SALMONID HABITAT LOSS

AND HATCHERY DEPENDENCE:

A CASE STUDY OF CHAMBERS CREEK, WASHINGTON

by

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ABSTRACT

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Wild Pacific Salmonid (*Oncorhynchus spp.*) populations are declining, and we have the responsibility to restore and protect remaining stocks. Scientific research has shown habitat loss, over-harvest, hydropower, and hatcheries to be the leading sources of salmonid decline. The research question of this document focuses on the issue of habitat loss and hatchery dependence on a small creek in University Place, WA. Salmonid ecology was explored to better understand fundamental life requirements and key habitat features that salmonids require. Cultural, biological, and physical descriptions of Chambers Creek provided background information on the research area. Habitat loss was approached from a historical perspective analyzing policy that has contributed to anthropogenic changes in watersheds across the western United States. Management strategies of mitigation, focusing on fish passage at dam sites and salmon hatcheries, along with restoration, focusing on reestablishing ecosystem services were examined for their impacts on fish and potential implementation on Chambers Creek. Interviews with local tribal members, biologists, and elected officials rounded out the research. Archival information as well as qualitative data from interviews elucidated the history of salmonids on Chambers Creek, a legacy of industrial resource extraction, and critical habitat areas that require restoration.

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Sarah Kyle, Jude Sebastian, and Callum River, I love you.

Mom, Dad, Uncle John, Pop-pop, and Ned Deaver—thank you for taking me fishing.

Wild Geese

You do not have to be good.
You do not have to walk on your knees
For a hundred miles through the desert, repenting.
You only have to let the soft animal of your body
love what it loves.
Tell me about your despair, yours, and I will tell you mine.
Meanwhile the world goes on.
Meanwhile the sun and the clear pebbles of the rain
are moving across the landscapes,
over the prairies and the deep trees,
the mountains and the rivers.
Meanwhile the wild geese, high in the clean blue air,
are heading home again.
Whoever you are, no matter how lonely,
the world offers itself to your imagination,
calls to you like the wild geese, harsh and exciting --
over and over announcing your place
in the family of things.

Mary Oliver

Chapter 1: Introduction

Pacific salmon support life and culture. Icons of the Pacific Northwest, salmon represent wild natural beauty, survival, and life's unity (Easwaran, 2007). Pacific salmon possess an extraordinary life history: rearing in freshwater, migrating to saltwater to mature, and journeying back to freshwater to spawn, die, and complete their cycle. Along this pilgrimage, salmon contribute to the well-being of a multitude of communities. By transporting and making available ocean derived nutrients, salmon are essential to the food web of the Cascadia region. In fact, the effects of salmon can be traced through trophic levels ranging from macro invertebrates to mega fauna, giving salmon distinction as a Pacific Northwest keystone species (Groot, 2010).

Salmon also provide spiritual significance. Stretching the Pacific arc from Korea to California, indigenous creation histories center around the Pacific salmon and the sacred cycle of life (Roche and McHutchison, 1998). Furthermore, salmon are an economic good. In 2006, the non-tribal commercial fishery in Washington State generated $148.3 million in personal income, along with 3,520 jobs (Coalition and Radtke, 2011). Adding to this, Tribal commercial fisheries grossed $50 million in 2006 (TCW Economics, 2008). Just as important as commercial fisheries are the recreational anglers who spend over $1 billion annually on fishing gear, licenses, food, lodging and fuel in Washington State (Why Save Salmon? | Long Live The Kings, 2015.). Salmon fishing is big business in the Pacific Northwest, and tribal, recreational, and commercial fishermen rely on the opportunity to catch salmon to survive.

Despite their perceived abundance, salmon are in peril of going extinct. Habitat loss, in particular, has damaged salmon stocks. It is important to note that historic Native cultural practices have had little impact on salmon and their habitat. Cultural mores and spiritual beliefs reinforced respect of salmon and restraint of their harvest. Fishing practices and techniques such as fish wheels, weirs, and reef nets resulted in minimal, short term habitat loss, if any (Montgomery, 2004). However, significant land modification transpired with the influx of white settlers to the West. Dams have been used to harness the power of rivers for industry and agriculture. Farmers diked, drained, and straightened waterways. Vast timberlands have been destroyed to supply a booming forestry economy. Thus, while the wealth of natural resources powered the creation of today's modern Pacific Northwest, the salmon have fallen victim to the conquest of the West, fatally wounded by habitat loss.

Several strategies have been put in place to mitigate the loss of salmon habitat. Where dams block returning adult salmon, engineers have manufactured elaborate fish passage systems, including ladders and lifts. In concert, fish hatcheries now generate salmon to replace stocks extirpated or terminally impacted by reduced habitat. Additionally, restoration ecologists are working to return ecosystem services to rivers impacted by anthropogenic changes. Restoration techniques include restoring connectivity, reestablishing natural flow regimes, managing erosion and sediment transfer, promoting riparian functions, and the use of in-stream modifications such as introducing gravel and woody debris. The goals of these efforts include rehabilitating salmon habitat, stimulating ecosystem services, and encouraging the survival of wild salmon.

Intricate environmental problems, such as salmon habitat loss, require an interdisciplinary approach. Chambers Creek, WA, will serve as a case study to better understand the larger Cascadia-wide problem. To better understand the issue, interviews with key informants will be combined with scientific technical reports. Grasping the social dynamics of salmon habitat loss, provided by the key informants, is meaningful in the recovery of Pacific salmon. The value of this approach is best understood in Aldo Leopold's "land ethic," where the sense of community expands to include nature (Leopold, 1986).

The remainder of this thesis will be devoted to elucidating the drivers of salmon habitat loss and hatcheries. Research methodology will be discussed, and then a brief introduction to salmon ecology will be provided. Next, Chambers Creek, WA, will be examined as a contemporary example of this issue. Then, salmon habitat loss will be illuminated in detail. After that, mitigation and restoration techniques will be explained, leading into an interpretation of key informant interviews. Finally, a conclusion will be provided reviewing the research and determining what's next.

Chapter 2: Methodology

The research for this thesis consisted of five main parts: 1. A historical review of anthropogenic impacts on salmonid habitat in the Pacific Northwest, with an emphasis on post-European settlement and technology; 2. A case study of Chambers Creek, WA, as an analog for the issue of salmonid habitat loss and hatchery dependence in the Pacific Northwest; 3. A review of mitigation techniques currently used to combat reduction in wild areas used by salmonids, concentrating on assisted migration and hatcheries, 4. A summary of restoration techniques used to promote wild salmon, focusing on reestablishing ecosystem services; and 5. Interviews with key informants to gain an informed perspective on this issue.

The history of anthropogenic impacts on salmonid habitat, Chapters 4,5, and mitigation techniques, such as fishways and hatcheries, Chapter 6, emerged from reading books on the subject, including *First Fish, First People: Salmon Tales of the North Pacific Rim* by Roche and McHutchinson, Joseph Taylor's, *Making Salmon: An Environmental History of the Northwest Fisheries Crisis*, *Mountain In The Clouds: A Search for the Wild Salmon* by Bruce Brown, and *Four Fish: The Future of the Last Wild Food* by Paul Greenberg. From scientific journals, such as *Conservation Biology*, *Restoration Ecology*, and *Fisheries Science*, came analyses of fisheries management with an emphasis on habitat degradation, biological impacts of hatcheries, and human assistance.

State and county documents, such as The Washington Department of Fisheries (WDFW) annual report for 1949, and Pierce County, *Public Works and Utilities Sewer and Water Utility: Chambers Creek Dam Study Final Report* provided critical historical and policy information on Chambers Creek, WA. The WDFW report documented species-specific runs in Chamber Creeks, WA. Adding to this, Pierce Co. provided a comprehensive review for potential restoration on Chambers Creek, WA focusing on: stakeholders, water rights, dam ownership, regulatory requirements, and environmental and infrastructure issues. Archived articles from *Salmon and Steelhead Journal, National Geographic, The Tacoma News Tribune and* other magazines and online newspapers depicted events in the time they occurred. Physical observations of migrating salmon in Chambers Creek, WA, during fall and winter of 2013 and 2014 provided inspiration to endeavor into salmon restoration research. Additionally, observation of salmon on the creek yielded evidence of delayed migration caused by dams, as well as increased predation associated with hatchery management.

Interview questions arose from historic review of salmonid habitat loss and hatcheries, coupled with onsite observations of Chambers Creek, WA. Conversational, informal interviews were conducted, with the goal of remaining as unbiased as possible, with a focus on being open and adaptable to the interviewee's nature and priorities (Kvale and Brinkmann, 2008). The interviews focused on obtaining a narrative of each participant's experiences. Opening the sessions, all participants were asked about salmonid habitat loss and hatcheries. After this initial question, the interviewees guided the conversation; interview questions evolved as each interview progressed. For example, if a participant's narrative focused on Federal recognition of tribal status, questions revolved around tribal membership and how it has impacted the tribe's ability to protect and utilize salmonids and salmonid habitat. This style of interview allowed for each individual to express how his or her story is relevant to the dilemma of Pacific salmonid habitat loss.

Interview participants fell into in three major groups: 1. Environmentalist, 2. Tribal voices, and 3. Elected Officials. Each group was selected for their involvement and knowledge of the subject. For example, environmentalists were chosen from non-profits, such as the Wild Fish Conservancy and the Wild Salmon Center. Additional interviewee's came out of conversations about the thesis topic, using a snowball sampling or chain referral sampling technique.

Chapter 3: Salmon Ecology

Pacific salmon (genus *Oncorhynchus*) are a unique and important key stone species in the Pacific Northwest. The range of Pacific salmon arcs from San Francisco Bay, in California, up the U.S. Canadian coast, and down again into coastal regions of Russia, Japan, and Korea. Salmon are not monolithic in life their history, each reproducing population evolves and adapts to environmental factors found on their home rivers. The sections that follow outline a generalized life cycle and key features that make salmon unique. After discussing this, each species will be explored in more detail.

Table 2. Common and scientific names of Pacific salmon (genus Oncorhynchus)

Common Name	**Scientific Name**
King Salmon, Chinook, Tyee	*O. tshawytscha*
Coho, Silver,	*O. kisutch*
Sockeye, Red, Blueback	*O. nerka*
Pink, Humpy, Humpback	*O. gorbuscha*
Chum, Dog, Calico	*O. keta*
Steelhead Trout, Trout Salmon	*O. mykiss*

Key Life History Factors

Three key factors characterize Pacific salmon: 1. Anadromy, 2. Homing, and 3. Semelparity. Anadromy pertains to the ability of salmon to navigate between salt and fresh water ecosystems. Salmon spawn in freshwater, inhabited by fewer predators than salt water. Next, salmon migrate to saltwater to reach sexual maturity; to take advantage of the superior energy content and nutrients availability in oceans compared to streams.

"Homing" reflects the salmon's return to their natal streams. Like a key to a lock, salmon have evolved to fit their home waters. Once they have reached significant size and sexual maturity, salmon migrate from the salt back to the freshwater stream where they were born. Salmon home because they are morphologically adapted to the specific conditions found within their natal streams. This physical adaptation minimizes the cost of movement, allowing salmon to spend more energy reproducing, which they do until death (Westley et al, 2013).

Death after reproduction is known as semelparity. This allows for millions of kilograms of ocean-derived nutrients in the form of salmon flesh to enrich nutrient-poor freshwater ecosystems (Groot, 2010). Not only does this pulse of nutrients provide insurance for the survival of the next generation of salmon, but it provides energy across trophic levels from macro invertebrates to mega fauna. The life history strategies of salmon, specifically anadromy, homing, and semelparity make them unique, and their role in the ecosystem as providers of ocean-derived nutrients makes them keystone species in the Pacific Northwest.

Generalized Life History

As indicated above, salmon begin their lives in freshwater systems as their parents spawn on gravel beds in creeks, rivers, streams, lakes, and wetlands. Female salmon dig nests, known as redds, with broad, undulating strokes of their tails. Mouths agape and bodies quivering, females and males pair up. Females deposit eggs and males coat the eggs and gravel nest with their sperm. Most salmon spawn in the fall; biologists associate this behavior to be timed with optimal in river flow and temperature regimes best suited for egg survival (Quinn, 2011). Adolescent salmon are categorized in four stages: 1. Egg, 2. Alevin, 3. Fry/Parr, and 4. Smolt.

Fertilized salmon eggs are translucent pink orbs about the size of a pencil eraser. As they transform from single-cells into complex organisms, they require clean, cool, oxygenated water for development and survival. Variation in development among fertilized eggs is a function of temperature and dissolved oxygen: metabolism and development increase with temperature. For example, fertilized eggs in water 5 degrees Celsius took 87 days to hatch compared to eggs in 14 degree Celsius water that hatched in 32 days (Quinn 2011).

