The Effects of Climate Change on the Fall-Run Chinook salmon in the American River

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Abstract

Chinook salmon have specific biological requirements that must be met throughout their developmental and spawning periods in both freshwater and oceanic systems. Climate change is projected to change the conditions of these habitats (IPCC, 2014). For the salmon’s oceanic habitat, climate change will increase sea surface temperatures and ENSO strength, which will affect the Pacific Ocean’s NPP, and thus the adult salmon’s food reliability (Behrenfeld et al., 2006, Timmerman et al., 1999). A decrease in both yearly snow pack size, precipitation rate, and an increase in drought duration will decrease American river flows during critical periods of Fall-run Chinook spawning, egg and Alevin development and emergence (CNAP, 2015, IPCC, 2014). Climate change predictions also reveal an increase in snow melt rate and high precipitation events during winter periods, which will detrimentally increase flow rate during incubation periods (IPCC, 2014, Jorgensen, 2013, CNAP, 2015). Mitigation measures from responsible state agencies will have to be implemented to prevent the American River’s Fall-run Chinook salmon from deteriorating.
Introduction and Background

Since the 1970’s approximately 52% of vertebrate species have diminished due to anthropogenic activities (WWF, 2014). Unsustainable development and over consumption of natural resources have led to the decline and degradation of wildlife habitats, which has compromised the ability for these species to adapt in a rapidly developing planet (WWF, 2014). The world’s biodiversity is facing another human caused threat, which is climate change (WWF, 2014). The earth’s climatic systems are being destabilized by the increasing emittance of green house gases (GHGs) like carbon dioxide (CO$_2$) and methane (CH$_4$) (Cline, 1991). These gases prevent the sun’s long wave radiation from leaving the earth’s atmosphere and thereby creating a magnified greenhouse effect (Cline, 1991). Many ecosystems are projected to be effected by climate change, especially ocean and freshwater systems (IPCC, 2014).

One such freshwater system is the American River, which originates in the Sierra Nevada mountain chain and is located in central California. It is primarily sustained by snow melt and precipitation. The American River consists of four defined sections—a north fork, middle fork, south fork, and a “lower” section where the forks converge prior to draining into the Sacramento River. The river stretches for approximately 240 miles west and contains a drainage area of 1,900 square miles (Coloma-Lotus Chamber of Commerce, 2014, Williams, 2001). This watershed provides essential riparian habitat for a variety of species of plants and animals, including the Chinook salmon (Oncorhynchus tshawytscha) (The American River Parkway Foundation, 2009).

Out of the five species of salmon found in the Pacific Ocean, Chinook salmon is considered to be the “largest” (NOAA, 2015). These anadromous species spend their
developmental stages of egg, alevin, and fry inhabiting freshwater ecosystems; however, as juveniles they make their way to estuaries for saltwater acclimation before migrating to the ocean (Williams, 2001). Chinook spend 1-6 years in the ocean before returning to freshwater systems to spawn and die, thus completing their semelparous lifecycle (NOAA, 2015).

Prior to the 1848 Gold Rush and the 1958 completion of the Folsom and Nimbus dams, the American River supported three yearly runs of Chinook (Williams, 2001, Yoshiyama et al., 2001). Historically, salmon were known to have migrated to the Mumford bar in the North Fork, the Rubicon River in the Middle Fork, and close to Eagle Rock in the South Fork (Yoshiyama et al., 2001). Although there is very little record of the exact number of Chinook present in the river before the Gold Rush Era, there is escapement data on the Fall-run’s size prior to the dams’ construction (Williams, 2001, Yoshiyama et al., 2001). From 1952-1954, there were approximately 25,000 to 29,000 Fall-run Chinook counted in the American River (Azat, 2014).

Presently, the dams have blocked and inundated 72% of salmon spawning habitat (Yoshiyama et al. 2001). With only a few miles of suitable spawning habitat left in the lower American River, only a Fall-run remains; a run dependent on the Nimbus Fish Hatchery, a mitigation hatchery that is funded through the U.S Bureau of Reclamation and managed by the California Department of Fish and Wildlife (CDFW, 2015).

