Cascadia Partner Forum

Iconic Species Report: Sockeye Salmon

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Introduction

For conservation efforts to lead to meaningful change, they must be rooted in a general shift in the attitude of a society. Moving from a mindset centered on the present, to one more encompassing of the future is critical if we are to utilize the best management practices possible. To facilitate such a shift in perceptions, it can be difficult to highlight broad scale ecological research and trends without linking it to a specific species or place. Interpreting the impacts of ecological conditions and trends through the health, movement, and distribution of a species today and over time affords us the ability to derive meaning by demonstrating tangible impacts to a specific fish or animal. Iconic species provide a face to the larger ecosystem, a metric to measure change by, and are easily recognizable and inspiring to those that learn about them.

It is because of this last point that iconic species must not only be scientifically relevant but must also be charismatic. The sockeye salmon (*Oncorhynchus nerka*) is one such charismatic creature in Cascadia. Not only do Pacific salmon provide interesting life history to study due to their fresh to salt water migrations and their fatal reproduction, but this species' vibrant ruby red and emerald green spawning colouration has earned it a place in the folklore and culture of communities throughout the Pacific Northwest for thousands of years. It is this closely knit relationship with aboriginal people from which the sockeye derive their name, from the coastal Salish words *sukkai* and *suk-kegh* meaning fish or red-fish.

Cascadia is home to many sockeye salmon, including major runs that pass through the Columbia and Fraser basins. The largest stock in the world famously runs through these ecosystems by way of the Adams River and through the Fraser River system. Sockeye salmon in the both the Fraser and Columbia basins have declined substantially from historic levels when runs were as large as 3 million fish in the Columbia and 40 million in the Fraser at the turn of the 20th century. Reasons for these declines are diverse and sometimes speculative. Uncertainty surrounding this species is raising concerns that have given birth to commissions and conservation efforts to preserve and learn more about the sockeye's status and their important role in the ecosystem.

This report presents background information on this iconic aquatic species in Cascadia, while exploring the research and networks of people working towards assuring its future on this landscape.

Sockeye Life History

The life history of sockeye salmon is complex but linear. In general, adult Pacific salmon migrate to their natal body of water and deposit their eggs in the same location as they were born. They die after spawning as a result of a life history trait referred to as semelparity. After a period of incubation and emergence from eggs, the young salmon spend several years preparing for their voyage into their oceanic adult life as anadromous fish. After a number of years of growth in the ocean, Pacific salmon transition back to fresh water and migrate upstream to the location of their birth where they proceed to spawn and die. The majority of sockeye salmon follow this basic life history outline but local adaptations have led to the emergence of several ecotypes of sockeye.

Ecotype of sockeye in Cascadia

The “lake ecotype” is the most common variety of sockeye present and is characterized by the generalized life strategy described above. Sockeye differ from other Pacific salmon in their utilization of lakes as their predominant spawning grounds as opposed to rivers, thus the term “lake ecotype” is used to describe the most common variety of sockeye. In addition to lake spawning sockeye there are varieties referred to as “river-type sockeye” or “sea-type sockeye”. These varieties are distinguishable by their shorter and more variable residence time in fresh water before their transition to salt water (weeks up to a year versus several years for lake ecotypes) and their tendency to reside in freshwater tributaries as opposed to lakes (Wood et al. 2008). Finally, a non-anadromous “kokanee ecotype” of sockeye has adapted to a life spent entirely in freshwater (Nelson 1968). The following, more detailed description of sockeye salmon life history is characteristic of the most common “lake ecotype” but is similar across all varieties of sockeye. Significant divergences between ecotypes will be noted where appropriate.

From lake to sea and back again

Life begins for sockeye salmon as eggs buried in the gravel or loose substrate of the body of water in which their parents were born. Length of incubation is often variable between stocks of sockeye salmon, due to the adaptive nature of spawn timing. Spawning occurs between late summer and fall so that emergence of young salmon (termed “alevin” once hatched) occurs at a time that is most beneficial for their survival, between 2 and 4 months after spawning occurs (Burgner 1991). During incubation, eggs are susceptible to a number of predators ranging from trout and charrs, to predatory birds such as gulls and water ouzels. Even late-spawning sockeye salmon will occasionally eat or disrupt the eggs (Burgner 1991). Alevin stay incubated under gravel for several weeks until their yolk sac is depleted at which point they emerge in groups at night to avoid predation (Burgner 1991).

Once the salmon have left the protection of the gravel they enter the first stage of their juvenile life and become “fry”. After a number of weeks of feeding on insects and pelagic zooplankton, the fry’s growth and darkening of camouflaging vertical bars and spots, signifies entry into their secondary juvenile stage as “parr” (NOAA 2013). Young salmon are vulnerable and at these early stages in the sockeye’s life, rainbow trout, juvenile Coho, Chinook salmon, and sculpins are the major predators to the species. Mortality at this stage has been shown to be as high as 25-69% in Cedar River of Washington Lake (Burgner 1991). This high mortality rate is likely due to the fact that salmon are visual predators and so must hunt in daylight. This increases the threat to sockeye from other visual, piscivorous predators. After spending between 1-3 years in their home lake (weeks to months for sea/river ecotypes), anadromous sockeyes will begin the process of transformation from parr to smolt in spring to prepare themselves for migration into the sea (Burgner 1991, NOAA 2013).

The transformation process (smoltification) occurs only once juveniles reach adequate size and is triggered by an increase in the daily photoperiod (Burgner 1991, Quinn 2005a). Ocean adaptive changes do not occur in the “kokanee ecotype”. Lengthening of days entrains an endogenous hormonal cycle which initiates the transformation necessary for seaward migration. Juveniles lose the lines and spots present on a parr and instead gain a more uniform dark blue-green back and light-silvery underside colouration common to many open water marine fish. Additionally the body of the juvenile salmon becomes slimmer and more streamlined for faster travel in the ocean (Burgner 1991). Hormonal changes result in increases in the sockeye's metabolism, increased growth rate, development of larger teeth, and induction of changes to the gills and kidneys of the fish to cope with the transition to salt water (Burgner 1991, NOAA 2013, Quinn 2005a).

Physiological changes that maintain proper ion concentration during the transition from fresh to salt water and back again, are some of the most significant changes that occur to Pacific salmon in their development. The body tissue of a sockeye salmon has a salt composition of ~10 ppt while freshwater is ~0 ppt and saltwater is ~33 ppt (Quinn 2005a,b). Salmon in freshwater must work to retain salt. They therefore refrain from drinking, they actively transport ions into the gills, and they excrete dilute urine (Quinn 2005b). In salt water they must accomplish the opposite, excreting concentrated urine, drinking often, and actively transporting ions out of the gills (Quinn 2005a). Although the large size of salmon helps to buffer against rapid osmotic changes, extensive change to the osmoregulatory system is still necessary before transition from one environment to the other (Quinn 2005a). Major changes must occur to the gills and kidney to prepare salmon for migration through estuaries into salt water. When ready to exit into the ocean, the juveniles travel in schools and exit the lake outlet late at night, with the majority occurring between 10pm and 2am in an effort to avoid predation (Burgner 1991).

