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Increasing freshwater Temperature and *Oncorhynchus tshawytscha*
A life Cycle Analysis

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Introduction. Climate change is creating new challenges for conservationists around the world. As habitats change due to shifting climates, species are faced with increasing threats. Salmon populations offer an excellent source of information on how climate change is impacting fish species due to their complex life-cycle stages. In this paper, the Pacific Northwest includes the US states of Oregon, Washington, Alaska, and the Canadian province of British Columbia. There are seven species of salmon in the Pacific Northwest. This paper will focus on Chinook salmon (*Oncorhynchus tshawytscha*). Research has demonstrated that Chinook populations are in a decline in the Pacific Northwest (Heard et al, 2007). Determining whether climate change is the cause of the decline is outside the scope of this paper. Instead, this paper will focus on the specific issue of increasing freshwater temperature and how this is impacting Chinook populations. Chinook's preference for specific water temperatures coincides with their optimal physiological functioning, meaning that changes in temperature can have detrimental impacts on their wellbeing. There are a variety of other challenges that Chinook face that could be causing their decline, such as overfishing, farmed salmon, and habitat loss. Understanding the future vitality of salmon populations in the Pacific Northwest is important because of salmon's cultural importance to the area, their contribution to the ecological integrity of freshwater and riparian ecosystems, and their use as a bioindicator for ecological and human health. Climate change is impacting Chinook salmon by altering yearly water flows and increasing water temperature, which is resulting in decreasing population levels throughout the Pacific Northwest.

Cultural. Maintaining healthy populations of salmon in the Pacific Northwest is vital for three reasons. First is their cultural importance. For centuries, salmon have played a pivotal role in the development of human culture in the Pacific Northwest (Thornton et al, 2015). The hunter-gatherer societies of the Pacific Northwest relied on salmon as their main source of protein. Studies suggest that salmon made up 89 percent of the protein intake for indigenous groups residing along the Olympic Peninsula (Glavin, 2003). Another study claims that a staggering 57.6 million kilograms of salmon were harvested annually in the area. This is more than the average annual catch of Sockeye in BC during most the 20th century (Glavin, 2003). Historically, salmon have played an important cultural and dietary role for indigenous groups in the Pacific Northwest. Contemporarily, wild salmon plays a significant role in the economy of the Pacific Northwest. Between 2008 and 2012, the total export value of processed wild salmon was over $100 million per year (Markets & Value, 2014). Salmon have, and continue to play a crucial role in the economic, cultural, and dietary well-being of Pacific Northwest communities.

Ecological. Another important function that salmon fulfill is contributing to the ecological health of river and riparian ecosystems. Salmon deliver marine-derived nutrients to the streams in which they spawn and die, increasing the abundance of stream biota. In Alaska, it has been estimated that salmon annually transfer about 100 million kilograms of carbon, 2 million kilograms of phosphorus, and 10 million kilograms of nitrogen from the ocean into freshwater systems (Tiegs et al, 2009). They also have a large impact on riparian plant diversity. A study comparing 50 watersheds in the Great Bear Rainforest of British Columbia found that salmon influence nutrient loading to plants and shifting plant communities toward nutrient-rich species (Hocking & Reynolds, 2011). Watersheds with low salmon density were lower in nutrients than watersheds with high salmon density. The watersheds with low salmon density had increased plant diversity while high-density watersheds were dominated by plants typically found in nutrient-rich riparian ecosystems (2011). Salmon contribute important nutrients to freshwater systems, as well as altering the plant makeup of streams. Chinook salmon are the main source of food for resident Orca Whales (Orcinus orca) in the Salish Sea, providing about 70 percent of their annual nutritional needs. Studies have suggested a strong correlation between Chinook abundance and Orca mortality (DFO, 2010). Salmon are significant contributors to nutrient flows in the Pacific Northwest.