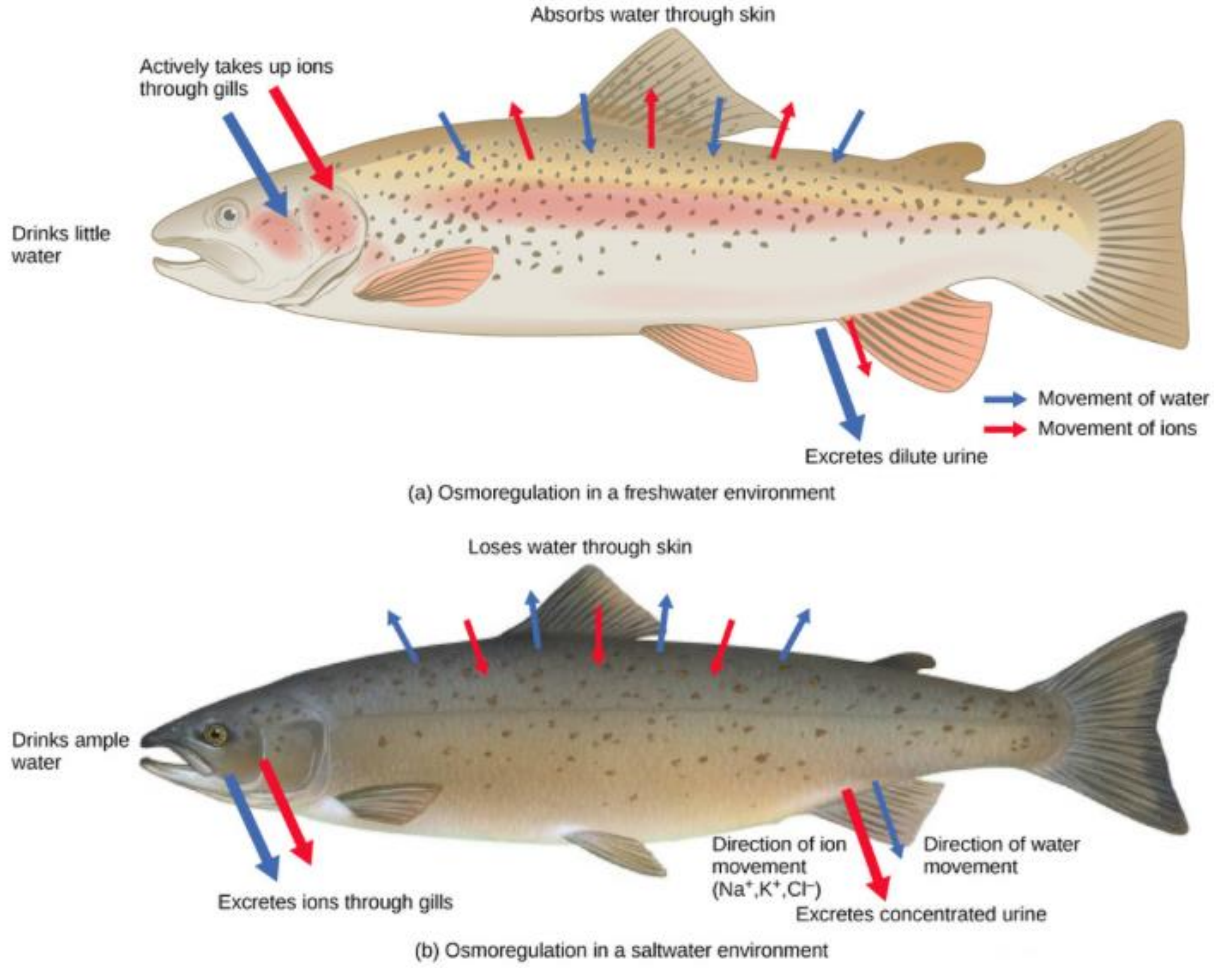
Breaking free from their shell, salmon can swim with their tail and take their first breaths through newly formed gills. In this chapter of life, salmon are referred to as alevin. For protection, alevin move down deeper into the gravel once they have hatched. Equipped with a lunch box in the form of their yolk sac, alevin develop and survive in the substrate of the stream. Physically, alevin are ~ two and a half centimeters long, transparent, have large eyeballs, and large bulging yolk sacs that resemble strawberry jam in color.

Once they have absorbed their yolk sac and emerged from gravel salmon become known as fry. Fry shelter behind fallen logs and in deep pools, and feed on organic matter, such as benthic macroinvertebrates. As they grow in size and strength, fry begin to develop dark vertical lines, running from their back to their belly, to camouflage them from hungry predators and unsuspecting prey. . Both the marks on their bellies and the salmon at this life stage are now called parr.

In the final juvenile freshwater phase, salmon begin their migration to salt water. At this stage, most salmon have grown significantly since emerging from gravel, become adept swimmers, and veracious predators. As the call of the ocean intensifies, salmon lose their prominent parr marks and transform into what is commonly known as “silver bullets,” and scientifically known as smolts. Journeying down river from headwater streams, salmon now start staging for smoltification in estuaries as they prepare for the open ocean. Morphologically, salmon elongate, their sides become silvery, their bellies become white, their backs turn a dark gray, and teeth develop on gums and tongue. This color scheme helps to conceal salmon in marine environments. Adding to this, salmon must adapt to the acute change in salinity between fresh and saltwater ecosystems.

Dehydration is the major obstacle salmon must overcome when transitioning from rivers to the sea, because salt in the ocean draws water from the cells of a fish. To adjust, salmon drink salt water, replacing the water lost in their cells Figure 1. They excrete surplus salt ions through their gills and urine, achieving osmoregulation (Dickhoff et al., 1997). Once they enter the ocean, salmon are referred to as juvenile adults. The remainder of their lives will be spent foraging ocean waters and gaining weight that will be used on the long journey back to their natal streams, where they will spawn and die. In fact, once adult salmon enter freshwater, they stop eating, and devote every moment they have to producing the next generation. This is an abbreviated life cycle of most Pacific salmon. Next, distinguishing attributes of each species of Pacific salmon listed in Table 1 will briefly be reviewed.

Figure 1. Osmoregulation (a) freshwater (b) salt-water



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Chinook Salmon (*Oncorhynchus tshawytscha*)

Chinook are the largest of all Pacific salmon, growing up to 45 kg, or 99 lbs. They generally spend one year in fresh water and two-five years in salt water. Life histories of Chinook can be described in two groups: 1. Stream type, and 2. Ocean type (Gilbert, 1913). Stream type Chinook are characterized by long freshwater residency at the juvenile stage. Adding to this, returning adults enter fresh water months before spawning. Furthermore, stream type Chinook spawn in headwater tributaries, traveling long distances to the interior of the country. Making extended upriver migrations without eating, stream type Chinook survive on their augmented fat reserves. Entering fresh water to spawn in the early spring and summer months, this subspecies is commonly referred to as Spring Chinook.

In comparison, ocean type Chinook can be described by a short freshwater residency as juveniles. Moreover, returning adults enter fresh water in late summer and early fall and spawn shortly after arrival. These fish are commonly referred to as Fall Chinook. Variation in life history allows Chinook to remain resilient in areas of dynamic and significant environmental changes, or stochastic perturbations including glacial encroachment and retreat, landslides, earthquakes, volcanic eruption, and major flood events (Stearns, 1976).

Chinook are morphologically distinct from other salmon species. In the marine phase of their lives Chinook can be identified by dark mouths with black gums, large sharp teeth, large spots on their back, and spots on both tail lobes. During the spawning phase, Chinook display all features listed above, and their silver color changes to a dark olive-brown.

Coho Salmon (*Oncorhynchu kisutch*)

Coho salmon, commonly known as silvers, are smaller than Chinook and chum, but larger than pink and sockeye at an average weight of eight pounds, or three kilograms (Bell, 1986). In the marine phase, coho salmon have light colored mouths with white gum lines, medium-sized sharp teeth, spots on the upper lobe of their tail, and a wide caudal peduncle (tail area). Most coho adults return to spawn at three years old, having spent one year in fresh water and two years in salt water (Godfrey, 1965). Coho spawn in coastal streams and small tributaries. After entering fresh water to spawn, coho are distinguished by black to olive colored heads and crimson to maroon colored bodies and male snouts develop into pronounced hooks.

Sockeye Salmon (*Oncorhynchu nerka*)

Sockeye salmon average around six pounds or two kilograms, spawn in streams and lakes and spend one-three years in fresh water, and one-four years in the ocean (Bell, 1986). Some sockeye populations have residualized and spend their entire life in freshwater, isolated by natural events (Ricker, 1940). These populations are referred to as kokanee. Populations migrating to the ocean do not possess spots, are nearly toothless, and have large smooth eyes, and white mouths with white gum lines. Developing contrasting colors during the mating season, sockeye develop brilliant red bodies with green heads. Additionally, males develop a noticeable hump in their back and large teeth.

Pink Salmon (*Oncorhynchu gorbuscha*)

Pink salmon are the smallest out of the group being profiled, averaging four pounds, or one kilogram. Found in the lower reaches of the river, pink salmon spawn in tributaries and the main stem. As soon as pink salmon fry hatch, they head toward the ocean, and have little to no freshwater residency time. Spending a year and half in the ocean, pinks have the fastest growth rate of all salmon. In the ocean, pinks have white mouths with black gums, no teeth, large black spots on their back, and very small scales. In the state of Washington, these fish return to spawn every odd-numbered year. Even-numbered year spawners can be found across the North Pacific; however odd-numbered year stocks dominate. Biologists' theories range from changing ocean conditions, fishing pressure, and genetics to explain the dominance of odd year pink runs (Irvine et al., 2014). During the spawning phase pink salmon turn a brown-green color, and the spots on their backs become oblong. Additionally, males produce great humps on their backs, earning the common name of humpy.

Chum Salmon (*Oncorhynchu keta*)

Chum salmon average around eight pounds or three kilograms, and also spawn in the lower reaches of coastal rivers and streams. In the ocean phase of their life, Chum can be identified by a white tip on their anal fin, vertical bars on their body (although faint on bright fish), no spots on tail or back, well-developed teeth, and a white gum line set in a white mouth. Chum fry spend little time in freshwater, heading to the ocean immediately after hatching. Adult chum salmon spend about two and a half to three years in the ocean before returning to spawn (Groot, 2010). Chum salmon trade their silver sides for a green and black combination during spawning. Females display green bodies with a solid black stripe along their lateral lines, while males develop a calico pattern of green, purple, and black. Subordinate males have been documented changing their color patterns to mimic females. This strategy allows the less dominant chum to gain access and spawn with females protected by alpha males (Arnes and Schroder, 1995).

Steelhead Trout (*Oncorhynchu mykiss*)

Steelhead are the state fish of Washington and among the most endangered. Steelhead trout got their name from early white fisherman who noticed it took several blows to the head to kill steelhead as compared to other salmon (Salmon and Steelhead Journal, 2013). Steelhead average around eight pounds, or three kilograms, have spots all over their body, including their dorsal fin, have a pronounced to muted rainbow coloring, and are anadromous forms of rainbow trout. Spawning throughout river systems, steelhead target small streams and tributaries for their redds. What sets steelhead apart from other salmon is that they survive after spawning; post-spawn steelhead are referred to as kelts.

Chapter 4: Chambers Creek

Introduction

This section discusses the Chambers-Clover Watershed (CCCW), and includes descriptions of the physical watershed, biological features, and human culture found in and along its banks. Chambers-Clover Creek Watershed is a key feature of Water Resource Inventory Area (WRIA) 12, located in central Pierce County, WA (Washington State Conservation Commission, 2002). WRIA 12 is triangular in shape and comprised of CCCW, Sequalitchew Creek, and Puget Creek basins (Washington Department of Ecology, 2013). Geographically, the Puyallup River, demarcates its northeast boundary, and the Nisqually River, marks its southwest boundary, framing WRIA 12. Foothills of the Cascade Mountain Range establish WRIA 12's southern and eastern limits, while the Puget Sound denotes WRIA 12's northwestern borderline (Savoca et al., 2010).

Within this area lie the cities of Dupont, Fircrest, Lakewood, Ruston, Steilacoom, Tacoma, and University Place; the unincorporated communities of Elk Plain, Fredrickson, Midland, Spanaway, and Parkland; and one military reservation: Joint Base Lewis McChord (JBLM) see Figure 2.

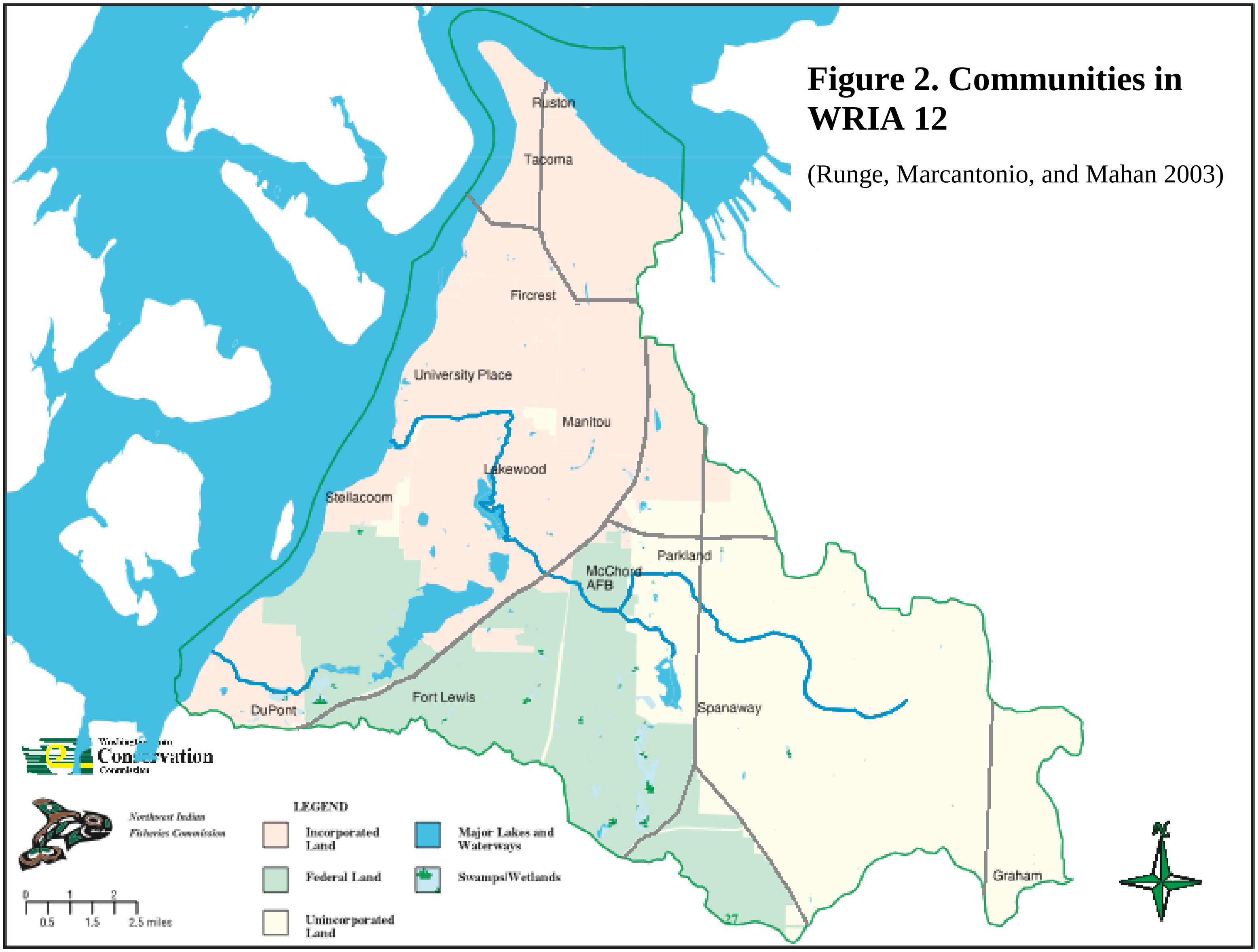


Figure 2. Communities in WRIA 12

(Runge, Marcantonio, and Mahan 2003)

Physical Description

CCCW is found in the Puget Sound lowlands; this distinct physiographic area is characterized by wide-ranging low-lying land flanked by the Cascade Mountains to the east and the Olympic Mountains to the west (Lasmanis, 1991). The topography in this region, shaped by the Cordilleran ice sheet, is typically flat, with elevations ranging from sea level to heights of 600 feet (PCPWU 1996).