Upon entering the ocean, sockeye salmon begin their more elusive adult lives. They will spend upwards of 4 years in the ocean, feeding constantly to increase their energy reserves necessary for homeward migration. Having large stores of energy are critical for the fitness of sockeye because in preparation of returning to their home stream, Pacific salmon experience a cessation of appetite and many will not eat for the remainder of their lives. Some male salmon return to freshwater after only a single year at sea, a quality that is characteristic of faster maturing salmon species such as Coho and pink. These "jacks" are notably smaller but can constitute a significant portion of some populations (Columbia and Fraser rivers) while being almost non-existent in more northerly populations such as the Chignik River stock (Burgner 1991). Early female migrants, termed "Jills", are significantly less common and make up only 4% of populations sampled from Fraser River (Burgner 1991).

Once sockeye salmon begin their migration upstream to spawn, many will not eat again in their lives. Because of this characteristic it is extremely important for sockeye to build the reserves necessary for their migration. Swimming upstream for distances that can be greater than 1000km for populations that migrate to Wenatchee and Osoyoos Lake is extremely energetically costly (Crozier et al 2008). With somatic energy being such a key component to the fitness of this species there is a large body of literature detailing the adaptive importance of endogenous reserves (Brett 1995, Crossin et al. 2004, Hendry and Berg 1999, Hendry et al. 2004, Kinnison et al. 2001). To fulfill their voracious appetite while at sea, sockeye eat a variety of marine organisms. Measurement of stomach contents of adult sockeye at 82 locations in the central North Pacific Ocean reveal that the majority of adult salmon diets consist of planktonic crustaceans (43%), small fish (12%), and squid (16%) (Burgner 1991).

During this period of energy acquisition and storage in the ocean, mortality can be substantial for adult sockeye with estimates ranging from 50 – 95% (Burgner 1991). It is thought that much of this mortality occurs in the beginning of the adult salmons' marine life and in fact survival has been shown to be quite high (85%) in some populations during the period of migration from sea to the mouth of the Fraser River (Crossin et al. 2007). Once adult sockeye have adequate somatic energy reserves they begin their migration back to fresh water and can travel at a rate of up to 33 km/day (Crossin et al. 2007). At the mouth of the river in which the salmon will begin their upstream migration, the salmon wait for 1-9 days as the necessary osmoregulatory changes occur to once again allow the fish to survive in fresh water (Crossin et al. 2007). Only roughly 5% of fry will have survived to this stage in adulthood (Cohen 2010b)

The time at which various stocks of salmon reenter freshwater can be can be variable and is modified by river temperature and the rate of discharge from the river (Crossin et al. 2007). As an example the extreme ranges of variability, the Alaskan Bristol Bay stocks (which accounted for >50% of the North American stock from 1950-1984) have over 80% of their stocks pass through the mouth of the river in a 14 day span from late June to July (Burgner 1980, Burgner 1991). In contrast, the sockeye runs to the more diverse habitat provided by the Fraser River occur over a span of three months (Killick 1955). Although there is variation between stocks, the timing of migration for individual populations rarely deviate more than a week from year to year (Cooke 2004). Variance in the time of sockeye entry into freshwater is related directly to variability in spawning sites' temperature regimes, and is a result of the adaptive flexibility of sockeye spawn timing that allows for synchronization of progeny emergence (Brannon 1987). The ability for adult salmon to migrate to the body of water from which they were born has long been a mystery but recent research shows that gonadotropin releasing hormone plays a leading role in homing migration along with olfactory cues from the salmon's home stream (Ueda 2011).

Migration upstream leads to extensive phenotypic changes in sockeye salmon. Sexual dimorphism becomes apparent in the species in anticipation of spawning. As they near their natal sites the males become laterally compressed and develop a large dorsal hump anterior to their dorsal fin. Additionally, males develop a long hooked snout and pointed teeth develop from their receding gums. In contrast, the females largely retain their fusiform shape with merely a swelling in the abdomen as eggs become enlarged (Burgner 1991). The spawning colouration of sockeye salmon is perhaps their most iconic and characteristic trait. Both female and male salmon shift from blue backs and silver sides to red backs with red to reddish grey sides and olive to emerald green heads, with males tending to have brighter colouration (Burgner 1991). In migrants to Wood River lakes there is a heavily male skewed sex ratio for bear kills and it is thought that the more conspicuous nature of the males morphological changes are potentially an adaptive measure to favor survival of females in areas of bear predation (Burgner 1991).

Once sockeye reach their spawning grounds the females dig into the loose substrate and lay their eggs into 3-5 nests called "redds" (NOAA 2013). Female sockeye lay between 2000-5000 eggs which is comparatively less than other semelparous fish of similar size. The "kokanee ecotype" lay only between 300-2000 eggs as a result of a life lived in the less productive lake habitat (Burgner 1991). With spawning complete the salmon have reached the end of their lifecycle. The adults soon perish and their bodies decompose, a critical process for the habitats surrounding the spawning locations. With rivers tending to flush nutrients and sediment downstream, the fertilizing property of Pacific salmon represents the rare instance of a return of nutrients upstream. It is perhaps this quality of giving back that has ensured the presence of sockeye in the culture and folklore of the North American First Nations people for thousands of years.

Sockeye History in the Region

"Only a few wild animals symbolize the heart and soul of a region. Tigers in India, lions and elephants in Africa, kangaroos in Australia. In North America the buffalo of the Great Plains and the salmon of the Pacific Northwest supported economies, cultures and human self- identities. And though white settlers destroyed the buffalo in greed and in genocide against the Natives, they embraced the salmon. Immigrants, like, Native peoples, saw in salmon something deep, powerful, moving and valuable. Even if they approached the fish with less awe, less reverence and consequently less success than the Natives had for millennia. Think of the Northwest and salmon soon come to mind. Whether they represent your demons or salvation, salmon loom large here. Certain other animals still symbolize their regions but salmon are unique because their symbolic power and their ability to bestow significant economic and nutritional benefits on human culture have survived together to the 21st century. And this comprises the best hope in the struggle for salmon and the people who need and desire them."

- Carl Safina from Salmon Nation (Gallaugher and Wood 2010)

First Nations People and sockeye

For millennia before European settlement, the Aboriginal peoples of the Pacific Northwest have relied on salmon as a yearly boon of nutrients brought from the ocean. Sockeye and the other species of Pacific salmon are so integral to the way of life for the First Nations people that its iconography can be found throughout their traditional artwork and lore. Stories of how the mythical creator Coyote first brought salmon to the communities along the Columbia River are an important part of Aboriginal oral history (Miller 1992). The tribes that rely on these fish regard them with respect and consider them to be valuable not only in a material sense but also as a spiritual and cultural cornerstone. The responsibility of governance of this resource was seen as an important role in many tribes. Elders of the Upper Skagit tribe would select a Salmon Priest, and members of the Okanagan bands would designate a Salmon Chief to ensure that there were adequate resources for all people to share (Miller date unknown, Marlowe 2008). Unfortunately, a history of over exploitation by European settlers and modern day North Americans threaten the traditional way in which the indigenous people of the Cascadia region incorporate sockeye and other Pacific salmon into their way of life.