Bioindicator. Salmon populations can also be used as bioindicators of an environment's overall ecological health. As already demonstrated, salmon play a large role in transferring nutrients from the ocean to freshwater systems. Studying the status of salmon populations can indicate the health of both freshwater and marine ecosystems in which salmon reside. Salmon growth, age-at-maturity, and survival are strongly influenced by conditions experienced in the marine environment (Burger et al, 2015). When salmon return to freshwater to spawn the condition of the ocean environment can be assessed by examining contaminant levels, size, age, and changes in migratory behaviour (Burger et al, 2015). For example, some populations of Chinook salmon migrate to the ocean in their first year of life and spend most of their time in an estuary and near-shore coastal areas. Declining returns of these Chinook populations could indicate poor conditions in coastal regions close to the point of natal stream entry (Burger et al, 2015). Salmon's special position in the cultural identity of the Pacific Northwest, their contribution to the ecological well-being of their habitats, and their use as bioindicators of ecological health make it vital to understand how they will be impacted by climate change.

Population Decline. Declines in salmon populations have been recorded throughout the Northwest in recent years. In 1999, wild salmon populations have disappeared from about 40 percent of their historic breeding ranges in Oregon and Washington (Salmon Recovery in Washington, 2010). On the Yukon River, populations of returning Chinook averaged around 300,000 in the mid-1990's. That number has dropped by half since 2007 (Schindler et al, 2013).

In the article “Chinook Salmon, Trends in Abundance and Biological Characteristics” researchers studied the long-term population trends of Chinook salmon in the Pacific Northwest. They analyzed data on population returns and catch data to come to the conclusion that there is a trend of population declines in the Pacific Northwest. Their research did not attempt to answer the question of what is causing the decline, but they list climate change as a likely culprit. One of the difficulties in identifying climate change as the driver of this downward population trend is the fact that there are a variety of other issues which could be decreasing populations. Though this paper is not a full discourse on identifying climate change as the source of this population decline, I will explain the possible consequences that climate change can have on Chinook salmon.

Climate Change and Life Cycle. The impacts of climate change can be distinguished when examining different parts of Chinook salmon’s life-cycle. Salmon have a very complex and diverse life-cycle. They spend the first portion of their lives, up to four years, in fresh water streams. Once they have reached an appropriate size, they venture out into the open ocean where they gain over 98 percent of their mature mass, only returning to their natal stream once they are ready to spawn (Rand et al, 2006). While climate change is surely having an impact on Chinook populations in ocean ecosystems (Abdul-Aziz et al, 2011) this paper will focus on the life-stages spent in freshwater ecosystems. Climate change presents two major threats to Chinook freshwater salmon populations.

Water Temperature. There have been observed increases in water temperature in a large portion of freshwater systems in the Pacific Northwest (Sykes & Shrimpton, 2010). Increasing water temperature impacts Chinook at their smelting stage and when they are returning to spawn. An analysis of climate in the Pacific Northwest from 1901 to 2012 showed a mean annual air temperature increase of 0.6-0.8°C (Crozier, 2015). Increasing water temperatures have been associated with physiological stress, increased susceptibility and exposure to disease, increased depletion of energy reserves, and disruptions to breeding patterns.

Increasing temperatures have been shown to impact Chinook at their smolting stage, which lasts an average of three months and takes place in estuaries. Smolting is when juvenile Chinook's undergo physiological and behavioural changes that allow them to osmoregulate in saltwater (Sykes & Shrimpton, 2010). Strong correlations between migration timing and water temperature have been demonstrated (Sykes & Shrimpton, 2010). As water temperatures increase, salmon enter estuaries to begin the smolting process earlier. As a result, migrations that begin too late, or that take longer than normal, can result in fish arriving at the estuary when food abundance is low (Sykes & Shrimpton, 2010). Smolting Chinook feed primarily on drifting aquatic organisms such as Mayflies, Stoneflies, and Caddisflies whose abundance changes throughout the seasons. Beginning the smolting process too early can result in a lack of available food, decreasing the chance that the Chinook will survive the smolting process. Changes in smolting timing due to increasing water temperatures is a threat to Chinook salmon because it can limit the amount of food available during the smolting stage (Skyes & Shrimpton, 2010).

