, as described above in "Climate Change in California" and "Climate Change Scenarios".

DROUGHTS

Natural climate variations such as droughts can dramatically affect habitat conditions for salmon and steelhead. Model output results show 2.5 times the number of critically dry years are possible (Luers *et al.* 2006) for California as a whole in the high emissions scenario. On the North Coast, including the area inhabited by CCC steelhead, NC steelhead, and CC Chinook salmon, other modeling has produced varying results for rainfall patterns. Different rainfall patterns may produce varying effects on salmonids and their habitat. For example, the impacts could be smaller if rainfall increases the duration of spring flows. Due to the uncertainties associated with rainfall on the North Coast, NMFS assumed a "worst case" reduction in precipitation similar to the 2006 statewide prediction, a 2.5 increase in the number of critically dry years. Based on the overall indicator and threats ratings for baseflows, migration flows, and severe weather patterns outlined in Table 1, Table 2, Table 3, and Table 4, NMFS expects increasing the level of droughts will dramatically reduce total available freshwater habitat and the habitat suitability of what remains. Large reductions in freshwater habitat are expected to reduce freshwater survival for CCC steelhead, NC steelhead, and CC Chinook salmon across their ranges. The greatest impacts are expected to occur in the CC Chinook salmon North Mountain Interior stratum, NC Steelhead Lower Interior stratum and CCC steelhead Interior and Coastal San Francisco Bay strata, where baseflows and passage flows are rated as in fair to poor condition in many of the watersheds containing salmonid populations. In these diversity strata, NMFS anticipates severe reductions or elimination of summer rearing habitat due to limited or depleted summer base flows, leading to increased (unsuitable) instream temperatures or complete stream dewatering. Not only are juveniles of these salmonids affected during baseflow conditions under this scenario, but migration flows for adults and smolts are expected to be severely curtailed, delayed, and/or absent in some years. Adults may experience increased energetic costs during migration because of low flow impediments that are more prevalent during drought than normal water years. NMFS anticipates the greatest negative impacts will be during smolt outmigration because spring flows will decline sooner under drought conditions, reducing migration opportunities.

Table 1: CC Chinook salmon focus populations and indicator or threat rankings expected to be most vulnerable to climate change. Indicators and threats were assigned a numeric value (for example VH = 3, H = 2, M = 1) and summed for each watershed. Watersheds were then ranked, with the highest sums indicating those at the greatest risk from climate related threats.

CC Chinook Salmon by Diversity Strata and Population			North Coastal							North Mountain Interior			North-Central Coastal		Central Coastal	
Life stage	Attribute	Indicator	Redwood	Little River	Mad River	Humbold Bay	L. Eel River - S. F. Eel River	Bear River	Mattole River	L. Eel River - Van Duzen	L. Eel River - Larabee Creek	Upper Eel River	Noyo River	Big River	Garcia River	Russian River
Adults	Hydrology	Passage Flow s	F	V	G	G	F	G	F	P	F	G	V	G	F	G
Adults	Passage/Migration	Passage at Mouth or Confluence	F	G	G	G	P	V	F	P	G	F	V	G	F	F
Adults	Velocity Refuge	Floodplain Connectivity	P	G	G	P	F	F	P	F	G	F	F	F	G	F
Eggs	Hydrology	Redd Scour	P	V	G	P	F	G	F	F	F	F	F	F	F	F
Pre Smolt	Estuary/Lagoon	Quality & Extent	P	F	F	F	P	F	P	P	P	P	F	F	G	P
Pre Smolt	Hydrology	Flow Conditions (Baseflow)	F	G	G	G	P	G	P	P	P	F	G	F	F	F
Pre Smolt	Water Quality	Temperature (MWMT)	P	V	F	G	F	F	P	F	G	F	G	G	G	F
Smolts	Estuary/Lagoon	Quality & Extent	P	F	F	F	P	F	P	P	P	P	F	F	F	F
Smolts	Hydrology	Passage Flow s	F	V	V	V	F	G	P	F	F	G	G	G	F	G
Smolts	Smoltification	Temperature	P	V	F	G	P	F	P	F	F	F	F	F	F	F
Watershed Processes	Riparian Vegetation	Species Composition	F	F	F	G	F	P	F	V	G	F	F	F	G	F
		Disease, Predation and Competition	H	M	M	M	M	M	M	H	H	M	-	-	M	M
Threats--->		Fire, Fuel Management and Fire Suppression	M	M	M	L	M	M	M	M	M	M	L	L	L	L
		Severe Weather Patterns	H	M	M	H	H	M	H	M	M	M	M	M	M	M
Total vulnerability			47	26	32	33	45	34	47	43	39	37	29	32	36	37

Table 2: NC steelhead focus populations and indicator or threat rankings expected to be most vulnerable to climate change. Indicators and threats were assigned a numeric value (for example VH = 3, H = 2, M = 1) and summed for each watershed. Watersheds were then ranked, with the highest sums indicating those at the greatest risk from climate related threats. Focus populations added late in the recovery planning process (Wages, Salmon, San Gregorio, and Soquel Creeks) were not included in this initial analysis.