Modern North American history of sockeye

Transboundary harvest issues have plagued Pacific salmon harvest since the end of World War I and it is not hard to see why. Representing over $311 million from 2009-2011 for BC and nearly $8 billion from 1950-2008 for the United States, sockeye salmon have the highest value density of any Pacific salmon species and have been a significant component of what is commonly referred to as the Pacific Salmon War (BCMoE 2011, Schindler et al. 2010, Williams 2007).

Non-native fishing of salmon began in the 1830's and was so prosperous that the industry exploded over the next 70 years. In 1901 the British Columbia Commissioner of Fisheries stated that both American and Canadian canneries were not only filling every can that they could purchase, but throwing away more salmon than was being used (Williams 2007). By the 1910's the effects of overzealous fishing began to become apparent and the summer season was closed for its first time.

Blasting of the mountainside at Hell's Gate, for the construction of railways in the narrowest point in Canada's Fraser River canyon, lead to rockslides in both 1913 and 1914 that halted the migration of sockeye salmon to their historic spawning grounds (Williams 2007). Hindered migration led to a reduction in stocks and the start of negotiations between the United States and Canada on the future of salmon conservation.

On May 26, 1930 the joint Convention for the Protection, Preservation and Extension of the Sockeye Salmon Fishery in the Fraser River System (the Fraser River Convention for short) was signed by both the United States and Canada. The convention detailed that for the harvest of half of the Fraser River sockeye stocks the United States would provide funds and technical support for the clearing of Hell's Gate (Williams 2007). The Convention was put in place to focus efforts on the enhancement of the Fraser River fishery for the mutual benefit of both countries.

Despite efforts to preserve Pacific salmon stocks, consistent declines in harvest led Canada and the United States to seize exclusive rights over fisheries within 200 miles of their shores in 1977. In 1982, this legislature was mimicked by the UN as the United Nations Convention on the Law of the Sea was enacted to give exclusive fishing rights, within 200 miles of their respective shores, to all countries (Williams 2007).

Recognizing the international distribution of Pacific salmon stocks and the potential for overexploitation of these shared stocks on either side of the border, Canada and the United States sought a way to communally manage this valuable resource. On December 15, 1984 the Pacific Salmon Treaty was agreed upon between the two countries to ensure communal conservation and rehabilitation of transboundary stocks (Williams 2007). Once ratified in 1985, the Pacific Salmon Commission was established to facilitate the implementation and advise on the Treaty. The Pacific Salmon Commission is a 16 person group composed of eight individuals from each side of the border. The group includes individuals from commercial fishers, federal, state, provincial, and First Nations governments (Cohen 2010a). Through this treaty Canada gained split management of southeast Alaskan transboundary rivers and greater control over Fraser River salmon. In exchange, the United States gained increased control over Canadian south coast fisheries' interception of stocks from Oregon and Washington (Williams 2007).

By 1995, tensions over what was seen as unfair harvest on both sides of the border led to the instatement of a neutral mediator to resolve disputes over the new Treaty. Upon completion of an assessment of the Treaty terms and implementation, the mediator recommended that the United States reduce its harvest rates of Canadian stocks or begin compensating Canada for excess catch of Pacific salmon. The United States in turn dismissed the ambassador and refused to comply with his recommendations.

Rising tension came to a pinnacle in 1997 when nearly 100 enraged Canadian fishing vessels blockaded an Alaskan ferry carrying 300 passengers in the Canadian Prince Rupert port. In response then-President Bill Clinton was called on by the US Senate, in a vote of 81 to 19, to send the US Navy to escort the ferry from the Canadian port. In the end the conflict was diplomatically defused and the Pacific Salmon Treaty was abandoned (Williams 2007).

In absence of any governing agreement there were continued declines in harvest and so in June of 1999 the Pacific Salmon Treaty was modified and reinstated. The new Treaty incorporated in-season monitoring to promote conservation of the stocks and reduce overfishing by encouraging abundance based management as opposed to the traditional fixed quota harvesting. Secondly, the modified Treaty made suggestions for fisheries management on a stock by stock basis as opposed to broad management of all stocks communally. Finally, US funded endowments were put in place with joint management from Canada for investment in fisheries research (Williams 2007). Additionally, the 1999 agreement included the creation of the Transboundary Panel and the Committee on Scientific Cooperation to increase cross boundary cooperation and management efforts (PSC 2013).

The Pacific Salmon Commission recommended in 2008 that a new agreement be reached and the Treaty amended for more modern conservation and harvest sharing of Pacific salmon. By December the new agreement to govern international fishing regimes was approved. This agreement replaced several chapters of the Treaty to further emphasize conservation and sustainable harvest and detailed additional investments from both countries for the continuation of fisheries research. The agreement will continue to govern fishing regimes through to the end of 2018 (PSC 2008).

Distribution and Conservation Status

Historic sources and current distribution of sockeye

As a migratory species that spends time in both fresh and salt water, sockeye have an extensive range. Although spawning grounds can be found spread throughout the coast of the Pacific Rim (Figure 1) the major spawning grounds in North America are found between the tributaries of the Columbia River and the Kuskokwim River in Alaska. Asian sockeye stocks are centered on spawning complexes in the Kamchatka Peninsula (Burgner 1991). In total the range of the species is estimated at 11.5 million km^2 (Goslin 2011).

