COHO SALMON RESPONSE TO CHANGES IN STREAMFLOW AND HARVEST PRESSURE IN BIG BEEF CREEK, WA

by

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ABSTRACT

Coho salmon response to changes in streamflow and harvest pressure in Big Beef Creek, WA

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Several factors were considered to look at population dynamics of wild stock coho salmon found in Big Beef Creek, Washington. Big Beef Creek is a rain dominated system and home to long term monitoring of coho salmon through weir operations run by the Washington Department of Fish and Wildlife. The date in which the mode of coho salmon returning to the weir was found to be changing over the past 20 years to an earlier date. Coho often face delays due to lack of streamflow and harvest pressure from the terminal net fishery. Because of the combined effects coho salmon at Big Beef that pass above the weir to spawn are smaller and may be of less fitness.

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Chapter One: Introduction

Salmon in the Pacific Northwest are an ecologically and economically important species as they support significant commercial and artisanal fisheries and are sensitive environmental indicators (Drenner et al., 2012). Factors that threaten the success of the species are of major concern as Pacific salmon also provide commercial and tribal cultural value (Ogston et al., 2015). There are seven species of Pacific Salmon (*Oncorhynchus spp.*) that spawn in rivers on the west coast of North America and all of these populations have declined significantly resulting in increased research and monitoring efforts (Ford et al., 2008). Causes for population decline are frequently attributed to habitat loss and overharvest. Artificial propagation of salmon is conducted with the intent to supplement populations. There are several negative effects of this artificial propagation that have been thoroughly researched. Hatchery practices can result in domestication, and evolutionary models suggest that this results in the decline of fitness within the natural populations they are supplementing (Ford et al., 2008). Wild females and males have been found to have significantly greater sexual characteristics than hatchery fish, have higher reproductive success, and higher smolt survival even in poor marine conditions compared to hatchery fish (Beamish et al., 2012; Crozier et al., 2008; Fleming & Gross, 2011). Therefore most management programs prioritize the protection and conservation of wild salmon specifically (Heard, 2012; Irvine, 2009).

Criteria for assessing and identifying salmonid stocks as well as managing them includes understanding location, timing, and abundance. Selecting the best available habitat for reproduction, arriving to spawning grounds early, and body size are all specific strategies and features that determine success for salmonids. Salmon also often respond strongly to environmental disturbances which can cause evolutionary changes for the fish within relatively few generations. For the purposes of this study, we will focus on wild stock coho salmon (*Oncorhynchus kisutch*) found in Big Beef Creek, Washington and population dynamics in response to synchronous environmental and anthropogenic pressures.

Study Area

Big Beef Creek drains into Hood Canal at (47°39'N, 122°46'W) (Figure 1.). The region is characterized by a depressed, glaciated area which is now partially submerged (Kennedy et al., 1981). Ethnographic research has indicated the area to be within traditional Twana (Skokomish Indian Tribe) territory (Kennedy et al., 1981). Between 1857 and 1886, during the Westward Expansion, the area was settled and used for logging and dairy farming (Kennedy et al., 1981). This large-scale anthropogenic activity resulted in major disturbances to the natural environment in Big Beef. It is also due to the presence of cattle during this time of settlement that Big Beef Creek earned its name.

Big Beef Creek is used as an indicator stream for long-term ecological studies and has been monitored by the Washington Department of Fish and Wildlife for over 30 years (Kodama et al., 2012). A weir is located at the mouth of the stream which has allowed researchers to monitor migrating fish passage. Pacific salmon and trout species that are found migrating in and out of Big Beef Creek are steelhead, cutthroat, coho, and chum (Table1.) Only wild stock coho salmon that return to the weir are passed above upstream to spawn. Hatchery-origin Coho Salmon are identified by mark status (adipose clip) and are not allowed above the weir (Kinsel & Zimmerman, 2011). This ensures the genetic integrity of the wild stock coho salmon.

Figure 1: Big Beef Creek highlighted in green which shows the 18km stretch and drains into Hood Canal. Line break corresponds to Lake Symington.

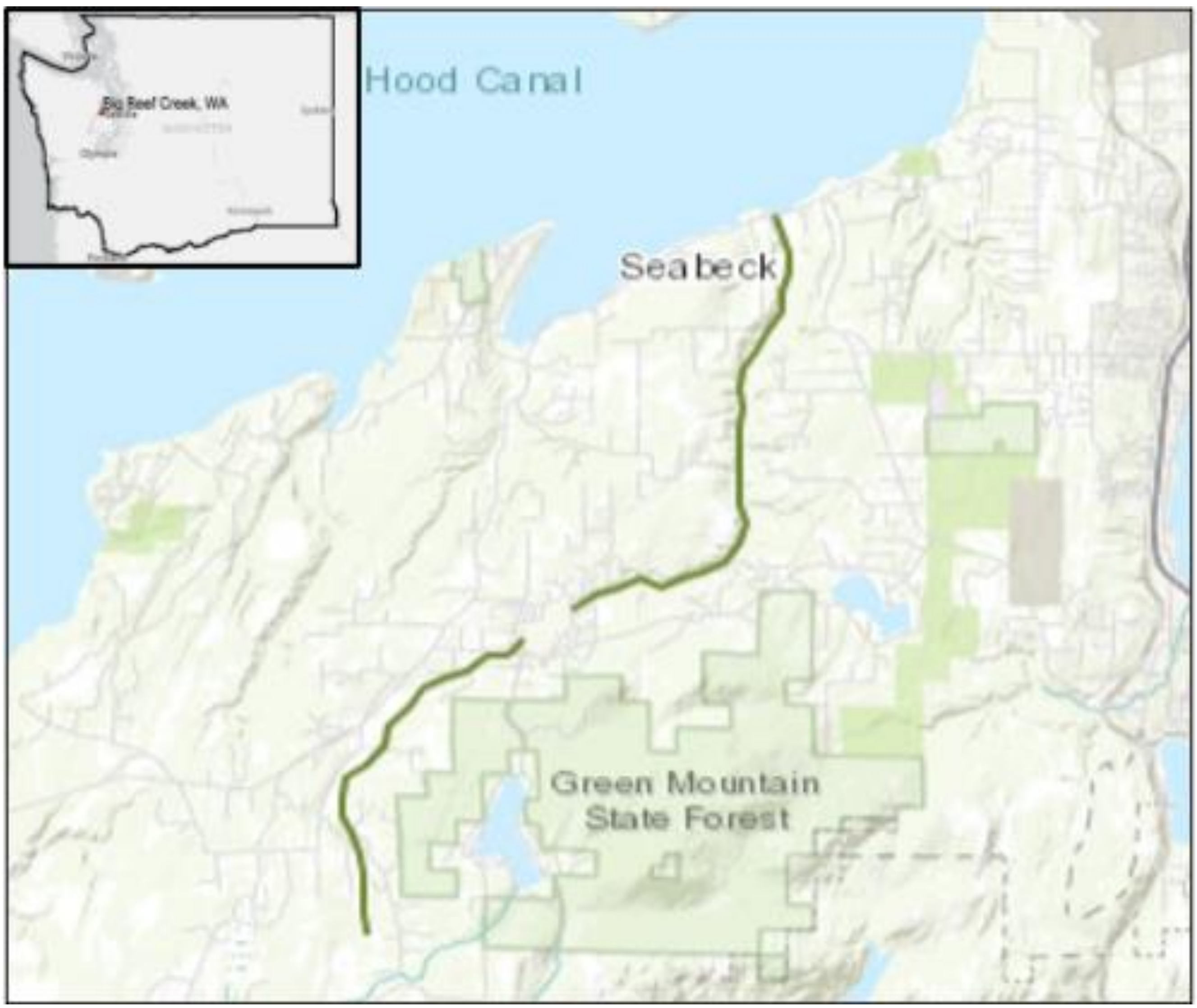


Table 1 List of Pacific Salmonids found in Big Beef Creek

Common name	**Scientific name**
Steelhead	*Oncorhynchus mykiss*
Cutthroat	*Oncorhynchus clarkii*
Coho	*Oncorhynchus kisutch*
Chum	*Oncorhynchus keta*

Coho salmon phenology

Coho salmon have been historically abundant in Washington state and typically select smaller streams and tributaries to reproduce in (Groot & Morgolis 1991). They spend 18 months of their initial life cycle in fresh water and 18 months in the ocean where rapid growth occurs. The initial life cycle is crucial and this length and development depends on temperature unit and seasonal accumulation of heat energy (Dittmer, 2013).

The phenology of coho salmon is highly dependent on long term-averages in abiotic conditions such as precipitation and flow found (Crozier et al., 2008). These flows dictate accessibility to spawning grounds for adults who return to spawn in native streams. The reproductive migration for coho salmon begins in the fall. At Big Beef

Creek, the weir is typically actively fishing and collecting data on fish from the end of August to the end of December annually, depending on weather conditions. According to the 2009 Washington Department of Fish and Wildlife (WDFW) report, the first coho returning to Big Beef Creek were detected in mid-September and the last returning individual returning was detected on November 25th (Kinsel & Zimmerman, 2011). Similar to reports by other researchers, a majority of these arrived after the first few rains that were significant enough to impact flow level of the creek.

Date is a crucial aspect of the success of the species since females determine the offspring's environment exclusively by spawning site and date (Anderson et al., 2010). Change in the arrival time to spawning ground or peak migration are phenological markers for salmon and deviations over time can be indicators of changing environmental conditions or anthropogenic stressors.

Streamflow timing

Warming climate can change the hydrologic cycle across temporal and spatial scales (Kam et al., 2018). Big Beef Creek is within a rain dominated watershed where flows are dictated by precipitation and significant delayed streamflow in recent years has been anecdotally noted by researchers in Big Beef Creek, alongside delayed coho salmon returns. Salmon have physiological responses to a multitude of factors within the freshwater and marine environment. For example, temperature also plays a strong role in determining migration as well as poor marine conditions.

This is crucial to consider when addressing the management for salmon. Phenological traits are generally heritable in salmonid populations and it has been previously hypothesized that microevolutionary changes in migration timing may be one mechanism salmon populations use when faced with climate change (Kovach et al., 2012). Coho salmon have a 2-3 year life cycle which makes them ideal candidates when examining evolutionary changes and shift in migration timing potentially related to changing environmental conditions or climate change.

Harvest

Simultaneous adult returns, commercial salmon fisheries are conducted in Hood canal. One fishery that specifically targets coho and as bycatch in the commercial chum fishery. This provides the fishery two different opportunities to catch coho as they may become bycatch in the chum fishery. The timing of this fishery occurring seasonally and annually has the ability to truncate the run of coho returning to Big Beef Creek. Differential mortality patterns from harvest of wild populations can result in a decrease in density, mean ages, and mean lengths of individuals (Kendall & Quinn, 2017). Furthermore, this harvesting gear that is used often selectively removes larger individuals and this results in a disruption of age and length at maturation among those that do survive to reproduce (Kendall & Quinn, 2017). Reports have shown, 30-50% of exploitation rates are seen within this fishery and fluctuating even to 60- 90% (Kinsel & Zimmerman, 2011; Russell et al., 2018). The fisheries that are not targeting coho salmon may also present a threat as species that are bycatch and released still suffer post-release mortality rates that can be substantial (Gale et al., 2011; Raby et al., 2018). Exploitation rates of coho salmon in Big Beef Creek can be precisely estimated because all fish are coded-wire tagged at the weir upon outmigration.