NC SteelHead by Diversity Strata and Population			Northern Coastal								Lower Interior				Interior					North-Central Coastal						Coastal		
Target	Attribute	Indicator	Redwood	Maple Creek/Big Lagoon	Little River	Mad River	Humbold Bay	South Fork Eel River	Bear River	Mattole River	Chamise Creek	Woodman Creek	Outlet Creek	Tomki Creek	Van Duzen River	Larabee Creek	North Fork Eel River	Middle Fork Eel River	Upper Mainstem Eel River	Usal Creek	Wages Creek	Ten Mile River	Noyo River	Caspar Creek	Big River	Navarro River	Garcia River	Gualala River
Winter Adults	Hydrology	passage flows	G	V	V	G	V	G	G	F	F	F	F	G	G	G	G	G	G	V	G	V	V	V	G	F	F	G
Winter Adults	passage/Migration	passage at Mouth or Confluence	G	V	G	G	G	G	V	G	G	G	F	G	G	G	G	G	G	G	V	V	V	V	V	G	F	G
Eggs	Hydrology	Redd Scour	F	V	V	G	P	F	G	F	F	F	G	F	F	F	G	F	F	F	G	G	F	V	F	F	F	G
Summer Rearing Juveniles	Estuary/Lagoon	Quality & Extent	P	P	F	F	F	P	F	F	P	P	P	P	P	P	P	P	P	P	F	G	F	G	F	F	G	F
Summer Rearing Juveniles	Hydrology	flow Conditions (Baseflow)	P	G	G	F	F	P	G	P	F	F	P	P	P	F	P	F	G	G	G	V	G	G	F	F	F	P
Summer Rearing Juveniles	Riparian vegetation	Canopy Cover	F	F	G	V	V	F	P	F	P	V	F	P	P	P	P	F	F	G	V	F	V	V	P	F	F	F
Summer Rearing Juveniles	Water Quality	Temperature (MWMT)	P	V	V	V	V	P	P	F	P	F	P	P	F	P	P	F	P	G	V	F	P	F	P	P	F	F
Winter Rearing Juveniles	velocity Refuge	floodplain Connectivity	P	F	G	G	F	F	F	P	G	G	P	F	F	G	G	F	G	G	G	F	F	P	F	F	G	F
Smolts	Estuary/Lagoon	Quality & Extent	P	P	F	F	F	P	F	P	P	P	P	P	P	P	P	P	P	P	F	G	F	F	F	F	F	F
Smolts	Hydrology	passage flows	F	V	V	G	V	F	G	F	F	G	F	G	F	F	P	G	G	V	G	G	G	V	G	F	F	F
Smolts	Smoltification	Temperature	P	F	V	F	G	P	F	P	F	G	F	F	F	G	P	F	F	V	V	V	G	V	G	F	G	F
WatersHed Processes	Riparian vegetation	Species Composition	F	F	F	F	G	F	P	F	F	F	F	F	V	G	F	G	F	V	V	G	G	G	F	P	F	G
		Disease, Predation and Competition	H	M	L	L	M	M	M	M	M	M		M	H	M	M	M	M	L	L	L		M			L	L
Threats-->		Fire, Fuel Management and Fire Suppression	M	M	L	M	M	M	M	L	L	L	L	L	M	M	M	H	M	M	M	H	L	M	L	L	L	L
		Severe Weather Patterns	M	M	M	M	M	H	M	VH	M	M	M	M	M	M	M	M	H	H	M	H	M	M	M	M	M	M
Total vulnerability			46	33	26	32	32	46	39	46	40	34	40	41	43	41	45	41	39	31	26	30	30	28	36	40	35	37

Table 3: NC steelhead focus populations and indicator rankings for summer-run steelhead. No ranking indicates no presence of a summer-run population. Indicators and threats were assigned a numeric value (for example VH = 3, H = 2, M = 1) and summed for each watershed. Watersheds were then ranked, with the highest sums indicating those at the greatest risk from climate related threats.

NC Steelhead by Diversity Strata and Population			Northern Coastal								Lower Interior				Interior					North-Central Coastal						Coastal		
Target	Attribute	Indicator	Redwood	Maple Creek/Big Lagoon	Little River	Mad River	Humbold Bay	South Fork Eel River	Bear River	Mattole River	Chamise Creek	Woodman Creek	Outlet Creek	Tomki Creek	Van Duzen River	Larabee Creek	North Fork Eel River	Middle Fork Eel River	Upper Mainstem Eel River	Usal Creek	Wages Creek	Ten Mile River	Noyo River	Caspar Creek	Big River	Navarro River	Garcia River	Gualala River
Summer Adults	Hydrology	Flow Conditions (Baseflow)				F		P		F					P		P	G	G									
Summer Adults	Hydrology	Passage Flows				G		F		F					P		G	G	G									
Summer Adults	Passage/Migration	Passage at Mouth or Confluence				G		P		F					F		G	G	F									
Summer Adults	Velocity Refuge	Floodplain Connectivity				G		F		P					F		G	F	F									
Summer Adults	Water Quality	Mainstem Temperature (MWMT)				F		P		P					F		P	F	F									
		Disease, Predation and Competition				L		M		M					H		M	M	M									
	Threats-->	Fire, Fuel Management and Fire Suppression				M		M		L					M		M	H	M									
		Severe Weather Patterns				M		M		VH					M		M	H	H									
			Totals			17		24		24					24		20	20	20									

Table 4: CCC steelhead focus populations and indicator or threat rankings expected to be most vulnerable to climate change. Indicators and threats were assigned a numeric value (for example VH = 3, H = 2, M = 1) and summed for each watershed. Watersheds were then ranked, with the highest sums indicating those at the greatest risk from climate related threats.

CCC Steelhead by Diversity Strata and Population			North Coastal					Interior				Santa Cruz Mountains								Coastal S. F. Bay					Interior S. F. Bay					
Target	Attribute	Indicator	Austin Creek	Green Valley Creek	Salmon Creek	Walker Creek	Lagunitas Creek	Mark West Creek	Dry Creek	Maacama Creek	Upper Russian River	Pilarcitos Creek	San Gregorio Creek	Pescadero Creek	Waddell Creek	Scott Creek	San Lorenzo River	Soquel Creek	Aptos Creek	Corte Madera Creek	Novato Creek	Guadalupe River	Stevens Creek	San Francisquito Creek	Petaluma River	Sonoma Creek	Napa River	Green Valley/Suisun Creek	Alameda Creek	Coyote Creek
Summer Rearing Juveniles	Estuary/Lagoon	Quality & Extent	P	P	P	F	F	P	P	P	P	P	F	F	F	F	F	F	F	P	P	P	P	P	P	P	P	P	P	P
Smolts	Estuary/Lagoon	Quality & Extent	F	F	P	P	F	F	F	F	F	P	F	G	F	P	F	F	F	P	F	P	P	P	F	F	F	F	P	P
Summer Rearing Juveniles	Hydrology	Flow Conditions (Baseflow)	F	P	F	F	F	F	F	P	F	P	P	F	G	F	P	P	G	P	P	F	F	F	P	F	P	P	P	P
Adults	Hydrology	Passage Flows	V	G	F	G	F	F	F	F	F	P	F	G	V	G	G	V	V	F	P	F	F	F	F	F	F	F	P	F
Smolts	Hydrology	Passage Flows	G	F	V	F	V	F	F	F	F	P	F	F	V	V	F	V	V	F	P	F	F	G	G	F	F	F	P	F
Eggs	Hydrology	Redd Scour	G	P	F	F	F	F	F	F	F	P	G	F	F	P	P	P	F	P	F	F	G	F	P	F	F	F	F	F
Adults	Passage/Migration	Passage at Mouth or Confluence	G	G	G	V	G	F	F	F	G	G	F	G	V	G	F	G	G	P	P	F	G	F	F	P	F	G	F	G
Smolts	Passage/Migration	Passage at Mouth or Confluence	G	P	G	V	G	V	V	F	G	G	F	G	V	G	G	V	G	P	F	F	G	G	F	P	F	G	F	G
Summer Rearing Juveniles	Riparian Vegetation	Canopy Cover	F	V	G	F	V	P	F	P	P	F	F	F	G	V	V	V	G	P	P	F	G	P	F	P	G	P	F	F
Watershed Processes	Riparian Vegetation	Species Composition	G	F	F	P	F	P	G	F	P	F	G	G	V	G	G	G	G	F	P	F	F	P	F	F	P	F	F	F
Smolts	Smoltification	Temperature	F	G	F	P	G	F	G	G	V	G	V	G	G	G	G	G	G	P	F	G	V	G	F	G	F	F	F	F
Adults	Velocity Refuge	Floodplain Connectivity	G	P	F	P	P	P	G	F	P	P	F	G	G	G	F	F	P	P	P	P	F	F	F	F	P	P	P	F
Winter Rearing Juveniles	Velocity Refuge	Floodplain Connectivity	G	P	F	P	P	P	F	F	F	F	F	F	G	G	F	P	P	P	P	F	F	F	P	F	P	P	P	P
Summer Rearing Juveniles	Water Quality	Temperature (MWMT)	G	F	F	P	F	P	F	F	P	G	P	P	F	F	F	F	F	P	P	F	F	G	F	F	P	P	P	F
Threats-->		Disease, Predation and	L	L	L	L	L	M	L	M	M	M	M	M	M	L	M	M	L	M	M	L	L	M	L	M	M	VH	M	M
		Fire, Fuel Management	M	L	L	L	M	L	L	M	M	M	H	H	H	M	H	M	H	M	M	-	-	L	L	M	M	L	M	L
		Severe Weather Patterns	L	H	M	M	M	M	M	M	M	VH	H	H	H	M	VH	H	H	H	M	M	M	L	M	H	VH	M	H	M
			37	48	43	47	42	51	42	50	49	53	48	45	35	38	48	41	41	60	58	47	41	46	49	51	54	53	57	49