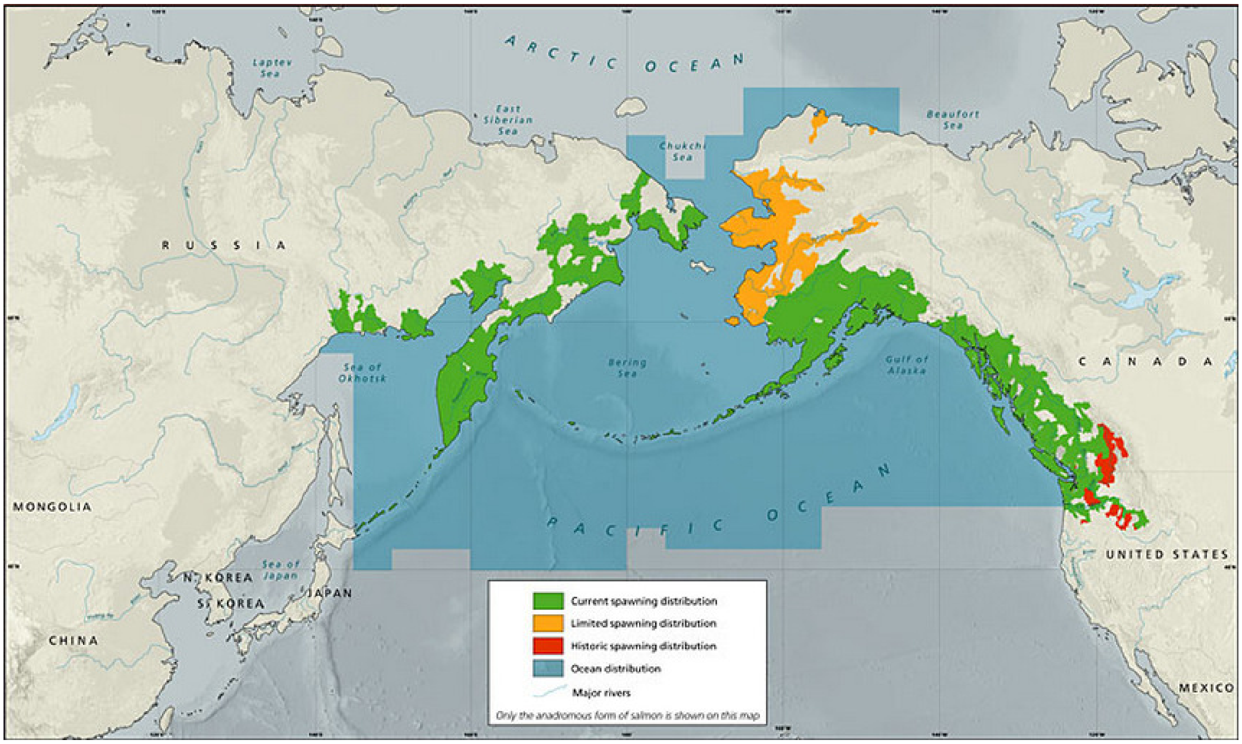

Figure 1: Anadromous sockeye current and historical distribution. Adapted from Status Map available at http://www.salmonnation.com/fish/meet_species.html#

It is suggested that the distribution of these salmon along the Pacific Rim is associated with colonization that occurred after the last glaciation (Wood et al. 2008). Microsatellite data supports that there were likely two major refugia on Kodiak Island and the Queen Charlotte Islands that led to the majority of sockeye populations today (Beacham et al. 2006, Karlstrom 1969, Warner et al. 1982). Genetic mosaics found in central BC sockeye populations suggest either a mixing of salmon from these two sources, or the potential of other local refuges in the Columbia River system (Beacham et al. 2006, Nelson et al. 2003).

It is perhaps because of the North American origins of sockeye that today North America is home to the two largest spawning complexes of sockeye in the world. The Alaskan Bristol Bay watershed supplied over 50% of the sockeye stock for North America from 1950-1984 while Cascadia's Fraser River Basin salmon runs constitute more than half of all the Canadian salmon stocks (Burgner 1991, Cohen 2010b). The Fraser River in fact supports the largest single sockeye stock of any river in the world (Cohen 2010b).

International to sub-national status of sockeye

In a 2011 reassessment of the international conservation status of sockeye, the IUCN determined that the species was to be declared of least concern. Ninety-eight subpopulations were assessed during the review and it was determined that overall the species is growing. The 62 subpopulations that had sufficient data for analysis showed that the median rate of increase for sockeye salmon populations is 9.0% (mean of 72.4%) (Goslin 2011). Although overall the species is thought of as doing well, the IUCN assessment is neither definitive nor flawless. Of the defined subpopulations five of them are extinct, representing a 7% decline in the species range (Goslin 2011). The 62 extant populations with sufficient data for analysis show that 19 of them are at some level of threat according to IUCN criteria and that two are near threatened. These threatened populations remain at differing level of vulnerabilities with four being critically endangered, twelve being endangered, and three vulnerable subpopulations (Goslin 2011). In general, populations at southern ends of the sockeye range are declining while populations in the north appear to be stable with the most severely threated populations occurring in BC.

There is uncertainty around the conclusions drawn from the IUCN assessment of sockeye. Perhaps most notably is the fact that nearly a third of the recognized subpopulations have insufficient data to draw any meaningful conclusions from (defined as having less than 12 years data with less than 60% of the series being complete). Adding to the uncertainty, data from which IUCN conclusions were drawn are not collected in a uniform manner. Fisheries escapement estimates are calculated using data collected from an array of means including foot and aerial surveys, sonar, tower, and weir observations made at varying levels of thoroughness (Goslin 2011). Compounding these added sources of uncertainty is the fact that trend estimates are determined using only three generations worth of data. When trends were analyzed for the entire time series of threatened populations, it was revealed that 12 of 19 had less negative or had positive population trends while the remaining 7 had significantly worse trends (Goslin 2011). Using shorter trend timeframes can lead to error, in particular when outlier data is at either ends of the time series. Considering that sockeye populations display a character trait known as cyclic dominance in which every four years there are significantly more fish spawning than the previous three, it is entirely possible that outlier data could be affecting trend estimates (COSEWIC 2003).

In the United States sockeye salmon have two federally listed threatened populations, neither of which are resident to Cascadia. The Puget Sound population of Ozette Lake is listed as threatened and the population of Snake River is currently endangered (USFWS 2013). Sockeye from both of these lakes are listed in Washington as “State Candidates” meaning that they will be reviewed for possible listing but have no official state listing (WDFW 2013). Due to changes in the structure of the organizations responsible for species conservation on a

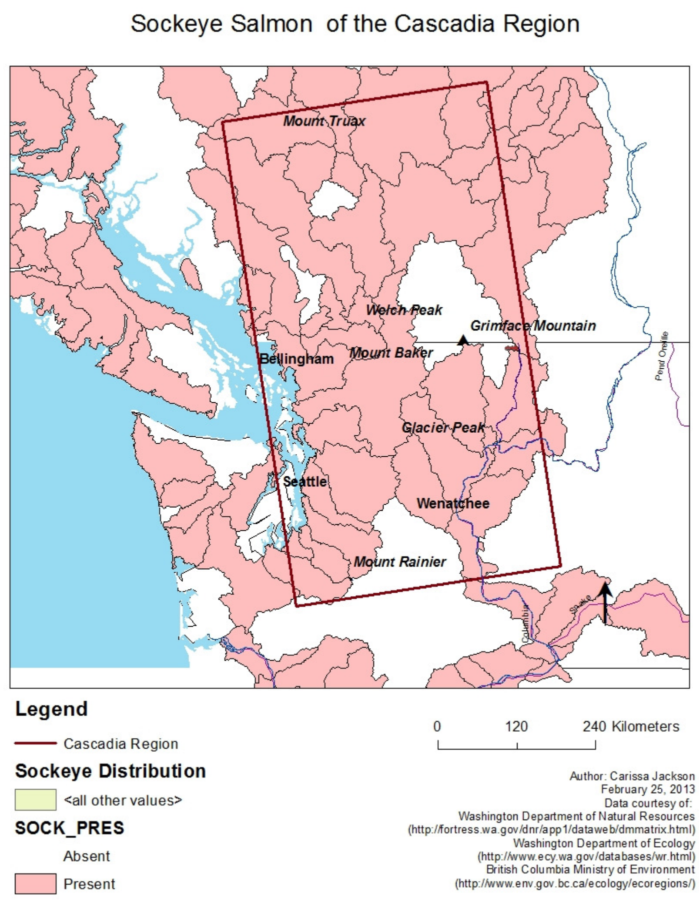

Figure 2. Sockeye salmon range throughout Cascadia.

state level, the Washington Department of Fish and Wildlife currently does not have the authority to change the status of the species. Therefore the populations are likely to remain as State Candidates despite their recognized decline.