Regional Mark Processing Center and Coded Wire Tagging program

The coded wire tag (CWT) was introduced to Alaska, British Columbia, Washington, Idaho, Oregon, and California in the late 1960's as an alternative to fin clip and external tag for identification of anadromous salmonids (Nandor et al., 2010). CWTs are small ~ 1 mm long and contains either a numeric code or binary code that is unique to a specific region and it is widely used by federal, state, and tribal fishery managers. This tag is inserted into juvenile salmonids and sits in the nasal cartilage of the fish. The use of CWT remains the most important tool for salmonid research and are most frequently used in studies examining multiple life stages as they allow management to gain insight on ocean distribution patterns, fishery impacts, and survival rates for Pacific salmon (Drenner et al., 2012; Nandor et al., 2010).

The Regional Mark Processing Center (RMPC) is designated by law to house and maintain the CWT database in the U.S. and to be the designated site for sharing data with Canada (Nandor et al., 2010). More specifically the RMPC manages data by (1) maintaining and upgrading regional database for all CWT releases and recoveries, plus release data for fish groups given other types of marks, (2) ensuring that reported data meet established format standards and pass validation procedures, (3) developing and maintaining on-line computer applications for querying and reporting from the database, (4) providing electronic copies of data sets upon request, and (5) implementing recommended changes in the regional database exchange formats to meet expanding requirements for new information (Nandor et al., 2010).

Researchers have often used this data from coded wire tagging which is provided by the RMPC. Specifically, this data is used to estimate ocean distribution patterns and marine survival. Studies that have worked with this data use coastal marine fisheries as samplers of CWTed coho salmon to investigate ocean distribution patterns (Weitkamp & Neely, 2002). Furthermore, these recoveries were used to determine the movements of adult coho salmon in coastal areas as they returned to their natal streams. This method is also routinely used at Big Beef Creek to determine movement and marine survival. This is an efficient method as sampling effort is broad enough to support statistically significant findings. Furthermore, fisheries are generally targeting salmon when and where they are aggregated and therefore easily caught (Weitkamp & Neely, 2002). Coho salmon are also considered a less complex salmon species to estimate marine survival as their life history is relatively consistent (Cochran et al., 2019). Most fish returning to spawn each year are from the same cohort of out-migrating smolts (Cochran et al., 2019) therefore, appropriate forecasts for each year may be made. It is this data and forecasts that fisheries managers use when attending the North of Falcon Meeting and assessing the SaSI, as mentioned previously.

Chapter Two: Literature Review

Big Beef Creek is part of the Hood Canal stream complex. The entire 18 km of Big Beef Creek habitat consists of 8km upstream from Lake Symington and 10km downstream to the mouth (Quinn & Phil Peterson, 1996). Lake Symington is a man-made lake that was constructed in 1970 by installing a 10 meter dam which includes a fish ladder for passage (Quinn & Phil Peterson, 1996). There has been extensive research and restoration efforts in attempts to create a more dynamic and beneficial habitat for juvenile coho and their 18-month initial freshwater stage at Big Beef Creek. This research is part of the Intensively Monitored Watersheds (IMW) program where Big Beef is used as a treatment stream to determine the effects of habitat restoration to fish production. Large woody debris was added to Big Beef Creek in order to create a more dynamic stream network and provide valuable habitat to salmonids at all life stages, with a focus on the benefits to coho salmon. A dike was also removed which opened up the lower floodplain for salmon use. The objectives for the IMW project are to (1) estimate abundance of coho parr and parr-to-smolt survival in all four creeks, (2) estimate juvenile production of coho, (3) compare timing of juvenile outmigration among watersheds, (4) determined escapement of coho and chum into Big Beef Creek, (5) describe spawning distribution and timing of coho in all four creeks, and (6) estimate harvest rate and marine survival of Big Beef Creek coho (Kinsel & Zimmerman, 2011). This serves as an excellent example of the effort and focus on freshwater studies for coho salmon and management. The freshwater lifecycle is frequently studied as there are inherent difficulties with studying salmon in the marine environment (Drenner et al., 2012). This leaves the marine phase of the lifecycle somewhat limited despite being recognized as a critical stage and resulting in a decline to salmon populations (Drenner et al., 2012).

There are gaps in research on the adult coho that return to Big Beef and shifts in migration timing and body size. There are studies available to the shifts in migration timing and evolution within salmonids. Often these shifts are linked to pressure from terminal net fisheries and where salmon are typically size selected, resulting in negative size trends. Salmon also are expected to face changes due to climate change; some populations may already be experiencing this. Research on these effects and changes to salmon and coho salmon specifically will be expanded on further in this literature review.

Habitat selection in coho salmon

Habitat selection is critical as it represents a behavioral adaptation that is assumed to increase individual fitness (Clark et al., 2014). Habitat selection within the stream for redd construction as well as the surrounding environment is critical as salmon exhibit limited parental care (Clark et al., 2014). It is possible that a poor selection in reproduction site can result in a complete loss of the females contribution to the next generation (Clark et al., 2014). Coho salmon are typically found in smaller creeks, rivers, and tributaries. Structurally complex systems with large woody debris, root wads, vegetation, and gravel bed are ideal areas that support coho reproduction. Researchers have found that about 85% of redds built by coho salmon occur in areas where the substrate contains gravel size of 15cm in diameter (Groot & Morgolis 1991). Furthermore redd construction has been typically consistent with maximum stream discharge periods (Clark et al., 2014). Three variables that were highlighted as significant factors by researchers studying habitat selection by female coho were (1) distance to nearest pool, (2) depth at the tailspill, and (3) maximum stream depth (Clark et al., 2014). These are all factors that will potentially affect success of offspring and provide protection for both the spawning adults and juveniles that emerge. Stream depth is also especially important as selecting these areas may further protect fish from predation.

Habitat selection is also a behavioral adaptation that can occur in females further contributing to evolutionary changes seen in coho (Clark et al., 2014). This adaptation is often overlooked or not mentioned in other studies that analyze evolutionary adaptations of coho salmon. Researchers have frequently studied the demographics of habitat loss and habitat loss specifically linked to anthropogenic processes however the evolutionary consequences rarely studied (McClure et al., 2008). A large reduction in habitat can, (1) reduce a systems capacity which could result in a reduction in effective population size and (2) decrease genetic variability within the system (McClure et al., 2008). All anadromous fish have experienced a dramatic change in habitat sites and accessibility which has resulted in extirpation of entire runs or evolutionary changes that result in dramatically altered selective regime (McClure et al., 2008). It is the loss of habitat is largest threat to endangered species in the United States (McClure et al., 2008). Researchers and literature have shown us the importance of habitat selection and we know that extensive habitat restoration has been done on Big Beef Creek by introducing large woody debris to create a more complex stream system which benefits coho even in its juvenile lifestage. There are however gaps in research to the evolutionary changes in habitat selection from coho salmon.

Stream flow timing

The biological processes and life stages of salmonids are driven by phenological traits. This is seen when river temperatures rise in the spring, signaling fry to emerge, and again in the fall when river flows and precipitation create access and cool oxygenated water. River entry is dominated by temperatures and associated flow and discharge rates. More specifically, return migration to the freshwater environment appear to be in two phases: an initial phase with navigation from feeding areas towards the coast and secondly more precise orientation in coastal waters (Davidsen et al., 2013). River entry has also been inherently linked to larger and older salmonids entering prior to younger and smaller salmon (Harvey et al., 2017). Researchers have also noted trends where females enter the river system prior to males (Harvey et al., 2017; Kodama et al., 2012). Streamflow timing may be highly affected by climate change. Several studies predict higher global averages, resulting in a warmer atmosphere which promotes grater hydrologic extremes, more severe drought in the summer and more intense precipitation and flooding in the winter (Crozier et al., 2008). There have also been extensive studies into the earlier streamflow timing associated with earlier snowmelt (W. D. Burke & Ficklin, 2017; Ficklin et al., 2013; Stewart et al., 2005). However, gaps in literature frequently occur when looking at rainfall dominated basins in coastal regions. An increase in temperature is also expected to having a dramatic effect on streamflow as well as precipitation. Studies in the Colorado River Basin suggest that water availability will significantly decrease with streamflow reductions of 30% (Ficklin et al., 2013)

There is an extensive body of evidence that the river entry by salmonids is linked to the amount of flow and discharge that is coming from the natal stream. There is also increasing research conducted on the change in timing among rivers and streams from rain dominated systems to snowmelt systems (Kam et al., 2018; N. Mantua et al., 2010; Stewart et al., 2005). These changes in timing will undoubtably result in changes to migration timing of salmon. Researchers have also found that changes in streamflow timing and the time in which salmon enter the river appear are more important in smaller stream systems (Davidsen et al., 2013). An example of smaller stream systems is known as intermittent streams. Intermittent streams only flow for a portion of the year and make up for 65% of streams found in the western U.S. (Wigington et al., 2006) and coho salmon spawning habitat is frequently found in intermittent stream systems. A study conducted in the West Fork Smith River in Oregon, U.S. showed that 21% of coho salmon spawned in neighboring intermittent streams (Wigington et al., 2006). This coincides with other researchers findings of coho persisting at higher rates in intermittent streams than mainstem perennial reaches (Larsen & Woelfle-Erskine, 2018). There are several small intermittent tributaries which provide ideal habitat for coho salmon both above and below the Lake Symington on Big Beef Creek. The researchers that survey Big Beef Creek specifically have noted that given the chance coho will largely be found in these intermittent tributaries, however they frequently do not have enough water flow to give them access.

Large scale climate studies have analyzed trends in ocean conditions as well as streamflow records across the Pacific North West and note that understanding climate change implications to fisheries management is critical because salmon production goals may simply not be attainable when environmental conditions are unfavorable (Mantua et al., 1997). These reductions in flow however will certainly reduce the availability of spawning habitat for salmon populations that spawn early in the fall (Mantua et al., 2010). This reduction of spawning habitat will be further emphasized by the elimination of intermittent tributaries which may remain dry all season, limiting access and site selection by coho.

A study conducted by Mantua et al., 2010 classifies Washington's watersheds into snowmelt dominant, transient, or rainfall dominant based. The Hood Canal stream network falls into the rainfall dominated category (Figure 1) (Mantua et al., 2010). These watersheds are predicted to face large changes in the coming decades and a trend in delayed stream flow timing has already been observed. Most of Washington's river basins are projected to experience reduced streamflow in summer and early fall that results in extended period of low summer flows, while rainfall-dominant basins are projected to have substantially lower base flows (Mantua et al., 2010).

Fish that arrive early in the season frequently experience inaccessibility to smaller tributaries that provide optimal spawning habitat. Researchers have found that the flow in Big Beef Creek are dominant from rains that occur between November and March (Quinn & Phil Peterson, 1996). More recently these averages have been published as being from October to mid-November (Kodama et al., 2012). This fluctuation is precipitation and streamflow is a driving factor for this study in looking at long term trends. Precipitation and stream flow may result in fluctuations in selection as well as affect timing of return fish (Kodama et al., 2012). This was seen by in a study where 80% of the 2006 cohort in Big Beef Creek was delayed until the beginning of November (Kodama et al., 2012). In the 2007 return migration of this study, adults were found to return in peaks ranging from the beginning of October to the end of November. Furthermore, the male to female ratio was higher in 2007 suggesting a directional selection for larger 3-year-old males. For females in this study, a larger body size and directional selection was favored in 2006 and intermediate size in 2007. This was determined based on reproductive success. This research along with that of others suggest that there is fluctuations in mode, directional selection and strength of selection on return date in both sexes of salmon (Anderson et al., 2010; Kodama et al., 2012).

The salmon fishery in the Pacific Northwest is generally managed by implementing gear restrictions and time and area closures, which limit the amount of fishing opportunity available (Vander Haegen et al., 2004).

Implications

The salmon fishery in the Pacific Northwest is generally managed by implementing gear restrictions and time and area closures, which limit the amount of fishing opportunity available (Vander Haegen et al., 2004).

