Evaluating the Affects of Climate Change on Chinook salmon Populations of the Pacific Northwest

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Introduction & Background:

North Pacific salmon (*Oncorhynchus spp.*) are an anadromous species, spending a portion of their life in fresh- and salt-water systems. This type of lifecycle is dependent upon adaptations to specific habitats occupied by the individual population (Crozier et al. 2007, 2008). The life history of Chinook salmon has resulted in the emergence of several distinct populations throughout a significant portion of their range following the large-scale decline in the late 1800’s and early 1900’s (Crozier et al. 2007). Historically salmon have faced and adapted to a variety of disturbances (Scheurell et al. 2005). Aside from natural climatic and weather based variability, Scheurell et al. (2005) identified the primary driver of the population decline in the 19th Century a result of the ‘4 H’s’. The ‘4 H’s’ refer to anthropogenic influences at the time: habitat degradation, harmful harvesting practices, dams (hydroelectric and other), and lastly hatchery production (Scheurell et al. 2005). While still a contributor to current population degradation, the ‘4 H’s’ no longer represent the only significant detriment to Chinook salmon populations (Scheurell et al. 2005). Today Chinook populations are threatened by climatic alterations/disruptions to both fresh- and salt-water systems. Successful completion of the Chinook life-cycle requires stable fresh-water habitats to facilitate the often long-distance migratory pathways during the early and late stages of ontogeny (Crozier et al. 2007). In addition optimal ocean conditions during early life-stages have been shown to have a significant effect on population longevity (Sharma et al. 2013). Figure 1, (below) is a graphical
representation of the salmonid life cycle including both fresh- and salt-water life stages.

**Figure 1: Complete adult life-cycle of salmon (Crozier et al. 2007) (Above).**

Due to the complexity and specificity of Chinook salmon, species viability projections are difficult to project beyond a single population.

Climate change is among the most uncertain of environmental stressors facing Chinook salmon; as it has the potential significantly alter different populations at varying life stages (Crozier et al., 2007, Crozier et al., 2008, Scheurell & Williams, 2005). The diversity of responses that have been observed and those projected to occur is directly related to the habitat/region specific adaptations of the populations affected. For example some populations in cooler stream systems showed positive population growth in response to warming temperatures (Crozier et al. 2008). Whereas a similar population in warmer stream systems showed
temperature is a formidable limiting factor. This variability is likely to be observed throughout Chinook populations in the Pacific Northwest, where differing habitats and associated population adaptations have created a web of complex responses to projected climatic alterations.

**Purpose & Focus:**

Climate change is projected to affect Chinook salmon populations differently dependent on the habitat and the adaptability of the population affected (Crozier et al. 2007, Crozier et al. 2008). Thus, I will be focusing my review on Chinook salmon in the Pacific Northwest (with a majority of the research analyzed pertaining to Chinook salmon of the Snake/Columbia River) of the United States and the associated climatic changes likely to have an effect on their lifecycle. To gauge the severity change effected I will analyze several related articles regarding possible threats to population longevity in response to climate change. Through this I hope to create a better understanding for the future of N. Pacific Chinook salmon in a rapidly changing environment.

**Habitat**

Ecological changes associated with climate change have already been shown to have a variety of effects on vital Chinook habitats in the Pacific Northwest (Crozier et al. 2007, 2008, Mantua et al. 2010). Severe habitat alterations and/or degradation are among several possible threats to Chinook populations as a result of climate change (Crozier et al. 2007, 2008, Mantua et al. 2010). Explained further in the following sections, climate change is and has the potential to alter ecological processes and distinctive habitat features. Climate change has the potential to have a range of effects on Chinook habitats and life-stages including, increases in water temperatures, decreased prey/nutrient availability, and habitat alteration/degradation (Crozier et
al. 2007, Mantua et al. 2010, Miller et al. 2013). Chinook salmon in the Pacific Northwest of the United States occupy specific habitats that are highly susceptible to climatic alterations (Crozier et al. 2007, 2008, Mantua et al. 2010). Chinook require stable salt- and fresh-water habitats to complete their complex anadromous life-cycle. Habitat quality and conditions is a primary driver of population growth and survival among Chinook populations (Crozier et al. 2008). However due to the varying populations’ adaptations to specific occupied habitats, there is a high likelihood for differing responses between the numerous distinctive populations (Crozier et al. 2006, 2008). The individualistic adapted nature of Chinook salmon is likely to result in strong selection forces specific to each of the remnant populations (i.e. seeking of cooler refuges in warming waters) (Crozier et al. 2007). While the habitats occupied by Chinook have bread population specific adaptations, Crozier et al. (2008) suggest this could be used as a buffer against rapid species decline. This is because cumulatively Chinook populations of the Pacific Northwest form a meta-population, in which independent population dynamics serve to protect the species as a whole (via potential re-colonization) (Crozier et al. 2008).