Flowing 18 miles through extremely altered land, CCCW reaches the south Puget Sound one mile north of the town Steilacoom. Groundwater runoff and natural springs produce the headwaters of CCCW. The area has a temperate marine climate, with warm, dry summers and cool, wet winters. The Pacific Ocean and the Puget Sound moderate temperatures with a mean monthly average (1971-2000) ranging from approximately 39 Fahrenheit in January to 64 Fahrenheit in August (National Oceanic and Atmospheric Administration, 2007). As a rain dependent system in the PNW, CCCW displays decreasing flows during drought periods, during the months of May to September, and increased flow during the wet season, from October to April. Visually explaining this are two hydrographs from United States Geologic Survey (USGS). Figure 3 presents 7 years of data, detailing the discharge of Chambers Creek in cubic feet per second and Figure 4 shows one year of height in feet for Chambers Creek.

Figure 3. Discharge of Chambers Creek in cubic feet per second

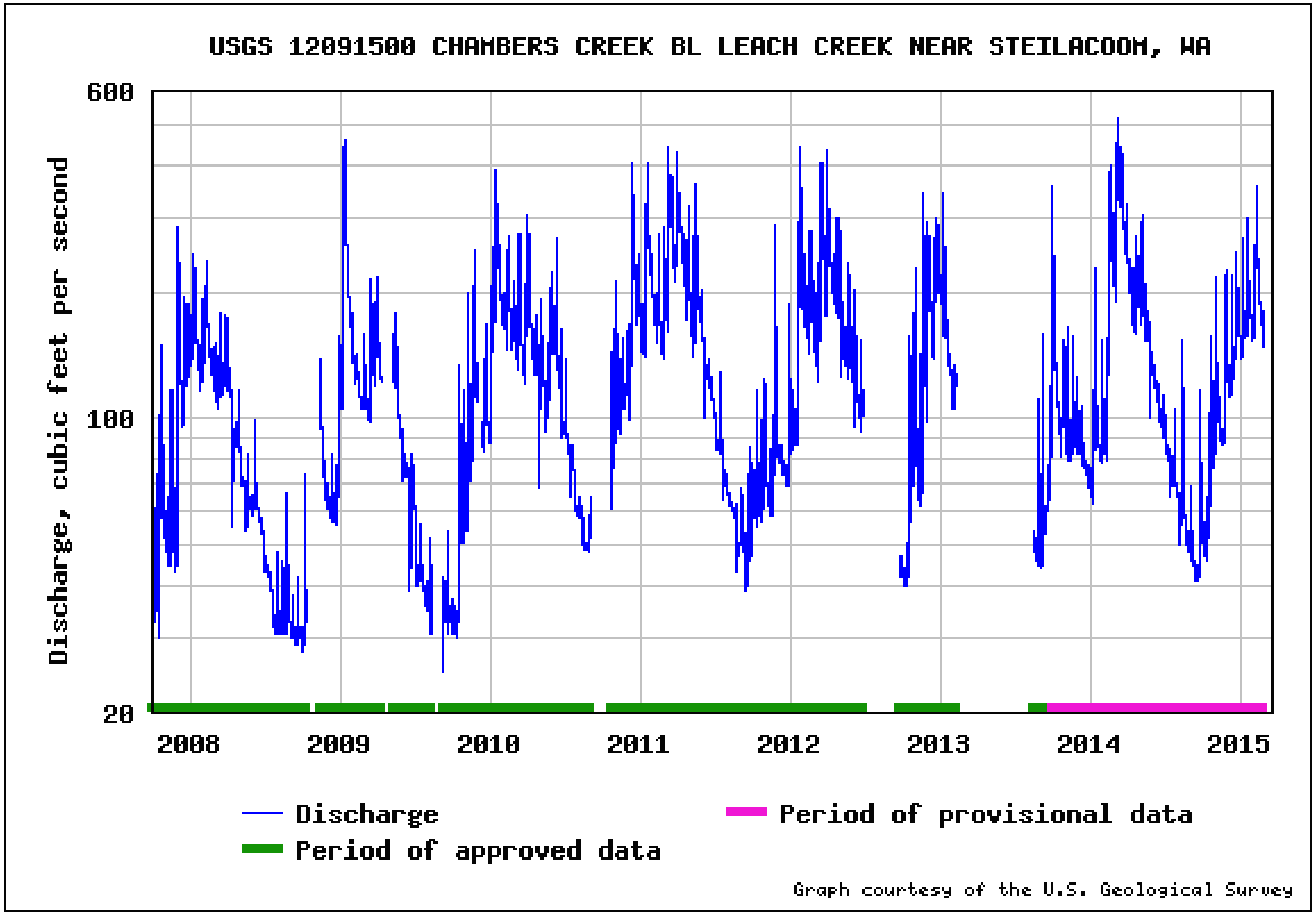
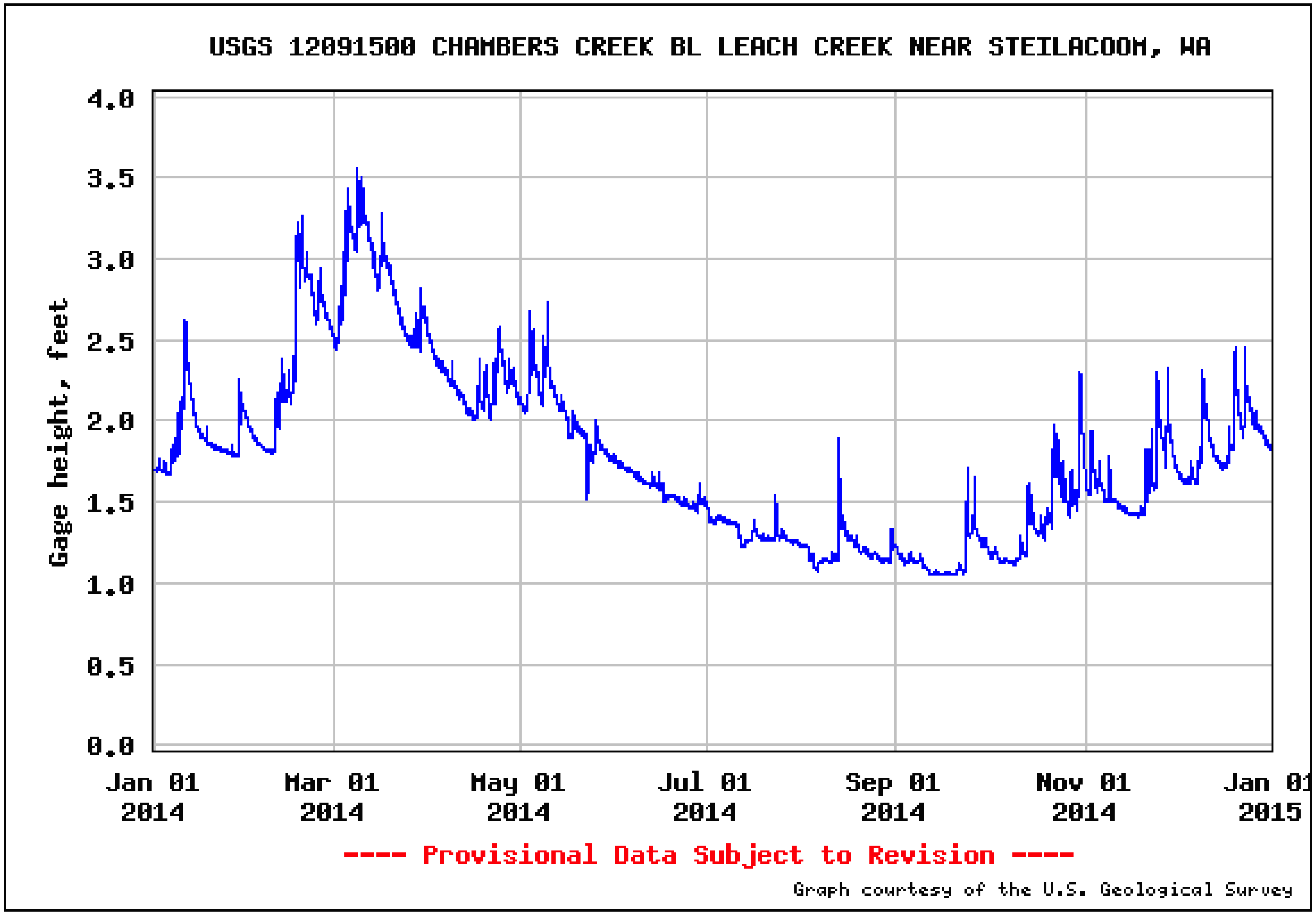
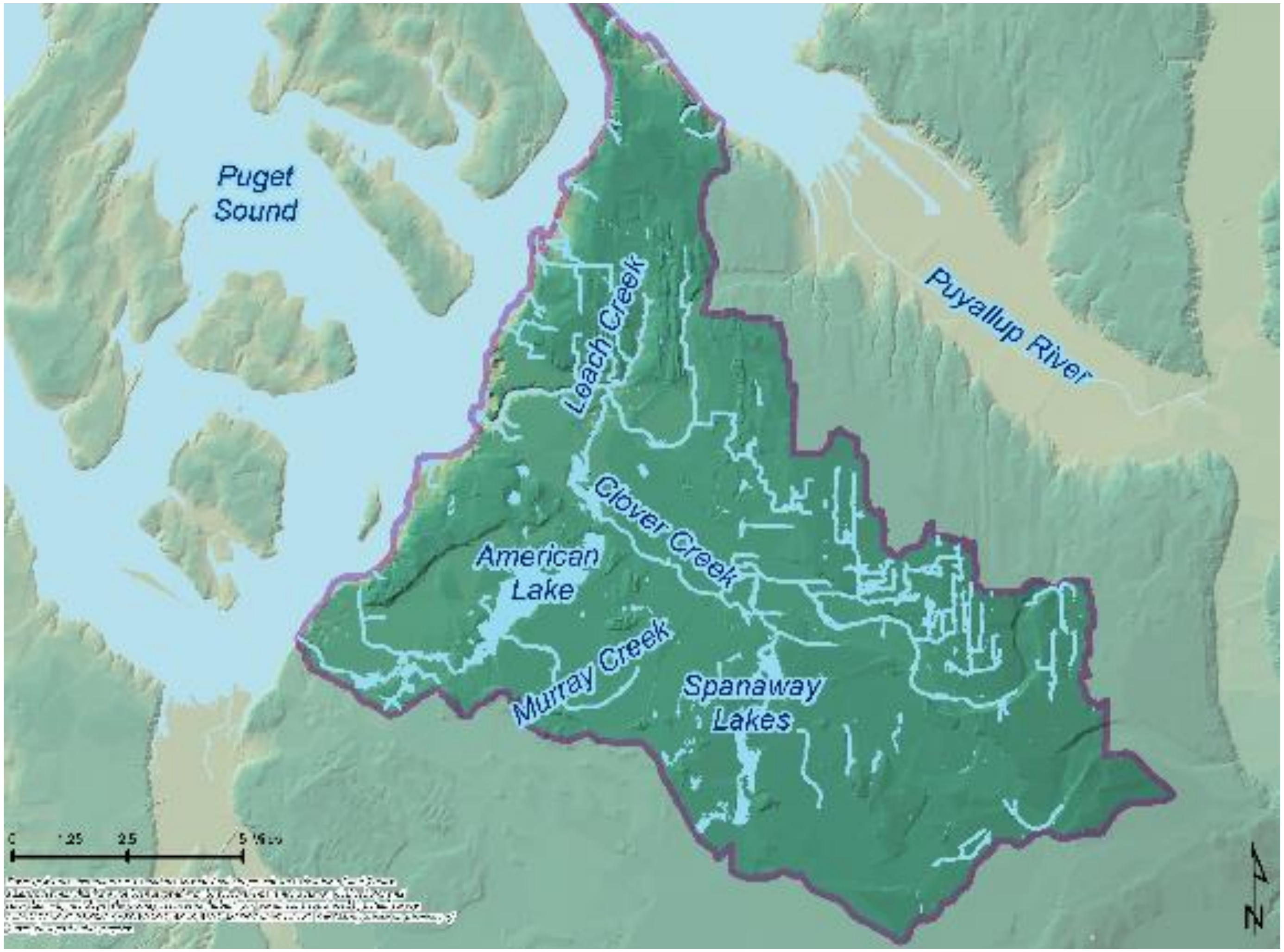


Figure 4. Height in feet for Chambers Creek



Clover Creek is the highest basin in the CCCW system. Meandering through the towns of Spanaway and Parkland before carving across McChord Air Field, and the City of Lakewood's business district, Clover Creek enters Lake Steilacoom. On the east side of JBLM, the north fork of Clover Creek fuses with the mainstream; this section runs 3.2 miles through the town of Parkland and is fed by seasonal surface runoff. Marshes and spring water bring into being Spanaway Creek, a tributary of Clover Creek. Outflowing north from Steilacoom Lake, Chambers Creek spills through the city of Lakewood and abruptly turns west in the city of University Place (U.P.). Kobayashi Park in U.P. marks the confluence of Flett Creek, Leach Creek, and Chambers Creek. A steep ravine ushers Chambers Creek towards the Puget Sound; mixing of CCCW freshwater and Puget Sound salt water creates Chambers Creek tidal estuary, see Figure 5.