The strain of commercial harvest on salmon has been well documented. There are however salmon fisheries that have been noted as archetypes of sustainable resources and management, such as the Bristol Bay, Alaska sockeye fishery (Atlas et al., 2021). Salmon are harvested during their oceanic feeding migration and numerous different populations of salmon are caught at once. This is seen in Big Beef Creek coho as well, although many are caught near the mouth or in the marine area nearby. The commercial fishery here typically uses gillnet which are known for being size selective, but also can result in delayed mortality from fish that experience unobserved entanglement or are released for conservation concerns (Baker et al., 2011; Bass et al., 2018). Beach seine are arguably the better method as post capture release survival rates for salmon are 95% compared to 40% in the gill net sets (Bass et al., 2018). However, this is only true when proper handling techniques are used. Fishermen may frequently allow fish to stay in nets that are pulled onshore and wait until fish become less active so they are easier to handle.

A study conducted by Vander Haegen et al., 2004 studied Chinook salmon caught in two different size nets, an 8 inch gill net and a 5.5 inch gill net. Nearly every fish from the study retained net marks or damage on the body with the 5.5 inch net producing all marks around the snout and the 8 inch resulting in net marks and damage on the body. This body damage was seen to be severe and resulting in a large loss of scales, slime, or scars and only 57% post capture successfully recovered (Vander Haegen et al., 2004). This is similar to post capture release survival found in a study conducted on sockeye salmon in Bristol Bay by Baker et al. 2011, however these researchers emphasize that this estimate is conservative and post release mortality may be up to 74%.

Differential mortality patterns from harvest of wild populations can have significant ecological effects, including reductions in density with associated increases in growth and decreases in mean ages and lengths of individuals (Kendall & Quinn, 2017). Furthermore, harvesting gear often selectively removes individuals with respect to length (Kendall & Quinn, 2017). Fishery selection may lead to genetic changes in life-history traits which may be harder to reverse than changes associated only with phenotypic plasticity (Law, 2000). There is a body of evidence of this effect for the last century on selective harvest resulting in a shift towards smaller sized fish and even a decreased age at maturity. Additional issues with size selective harvest include:

(1) decreased fecundity

(2) increased sexual dimorphism

(3) lowered reproductive rates

(4) reduced yield

(5) increased variability in abundance

(6) stock collapse

283 years of size selection patterns were quantified from nine Alaskan sockeye salmon fisheries and direction and size selection patterns were analyzed (Kendall & Quinn, 2017). In 72% and 84% of the years the fisheries caught larger than average male and female fish, respectively, leaving smaller fish to spawn (Kendall & Quinn, 2017). The results of this study also showed that nonlinear selection differential values for males were significantly larger than females, indicating males experienced more disruption than females (Kendall & Quinn, 2017).

In a study conducted by Ohlberger et al. 2018, Chinook salmon size at the time of their return to native streams were analyzed. This study showed a negative trend in body size in recent decades. Results from wild fish populations analyzed in Alaska, British Columbia, Washington, Oregon, and California showed a negative trend and a decline in mean age, with the strongest of this change seen in Alaskan populations. Furthermore, an interesting find in the relation of size and age showed that the younger individuals (1-2 years) experienced an increase in size where older individuals (4-5) experienced a decrease in size over time. This result was glaring for individuals in the 4-5 year class for wild stock and less so for 1-2 year class of wild stock. Specifically this is a 5% decrease in size at age for 3 year olds, 7% decrease for 4 year olds and, 9% for ages 4-5 (Ohlberger et al., 2018). Most importantly, researchers in this study noted that the decline in size-at-age was most attributed to size selective harvest. Size selection on Chinook through commercial fishing is incredibly effective and has shown to produce an evolutionary response towards smaller average size of fish (Ohlberger et al., 2018). This is documented through this study and among many others. This study is important as it shows a growing concern for size selection as well as size-at-age for Pacific Salmon. While this occurred in Chinook salmon, we may draw similar conclusions for coho salmon in Big Beef Creek.

Alternative methods

Alternative methods are seen in a study done by Atlas et al. 2021 where it is argued that by returning to true traditional indigenous methods of fishing such as, reef nets, dip nets, or fish wheels, fish may be harvested more sustainably by being in control of selection and having the ability to release wild fish.

Phenotypic plasticity and evolutionary changes:

Reproduction in teleost fish as with other vertebrates is characteristically cyclical. Where, cyclicity is imposed by the factor that environmental conditions tend to recur cyclically or seasonally. Furthermore, these reproductive cycles are adaptive for each species and they depend on the evolutionary and ecological niche of the species (Miller, P. J 1979). Changes in one life state can have extensive repercussions for later life states, particularly in migratory animals where multiple life-stage transitions are finely tuned to conditions in radically different environments (Crozier et al., 2008). Furthermore, plasticity and change in response to climate change are not certain as salmon face a variety of other stressors from hatcheries, harvest, and dams (Crozier et al., 2008).

Evolutionary changes that occur in salmonids has become increasingly available as its value towards conservation and management practices becomes more apparent. This includes changes in migration timing and shaping alternative phenotypes. Data has shown that over the past century spring and summer Chinook as well as sockeye have been migrating at earlier times (Crozier et al., 2008). Coho may also deviate from established run timing in response to environmental conditions such as flow availability and stream accessibility (Groot & Morgolis 1991). These migration events are timed to coincide with environmental conditions that maximize individual fitness and many species including coho salmon will change migration timing to match new conditions produced by climate change (Kovach et al., 2012). In a study by Kovach et al 2012, pink salmon in Auke Bay, Alaska were found to have directional selection for earlier migration. Furthermore, these researchers have discussed there being a strong correlation between the migration timing and recent climate changes (Kovach et al., 2012). This idea is further supported by reviewing other studies in the Pacific Northwest specifically where salmon populations are seen shifting migration timing.

Directional selection in migration timing is also seen in sockeye salmon in Bristol Bay, Alaska. Quinn et al., 2007 compiled data from returning fish counts and commercial harvest data and observed that the median dates of returning migrating fish became earlier from 1969 to 2003 in both districts' studies. This study also notes an interesting correlation between the harvest timing and the sockeye response where, when harvest pressure heavily increased at the tail end of the run, the larger the directional selection for an earlier migration timing was for sockeye (Quinn et al., 2007).

Anderson et al., 2010 also studied directional selection in reproductive timing specifically for coho salmon in the Cedar River, Washington, while also looking at body size in relation to reproductive success of the species. These researchers found that selection on breeding timing changed in form while selection on body size changed in magnitude (Anderson et al., 2010). Body size as argued in this study and others is among the most important traits that influence production and survival of offspring (Anderson et al., 2010). This is because larger individuals often experience more reproductive success. Specifically, large females can produce more numerous and larger offspring and have more advantages competition for nesting sites (Anderson et al., 2010). Furthermore, to loose older and larger individuals of a population result in overall reduction of population productivity. This is because smaller salmon have lower fecundity, lower offspring survival and, may not be able to dig deep enough redds to reduce susceptibility to scouring (Ohlberger et al., 2018).

We know that size selection is a common issue in the harvest of salmon. This is also documented in a study by Kendall & Quinn, 2017 where 283 years of size selection on sockeye salmon from 9 different fisheries in Alaska were analyzed. The results revealed a staggering 72-84% of larger individuals within the population being caught and leaving smaller individuals to spawn (Kendall & Quinn, 2017). Furthermore, it was seen that a disruptive size selection was more prevalent in males than females and the length of fishing season also resulted in a greater size selection impact (Kendall & Quinn, 2017). This is due to the fact that fish of different lengths often vary in run timing making the timing and length of harvest critical factors.

A study using 20 years of data from coho salmon in Oregon showed a synchronous relationship between adult males and jack males. The proposed explanation for male fish adopting the jack phenotype depends on growth during early life and in the freshwater environment with climatic variables such as precipitation providing supporting evidence (Koseki & Fleming, 2007).

It has also been argued that with the strategy employed by salmon where females enter the river system first, harvest pressure may be biased towards sex of the fish (Harvey et al., 2017).

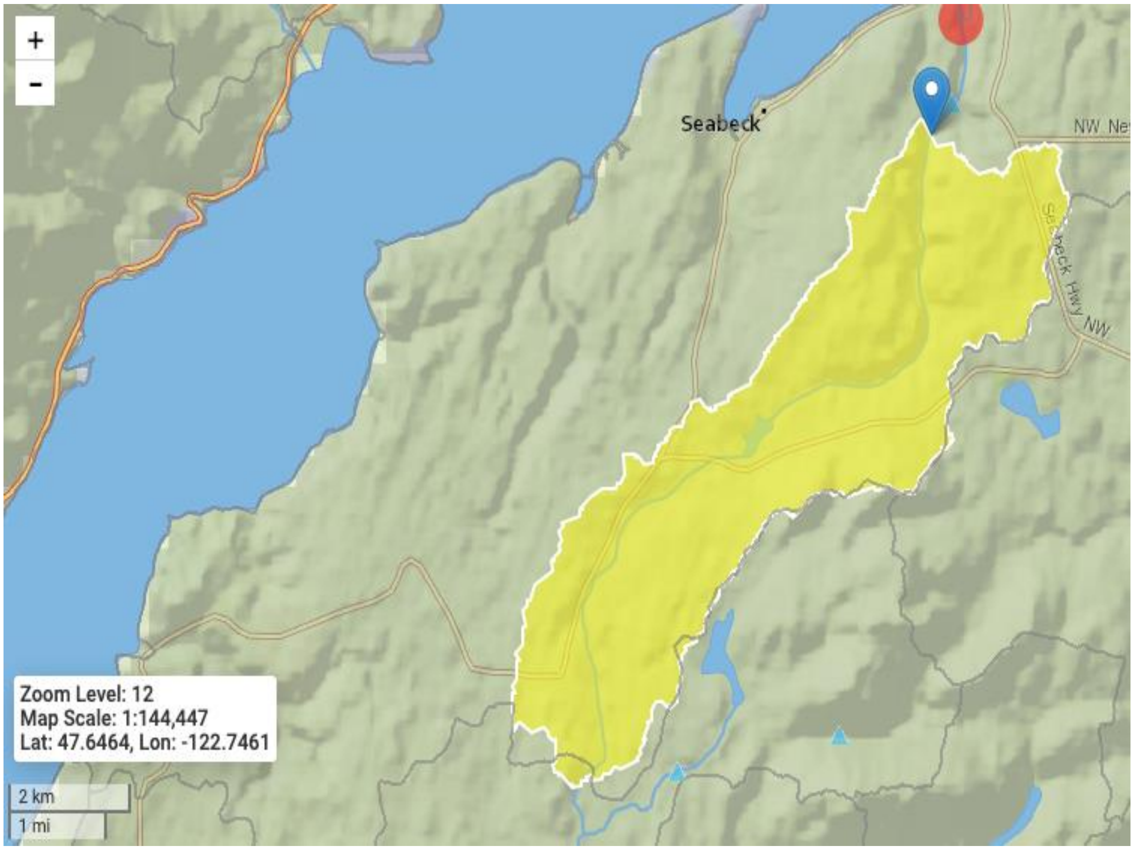
Chapter Three Methods:

Streamflow:

Streamflow data from water years 2000-2020 were collected from the USGS water data archives (USGS Water Resources, 2021) and Kitsap County Public Utility Department (KPUD) database (KPUD Hydrological Data, 2021). The flow gage was active under the USGS until 10/4/2012 in which time the KPUD took over. All data collected had been approved by the respective agencies as opposed to being in the provisional stage.