**Future Climate Change Projections and Population Level Ramifications**

Chinook salmon require consistent/adaptable environmental conditions to successfully complete their anadromous lifecycle. Current climatic projections however threaten life-cycle stability and increase the risk of Chinook population declines through alteration/degradation of necessary habitats (Crozier et al. 2007, 2008, Mantua et al. 2010). Facilitating a large portion of the complex life-cycle, freshwater systems are crucial to Chinook longevity and are at risk of alteration through climate change (Crozier et al. 2007, Mantua et al. 2010). Under current climatic projections freshwater ecosystems are likely to be influenced by a variety of changes including, increasing temperatures, and decreased flows (discussed in depth in the following
subsection) (Crozier et al. 2007). The alterations associated with projected climatic changes in the Pacific Northwest are likely to affect varying degrees of disturbance among the Chinook populations (Crozier et al. 2007, 2008, Mantua et al. 2010). Mantua et al. (2010) explained that the effects of climate change are believed to act as a limiting factor, differing in severity between populations. As a part of Chinook ontogeny individuals spend extended periods in freshwater ecosystems, resulting in key life stages being vulnerable to physical habitat specific change from projected climate change scenarios (Mantua et al. 2010). The diversity between populations is similarly shown in the limiting factors enacted by climate change, where some populations are limited by thermal variability, others are limited by variability pertaining to flow etc. (Mantua et al. 2010). For those populations limited by thermal stress, distribution, migratory alterations, and developmental processes (associated with overall population fitness/survivability) are likely to be altered and/or disrupted by climate change (Mantua et al. 2010). Chinook are vulnerable to factors beyond that of just the physical alterations caused by climate change including density-dependent variables (i.e. species interactions interrelated to ecological and climatic conditions) (Zabel et al. 2005, Wells et al. 2012). Additionally predator-prey and competitive trophic interactions are likely to be altered through decreasing salmon fitness, and reduced prey availability (Wells et al. 2012). Several of the following climatic conditions addressed, entail certain complex density dependent population level responses. For example, density-dependent recruitment of juveniles occurs between mature females competing for optimal rearing sites (Zabel et al. 2005). Zabel et al. (2005) found that density dependence of Chinook salmon populations was a significant factor in regulating overall population abundance. Additionally there are signs that the density dependent nature of Chinook salmon can act as a mitigating factor toward some of the negative population affects resulting from climate change disturbances (i.e.
decreased survival rates resulting in increased fertility rates) (Zabel et al. 2005). Discussed in the following sections, salmon are a highly adaptable (and adapted) species, which is likely to result in a variety of diverse population level adaptations (Crozier et al. 2007, Mantua et al. 2010). However, these adaptations are unpredictable due to complex inter- and intra-species reactions paired with uncertainties regarding the extent and degree of change affected by climate alterations (Zabel et al. 2005, Crozier et al. 2007, 2008, Mantua et al. 2010).

