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Recovery of Oregon Coast Coho Salmon (Onchorhynchus kitsutch) through Restoration of Freshwater Habitats

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This Master's Project

RECOVERY OF OREGON COAST COHO SALMON (*Oncorhynchus kitsutch*)
THROUGH RESTORATION OF FRESHWATER HABITATS

by
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ABSTRACT

RECOVERY OF OREGON COAST COHO SALMON (*Oncorhynchus kitsutch*) THROUGH RESTORATION OF FRESHWATER HABITATS

by

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Under the Supervision of Gretchen Coffman, Ph. D.

Pacific salmon populations are significantly lower than historic levels on the Western Coast of the United States. The Oregon Coast coho salmon Evolutionary Significant Unit (ESU) was listed as threatened under the Endangered Species Act in February 2008. The total number of adult coho salmon returning to Oregon Coast rivers today are between 5-20% of historic levels. The Oregon Coast Coho Conservation Plan (2007) stated that habitat management was the key to preservation and recovery of coastal coho salmon. Since the 1980s, restoration of freshwater habitat has become a common practice in the attempt to recover Pacific salmon populations. I used two databases, the Oregon Watershed Restoration Inventory, and the Salmon Recovery Tracker, to analyze habitat restoration and coho salmon population recovery on the Oregon Coast. A total of $145,620,716 was spent on 4,173 restoration projects on the Oregon Coast streams from 1997-2012. I hypothesized that the restoration actions had resulted in a significant increase in adult coho abundance on the Oregon Coast. My analysis showed that from 1994 to 2012 only 3 of the 21 independent populations from the ESU, the Alsea, Salmon, and Tillamook had statistically significant recovery. To evaluate the relationship between habitat restoration and coho recovery, I ran a correlation between the rate of recovery and the amount spent on restoration for each ESU population. The rate of recovery increased as total dollars spent on restoration increased, but it was a very weak relationship. The correlation coefficient was a positive 0.15. Additional monitoring and more advanced statistical analysis may provide a greater understanding of the relationship between coho salmon and their freshwater habitat. Coho recovery on the Oregon Coast can be enhanced by creating individual recovery plans for each independent population. Restoration effectiveness can be improved through more strategic location and treatment selection. Lastly, restoration of ecological processes will contribute to the long-term formation of diverse and complex habitats.

1.0 INTRODUCTION

Current salmon populations are significantly lower than historic levels on the Pacific Coast of North America (Andrew and Wulder 2011). Habitat loss and degradation are considered to be the main reasons for the population decline (Ward et al. 2012; Bisson et al. 2009). Since the 1980s restoration of freshwater habitat has become a common practice in the attempt to recover salmon populations (Bellmore et al. 2012). However, salmon species have not clearly responded despite the hundreds of millions of dollars being spent annually on habitat restoration (Katz et al. 2007). Restoration is still widely regarded as the best action for the recovery of native Pacific salmon populations, but environmental managers must improve effectiveness of restoration if there is to be consistent, measurable recovery (Honea et al. 2009).

Significance of Pacific Salmon

Salmon have ecological, cultural, economic, and recreational, significance (Andrew and Wulder 2011). Pacific salmon provide numerous ecological benefits. Most of their feeding and growth occurs in ocean, and they transport the marine derived nutrients into freshwater ecosystems when they return to spawn (Giannico and Hinch 2007). Native American tribes living on the Pacific Coast relied on a year-round supply of protein from salmon for at least 10,000 years (Meengs and Lackey 2005). The productivity of the land at one time supported over 200,000 Native Americans from Alaska to California, creating one of the most densely populated nonagricultural regions in the world. Now Pacific salmon support a commercial fishing industry and provide recreational fishing opportunities, both of which have significant impacts on local economies in the region (Wigington et al. 2006).

Pacific Salmon Biology

Salmon populations are geographically distributed from California in the south to Canada and Alaska in the north. There are five species of Pacific salmon: Chinook (*Oncorhynchus tshawytscha*), chum (*Oncorhynchus keta*), coho (*Oncorhynchus kitsutch*), sockeye (*Oncorhynchus nerka*), and pink (*Oncorhynchus gorbuscha*). They only inhabit watersheds that drain into the Pacific Ocean due to their unique anadromous life cycle. Some salmon streams are a few miles long, while other watersheds such as the Sacramento or Columbia Rivers allow salmon to migrate hundreds of miles inland.