Flow gage for Big Beef Creek is located at Latitude 47°38'27”, Longitude 122°47'02" and has a drainage area of 13.8 square miles (Figure 2). The retrieved water data sets were used to create twenty-year average trends and plotted against daily average discharge for years 2000-2020 during the months of August to December. This allows for a twenty-year time period to be analyzed in initial plots for any significant changes against each year.

Figure 2 Map of drainage area to streamflow gauge located on Big Beef Creek.



Weir

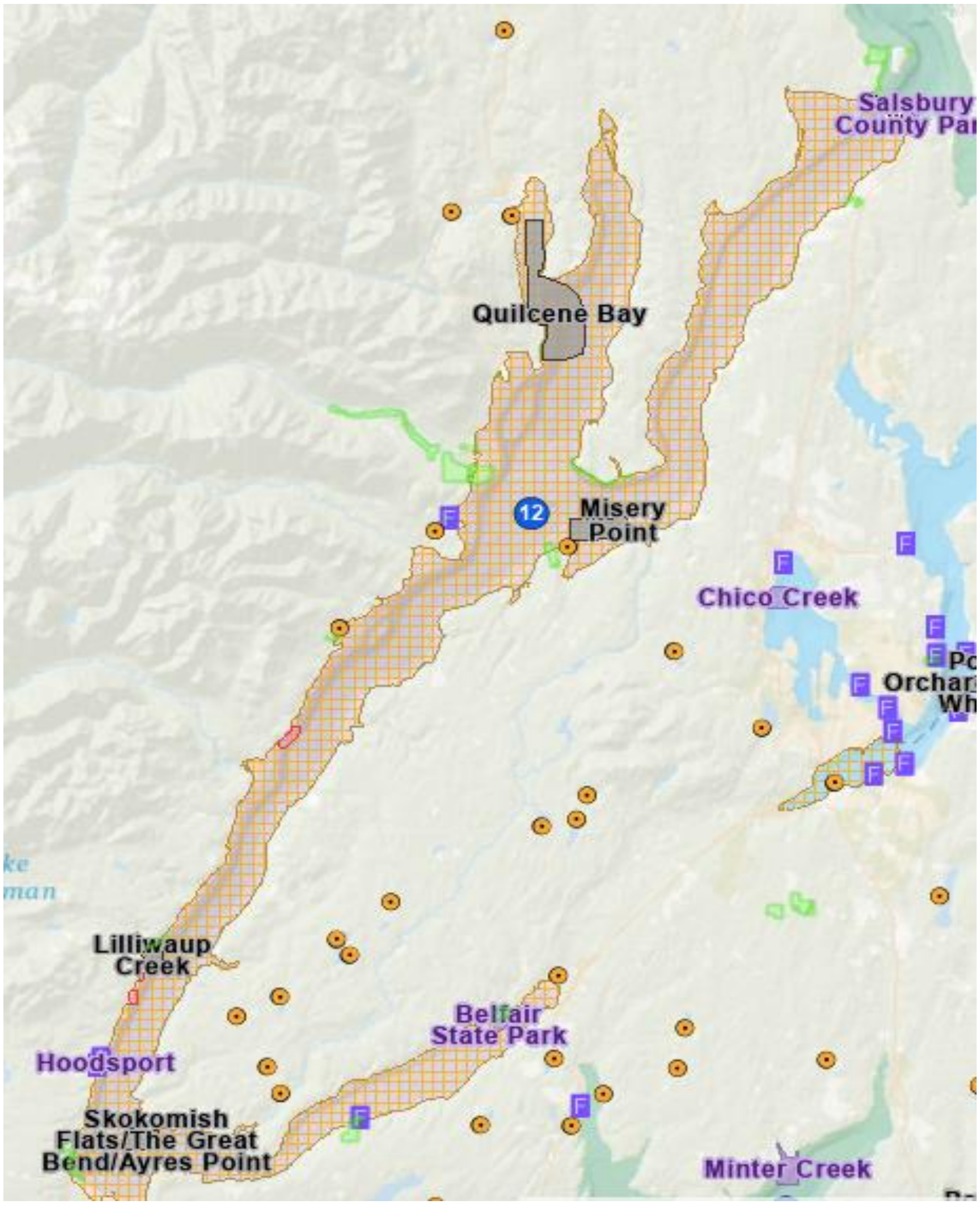
A weir is put in place each year from mid-August to the end of December annually to collect data from the adult coho return migration. Fish are processed within 12 hours of entering the weir (Kinsel & Zimmerman, 2011). Coho are enumerated, checked for tag status, sex, mark status, length, and scales are taken as an ageing structure. Only coho with the presence of an adipose fin are passed above the weir, this allows researchers to identify wild stock vs. hatchery stock fish. Scales and body size differentiate two different age classes of males with males < 35 cm as jacks and males between 35 – 45 cm assumed to be jack males (age 3) (Kinsel & Zimmerman, 2011).

Harvest

The Regional Mark Processing Center (RMPC) online database was used to download harvest data based on tag codes from out migrating juvenile coho tagged at the Big Beef Creek weir. Data was organized by statistical week and from the Marine Area 12, 12B, and 12C fishery only, this is highlighted in Figure 3. This accounts for 92% of coho salmon harvested in the terminal commercial fishery. Because this study researches the effects of streamflow on harvest rates, it would not be pertinent to include harvest data from those caught farther out in other marine areas. Although it is important and worth mentioning the harvest rates in this study reflect that of a certain marine area and not of the entire run.

Bar graphs were used to view relationship between harvest and fish that migrated upstream.

Figure 3 Marine 12 fishing area, highlighted in orange cross marking. Map courtesy of the Washington Department of Fish and Wildlife.



Peak adult migration and lengths:

Data collected from the weir at Big Beef Creek containing the total number of fish that returned to the weir each day were organized by total adults that arrived at the trap. For this study coho jacks were excluded to maintain consistency among the available datasets. Furthermore, since I used harvest data to make comparisons and, jack coho are rarely kept in the commercial fishery, they were excluded. Lengths were then extracted from both the harvest data and total returned adults to the weir each year. Jack and jack male fish are 100% sampled. These are determined by their size class, either a jack under 35 cm or a jack-male that is between 35-45cm. Once the data has been processed and scales aged jack males are either found to be jack or males and reassigned. Because of the differences in sample rates the male sample rate was determined for each year and then applied to jack males, these were then randomly sampled using R Studio (Version 1.2.5033) (rstudio.com) using the following code:

```
Df[sample(nrow(df) # of samples needed),]
```

Juvenile outmigration and tagging

Juvenile outmigration data is collected from April to June annually when smolts are processed through the juvenile fan trap at Big Beef Creek. Coho smolts are tagged with Coded Wire Tags (CWT) using wire, Mark IV Tag Injector ©, and V Detector © from Northwest Marine Laboratories to ensure placement. Tag numbers were assigned to groups leaving in early, middle, and late groups which were determined by staff that processed the fish as the trap based on timing throughout the season. Each group was assigned different tag codes for migration time. These were not always consistently divided into three groups due to the number of fish available each year, therefore resulting in years with only an early and late grouping. For example, 2014 had 63 days of juvenile tagging and 2013 with the shortest amount of tagging days at 39. The previously established migration timing categories for juvenile outmigrants began for smolts in 2007, so the available dataset it shorter than the rest of the data available in this study. This was also used up until the most recent RMPC available data set for harvest. The average duration for outmigration was 47 days and tags were switched on average 19 days for early classified fish, 11 days for middle classified fish, and 21 days for late classified fish. Some years only early and late groups were established among outmigrants. The data used to compare return timing came from the terminal net fishery and was broken up into early, early middle, late middle, and late. This was to delineate even comparisons in the return data from weeks 38-45, with each category consisting of two weeks.

Statistical analysis

To calculate a change in time among streamflow from 2000-2020, methods from Stewart et al., 2005 were followed where:

1. The seasonal fractional flows (SFF) are calculated by the streamflow that occurs in a given month to the total amount of streamflow for the season each year. Where a season in this study is defined as September 1 – December 31. Water year is calculated from October 1- September 29 annually, as defined by the USGS.
2. The date marking the timing for the center of mass of flow timing (CT) for each water year was calulated.

The equation for determining the CT for each year is:

$$CT=\sum(q_i t_i)/\sum qi$$

Where q_i = daily flow and t_i = the number of days from the beginning of the season (Stewart et al., 2005).

A three-year moving average was then calculated for SFF as outlined by Ditmer, 2013 to enhance statistical robustness of the annual data. The SFF was then compared to that of the SFF from the years 1971-1979 and 1980-1999, and a two sample t-test was run to determine significance to historical water data. The water data from the USGS had gaps from the years 1981-1995, therefore these years were not included in our past comparison of SFF. The results from CT calculations were then run in a simple linear regression. Spearmans correlation rank test was used to look at trends in discharge (flow in cfs) and adult return fish, as neither of these data sets were normally distributed. Spearmans correlation rank test was also used for weekly harvest and discharge data to determine if low flows corresponded to a larger harvest rate. Harvest and discharge were also plotted in simple historgram graphs to visualize this relationship.

Contingency tests were used to determine if migration timing between juveniles and returning adults was independent or not. For some years where the data did not meet the assumptions of the contingency test, meaning 20% of cells having less than an expected frequency of 5 or cells having less than one (Whitlock & Schulter2015), a Fisher's exact test was employed. Mosaic plots were also used to visualize comparison of this data.

Average lengths for each year were then calculated and a two-sample t-test was run on average annual lengths from coho caught in the commercial fishery and those that returned to the weir to test a potential size selective harvest.

```
t.test(x~y, data= , alternative = "two.sided", var.equal = FALSE)
```

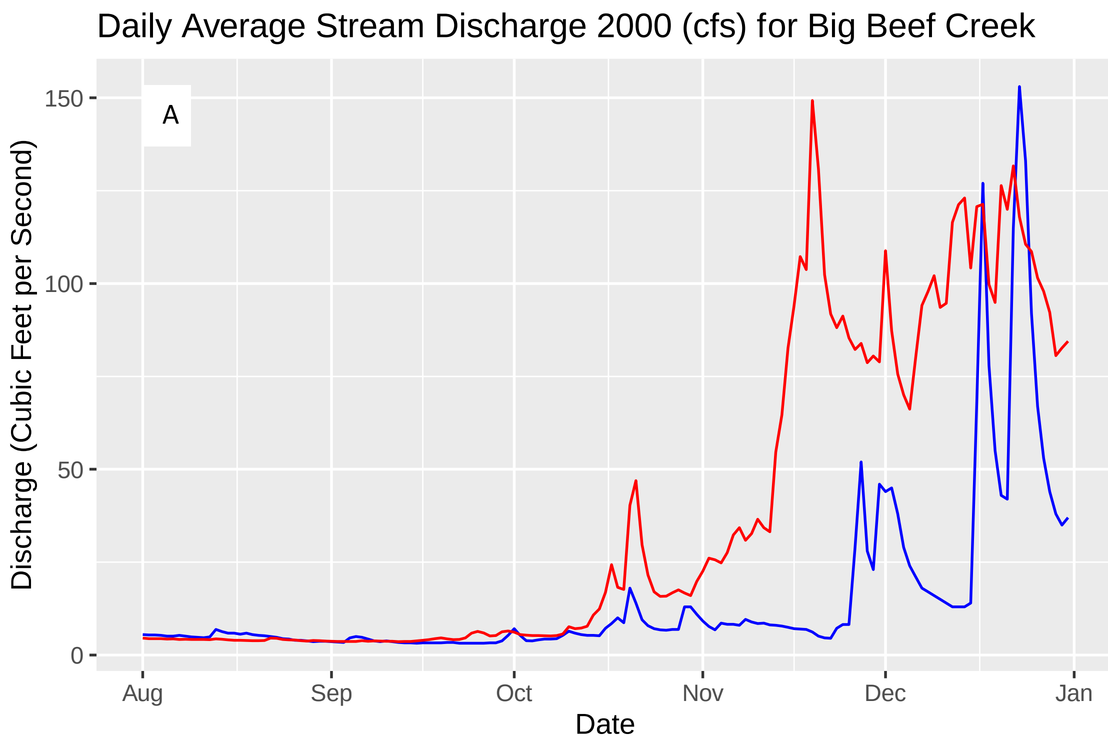
Lastly, a multiple regression was run on center of mass flow timing, seasonal fractional flow, total harvest, date of peak return, and year variables.