Figure 5. Chambers Clover-Creek Watershed Map



http://www.co.pierce.wa.us/ArchiveCenter/ViewFile/Item/589

Biological Description

Biologically, CCCW contains a diverse range of habitat, fauna, and flora representative of the PNW. Habitat in CCCW is comprised of meadows, forest, lakes, ponds, streams, creeks, and an estuary. Each habitat type has been impacted by contemporary human development; this topic, along with management efforts, will be discussed in detail in the following sections. The United States Fish and Wildlife Service (USFW) completed an assessment of biodiversity in the Puget Sound (U.S. Fish and Wildlife Service, 2013). Despite not being mentioned specifically, the fauna of CCCW is similar to the surrounding watersheds of the Puyallup and Nisqually. Songbirds, waterfowl, raptors, and shorebirds use the area, along with mammalian species, such as coyote (*Canis latrans*), deer (*Odocoileus hemionus columbianus*), beaver (*Castor canadensis*), river otter (*Lontra canadensis*), and mink (*Neovison vison*). Adding to this list are amphibians and reptiles, including rough-skinned newts (*Taricha granulosa*), garter snakes (*Thamnophis sirtalis*) , and Pacific tree frogs (*Pseudacris regilla*). Furthermore, several fish species are found in the watershed. Historic records indicate that Chinook (*Oncorhynchus tshawytscha*), coho (*Oncorhynchus kisutch*), chum (*Oncorhynchus keta*), pink (*Oncorhynchus gorbuscha*), sockeye (*Oncorhynchus nerka*) and steelhead trout (*Oncorhynchus mykiss*) formerly spawned within CCCW (Nadeau, 1984, Runge, Marcantonio, and Mahan, 2003, Savoca et al., 2010, Tobiason, 2003). Additionally, forage fish, key prey items of larger predatory fish, occupy near shore marine and estuarine habitat of CCCW. Sand lance (*Ammodytes hexapterus*), surf smelt (*Hypomesus pretiosus*), and Pacific herring (*Clupea pallasii)*, round out this group, and have been documented spawning in the South Puget Sound near Chambers Creek estuary (Penttila, 2007). The riparian areas along CCCW are made up of Western red cedar

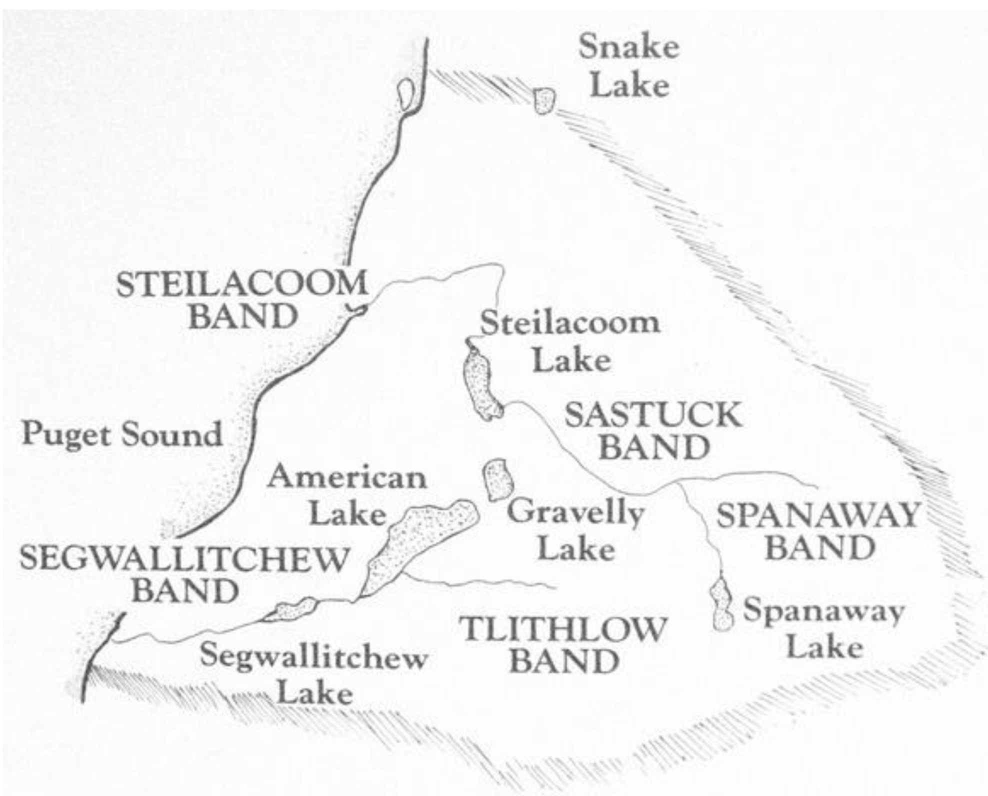
(*Thuja plicata*), Douglas fir (*Pseudotsuga menziesiii),* Indian plum (*Oemleria cerasiformis*), Oregon grape (*Mahonia nervosa*), red elderberry (*Sambucus racemosa*), and bracken fern (*Pteridium aqilinum*) (Clothier et al., 2003).

Cultural Description

Many nations have lived and lay claim to this area along the Puget Sound because of its beauty and rich natural resources. Steilacoom Indians, Coast Salish native peoples, lived in and around CCCW for thousands of years. Prior to white settlement, around five bands comprising about 600 Steilacoom inhabited the area, see Figure 6.

Figure 6. Steilacoom Nation Map

http://steilacoomtribe.blogspot.com/2009/01/history.html



Steilacoom is a native word that roughly translates to "native pink area" its meaning is derived from the small-flowered woodland star (*Lythophragma parviflorum*), a central feature of the watershed. The term became synonymous with the people of the area and the present day town (Ward, 2007). The Steilacoom band lived along the mouth of Chambers Creek, near the present-day town of Steilacoom. The Sastuck Band resided among three sites along Clover Creek, which flows through the towns of Spanaway and Parkland, as well as through Joint Base Lewis McChord. The Spanaway band subsisted on the banks of Spanaway Lake, located on the east side of McChord Field in the town of Spanaway. The Tlithlow presided over Murray Creek, a tributary of American Lake. Murray Creek, originates in the heart of Joint Base Lewis McChord, east of Madigan Army Medical Center. And the Segwallitchew existed on Segwallithchew Creek, which flows west through Joint Base Lewis McChord and the town of Dupont before reaching the Puget Sound.

The Hudson Bay Company arrived on the shores of Chambers Creek in the year 1832, establishing the Puget Sound Agricultural Company (PSAC). Recruiting and permanently establishing British subjects in the Oregon Country was PSAC's focus (Pierce County 2014). This early settlement evolved into Fort Steilacoom, which became a U.S. Army post in 1846, commissioned with establishing order after the creation of the United States Canadian border. Four years later gristmills were built and commercial timber harvest began along Chambers Creek (Pierce County, 2014). Washington became a state in 1889 and one year later the Pacific Bridge Gravel Mine was constructed on the north side of Chambers Creek. Cascade Paper Company began its operations adjacent to Pacific Bridge's mining site in 1916. Glacier Gravel Company and Everett Pulp and

Paper entered into a joint venture in 1933, damming the mouth of Chambers Creek (Pierce County, 2013). The Abitibi dam was erected to create a water impoundment used by both companies in daily operations.

In the following decades, both commercial properties were bought and sold several times. Pierce County bought into the gravel mine, and is the current owner of the property. The paper mill is now owned by Falls Development Group, which is associated with the commercial real estate firm Managing Green LLC in Tacoma, WA. Adding to this, the county acquired pieces of Chambers Creek Canyon, located directly above the dam, through donations and land purchases. In 1984, the county built the Chambers Creek Regional Wastewater Treatment Plant (Pierce County, 2014). Ten years later in an effort to reclaim and restore the lands surrounding Chambers Creek, Pierce County established the Chambers Creek Public Work's Properties. This project has transformed the gravel mines of Chambers Creek into a county office, a championship golf course, and a restaurant. Several trails connect the property, now known as Chambers Creek Regional Park.

Today a diverse range of stakeholders uses the area (Pierce County, 2013). As mentioned above, Peirce County owns a portion of the dam, through its ownership of the former mining operation. Moreover, the county maintains and coordinates recreational activities at the Chambers Creek Regional Park. Falls Development Group owns the Abitibi Mill property adjacent to the Chambers Bay Properties owned by the county, and shares ownership of the dam. Along the impoundment behind the dam, the Washington Department of Fish and Wildlife owns and operates a fish propagation and acclimation facility associated with their Puget Sound hatchery projects. Linked with this is a

Chinook salmon terminal hatchery, used by Indians and sport fishers. The Chambers Creek Boat Owners Association operates a boat moorage at the mouth of the Creek. The Town of Steilacoom owns and operates a wastewater main located within the impoundment. Moreover, Steilacoom owns the dam with the Abitibi Mill site. When in operation this zoned industrial site provided significant tax revenue for the town. The causeway spanning the creek is partially owned by the City of University Place. At the mouth of the estuary, the Burlington Northern Santa Fe Railroad Line owns and operates a train trestle spanning the creek, along with rail lines along the near shore areas of the City of University Place and the Town of Steilacoom.

The area also is used for multiple recreational purposes. During the summer the impoundment becomes the skim-boarding mecca of Pierce County. As fall arrives and the salmon return, fishers from every walk of life try their hand at landing a Chinook salmon. Winter brings native runs of chum salmon into the CCCW. The first sign of spring encourages hikers, kayakers, and photographers to revel in the natural beauty of the area.

Chapter 5: Habitat Loss

Introduction

Degraded and altered habitats play primary roles in declining Pacific salmonid populations in Washington State (NOAA, 2015). In this section, a brief explanation of salmon habitat will be provided. The idea of man's conquest of nature will be discussed next, with a particular emphasis on loss of freshwater salmon habitat. Examining this subject from a global perspective, then from a Washington State point of view will frame the discussion. Finally, an in depth analysis of Chambers Creek will articulate the issue, providing an analog to the statewide problem of escalating of habitat loss and salmonid decline.

Salmonid Habitat

A point of entry to better understand salmon and their habitat is to grasp the basic water cycle and its power. Mountain ranges on the coast and the interior of the Northwest catch and hold water in the form of rain, snow, and ice. This water makes its way back to the Pacific Ocean, over time carving rivers, creeks, and lakes. Along the way, soils filter the water; flora and fauna depend on it for life. Spring returning salmon depend on the annual spring glacial melt to provide water to ascend high into the Olympic and Cascade Mountains. Fall rains and their life-giving waters govern when salmon move into the rivers after the long dry summer. Salmon require water, particularly clean, cool, oxygenated water. Juvenile salmon require healthy river systems full of macroinvertebrates and other fish to eat (Quinn, 2011). In the freshwater world of salmon, shelter comes in the form of dynamic river-scapes and terrestrial inputs. Flood plains, side channels, and abundant riffle pool sequences comprise dynamic river-scape attributes, all of which salmon require. Allochthonous material--items originating outside of the river system--such as boulders and woody debris, create pools and riffles, as well as degrade into gravel that salmon use during spawning (Allan and Castillo 2007). Woody debris also can form log jams, creating deep-pool habitats and side channels, both aggrading the main channel into the flood plain recruiting more allocthonous inputs.

Natural Salmonid Habitat Disturbance

Salmon habitat is alive and ever-changing. Natural disturbances such as volcanoes, earthquakes, floods, landslides, and storms continually destroy and recreate the environment salmon depend on (Montgomery, 2004). Rivers, streams, and creeks for example, constantly create habitat by wearing away clay, silt, sand, and cobble from the land. High flows during storm events amplify the river's ability transport sediment. This increased pulse of material provides salmon with dynamic habitat in the form of side channels, gravel bars, and islands. Large woody debris in the form of fallen trees recruited into the river during spring and winter floods provide shelter for both adult and juvenile fish. Lahars and high flows illustrate the destructive side of natural habitat building processes. High flows scour redds, exterminating salmon embryos, and lahars boil water and obstruct rivers with trees, boulders, and mud.

Salmon have evolved strategies to deal with some of these natural perturbations (Quinn, 2011). Salmon in the Toutle River, Washington for example, were completely destroyed during the eruption of Mount Saint Helens. However, salmon returned to the river two years after the explosion. While the adult salmon in river died, reserve stocks of Toutle River salmon in the ocean at the time of volcanic eruption were able to later recolonize the river. This situation helps in understanding the varying age cohorts of salmon, a strategy salmon have developed to cope with natural disturbances (Groot 2010, Montgomery 2004). Salmon are resilient and able to survive in a continually shifting environment. The elasticity of salmon is significantly compromised when their basic requirements of unobstructed waterways with clean, cool, oxygenated water are altered or destroyed.