FIRES

Increases in fire frequency or areas affected by fire were not modeled by CEPA (CEPA 2006) for this scenario; however, the prevalence of fires is expected to increase under higher emission scenarios. NMFS assumes that fire frequency and areas affected will be greater than the modeled results for the medium-high emissions scenario described below. Impacts from increased fires are likely to include additional sedimentation in streams. Sedimentation may fill in pools in some areas, decreasing or eliminating the value of in stream restoration efforts to increase the amount of complex habitats available for salmonids.

Our CAP threats assessment identified CC Chinook populations as having low or moderate vulnerability to fire (Table 1). We identified the Middle Fork of the Eel River and Ten Mile River as the NC steelhead populations most vulnerable to fire (Table 2). Five CCC steelhead populations in the Santa Cruz Mountains diversity stratum (San Gregorio Creek, Pescadero Creek, Waddell Creek, San Lorenzo River, and Aptos Creek) were the most vulnerable to fire (Table 4).

Storms and Flooding

Due to the wider range in modeling results for precipitation described above under "Climate Change in California" and "Climate Change Scenarios", NMFS has chosen to assume a worst-case high emissions scenario where storms (rain events) and flooding dramatically increase during the winter months (see, for example, CEC 2012). A large body of work has examined the impacts of increased storm and flooding magnitudes and frequencies on salmonid life-stages, behavior and habitat (Montgomery *et al.* 1996; DeVries 1997; Solazzi *et al.* 2000; Quinn 2005; Battin *et al.* 2007; Healey 2011; Goode *et al.* 2013). These studies show that increased frequency and magnitude of flows from storms and flooding are likely to increase redd scour and may affect the quantity and quality of spawning gravels, and the amount and quality of pool habitat in many watersheds. In winter (steelhead) and spring (steelhead and Chinook salmon), rearing juveniles without access to velocity refugia are vulnerable to losses due to increases in flood flows Bustard and Narver 1985, Spence et al. 1996).

In addition, the compounding effects of roads are also a medium to very high threat for all targeted populations in the ESU and DPSs. Therefore, increased magnitudes and frequency of storm and flood events are likely to cause greater sediment output and turbidity from roads. Consequently, these heightened events overwhelm the drainage capacity of many road crossings, especially under the high emission scenario. CC Chinook populations most vulnerable to redd scour and loss of velocity refuge include Humboldt Bay Tributaries, Redwood Creek, and the Mattole River. NC steelhead populations most vulnerable include Humboldt Bay Tributaries, the Mattole River, and Redwood Creek. CCC steelhead populations most vulnerable include Green Valley Creek, Soquel Creek, and Corte Madera Creek.

TEMPERATURE

Fish, including salmonids, are very sensitive to water temperature changes. Previous sections of this document explain the temperature requirements of steelhead and Chinook salmon and how NMFS evaluated current stream temperature conditions in each ESU or DPS. NMFS used, in part, the current condition ratings for temperature to identify populations most susceptible to increases in water temperatures due to climate change. Under the high emissions scenario, NMFS assumed 4.4° to 5.8° C warming of statewide average annual air temperature (Figure 6). The 5° C warming map (7) from (Lindley *et al.* 2007) shows areas that may experience August mean air temperature over 25° C. These higher air temperatures are likely to cause an increase in water stream temperatures, unless other factors, such as cold groundwater input are present. The maps below in 8-10 illustrate where CCC steelhead, NC steelhead, and CC Chinook salmon populations may be vulnerable to air temperature increases, based on the information in Lindley (2007). Based on these maps, populations of these species in interior strata appear more vulnerable to increased temperatures and may experience high air and water temperatures that dramatically reduce the amount of stream habitat available to these species during the summers. This impact appears most pronounced in the Russian, Upper Eel, and Napa River populations, as well as the populations in Alameda, Coyote, and Sonoma Creeks. However, and as noted above, the Ukiah Valley (which contains much of the interior Russian River watershed) currently appear to be cooling, leaving this high temperature scenario somewhat in doubt for all interior watersheds with populations of these species.