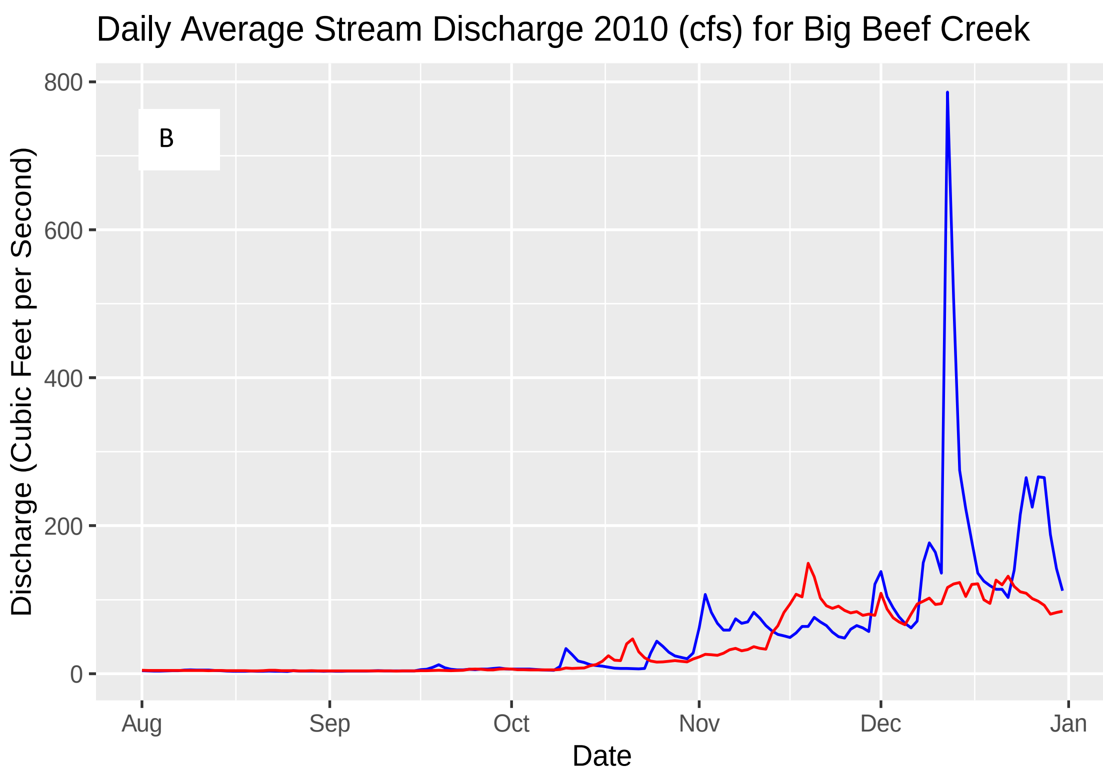
```
lm(Date_of_peak ~ year + var 1 + var 2…, df)
```

Chapter Four Results:

Initial Daily average flow compared to the twenty-year average showed extreme variation, with many years having flood events exceeding the twenty-year average. Graphs are included from 2000, 2010, and 2020 as they represent the beginning, middle, and end of the dataset (Figure 4). 2003 specifically shows a large spike in discharge at the end of October. This is likely responsible for the flow bump we see in the twenty-year average across all plots. For comparison, a flow plot where discharge values that were within two standard deviations of the average for October in the twenty-year database is included (Figure 5) to show how this affected the twenty-year average.

Figure 4 Streamflow for seasonal duration of August to December for A. 2000, B. 2010, and C. 2020. Where red is the same in each, being the twenty year average and blue indicates each years flows




Daily Average Stream Discharge 2010 (cfs) for Big Beef Creek
B
Discharge (Cubic Feet per Second)
800
600
400
200
0
Aug
Sep
Oct
Nov
Dec
Jan
Date

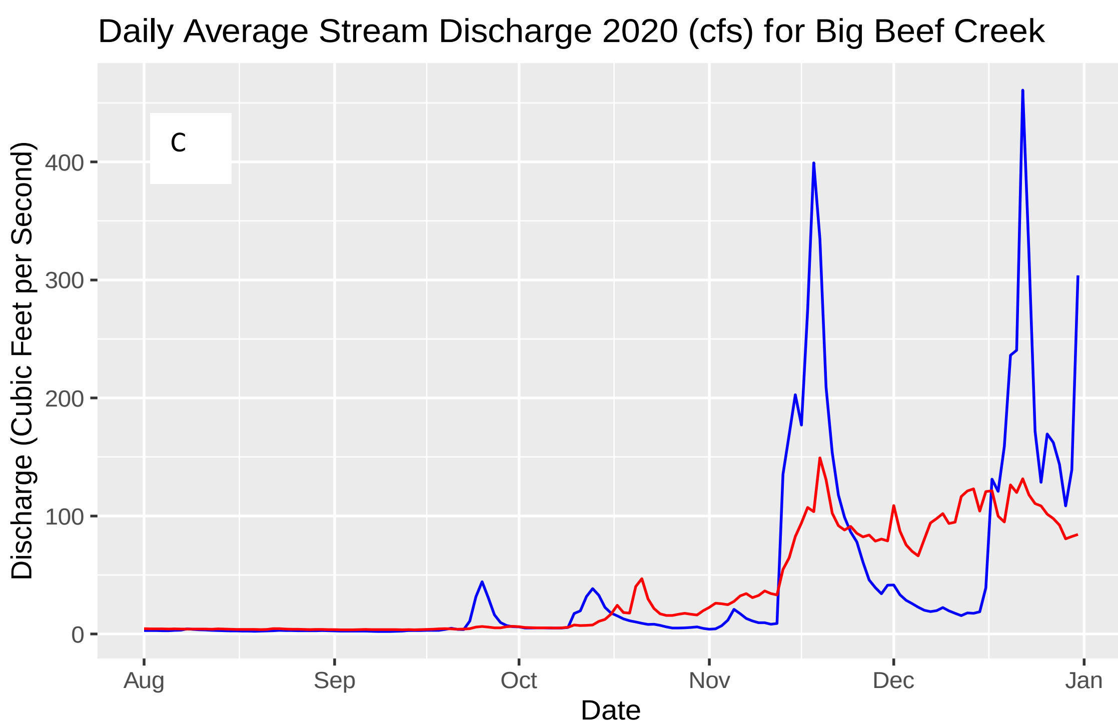
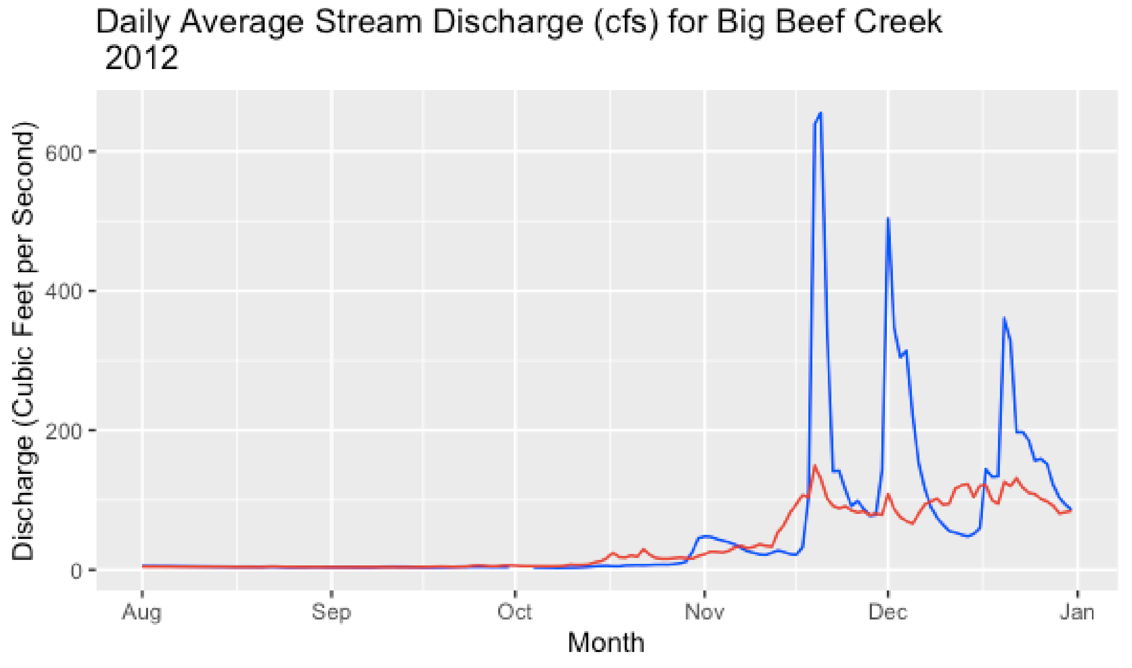

Daily Average Stream Discharge 2020 (cfs) for Big Beef Creek
C
Discharge (Cubic Feet per Second)
400
300
200
100
0
Aug
Sep
Oct
Nov
Dec
Jan
Date

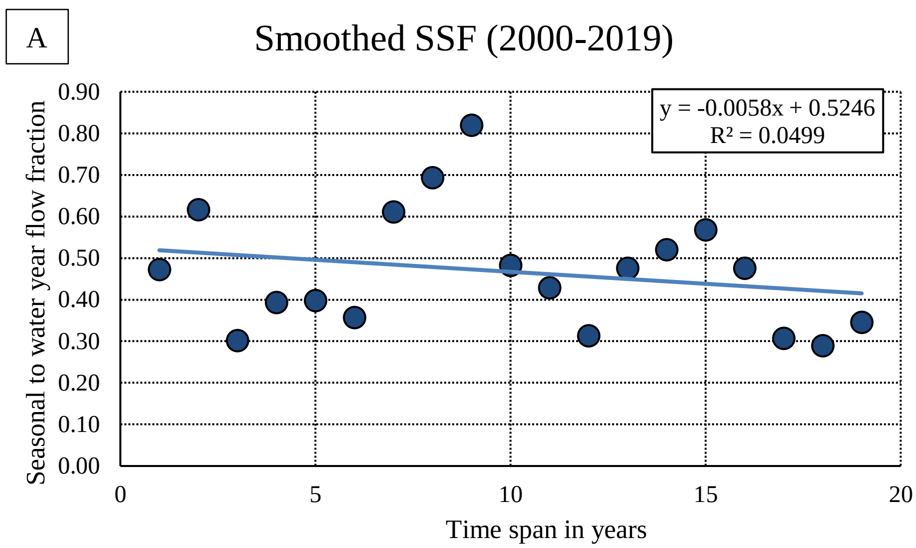
Figure 5 Adjusted plot to compare the effects of the 2003 early flooding event

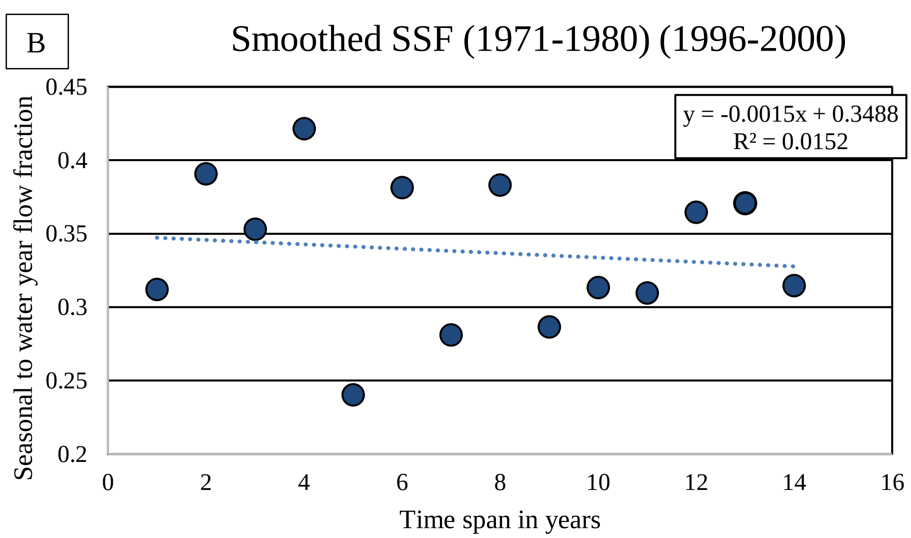


Seasonal Fractional Flow for Big Beef:

The three year moving average for SFF showed a negative trend with up to a 58% decrease seen Figure 6. The SFF from years 1971-1980 and 1996-2000 showed a slight decline in flow however much less at 15% decrease, suggesting more significant flow changes in the last twenty years. The two sample t test between these two data sets also showed a significant change ($p<0.05$).