This dependency on mitigation hatcheries has led to the loss of heterozygosity within the central valley Fall-run Chinook, which is considered to be one of the most homogenized runs in California (Williamson & May, 2005). A lack of genetic diversity can lead to a diminishment of the run’s ability to be resilient and adapt to environmental
changes and thereby place the run in danger of deterioration (Falk, et. al, 2001). Both the lack of heterozygosity and the species’ specific needs make the Chinook especially vulnerable to stressors caused by climate change. This report addresses the effects of climate change on the American River’s Fall-run Chinook by exploring potential climatic stressors on the species’ physiological and biological needs throughout their anadromous lifecycle.

**Purpose and Approach**

The purpose of the report is to provide insight on the adverse effects of climate change on the American River's Fall-run Chinook salmon, so that adaptive management measures can be constructed by field experts and policy makers to help minimize proposed impacts. The goal of this report was met through the utilization of projections from the Intergovernmental Panel on Climate Change 2014 Report, climate change models from the 2009 Climate Scenarios Project, scientific peer reviewed articles, and public data from relevant resource agencies like the California Department of Fish and Wildlife (CDFW), National Oceanic and Atmospheric Administration (NOAA) and others. The data collected places emphasis on the American River’s historical and current Fall-run Chinook salmon escapement numbers (the yearly number of spawning salmon in the Central Valley classified by their run), flow rates, and water quality, including temperature and dissolved oxygen, as they are considered to be essential factors throughout the critical period of Chinook egg and alevin development (Beer & Anderson, 2001, Bergman, et al. 2012, Heming, 1982).
Climate Change and Food Reliability

In the Pacific ocean, smolts and adult Chinook begin the process of accumulating fat reserves for the final journey to their natal freshwater systems by consuming smaller fish like herring, anchovies, and in smaller quantities, crustaceans, cephalopods, and euphausiids (krill) (Brodeur, 1990). The majority of their prey relies on ocean upwelling for their food source, a process where cold, nutrient laden water is brought up to the surface by coastal currents and trade winds (Wells, Grimes, & Waldvogel, 2007).

Climate change is projected to have an affect on the Pacific Ocean’s net primary productivity (NPP) that supports the salmon’s oceanic diet (Timmerman et al., 1999). If present day emission levels continue, the result will be a warmer, deeper thermocline layer caused by the El Niño Southern Oscillation (ENSO) cycles which could result in lower ocean productivity (Timmerman et al., 1999). During an El Niño year, trade winds, which help catalyze nutrient mixing by displacing surface water, subside, sea surface temperature (SST) increase and precipitation also increases in the east Pacific Ocean (Timmerman et al., 1999, Smith & Smith, 2012). While the epilimnion, or the uppermost layer of the ocean’s three layer vertical profile, becomes warmer and less dense, through increased temperature and precipitation, it influences the thermocline (middle layer) which also increases in temperature and decreases in density (Smith & Smith, 2012). The loss of density in the thermocline disables its ability to sink and displace the cold and dense water of the bottom layer also known as the hypolimnion (Smith & Smith, 2012). It’s this displacement of deepwater that allows for nutrient upwelling to occur (Smith & Smith, 2012). If green house gas levels continue to increase, projections show that an increase in
both ENSO strength and frequency will likely occur, which could have severe impacts on marine wildlife through this suppression of ocean upwelling (Timmerman et al., 1999).

Since the 1880’s, the average world’s SST have increased by approximately 0.85 °C with a likelihood of increasing due to climate change (IPCC, 2014). There is a positive correlation between higher SST and ENSO strength (Behrenfeld et al., 2006). This correlation has a negative impact on the ocean’s NPP and chlorophyll biomass (plankton), which can affect the survivability of Chinook’s primary prey like Northern herring, Pacific anchovies, and krill (Behrenfeld et al., 2006, Farallones Marine Sanctuary Association, 2002).