Salmon go through many life stages including: egg, alevin, fry, overwintering juvenile, smolt, ocean adult, migratory adult, and adult spawner (Honea et al. 2009). Salmon spend their early stages in freshwater river systems (Honea et al. 2009). Juvenile salmon (smolt) then migrate downstream to the Pacific Ocean to feed until maturity. After 1-4 years depending on species, the adult salmon return to the freshwater stream where they were born to reproduce or spawn (Bisson et al. 2009). Adult salmon die in freshwater after spawning.

Population Decline from Historic Levels

Pacific salmon populations have dramatically declined due to overharvest and severe anthropogenic habitat alterations that began in the 19th century (Honea et al. 2009). The decline has gained wide recognition, resulting in the implementation of various recovery measures over the last half century. For conservation purposes, populations with similar geographic, ecologic, and genetic characteristics have been grouped into Evolutionary Significant Units (ESU) (ODFW 2007). All five Pacific Salmon species have had at least one ESU listed as threatened or endangered by the United States Endangered Species Act (ESA). Not one listed ESU has ever recovered enough to warrant delisting (Bisson et al. 2009; Jensen et al. 2009).

Loss of Freshwater Habitat

The loss of freshwater habitat is identified more than any other factor in the decline of Pacific Coast salmon populations (Bisson et al. 2009). Salmon habitat is a mosaic of many conditions which are constantly changing (Waples et al. 2009). Freshwater salmon habitat is shaped by processes that supply physical structure such as large wood and coarse sediment, as well as processes that transfer energy and nutrients (Bisson et al. 2009). Climate related characteristics such as streamflow and water temperature are also critical to availability of freshwater habitat (Wainwright and Weitkamp 2013). Many anthropogenic activities including agriculture, timber harvest, floodplain development, and channel modifications have reduced the presence of high quality habitat, and impaired the ecological processes that regulate habitat formation and maintenance (Honea et al. 2009; Meengs and Lackey 2005; Waples et al. 2009).

The complexity of the salmon life cycle makes a diversity of habitat critical, as salmon require different habitat conditions at each stage of development (Null and Lund 2012). Salmon also use the entire watershed from headwaters to the Pacific Ocean (Koski 2009). Unsuitable habitat at any point in the watershed that negatively impacts just one stage of development can reduce the productivity of an entire salmon population (Wainwright and Weitkamp 2013).

Habitat Restoration for Pacific Salmon

The potential for recovering many Pacific salmon populations is constrained by the availability of freshwater habitat (Meengs and Lackey 2005). This realization has resulted in freshwater habitat restoration becoming a common practice over the last several decades (Bellmore et al. 2012). Millions of dollars are now spent annually to improve salmon spawning and rearing habitat (Flitcroft et al. 2012). Freshwater salmon habitat restoration predominantly includes one or more of the following elements: barrier removal, nutrient enhancement, erosion and sedimentation prevention, establishment of off-channel habitats, creation of physical in-stream structure, increase of riparian ecosystem function, improvement of water quality, and restoration of hydrologic flow regimes. The success of restoration projects has been varied. However, it is still thought that habitat restoration has the potential to increase salmon abundance and productivity (Bellmore et al. 2012; Honea et al. 2009).

Research Objectives

This paper assessed the ongoing recovery of the Oregon Coast ESU coho salmon populations. The goal of this paper was to evaluate the effects of freshwater habitat restoration actions on populations in the ESU. I hypothesized that restoration actions have improved habitat conditions resulting in a significant, measurable increase in adult coho abundance on the Oregon Coast. Based on my literature review and data analysis, I provided population management recommendations and habitat restoration recommendations to improve effectiveness of Oregon Coast coho population recovery.

2.0 METHODS

I reviewed the best available scientific literature on the recovery of coho salmon from the Oregon Coast ESU. The literature review identified habitat conditions that have contributed to the decline of Oregon Coast coho populations. I used findings from the review to discuss management actions for coho recovery, focusing on restoration treatments that improve habitat.

This research also included statistical analyses components that evaluated the impact that habitat restoration had on the ESU. I used the Salmon Recovery Tracker (SRT), a database maintained by the Oregon Department of Fish and Wildlife (ODFW), for data regarding Oregon Coast coho populations. The data used from the SRT database were the yearly adult coho observed abundance, and the yearly abundance goal, a projection based on ocean conditions. For this analysis, I used data from the years 1994-2012, because 1994 was the first year that the abundance goals were calculated by the ODFW.

Coho recovery for the ESU was evaluated using a linear regression. The percent of abundance goal (observed abundance divided by goal) was the dependent variable plotted on the y-axis. The year was the independent variable on the x-axis. A regression was run for the entire ESU and then for each of the 21 major populations. I considered a positive slope for the regression an indicator that the population was recovering. The slope of the regression was called the rate of recovery. A slope near zero indicated that the population size had not changed over the 19 year dataset. I considered a negative slope to mean that the population was declining.