Figure 6 Seasonal fractional flows for A. 2000- 2020 and B. historical data 1971-1980

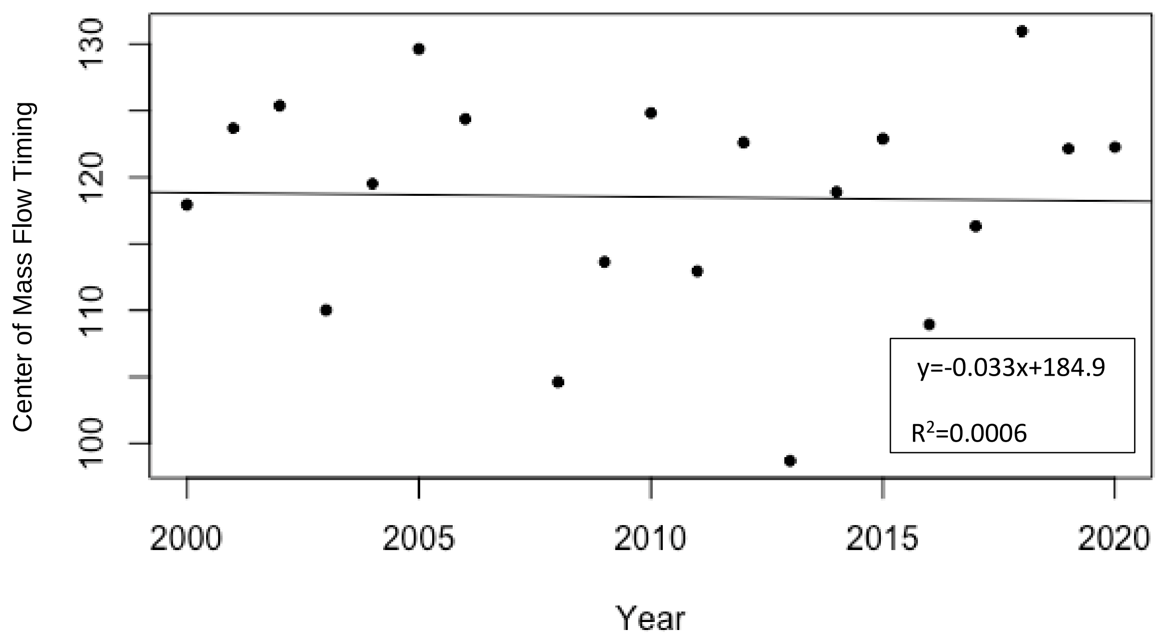




The centroid of mass flow (CT) was calculated for each year as defined by (Stewart et al., 2005) and placed in a linear regression as seen below Figure 7.

The CT for the twenty year data set has a weak linear regression with R squared value of 0.006 (Figure 7). However t.test results show significant difference ($p \leq 0.05$) of mean flows. The difference from 2000 to 2020 is a delayed CT of 4.32 days. The earliest CT is seen in 2013 and the latest CT in 2005, the difference between these being 30 days.

Figure 7 Central mass flow timing for Big Beef creek over the years 2000-2020



Harvest

On average about 50% of the coho salmon are caught in the commercial terminal net fishery annually over the past twenty years Table 2 from Marine Area 12.

Table 2 Percent of coho harvested in terminal net fishery for each year

Year	% of total run harvested
2001	10%
2002	29%
2003	1%
2004	21%
2005	46%
2006	40%
2007	52%
2008	53%
2009	65%
2010	63%
2011	58%
2012	55%
2013	69%
2014	47%
2015	16%

2016	15%
2017	59%
2018	83%
2019	45%

Harvest data is broken into statistical week. Coho are harvested over an 8 week period from stat week 37 to 45. This is typically the from September to mid-November.

The Spearmans rank correlation used to test the hypothesis on harvest and streamflow discharge as well as discharge to fish return at trap showed expected relationships Table 3. Harvest to discharge was mostly negatively correlated to stream discharge, with the exception of years 2001, 2004, 2006, and 2007. The interpretation of this is that harvest was found to be mostly productive where flows were too low to induce fish migration, supporting the hypothesis. Alternatively fish return was positively and strongly correlated with stream discharge with -.08 Spearmans rank in 2006 and -0.9 in 2009 for example. There was no relationship however found in stream discharge and fish return for years 2001and 2006.

Table 3 Spearmans rank correlation for upstream fish passage and harvest to streamflow discharge relationships.

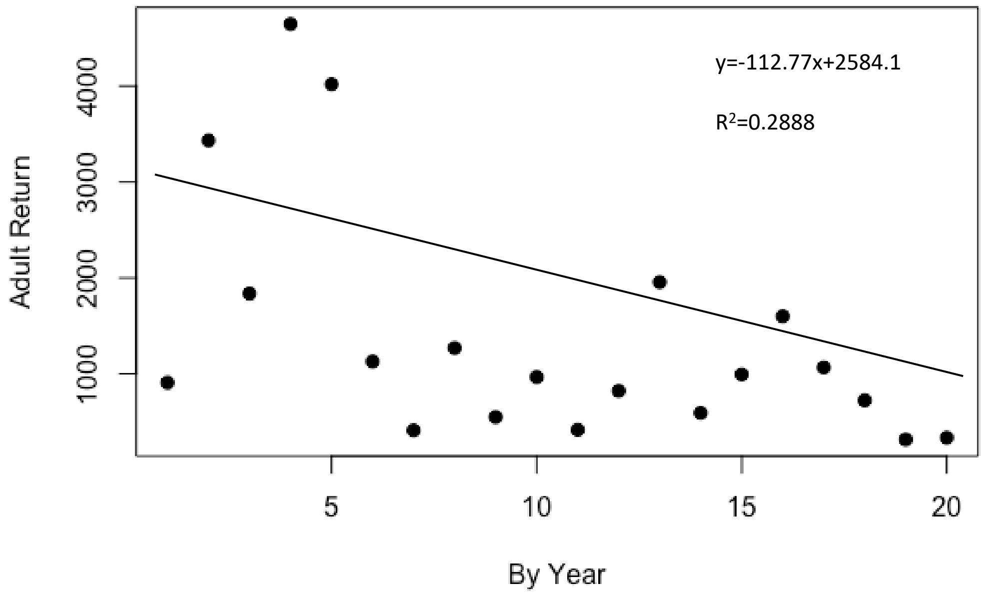
Year	Fish return to discharge	Harvest to discharge
2001	-0.0093709	0.3567338
2002	0.4440706	-0.4191692
2003	0.1283883	-0.463713
2004	0.3282476	0.5952381
2005	0.2130638	0.5389318
2006	-.06754507	-0.8095238
2007	0.6994494	0.6190476
2008	0.3449361	0.1317389
2009	0.8530918	-0.9047619
2010	0.6962682	-0.1077864
2011	0.2541243	0.2634778
2012	0.5141565	-0.6428571
2013	0.2140568	0.0952381
2014	0.5734611	-0.2380952
2015	0.6377554	-0.6107894
2016	0.6496628	-0.09759001
2017	0.5288116	0.3712641
2018	0.5358567	-0.7319251
2019	0.5177585	-0.7319251

A negative relationship, indicating correlation supporting the hypothesis was detected for all years with the exception of four years, 2008, 2011, 2013, and 2017. However, these are relatively weak positives with 2011 and 2017 having the highest spearmans rank at 0.26 and 0.37 respectively.

Timing

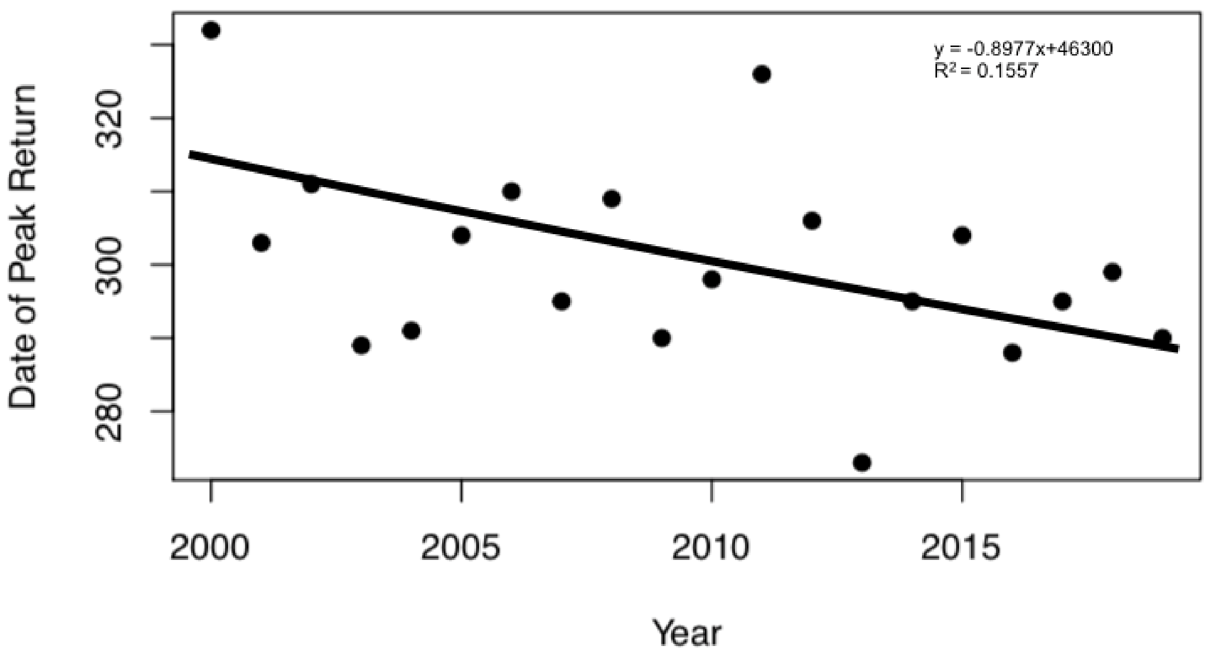
Overall coho salmon recorded as returning to the trap are in decline. The last large return at Big Beef was seen in 2004 and the simple linear regression for the entire data set in this study returns R^2 of 0.28 Figure 8.

