Appendix A

Marine and Climate Scenarios for CCC coho salmon

MARINE HABITAT

"Thus blaming ocean conditions for salmon declines is a lot like blaming the iceberg for sinking the Titanic, while ignoring the many human errors that put the ship on course for the fatal collision. Managers have optimistically thought that salmon populations were unsinkable…ocean conditions may be the potential icebergs for salmon populations but the ship is being steered by us humans."

Dr. Peter Moyle, UC Davis Professor of Fish Biology

MARINE DISTRIBUTION OF CCC COHO SALMON

CCC coho salmon spend the majority of their lives at sea, therefore evaluating marine distribution and associated stresses and threats is a necessary component for recovery planning. The evaluation is challenging because migration patterns and ecology of coho salmon in the marine environment are highly variable and incompletely understood.

Coho salmon occur in the epipelagic zone (top layer of the water column) in the open ocean, at observed depths of from about 10 to 25 meters (summarized by Quinn 2005). Work based on recoveries of tagged hatchery fish indicates coho salmon south of Cape Blanco have a southern coastal distribution pattern (Weitkamp and Neely 2002). Information from hatchery releases in the range of the CCC coho salmon ESU, found that most individuals were recovered in northern California, followed by southern Oregon, with a small number found in Washington state waters (<1 percent). Based on these data, and assuming a correlation in migration patterns between hatchery and wild populations, it appears the majority of adult CCC coho salmon are located off of California and Oregon. Within their ocean distribution Weitkamp and Neely (2002) found a high diversity of ocean migration patterns which suggests individuals within a population may be widely distributed in the coastal ocean areas.

MARINE PHASE OF THE COHO SALMON LIFE CYCLE

Two life stages of coho salmon occur in the eastern Pacific Ocean; sub-adults and adults. These life stages occupy different environments and are exposed to different associated stresses and threats encountered within those areas. The sub-adult life stage is defined as individuals inhabiting nearshore marine areas, generally near the continental shelf. The adult life stage is defined as individuals occupying the larger offshore marine environment. Coho salmon utilize nearshore areas of the ocean for a number of months before they enter the open ocean, where they remain for eighteen months or more before they return to their natal streams as spawners. Some coho salmon never move offshore to the open ocean, but instead move north along the continental shelf and grow to adulthood in nearshore areas before returning to spawn (Sandercock 1991). To the extent adults remain in nearshore areas, they face the same stresses as do sub-adults. Coho salmon survival in the marine environment is largely affected by individual attributes, such as body size, growth rate, and ocean entry date; as well as environmental conditions, predation and competition (Quinn 2005).

Sub-Adult Life Stage

CCC coho salmon appear to remain in nearshore habitats close to their watershed of origin for the first few months of ocean residency. The life history study by Shapovalov and Taft (1954) on coho salmon in Waddell Creek on the central California coast, showed coho stayed within 150 kilometers of shore for a few months following ocean entry. Other studies using recoveries of coded-wire tags (CWTs) also indicate coho salmon remain in the region of their natal stream during their first summer in the ocean (Fisher and Pearcy 1988). Residency in natal nearshore areas may be linked to smolt density and feeding conditions in those areas and likely varies from year to year (Healy 1980).

The first summer and fall at sea critically influences the likelihood of survival to adulthood (Hartt 1980; Beamish *et al.* 2004). Van Doornik *et al* (2007) and Beamish and Mahnken (2001) correlated the abundance of juveniles caught in September, with adult abundance the following year and determined the success of each year-class was largely set during the first summer in the ocean. The close correlation between jack (two-year old male) abundance and adult abundance further indicates the early ocean period is critical to adult salmon abundance, and that most mortality occurs after the first summer of ocean residency (Quinn 2005). Juvenile salmon that fail to reach a critical size by the end of their first marine summer do not survive the following winter, suggesting that attaining a large size in a short period of time is necessary for survival. Beamish *et al.* (2004) and Holtby *et al.* (1990) found a strong link between growth and survival, with faster growing coho salmon being more likely to survive the winter than slower growing fish, especially in years of low ocean productivity. Increased growth rates are influenced by both genetic disposition (Beamish *et al.* 2004) and feeding opportunities. Upon ocean entry, juvenile coho primarily feed on marine invertebrates, but transition to larger prey (predominantly fish) as they increase in size (Groot and Margolis 1991). Beamish and Mahnken (2001) also found within the first six months of ocean entry, early mortality is influenced by predation, and to a lesser degree a physiologically-based mortality.

Adult Life Stage

Once coho salmon enter the open ocean, they are subject to different food availability, environmental conditions, and stressors than present in the nearshore environment. The growth and survival of adult coho is closely linked to marine productivity, which is controlled by complex physical and biological processes that are dynamic and vary over space and time. Shifts in salmon abundance due to climatic variation can be large and sudden (Beamish *et al.* 1999). Short and long-term cycles in climate (*e.g.*, El Niño/La Niña and the Pacific Decadal Oscillation (PDO)) affect adult size, abundance, and distribution at sea, as does inherent year-to-year variation in environmental conditions not associated with climatic cycles.

Several studies have related ocean conditions specifically to coho salmon production (Cole 2000), ocean survival (Ryding and Skalski 1999; Koslow *et al.* 2002), and spatial and temporal patterns of survival and body size (Hobday and Boehlert 2001; Wells *et al.* 2006). The association between survival and climate operate via the availability of nutrients regulating the food supply and competition for food (Beamish and Mahnken 2001). For example, the 1983 El Niño resulted in increased adult mortality and decreased average size for Oregon's returning coho and Chinook salmon. Juvenile coho salmon entering the ocean in the spring of 1983 had low survival rates, resulting in low adult returns in 1985 (Johnson 1988). Larger-scale decadal to multi-decadal events also have been shown to affect ocean productivity and coho salmon abundance (Hare and Francis 1995; Mantua *et al.*1997; Beamish *et al.* 1997; Beamish *et al.* 1999; Pearcy 1992; Lawson 1993). Although salmon evolved in this variable environment and are well suited to withstand climactic changes, the resiliency of the adult population has been reduced by the loss of life history diversity, low population abundance, cohort loss, and fragmentation of the spatial population structure. Changes in the freshwater environment (*e.g.,* loss and degradation of habitat resulting in decreased carrying capacity and freshwater survival) have further adversely affected the ability of coho salmon to respond to the natural variability in ocean conditions.

Marine Survival

As noted above, marine survival and successful return as adults to spawn in natal streams is critically dependent on the first few months at sea (Koslow *et al.* 2002; Unwin 1997; Ryding and Skalski 1999; Peterman 1982). In a detailed study of Puget Sound hatchery coho salmon, Mathews and Buckley (1976) estimated 13 percent survival during the first six months at sea; and after twelve months survival was estimated at nine percent. The survival rate during the second year at sea was 99 percent.

Marine environmental conditions are also a major determinant in adult returns (Bradford 1995; Logerwell *et al.* 2003; Quinn 2005). In general, coho salmon marine survival is about 10 percent (Bradford 1995), although there is a wide range in survival rates (from <1 percent to about 21 percent) depending upon population location and ocean conditions (Beamish *et al,* 2000; Quinn 2005)[1]. Changes in marine survival rates often have large impacts on adult returns (Beamish *et al.* 2000; Logerwell *et al.* 2003). Recent data from across the range of coho salmon on the coast of California and Oregon reveal a 72 percent decline in returning adults in 2007/08 compared to the same cohort in 2004/05 (SWFSC 2008). The Wells Ocean Productivity Index, a measure of Central California ocean productivity, predicted poor conditions during the spring and summer of 2006, when juvenile coho from the 2004/05 cohort entered the ocean (SWFSC 2008). However, strong upwelling in the spring of 2007 may have resulted in better ocean conditions for the 2007 coho salmon cohort.

STRESSES

Major stresses identified which potentially affect coho salmon marine survival include: (1) reduced quantity and/or quality of food resources; and (2) reduced genetic and life history diversity. Although poorly understood, the complex physical and biological processes determining feeding opportunities have a large influence on the growth and survival of coho at sea, especially in the first six months of ocean residency. What we do know is that the life history plasticity and genetic diversity of coho salmon entering the ocean environment has been dramatically decreased. The loss of diversity has reduced the growth opportunities, the survival of populations, and the overall resiliency of the ESU. Predation and competition can also influence the size of the population in certain circumstances. An analysis of stresses affecting coho salmon at sea is summarized by life stage below.

Reduced quantity or quality of food

Oceanographic condition (*e.g.,* upwelling rates, sea-surface temperatures, *etc.*) is the major factor influencing salmonid food quantity and quality in the marine environment. The first few months in the

[1] Few data exist for coho salmon from California. Most marine survival data reported above are from Oregon, Washington, and Canadian coho populations. NMFS assumes marine survival rates for CCC coho salmon will be similar.

ocean are critical for sub-adult coho salmon survival. As previously discussed, sub-adult fish must quickly grow to a large size prior to their first winter in the ocean or be subject to high mortality, thus survival is highly correlated with the amount and type of food available.

The availability and type of food resources in the nearshore environment is dependent upon the location and magnitude of upwelling and its influences on ocean productivity. Upwelling is caused by northerly winds that dominate from spring to early fall along the coastal region of the Pacific Northwest within the California Current marine ecosystem. These winds transport offshore surface water southward, while also transporting surface water away from the coastline (westward). This offshore, southward transport of surface waters is balanced by onshore northward transport (upwelling) of deep, cool, high-salinity, nutrient-rich water (Peterson *et al.* 2006). The shifting of this highly productive water to the surface of the nearshore environment triggers the formation of large phytoplankton blooms. Phytoplankton (minute aquatic plants) form the base of the marine food chain and are eaten by zooplankton (microscopic animals, such as copepods, that move passively with ocean currents). Zooplankton in turn, are preyed upon heavily by forage fish species and sub-adult coho salmon.