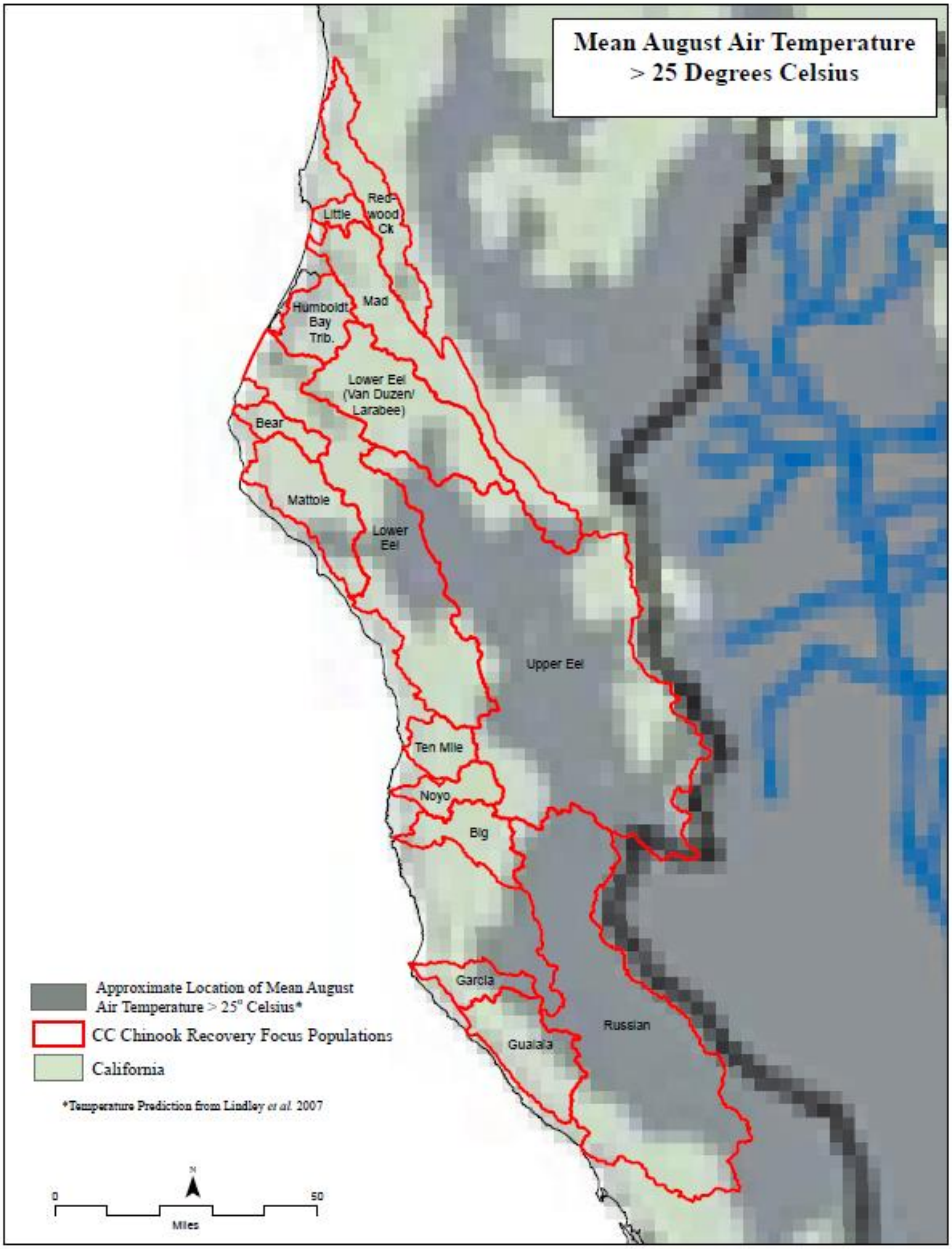

Figure 8: Approximate location of mean August air temperatures greater than 25° C in relation to CC Chinook salmon focus populations, under a 5° C warming scenario (modified from (Lindley *et al.* 2007).

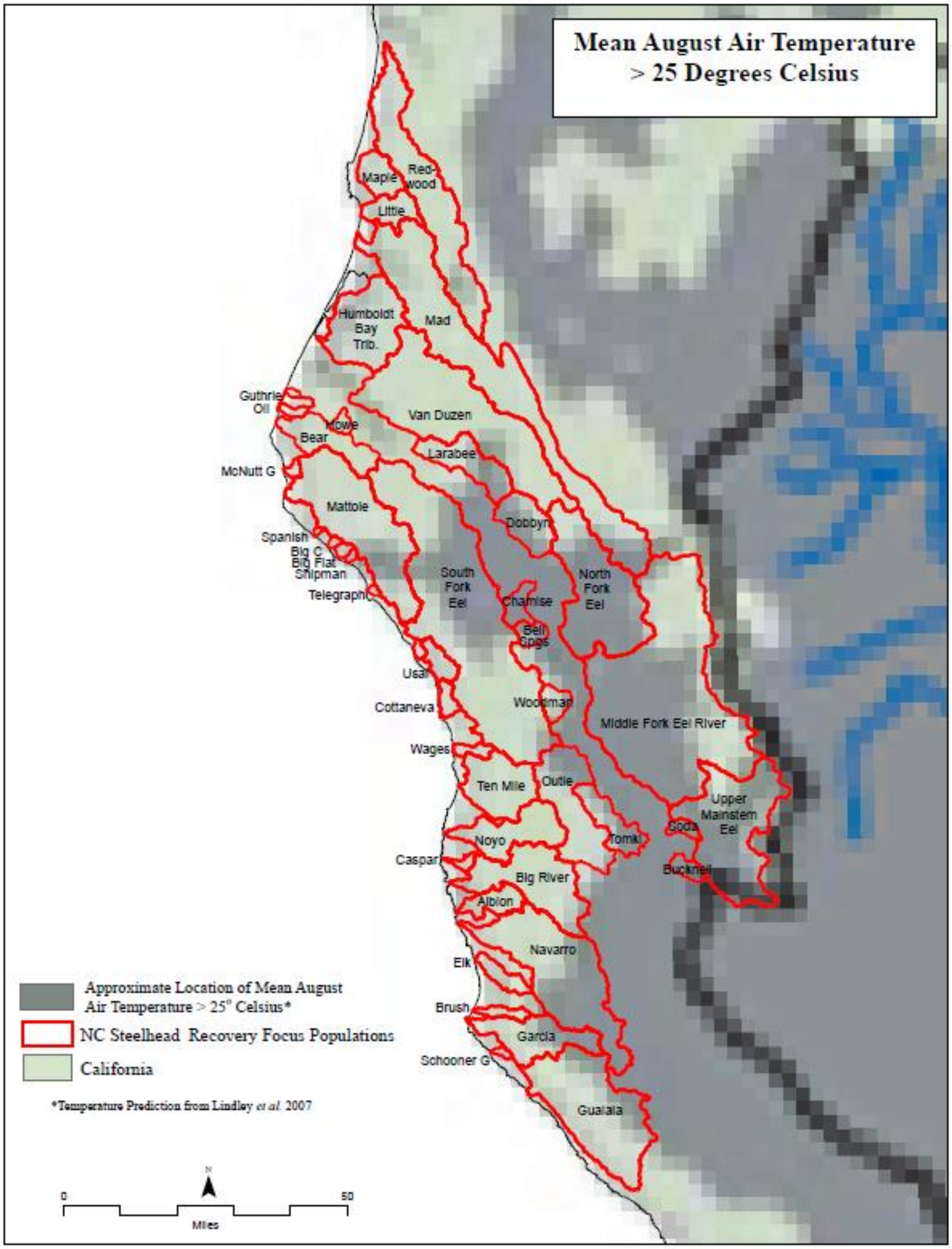

Figure 9: Approximate location of mean August air temperatures greater than 25° C in relation to NC steelhead focus populations under a 5° C warming scenario (modified from Lindley *et al.* 2007).