Figure 8 Total adult coho return to Big Beef creek that are passed upstream to spawn over the past 20 years



The linear regression of dates of peak migration change for adult coho signals a trend toward an earlier migration timing. R squared value for the twenty-year peak migration is 0.1557 and the difference from 2000 to 2020 peak is 30 days. The most significant deviations in from this timing trend change was seen in 2011 and 2013. In 2011 the flow was below the twenty-year average until close to the end of November. Although, this overall trend of earlier arriving fish was found to be significant with a p value of 0.04441. 58% of the fish were harvested this year and the spearman's rank correlation value for discharge to migration upstream was 0.25. In 2013 the peak return coincided with initial fish movement upstream at 09/30, a much earlier migration timing which also is associated with the earliest CT seen in this study. This year 69% of the total run was harvested and the Spearman's rank correlation value for discharge to migration upstream was 0.095. 2013 actually carried a streamflow daily average above the twenty-year average which would have allowed fish to pass as early as September. These values and relationships reinforce the hypothesis between flow and fish migration.

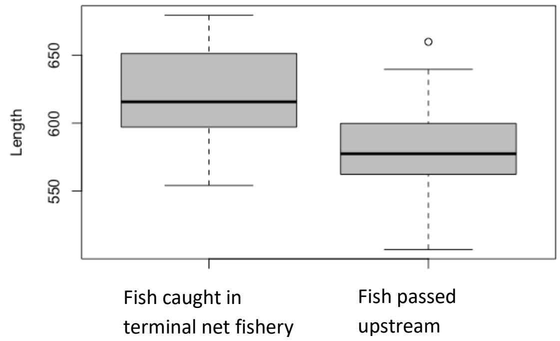
Figure 9 Peak return of coho at Big Beef Creek that are passed upstream to spawn. Where date is in julian or calendar day.



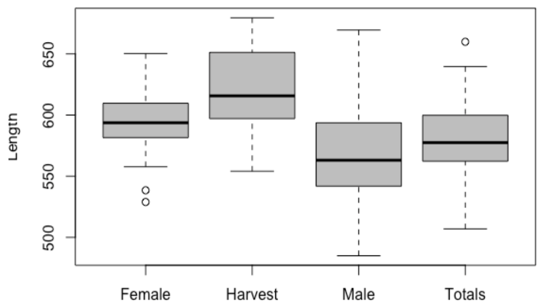
Size

Body size in coho salmon found in Big Beef Creek were shown to be decreasing. Furthermore, the size of individuals caught in the terminal net fishery are larger than those that arrive at the trap up stream, as well as a more significant negative size trend seen in male coho (Figure 10). The differences in means of coho salmon are 622 mm in mean length for those harvested and 581mm in mean length of those that arrive at the trap (p-value 0.0013)

Figure 10 Box plot of lengths of coho that are caught in the terminal net fishery and those that are passed upstream. Box plots further browkn down into sex, where harvest represents those that are caught in the terminal net fishery and female and male are those that were passed upstream. Lastly, totals represent both male and females combined that were passed upstream.



.




```
        Welch Two Sample t-test

data:  Length by Origin
t = 3.4804, df = 35.792, p-value = 0.001336
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 17.10306 64.89393
sample estimates:
mean in group Harvest  mean in group Totals
             622.2996              581.3011
```

Simple linear models also show a general decline across both female (Figure 11) and male (Figure 12) coho, male and female combined (Figure 13) and those that are caught in the terminal net fishery (Figure 14).

Figure 11 Female coho length trend over time, p value of 0.02725.

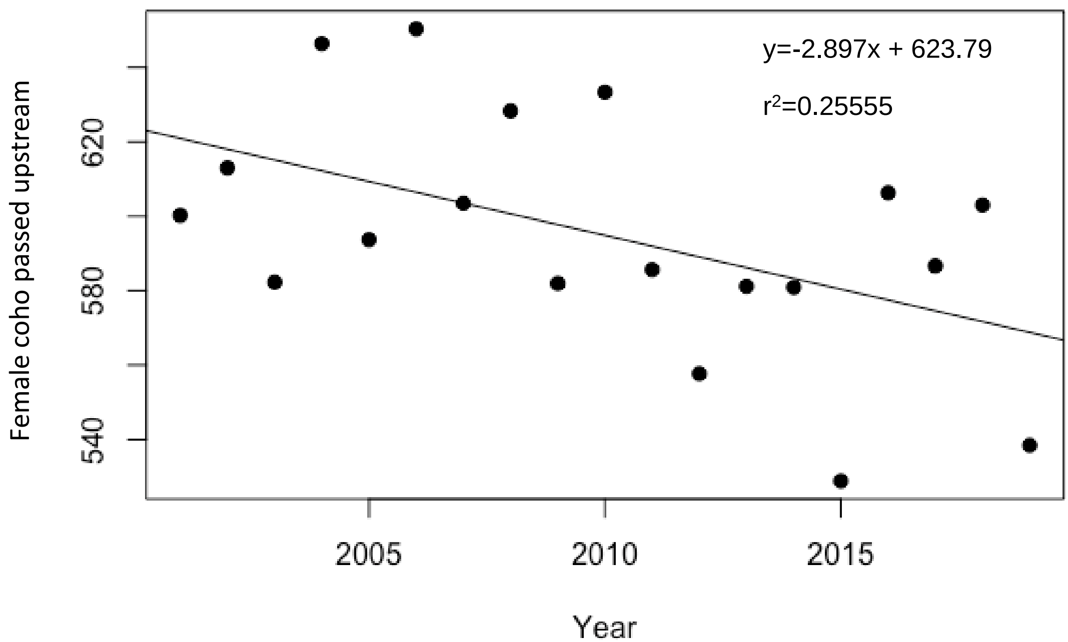


Figure 12 Male coho length trend over time, p value 0.005295.

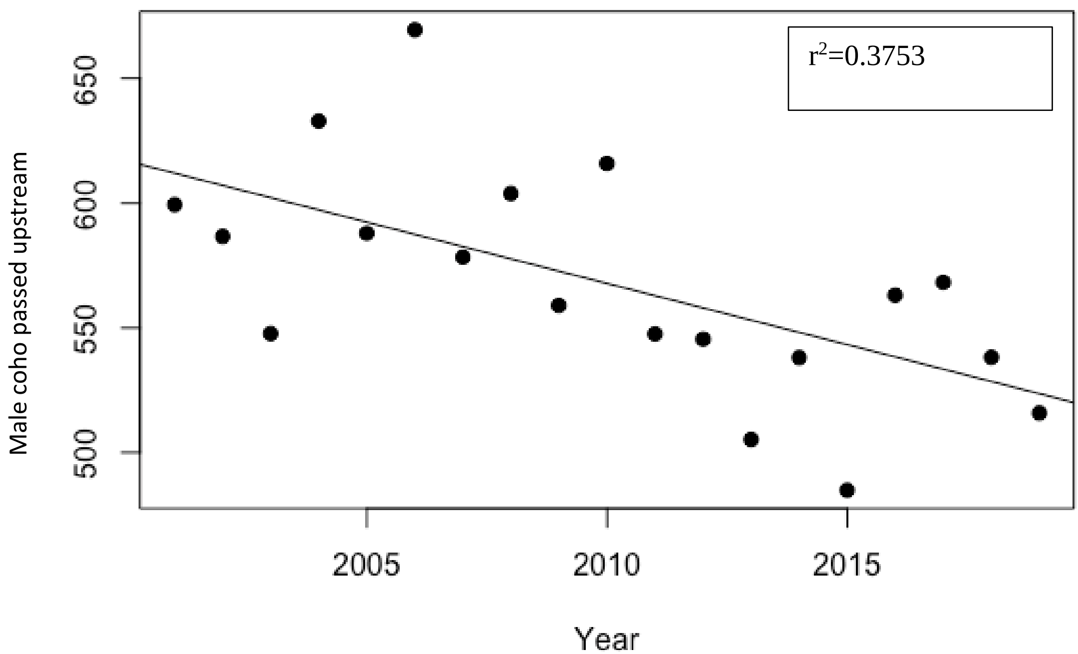


Figure 13 Total length of coho salmon that are passed upstream and arrive to spawning grounds on Big Beef Creek. P value 0.008715

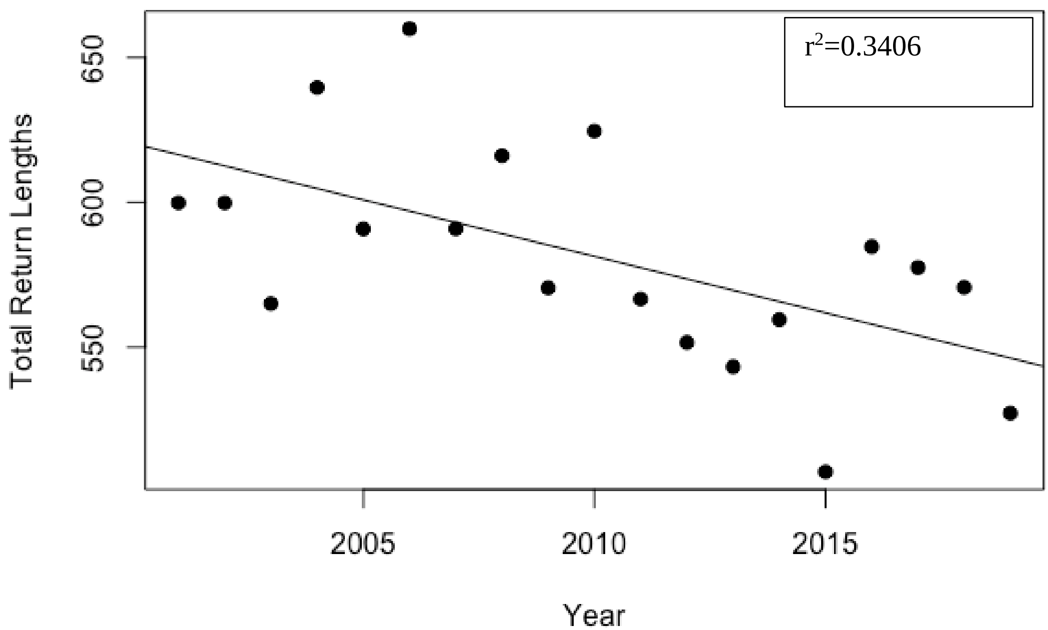
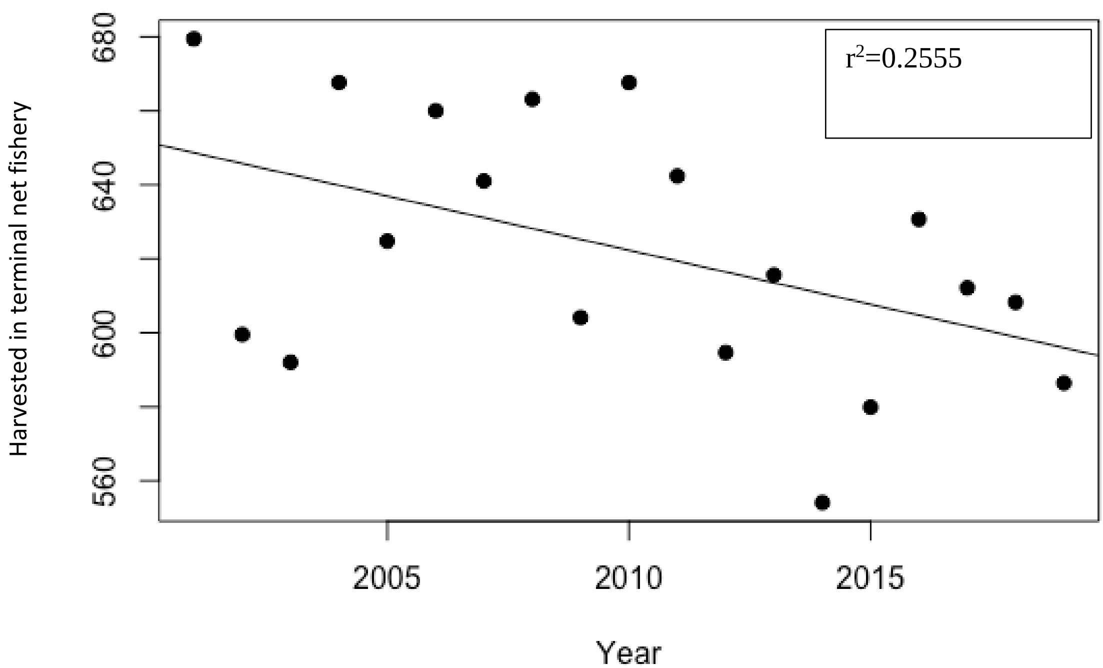


Figure 14 Lengths of coho caught in the terminal net fishery, p value 0.04103.