Coastal upwelling therefore, is a critical process affecting plankton production, and corresponding food availability. Moreover, the strength and timing of the upwelling event effects salmon survival by influencing the overall abundance and spatial distribution of plankton within the nearshore marine environment. Many studies have demonstrated this direct relationship. For example, Gunsolus (1978) and Nickelson (1986) correlated salmonid marine survival and the strength and/or timing of marine upwelling. Holtby *et al.* (1990) examined the scales of returning adult coho salmon in order to determine growth rates, and found that rapid ocean growth was "positively correlated with ocean conditions indicative of strong upwelling." Better ecosystem productivity is also related to earlier seasonal upwelling events (Peterson *et al.* 2006). Additionally, Cury and Roy (1989) demonstrated a relationship between upwelling and recruitment of several pelagic forage fishes in the Pacific.

The cooler water temperatures resulting from upwelling currents along the eastern Pacific Ocean originating from the subarctic region support high plankton productivity and salmon survival. Marine productivity and salmon survival are typically much lower when warmer, less-saline water upwells from sub-tropic marine regions. Survival is also likely influenced by the species of zooplankton occupying the two water types (cooler subarctic waters, and warmer subtropical waters); sub-arctic copepods are larger and have more fat than sub-tropical ones, promoting better support growth and survival of salmon which prey on them, and on forage species which eat them (Peterson *et al.* 2006). Peterson *et al.* (2006) developed an index to predict salmonid year-class strength based on the species of copepods present over the continental shelf and the inferred source of the water transport.

Unfavorable oceanographic conditions also affect adult coho salmon through their impacts on forage fishes, the primary food of adult coho salmon. For example, Pacific herring recruitment in the Bering Sea and northeast Pacific was accurately forecast based on the air and sea surface temperatures when spawning occurred (Williams and Quinn II 2000), and many Pacific herring starved during a winter of low zooplankton abundance in Prince William Sound, Alaska (Cooney *et al.* 2001).

Reduced genetic and life history diversity

A number of life history and genetic traits also influence coho salmon growth and survival. For sub-adults these include timing of ocean entry, size and age at entry, growth characteristics, migration pathways, feeding behaviors, straying, and age and size at maturity (Quinn 2005). The influence of each of these traits on growth and survival is dependent on ocean conditions, and salmon have a diversity of life history and genetic traits to take advantage of the full range of variability which maximizes their resiliency. Overall, coho salmon have experienced a net loss of diversity and may not be able to exploit the full range of ocean conditions, which may place them at a greater risk of extinction.

As noted above, the timing of ocean entry can affect likelihood of survival. Ryding and Skalski (1999) documented a relationship between the marine survival rate of coded-wire tagged coho salmon released from Washington state and the ocean conditions when released. The authors concluded there are optimal environmental conditions for coho marine survival, and thus optimal dates for ocean-entry, for any given year. Similar patterns have been observed with pink salmon in Alaska (Cooney *et al.* 1995). Research by Mortensen *et al.* (2000) also suggests an indirect relationship between time of ocean entry and growth and vulnerability to predators of sub-adult coho salmon.

Although the date of ocean entry is critical to coho survival, the timing of peak ocean upwelling and productivity is quite variable and cannot be reliably predicted. Between 1967 and 2005, the date of spring transition (the start of upwelling), at 39 degrees North latitude, has varied from January 1 to early April (Bograd 2007). Salmonids have responded to this variable environment by maintaining variation in several life history characteristics, including timing of ocean entry. Coho salmon migrate to sea over a number of months, which may increase salmonid year class strength because, although the timing of the upwelling event is variable, at least some coho should enter the ocean when conditions were favorable. Size and age variation during outmigration is an important mechanism to improve a population's ability to track environmental change and persist in the marine system[2].

The relationship between size and survival of sub-adult coho salmon has been documented in a number of studies (*e.g.,* Quinn 2005). Size-selective mortality in the ocean (mainly through predation) suggests larger individuals likely experience higher survival rates than smaller individuals (Holtby *et al.* 1990). Depending on various physical and biological factors in the freshwater environment, however, it can be an advantage to migrate at a smaller size to take advantage of increased growth opportunities at sea. Some individuals may also have a size advantage due to their genetic disposition, and this, in turn, may translate to increased growth and survival at sea (Beamish *et al.* 2004).

Once coho salmon reach the ocean they are thought to display a range of different migratory pathways depending on their behavior, life history, and genetic makeup (Weitkamp and Neely 2002). A wide

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[2] In Redwood Creek, California, some coho remain in freshwater for one year before outmigration to the ocean, while a small number remain for an additional year and smolt as two year-olds (Bell and Duffy 2007). In Pudding Creek, California, 12 percent of the smolts were two year-olds (Wright pers. comm. 2009). Two year-old coho salmon migrate at a larger size and may experience higher marine survival than smaller, one year-old fish, but are consequently exposed to an additional year of stresses unique to the freshwater environment. Depending on both ocean conditions and conditions in the freshwater environment, one or both life histories will likely succeed and contribute to the persistence of the population.

distribution allows populations and the ESU to take advantage of numerous feeding opportunities and spreads the risk of isolated mortality events (such as predation, fisheries impacts, or ocean conditions). In turn, a wide distribution decreases the risk of any one population being extirpated in concentrated mortality events.

As adults, some coho salmon display a limited range of life history strategies in terms of their age and size at maturity. Coho return to their natal streams to spawn either after only a few months at sea as two year-olds (called jacks or grilse) or, typically, after a year at sea as three year olds. Maintaining a healthy abundance of jacks in any population ensures some genetic overlap between brood years and is thought to increase the overall productivity of the population. Also important to the overall health and resilience of the ESU is the presence of strays, which do not return to their natal spawning grounds and consequently help to colonize new spawning areas and re-establish diminished populations. However, the majority of coho return as three year olds and overall, this is considered to be a relatively inflexible life history attribute.

A diverse array of behaviors and environmental sensitivities, such as those seen in salmon populations, are evolutionary responses to successful adaptation in uncertain environments (*e.g.*, *see* Independent Scientific Group (ISG) 2000). At the metapopulation level, each species of Pacific salmon exhibits many such risk-spreading behaviors via a broad diversity of time-space habitat use by different stocks and substocks of the same species. Through reduced population size, lost connectivity between remaining populations, and the genetic dilution resulting from (past) hatchery use of non-native stock (Weitkamp *et al.* 1995), the CCC ESU has lost much of its historical life history and genetic diversity. The remnant life history characteristics likely limit extant populations from taking full advantage of the range of ocean conditions, diminishing overall productivity. In the marine environment, the impact from lost phenotypic diversity is probably most pronounced at the sub-adult life stage, since success at that life stage is closely correlated with ocean conditions. Because of the importance of maintaining a diverse set of life history strategies and genetic pool to the survival and growth of coho salmon at sea, the loss of these traits is considered a medium to high stress.

THREATS

Overview of Threats

Major threats potentially affecting CCC coho salmon in the marine environment include incidental take from commercial and recreational fisheries, aquaculture, predation, harvest of kelp, wave energy generation, management of prey and competitors, hazardous spills, and introduction of non-native species. The threat of climate change also influences ocean productivity, but is discussed separately in the Climate Scenarios section of this appendix.

Commercial and recreational fishery bycatch

Directed commercial and sport fishing take

In 1993, the retention of coho salmon in ocean commercial fisheries was prohibited from Cape Falcon, Oregon south to the U.S.-Mexico border. The following year, coho salmon retention was prohibited in ocean recreational fisheries from Cape Falcon, Oregon to Horse Mountain, California, and expanded to include all California waters in 1995. These prohibitions prohibit direct sport and commercial harvest of coho salmon off the California and Southern Oregon coast, the sole exception being a mark-selective recreational coho salmon fishery that has taken place in recent years in Oregon waters. While the number of CCC coho harvested within the Oregon mark-selective fishery is difficult to determine, the percentage is likely lower than the projected 3.3 percent non-retention exploitation rate for Rogue/Klamath coho salmon (PFMC 2007) due to the more southern marine distribution of CCC fish versus Southern-Oregon Northern California Coast ESU (NMFS 1999a)[3]. Therefore, the primary harvest-related impact on CCC coho salmon likely arises from incidental take through other fisheries. This impact is likely largely restricted to adult fish and has little affect on the sub-adult life stage, which is likely too small to be efficiently captured in this fishery.

The State of California has recently begun implementing a series of underwater parks and reserves along the California coast as part of the Marine Life Protection Act (MLPA) of 1999. The goal of the MLPA is to "protect habitat and ecosystems, conserve biological diversity, provide a sanctuary for fish and other sea life, enhance recreational and educational opportunities, provide a reference point against which scientists can measure changes elsewhere in the marine environment, and may help rebuild depleted fisheries (DFG 2008)". Fishing will be closed or severely restricted in most protected areas, which will ultimately account for approximately 20 percent of state coastal waters (out to three miles off-shore). However, many of the restricted areas coincide with rocky benthic habitat which salmon may inhabit only sporadically, and many of the more popular salmon fishing areas are not expected to be part of the MLPA program. Furthermore, some MLPA areas where fishing is restricted make exceptions with regard to salmon fishing. For these reasons, NMFS does not expect a significant reduction in ocean salmon harvest resulting from the MLPA program.

<u>Bycatch in Federal salmon fisheries</u>

The Pacific Fishery Management Council (PFMC) manages salmonid fisheries in Federal waters. The CCC coho salmon ESU is one component of the Oregon Production Index (OPI) area coho stocks. Because there are insufficient hatchery releases from within the CCC coho ESU to support an estimate of fishery bycatch in the Chinook salmon fishery (DFG 2002), the projected marine fishery impacts on Rogue/Klamath River (R/K) hatchery coho were used as a surrogate.[4] Coho are intercepted in Chinook-directed fisheries and must be immediately released. However, some will die, as reflected by the 13.0 percent marine fishery mortality rate allowed for R/K hatchery coho salmon (NMFS 1999a). Given that the estimated discard mortality rate for R/K hatchery coho salmon has been the 13 percent maximum for at least the last three years (PFMC 2007), and prohibitions on take of OPI area coho stocks have not changed, the Federal salmon fishery was determined to pose a low threat to the CCC coho salmon ESU.