Next, global anthropogenic habitat destruction will be profiled through a photo essay recently published in The Guardian Newspaper. Then books by Bruce Brown and David Montgomery will be used to examine several anthropogenic examples of habitat loss in the state of Washington. Finally, several governmental reports created by the United States Geological Survey, Pierce County, and the city of Tacoma will be used to present salmon habitat loss in the Chambers Creek.

Habitat Loss

Broadly, salmonid habitat loss can be understood in direct correlation with modern-day society's conquest of nature. David Quammen speaks to this conquest in his 1996 book *The Song of The Dodo*, which details resource extraction, habitat fragmentation, and species extinction throughout the world. Quammen likens the natural world to a Persian carpet: a tapestry of ecosystems, services, species, and relationships. Focusing on individual extinctions, such as the Dodo bird of Madagascar, and the Passenger pigeon of North America, Quammen details the way that inconsiderate human actions are knifelike, serving the fibers and unraveling the carpet.

A visual representation this concept of human domination over nature appears in photo essay published by The Guardian Newspaper, titled *Overpopulation, Overconsumption-in Picture* (2015). In 13 photographs The Guardian artfully displays the consequences of unbridled human development. *Waves of Humanity,* by Pablo Lopez

Luz, is an aerial photograph of Mexico City, showcasing the displacement of natural habitat and the sprawl of housing developments along uneven terrain as far as the eye can see. *Oil Spill Fire,* by Daniel Beltra, is a visually stunning capture of the Deepwater Horizon oil spill; helpless oil booms attempt to corral the spill while the emerald green Gulf of Mexico ablaze in an orange and black fury, sends plumes of gray smoke into the air. *Feedlot*, by Peter Beltra, details efficient industrial farming of cattle. The pens overflowing with livestock stretch across the frame. Neatly ordered to exploit space and maximize production, animals live on top of one another, defecating, eating, and sleeping. *British Columbia Clear-Cut*, by Garth Lentz brings this problem home to the Pacific Northwest. Flowing hills, evergreen trees, a cloud-covered bay, and the Pacific Ocean set the scene. In the fore ground sits a bald hill, sporting a mohawk of Douglas Fir and the deep scars carved by logging trucks.

Salmonid Habitat Loss in Washington State

Bruce Brown's 1982 book, *Mountain In The Clouds: A Search for the Wild Salmon*, and David Montgomery's 2004 book, *King Of Fish: The Thousand Year Run of Salmon,* provide a starting place for better comprehending salmon habitat loss in Washington State. Both authors highlight salmon habitat loss through historical narrative and exemplify how salmon have become endangered. As explained in more detail below, Brown details why wild salmon are in peril and how the ecological stability of the Pacific Rim rest on human choices and management of salmon. Montgomery explores successional historical experiences of human and salmon extinction, starting first in Europe, then on the Atlantic Coast of the United States, and finally in the Pacific Northwest. In its listing of salmon as an endangered species NOAA specifically cites critical habitat loss as a contributing factor among over harvest, hydropower, and hatcheries (United States Government, 1987). Brown's and Montgomery's books will be used to provide detail of anthropogenic habitat destruction in Washington State leading to the decline of salmon and eventual listing as an endangered species.

Significant salmon habitat loss began with expansion of white settlers into the Pacific Northwest; natural bounty, temperate climates, and opportunity all motivate people to this day, to immigrate to the west coast. During the Civil War, the United States Government passed the Homestead Act of 1862 that allowed farmers to claim up to 160 acres of Government land after five years of residence. The Homestead Act was created for free Union farmers with the goal of feeding soldiers during the Civil War (The Homestead Act, 1862). Homesteaders rapidly moved west and staked claims in the floodplains along the banks of America's West Coast Rivers. Farmers took creative liberty to drain, dam, dike, and straighten water on their property. Water quality, quantity, in-stream temperature, and habitat connectivity have all been impacted considerably by this rapid expansion of farmland.

As the country moved on from war, it seized the potential of development in the West with the Reclamation Act of 1902. Over 3 million acres of the arid west was "reclaimed" as the result of the construction of dams and irrigation systems for farming (Reclamation Act, 1902). Continuing with this movement, during the progressive era conservationism, dams rose to supply water and electricity to the growing population of Washington State. Dams reshaped The West: mighty rivers, such as the Columbia, once a ragging torrent, have been transformed into a series of lakes (White 1996). Likewise, dams have disconnected the rivers that salmon use to navigate to and from the ocean.

What is more, dams have wreaked havoc on biological and natural processes that create dynamic equilibrium within lotic environments (Fausch et al., 2009). These processes include the delivery of marine-derived nutrients from returning adult salmon, and the starvation of sediment and woody debris to stretches of river downstream of the dam.

Along with agriculture and dams, timber harvest has left a lasting impact on salmon habitat. Pacific Northwest timber has provided for the inhabitants of this area for centuries. Aboriginal cultures used large cedar trees to fashion canoes, shelter, clothing, tools, and art (McFeat, 1967). Intensive logging practices arrived in the area with white settlers. Seattle, Washington's present day cultural and economic center began as a logging camp. Sharing a common history with Seattle, most early white communities in the state were established for the removal of timber (Montgomery, 2004). As time and technology advanced, bulldozers and semi-trucks replaced mule teams. Mechanized chain saws substituted for handsaws; heavy equipment hastened the removal of trees and the ability to get them to market. Also, heavy equipment accelerated the destruction of salmon habitat. Large machines increased sediment flow into rivers, burying salmon redds, clogging the gills of salmon, and making the environment inhospitable for juvenile salmon prey. Increased removal of trees has reduced large woody debris in streams, eliminating key habitat features that salmon depend on. Adding to this, lack of streamside shading has increased solar radiation, heating streams to lethal levels for salmon (Reeves et al., 2006).

Habitat loss is a major contributing factor to salmonid decline in Washington State. Historically, agriculture, timber harvest, and damming of rivers were the major drivers of salmonid habitat loss. In the next section vestiges of habitat loss and contemporary drivers of salmonid habitat destruction will be profiled by several governmental reports conducted on the Chambers Creek.

Salmonid Habitat Loss in Chambers Creek

Using reports from Tetra Tech/KCM, Tacoma-Pierce County Health Department, Pierce County Public Works Utility, and Pierce County Conservation District along with other sources this section will review a brief history of salmon habitat loss in Chambers Creek, key habitat features as defined by the Washington Conservation Comission, and a thorough inspection of salmon habitat loss in Chambers Creek. The spectrum of degradation in the CCCW ranges from slightly influenced to significantly impaired. Pierce County Conservation District reported that the difference in habitat loss in the watershed is due varying land usage, such as agriculture, commercial, residential, and urban (Runge, Marcantonio, and Mahan, 2003). The report cites elimination of riparian zones, non-point source pollution, industrial discharge, fish passage barriers, removal of large wood from channels, dredging, ditching, rerouting stream channels, and burying the stream as major factors contributing to salmon habitat loss.

Looking back in history, among the first anthropogenic disturbances to the creek occurred around 1853, when a sawmill and dam were constructed on its upper reaches (Dallas, 1990). Gene Nadeau reports multiple instances of landowners rerouting the stream channel, with the earliest instance occurring in the 1880s (Nadeau, 1984). Highlighting the pattern of in stream modification occurring in the watershed is the dredging, diking, and channelizing during the 1940s after the construction of McChord Air Force Base (PCPWU, 1997). What is more, Clover Creek, the headwaters of Chambers Creek, has been funneled into two 12-foot diameter culverts, approximately

0.6 miles long, flowing under the primary runway of the McChord Air Force Base (Runge, Marcantonio, and Mahan, 2003).

Key Habitat Features

In this section, several parameters used to gauge salmon habitat loss as determined by the Washington State Conservation Commission will be defined (WSCC). Then an analysis of Chambers Creek will be provided as an analog to the issue of salmon habitat loss statewide. WSCC has developed several features for assessing the health of salmon streams, they include: loss of access to spawning and rearing habitat, floodplain conditions, channel and substrate conditions, riparian conditions, and estuarine and near shore habitat, lake habitat, and biological process. These habitat features are interdependent and overlapping; alteration of one element will cause substantial change to all other elements. Below, five out of the eight features defined by the WSCC are profiled in detail with their relevance to salmon habitat loss in Chambers Creek.

Loss of Access to Spawning and Rearing Habitat

This metric focusses on impediments to adult and juvenile salmon migration, including culverts and dams. Dams divide stretches of river from each other, fragmenting ecosystems, and isolating upstream and downstream stretches. Moreover, spawning anadromous fish are confined to reaches of the river below the dam or are dependent upon man made strategies to reach spawning grounds above the dam. This delay depletes vital energy stores and increases prespawn mortality and reduced spawning success (Keefer et al., 2010). For example, salmon will continue to scale a dam until they die or pass up stream. Even with fish passage facilities, prespawn mortality is high due to fish beating themselves against dam structures. Furthermore, out migrating fish are impeded by reduction in water flow and suffer increased mortality due to presence of hydroelectric power structures.

Floodplain Conditions

Floodplains provide the river water storage, sediment, and woody debris. For salmon, floodplains offer refugia, spawning and rearing habitat, and food sources, such as terrestrial invertebrates. Floodplains can be destroyed by building development, dikes and levees. Channel incision disconnects a river from its floodplain: this is caused by a dearth of sediment or changes in hydrology associated with damming or constricting the natural flow of a river.

Channel and Substrate Conditions

This habitat element concentrates on sediment movement impacted by human activity. Impervious surfaces, timber harvest, agriculture, and construction activities strengthen sediment transport. An increase of the sediment budget can accelerate erosion, and channel instability. Intensified sediment loads can bury redds, diminish benthic invertebrate populations, and fill pools. Dams and floodplain constriction reduce sediment transport. A decrease in sediment can starve rivers of the building blocks required for dynamic salmon habitat: these raw materials include large woody debris and gravel of various sizes.

Riparian Conditions

The riparian zone is the threshold between the aquatic ecosystem and the terrestrial ecosystem, where land and water meet and is critical habitat for salmon. Urbanization in the form of houses built along the waterfront and logging up to the water's edge are limiting factors in this zone. The riparian zone is described as a "three-dimensional area of direct physical and biotic interactions between terrestrial and aquatic ecosystems, with boundaries extending outward to the limits of flooding and upward into the canopy of streamside vegetation" (Gregory et al., 1991). The first dimension is linear, describing the beginning of the zone at the headwater and the terminus of the zone at the sea (Vannote et al., 1980). The second dimension is vertical, starting beneath the ground ranging up to the vegetation canopy (Dwire and Kauffmann, 2003). The third dimension is lateral, confined to the area of flooding on each bank (Dwire and Kauffmann, 2003). Examples include bay and ocean shores, along with creek, stream, river and lake banks. Riparian zones are important because they serve as an exchange between aquatic and terrestrial ecosystems, regulating the movement of species, water, and nutrients (Reeves et al., 2006, Dwire and Kauffmann, 2003). Moreover, "riparian areas are considered the most productive and species rich environments on many landscapes" (Kardynal et al., 2008).

Estuarine and Near Shore Habitat

Estuaries are tidally influenced zones around river mouths. Allowing salmon staging areas to osmoregulate, consider estuaries as thresholds, as in this case, between the salty Puget Sound and the freshwater of Chambers Creek. Near shore habitat is the tidally influence saltwater zone adjacent to land. Salmon use both estuarine and near shore habitat for the safety they provide and for their abundant nutrients. These zones provide both adult and juvenile salmon structure such as eel grass, large woody debris, and kelp beds to hide from predators and ambush prey. Habitat loss in this zone comes in the forms of dams, bulk heads, logging operations, roads, bridges, mills, and ports. Because of their strategic location as thresholds between fresh and saltwater and saltwater and land, estuaries and near shore habitats are highly degraded and developed.

Chambers Creek Analysis

In June 2003, the Pierce Conservation District published an analysis of salmonid habitat limiting factors for WRIA 12 with an emphasis on the Chambers Clover-Creek Watershed. They determined fish access, floodplain modification, riparian condition, water quality, in stream flows, lakes, and estuary condition as degraded habitat features that are limiting salmon in the watershed (Runge, Marcantonio, and Mahan, 2003). Using the key findings from this report and personal observation I will discuss habitat loss on Chambers Creek.

Fish Access and Estuary

A railroad trestle, a fish collection facility, and a small dam found in the estuarine zone interrupt fish access on Chambers Creek (Runge, Marcantonio, and Mahan, 2003). The Burlington Northern Santa Fey Railroad trestle, impacting tidal exchange processes between the creek and Puget Sound, bottlenecks the mouth of Chambers Creek estuary. Moreover, the Abitibi Dam disconnects the creek from the estuary, impeding the movement of migrating salmon and the transport of sediment and woody debris. Adding to this Washington Department of Fish and Wildlife operate a fish collections facility at the Dam. Salmon navigating the dam's fish ladder are directed into a holding pool, where WDFW then pass the fish upriver or use them in hatchery operations.

Floodplain Modification

The Chambers Clover-Creek Watershed floodplain has been significantly modified (PCPWU, 1997). Residents have armored the shoreline to protect their properties from potential flooding by diking, channelizing and paving the banks with large stones. Riparian vegetation has been removed to allow homeowners access to the creek and decreased the recruitment of large woody debris. This has decreased bank stability, increased ambient in-stream temperatures due to lack of shade bearing trees, and decreased allochthonous inputs that provide salmon food and shelter.

Riparian Condition

Riparian conditions have been altered on private land, however within the ravine, owned by Pierce County, behind and east of the dam, riparian conditions are as close to pristine as can be found within the watershed. Mixed shrub and deciduous as well as evergreen trees, which provide ample shade, keeping temperatures cool for salmon comprise the Chambers Creek ravine. Moreover, in the ravine the creek is allowed freedom to meander from its channel into the floodplain and back again, creating side channels, islands, pool and riffle sequences, logjams, and waterfalls.