I also needed to quantify habitat restoration actions on Oregon Coast streams in order to test my hypothesis. I used the database Oregon Watershed Restoration Inventory (OWRI) for data on freshwater habitat restoration in the Oregon Coast ESU watersheds. The OWRI has been documenting restoration projects in Oregon since 1997. I was able to get restoration data up through 2012. For this analysis I only used projects on streams with Oregon Coast coho populations that had the goal of improving salmon habitat. For each project, the data used was location, total cost, and goal(s).

To evaluate the relationship between habitat restoration and coho recovery, I ran a correlation between the rate of recovery and the amount spent on restoration for 18 ESU populations. Three populations could not be tested, either because restoration was not documented or the location of restoration was unclear.

3.0 OREGON COAST COHO ESU

The Oregon Coast coho salmon ESU is made up of 56 populations. Twenty-one of these populations are considered independent, meaning the production capacity of the habitat within each watershed can sustain the population with little influence from neighboring populations (ODFW 2007). The independent populations have historically produced 95% of the coho salmon from the Oregon Coast ESU (ODFW 2007). The other 35 populations are dependent. These populations are from smaller watersheds and must rely on periodic contributions from the larger independent populations (ODFW 2007). The populations are further categorized into geographic sub-groups called stratums. Table 1 presents the five stratums (Northern, North-Central, Umpqua, Lakes, and South-Central) and their respective independent populations. Coho salmon were historically the most abundant salmon species of the Oregon Coast. Although there has been a reduction in numbers they still remain widely distributed throughout geographic stratum (ODFW 2007).

Table 1. Oregon Coast ESU geographic stratum and respective independent populations (ODFW 2007).

Geographic Stratum	Populations
Northern	Necanicum Nehalem Tillamook Nestucca
North-Central	Salmon Siletz Yaquina Beaver Alsea Siuslaw
Umpqua	Lower Umpqua Mid Umpqua North Umpqua South Umpqua
Lakes	Siltcoos Tahkenitch Tenmile
South-Central	Coos Coquille Floras Sixes

3.1 Oregon Coast Geographic Characteristics

Watersheds from the Oregon Coast ESU populations cover a 10,918 mi^2 area, and span approximately 250 miles of Oregon coastline (ODFW 2011). The Necanicum River is the farthest watershed to the north, discharging into the Pacific Ocean near Seaside, about 20 miles from Washington State (Figure 1). The Sixes River is the farthest south, about 60 miles from California.