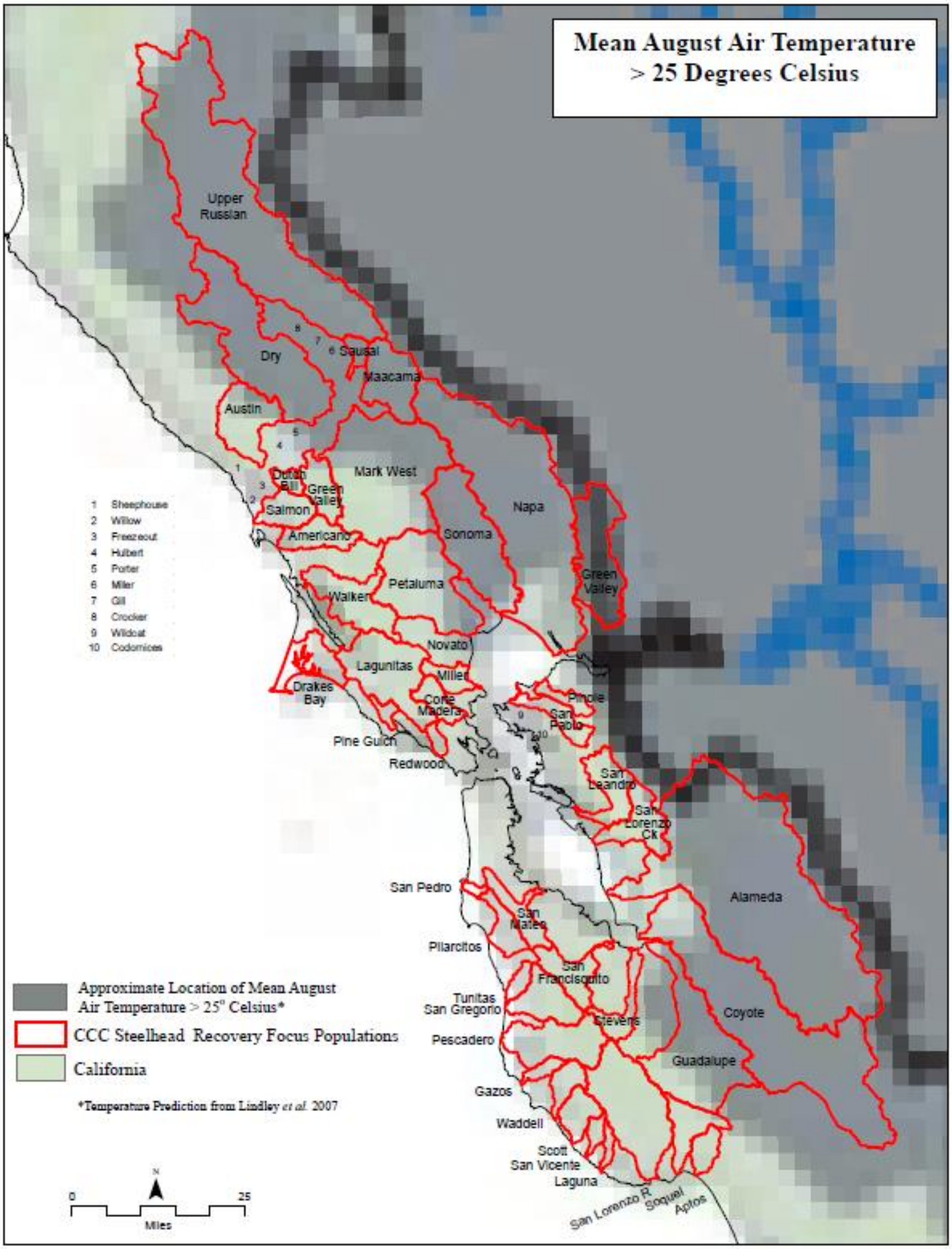

Figure 10: Approximate location of mean August air temperatures greater than 25 °C in relation to CCC steelhead focus populations under a 5° C warming scenario (modified from Lindley *et al*. 2007).

Riparian Species Composition, Size, and Canopy Cover

As described above, vegetation near streams can provide shade for cooler water temperatures, bank stability, large woody debris to stream channels, and habitat for salmonid prey items. Climate change is likely to affect vegetation in California, favoring some vegetation types over others based on potential changes to air temperatures and rainfall. Scenarios developed for CEPA (CEPA, 2006) concerning vegetation did not include the high emissions scenario. NMFS assumes changes in vegetative cover under the high emissions scenario will be more pronounced than those described under the moderate high emissions scenario described below. We make this assumption because higher emissions scenarios are likely to lead to greater changes in precipitation and rainfall, further changing vegetation cover.

There is uncertainty regarding current information on potential changes in forest productivity. Some studies indicate the potential for increased forest productivity, while others suggest a decline (CEPA 2006). Due to this uncertainty, scenarios for tree size and canopy cover are not included here[6]. Our vulnerability analysis indicates that for CC Chinook salmon, Bear River has the poorest riparian species composition. This population may be more vulnerable to vegetation changes. Similarly, for NC steelhead, Bear River and Navarro River have the poorest riparian species composition and may be the most vulnerable. In the CCC steelhead DPS, several watersheds have poor riparian species composition, including Walker Creek, Mark West Creek, Novato Creek, and the Napa River. Only the Santa Cruz Mountains diversity stratum has populations without poor riparian species composition ratings.

Disease, Predation, and Competition

CEPA (CEPA 2006) scenarios do not include disease, predation, or competition information directly related to salmonids. TCEPA (CEPA 2006) and others (Harvell *et al.* 2002) note that increasing instream temperatures can allow pathogens to spread into areas where they are

[6]Linking tree productivity scenarios to changes in instream habitat will be difficult in this and other scenario exercises. For example, if forest productivity decreases, LWD sizes might decline over time. However, droughts and higher temperatures are likely to raise vulnerability to pests and pathogens, which could increase tree death and thus the contribution of LWD to streams.

currently absent as temperature limitations on their range change. In some cases, increasing temperatures may limit or restrict diseases (Harvell *et al.* 2002; Kuehne *et al.* 2012). Reduced growth was noted as the result of predators plus warmer temperatures for Chinook salmon (Kuhne *et al.* 2012). NMFS acknowledges increasing temperatures have the potential to increase salmon and steelhead susceptibility to disease. Given the potential for increasing droughts, disease outbreaks will likely increase if salmon and steelhead are crowded together in areas of low stream flow. Our vulnerability analysis indicates that CC Chinook salmon may be the most vulnerable in the Lower Eel River. NC steelhead may be the most vulnerable in Redwood Creek and the Van Duzen River. CCC steelhead may be the most vulnerable in Alameda Creek and Novato Creek.