*Climate change and Freshwater Habitats*

Crozier et al. (2007) outlined a spectrum of the climatic effects likely to be observed in the Pacific Northwest (with a concentration on populations of the Snake/Columbia River) in addition to possible population responses. The first climatic change assessed was the likely increase of peak summer and fall temperatures, which has been shown to have a wide range of impacts on population survivability and inter-/intra-specific species interactions. The likelihood of increased seasonal temperatures is among the most widely agreed upon effects of climate change in this area, and poses a significant threat to Chinook populations via population disturbance and habitat alteration/degradation (Mantua et al. 2010). While there are several plastic and evolutionary responses believed to be enacted, these adaptations address only thermal stress (Crozier et al. 2007). However, it is still unclear the interplay between differing climatic alterations and the associated plastic/evolutionary adaptations. Increasing temperatures is likely to result in the reduction of thermal refuges, potentially increasing thermal barriers to migration (Crozier et al. 2007, Mantua et al. 2010). Chinook salmon have an optimal thermal range of 4 °C to approximately 18 °C (Hasler et al. 2012). Prolonged exposure to freshwater temperatures above 21 °C is likely to result in increased levels fish mortality for a majority of Chinook populations (Mantua et al. 2010). Climatic temperature increases acts as a limiting factor on
several Chinook populations as it requires specialized life-cycle modifications to mitigate the effects of the stressor. Thermal stress is similarly likely to alter predator-prey relationships favoring species with a competitive advantage toward warmer conditions (Mantua et al. 2010). One such fish that outcompetes and feeds on Chinook smolts is smallmouth bass (*Micropterus dolomieui*) (Mantua et al. 2010). This paired with out-competition for limited resources by other native and non-native fish species adapted to warmer waters pose a serious threat to Chinook longevity in the Pacific Northwest (Mantua et al. 2010). Similarly, increased exposure to warmer freshwater systems is believed to be related to increases in parasitic/bacterial diseases outbreaks in salmon populations (Crozier et al. 2007). The increase in the prevalence of disease at these higher temperatures can be explained by the affect of thermal stress on salmonid disease resistance (higher temperatures shown to lower resistance, while propagating pathogenic growth rates) (Crozier et al. 2007). Eventually this and other associated ramifications of increased levels of thermal stress have the potential to be mitigated, to a degree, by adaptive natural selection processes, however, the rate and efficacy of said selection is determined by region and adaptability of the population affected (Crozier et al. 2007, 2008, Mantua et al. 2010).

Shorter and milder winters, in addition to the associated decrease in summer and fall flows are similarly likely to affect Chinook migratory patterns and thus population fitness (Crozier et al. 2007). Similar to the effects of increasing seasonal temperature, shorter/milder winters are likely to disrupt key developmental processes necessary to population survival (Crozier et al. 2007). Chinook populations of the Pacific Northwest are highly dependent on the distinct seasons and have adapted migratory patterns to match the timing of said seasons (Crozier et al. 2007, 2008). Effects associated with the alteration of seasons include, disturbances to optimal rearing habitat flow and reduction of oxygen (via increased sedimentation deposits).
Seasonal alterations and the resulting impacts to flow patterns are likely to decrease population longevity/fitness (Crozier et al. 2007, Mantua et al. 2010). Additionally, flood occurrences/prevalence, related to seasonal alteration, have been shown to be an indicator of Chinook survival and return rates in the Skagit River (Mantua et al. 2010). The Pacific Northwest freshwater systems are typically dominated by one of the following, snowmelt runoff, transient (mixture of rain and snow runoff), or rainfall (Mantua et al. 2010). Using climate projections regarding projected warming trends from 2020-80's, Mantua et al. (2010) indicates that a shift is likely to occur from snowmelt to transient dominated flows. In addition to a similar shift from transient flow dominated systems to rainfall dominated systems (Mantua et al. 2010). By 2080 it is possible that snowmelt dominated basins in Washington will be eradicated entirely, while transient basins will be significantly limited, suggesting that Chinook migration will be secluded to rainfall dominant systems (Mantua et al. 2010). The likely decrease in summer and fall flows as a result of the increasing seasonal temperatures, and shortening winters is likely to result in a reduction of parr survival and return rates (Crozier et al. 2007, Mantua et al. 2010). Under future climate change projections for Washington, transient basins are likely to experience the most dramatic increase in flood occurrences during the months of December and January (Mantua et al. 2010). The likely increase of peak flows is projected to negatively affect parr-to-smolt survival as slow-flow rearing habitats are needed to prevent juvenile displacement (Mantua et al. 2010). Additionally the effect of decreased spring snowmelt has the potential to disrupt seaward smolt migration, having adapted migratory patterns to match optimal flow patterns (Mantua et al. 2010).