<u>Bycatch in State salmon fisheries</u>

All marine fishing occurring within three miles of the California shore is managed by DFG. Chinook salmon harvest is allowed in California waters subject to area restrictions, gear restrictions, seasonal

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[3] NMFS (1999) suggests exploitation rates for CCC coho salmon may be higher than SONCC coho salmon due to the overwhelming effect of the central and northern California sport and commercial Chinook fishery. However, due to recent declines in Klamath and Sacramento River Chinook salmon populations, Chinook salmon fishing off the California coast has been severely restricted in 2007, 2008, and 2009, and the size and extent of future seasons is uncertain.

[4] The assumption is that exploitation rates of hatchery and wild coho salmon stocks are similar.

closures, and bag limits (DFG 2007). Harvest of coho salmon is prohibited in California waters (except Lake Oroville), and any incidentally hooked coho salmon must be immediately released unharmed (DFG 2007).

The impacts of state-regulated Chinook salmon and steelhead fisheries on CCC coho salmon have not been evaluated but could be significant. Listed salmon and steelhead are likely to occur within the marine environment at the same time, and in the same locations, as non-listed salmonids, and are likely to be captured by the same gear and fishing methods. Bycatch mortality may be enough to hinder recovery due to the extremely low size of the population. In parts of California, ocean fishers use a "drift mooching" method of capturing salmonids, where bait is suspended in the water column and moved by the ocean currents as the boat drifts. Salmon are more likely to swallow the hook when caught using drift mooching than when caught while trolling, and are less likely to survive when released. The survival of Chinook salmon caught and released off Northern California from drift mooching was monitored for four days and compared to a control group (Grover *et al.* 2002). The overall hook-and-release mortality rate for the study was estimated at 42 percent, significantly greater than the 13 percent mortality cap in Federal ocean fisheries. While the study did not evaluate impacts to coho salmon (due to the statewide prohibition on harvest of this species) the impacts between species are likely similar. Given coho occur higher in the water column than Chinook salmon, fishers targeting Chinook salmon may not encounter coho salmon. However, since most of the lifetime mortality suffered by a coho salmon occurs before they reach adulthood (Quinn 2005), an adult coho salmon that has survived at least a year of ocean life and is not far from spawning age is particularly valuable for recovery. The PFMC salmon FMP includes the 42 percent bycatch mortality rate from mooching as part of its recreational bycatch mortality rate for the area south of Point Arena. However, as coho recover, this mortality rate could have a proportionately greater impact on the ESU than it does now, as the rate CCC coho are encountered increases. This fishing method could hinder recovery. Given the impact the state salmonid fishery on CCC coho salmon is unknown but potentially significant; this fishery was determined to pose a medium threat to the recovery of this ESU.

<u>Federal non-salmon fisheries</u>

The PFMC manages four stocks (*aka* stock complexes) in Federal waters potentially affecting CCC coho salmon through fishery bycatch: groundfish, coastal pelagic species (CPS), highly migratory species (HMS), and Pacific halibut. NMFS evaluated the impacts of the groundfish fishery on listed salmon and steelhead and concluded it was not likely to adversely affect salmon or adversely modify critical habitat (NMFS 1999b, NMFS 2005a). Salmonids could be accidentally captured in fisheries targeting CPS, but NMFS determined, although some ESUs of coho salmon are captured in CPS fisheries, CCC coho are not captured (PFMC 2005b). The HMS fishery targets various species of tunas, sharks, and billfishes as well as mahi-mahi. A 2004 Biological Opinion stated, although all listed salmonid ESUs could occur in the area where HMS fishing occurs, there are no records indicating any instance of take of listed salmon in any HMS fisheries.

Pacific halibut occur on the continental shelf from California to the Bering Sea. Harvest of this species is managed by the International Pacific Halibut Commission (IPHC), which determines allowable catch. Although fishing for this species is allowed in California, in the past ten years only one Pacific halibut was commercially landed in waters off California (Leaman 2007). Based on surveys from 1200 stations off of Washington and Oregon, an average of less than one salmon is captured per year survey wide (Dykstra 2007). The number of salmon caught in the recreational halibut fishery off California appears very small (Palmer-Zwahlen 2007).

Marine aquaculture

Concerns have been raised over environmental impacts of salmonid culture activities in nearshore or open ocean areas. Potential impacts include disease and parasite transmission, water quality impairment, and genetic interactions. The recovery of CCC coho salmon is unlikely to be hindered by current marine aquaculture activities because, aside from the shellfish farming (*e.g.,* oysters and abalone) occurring in estuaries, marine aquaculture is largely absent from the waters off the California coast where CCC coho salmon spend most of their ocean residency. Further, marine culture of salmonids cannot occur in California's jurisdictional waters (State of California 2006), which extend three miles into the Pacific Ocean. In Federal waters (between three and 200 miles from the west coast), the process for obtaining a permit to carry out aquaculture is unwieldy, time consuming, and unattractive to investors (NOAA 2007). A bill to establish Federal guidelines for offshore aquaculture and improve the permitting process was recently considered by congressional committees. This legislation would retain NMFS' review of permit applications to ensure they do not jeopardize the continued existence of CCC coho salmon. Given the low likelihood of any additional aquaculture operations off the California coast in the next five plus years, and the expected close evaluation of any proposals by NMFS, EPA, and other agencies, the threat to listed salmonids from the culture of animals in nearshore and offshore marine areas is rated as low.

Marine mammal predation

Predation by marine mammals (principally seals and sea lions) is of concern in areas experiencing dwindling run sizes of salmon (69 FR 33102). However, salmonids appear to be minor component of the diet of marine mammals (Scheffer and Sperry 1931; Brown and Mate 1983; Hanson 1993; Goley and Gemmer 2000; Williamson and Hillemeier 2001). Harbor seal and California sea lion numbers have increased along the Pacific Coast since passage of the Marine Mammal Protection Act of 1972, but available information indicates salmon are not a principal food source for pinnipeds (Quinn 2005). At the mouth of the Russian River in western Sonoma County, Hanson (1993) reported foraging behavior of California sea lions and harbor seals with respect to anadromous salmonids was minimal. Hanson (1993) found predation on salmonids coincidental with the salmonid migrations, and the harbor seal population at the mouth of the Russian River was not dependent upon them. Nevertheless, this type of predation may, in some cases, kill a significant fraction of a run and local depletion might occur (NMFS 1997; Quinn 2005). At the ESU level, NMFS considers the threat of marine mammal predation low.

Avian predation

Avian predation is not expected to constitute a significant threat to adult CCC coho salmon because of their relatively large size once in the ocean. All documented incidences of significant effects of avian predation on juvenile salmonids have occurred in estuarine areas near large nesting colonies with high avian densities. While birds are also known to feed on schools of fish in the open ocean (Scheel and Hough 1997), indirect evidence shows salmonids do not generally occur in tight schools. Many salmon probably do not swim in sight of other salmon, and when they have been observed together it is usually in groups of less than four (Quinn 2005). Avian predation is not expected to constitute a significant threat to sub-adult coho salmon when they occur in nearshore oceanic areas used by CCC coho salmon.

Management actions affecting nearshore marine habitat

Harvest of kelp from nearshore marine areas

Both bull and giant kelp are currently harvested from California waters (Springer *et al.* 2007). Small quantities of each species are currently harvested, due to limited commercial demand. The upper four feet of canopy and leaves of giant kelp are harvested, allowing the plant to continue to grow and reproduce (Springer *et al.* 2007); therefore, giant kelp are essentially a renewing crop. However, when bull kelp are harvested, the pneumatocyst and associated fronds are removed, which eventually kills the plant. Harvest of bull kelp before it reproduces may destroy beds of this species and reduce the amount of habitat available to juvenile CCC coho salmon. The extent CCC coho salmon utilize kelp is unknown.

Surveys of the fish communities in kelp beds off California south of the CCC coho salmon ESU range are focused on rockfishes and do not mention salmon (*e.g.*, Paddack and Estes 2000). No salmon were found in studies of beds of bull kelp off South-central Alaska (Hamilton and Konar 2007), but salmon were found in beds of brown kelp off Southeastern Alaska (Johnson *et al.* 2003). In Washington's Strait of Juan de Fuca, juvenile Chinook and chum salmon appeared to preferentially use kelp beds (which included both bull kelp and giant kelp) over unvegetated habitats (Shaffer 2004).

The above studies suggest coho salmon could use kelp beds, and some of these kelp beds and may be negatively affected by harvest. At this time, there is no evidence CCC coho salmon rely on kelp beds for shelter in the nearshore marine environment, and no harvest of the kelp beds occurs within the CCC coho salmon ESU range. The threat to CCC coho salmon from the harvest of kelp from nearshore marine waters was rated as Low.

Wave energy generation in the nearshore environment

Wave energy can be harnessed to provide electricity, and there are three proposals to do so in the marine range of the CCC coho salmon ESU (Boehlert 2008). The production has a potential to impact CCC coho salmon and their marine habitat. According to the proceedings of a recent workshop on the ecological effects of wave energy generation in the Pacific Northwest (Boehlert 2008), the electromagnetic fields and noise associated with wave energy's underwater structures have the most potential of all wave energy efforts to negatively affect salmon. Salmon may avoid the structures due to electromagnetic fields and/or noise, and such avoidance could interfere with the migration of juveniles along the coast, disrupt adult spawning migrations, or both. The generation of electricity from waves reduces wave energy, changing nearshore wave processes and potentially altering benthic communities where juvenile salmon feed. The harnessing of wave energy may affect transport of zooplankton (Boehlert 2008), and so could impact CCC coho salmon's food supply. The workshop participants acknowledged a high degree of uncertainty regarding the actual effects of wave energy generation on salmon, because little data documenting effects exists. Currently, wave energy poses a low threat to sub-adult and adult CCC coho salmon since no operational projects exist at this time. However, thorough research investigating potential adverse impacts on salmon and nearshore habitat should be required before future wave energy projects are permitted.