Aside from increasing the frequency of ENSOs cycles and warming surface water temperature, greenhouse gases also cause ocean acidification, which is another anthropogenic threat that undermines the salmon’s food source (Dupont and Thorndyke, 2009). Through air-sea gas exchange processes, oceans sequester CO₂ and act as carbon sinks; thus, the more atmospheric CO₂ is emitted, the more it absorbs thereby lowering pH (IPCC, 2014, NOAA, 2015). About 30% of the CO₂ that is taken in by the world’s ocean is human caused (IPCC, 2014). The increasing acidification is known to hinder early periods of development for zooplankton by delaying their growth, which leaves them more susceptible to predation at earlier, more vulnerable stages (Dupont & Thorndyke, 2009). Chinook’s prey, such as herring, rely upon zooplankton, like copepods, which are being consumed at quicker rates because of ocean acidification (Dupont & Thorndyke, 2009, Maravelias & Reid, 1997). From a tertiary standpoint, this affects not only the survivability of those dependent on zooplankton for sustenance, but it also threatens the salmon’s food source as well (Dupont & Thorndyke, 2009).
Climate Change and Migration to the American River

Once mature Fall-run Chinook begin their migration from the Pacific Ocean to the American River, they stop feeding for the approximately 131 mile journey from the ocean to the Nimbus hatchery (U.S. Fish and Wildlife Service, 2013). Although they begin to make their way into the river system to spawn in September, the majority of the run will not migrate until October and will cease in January (Williams, 2001).

Since 1955, the federally funded and state run anadromous fish hatchery artificially spawns approximately 9,785 adult Chinook yearly and raises and releases an estimated 4.2 million Chinook salmon and 400,000 steelhead trout yearly (California Department of Fish and Wildlife, 2011, Azat, 2014). The California Department of Fish and Wildlife use a mark and recapture carcass survey to determine how many Chinook return to the river to spawn each salmon season (Bergman, Nielson, & Low, 2012). This type of data collection method produces “escapement” data, which are used to monitor the size and health of the runs (Bergman, Nielson, & Low, 2012). Since the early 1950’s, the escapement numbers for the American River Fall-run have ranged from 5,746 individuals in 2008 to 178,629 in 2003 (Azat, 2014). Since 1952, the Fall runs in the American River have averaged approximately 47,699 (Azat, 2014).

Climate change is projected to have an effect on climatic conditions that control the American river’s flow (IPCC, 2014). Yearly surface temperatures are projected to increase, thereby increasing the potential for higher snow pack melt and higher freshwater evaporation rates (IPCC, 2014). Depending on emission levels, models suggest that an increase in monthly surface temperatures of up to 5°F could occur by the year 2080 in the Sacramento, Auburn, Placer County Area (CNAP, 2015). Both higher and lower
precipitation events are also being predicted during the winter times (CNAP, 2015). Early snowmelt combined with higher winter precipitation rates, could result in high flows, which would affect the stability of the river’s banks and thereby increase further flood management techniques like riprap to be implemented (CNAP, 2015, Jorgensen, 2013). The effects of the usage of riprap could alter the availability of potential spawning areas, which are needed for not only spawning salmon, but developing eggs, and rearing alevin (Jorgensen, 2013, Knudsen and Dilley, 1987). With only 18 miles of spawning habitat left in the lower American River, the remainder of the run will look for ideal spawning areas, which consist of relatively shallow submerged gravel banks approximately 1-13 ft in depth to construct their redds or “salmon nests” to lay their eggs in (Bergman, et al., 2012, Geist & Dauble, 1998).

In the Sacramento Valley, Climate change models also predict an increase in water temperatures, which might prove to be detrimental during spawning season (Yates et al., 2005). Spawning salmon need water temperatures to be no higher than 68°F, and anything higher can either delay runs or cause higher mortality in both spawning adults and eggs (EPA, 2003, California Department of Fish and Game, 2010, Yates et al., 2005). If stressors are left unmitigated, the size of the run could be in danger of declining.