Water Quality

Water quality in Chambers Creek is influenced primarily by the land usage in its headwaters. Military and industrial land use in the watershed contributes to chemical inputs that are lethal to fish and other life. Adding to this toxic duo, are countless storm drains in the watershed that empty directly into the creek, carrying antifreeze, gasoline, and other contaminants found on impervious roadways. Sandi Doughton of the Tacoma News Tribune reported in December of 1993 of 40 coho salmon killed after a rainstorm. State agencies could not determine the cause of death of the coho, however, biologist suspect storm water runoff killed the salmon (Doughton, 1993).

In Stream Flows

Perennial flows characterize Chambers Creek, however moving up the watershed flows are ephemeral and rain dependent. Clothier, et al. (2003) cite increased use of water, increased impervious surfaces, disconnection to the floodplain, and management of water levels of several lakes in the area as a combination that has lowered the water level in WRIA 12. Compounding this is the altered or lack of riparian zone vegetation along the creek, reducing water storage leading to low or no in stream flow.

Lakes

A common problem associated with development around lakes and bodies of water is eutrophication. Increase input of sewage, fertilizers (particularly nitrogen and phosphorous) from homes and farms causes rapid and intense algal blooms. This results in hypoxic or oxygen poor water that is fatal to fish and other respiring organisms. Algal blooms associated with eutrophication also color the water brilliant shades of green and red. Upstream of Chambers Creek is Steilacoom Lake, as of 1992, aluminum has been dumped into the lake for 25 years to combat unsightly eutrophic algal blooms associated with the Lake Steilacoom neighborhood (Bennett and Cubbage, 1992). This use of heavy metal along with urban and storm water runoff continue to pollute Chambers Clover-Creek Watershed and limit salmon habitat.

Chapter 6: Mitigation

Introduction

Salmon habitat has been fundamentally altered by anthropogenic means. In the discourse of salmon, it has been argued habitat loss continues in malice while on the other hand degradation of salmon bearing streams is just an unintended consequence of progress. These two conversations do not encompass the entire dialogue, nonetheless in an attempt to aid salmon, society has developed a management strategy known as mitigation. In this section fish passage or fishways will be discussed along with hatcheries.

By definition, to mitigate is to excuse a crime, or to make (an incident) less severe. In the case of dams, Washington's first legislative body produced a fish passage law in 1890, requiring fish ladders at dam sites (Brown, 1995). However, this law has not been strictly enforced, as evidenced by the construction in the early 1900s of the Elwha dams, Port Angeles, WA, without fish passage. A short five years after the Elwha dams were built, the fish passage law was amended by the legislature at the behest of Governor Ernest Lister, fish commissioner Leslie Darwin, and Elwha dam owner Thomas Aldwell to allow fish hatcheries in lieu of passage (Brown, 1995). The creation of large hydroelectric dams, fishways, and hatcheries set into motion the reality that is modern salmon. The Abitibi dam at Chambers Creek is managed by the Washington Department of Fish and Wildlife using a vertical slot fishway (explained in more detail below) and a terminal hatchery of Chinook salmon.

To better understand fishways, both upstream and downstream fish passage technology will be discussed. Fishways were created because dams block salmon migration and impair salmon spawning. Hatcheries have been created because the natural environment, significantly degraded by anthropogenic impacts, can no longer sustain and produce large numbers of salmon.

Fishway Technology

Upstream

Fishway technology in the Unites States includes fish ladders, pool and weir, Denil, Alaska steepass, vertical slot, hybrid methods, fish lifts, trap and haul and fish pumps to move salmon above dams.

Fish ladders are the physical structures that carry or allow fish to swim to higher elevation (Fish Passage Technologies, 1995). Ladders are categorized based on their own design and function: pool and weir, vertical slot, roughened channel, hybrid, mechanical and climbing passes.

Pool and weir ladders provide plunging flow with resting space and hydraulic assistance for jumping fish. This method mimics the pool riffle segment of a river, with pools arranged in a stepped pattern connected by overflow weirs (Fish Passage Technologies, 1995). The pool and weir method impedes fish during high flows, since they are unable to crest the weir. To combat this, some pool and weir fishways have submerged orifices to allow upstream passage.

Denil fishways are rectangular in shape and are considered chutes or flumes. The key to the Denil fishway method is the upstream positioning of the baffles. Baffles extend from the bottom and sides of the chute to control flow and provide fish passage. Denil fishways are primarily used in the eastern part of the country because where dams have lower head and weirs as compared to those in the Northwest (Fish Passage Technologies, 1995).

The Alaska steeppass is an evolution of the Denil fishway-- a smaller rectangular chute with baffles. What makes it unique is its size and ability to be installed in remote locations. Adding to its uniqueness is its ability to operate at steeper slopes as compared to the Denil. The Alaska steeppass does this with a more complex configuration of baffles (Fish Passage Technologies, 1995). Despite its utility, the United States Fish and Wildlife Service Region 5 (Northeast United States), has banned the Alaska steeppass at hydropower facilities because it does not operate under a range of flows.

Vertical slot fishways have distinct steps like the pool and weir method. The design of the vertical slot is a rectangular channel with partitioned resting pools created by baffles (Fish Passage Technologies, 1995). Fish swim from pool to pool using a burst/rest pattern. The advantages of the vertical slot fishway are that it can be built in high velocity water and it is self-regulating. The highest velocity water in the fishway is created by the slots and dissipated as the jets of water mix with the resting pools. The vertical slot method is used throughout the country and has had considerable application in the Northwest.

The hybrid fishway combines several methods, such as a combination of pool and weir with Denil or vertical slot to address variations in flow or multiple target fish. The lack of thorough testing has slowed the implementation of this method (Fish Passage Technologies, 1995).

Fish lift fishways are elevators that transport fish. They are desirable because they do not depend of flow nor do they select for species. Fish lifts collect fish at the base of a dam and move they up above the dam. They work best for high volume runs and for weak swimmers. The drawbacks to lifts include overcrowding, finding a way to attract fish to the gallery and a way to encourage fish to leave the gallery once transported. Maintenance on elevators is expensive and mechanical failure is deadly to fish (Fish Passage Technologies, 1995).

The trap and haul method is used when a dam lacks a fishway. Step pools lead to a terminal trap that transfers fish into tanker trucks that transport the fish around the dam or project (Fish Passage Technologies, 1995). This method is highly successful throughout the country, in places like Buckley, WA, for transport fishing from the Buckley diversion dam up around Mud Mountain Dam to spawning grounds in the upper White River watershed. The downsides to this method include a reliance on workers to transport at a rate that can keep up with returning fish. Also, mechanical failure is always present. However, the biggest issue with trap and haul is the impact on the fish. Studies show that prespawn mortality rates increase with trap and haul operations due to stress caused by navigating the trap, overcrowding in the tanker truck, and being dumped into the headwaters (Waples et al., 2008).

Fish pumps are another method of moving fish. The use fish pumps is not widely accepted or used. With that, recently the Wanapum dam on the Columbia River used experimental fish pumps to transport adult salmon upriver. The fishways on the Wanapum were inaccessible to returning salmon because water levels were reduced to relieve pressure on a crack found in the foundation of the dam. However, the pumps did not last long, modified ladders that were more beneficial to the fish health, took their place. Fish pumps can cause injury in the form of disorientation, descaling and crowding in the pumping tube (Fish Passage Technologies, 1995).

Downstream

Downstream fishway technology in the Unites States is comprised of bypass systems, screens, angled bars or trash rock, louvers, pumps, spillings, turbine passage and transportation to assist juvenile salmon migration. It is critical to understand that juvenile salmon are limited in their swimming ability and orient themselves into the flow (head first into the current), conserving energy by allowing the river to carry them downstream (Fish Passage Technologies, 1995, Schilt, 2007).

Bypass systems are vital to outmigrating juvenile salmon survival. Bypass systems allow juvenile fish to maneuver safely around a dam. The drawbacks include the predation associated with the concentration of disorientated juvenile fish. Opportunistic predators, such as otter, pike minnow, heron, turns, cormorants, and seals wait at bypass exits for unsuspecting juvenile salmon (Fish Passage Technologies, 1995).

Bypass system screening guides the downstream migration of fish. Screens provide physical exclusion from dam intake pipes that lead to injury and death from mechanical operations of the dam. Screens are made out of various materials, such as mesh, wire, metal bar and plate screens. Unfortunately, not all dams screen their intake pipes.

Other structural guidance systems include angled bar, trash rock, and louvers. Unlike screens, these guidance systems do not exclude fish from intakes, instead creating turbulence to guide fish away from the intake and toward a bypass system (Fish Passage

Technologies, 1995). The drawback to this method is that the turbulence created by structural guidance systems is dependent on flow and may impact species differently.

The pump method is not widely used, as it causes stress from descaling, crowding and disorients fish. In practice, dam facilities could congregate juvenile salmon then pump them through tubing around the project or into a bypass system. Several pumping systems are currently being tested (Fish Passage Technologies, 1995).

The spilling method for downstream transport is the most cost efficient and easiest to implement. Water is released independent of power generation to allow fish to ride over the dam. "The Army Corp of Engineers maintains that spilling water to pass juvenile fish has been demonstrated to be the safest, most effective, and one of the lowest-mortality means of getting juvenile anadromous fish past hydropower projects in the Columbia River Basin" (Fish Passage Technologies, 1995). Despite this opinion spilling water to ensure safe fish passage means lost revenue. Adding to this, the spilling method causes pressure-induced injuries.

The transportation method for downstream migration is very similar to upstream migration with trap and haul facilities. Transportation reduces predation at outfall sites associated with bypass systems, limits juvenile residence time in reservoirs behind dams, negates mortality associated with passing through the turbines, and mitigates for low water levels. The Columbia River uses trap and haul and barging in tandem to increase juvenile salmon survival rates (Fish Passage Technologies, 1995). The State of California trapped and hauled on many rivers this year because of low flow resulting from drought. The negative aspects of transporting fish are the same going up or downstream.

Salmon migration runs will continue to be impeded and human assistance will be required until dams are removed and alternatives to hydroelectricity become the standard (Garlesky, 2015). In addition to restricting access to habitat, anthropogenic impacts have reduced the ability of salmon to produce large self-sustaining populations. In an attempt to counter a world without salmon, hatcheries now produce the majority of fish found within Washington State Rivers (Montgomery, 2004). "The state of Washington has the largest system of salmon hatcheries in the world, raising more than 200 million juvenile fish at 128 state, federal, and tribal facilities each year. These hatcheries produce the majority of all salmon caught in Washington waters" (Mass Marking Fact Sheet | Washington Department of Fish & Wildlife, 2015). Studies completed by the state have determined three out of four fish caught in the Puget Sound are of hatchery origin. Adding to this, nine of ten fish caught on the Columbia River are from hatcheries (WDFW Hatcheries, 2015). The contribution of these hatchery fish to the declining wild fish populations will be explored in the next section.

Salmon Hatcheries

Since the late 1800s, development of the West in the form of clear-cutting timberland, damming rivers for flood control and hydroelectric power, overfishing, and urbanization have had deleterious impacts on Pacific salmon and their habitat. Fishing economies of Oregon and Washington, based on canneries along major rivers, like the Columbia, began to falter during the late nineteenth century. Science, in the earliest form of progressive era conservationism, provided the solution to this dilemma. In 1875, Spencer Baird, the United States Fish Commissioner, advised that fish hatcheries could solve the problems of unsustainable returns and harvest regulations by increasing the abundance of Pacific salmon (Taylor and Cronon, 2001). Government sponsored hatcheries assuaged powerful fishing interests and provided a path for successful fish culture and management. "Hatcheries produced fish, fish produced commercial fishing opportunity, and opportunity put people to work" (Harrison, 2012). However, 139 years later, despite the best efforts by Baird and the implementation of hatcheries, Pacific salmon numbers continue to decline. Wild Salmon runs in California, Oregon, Idaho, Washington, and southern British Columbia have been reduced to less than 10% of their historical numbers (Lackey 2000).

The question then becomes: What impact have hatchery fish had on wild salmon? This section will provide a discussion of hatchery practices and an argument that hatchery fish and their maladaptive genes pose a significant threat to wild populations through domestication, ecological risks, decreased fitness, straying, and genetic introgression. Furthermore, a lawsuit that incorporates all of these harms to wild fish, filed by the Wild Fish Conservancy (WFC) against the Washington Department of Fish and Wildlife will be explored (Smith and Lowney 2014). This suit has a direct correlation to Chambers Creek and will be discussed in detailed. Finally, a conclusion will be provided recapping the negative impacts of hatcheries, revisiting the positive impacts of hatcheries and exploring paths to best hatchery practices.

Hatchery Management Practices

Hatcheries have a two distinct management practices, augmentation and supplementation. The words sound the same and are often misused. Supplementation has as its objective an increase in the abundance of a natural population. This form of management is used to restore or conserve a threatened or endangered run, by using natural origin fish as brood stock. For example, on the Snake River, Idaho, the Nez Perce Nation manages a fall Chinook supplementation hatchery. Before the supplementation program was in place, during the 90's the Nez Perce documented less than 100 fall Chinook returning to the Snake River, Idaho (Hatchery and Wild, 2014). In 2013, with the supplementation program in place, the Nez Perce surveyed over 56,000 fall Chinook, and of those, 40,000 were actively spawning in the wild (Outside Communications, 2014).

Conversely, augmentation is a hatchery program that aims to provide increased numbers of adult salmon to a fishery, using hatchery fish or non-origin fish as brood stock. Augmentation is required to sustain commercial, tribal and sport fisheries and mitigate population loss due to dams, water quality and loss of habitat. Examples of augmentation hatcheries are those along the Columbia River, Oregon as well as the majority of salmon hatcheries in Washington. Keep in mind, the basis of salmon productivity and resiliency is their genetic diversity (Bottom, 2011). Rearing fish in a closed environment, generation after generation, diminishes their genetic diversity through interbreeding and hatchery selection (Bottom. 2011).