Multiple Regression

Multiple regression results for the variables year, peak migration timing, center of mass flow, seasonal fractional flow, and total harvest were insignificant. These variables resulted in weak p values (Table 4) with the exception of length and seasonal fractional flow. This signifies no direct relationship on each other with the exception of length over time and flow. This possibly shows that over time fish are not only getting smaller but that larger fish cannot enter the system with little to no flow available.

Table 4: Statistical significance results (p values) of multiple regression.

	Peak Migration, Year + CT	**Peak Migration, Year + SFF**	**Peak Migration, Year + Total Harvest**	**Peak Migration, Year + Length + SFF (y=3.89x+620.16)**	**Peak Migration, Year + CT, SFF, Total Harvest**
p value	0.255	0.7207	0.7103	0.04539*****	0.526

Juvenile outmigration to adult migration

Coho salmon may follow patterns on early, middle, and late migration. Data from tagged juvenile coho out-migrants were compared to that caught in the terminal net fishery in attempt to find a relationship between timing as a strategy at different life stages. Tag codes allowed for fish to be identified based on their out-migration status and timing of either early, middle, or late. In some years only early and late classifications were achieved. A Pearson's chi-squared test was conducted on all years to determine if outmigration and return migration were independent of each other or not. Based on the initial results from the chi-squared test we can assume that these migration timings are not independent of each other, with the exception of 2008, 2009, and 2016. Results from test can be seen in Table 8. The three years where the data did not meet the contingency assumptions and a Fishers test was used to determine p-values (2011 p=2.562e-13, 2015 p=0.0059, 2019 p=0.0013).

Chapter Five Discussion

Understanding the relationships and dynamics of combined pressures to coho salmon at Big Beef Creek is important for future management and recovery goals. The harvest is often much greater than those fish that arrive at the trap and subsequently upstream to spawn. In this study I examined 20 years of data and harvest trends with 2018 having the largest number of fish harvested at over 80%. Again, this included only Marine Area 12 harvest data. Coho salmon from Big Beef are also caught in other mixed ocean fisheries. Pre-season forecasts are created which allow harvest quotas to be determined each year. Successful recovery and conservation of Pacific salmon species while maintaining the availability of unlisted fish for harvest requires a strong understanding of biological, chemical, physical and hydrological dynamic, each of which greatly influence population dynamics (B. J. Burke et al., 2013).

Streamflow

The return migration of coho salmon is a phenological trait. When faced with changes to habitat or climate coho salmon may experience phenological or evolutionary changes in response. The pressure on salmon by anthropogenic influences such as habitat loss and increased harvest has been well documented. In this study we attempted to view any resultant changes in migration and timing of adult salmon returning to Big Beef Creek, WA.

Big Beef Creek discharge showed variability, a slight delay in streamflow, and increased peak flows. The incredible variability seen in flow among the years included delays of up to 30 days, which directly affected salmon migration upstream. Flood events that resulted in increased flow averages often exceeded the twenty-year average. This resulting data is indicative of a system that is experiencing such fluctuations that are in support of many hypothesis on climate projections. Global climate changes have been extensively documented as well as the effect it will have on salmon. Changes in global climate directly affect the water cycle, precipitation and snowpack (W. D. Burke & Ficklin, 2017). In addition to these changes, shifts in evapotranspiration (ET) and infiltration are expected which lead to an altered streamflow quantity and timing (W. D. Burke & Ficklin, 2017; Stewart et al., 2005). When analyzing trends in streamflow many researchers have studied the effects of temperature, snowmelt, and thus an earlier spring flow timing. However, the coastal, low elevated, rain-dominated basins have been less thoroughly studied (W. D. Burke & Ficklin, 2017). In this study I assessed timing by calculating the CT as defined by Stewart et al., 2005. This CT measures the timing and magnitude of streamflow. The difference in CT among the years was found to not significant therefore future studies may incorporate a larger data set as well as include precipitation and temperature data as these are also significant environmental factors relating to salmon. This research may however support projections by Burke & Ficklin, 2017, where a rain dominated Washington water shed was expected to have a higher percent increase in precipitation and an increase in peak streamflow during the season.

This would explain the flow and discharge levels continually exceeding those of the years prior.

This study specifically analyzed the streamflow of the mainstem Big Beef. We know that Big Beef has smaller intermittent tributaries which may be favored by coho salmon as they offer better habitat. Future studies may also analyze the changes seen specifically in these tributaries as they are experiencing complete droughts that last a majority of the spawning season.

Pacific Northwest hydroclimatology

The Pacific Northwest interannual variability is driven by the Pacific Decadal Oscillation and El-Nino Southern Oscillation (ENSO), a phenomenon that includes interdecadal climate variability (Dittmer, 2013; N. J. Mantua et al., 1997). It has been well documented that the PDO and ENSO have significant effects on precipitation which influences streamflow. The PDO at the beginning of our dataset was cold which in combination with a ENSO can mean above average winter temperatures and below average winter precipitation (Mantua, 1999). Including PDO and ENSO effects into changes in streamflow is a confounding reality. We know that it has an effect on streamflow and future studies may take into account the PDO climate dataset in comparison to streamflow on Big Beef Creek.

Migration Timing

Migration of coho salmon is variable, where some of the juvenile population either migrates or differential migration occurs where individuals undertake journeys of variable distance (Beacham et al., 2019).

The timing of migration is critical, and early migration is often associated with being the best strategy for both adults as well as juveniles. Another frequently employed strategy for out migrating juveniles is simply in mass, where the number of individuals at a certain time plays a larger role than time. Ultimately, the actual timing migration is a response to environmental changes, and the selection on reproductive timing can accelerate the evolution of other traits (Anderson et al., 2010). If adaptive evolution occurs population fitness and colonization success may increase (Anderson et al., 2010).

In this study where flow was available, the 2013 adult salmon elected to enter spawning ground habitat as soon as it was accessible. In contrast to this the 2011 flow delayed the returning adults two months.

The overall return rates of coho salmon to Big Beef Creek were variable with the number of adults arriving to the weir ranging from 316 – 4647. While the population has been able to sustain this drastic drop in peak of fish return to weir is concerning and certainly shows a population in serious decline. When these adults return upstream there are multiple strategies that are employed in order to ensure success for offspring. This includes timing strategies, early arrival and egg deposition at a time that ensures an incubation period that will last until favorable conditions in the spring for emergence (McClure et al., 2008). Density of individuals can also influence fitness. When fish densities are high most highly suitable breeding site locations may be used, limiting and forcing some females to be less selective about site selection and ultimately choosing less protected sites (Clark et al., 2014). It is possible that on some years this may have been a further impact, coupled with harvest pressure and streamflow timing to low numbers seen in Big Beef Creek. For example, a larger number of fish forced to spawn in the main stem

Big Beef as opposed to smaller tributaries. Further studies could be done involving site selection of adults in comparison to flow and more ideal habitat such as smaller tributaries with more protective vegetation. It is also possible that low flow results in a form of habitat loss which has been known to affect evolutionary trajectories (McClure et al., 2008). We also know temperature greatly affects the health and condition of salmon. Low stream flows are likely associated with higher temperatures which is a critical factor when considering the healthy reproduction of salmon, as fitness in warm water is reduced and high temperatures can even be lethal. Temperatures approach lethal limits regularly in rivers that are found in Washington and Alaska which affect the times fish can migrate as well (Crozier et al., 2008; Gale et al., 2011). This thermal stress may even be increased when fish interact with fishing gear, whether an intentional or non-intentional release.

Migration timing relationships

It was found that the relationship between outmigration timing and returning adult timing is not independent of each other with the exception of three years. This relationship is reflected from the harvest data collected on the tag codes placed in smolt coho from 2007-2019. This is the same data set where marine survival is estimated for the population annually. On years 2015 and 2016 less than 16% of fish were harvested. While the contingency test gives reason to support the hypothesis these years may not be best suited for drawing a relationship since the harvest rates were so low, and the data is based only on harvest associated with wild tagged coho. The remaining years in this study harvest rate was 45% and greater, providing better data to represent the entire run relationship. Furthermore, the varying harvest rate values are expected and agree with previous estimates which was seen in other literature.

The selective pressure on early and middle migrants, in combination with streamflow delays, means that late returning adults may actually be favored in this system.

Lastly, since we see so few late category tag groups in our data, this may further emphasize the relationship and may be indicative that those adults that are passed upstream are part of this "late" category. This is interesting as the strategy that arriving to spawning grounds early has been extensively researched and given as an explanation for a more successful reproduction strategy. Our study suggests that a majority of the individuals returning still attempt at employing an early migrating strategy, however this coincides with the most anthropogenic and environmental condition pressures. If late migrating coho salmon are part of the only population that is migrating upstream without being harvested at a larger rate, then these are individuals are also now given neutral advantages to spawning grounds and less competition to individuals who are more fit.

Size

Smaller individuals are left to spawn upstream. This was found in the significant difference of size among those that were harvested and those that returned to the weir, likely due to the size selection that occurs as a result of using nets. Small body size in salmonids is a trait that is often related to low fitness (Beacham et al., 2019). Phenotypic change that has been recently observed in other studies might largely be due to plastic (non-genetic) changes (Crozier et al., 2008). The results in this study are also similar to that in of Kendall & Quinn 2017, where the effects of disruptive size selection were greater in males than in females.

Chapter Six Conclusion:

The results of this study are significant and can contribute to further examination of population dynamics to wild stock coho salmon found in Big Beef Creek. Understanding size, distribution, and timing are critical aspects of these dynamics and allow managers to make better forcasts and predictions regarding the run of coho at Big Beef Creek. Evolutionary changes may occur in some populations that experience constant stress or pressure. This research highlighted the multivariate effects on coho salmon and specifically those that occur in synchronous during the adult lifestage. It is interesting to find an earlier trend in migration given the pressure the that harvest inflicts on the population, as well as the decrease in seasonal fractional flow found. We know that these play a significant role in the success of coho spawning, however it may be that the increase in flood eventsthat occur at the end of the season may pose a larger threat by redd scrouring. These are certainly areas for further research. Most noteably however, is the decrease in size seen in fish through this research. Pointing toward significant negative impacts inflicted upon the species. While I was not able to statistically link all variables in this study together and build a relationship pattern among them, I was able to show the effects individually and highlight the many stressors that coho salmon face. As more data becomes available these effects combined with the historical data may show relationships of the combined stressors.

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Appendices