Management of coho prey and competitors

As coho grow in the ocean, their diet becomes more and more reliant on other fish species. Some concern has been raised over the possibility human harvest of salmon prey species may disrupt the aquatic ecosystem. If enough forage fish were harvested, there may not be enough prey items for higher level predators such as salmon and marine mammals. The effects of forage fish availability on salmonid predator behavior was recognized as a factor influencing the species when CCC coho were listed (69 FR 33102):

> *"The federally-managed fishery with the most potential to impact prey availability for CCC coho salmon is the coastal pelagic species (CPS) fishery. This group includes northern anchovy, market squid, Pacific bonito, Pacific saury, Pacific herring, Pacific sardine, Pacific (chub or blue) mackerel, and jack (Spanish) mackerel. Anchovy and sardine are known as important forage species for predators including salmon and steelhead (PFMC 2003, Quinn 2005). CPS are extremely important links in the marine food chain, and disruptions in their distribution and abundance may impact salmon population dynamics (PFMC 2003)".*

CPS harvest could indirectly affect salmon if it resulted in an inadequate amount of prey species for foraging salmon. The PFMC has adopted a conservative, risk-averse approach to management of CPS that reduces the likelihood of such negative effects. The need to "provide adequate forage for dependent species" is recognized as a goal and objective of the CPS FMP (PFMC 1998). A control rule is a simple formula used by the PFMC in evaluating allowable harvest levels for each of the CPS. The CPS control rules contain measures to prevent excessive harvest, including a continual reduction in the fishing rate if biomass declines. In addition, the control rule adopted for species with significant catch levels explicitly leaves thousands of tons of CPS biomass unharvested and available to predators. No ecosystem model currently exists to calculate the caloric needs of all predators in the ecosystem, so the amount of unharvested CPS biomass is an estimate which may be modified if new information becomes available. Ocean temperature is a factor in the control rule for Pacific sardine, in recognition of the effects of varying ocean conditions on fish production rates. Allowable harvest rates are automatically reduced in years of poor production.

The impacts of these fisheries on Federally-listed ESUs of salmon and steelhead were not evaluated by NMFS. However, due to the conservative control rules used to manage CPS and the preservation of a portion of the biomass for predator consumption, the CPS fishery poses a Low threat to CCC coho salmon recovery.

Transportation-related hazardous spills

Oil spills can have significant, catastrophic effects on aquatic ecosystems (NRC 2003), including acute mortality of fishes. The effects of crude oil on pink salmon were studied extensively since the Exxon Valdez oil spill in Prince William Sound, Alaska. Although some researchers found the oil spill affected growth rates of juvenile pink salmon (Willette 1996; Moles and Rice 1983), a review of all research on this topic showed the spill posed a low risk to this species (Brannon and Maki 1996). The relatively low depth of the oil entering the water column and the short time it remained in important natal gravel beds (Brannon and Maki 1996) may account for this effect. Oil spills appear to have the greatest effect on aquatic birds and marine mammals and benthic (bottom-dwelling aquatic) organisms (Boesch *et al.* 1987). The egg, alevin, and fry life stages of salmonids utilize benthic habitat in freshwater and brackish areas, and indeed toxic effects of crude oil were documented on the embryos and larvae of herring on oil-affected beaches (Hose *et al.* 1996). However, none of these salmonid life stages occur in nearshore marine areas or the open ocean, and direct effects of oil spills on salmon occurring in these areas is likely low. Indirect effects could include degradation of submerged aquatic vegetation such as kelp and eelgrass used by some juvenile salmonids in nearshore areas (Thorpe 1994). Disruption of the food web could also be detrimental to these fishes. Although in some circumstances crude oil may inhibit photosynthesis of natural phytoplankton communities in inland areas of Nova Scotia, Canada, researchers determined that in open marine waters oil did not negatively affect photosynthesis (Gordon and Prouse 1973).

Introduction of non-native species

Some invasive species are detrimental to salmonids, particularly in the freshwater or estuarine environments. Conditions in the open ocean are less hospitable to many invasive species than estuaries[5], and non-marine fish do not tend to survive when released into marine waters. Of 22 fish species successfully introduced into marine waters, all of them came from marine waters, indicating introductions of freshwater or brackish fish species into marine waters were unsuccessful (Hare and Whitfield 2003). All but one of these 22 marine fish species was released from an aquarium or accidentally or intentionally stocked (Hare and Whitfield 2003). Since the sub-adult and adult life stages of CCC coho salmon occur in the ocean, introduction of non-native species is unlikely to affect them because the introduced species are unlikely to survive. Proposed national offshore aquaculture legislation would usually only allow marine culture of native species in Federal waters (NOAA 2007), making it is unlikely further stocking of potentially harmful non-native species will occur in marine waters off California. The threat to sub-adult and adult CCC coho salmon from introduction of additional non-native species was therefore rated low.

[5] This has led to a requirement to replace ballast water in the ocean before entry into California state waters if the vessel intends to dock at any California port (State of California 2003).

RECOVERY STRATEGY FOR CCC COHO IN THE EASTERN PACIFIC

Marine factors will strongly influence CCC coho salmon recovery, but not solely due to obvious threats such as pollution or over-harvest. Rather, freshwater and marine impacts have reduced CCC coho salmon genetic and life history diversity, leaving the species less equipped to deal with variable, unpredictable, and often hostile oceanic conditions. The best means to improve CCC coho salmon survival in the marine environment is to preserve and strengthen the existing genetic and life history diversity in the ESU, which will likely improve population abundance over the long-term. In addition, a better understanding of the ocean conditions each year is necessary so that managers could account for periods of poor ocean productivity and high marine mortality when estimating population abundance, harvest levels, and ultimately the progress toward ESU recovery.

Improve the quantity and/or quality of food resources

This is the top-ranked stressor for sub-adult and adult CCC coho salmon, because it results from unfavorable ocean conditions. As ocean conditions are not under human control in the time frame relevant to CCC coho salmon recovery (*e.g.*, 50 years), there are no recovery strategies which could "improve" them. However, strategies which improve genetic and life history diversity in the CCC coho salmon ESU would effectively equip the salmon to better survive an unpredictable ocean environment. Further research is necessary to discern possible connections between global climate change and cyclic patterns of ocean productivity. If a link is found, actions identified to alleviate or diminish global climate change may have value in moderating marine productivity patterns and improving salmon survival.

Increase genetic and life history diversity

Before anthropogenic stressors within the freshwater, estuarine, and marine environment depressed the CCC coho salmon population to a level requiring protection under the ESA, abundant, genetically diverse juvenile salmon entered the ocean each year over a wide range of dates, seasons, and ages from approximately 76 CCC coho salmon populations identified by Bjorkstedt *et al.* (2005). It is necessary to restore this lost diversity and life-history adaptation to allow CCC coho salmon populations to adapt and persist within the variable ocean environment. To foster greater life history and genetic diversity, recovery actions must be undertaken to improve the various habitats supportive of diverse life history strategies. Management and recovery strategies must adapt to address and conserve the full range of life history potential of a given populations, and hatchery practices must be managed to avoid degrading the genetic diversity of wild stocks.

Increase population size

Federal fisheries have been evaluated and appear to pose a low threat to CCC coho salmon, likely due to coho salmon harvest prohibitions in California and a low allowable CCC coho salmon bycatch mortality rate for Federally-managed ocean fisheries. The harvest prohibition extends into ocean waters managed by the state of California. All existing prohibitions and bycatch mortality rates should be retained or made more conservative. Salmonid fisheries in state waters have the potential to negatively impact the ESU and the extent of such impact has not been evaluated. Development of a Fishery Management Evaluation Plan (FMEP) is necessary for NMFS to determine what risk, if any, these fisheries pose to the CCC coho salmon ESU. The effects of drift mooching on CCC coho salmon should be minimized through educating anglers on the use of drift mooch methods that lessen the probability of gut hooking, as suggested in Grover *et al.* (2002).

Climate Scenarios

"There are two key sources of greenhouse gas emissions: fossil fuels and forest change. Any successful climate strategy must address both."

Laurie Wayburn, President, Pacific Forest Trust

CLIMATES SCENARIOS AND CCC COHO SALMON RECOVERY

Reducing the amount of greenhouse gasses in the atmosphere will take 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 (NMFS 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 this is particularly true in the NCCC Domain, where coho salmon exist at the southern extent of their range. NMFS (Good 2005), and CDFG (2002) agree coho salmon are in danger of extirpation at the southern end of their range. Nearly 75 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 2008). Climate shifts can affect fisheries, with profound socio-economic and ecological consequences (NMFS 2008). This chapter provides an overview of probable climate change impacts on CCC coho salmon, examines three climate change scenarios in California, describes which populations may be the most impacted, and recommends actions to improve the resiliency of the species.

Overview

A preponderance of the best available scientific information indicates that Earth's climate is warming, driven by the accumulation of heat-trapping greenhouse gasses in the atmosphere (Lindley 2007)(Battin 2007)(Oreskes 2004). 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, removal of trees are largely responsible for the increase in greenhouse gases (Solomon 2007). Concentrations of these gases in the atmosphere affect the amount of incoming solar radiation and outgoing thermal radiation (Forster, 2007). These gasses absorb some of the outgoing thermal radiation, preventing it from leaving Earth's atmosphere (Forster 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.

Appendix A: Marine Habitat and Climate Scenarios

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 (Solomon, 2007). Concentrations of CO_2 in the atmosphere are increasing rapidly and currently exceed the highest concentrations reached during the last 400,000 years (IPPC 2007, Feely 2004).

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 (Dybas 2007, Feely, 2004) and terrestrial systems approximately 20% of the CO_2 (Feely 2004).