The Canadian government's Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2003 listed two populations in BC as endangered, Cultus and Sakinaw lakes. The Cultus Lake populations lies on the western edge of Cascadia's border and has been monitored since 1925. It is listed as endangered because in the years from 1991-2002the population has shown a 3.3% decline per year (COSEWIC 2003). With only these two populations federally listed as of concern, the Ministry of Environment's B.C. Conservation Data Centre has "yellow listed" the species and therefore provincially recognized them as a secure population not at risk of extinction (BCMoE 2013).

Although sockeye salmon are generally listed as of little conservation concern, with incomplete data on nearly a third of the subpopulations of this species and localized declines, it is likely more data is needed before a definitive conclusion can be drawn about the species overall status. The potential for climate change to so strongly affect this species also highlights the need for more complete monitoring of uncertain sockeye populations in anticipation of potentially rapid changes to habitat and abundance.

Concern in the Fraser

The Cascadian Fraser River sockeye run has proved to be an example of one such uncertain population. Being the largest single sockeye salmon run in the world, continual, unexpected declines of salmon abundance led to a $26 million investigatory panel tasked with determining the cause of decline. At the turn of the 20th century, sockeye numbers ran as high as 40 million during dominant years in the Fraser River system and its tributaries (Cohen 2010d). Human induced rockslides at Hell's Gate in 1913 and 1914 reduced numbers to around 2 million returning sockeye. Increases in stock size occurred from the late 1970's to 1992 peaking at 24 million but have been in decline since (Cohen 2010d). Recent years, including from 2007-2009, have resulted in returns below 2 million sockeye. These low numbers are of concern by themselves but are additionally concerning in that the return in 2009 was nowhere near the pre-season assessment of 11.4 million. Despite these consistently low numbers, the 2010 run of 29 million salmon constituted the largest return since 1912 (Cohen 2010d). Return numbers for further years are still preliminary and one year of increased stock does not indicate a trend but is promising in light of past years low numbers and unreached estimates. Overall the commission could not identify any single factor that was greatly influencing this famous Cascadian stock but instead highlighted a number of possible interplaying factors.

INSERT: There is a need to speak to the huge runs in the Fraser and tribs since it is this huge local distribution that influenced our choice for this species. Bring this larger discussion of distribution home to Cascadia in a paragraphy.

Climate Change and Sockeye Salmon

The complexity of the life cycle of sockeye salmon and the significant physiological changes that occur between each stage of the salmon's life make them particularly susceptible to a changing environment. A metastudy of the state of climate change research on sockeye salmon reveals that the temperature increases expected as a result of climate change have been closely examined for every life stage of the sockeye salmon (Martins et al. 2012). Although information on temperature effects are thorough (83.4% of 80 studies examined this climatic variable), information on other potentially fluctuating key environmental variables is lacking (Martins et al. 2012).

Perhaps one of the most critical times in a sockeye's life is during migration to spawning sites. During this time, sockeye cease eating and must rely solely on somatic reserves to not only complete their migration, but fuel the energetically costly act of spawning. Considering this, timing of a salmon's migration and entry into fresh water is of critical importance. If a salmon enters fresh water too soon, but the date of spawning remains later in the season, the salmon may not have the energy necessary to complete the journey and survive until spawning. Considering that after upstream migration some Lake Washington salmon already wait for up to six months in the lake before spawning, it may not take much of a lengthening in freshwater residence time to severely affect sockeye fitness (Newell et al. 2007).

River temperature regimes and outflow have an important effect on when adult salmon choose to reenter fresh water (Brannon 1987, Crossin et al. 2007). Warming at the end of the 20th century has led to a significant advancement in the timing of snowmelt runoff in the Cascadia region (Stewart et al. 2005). This trend is predicted to continue and result in further advancement of snowmelt in many rivers that have snowpack that currently remains present into the summer (Crozier et al. 2008). In addition to increased runoff, warming of Cascadia salmon habitats, both marine and freshwater, are expected to result in water temperatures that are an additional 2-5°C warmer within the next 100 years (Healy 2011). These trends are likely to have severe impacts on salmon populations. Indeed, since 1995, between 60-90% of salmon originating from the Fraser River that enter in late summer have freshwater entry dates that are as much as 8 weeks earlier than historic averages (Crossin et al. 2007). Since this trend has been observed, over 4 million late run sockeye salmon have died in the process of early migration (Crossin et al. 2007). The combination of these factors has led to advancement of migration for salmon that pass Oregon's Bonneville Dam by 2.5 days for each generation of sockeye (Crozier et al. 2008).

There are a number of further impacts that increased temperature can have on populations of sockeye salmon that can affect the fish throughout their life cycles. It is anticipated that increased water temperatures will have a positive effect on the productivity of some salmon populations, particularly where temperatures are below optimal at the northern edge of the sockeye's range (Crozier et al. 2008, Wood et al. 2008). Indeed, a 20 year experimental distribution of sockeye from a communal hatchery in Alaska to two lakes that varied in temperature regimes showed that fish exposed to warmer waters had higher growth rates and better freshwater and marine survival (Reed et al. 2010). This is not to say that warmer temperatures are always better for sockeye, in fact it can become quite the contrary. There is an upward limit which suggests that sockeye cannot physiologically tolerate temperatures above 23°C regardless of acclimatization (Crozier et al. 2008). Some populations from colder environments have been shown to have 100% mortality when introduced to temperatures of >20°C (Cohen 2010c).These limits to temperature adaptation will likely result in reduced fitness for southern most salmon populations and negatively affect lake-ecotype salmon habitat while potentially benefiting and expanding kokanee-ecotype habitat (Wood et al. 2008).