Under the climate change projections assessed by Crozier et al. 2007, climatic changes to the Pacific Northwest are also likely to result in the occurrence of earlier/weaker spring freshets
(freshwater streams). Freshet degradation is linked to projected decreases in flows, increasing temperatures, and alteration of the winter season (Crozier et al. 2007, Mantua et al. 2010). Similar to the aforementioned climatic alterations, freshet alteration/degradation has the potential to further lower smolt survival rates in some areas (via habitat degradation/loss, and increased thermal stress) (Crozier et al. 2007). Increasing seasonal temperatures paired with projected flow reductions are believed to result in decreased availability of optimal freshwater rearing habitats for Chinook populations (Mantua et al. 2010).

*Climate Change and Oceanic Habitats*

After entering the ocean, juveniles spend a large portion of time on the coastal shelf at this stage Chinook are highly susceptible to changes in oceanic conditions (Sharma et al. 2013). Sharma et al. (2013), state that early ocean life-stages are vital in predicting population survival and longevity. Alteration of seasonal transitions is likely to alter upwelling occurrences, which in turn affects prey availability, Chinook development, and migration timing (Sharma et al. 2013). During this portion of their life, the size of returning Chinook serves as a reflection of several oceanic habitat parameters including, prey availability, species interactions (i.e. competition), and habitat quality (Sharma et al. 2013). Increasing Pacific Ocean temperatures are likely to result in altered species interactions entailing potentially negative effects on Chinook population fitness (Miller et al. 2013). Similar studies conducted on salmonid and other fish species in the Pacific Northwest have concluded that upwelling is a possible predictor of population survival (discussed further in the following section). The affects of upwelling on juvenile Chinook salmon, have effects similar to those observed in freshwater habitats when temperatures reach above optimal levels (i.e. reduced prey availability, migratory timing alteration). Wells et al. (2012), identify a number of oceanic physical, biological factors
affecting juvenile productivity having a positive connection with future population abundance. The factors outlined include, increased northerly winds (directly related to the degree of upwelling present), habitat quality, and prey availability (and quality).

**Bottom-up VS Top-Down Trophic Relationship during Early Ocean Ontogeny**

The most common food sources for juvenile Chinook during the early ocean stages of their lifecycle range from, juvenile fish, crab to krill (Wells et al. 2012). However this like many other aspects of the highly individualistic Chinook life-cycle varies by region and population. For the purpose of this article only krill will be analyzed in regard to Chinook survivability in relationship to climate change conditions. Krill while not the most consumed source of food, accounting for roughly 7% of the total diet, have been shown to have a direct effect on juvenile Chinook survival (Wells et al. 2012). Juvenile Chinook survival requires a correspondence with the temporal and spatial relationship to krill (Wells et al. 2012). Krill acting as a primary food source for juvenile Chinook salmon are likely to experience population alteration as a result of climate change (Wells et al. 2012). Juvenile Chinook are directly limited by not only krill availability but also by the primary productivity of phytoplankton/zooplankton (krill food source) (Wells et al. 2012). Without the presence of these primary producers is likely to alter trophic dynamics through bottom-up control by limiting the abundance of Chinook prey (krill and others) (Wells et al. 2012). This however, is also subject to variability by region where certain prey sources are relied upon more heavily than others to sustain Chinook populations.