ESTUARIES/LAGOONS

NMFS expects large changes in estuarine/lagoon habitat by the end of the 21st Century under the high emissions scenario due to reduced stream flows and higher air and water temperatures. These changes are likely to be detrimental to salmonids. Reduced stream flows and higher air and water temperatures are likely to cause reduced habitat space and dilution, and increases in salinity, water temperature ranges, vertical stratification, and incidences of eutrophication. North Coastal and North Mountain Interior CC Chinook populations are likely most vulnerable to these estuarine changes (Table 1), and Humboldt Bay tributaries, Redwood Creek, the Mattole River, and the Eel River may contain the most vulnerable populations. NC Steelhead populations most vulnerable to these changes are in the Lower Interior and Interior Strata. CCC steelhead populations in the Interior Stratum and Coastal and Interior San Francisco Bay Strata are likely the most vulnerable, with the rivers and creeks of the Coastal S.F. Bay stratum as potentially the most vulnerable populations based on estuarine conditions. Salmon Creek in the North Coastal stratum, and Pilarcitos Creek in the Santa Cruz Mountains stratum are also likely some of the most vulnerable.

Moderate High Emissions Scenario

Under the moderate-high emissions scenario, statewide average annual temperature is expected to rise between about 2 and 5° C (Cayan *et al.* 2012, Figure 6). Statewide consequences are similar to the high emission scenarios and include loss of most of the Sierra snowpack, increase in droughts and heat waves, increase in fire risk, and changes in vegetation. Changes for the North Coast are most likely similar (with the exception of loss of snowpack),

Droughts

Statewide, there is a 2-2.5 times greater probability of a critical dry year during the medium-high emission scenario (Luers *et al*. 2006). On the North Coast, including the area inhabited by Chinook salmon and steelhead, modeling has produced varying results for rainfall patterns. The work done by Cayan *et al.* (2012) indicates that overall precipitation would probably decline, but the amount of decline is dependent on the method used to downscale information from global climate models. The precipitation season normally associated with California's Mediterranean climate may shorten, with less late winter and spring rain (Cayan *et al.* 2012). Different rainfall patterns may produce varying effects on CC Chinook salmon, NC steelhead, and CCC steelhead and their habitat. For example, the impacts could be magnified if lower rainfall reduces the duration of spring flows. Due to the uncertainties associated with rainfall on the North Coast, NMFS will assume a "worst case" scenario where spring flows in North Coast streams are reduced. Impacts to CC Chinook salmon, NC steelhead, and CCC steelhead and their freshwater habitat are likely to be similar, but somewhat less than those described in the high emissions scenario.

Fires

Fires are also expected to increase under this scenario. The approach used in 2006 predicts an overall 55% increase in the risk of large fires in California (Luers *et al.* 2006). In particular, Northern California modeling results predict an overall 90% increased risk of fires (Westerling and Bryant 2006). In 2012, CEC projected an increase in the number of large fires from 58% to 169%, depending on location in California (Moser *et al*. 2012). Areas like the North Coast, with more vegetation, would likely see more fire increase, although currently dry areas could see increases as well if those areas become wetter and grow more vegetation (Moser *et al.* 2012). NMFS infers (Westerling and Bryant 2006) by the end of the Century the risk of fire occurrences will likely increase, even in some coastal areas that currently experience fog and cool temperatures in the summers. Similar to the high emission scenario, impacts from increased fires are likely to include additional sedimentation in streams potentially decreasing or eliminating the amount of complex habitat for salmonids.

STORMS AND FLOODING

As described, scenarios for increased magnitudes and frequencies for storm and flood events were not modeled for Northern California. NMFS assumed a worst-case moderate-high emissions scenario where storms and flooding dramatically increase during the winter months. Impacts under this scenario are likely similar to those expected for the high emissions scenario described earlier, although the magnitude and frequency of storm flows may be less.

TEMPERATURE

NMFS used, in part, the current condition ratings for temperature to identify targeted populations susceptible to increases in water temperatures due to climate change. Under the moderate high emissions scenario, statewide average annual air temperature is expected to rise about 3-5° C (Cayan *et al.* 2012, Figure 6). As with the high emissions scenario, NMFS used the 5° C warming-map[7] from Lindley et al. (Lindley *et al.* 2007), which shows areas that may experience August mean air temperature over 25° C (Figure 7). These higher air temperatures are likely to increase stream temperatures, unless other factors, such as cold groundwater input, are present. Impacts to salmon, steelhead, and their freshwater habitats due to air temperature increase are likely to be similar, while somewhat less than, the impacts described above under the high emissions scenario.

[7] The 5° C map is the closest in temperature to both scenarios.

RIPARIAN SPECIES COMPOSITION, SIZE, AND CANOPY COVER

Climate change is likely to affect vegetation in California, favoring some vegetation types over others based on potential changes to air temperatures and rainfall. Based on the maps produced by CEPA for the California moderate high emissions scenario for tree species distribution (Lenihan *et al.* 2006), NMFS inferred mixed evergreen forest (Douglas-fir, tanoak, madrone, oak) may expand toward the coast and into areas currently dominated by Evergreen conifer forest (coastal redwoods) by the end of the Century. Some areas in the San Francisco Bay region may see a decrease in coastal redwoods and increase in chamise (a shrub) by mid-Century (Ackerly *et al.* 2012).

Increases in tanoak, a hardwood, and shrubs in coastal riparian areas could decrease the value of future LWD. Streams in riparian forests composed of hardwood and shrub species generally have less LWD volume than streams in conifer riparian forests (Gurnell 2003). LWD is an important component of pool formation in some streams, and large decreases in conifer LWD could reduce the number, depths, and longevity of pools in IP-km, ultimately reducing the amount of high quality rearing and, for steelhead over wintering habitat, available.

DISEASE, PREDATION, AND COMPETITION

Similar to the high emission scenario, CEPA scenarios do not include disease, predation, or competition information regarding salmonids. NMFS assumed increasing temperatures have the potential to increase salmonids exposure risk given the potential for droughts to increase under this scenario, NMFS assumed if droughts increase in the range of CC Chinook salmon, CCC and NC steelhead, disease outbreaks will likely increase if these fish are crowded together in smaller amounts of wetted habitats. As described above, our vulnerability analysis indicates that CC Chinook salmon may be the most vulnerable in the Lower Eel River. NC steelhead may be the most vulnerable in Redwood Creek and the Van Duzen River. CCC steelhead may be the most vulnerable in Alameda Creek and Novato Creek. Potential impacts are expected to be somewhat less in the moderate high emissions scenario than in the high emissions scenario.