Extreme temperatures can be lethal on their own and additionally produce a number of sublethal impacts. As temperatures increase, heat stress can negatively affect smoltification, maturation, and egg development, along with causing a shift in behaviour to favour heat avoidance (Crozier et al. 2008). High temperatures also increase fish susceptibility to pathogens in the water and allow for disease to spread more quickly in a salmon's body (Crozier et al. 2008). In many of the sockeye habitats throughout Cascadia such as the Okanagan, Columbia, and Snake rivers, temperatures already approach lethal limits regularly (Hodgson and Quinn 2002, Hyatt et al. 2003). Not only are temperatures warmer, they last for increasingly long periods of time. In comparison to averages of the 1930's, stressfully high temperatures occur up to four weeks earlier and last for up to three weeks later in the region (Quinn and Adams 1996).

Warmer year round temperatures will hasten in-egg development and lead to an advancement of optimal emergence time (Crozier et al. 2008). It is predicted that this will cause the optimal spawning time of sockeye to become delayed in an effort to prevent premature fry emergence (Crozier et al. 2008). It has been shown that transplanted Chinook salmon do in fact adjust spawning date to diverging emergence dates in salmon populations transplanted to warmer climates in New Zealand (Quinn et al. 2000, 2001). The combination of earlier freshwater migration and later spawning results in a greater amount of time spent in freshwater. This is not only energetically costly for the fasting fish, but it increases their susceptibility to thermal stress and predation leading to reduced fitness (Crozier et al 2008).

Our understandings of some of the potential effects of climate change are thorough but far from all encompassing. A better understanding of how non-temperature related variables affect salmon and how climate change will affect salmon marine habitat would better equip the agencies responsible for the management and conservation of these stocks. Climate change induced population decline and habitat destruction are complex issues and highlight the need for collaborative efforts to manage this species as effectively as possible.

People and partners

Due to their migratory nature, the protection of sockeye is dependent on cooperation between many groups: governmental, aboriginal peoples, industry, and non-governmental organizations. On a governmental level, the United States Fish and Wildlife Service (USFWS) and Canadian Department of Fisheries and Oceans (DFO) oversee federal involvement in salmon conservation. At a state and provincial level the Washington Department of Fish & Wildlife (WDFW) and the B.C. Ministry of Environment (BCMoE) manage legislation and governmental research into sockeye salmon in the region. Of these governmental bodies, the DFO has been highlighted as being of critical importance in developing and implementing effect conservation management for the species due to their position in managing large portions of spawning grounds (Goslin 2011).

The Pacific Salmon Commission (PSC) was created in 1986, a year after the ratification of the Pacific Salmon Treaty. The PSC is an equally funded 16 person group with eight commissioners and eight alternates, four from each country (Cohen 2010a, Williams 2007). The purpose of the PSC is to bring together a range of individuals from the fisheries industries, all levels of government, and Aboriginals' governments to collaborate on the proper implementation of the Pacific Salmon Treaty to ensure the mutual benefit of improved Pacific salmon conservation for both countries.

The Fraser River Panel was created under the PSC to make regional management recommendations and provide technical support for the PSC. The Panel has six members and six alternates from each country and in addition to advising the PSC, is tasked with performing the yearly in-season management of non-First Nations commercial fisheries in the Fraser River system (Cohen 2010a).

Despite work by the Fraser River Panel and PSC, unresolved declines in the Fraser River prompted the creation of the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (the Cohen Commission) in 2009. The finalized report, nearly 1,200 pages long, did not have the definitive “smoking gun” that many hoped would be apparent after this $26 million investigation (Hutchison 2012).

Fisheries management in Washington is facilitated by the NOAA’s National Marine Fisheries Service (NMFS) and the regional Pacific Fishery Management Council (PFMC). The NMFS is responsible for the conservation and stewardship of the United States’ marine resources while the PFMC is responsible for the regional management of almost 120 species that travel along the western coast of the United States (PFMC 2013). The PFMC is active in various international management initiatives of highly migratory species that pass through their 317,000 mi^2 jurisdictional range, species such as tuna and salmon (PFMC 2013).

Since non-Native exploitation of sockeye began, the First Nations peoples of Cascadia have had severely reduced input on the management of stocks compared to a time when Salmon Chiefs and Salmon Priests governed this shared resource. In recent years, Canadian and American governments have recognized the value of Aboriginal traditional knowledge and have looked to incorporate it into management practices. The First Nations Fisheries Council of British Columbia and the Northwest Indian Fisheries Commission aim to provide input on fisheries management and facilitate effective policy change in the context of the First Nations people whom rely on this resource.

Non-governmental organizations such as the Pacific Fisheries Resource Conservation Council, the Salmon Nation, the Wild Salmon Center, Pacific Salmon Foundation, and Watershed Watch Salmon Society conduct independent research, advise governmental bodies and work towards educating and engaging the public. In general, groups like these promote the conservation and sustainable harvest of sockeye and other Pacific salmon. This is a critical role to play, in particular public education, to raise awareness about sockeye salmon and their critical role in Pacific Northwest ecosystems. By bringing attention to the species, it becomes easier to justify investigating some of the mysteries still surrounding this charismatic creature.

Gaps, needs, opportunities for adaptation planning and projects

Sockeye salmon are largely listed as a species of little conservation concern at all levels of government and globally. Having such a status will reduce research efforts and funding for the conservation of the species. Although there is nothing inherently wrong with a conservation status of less concern, if these labels are improperly given to a threatened species it can lead to a hastening of the destruction of the species and their habitats as they are believed to not be at threat of extinction. Nearly one third of the recognized sockeye salmon subpopulations that make up the entirety of the species have insufficient data to draw conclusions on population trends (Goslin 2011). These unassessed populations represent the largest gap in the knowledge of the species and should be reviewed to acquire a more complete picture of the conservation status of the species.

The IUCN's Salmonid Specialist Group (SSG) recognizes that not only is improved monitoring necessary but that a refocus on fisheries practices and conservation efforts is necessary. The SSG recognize the Canadian DFO is a critical player in the conservation of the species and that partnerships should be built upon this pivotal role to achieve communal goals (Goslin 2011). The group also suggests that fishery practices should be modified to prevent mixed stock catching which can result in unintentional catch of threatened populations. Finally, the SSG indicates that funding for enhancement activities that have shown little effectiveness should be repurposed to more beneficial practices and that these practices should be focused on research that can be applicable outside of the ocean given the lack of control we have over the marine environment (Goslin 2011).

In contrast to the suggestion of efforts being focused on in stream mechanics, in a recent review of the state of climate change research on the species, Martins et al. (2012) postulates that filling our gap of knowledge surrounding how climate change will affect sockeye salmon at sea is of utmost importance. Martins et al. (2012) suggests that experimental trials of how early life climate stress imposed in the lab can change the fitness of adult individuals could be beneficial in expanding our understanding of how changes at various stages of sockeye affect them over their lifespan. Additionally, further research on the effects of non-temperature climate change variables on salmon would help increase our understanding of how a changing climate can affect the species. For example, knowing how changing hydrology will affect egg survival could help develop appropriate management tactics for spawning grounds. Finally, further information on how climate variables and non-climate variables interact are critical for a species that is subject to not only a changing environment but also ever changing demands from the commercial harvest of the species.