**Development and Emergence**

On average, female Chinook salmon lay 5,000 eggs (California Department of Fish and Wildlife, 2011). Development and hatching occur within 40-50 days of being dispersed (California Department of Fish and Wildlife, 2011). For the Fall-run, the incubation period for egg and Alevin ranges from October to April and they begin to emerge from January
through April (Williams, 2001). The ideal water temperature for egg incubation is from 43 °F to 58 °F (Williams, 2001). Any temperature higher than 58 °F threatens the tolerance point and survivability of eggs (Williams, 2001).

After hatching, tolerance level drops and alevins being raised in 50 °F or higher water temperature have higher mortality rates than those exposed to lower temperatures (Heming, 1982). The period in which the yolk sac is fully absorbed is also found to be shorter in higher temperatures (Heming, 1982). Alevins developing in warmer, but tolerable water temperatures can prevent the young salmon from reaching their potential mass before emerging from their redds (Beer & Anderson, 2001). Warmer waters can also have an affect on their emergence timing, which prompts alevins to emerge prematurely before their yolk sac is fully absorbed thereby leaving them vulnerable to predation (Beer & Anderson, 2001). Alevins that experience a stunted development period have a higher chance of not developing properly and tend to be smaller and weaker than those raised in cooler temperatures (Heming, 1982).

The ideal redd site contains flows ranging from 1-6ft/sec, so that enough dissolved oxygen (DO) can reach the eggs (Williams, 2001, Geist & Dauble, 1998). Eggs in low DO containing water tend to develop much slower compared to those in higher DO water (Alderdice, Wickett, & Brett, 1958). Pre-hatching sac fry exposed to low DO levels tend to hatch before their normal hatching period (Alderdice, Wickett, & Brett, 1958). The eggs exposed to extremely low levels of DO also have a higher mortality rate (Alderdice, et al. 1958).

Since these environmental conditions are essential during the Chinook egg and alevin stages, it leaves them vulnerable to sudden changes in climatic patterns, which are
expected to become more destabilized due to climate change (IPCC, 2014). Because climate change is projected to have an effect on yearly precipitation rates, this can drastically affect flow rate, water temperature, and DO levels of the remaining salmon habitat in the American River (IPCC, 2014). As previously mentioned, both higher precipitation rates during the Winter period, and earlier snow melt due to higher surface temperatures, threaten redd stability for the Fall-run’s developing eggs and alevin during winter and spring seasons (IPCC, 2014, Jorgensen, 2013).

Although water levels are managed by the Folsom and Nimbus dams, the combination of both extreme snowmelt and high precipitation might prove to be too much for both dams’ holding capacity (Williams, 2001). Too much water in the river can destabilize the integrity of the Chinook redds, which can leave the progeny vulnerable to being “washed out” (WRIA 8 Technical Committee, 2007).

Climate Change and Juvenile Chinook and Smolts

Drought duration is also expected to increase in California (IPCC, 2014). Currently, the state is in its fourth year of drought. In the beginning of 2014, California’s governor Edmund G. Brown declared a “State of Emergency” because of low precipitation and snow melt (California Fish & Game Commission, 2014). That year Folsom lake was only at 19% of water capacity (California Fish & Game Commission, 2014). Water conditions were so low that Chinook young were observed stranded at redd sites and unable to move on in the American River (California Fish & Game Commission, 2014). Although juvenile fry stranded in warm isolated pools caused by low water levels in rivers can cause thermal stress, the temperature itself does not increase their mortality rates, however their exposed state
does leave them more susceptible to predation (Mesa, et al. 2002). Juvenile fry have heat shock proteins that help them cope with and recover from dramatic changes in heated water environments (Mesa, et al. 2002). However in 2014, it was observed that low water conditions not only left the juveniles vulnerable to high predation by birds and other predators, it also exposed redds to trampling by human foot traffic (California Fish & Game Commission, 2014). For the sake of both juvenile Chinook and spawning steelhead, sections of the lower American River were closed for angling (California Fish & Game Commission, 2014). Because climate change is projected to decrease yearly snow pack size up to 90%, as well as overall yearly precipitation, scenarios like these will only increase in frequency throughout the years to come (CNAP, 2015).