Estuaries/Lagoons

NMFS expects large changes in estuarine/lagoon habitat by the end of the 21st Century under the moderate high emissions scenario due to reduced stream flows and higher air and water temperatures. These changes, while perhaps of less magnitude than those from the high emissions scenario above, are likely to be detrimental to salmonids. As described above, reduced stream flows and higher air and water temperatures are likely to cause reduced habitat space and dilution, and increases in salinity, water temperature ranges, vertical stratification, and incidences of eutrophication. North Coastal and North Mountain Interior CC Chinook strata are likely most vulnerable to these estuarine changes (Table 2). NC Steelhead populations most vulnerable to these changes are in the Lower Interior and Interior Strata. CCC steelhead populations most vulnerable are likely the Coastal and Interior San Francisco Bay strata.

Low Emissions Scenario

Under this emissions scenario, statewide average annual temperature is expected to rise between 1.7° and 3.0° C (Luers *et al.* 2006; Cayan *et al.* 2012). Statewide consequences are expected to include loss of 1/3-1/2 of the Sierra snowpack, increase in droughts and heat waves, increase fire risk, and changes in vegetation type and composition. Changes for the North Coast are likely to be similar, although changes in the incidence of large storms appears to be model dependent, as described above.

Droughts

Statewide the probability of critically dry years increases 1-1.5 times for the low emission scenario (Luers *et al.* 2006). On the North Coast, including the area inhabited by CCC steelhead, NC steelhead, and CC Chinook salmon, other modeling has produced varying results for rainfall patterns. Different rainfall patterns may produce varying effects on these species and their habitat. For example, the impacts could be smaller if rainfall increases the duration of spring flows. Due to the uncertainties associated with rainfall on the North Coast, NMFS assumed a "worst case" reduction in precipitation similar to the statewide prediction, a 1-1.5

increase in the number of critically dry years (Luers *et al.* 2006). In comparison to the High and Medium emission scenarios, CCC steelhead, NC steelhead, and CC Chinook salmon and their freshwater habitat are less likely to be adversely affected. Although lower emissions levels are less likely to impact Chinook and steelhead, the CC Chinook salmon North Mountain Interior stratum, NC Steelhead Lower Interior stratum and CCC steelhead Interior and Coastal San Francisco Bay strata are the most likely to be affected, as described above under the high emissions scenario.

FIRES

Fires are also expected to increase under this scenario. An overall 10-35% increase in the risk of large fires in California is expected (Luers *et al.* 2006). For northern California, modeling produced an overall 40% increase in the risk of fires (Westerling and Bryant 2006). By the end of the Century, NMFS inferred (from the fire risk maps provided by (Westerling and Bryant 2006)) the risk of fire near the coast may increase, although the increase appears limited. Impacts from increased fires are likely to include additional sedimentation in streams as described above in the *Overview*. This sedimentation may fill in pools in some areas, decreasing or eliminating the value of instream restoration efforts to increase the amount of complex habitats available.

STORMS AND FLOODING

As discussed above, scenarios for increases in storms and flooding are not available because of variation in model results for climate change impacts on precipitation in Northern California. For storms and flooding, NMFS assumed a worst case lower emissions scenario where storms and flooding increase during the winter months. Impacts under this scenario are likely to be less than those expected for the moderate high and high emissions scenarios described above. Populations most vulnerable to impacts (redd scour, and limited floodplain habitat) from increased storms and flooding are shown in Table 1, Table 2, and Table 3 above.

Temperature

NMFS used, in part, the current condition ratings for temperature to identify populations susceptible to increases in water temperatures due to climate change. Under the low emissions scenario, NMFS assumed 1.7° to 3.0° C warming of statewide average annual air temperature. NMFS used the 2° C warming map from Lindley (Lindley *et al*. 2007), which shows areas that may experience August mean air temperature over 25° C (Figure 7). These higher air temperatures are likely to increase stream temperatures. According to this map, CC Chinook populations in the Russian River and Upper Eel River may be the most likely affected (although see our caveat about the current temperature trend in the Ukiah Valley above). For NC steelhead the most vulnerable populations may be the Upper and Middle Fork Eel and the Navarro. For CCC steelhead, the most vulnerable populations are likely in the Upper Russian and Maacama Creek.

Riparian Species Composition, Size, and Canopy Cover

See the discussion above under the moderate high emissions scenario. These potential impacts are likely to be less than those in the moderate high emissions and high emissions scenarios.

Disease, Predation, and Competition

See the discussion above under the moderate high emissions scenario. These potential impacts are likely to be less than those in the moderate high emissions and high emissions scenarios.

Estuaries/Lagoons

See the discussion above under the moderate high and high emissions scenarios. The potential impacts are likely to be of less magnitude than those described above for the above scenarios.

Most Vulnerable Populations

NMFS used the Indicators and Threats from Table 1, Table 2, and 4 above to identify the salmonid populations most vulnerable to climate change. We compared each population's or stratum's threat level and the current condition of specific habitat attributes most likely to be negatively affected by climate change. Each of the selected key habitat attributes was assigned a numeric score representing very good, good, fair, or poor conditions. These scores were summed and ranked from least to greatest. Each threat level was assigned a numeric score representing low, medium, high, or very high threat ranks. Numeric scores were summed, then ranked from least to greatest. These scores were then combined for each population in each ESU or DPS in Tables 5, 6, and 7. Highest ranked values suggested those populations are at greater risk. Note that we did not add in the scores for summer-run NC steelhead. These steelhead populations are assumed to be the highest risk NC steelhead populations because of adults holding in mainstems during the summers as described above.

Table 5: Population current habitat condition and threat ranking for CC Chinook salmon in relation to climate change vulnerability. A higher number indicates a population may be more vulnerable. Threat rankings were added to current condition rankings to determine overall vulnerability to climate change.

Population	Current Condition Ranking (Attributes and Indicators)	Total Rank (Includes Threats)
Mattole River	40	47
Redwood	39	47
L. Eel River - S. F. Eel River	38	45
L. Eel River - Van Duzen	36	43
L. Eel River - Larabee Creek	32	39
Russian River	32	37
Upper Eel River	31	37
Garcia River	31	36
Bear River	28	34
Humbold Bay	27	33
Big River	29	32
Mad River	26	32
Noyo River	26	29
Little River	20	26

Based on this information, NMFS believes the CC Chinook salmon populations in the Mattole River, Redwood Creek, and Eel River are at most risk from Climate Change. We caution these methods cannot be used to precisely rank population vulnerability due to a variety of factors, many of which are identified above. Nevertheless, the rankings are our best prediction of the relative vulnerability of these populations. The highest ranked populations are predicted to be more vulnerable to climate change impacts than those ranked the lowest. As more information becomes available, these rankings will likely need to be adjusted.