Sockeye salmon spend a large portion of their life at sea, feeding. Any threat to a sockeye's food source is likely to have an effect on the salmon as well. Ocean acidification, as a result of the annual absorption of one third of CO_2 emissions into surface waters have caused a 30% increase in acidity (a 0.1 decrease in pH) over the past 200 years (DFO 2010). This is likely to affect organisms that use calcium carbonate to form shells and skeletons, such as some of the zooplankton that sockeye feed predominantly feed on. With a projected decrease of up to another 0.5 pH by the end of the century, the effect of ocean acidification on sockeye is an important avenue of research yet there is currently no empirical evidence on the interaction between the two (DFO 2010, Martins et al. 2012).

The decline of stocks has prompted the reintroduction of salmon into some lakes from sockeye reared in artificial hatcheries. These introduced salmon have the potential to skew any natural decline that is occurring in the population (Goslin 2011). Hatchery reared fish also have the potential to skew the natural genetic makeup of a population which can have negative effects on fitness (DFO 2010).

Recent research into genetically engineered fish shows that sterility can be induced in 99.8% of hatchery populations (DFO 2010). Sterilizing the fish would likely reduce the chance of negative genetic impacts of introduced salmon but findings from this research have yet to be incorporated into abundance modelling or management strategies (DFO 2010).

Prevention of the destruction of critical salmon habitat is also a critical measure to ensure the species' sustained well-being. Projects like the Pacific Fisheries Resource Conservation Council's Salmon Stronghold project seek to preserve critical habitat in vulnerable locations. In 2010 they designated their first river, Harrison River, as the inaugural Salmon Stronghold (PFRCC 2013). Protected areas like these may play a critical role in the future of the sockeye salmon in Cascadia and throughout the Pacific Northwest in general as climatic changes, urbanization, and industrialization further threaten this iconic species and the people who rely on them.

Literature Cited

Beacham, T.D., B. McIntosh, C. MacConnachie, K.M. Miller, R.E. Withler, and N. Varnavskaya. 2006. Pacific Rim Population Structure of Sockeye Salmon as Determined from Microsatellite Analysis. Transactions of the American Fisheries Society 135:174-187.

Brannon, E.L. 1987. Mechanisms stabilizing salmonid fry emergence timing. *In* H.D. Smith, L. Margolis, and C.C. Wood (eds). Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Canadian Special Publication of Fisheries and Aquatic Sciences. 96p

Brett R. 1995. Energetics. *In*: Groot C, Margolis L, Clarke WC (eds) Physiological ecology of Pacific Salmon. University of British Columbia Press, Vancouver, pp 1–68

British Columbia Ministry of Environment (BCMoE). 2011. British Columbia seafood industry: year in review 2011. British Columbia Ministry of Environment, Victoria. Available at http://www.env.gov.bc.ca/omfd/reports/Seafood-YIR-2011.pdf

British Columbia Ministry of Environment (BCMoE). 2013. BC Species and Ecosystems Explorer: sockeye salmon. BC Conservation Data Centre Home. Accessed June 4th, 2013. Available online at http://www.env.gov.bc.ca/cdc/

Burgner, R.L. 1980. Some features of ocean migration and timing of Pacific salmon. *In* W.J. McNeil and D.C. Himsworth (eds.). Salmonid ecosystems of the North Pacific. Oregon State University Press, Corvallis, Oregon.

Burgner, R. L.. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). In C. Groot, and L. Margolis, eds. Pacific salmon life histories, pp. 1–117. University of British Columbia Press, Vancouver

Cohen, B.I.. 2010a. Chapter 5 Management of the Fraser River sockeye salmon fishery. *In* The Uncertain Future of Fraser River Sockeye Volume 1: The Sockeye Fishery. Ministry of Public Works and Government Services, Canada.

Cohen, B.I.. 2010b. Chapter 2 The life cycle of Fraser River sockeye salmon. *In* The Uncertain Future of Fraser River Sockeye Volume 1: The Sockeye Fishery. Ministry of Public Works and Government Services, Canada.

Cohen, B.I.. 2010c. Chapter 4 Decline-related evidence. *In* The Uncertain Future of Fraser River Sockeye Volume 2: Causes of the Decline. Ministry of Public Works and Government Services, Canada.

Cohen, B.I.. 2010d. Chapter 5 Findings. *In* The Uncertain Future of Fraser River Sockeye Volume 2: Causes of the Decline. Ministry of Public Works and Government Services, Canada.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2003. COSEWIC assessment and status report on the sockeye salmon *Oncorhynchus nerka* (Cultus population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 57 pp.

Cooke S.J., S.G. Hinch, A.P. Farrell, M.F. Lapointe, S.M.R. Jones, J.S. Macdonald, D.A. Patterson, M.C. Healey, and G.V.D. Kraak. 2004. Abnormal migration timing and high en route mortality of sockeye salmon in the Fraser River, British Columbia. Fisheries 29:22–33.

Crossin G.T., S.G. Hinch, A.P. Farrell, D.G. Higgs, A.G. Lotto, J.D. Oakes, and M.C. Healey. 2004. Energetics and morphology of sockeye salmon: effects of upriver migratory distance and elevation. Journal of Fisheries Biology 65:788–810.

Crossin G.T., S.G. Hinch, S.J. Cooke, D.W. Welch, S.D. Batten, D.A. Patterson, G.V.D. Kraak, J.M. Shrimpton, and A.P. Farrell. 2007. Behaviour and physiology of sockeye salmon homing through coastal waters to natal river. Marine Biology 152:905–918.

Crozier, L.G., A.P. Hendry, P.W. Lawson, T.P. Quinn, N.J. Mantua, J. Battin, R.G. Shaw, and R.B. Huey. 2008. Potential responses to climate change in organisms with complex life histories: evolution and plasticity in Pacific salmon. Evolutionary Applications 2008 (1)252-270.

Gallaugher, P. and L. Wood (eds). 2010. Speaking for the Salmon Proceedings of the Summit on Fraser River Sockeye Salmon: Understanding Stock Declines and Prospects for the Future. Simon Fraser University 199p

Goslin, M. 2011. Sockeye Salmon (*Oncorhynchus nerka*): Supporting documentation and summary for Red List assessments at species and subpopulation levels. International Union for Conservation of Nature and Natural Resources. Available online at http://www.iucnredlist.org/attachments/1052

Healey, M.. 2011. The cumulative impacts of climate change on Fraser River sockeye salmon (*Oncorhynchus nerka*) and implications for management. Canadian Journal of Fisheries and Aquatic Science 68:718-737

Hendry A.P. and O.K. Berg. 1999. Secondary sexual characters, energy use, senescence, and the cost of reproduction in sockeye salmon. Canadian Journal of Zoology 77:1663–1675.