Case Studies & Experiments

Domestication

Hatcheries have a negative impact on wild salmon populations through the process of domestication, or the adaption of hatchery fish to human controlled environments (Waples, 1999). Domestication can also be described as the intentional human selection for a desired trait (such as an early return rate or adult body size) and unintentional or natural selection of the hatchery environment (Waples, 1999). Hatchery environments are predictable and homogenous compared to the unpredictability and variation found in lotic environments (Johnson et al., 2001).

Johnson et al. of Norway conducted an experiment to examine behavioral response to predation in domesticated and wild Atlantic salmon. The researchers studied the cardiovascular responses induced by predation risk. In particular, this study focused on cardioventilatory responses to predation, measured as the ability of fish to detect, evaluate, and respond to a predator. Freezing or hiding responses are associated with a decreasing heart rate known as bradycardia, and defense or flight responses are associated with increased heart rate known as tachycardia (Johnson et al., 2001). Johnson et al. predicted that hatchery salmon would show lower standard heart rates than wild salmon (2001). In the experiment, individual hatchery and wild salmon were placed in a tank and subjected to two simulated attacks. The attacks consisted of a plastic heron plunging its beak down through the water to the bottom of the tank.

In the first round, wild salmon displayed a 100% escape reaction, compared to the hatchery salmon, which displayed a 72% escape reaction (Johnson et al., 2001). (Escape reaction was measured by fish fleeing from the predation stimulus). Even more telling, heart rate data collected in the first round indicated that wild fish had a strong reaction displaying bradycardia, then tachycardia, while hatchery salmon had a weaker response, displaying a subdued bradycardia, then tachycardia reaction (Johnson et al., 2001).

Without any significant difference in heart rates, less escapement reaction was observed in both wild and hatchery salmon, in the second round of predation tests. Johnson et al. explained this by the ability of both wild and hatchery fish to discount the danger from repeated simulated heron predation (2001). Johnson et al. credited the reduced heart rate and escape reaction of hatchery salmon to domestication. In this experiment, domestication of salmon significantly reduced their ability to detect, evaluate, and respond to predation stimuli.

Ecological Risks

Hatcheries have a negative impact on wild salmon populations by creating ecological risks. Kostow describes this risk as anything that determines the interaction of wild fish with other fish, the environment and the entire species assemblages (the sum of all interactions) (2008). Specific examples include predation of wild fish by hatchery fish, direct competition for food resources by hatchery fish, attraction of other predator species (due to the concentration of hatchery fish in time and space), and transmission of disease (Kostow, 2012). In a 2008 study, Kostow identified two major factors that contribute to ecological hatchery risks: large releases of hatchery fish and the observation that hatchery fish do not out-migrate after release.

Large numbers of released hatchery fish amplify the impacts of these risk factors. For example, during a 25 year period on the Clackamas River, Oregon, Kostow and Zhou observed an average of 86% of steelhead smolts were hatchery releases, and that an average of 70% of adult steelhead on the spawning grounds were hatchery adults (2006). They were able to demonstrate a 50% decline in wild steelhead productivity during these years, as compared to years when no hatchery fish were present (Kostow and Zhou, 2006). Increased predation was associated with exceptionally high concentrations of fish that occur when hatchery fish are released. What is more, hatchery fish tend to out-migrate in unnatural, concentrated groups, in contrast to wild fish which out-migrate in dispersed and variable groups (Kostow, 2004). The abundance of hatchery fish also attracts human predators. Consequently, wild fish survival drops as the presence of hatchery fish causes the overharvest of small wild populations. For example, on the Columbia River, Washington, hatchery releases of coho lead to a 90% harvest rate, while wild populations were near extinction (Kostow, 2008). The ecological risks are most severe when both wild and hatchery populations share a finite space for a substantial period of time.

Kostow's studies have shown that hatchery fish do not out-migrate to the sea when released during pre-smolt stages. On one hand, hatchery fish released as smolts journey to the salt water. On the other hand, most hatcheries release fish pre-smolt stage, meaning they need to rear in fresh water before heading to the sea. When this happens, a significant number of hatchery fish become residents, meaning they fail to out-migrate, choosing to complete their life history in stream. This puts a considerable strain on wild populations. Kostow's 2008 study showed that 14% of steelhead planted in the Tucannon, River, a tributary of the Snake River, Idaho, became residents. Similarly, in 2006, on the Hood River, a tributary of the Columbia River, Oregon, 25% of returning hatchery Spring Chinook salmon males were micro-jacks. Another study at Willamette Falls, Oregon, showed 14% of all returning hatchery male spring chinook were micro-jacks. (The term micro-jack describes a Chinook that has reached sexual maturity within the first years of its life: micro because its size is nutrient-limited by remaining in stream, and jack because it is a male.)

It should be noted that a period of residency occurs during the life of all salmonids, however, hatcheries increase the percentage of residents among populations (Kostow, 2008). Thus, resident fish create ecological risks to wild fish by occupying rearing habitats, competing for food, or by direct predation (Kostow, 2008).

Decreased Fitness

Hatcheries have a negative impact on wild salmon populations by decreasing fitness, defined as the reproductive potential or survival of a species, associated with growth and fecundity (Bowbly and Gibson, 2011). Recently, fisheries biologists and hatchery managers have taken an interest in fitness as some hatcheries have switched from fisheries enhancement (producing fish to catch) to restoration (conservation of an endangered population).

A growing body of evidence demonstrates that captive breeding in hatcheries decreases fitness among fish. Bowbly and Gibson wanted to learn the point at which loss of fitness attributed to captive breeding in a hatchery might offset the predicted recovery potential and viability of an endangered population. They experimented with a captive breeding hatchery program supplemented by a live gene bank program (LGB) to conserve endangered Lundy Bay salmon. An LGB establishes a living reservoir of genetic material that can be used for re-establishment, or restoration of a natural stock. To achieve this, an area or river is designated an LGB and a moratorium on fishing is established there. Bowbly and Gibson found that a hatchery infused with an LGB increased the overall population. However, at the end of 50 years, loss of fitness in that population substantially reduced predicted abundance, slowed the rate of population increase, and increased the probability of extinction of the wild population (Bowbly and Gibson, 2011). This long-term case study demonstrates that hatcheries can decrease fitness and lead to extinction of wild populations.

Straying

Hatcheries also have a negative impact on wild salmon populations in the form of straying. The opposite of straying is homing: the unique trait of salmon that allows them to return to their natal sites. Homing increases salmon’s chances for finding a suitable habitat and mates, furthering their survival. In addition, homing salmon are morphologically adapted to their natal waters, helping to minimize the cost of movement, and allowing them to spend more energy on reproduction (Westley et al., 2013). In addition, homing salmon allow hatchery managers the opportunity to harvest and reduce the exposure of hatchery fish to wild fish.

While homing is relatively well researched, straying is not often discussed in the literature. Westley et al., explain that straying occurs when salmon return and spawn in non-natal waters (2013). In contrast to homing, straying salmon facilitate the colonization of newly accessible habitat (Westley et al 2013). Straying salmon provide protection against total offspring loss caused by catastrophic events (floods, volcanic eruptions, droughts) that have decreased the habitability of natal rivers. Two theories explain why salmon stray. The first is that some individuals fail to imprint as juveniles and stray because they do not know “home.” The other theory is that straying is an adaptive life history, used for colonization of new habitat and as a mechanism to diversify the gene pool in the form of donor populations (Westley et al., 2013). Homing and straying are both explained by a salmon’s ability to smell home. Salmon use olfactory recognition to detect their natal streams.

To determine the rate of straying that occurs among hatchery fish, Westley et al. conducted a study of Columbia River, Oregon, hatcheries. They assembled tagging data from the Regional Mark Information System (RMIS http://www.rmpc.org/), built through the detection of coded wire tags (CWT), which are ~1 mm sections of coded magnetized wire that are inserted into the cranial cartilage of juvenile hatchery salmon. A total of 445 CWT recovery locations were used; of those 285 were hatchery sites and facilities, and 160 were spawning ground sites. As fish return from the sea their coded wire tag was detected as they swam through dams and hatcheries. On the spawning grounds, researchers used a detection wand to collect positive identification. Westley et al. determined that Chinook strayed the most, followed by coho and steelhead. In their studies straying percentages across all fish ranged from 1% to as high as 60% (Westley et al., 2013).

A similar straying study was conducted by the Alaska Department of Fish and Game. The Department discovered hatchery fish in 81 summer chum index streams (Piston and Heinl, 2012). Thus, most chum salmon streams in Southeast Alaska, even those far removed from hatchery release sites, have hatchery fish present (Piston and Heinl, 2012). It is difficult to determine if straying differs between hatchery and wild population, because information on hatchery populations greatly outnumbers that of wild populations (Quinn, 2007). However, both studies exemplify the capacity for hatchery fish to access and compete with wild populations for breeding habitat and to breed with wild populations, as outlined in the next section.

Genetic Introgression

Hatcheries have a negative impact on wild salmon populations in the form of introgression, also known as hybridization or the interbreeding of hatchery and wild fish. Introgression represents the last failing battle of wild salmon populations. Hatcheries alter the genetics of salmon through domestication, create ecological competition in the form of above carrying capacity juvenile populations and decreased reproductive viability in the form of degraded fitness. As indicated earlier, hatchery fish reach wild salmon populations through the mechanism of straying and LGB hatchery management strategies. In this vein, Reisenbichler and Rubin combined several studies focusing on domestication, fitness, and survival of hatchery/wild progeny to test if introgression poses a genetic threat to wild populations. Reisenbichler and Rubin conclude that hatchery production of Pacific salmon genetically changes the population and reduces the reproductive success when hatchery or hybrid hatchery/wild fish spawn naturally (1999).

These five examples provide the scientific reason why negative impacts of hatcheries on wild salmon populations need to be addressed. The next section will focus on a real world application of the negative impacts hatcheries have on wild fish populations.

Wild Fish Conservancy vs. Washington Department of Fish and Wildlife

On January 23, 2014 Smith and Lowney published a letter on behalf of the Wild Fish Conservancy (WFC) giving notice to the Washington Department of Fish and Wildlife of intent to sue for violation of section 9 of the Endangered Species Act associated with WDFW's Chambers Creek steelhead programs (Smith and Lowney, 2014). In particular, the WFC accuses WDFW of violating section 9 of the ESA which pertains to "take" which includes actions that harass, harm, pursue, wound, kill, trap, capture or collect a protected species (United States Government, 1998). Listed species affected in Washington State include steelhead, bull trout and Chinook salmon.

The Chamber's Creek hatchery program was established in the 1920's. Hatchery managers noticed wild Chambers Creek steelhead had an early return trait and displayed an ability to tolerate warmer water (Smith & Lowney, 2014). These fish where ideal candidates to propagate and manage for two reasons. First, managers assumed the fish's early return trait would segregate them from wild populations. Second, the stocks ability to tolerate warmer water accelerated spawning maturation time, allowing hatcheries to produce these fish faster than ever before. In the ensuing years, Chambers Creek steelhead stock has been introduced all over the state of Washington and in the Luarentian Great Lakes.

The WFC lawsuit attempted to demonstrate "take" through genetic introgression. WFC's letter explains:

> This (*genetic introgression*) is perhaps the most detrimental harm caused by these programs. Fish become *domesticated* in a hatchery environment and thereby *less fit* to survive and reproduce in the wild. Chambers Creek steelhead are highly-domesticated due to decades of artificial production and now have genetically heritable life history traits that contrast significantly with most populations within the Puget Sound steelhead distinct population segment.(DPS)(Smith and Lowney, 2014)

Take through genetic introgression occurs when Chambers Creek steelhead are allowed to spawn in the wild (a product of *straying*) and thereby pass their maladaptive genes to the wild populations within the Puget Sound steelhead DPS. The resultant offspring have markedly *reduced fitness*, dying at a much higher rate before spawning than would occur with two wild parents (Smith and Lowney, 2014)."

Thus, in the case of Chambers Creek, domestication, ecological risk, decreased fitness, straying and introgression of hatchery fish have become fatal to wild populations. Moreover, it should be known that Chambers Creek steelhead programs are significantly responsible for the homogenization and decline of Washington State steelhead. WDFW settled outside of court with the WFC in 2014. WDFW agreed to cease its use of Chambers Creek steelhead and to produce Hatchery Genetic Management Plans (HGMP), approved by NOAA, for all of its hatchery operations. The goal of each HGMP is to ensure the conservation and recovery of salmon and steelhead populations. (Wild Fish Conservancy, 2014).

Conclusion

Salmon culture, once seen as the solution to reduced runs, now contributes to the collapse of wild salmon fisheries. As wild salmon populations collapse, more hatchery fish are produced to replace them, creating a negative feedback loop supporting a system of decline in wild salmon populations.

On the other hand hatcheries provide opportunity for commercial, tribal and sport fisherman. More importantly hatcheries provide jobs for fishermen, biologist, shopkeepers and government employees.

The natural environment cannot handle the demand upon which we (humans) place on salmon (M. Scharp, WDFW Grays Harbor Fisheries Biologist, personal communication, February 8, 2014). All things being equal, we could eliminate hatcheries and allow the resiliency and genetic diversity of wild salmon populations to take hold and stage a comeback. Nonetheless, supplemental hatcheries will play a role in salmon enhancement, increasing the abundance of natural populations as we move forward. The

Snake River Chinook, for example, have staged a comeback with the help of the Nez Perce supplemental hatchery program. From a policy point of view, The Hatchery Scientific Review Group (HRSG) was formed at the behest of the U.S. Congress to determine best hatchery management practices. HRSG members consisted of professionals from WDFW, US Fish and Wildlife Service, NOAA Fisheries, the Yakima Nation, Bonneville Power Administration, Idaho Department of Fish and Game, Oregon Department of Fish and Wildlife, and the Northwest Power and Conservation Council (Mobrand et al., 2004). The group recommended a 20% wild brood stock (natural origin) be included to each generation of hatchery fish produced to preserve the genetic diversity within a population. The HRSG, and the practices suggested, mark a significant shift from producing fish with disregard to their origin and impacts on the wild, to a concerted approach acknowledging past mistakes and providing a path forward.