Table 6: Population current habitat condition and threat ranking for NC steelhead in relation to climate change vulnerability. A higher number indicates a population may be more vulnerable. Threat rankings were added to current condition rankings to determine overall vulnerability to climate change.

Population	Current Condition Ranking (Attributes and Indicators)	Total Rank (Includes Threats)
All summer-run populations	Highest	Highest
Redwood	39	46
South Fork Eel River	39	46
Mattole River	39	46
North Fork Eel River	39	45
Van Duzen River	36	43
Tomki Creek	36	41
Larabee Creek	35	41
Middle Fork Eel River	33	41
Outlet Creek	37	40
Navarro River	37	40
Chamise Creek	35	40
Bear River	33	39
Upper Mainstem Eel River	32	39
Gualala River	33	37
Big River	33	36

Garcia River	31	35
Woodman Creek	29	34
Maple Creek/Big Lagoon	27	33
Mad River	27	32
Humbold Bay	26	32
Usal Creek	25	31
Noyo River	27	30
Ten Mile River	23	30
Caspar Creek	22	28
Little River	22	26
Wages Creek	21	26

Based on this information, NMFS believes the NC steelhead populations in Redwood creek, the South Fork Eel River, and the Mattole River, are at most risk from Climate Change. As above, we caution these methods cannot be used to precisely rank population vulnerability due to a variety of factors, many of which are identified above. Nevertheless, the rankings are our best prediction of the relative vulnerability of these populations. The highest ranked populations are predicted to be more vulnerable to climate change impacts than those ranked the lowest. As more information becomes available, these rankings will likely need to be adjusted.

Table 7: Population current habitat condition and threat ranking for CCC steelhead in relation to climate change vulnerability. A higher number indicates a population is likely more vulnerable. Threat rankings were added to current condition rankings to determine overall vulnerability to climate change.

Population	Current Condition Ranking (Attributes and Indicators)	Total Rank (Includes Threats)
Corte Madera Creek	53	60
Novato Creek	52	58
Alameda Creek	50	57
Napa River	46	54

Green Valley/Suisun Creek	46	53
Pilarcitos Creek	45	53
Mark West Creek	46	51
Sonoma Creek	44	51
Maacama Creek	44	50
Petaluma River	45	49
Coyote Creek	44	49
Upper Russian River	43	49
Green Valley Creek	43	48
San Gregorio Creek	40	48
San Lorenzo River	39	48
Guadalupe River	44	47
Walker Creek	43	47
San Francisquito Creek	42	46
Pescadero Creek	37	45
Salmon Creek	39	43
Dry Creek	38	42
Lagunitas Creek	37	42
Stevens Creek	38	41
Soquel Creek	34	41
Aptos Creek	34	41
Scott Creek	33	38
Austin Creek	33	37
Waddell Creek	27	35

Based on this information, NMFS believes the CCC steelhead populations in Corte Madera Creek and Novato Creek, followed by the populations in Alameda Creek and the Napa River are at most risk from Climate Change. As above, we caution these methods cannot be used to precisely rank population vulnerability due to a variety of factors, many of which are identified above. Nevertheless, the rankings are our best prediction of the relative vulnerability of these populations. The highest ranked populations are predicted to be more vulnerable to climate change impacts than those ranked the lowest. As more information becomes available, these rankings will likely need to be adjusted.

RECOVERY PLANNING AND CLIMATE CHANGE

Our analysis indicates that climate change will result in many challenges for CCC steelhead, NC steelhead and CC Chinook salmon recovery. Areas with stream temperatures near steelhead or Chinook salmon thermal maxima may become uninhabitable as temperatures increase. Areas with adequate stream temperatures may see temperatures become marginal. Precipitation patterns may or may not exacerbate temperature problems. Areas subject to low summer flows may experience further summer flow decreases from less precipitation including declining snow packs. Water withdrawals that are currently of limited impact on salmonids may increase in impact as stream flows diminish.

We cannot currently predict the precise magnitude, timing, and location of impacts on steelhead and Chinook salmon populations or their habitat due to climate change. Some populations are likely to be more vulnerable than others, and we have taken a first step toward identifying these populations. Monitoring and evaluating changes across this ESU and these DPSs as this Century progresses will be a critical next step to devising better scenarios and adjusting recovery strategies.

The survival and recovery of CCC steelhead, NC steelhead, and CC Chinook salmon under any of the climate change scenarios will depend on achieving viable salmonid populations as soon as possible. Viable populations will be better able to withstand change in the environment.

Viable populations have a better chance of surviving loss of habitat, and can likely persist in the advent of range contraction if habitat conditions in inland and at the southern extent of the range become more tenuous. Major differences in the environmental impacts of high and low emissions scenarios may not become evident until about mid-Century. NMFS currently expects there remain approximately 30-40 years to establish as many viable salmonid populations as possible. To do this, we need to work together to implement this Recovery Plan.

RECOMMENDED ACTIONS:

1. Conduct public outreach and education on the anticipated effects of climate change to salmonids and increase awareness that human actions can offset these effects.
   1.1. The general public, and local, state and federal agencies should become familiar with, and implement as necessary through lifestyle and policy changes, recommendations of the Intergovernmental Panel on Climate Change (IPCC).
      1.1.1. See the website **http://www.ipcc.ch** to view a summary of climate change issues for North America and the suite of actions from the IPCC to be considered for ecosystem (and human health) as our climate changes.
2. Expand research and monitoring to better predict the impact of climate change on salmon recovery.
   2.1. Invest in marine climate change research to enable informed decisions by resource managers and society in order to ensure the future utility and enjoyment of coastal and marine ecosystems under changing climate conditions.
   2.2. Fund research that aids in predicting the effects of climate change on salmon recovery.
3. Ensure continued flow of upstream cool water, in adequate quantity, to protect downstream water temperatures.
   3.1. Identify cool water sources and develop measures to protect them.
4. Given the larger uncertainties associated with changes in precipitation from climate change, evaluate the resiliency of recovery actions for a range of potential future stream flows. For example, floodplain rehabilitation projects should consider the potential for increases or decreases in the frequency and magnitude of high flow events. Such projects may need to

be designed to function for salmon and steelhead in a variety of different potential storm flow future scenarios.

5. Focus on forestlands to store carbon and reduce greenhouse gasses (See also Logging and Wood Harvesting Strategies):
    - Prevent or minimize forest loss by managing forests for long-term sustainability.
    - Conserve and manage for older forests.
    - Restore forests where they have been converted to other uses.
    - Use wood products from sustainable forests in place of more CO^2 emissions intensive building materials and energy sources.
        - Encourage and increase voluntary carbon accounting in the forest sector through certification with the California Climate Action Registry and their Forest Protocols.

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