Hendry A.P., Y.E. Morbey, O.K. Berg, and J.K. Wenburg. 2004. Adaptive variation in senescence: reproductive lifespan in a wild population of salmon. Proceedings of the Royal Society of London 271:259–266.

Hodgson, S., and T. P. Quinn. 2002. The timing of adult sockeye salmon migration into fresh water: adaptations by populations to prevailing thermal regimes. Canadian Journal of Zoology 80:542–555.

Hutchinson, B. 2013. Report on B.C. salmon decline short on details, long on maybes. National Post. Available online at http://fullcomment.nationalpost.com/2012/10/31/brian-hutchinson-report-on-b-c-salmon-decline-short-on-details-long-on-maybes/

Hyatt, K. D., M. M. Stockwell, and D. P. Rankin. 2003. Impact and adaptation responses of Okanagan River sockeye salmon (*Oncorhynchus nerka*) to climate variation and change effects during freshwater migration: stock restoration and fisheries management implications. Canadian Water Resources Journal 28:689–713.

Karlstrom, T. N. V., and G. E. Ball (eds). 1969. The Kodiak Island refugium: its geology, flora, and history. Ryerson Press, Toronto.

Killick, S.R. 1955. The chronological order of Fraser River sockeye salmon during migration, spawning and death. International Pacific Salmon Fisheries Communications Bulletin. 7:95 p.

Kinnison M.T., M.J. Unwin, A.P. Hendry, and T.P. Quinn. 2001. Migratory costs and the evolution of egg size and number in introduced and indigenous salmon populations. Evolution 55:1656–1667

Marlowe, S. 2008. Water Governance and First Nations: Syilx water governance. Prepared for Okanagan Water Stewardship Council Workshop 15 May 2008. Available online at http://www.obwb.ca/fileadmin/docs/080515_presentation.pdf

Martins, E.G., S.G. Hinch, S.J. Cooke, D.A. Patterson. 2012. Climate effects on growth, phenology, and survival of sockeye salmon (*Oncorhynchus nerka*): a synthesis of the current state of knowledge and future research directions. Reviews in Fish Biology and Fisheries 22:887-914.

Miller, J. 1992. Earthmaker: Tribal Stories from Native North America. *In* Salmon. New York: Perigee Books, pp 93-98.

Miller, J. Date unkown. The Life Giving Gift. Native Americans of the Pacific Northwest, 4. Available online at http://content.lib.washington.edu/aipnw/miller2.html#scanned.

National Oceanic and Atmospheric Administration (NOAA). 2013. Sockeye Salmon (*Oncorhynchus nerka*). Office of Protected Resources. Available online at http://www.nmfs.noaa.gov/pr/species/fish/sockeyesalmon.htm

Nelson, J. S.. 1968. Distribution and nomenclature of North American kokanee, *Oncorhynchus nerka*. Journal of the Fisheries Research Board, Canada 25:409–414.

Nelson, R. J., C. C. Wood, G. Cooper, C. Smith, and B. Koop. 2003. Population structure of sockeye salmon of the central coast of British Columbia: implications for recovery planning. North American Journal of Fisheries Management 23:703–720.

Newell, J.C., K.L. Fresh, and T.P. Quinn. 2007. Arrival Patterns and Movements of Adult Sockeye Salmon in Lake Washington: Implications for Management of an Urban Fishery. North American Journal of Fisheries Management 27:908-917.

Pacific Fishery Management Council (PFMC). 2013. Who We Are and What We Do. Retrieved online June 10th, 2013. Available online at http://www.pcouncil.org/

Pacific Fisheries Resource Conservation Council (PFRCC). 2013. Salmon Strongholds. Retrieved June 8th, 2013. Available online at http://www.fish.bc.ca/salmon-strongholds

Pacific Salmon Commission (PSC). 2013. The Pacific Salmon Treaty – 1985. Available online at http://www.psc.org/about_treaty.htm

Pacific Salmon Commission (PSC). 2008. Letter of Transmittal 21st of May 2008. Available online at http://www.psc.org/pubs/AnnexIV/LetterOfTransmittal21May08.pdf

Quinn, T.P.. 2005a. Chapter 3: Migrations in Coastal and Estuarine Waters. *In* The behavior and ecology of Pacific salmon and trout. Univ. Press, Seattle. 320 p.

Quinn, T.P.. 2005b. Chapter 12: Downstream Migration: To Sean or Not to Sea. *In* The behavior and ecology of Pacific salmon and trout. Univ. Press, Seattle. 320 p.

Quinn, T. P., and D. J. Adams. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon.Ecology77:1151–1162.

Quinn, T. P., M. J. Unwin, and M. T. Kinnisona. 2000. Evolution of temporal isolation in the wild: genetic divergence in timing of migration and breeding by introduced Chinook salmon populations. Evolution 54:1372–1385.

Quinn, T. P., M. T. Kinnison, and M. J. Unwin. 2001. Evolution of Chinook salmon (*Oncorhynchus tshawytscha*) populations in New Zealand: pattern, rate, and process. Genetica 112-113:493–513.

Reed, T.E., G. Martinek, and T.P. Quinn. 2010. Lake-specific variation in growth, migration timing and survival of juvenile sockeye salmon *Oncorhynchus nerka*: separating environmental from genetic influences. Journal of Fish Biology 77:692-705.

Schindler D.E., R. Hilborn, B. Chasco, C.P. Boatright, T.P. Quinn, L.A. Rogers, and M.S. Webster . 2010. Population diversity and the portfolio effect in an exploited population. Nature 465:609–613. doi:10.1038/nature09060

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2005. Changes toward earlier streamflow timing across western North American Journal of Climate 18:1136–1155.

Ueda, H. 2011. Physiological mechanism of homing migration in Pacific salmon from behavioural to molecular biological approaches. General and Comparative Endocrinology 170:222-232.

United States Fish & Wildlife Service (USFWS). 2013. Species Profile: Sockeye salmon. Accessed June 8th, 2013. Available online at http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=E06Y

Warner, B. C., R. W. Mathews, and J. J. Clague. 1982. Icefree conditions on the Queen Charlotte Islands, British Columbia, at the height of the late Wisconsin glaciation. Science 218:675–677.

Washington Department of Fish & Wildlife (WDFW). 2013. Conservation : Washington State Species of Concern Lists for sockeye salmon. Retrieved June 4th, 2013. Available online at http://wdfw.wa.gov/conservation/endangered/lists/search.php?searchby=simple&search=sockeye&orderby=AnimalType%2CCommonName&x=-987&y=-422

Williams, A. 2007. The Pacific Salmon Treaty: A Historical Analysis and Prescription for the Future. Journal of Environmental Law Litigation 22:153–195

Wood, C.C., J.W. Bickham, R.J. Nelson, C.J. Foote, and J.C. Patton. 2008. Recurrent evolution of life history ecotypes in sockeye salmon: implications for conservation and future evolution. Evolutionary Applications 1(2008):207-221.