Be that as it may, the current management of hatcheries will need to be addressed further in regards to understanding the continued decline of wild salmon populations

Chapter 7: Restoration

In contrast to mitigation, restoration attempts to give back, or return to a former condition. This strategy will be explored in this chapter using key drivers in salmon survival (based on Beechie et al. (2012)). The focus will be on why it is important to restore connectivity, re-establish stream flow regimes, manage erosion, promote riparian functions, and create in-stream modifications—all elements of a restoration rather than mitigation approach. When implemented these actions will have an immediate and dramatic impact on the survival of salmon and salmon habitat fragmentation on Chambers Creek and in the Pacific Northwest. Restoration efforts on the Chambers Clover-Creek Watershed to date have included a small dam removal the in headwaters, around the Lakewood area, and near shore de-armoring along the Puget Sound (Clothier 2003, Runge, Marcantonio, and Mahan, 2003).

Restoring Connectivity

Rivers are dynamic landscape features that flow from headwaters to the sea. Connectivity implies that all aspects of the river join seamlessly without obstruction. . Restoring connectivity promotes both biological and physical functions of the river. These functions include upstream and downstream salmon passage, the creation of dynamic habitat and the flow of nutrients in the form of sediment, wood, and organic matter (Beechie et al., 2012). This section will discuss two dimensions of river connectivity: longitudinal and lateral. Longitudinal connectivity focuses on barrier removal, while lateral connectivity is geared toward flood plain reconnection.

Longitudinal connectivity restoration efforts revolve around dam breaching and barrier removal. Dams can fragment ecosystems, dividing stretches of river from each other, isolating upstream and downstream ecosystems

(Katopodis and Williams, 2012). Resulting habitat loss and fragmentation threaten both terrestrial and aquatic biodiversity. Dams also obstruct the movement of organisms and nutrients (Noonan et al., 2012).

Lateral connectivity restoration has the goal of rejoining current river channels with their floodplain. Restored floodplains create critical off channel habitat in the form of sloughs and oxbows beneficial to salmon and other creatures. Moreover, restored floodplain connectivity helps to mitigate peak flows during floods, storing water that would otherwise flood downstream reaches. In many instances, this restoration goal can be achieved by levee removal (Beechie et al., 2012). However, levee removal is costly and exposes the riparian zone to grading and heavy equipment. Researchers in Oregon and Washington are using beavers instead of heavy equipment to restore lateral connectivity (Pollock et al., 2004). Dams created by beavers aggregate incised river channels, reconnecting them with their floodplain. Reintroducing beavers provides a positive feedback loop of restoring the ecosystem services provided by the floodplain and creating refugia for salmon and other creatures in the form off channel habitat (Pollock et al., 2007, Pollock et al., 2012).

Re-Establishing Stream Flow Regimes

Getting back to natural stream flow regimes is critical for the survival of salmon because they have evolved to take advantage of the unique flow and temperature of their natal river. Rapid runoff affects the relationship between stream flow regimes and salmon (Beechie et al., 2012). Rapid runoff occurs when water rapidly travels through an altered landscape without storage. Contributing to rapid runoff are the construction of storm drains, the use of impervious surfaces, clear cut logging, industrial animal grazing and degraded riparian zones. Another change to natural flow regimes comes in the form of dams that withhold water in reservoirs and irrigation systems that suck water out of the watershed, intensifying seasonal low flow periods. On the extreme end entire river ecosystem services are lost, such is the case with the Colorado River delta (Poff et al., 2010).

Restoration strategies that promote natural stream flow regimes fall into three categories: cultural, structural, and managerial. On the cultural side of flow regime restoration humans, as conscious and aware stewards of the environment, can use less water. We can limit the impact our rapid runoff has into river systems by reducing the fertilizers and pesticides we use, drive our vehicles less, and keep them maintained and free of leaks. Adding to this, we can reduce bacterial pollution by using proper septic systems and scooping our animal waste (Washington Department of Ecology, 2014). On the structural side of flow regime restoration, water retention systems can be designed into parking lots, roads and highways. Water retention can be included in building design in the form of green roofs, rain barrels, and rain gardens. On the management side, dams can be operated to mimic natural flow regimes (Waples et al., 2009). Alternatives to water retention dams are run of the river facilities. At run of the river facilities, hydroelectricity is produced by the natural run of the river as compared to computers controlling the release of water behind a dam's reservoir.

Managing Erosion

Erosion and sediment transport are part and parcel of a dynamic river ecosystem. Salmon and other species depend on the dynamic habitat that erosion creates. For example, gravel on the spawning grounds at one point eroded from upstream and was recruited and aggregated downstream. On the other end of the spectrum, erosion can create deep pools and off channel habitat that provide flow and temperature refugia to salmon (Groot, 2010). Another aspect of erosion is the recruitment of large woody debris, which, in turn, creates habitat and provides nutrients to macro invertebrates that juvenile salmon feed on (Quinn, 2011).

Erosion can also have deleterious impacts on river ecosystems. Natural checks and balances exist to manage erosion and sediment transportation. However, these natural checks and balances are counteracted by hillside grazing, incised streams, riparian degradation, roads, and logging. Sedimentation can kill salmon in many ways. A flush of sediment downstream can result in decreased stream bed particle size, smother and kill fish eggs, clog fish gills, obscure vision and destroy habitat for juvenile fish and their prey items (Stanley and Doyle, 2003, Canada Fisheries and Oceans, 2000). Restoration efforts include planting and reinforcing robust riparian zones that can act as a catchment or strainer for sediment flow. Also, rotating the pastures of grazing livestock, extending time between grazing sites, and outright prohibition of grazing in significant areas may be beneficial for reducing sedimentation (Medina et al., 2005).

Promoting Riparian Functions

The riparian zone is the threshold between the aquatic ecosystem and the terrestrial ecosystem, where land and water meet, and is critical habitat for salmon. Riparian zone functions such as the supply of woody debris, stream shading, bank reinforcement, sediment trapping, and nutrient filtering can be restored by creating buffers, replanting native flora, and most interestingly by fire (Kauffman et al., 1997). In the riparian zone, fire is critical in shaping both terrestrial and aquatic communities (Arkle and Pilliod, 2010). Moreover, fire is an integral driver of energy, impacting food chain interactions (Arkle and Pilliod, 2010). Erosion, snags, and large woody debris associated with fire disturbance can help recreate structural elements of the riparian zone such as pools, eddies and side channels (Arkle and Pilliod, 2010). These unique riparian zone structures are critical habitat to macro invertebrates and the predators that eat them, such as juvenile salmon.

In-Stream Modifications

Restoration ecologists for state and tribal agencies address the degradation of streams by adding boulders, large woody debris, and spawning gravel in hopes of creating habitat lost from ecosystems (Beechie et al., 2012). In the most extreme cases dynamite has been used to blast navigable channels, as on the Skokomish River in 20XX, to allow fish passage around a natural fall (Tacoma Power, 2014).

Chapter 8: Key Informant Interviews

Introduction

Seeking information and perspectives outside of academia about salmon habitat loss and hatchery dependence, interviews were conducted. A multitude of stakeholders were contacted, and due to the restraint of time, seven interviews took place. The interviewees were placed into three categories: 1. Tribal Members, 2. Biologists, and 3. Elected Officials. Interviews lasted around 30 minutes, and were conducted in person and on the telephone. Participants were asked their point of view on the topic of salmon habitat loss and hatchery dependence. From there, interviewees had control to drive the conversation. In most interviews, participants spoke at length about projects they are involved in, at times leading to a tangent. However, the conversation was brought back to salmon habitat loss with more focused questions. Themes arising from the interviews are interpreted below.

Tribal Members

Speaking with members of the Steilacoom, Puyallup, and Muckleshoot Nations, several key themes emerged. First, natives have a respect for salmon and depend on salmon for both cultural and nutritional value. Encapsulating the feeling of the interviews was this quote: "Tribes are eager for a voice, recognition, and power." This statement pervaded all interactions with tribal members. When inquiring the history of Chambers Creek and the Steilacoom Tribe's relation to salmon in the area, federal recognition dominated the conversation. Despite being a participating member in the Medicine Creek Treaty of 1854, the Steilacoom Nation has never been recognized by the U.S. Government. Presently, around 60% of the tribe lives in Pierce County. Keeping their culture alive, the Steilacoom Indians operate a museum in town and participate in

Coast Salish gatherings, such as canoe journeys and pow-wows. Adding to this conversation was a Muckleshoot Indian who is researching how to better incorporate native perspectives into resource management in the Pacific Northwest. Moreover, it was explained that "wild salmon are going the way of the Indian," sharing the same history of habitat destruction and concentration to designated areas in the form of hatcheries and reservations. This sentiment about hatchery fish among tribal members interviewed is best described by Lorraine Loomis, Swinomish tribal member, chair of the Northwest Indian Fisheries Commission, and Swinomish fisheries manager:

> Hatcheries are the result of choices made in the past and choices that are still being made today about how we treat our environment. We think hatcheries work best when they work hand-in-hand with good harvest management and efforts to protect and restore good salmon and steelhead habitat. (Loomis, 2015)

Additionally, treaty rights are dependent upon fish being available in Washington State Rivers. Since the natural habitat cannot produce fish, state hatcheries manufacture salmon for harvest, which is the government's way of honoring the 1855 treaty rights.

Biologists

Comprising the group were biologists from the Wild Fish Conservancy, the Wild Salmon Center, and the Puyallup Tribe of Indians. These individuals encounter salmon on a daily basis, as it is their job to conserve and restore stocks. Major themes among this group pertained to education, imperiled wild salmon stocks, hatcheries, and habitat loss. In all three interviews, the lack of education on salmon decline was emphasized. The average individual in society is not aware, and does not care about, dwindling wild salmon stocks. What is more, one of the biologists claims, "State management practices have been part of the problem, and until the State can acknowledge this, recovery is not possible." Author Daniel Jack Chasan best describes the feeling of this group in his article *Fish Hatcheries: A 19th Century Fix That Won't Die*, in which he explains:

> In the 21st century, hatcheries offer a way to avoid significantly changing our hydro system, our agricultural water diversions, our use of oil-leaking automobiles, and our development of urban sprawl — and still produce enough fish to satisfy commercial fishers, sport fishers, and tribes. (Chasan, 2015)

Elected Officials

Officials from Pierce County Council and the Lakewood City Council made up this group. Civic leaders are largely involved in serving on a multitude of boards, committees, and task forces. However, these policy makers are limited in their relationship with salmon, lacking the biologist's and tribal member's more personal and practical connections to this keystone species. When asked about hatchery and wild fish, both interviewees professed a lack of education on the subject; however, they both advocated for a balance between hatchery and wild salmon. When prompted about removal of the Abitibi dam, both politicians questioned the benefits of removal, while explaining how convoluted the ownership situation is. The takeaway from this set of interviews was one elected official's declaration, "Salmon don't pay taxes." This speaks to the priorities of lawmakers and the pressure of being elected to hold office and retaining that office.

Chapter 9: Conclusion

Salmon are a keystone species in the Pacific Northwest, providing cultural significance and enriching the physical environment with nutrients from the ocean. Despite their importance and perceived abundance, wild salmon populations are declining. To better understand salmon, habitat loss, and hatcheries, peer-reviewed journals, government reports, books, and newspaper articles were researched, and interviews with key informant groups were conducted. Adding to this, a case study focusing on the historical, physical, biological, and cultural aspects of Chambers Creek, Washington were explored, providing a local example of this issue.

Researching salmon habitat loss and hatchery dependence brought to light the history of anthropogenic environmental change in the Pacific Northwest, as well as the seemingly infinite obstacles associated with uniting multiple resource users for natural resource recovery. Salmon are unique and meaningful creatures, transcending the boundaries of fresh and saltwater, nations, states, and cultures. These extraordinary fish provide meaning and life to this world. In Washington State, the history of Chambers Creek provides an example of wild salmon that have been extirpated from their natural habitat. Digging into habitat loss on Chambers Creek revealed industrial resource extraction at the heart of salmon loss in the watershed. Further research showed that the State of Washington has embarked on two management strategies: *mitigation and restoration*. Fish ladders at dams and hatchery production of lost populations define *mitigation*, while *restoration* seeks to amend the root of the problem by removing fish-blocking dams and rebuilding salmon habitat to encourage the repopulation of watersheds. Interviewing local tribal members, biologists, and elected officials elicited protracted opposing opinions about past management techniques as well as the future of salmon recovery. However, all parties agreed that the influence of local perspectives is missing from policy and from the allocation of project-funding dollars.

Three recommendations have arisen as a result of this research: 1. The creation of a local stakeholder group to provide a foil to the Chambers Clover Watershed Council, which is populated by individuals from state agencies; 2. The immediate removal of the Abitibi Dam, which will allow salmon unimpeded access to the watershed; and 3. Suspension of Chambers Creek Hatchery Chinook production, providing wild fish the best opportunity to repopulate the area.

The history of Chambers Creek can be found throughout the state of Washington. You can impact change on this situation by becoming an informed and involved individual. Grow closely acquainted with your local watershed. Volunteer with your local conservation district and watershed groups. As President Theodore Roosevelt said:

> Far better is it to dare mighty things, to win glorious triumphs, even though checkered by failure . . . than to rank with those poor spirits who neither enjoy nor suffer much, because they live in a gray twilight that knows not victory nor defeat.

Let us live by this mantra, and let us dare to recover wild salmon in the Pacific Northwest. And when our ancestors look back in history, they can hold their heads high, knowing that we fervently tried to restore to the waters of the Salish Sea this most vital Pacific Northwest species.

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