Climate change is expected to have an effect on animal migration patterns and this is especially true for Chinook smolt (IPCC, 2014). Prior to entering the brackish waters of estuaries, juvenile Chinook go through a process of smoltification, which helps transition the young fish from inhabiting freshwater systems to oceanic saltwater, which they will inhabit throughout their adult lives (Folmar & Dickhoff, 1980). The American River Fall-run normally go through smoltification by April or May (Williams, 2001).

Both river flow and in-river temperatures play a vital role for smolt migration (Sykes et al., 2009). High in-river flows and high accumulated thermal units (ATUs)/water temperature have an adverse affect on the smolt migration (Sykes et al., 2009). These water conditions reduce migration timing, which hinders the Chinook smolts’ ability to migrate during their normal period (Sykes et al., 2009). In contrast, cool and minimal flows can also postpone and pushback migration periods (Sykes et al., 2009). Both of these scenarios are possible under the climate change projections (CNAP, 2015, IPCC, 2014). As
previously stated, early snow pack melt and increasing precipitation rates during winter periods can cause high river flows in the springtime during smolt migration (CNAP, 2015). However, extremely low flows can also arise during years of extended drought (IPCC, 2014).

**Conclusion**

Climate change will affect the food stability of the American River’s Fall-run adult Chinook in their oceanic habitat by increasing ENSO strength and thereby decreasing NPP (Behrenfeld et al., 2006, Timmerman et al., 1999). Climate change will also decrease yearly precipitation rates and snow pack size, which will decrease flows in the American River (CNAP, 2015, IPCC, 2014). Decreased flows will likely delay migration periods of spawning Chinook and outgoing smolts, as well as increase predation on Chinook fry (California Department of Fish and Game, 2010, EPA, 2003, Mesa, et al. 2002, Yates et al., 2005). The survivability of salmon eggs and alevins are also threatened by climate change due to increased flows during incubation periods (IPCC, 2014, Jorgensen, 2013, CNAP, 2015).

If the projected effects are left unmitigated, the size of the Fall-run of Chinook in the American River will likely decrease. During low water conditions in the American river, greater attention should be placed in the management of cold water releases from the Folsom and Nimbus dams (Yates et al.,2008). Effective management of these releases could help alleviate stress on Chinook throughout critical periods of their life cycle, like spawning, egg and alevin development, as well as fry emergence (Yates et al., 2008). Another mitigation measure is to expand and expedite the implementation of fishing restrictions on the entire lower American River to prevent redd degradation. In order for
any adaptive management measures to be successful, the public needs to be engaged. That’s why during this time of drought, it is also critical that an outreach campaign is executed. If the public is educated on how their actions (usage of water, utilization of the river, etc.) can negatively alter their natural environment, there will likely be less of an outcry when restrictions on the recreational use of the river are placed and enforced. It is essential to educate the public on not only the importance of following regulations and water conservation, but to also educate them on the importance of Chinook salmon.

Economically, the salmon industry, which the Central Valley Fall-run Chinook is an important part of, represents up to two billion dollars in revenue and provides jobs for many Californians (California State Legislature, 2010). Chinook also play a critical role in their ecological environment by being both a food source and a predator for a plethora of species in their oceanic and riverine habitat (Cederholm et al. 2000). Through the release of nitrogen and phosphorous from their decaying bodies, the Fall-run also supports the health of the American River’s riparian vegetation (Cederholm et al., 1999). And finally, Chinook are a vital cultural and spiritual species for California’s Native American tribes (Winnemem Wintu, 2014). The Fall-run of Chinook salmon in the American River is intricately tied to California’s history and its legacy. Whether the run survives, depends on the actions of everyone.
Works Cited