Changes in seasonal temperature regimes are already affecting fish and wildlife (Walther 2002, Schneider and Root 2002, Quinn and Adams 1996). These effects manifest themselves in diverse organisms as 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 2002). A number of fish have been observed to shift their distributions to deeper water, or poleward in response to warming waters (NMFS 2008). As global temperatures rise, temperatures, winds, and precipitation patterns at smaller geographic scales are expected to change (Osgood 2008, CEPA 2006). In terrestrial environments, freshwater streams important to salmonids may experience increased frequencies of floods, droughts, lower summer flows and higher temperatures (Osgood 2008, Luers, 2006, CEPA 2006, Lindley 2007, Schneider 2007). 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 (Osgood 2008, Brewer 2008, Turley 2008, O'Donnell 2009, Diffenbaugh 2003, Barth, 2007).

Climate variability is a key factor controlling the distribution and abundance of marine organisms and ecosystem structure. The physical ecosystem drivers related to climate will impact growth rates and reproductive success of marine species at all trophic levels. Estuarine and lagoon areas are likely to experience sea level rise and changes in stream flow patterns (Scavia 2002).

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

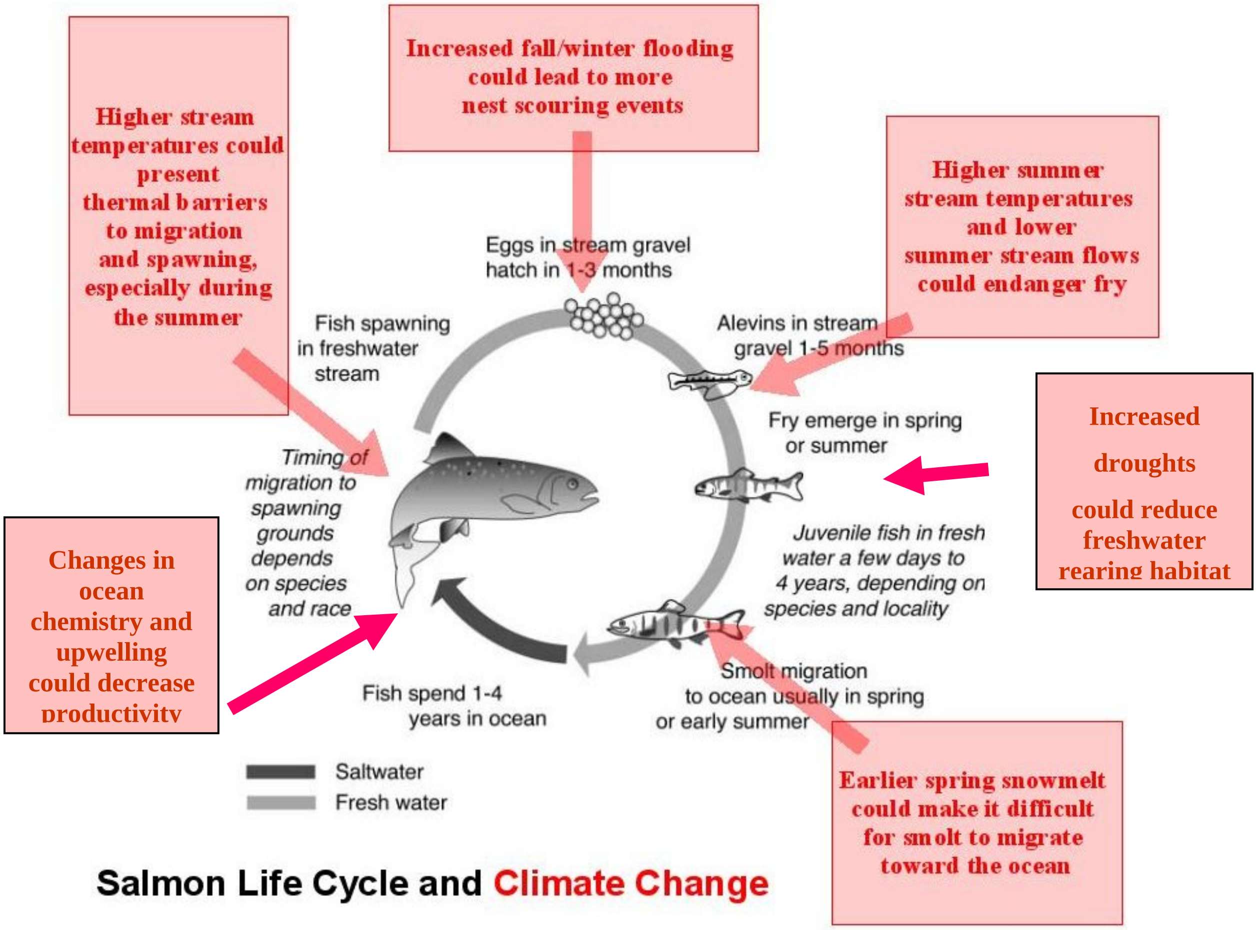


Figure 1: Generalized Salmon Life Cycle and Climate Change Impacts (Reeves 2009 and modified from Casola 2005)

Climate Change in California

A number of climate models are being used to manage the uncertainties surrounding climate change and forecast future climate conditions. These models provide results useable at global and regional scales, including the State of California. Model predictions show a range of relatively low to high impacts depending upon which model is used and which greenhouse gas emissions scenario is considered. Even the low impact predictions show changes in California's temperatures, rainfall, snowpack, vegetation, as well as potential changes in ocean conditions that are likely to have serious negative impacts on salmonid population numbers, distribution, and reproduction.

Impacts on Freshwater Streams

Modeling of climate change impacts in California suggest average summer air temperatures are expected to increase (Lindley 2007). Heat waves are expected to occur more often, and heat wave temperatures are likely to be higher (Hayhoe 2004). Total precipitation in California may decline; the frequency of critically dry years may increase (Lindley 2007, Schneider 2007). Wildfires are expected to increase in frequency and magnitude, by as much as 55 percent under the medium emissions scenarios modeled (Luers 2006). 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 coho salmon as described below.

Air temperature

Changes in air temperature significantly impact stream temperature (Poole 2001). Increasing air temperatures have the potential to limit the quality and availability of summer rearing habitat for CCC coho salmon. 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 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 coho salmon ESU are at or near the high temperature limit of coho salmon and increasing water temperatures may limit habitat suitability in many stream reaches.

Precipitation

The likely 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 2004). 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 (Westerling 2006, Luers, 2006). 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 1991, Waters 1995).

Vegetative cover

Changes in vegetative cover can impact coho salmon 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 CCC coho salmon 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 salmonids. In streams, large conifer trees can also interact with stream flows and stream beds and banks, creating deep stream pools needed by salmonids to escape high summer water temperatures. For coho salmon, these pools are essential for feeding and rearing.

Impacts on the Marine Environment

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 increased climate variability, changes in the timing and strength of the spring transition (onset of upwelling), warming and stratification, and changes in ocean circulation and chemistry (Osgood 2008)(Diffenbaugh, 2003)(Feely, 2004)(Scavia, 2002). Estuaries and lagoons will also likely undergo changes in environmental conditions due to sea level rise (Scavia, 2002).

Climate Variability and the Spring Transition

Global warming is likely to change the frequency and magnitude of natural climate events that affect the Pacific Ocean (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 (Osgood 2008, Mantua 1997). 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 (Osgood 2008, Diffenbaugh 2003). 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, 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 coho survival and growth in the ocean are similar to copepod (a salmonid food item) biomass fluctuations, which are also linked to climate variations (Mackas 2007). Salmon smolts entering California coastal waters could be impacted by reduced food supplies, which lower marine survival rates during the critical first months of their ocean life phase (Osgood, 2008).

Ocean Warming

Ocean warming has the potential to shift coho salmon 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 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.* 1988). The precise magnitude of species response to ocean warming is unknown, although recent modeling suggests that 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 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 coho salmon 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 2009). The world's oceans absorb CO_2 from the atmosphere, and rising levels of atmospheric CO_2 are increasing the amount of CO2 in seawater (Feely 2004, Turley 2008). Chemical reactions fueled by this CO_2 are increasing ocean acidity and the speed by which acidity is increasing is matched only by rates during ancient planet-wide extinction events (Sponberg 2007, Brewer 2008, Turley 2008). 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 2008, O'Donnell, 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 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 have greater effects on CCC coho salmon in the northern portion of their range because coho salmon may use northern estuaries for extended rearing. CCC coho salmon in the southern portion of their range are less dependant on estuaries for rearing. In southern lagoons, observations of coho salmon occurred in April and May (Smith 1990) suggesting these fish were smolts on their way to the ocean. In the northern portion of their range, coho salmon were observed in Albion River estuary from late May through late September, suggesting that some or all of these fish may be spending more time rearing in this estuary prior to smolting (Maahs 1998)

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, 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, 2002). If these impacts occur elsewhere, the result may be reduced food supplies for coho salmon that use estuaries for rearing before going to sea. Fewer coho would be expected to survive to complete their life cycle.

SCENARIOS FOR RECOVERY PLANNING

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 developed scenarios based on reasonable assumptions from available information. These scenarios describe how climate change may affect various aspects of the environment. NMFS used these climate change scenarios to evaluate the impacts of climate change on CCC coho salmon and their habitats.

NMFS has relied mainly on the scenario analysis done by the California Environmental Protection Agency (CEPA 2006)[6]. CEPA considered three CO_2 emissions scenarios: high emissions, medium high emissions, and lower emissions. Details of the environmental, population, economic, resource use, and technological assumptions behind each scenario are described in CEPA 2006. These scenarios are not precise predictions of how California will be affected by climate change. Rather, they are rough estimates of changes by the end of this century in temperature, rainfall, vegetation, *etc*., due to different emission levels at a Statewide, West Coast wide, or larger eco-region scales.

Climatic changes during shorter time scales may be 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 2007). Progress is being made on forecasting changes from climate change within short time periods at global and large regional scales (Smith 2007). Unfortunately, predicting impacts on more local geographic areas in short time frames, such as the first decade of CCC coho salmon recovery plan implementation, remain elusive. Given California's complex topography and variety of micro climates, particular local areas in the CCC coho salmon ESU may respond differently to climate changes[7].