Climate change threatens to uncouple the spatial and temporal relationship of Chinook and their prey during a crucial period of their life-stage (Winder & Schindler 2004, Wells et al. 2012). This is especially detrimental to the Chinook life-cycle, whom are dependent upon
specific predator prey interactions (Winder & Schindler 2004, Sharma et al. 2013, Wells et al. 2012). Chinook maturation and survival is directly affected by bottom-up and top-down regulatory methods differing primarily by region (Miller et al. 2013). Thompson et al. 2012 found that in regard to seasonal upwelling events Chinook salmon abundance is related to upwelling events affecting prey availability (Thompson et al. 2012). The complexity of Chinook salmon populations makes projecting the degree of impact of climate change on key development stages difficult. Gauging the dynamic of the population correctly is essential to predicting the scale of degradation resulting from climate change alterations to trophic dynamics. Chinook have several biotic limiting factors including, primary productivity rates (affecting prey availability) degree of inter-specific competition, and population fitness under stressed conditions (Miller et al. 2013). Climate change is believed to have the potential to alter the availability of prey, and the ability of Chinook to compete for said prey. Additionally the potential for altered seasonal upwelling occurrences would force salmon to adapt migratory patterns to meet those of the preferred food sources.

**Climate change and Population specific adaptations**

While salmon populations in general have the ability to adapt to habitat changes similar to historic disturbances (yearly climatic variability, anthropogenic influences etc.), climate change poses a new threat acting upon several aspects of salmon ontogeny.
requiring numerous simultaneous adaptations (Crozier et al. 2007, Waples et al. 2008, Mantua et al. 2010). Alterations to the highly specialized life-cycle of Chinook salmon in the Pacific Northwest are likely to result in changes and adaptations specific to the remaining populations. These changes are projected to range from eventual evolutionary adaptations to behavioral modifications to meet the demands of new environmental conditions (Crozier et al. 2007). Crozier et al. 2007 outlined potential plastic and evolutionary responses to the effects of climate change. In response to the projected increase in average peak temperatures several plastic responses are projected including seeking out cool refuges and alteration of migratory patterns (Crozier et al. 2007). Similarly there is a potential for future evolutionary responses to climate change including, increased heat tolerance, increased energy efficiency, and increased disease resistance (Crozier et al. 2007). Other potential plastic responses to differing climate change effects are further alteration of migration timings, and likely also an eventual habitat change (Crozier et al. 2007, 2008). However it is difficult to project with certainty the full extent of plastic and evolutionary changes in regard to the interplay between climate/population variability by region. Figure 2 (Above), is a graphical representation of the believed effects of shifting environmental optimal conditions as a result of climate change and the associated population response, indicating a potential population shift toward future conditions. While the degree of change may differ, the likelihood of broad-scale change is ensured by climate change and the associated alterations to the Chinook life-cycle (Crozier et al. 2007).

Conclusion

Significant research is still required to gauge the full scale and degree of change likely to be effected upon Chinook salmon populations by climate change. However, the projected effects of climate change are in need of immediate mitigation to save at risk populations. Without
anthropogenic conservation and preservation efforts habitat loss/degradation is likely to drive the remaining salmonid populations toward extinction. Rapid plastic and evolutionary adaptations to increasing stream temperatures, altered flow patterns, and historic limiting factors, is likely to have a variety of population specific responses regarding freshwater system alteration (Mantua et al. 2010). Additionally, many of the reviewed studies indicate that as a result of the highly specialized nature of the Chinook salmon life-cycle, climate change is unlikely to entirely result in species extinction (Crozier et al. 2008). Rather the distinctive populations comprise a meta-population which provides a degree of security to Chinook population preservation. However, these mitigating affects associated with meta-population dynamics are in need of supplementation via anthropogenic conservation efforts. However, these efforts require trade-offs between anthropogenic desires, and Chinook habitat requirements. There is still significant knowledge missing surrounding the full extent of climatic changes to the Pacific Northwest.
Works Cited


Mantua, N., Tohver, I., and Hamlet, A. 2010. Climate change impacts on streamflow extremes


population dynamics of Chinook salmon *Oncorhynchus tshawytscha* relative to prey availability in the central California coastal region, *Marine Ecology Progress Series*, 457:125-137.