Another issue related to the development of juvenile Chinook is the increased occurrence of disease as a result of changing water temperature. Certain diseases are prevalent in cold water, but most diseases increase in virulence as water temperature increases (Lafferty, 2009). An example is the parasite *Ceratomyxa shasta,* which develops much more rapidly in temperatures above 10°C. *Ceratomyxa shasta* has been shown to cause mortality through intestinal perforation and co-occurring bacterial infections, as well as loss of body mass and kidney postules (Kennedy, 1988). Disease can impact Chinook at any life-stage, but are most prevalent at the early stages (Lafferty, 2009). As temperatures continue to increase, Chinook will be faced with more numerous and lethal diseases that could pose a threat to stable population levels.

Increased water temperature poses a challenge to Chinook when they are returning to their natal streams to spawn. Although this life stage is relatively brief, lasting only a month, it is vital in maintaining Chinook populations. Once Chinook leave the ocean they rely on stored energy to complete the migration and spawn (Rand et al, 2006). Studies have shown that in years of normal water temperature, Chinook use about 50 percent of their stored energy reserves when they are returning to their natal streams (Rand et al, 2006). In years when temperatures are higher they are forced to use larger amounts of stored energy, increasing their mortality rates (Rand et al, 2006). Spawning Chinook mortality rates are positively correlated with increased water temperatures (Rand et al, 2006). The oxygen content of water is inversely related to water temperature, which explains why Chinook must use more energy to travel through warmer water. An oxygen level of 6 mg/L is required by salmon, so that at temperatures tolerated by salmon, oxygen levels at saturation should be adequate (Kennedy, 1988). Higher temperatures increase organic decomposition and respiration rates of other aquatic organisms which can create unsuitable conditions for Chinook by removing oxygen from the water (Kennedy, 1988).

Action. In 2014 the Warm Springs National Fish Hatchery in Oregon demonstrated what is necessary to conserve Chinook populations. In an average year the hatchery produces about 800 thousand juvenile Chinook. In 2014 the hatchery produced less than 200 thousand (Peach, 2015). An unusually early and warm summer that resulted in increased water temperatures was cited as the cause of the low yield. In order to conserve the population, wildlife managers trucked over 160 thousand salmon from the hatchery, located in central Oregon, over 100 miles to the Columbia River Gorge which had lower water temperatures (Peach, 2015). While this is not an ideal solution, it demonstrates the severe challenge that conservationists face in protecting Chinook salmon populations from increased water temperature (Peach, 2015).

Conclusion. Despite the challenges that climate change imposes on Chinook salmon populations in the Pacific Northwest, certain populations could have the ability to adapt to increasing water temperatures. Chinook live in a variety of freshwater habitats, each with different environmental characteristics and constraints. In their research, Beer and Anderson studied the adaptivity of juvenile Chinook salmon to increased water temperatures. They found that while populations occupying the warmest and most degraded habitats are likely to experience increased stress with future warming, populations occupying the colder parts of Chinook habitat might see increased productivity (Beer & Anderson, 2010). For example, some Chinook populations have been able to colonize areas in Glacier Bay, Alaska, which were previously inaccessible (Beer & Anderson, 2010). Chinook salmon face a variety of challenges, such as habitat destruction, dams, and water pollution. Conservationists face a tough challenge in deciding how to best preserve Chinook populations. Protecting Chinook populations in the Pacific Northwest is vital due to the cultural and ecological role they play. Climate change poses a risk to Chinook populations by altering their smolting times, increasing the prevalence and severity of disease, and decreasing the amount of oxygen available for migratory Chinook to be able to spawn.

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