NMFS considered the potential effects of the three (CEPA 2006) scenarios on future habitat conditions and threats for CCC coho salmon in the freshwater environment[8]. We used many of the same habitat

[6] These scenarios are being re-evaluated by CEPA based on current information (Franco 2008). When new scenario information becomes available, NMFS will incorporate it into this recovery plan.

[7] For example, a recent 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 (Press Democrat 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*.

[8] We focused on the freshwater environment 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. Estuarine habitat was not analyzed because available information suggests CCC coho in the southern portion of their range use these habitats for a relatively brief interval as transitional habitat between fresh and saltwater rather than for protracted rearing as do steelhead. However, more studies are necessary from estuaries in the northern portion of the range to determine if this trend holds true throughout the ESU or if it is in response to available habitat conditions.

attributes, indicators, and threats used to evaluate the current and future condition of coho salmon habitat in this Recovery Plan. In many cases, the scenarios available for California are not specific enough for us to project changes in habitat indicators or threats with much confidence. We do conclude that greater detrimental changes are likely under higher CO_2 emissions. After we evaluated future habitat conditions and threats under the three emissions scenarios, we considered changes that may be needed to recovery priorities and strategies for CCC coho salmon.

<u>Ecological attributes, indicators, and threats most likely affected by climate change.</u>

Our analysis focused on the following habitat attributes/indicators and threats:

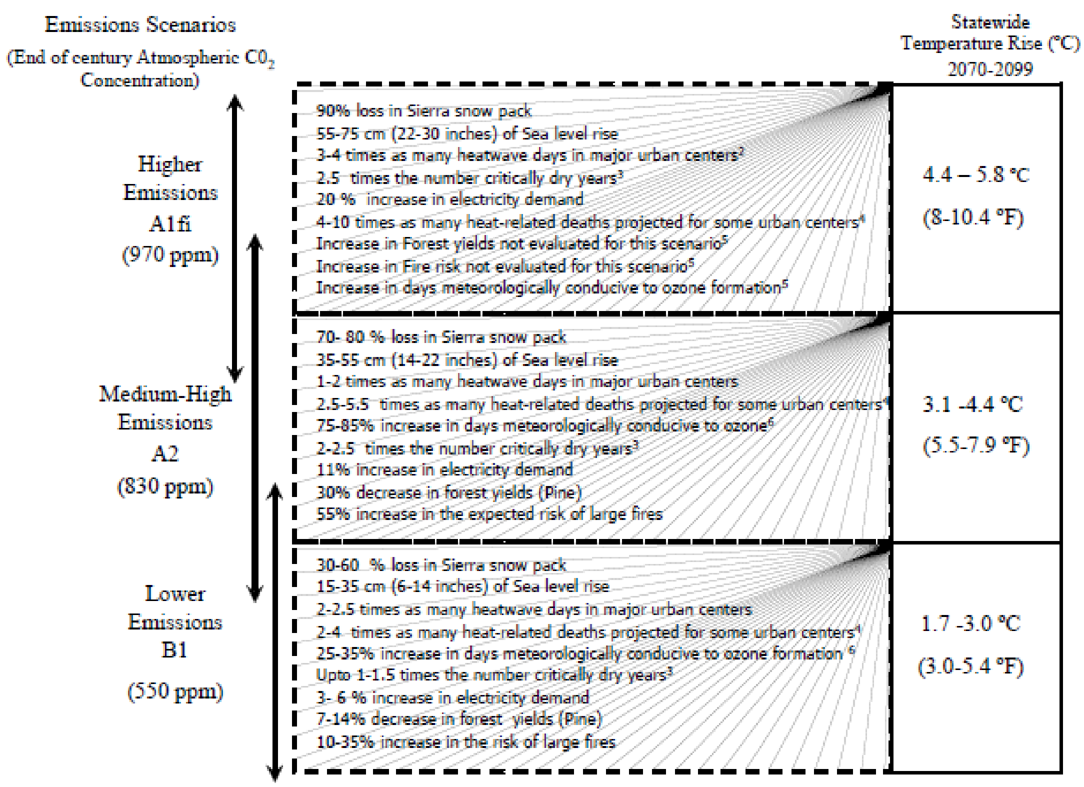
- Droughts
  - Passage flows (all life stages)*
  - Passage at River Mouths (adults and smolts)*
  - Baseflow*
  - Water Diversion and Impoundment*
  - Fire and Fuel Management*
- Storms and Flooding
  - Redd Scour*
  - Pool habitat (shelter, LWD, *etc*.)*
- Temperature
- Riparian Species composition, size, and canopy cover
- Disease, Predation, and Competition

*For this analysis, these habitat attributes/indicators, or threats, are primarily influenced by either Droughts, Storms or Flooding.

We did not address the other habitat attributes, indicators and threats identified for CCC coho salmon in this Recovery Plan because: (1) they can be easily linked to changes in the above attributes, or (2) we cannot make reasonable predictions regarding the impacts of global climate change on these attributes, indicators, or threats based on the available information. For example, agricultural practices (identified as a threat in the Recovery Plan) can result in sedimentation and turbidity. It is unclear how farmers will respond to increased droughts and changes in vegetation growth patterns, and what resulting impacts on sediment and turbidity would be. Farmers may respond by (1) stopping farming and allowing the land to go fallow, (2) stopping farming and selling the land for residential or urban development, (3) changing or modifying crop rotations, (4) building additional reservoirs and/or, (5) conserving water resources, *etc*.

EMISSION AND TEMPERATURE SCENARIO OVERVIEW

The CEPA modeling approach consist of three emissions scenarios high (970ppm), medium-high (830 ppm), and low emissions (550 ppm) and their predicted condition outcomes CEPA (2006). Modeling results indicate minor differences among the environmental impacts for different emissions scenarios between the years 2035-2050. Past these years, the environmental impacts of high emissions scenarios begin to show marked differences from lower emissions scenarios (CEPA 2006, IPCC 2007, Burgett 2009) The following emissions and air temperature scenarios from (Lindley *et al*. 2007) were used in our analysis (Figures 2 and 3). The modeling effort focused on Central Valley salmonids but their analysis was illustrative because their temperature scenario maps include projections for coastal areas used by CCC coho salmon Lindley *et al*., (2007). 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.



1. Impacts presented relative to 1961–1990.
2. Los Angeles, San Bernardino, San Francisco, Sacramento, and Fresno.
3. Measures for the San Joaquin and Sacramento basins.
4. For Los Angeles, Riverside, and Sacramento.
5. Impacts expected to be more severe as temperatures rise. However, higher temperature scenarios were not assessed for the project.
6. Formation in Los Angeles and the San Joaquin Valley.

Figure 2: Emission scenarios for California for a 30-year period, identifying increased threats associated with average annual air temperature (Lindley 2007).

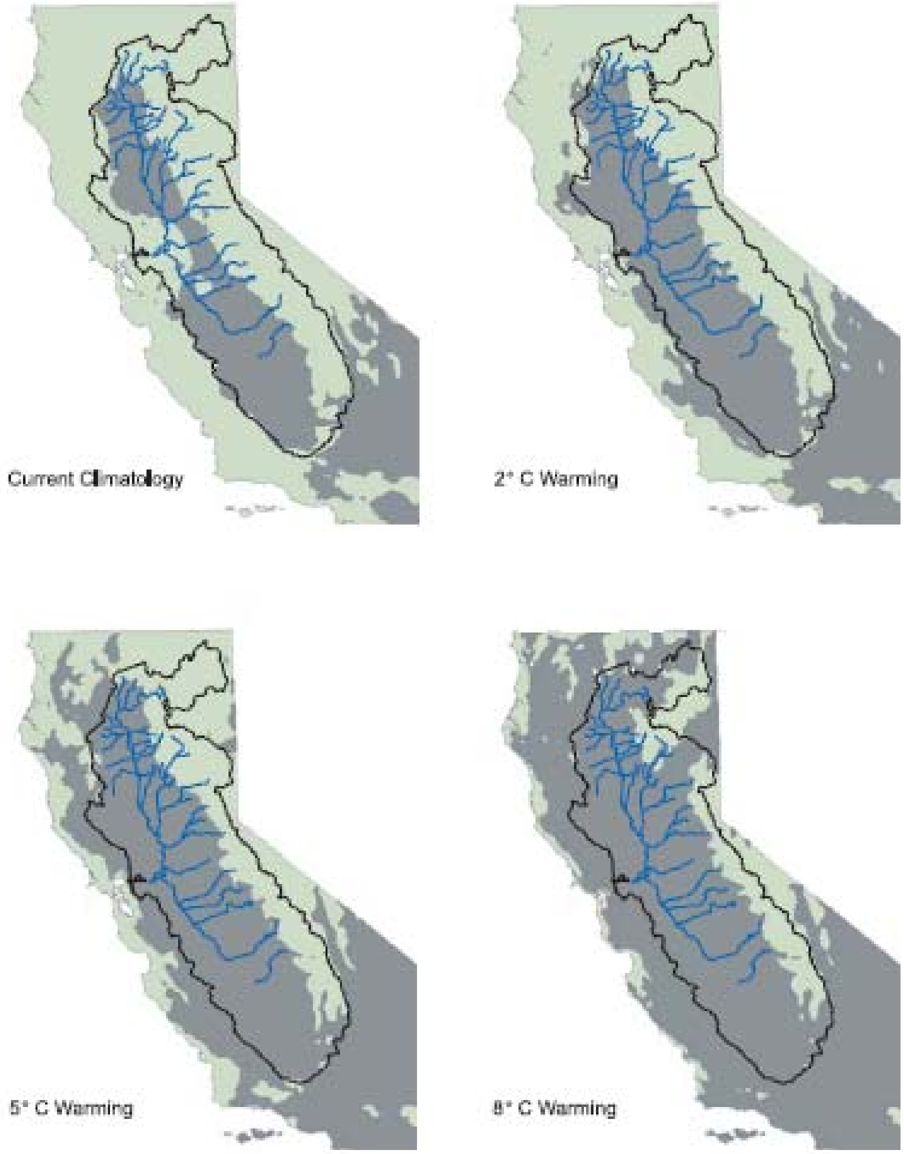


Figure 3: Geographic areas in California experiencing a mean August air temperature >25 C by year 2100 under different warming scenarios (Lindley 2007).

High emissions scenario

Under this emissions scenario, statewide average annual temperature is expected to rise between 4.4 and 5.8 C (Luers, 2006). This rise 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 model appears to differ regarding the incidence of large storms, as described above.

Droughts

Natural climate variations such as droughts can dramatically affect habitat conditions for CCC coho salmon. Model output results show a 2.5 times the number of critically dry years are possible (Luers 2006) for California as a whole in the high emissions scenario. On the North Coast, including the area inhabited by CCC coho salmon, other modeling has produced varying results for rainfall patterns. Different rainfall patterns may produce varying effects on CCC coho salmon 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 2.5 increase in the number of critically dry years. Based on the overall threats ratings for droughts, and water diversions and impoundments outlined in Table 1, 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 coho across their range. The greatest impacts are expected to occur in the Coastal and Santa Cruz Mountains Diversity Strata, where droughts are rated as very high threats in many of the targeted watersheds containing coho salmon 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 CCC coho salmon affected during baseflow conditions under this scenario, but migration flows for adults 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: CCC coho salmon focus populations and threat rankings expected to be most vulnerable to climate change. Threat Ranks were assigned a numeric value (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. For example, Pine Gulch Creek, Pescadero Creek, the San Lorenzo River, and Aptos Creek all received a score of 8, indicating a high risk to recovery in these watersheds from these threats. Focus populations added late in the recovery planning process (Usal, Wages, Salmon, San Gregorio, and Soquel Creeks) were not included in this initial analysis.

Threat	Cottaneva	Ten Mile	Pudding	Noyo	Caspar	Big	Albion	Big Salmon	Navarro	Garcia	Gualala	Russian	Walker	Lagunitas	Pine Gulch	Redwood	Pescadero	Gazos	Waddell	Scott	San Vicente	San Lorenzo	Aptos
Droughts	H	H	H	H	M	H	H	H	H	H	H	VH	H	VH	VH	VH	VH	VH	H	H	VH	VH	VH
Fire and Fuel Management	M	M	M	M	M	M	M	M	M	M	M	M	M	M	H	H	M	M	M	M	M	M	H
Storms and Flooding	M	M	M	M	M	H	M	M	H	M	M	M	M	M	M	M	H	M	H	H	M	H	H
Water Diversion and Impoundment	M	M	M	M	M	M	M	M	M	M	M	H	M	H	H	M	H	M	M	M	H	H	M
Threat Rank Totals:	5	5	5	5	4	6	5	5	6	5	5	7	5	7	8	7	8	6	6	6	7	8	8

Under this scenario, impacts from increased droughts in northern coastal watersheds would be somewhat less, although NMFS expects some watersheds to exhibit large reductions in the availability of summer rearing habitat due to lack of stream flows. In order to assess threats under this scenario, NMFS has extracted the threat ratings for indicators are most vulnerable to climate change.

NMFS also analyzed key habitat attributes at risk from climate effects. The current condition indicators most likely to worsen due to climate change for each watershed are illustrated in Table 2. NMFS assumed that the vulnerability of individual CCC coho salmon populations to specific impacts due to drought mostly relates to the current condition of specific habitat indicators. For example, the San Lorenzo River, Gazos , Pescadero Creeks, the Russian, Gualala, and Navarro Rivers are likely to be the most vulnerable to reduced adult passage flows due to drought conditions under any emissions scenario.

Table 2: Current condition indicators for 23 of 28 coho focus populations and life stages expected to be adversely affected by climate change. Condition ratings were assigned a numeric value (VG = 1, G = 2, F = 3, P = 4) The higher the current condition rank, the poorer current condition of habitat. Watersheds were then ranked, with the highest sums indicating those at the greatest risk from climate related threats. For example, The Russian and San Lorenzo Rivers, both received a score of 28, indicating a high risk to recovery in these watersheds for these attributes. Focus populations added late in the recovery planning process (Usal, Wages, Salmon, San Gregorio, and Soquel Creeks) were not included in this initial analysis.

Target	Attribute	Indicator	Cottaneva	Ten Mile	Pudding	Noyo	Caspar	Big	Albion	Big Salmon	Navarro	Garcia	Gualala	Russian	Walker	Lagunitas	Pine Gulch	Redwood	Pescadero	Gazos	Waddell	Scott	San Vicente	San Lorenzo	Aptos
Spawning Adults	Hydrology	Passage Flows	VG	G	G	G	VG	G	G	VG	F	G	F	F	G	VG	G	G	F	F	VG	G	G	P	VG
Spawning Adults	Passage	Passage at Mouth	G	F	G	VG	G	VG	VG	VG	G	G	G	G	VG	VG	VG	G	G	G	F	F	VG	G	G
Eggs	Hydrology	Redd Scour	VG	G	G	F	VG	F	F	G	P	F	F	P	G	G	VG	G	F	F	F	P	F	P	F
Summer Rearing	Hydrology	Baseflow	G	G	F	F	G	F	F	F	P	F	F	P	F	F	F	F	F	G	G	F	F	P	G
Summer Rearing	Water Quality	Temperature	F	P	F	P	G	P	F	F	P	P	P	P	P	P	G	G	P	F	F	F	G	P	F
Winter Rearing	Floodplain	Complex Habitat	P	P	F	P	F	P	P	F	P	P	G	P	P	P	F	P	P	P	F	P	P	P	P
Smolts	Hydrology	Passage Flows	VG	G	G	G	G	G	G	G	F	G	F	P	F	VG	G	G	F	F	G	F	G	P	G
Mult. Life Stage	Riparian Veg.	Sp. Composition	G	G	G	G	F	F	G	G	F	F	F	F	P	G	G	F	F	G	VG	G	G	G	G
Summary of Current Condition Rankings:			16	21	19	21	16	22	20	17	27	23	23	28	23	18	16	20	25	22	18	24	19	28	19

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.

Storms and Flooding

A large body of work has examined the impacts of increased storm and flooding magnitudes and frequencies on salmonid life-stages, behavior and habitat. Due to differences in modeling results, scenarios for climate change impacts on precipitation in Northern California are not included in the modeling exercise. For these reasons, NMFS has chosen to assume a worst-case high emissions scenario where storms and flooding dramatically increase during the winter months. Previous studies have shown, 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. Winter rearing populations without access to velocity refugia are vulnerable to losses due to increases in flood flows.

In addition, the compounding affects of roads are also a high threat for all targeted populations in the ESU. 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. Populations most vulnerable to these impacts include Scott Creek and the Russian and San Lorenzo Rivers. Based on the threat rankings, coho populations in the Santa Cruz Mountains Diversity Stratum are the most vulnerable to storms and flooding events.

In the analysis, NMFS pool habitat indices, LWD, cover and shelter data were not included in the tables above; these parameters may fluctuate based on climate change impacts. However, in areas where pool habitats may improve, large floods have the potential to remove sediment that accumulate and fill in pool habitats. Furthermore, large floods may trigger landslides that supply LWD to streams. Conversely, large floods may remove LWD and deposit large amounts of sediment into streams further degrading CCC coho habitat.

Temperature

Fish, including salmonids, are very sensitive to water temperature changes. Previous sections of this document explain the temperature requirements of coho salmon and how NMFS evaluated current stream temperature conditions in the ESU. 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. The 5° C warming map (Figure 4) from (Lindley, 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 map below illustrates where CCC coho salmon may be vulnerable to air temperature increases, based on the information in Lindley (2007). Based on this map, the interior watershed areas used by the Navarro, Big, Garcia, Gualala, and Russian River populations may experience high air and water temperatures that dramatically reduce the amount of stream habitat available to coho juveniles during the summers. This impact appears most pronounced in the Russian River, where most of the watershed, except for tributaries near the coast, may experience these high temperatures. 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 for the coast in somewhat in doubt.

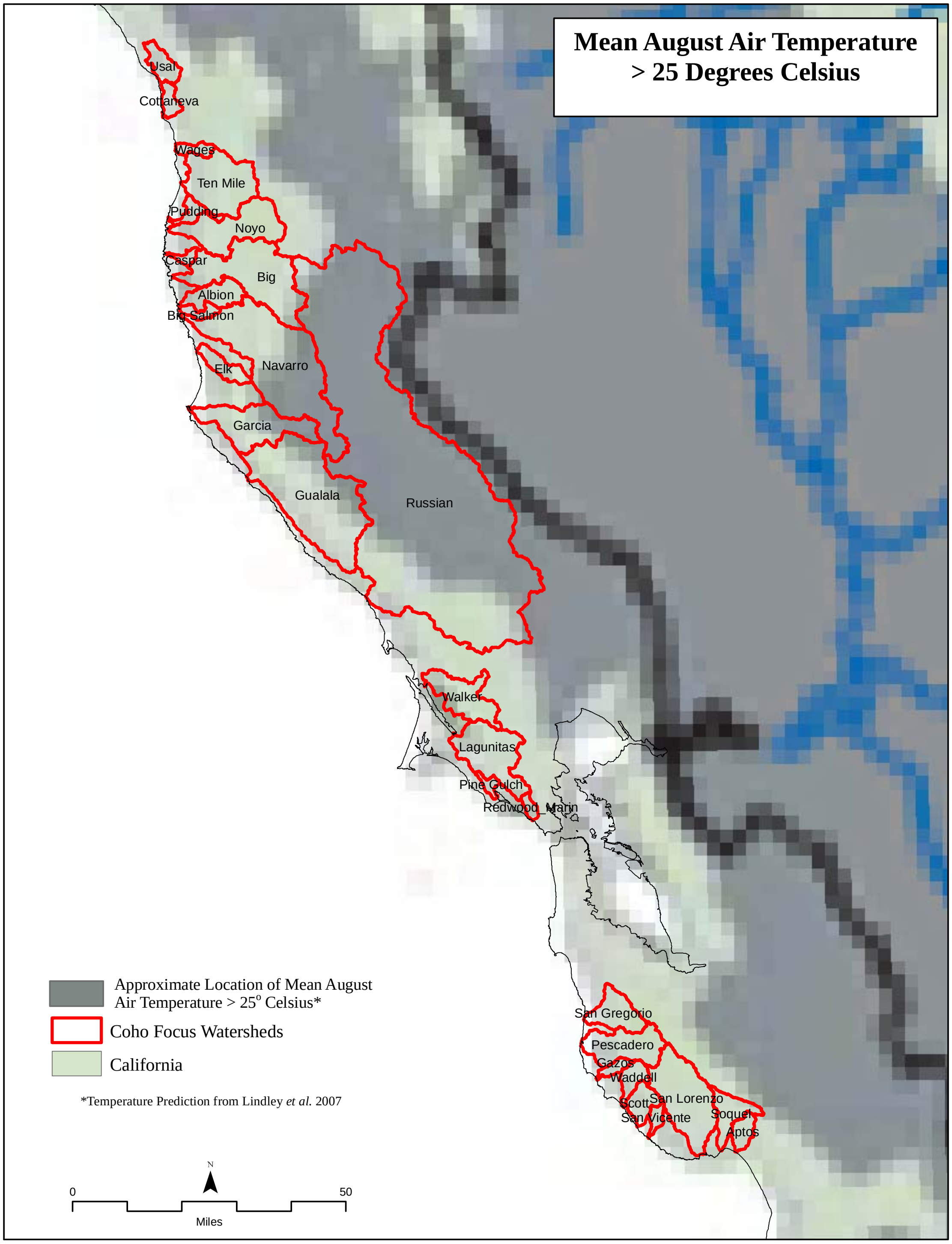


Figure 4: Approximate location of mean August air temperatures greater than 25°C in relation to coho salmon focus populations, under a 5° C warming scenario (modified from (Lindley, 2007).

Riparian Species Composition, Size, and Canopy Cover

Vegetation

As described above, vegetation near streams can provide shade for cooler water temperatures, bank stability, large woody debris to stream channels, and habitat for salmonids 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 will be more pronounced than those described under the moderate high emissions scenario describe below.

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 in this scenario exercise[9].

Disease, Predation, and Competition

CEPA (CEPA, 2006) scenarios do not include disease, predation, or competition information directly related to salmonids. However, CEPA (CEPA 2006) and others (Harvell 2002) note that increasing instream temperatures can allow pathogens to spread into areas where they are currently absent as temperature limitations on their range change. In some cases, increasing temperatures may limit or restrict diseases (Harvell 2002). NMFS acknowledges increasing temperatures have the potential to increase the susceptibility to disease. Given the potential for increasing droughts, disease outbreaks will likely increase if coho salmon are crowded together in areas of low stream flow.

Moderate High Emissions Scenario

Under the moderate-high emissions scenario, statewide average annual temperature is expected to rise between 3.1 and 4.4° C (Luers 2006). 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), although the frequency of large storms appears to differ in this scenario.

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[9]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.

Droughts

Statewide, there is a 2-2.5 times greater probability of a critical dry year during the medium-high emission scenario (Luers, 2006). On the North Coast, including the area inhabited by CCC coho salmon, other modeling has produced varying results for rainfall patterns. Different rainfall patterns may produce varying effects on CCC coho salmon 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 will assume a "worst case" reduction in precipitation similar to the statewide prediction, a two to 2 -2.5 time increase in the number of critically dry years. Impacts to CCC coho salmon and their freshwater habitat are likely to be similar to those described in the high emissions scenario.

Fires

Fires are also expected to increase under this scenario. The model predicts an overall 55% increase in the risk of large fires in California (Luers 2006). In particular, Northern California modeling results predict an overall 90% increased risk of fires (Westerling 2006). NMFS inferred (Westerling, 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 coho.

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. Similar to the high-emission scenarios, coho populations in the Santa Cruz Mountains Diversity Stratum are the most vulnerable to storms and flooding events.

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, NMFS assumed 3.1 to 4.4° C warming of statewide average annual air temperature. As with the high emissions scenario, NMFS used the 5° C warming-map from Lindley et al. (Lindley 2007), which shows areas that may experience August mean air temperature over 25° C (Figure 4 above). These higher air temperatures are likely to increase stream temperatures, unless other factors, such as cold groundwater input, are present. Impacts to coho salmon 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.

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 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. Increases in tanoak, a hardwood, in coastal riparian areas could decrease the value of future LWD. Streams in riparian forests composed of hardwood 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 over wintering habitat available for CCC coho salmon.

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 CCC coho salmon, disease outbreaks will likely increase if coho salmon are crowded together in smaller amounts of wetted habitats. These potential impacts are expected to be somewhat less in the moderate high emissions scenario than in the high emissions scenario.

Low Emissions Scenario

Under this emissions scenario, statewide average annual temperature is expected to rise between 1.7° and 3.0° C (Luers, 2006). 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 model results appear to differ regarding the incidence of large storms, as described above.

Droughts

Statewide the probability of critically dry years increases 1-1.5 times for the low emission scenario (Luers 2006). On the North Coast, including the area inhabited by CCC coho salmon, other modeling has produced varying results for rainfall patterns. Different rainfall patterns may produce varying effects on CCC coho salmon 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. In comparison to the High and Medium emission scenarios, CCC coho salmon and their freshwater habitat are less likely to be adversely affected. Although low emissions levels are less likely to impact CCC coho salmon, Coastal and Santa Cruz Mountains Diversity Strata are targeted as most likely to be impacted.

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 2006). For northern California, modeling produced a overall 40% increase in the risk of fires (Westerling 2006). By the end of the Century, NMFS inferred (from the fire risk maps provided by (Westerling 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 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. Based on threat rankings, Santa Cruz Mountain Diversity Statrum coho populations are likely, in general, the most vulnerable to storms and flooding. 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 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 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, 2007), which shows areas that may experience August mean air temperature over 25° C (Figure 4 above). According to this map, the interior Russian River and Navarro River are the most likely areas affected by air temperature increase – fewer subbasins within these watersheds are affected than in the other emission scenarios. These higher air temperatures are likely to increase stream temperatures.

Riparian Species Composition, Size, and Canopy cover

See 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 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.

Most Vulnerable Populations

NMFS used the Viability and Threats results for each population to identify the CCC coho salmon populations most vulnerable to climate change. We compared each population's threat level and the current condition of specific habitat attributes most likely to be negatively affected by climate change. Each threat level was assigned a numeric score representing medium, high, or very high threat ranks. Numeric scores were summed, then ranked from least to greatest. Highest ranked values suggested those populations are at greater risk. Similarly, each of the selected key habitat attributes were summed and ranked. Populations with the worst current habitat conditions were predicted to be at greatest risk.

These results are a "best guess" at populations likely to experience negative impacts from climate change first under any of the three scenarios above.

Table 3: Population current habitat condition and threat ranking. A higher number indicates this habitat is in worse condition. Current conditions in addition to threats add the threat ranking to the current condition numeric to determine overall risk from climate change. Focus populations added late in the recovery planning process (Usal, Wages, Salmon, San Gregorio, and Soquel Creeks) were not included in this initial analysis.

Population	**Current habitat condition rank total from Table 2**	**Current condition total plus climate change threat total from Table 1**
San Lorenzo	28	36
Russian	28	35
Navarro	27	33
Pescadero	25	33
Scott	24	30
Big	22	28
Garcia	23	28
Gualala	23	28
Walker	23	28
Gazos	22	28
Redwood	20	27
Aptos	19	27
Ten Mile	21	26
Noyo	21	26
San Vicente	19	26
Albion	20	25
Lagunitas	18	25
Pudding	19	24
Pine Gulch	16	24
Waddell	18	24
Big Salmon	17	22
Cottaneva	16	21
Caspar	16	20

Based on this information, NMFS believes the San Lorenzo and Russian populations are at most risk from Climate Change, followed by the Navarro River and Pescadero Creek. 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 may be more vulnerable to climate change impacts than those ranked the lowest.

RECOVERY PLANNING AND CLIMATE CHANGE

Our analysis indicates that climate change will result in many challenges for CCC coho salmon recovery. Areas with stream temperatures near coho salmon thermal maxima may become uninhabitable as temperatures increase. Areas with adequate stream temperatures may see temperatures become marginal. Rainfall patterns may or may not exacerbate temperature problems. Areas subject to low summer flows may experience further summer flow decreases. 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 coho populations or their habitat due to climate change. Some CCC coho 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 the CCC coho salmon ESU as this Century progresses will be a critical first step to devising better scenarios and adjusting recovery strategies.

The survival and recovery of CCC coho salmon under any of the climate change scenarios will depend on achieving viable CCC coho salmon 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 CCC coho salmon 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 public, 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 climate change and its effects 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. See Appendix K for specificity of the research needs and strategies for which NMFS has management responsibilities.
   - 2.2. Put in place funding of active research that aids in predicting the effects of climate change on salmon recovery with Federal and state commitments to respond to findings from the research (Northwest Region).

3. Ensure continued flow of upstream cool water, in adequate quantity, to protect downstream water temperatures.
   - 3.1. Identify sources of cool water inputs and develop measures to protect these sources from withdrawal.

4. Focus on forestlands to store carbon and reduce greenhouse gasses (See also Logging and Wood Harvesting Strategies)
   - 4.1. Prevent forest loss.
   - 4.2. Conserve and manage for older forests.
   - 4.3. Restore forests where they have been converted to other uses.
   - 4.4. Use wood products in place of more CO_2 intensive building materials and energy sources.
     - 4.4.1. Encourage and increase voluntary carbon accounting in the forest sector through certification with the California Climate Action Registry and their Forest Protocols.