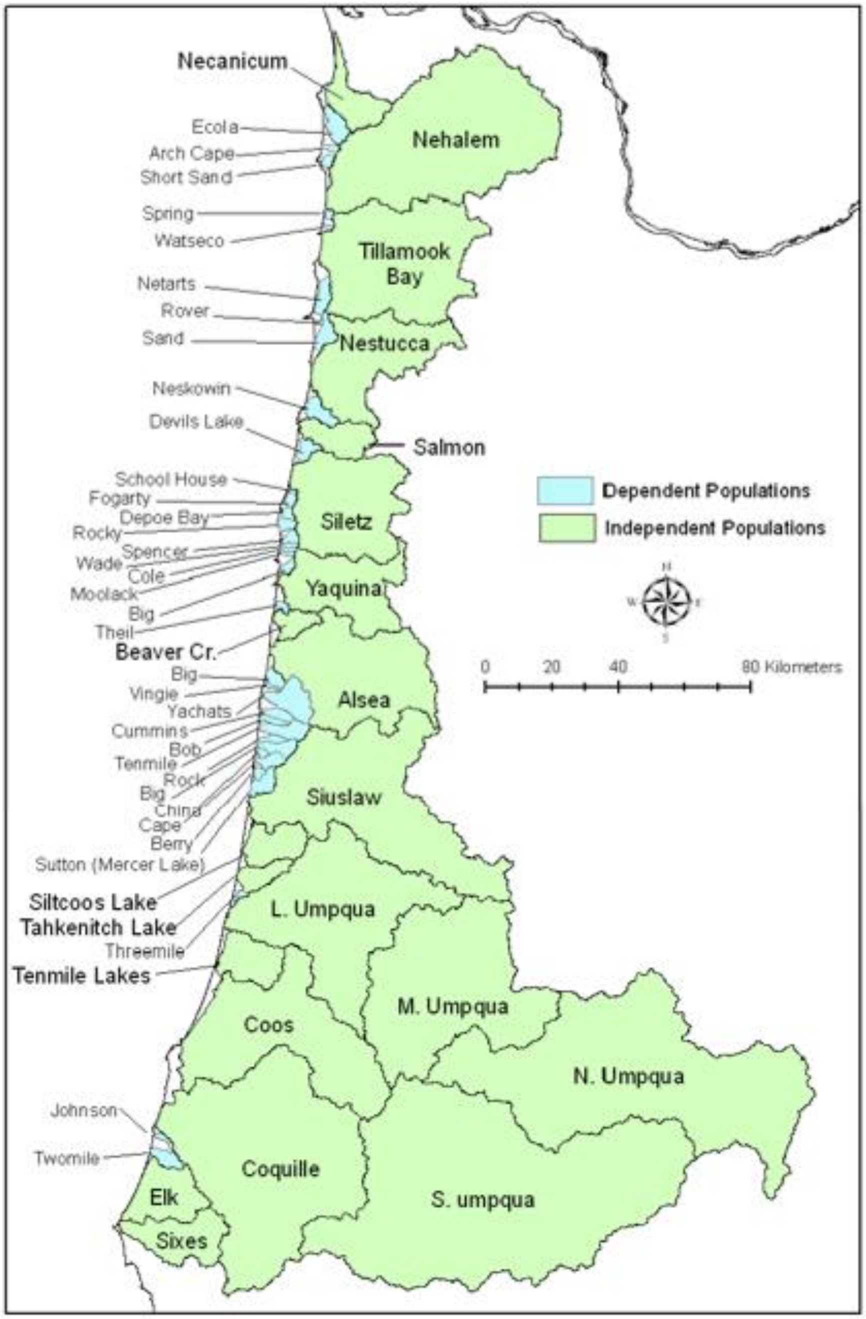

Figure 1. The 21 independent (green) and 35 dependent (blue) coho salmon populations that make up the Oregon Coast ESU (ODFW 2011).

The Oregon Coastal region is dominated by steep ridge and valley topography (May et al. 2013). The elevation ranges from 1,250 m to sea-level, however, coho habitat is usually below 700 m in elevation where the stream gradients are lower (Steel et al. 2012). Coho salmon most frequently inhabit streams with a gradient less than 5% (May et al. 2013). Typically, the watersheds they inhabit are characterized by narrow river valleys less than 75 km in length (Wainwright and Weitkamp 2013).

The Oregon Coast has a mild marine climate (Flitcroft et al. 2012). Winter air temperatures are typically between 5 and 15°C, while summer air temperatures average 20 to 25°C (Johnson et al. 2005). The marine climate is characterized by high precipitation winters and dry summers (Johnson et al. 2005). Annual precipitation averages 180 to 230 cm per year (Johnson et al. 2005). Coastal river flows in Oregon are predominately based on rainfall as there is very little snow accumulation to contribute to spring runoff (Lawson et al. 2004). Typically by mid-October the fall rains have elevated the streamflow above summer levels (Lawson et al. 2004). Flows often peak several times throughout winter and early spring due to numerous rain events (Lawson et al. 2004). The flows decline into summer with lowest baseflow occurring in early fall (Lawson et al. 2004).

High rainfall levels along the Oregon Coast have created lush riparian ecosystems that shade streams and provide cool water temperatures for the coho salmon. The Oregon Coast riparian overstory is a mixture of deciduous and coniferous trees. Dominant conifers are Sitka spruce (*Picea sitchensis*), western red cedar (*Thuja plicata*), Douglas fir (*Pseudotsuga menziessi*), and western hemlock (*Tsuga heterophylla*). Red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllium*) are the common hardwoods. Salmonberry (*Rubus spectabilis*), salal (*Gaultheria shallon*), vine maple (*Acer circinatum*), and sword fern (*Polystichum munitum*) are the dominant understory vegetative species (Johnson et al. 2005).

The headwaters of the 21 independent coastal watersheds originate in the Oregon Coast mountain range (Flitcroft et al. 2012). The dominate land use in the headwater region is timber harvest of coniferous forests on private land. A smaller portion of headwaters land is managed as public wilderness for recreation (Flitcroft et al. 2012; Morley et al. 2005). In total, one third of the land area within the ESU boundary is publically managed, which includes 20% of the total stream miles (ODFW 2007; Steel et al. 2012). However, the public land and public stream miles are at higher elevations and make up only 10% of coho salmon habitat. Coho salmon distributions spans 6,978 stream miles. Ninety percent of coho habitat is on private land in the lowland regions where low-density residential housing, agricultural, and grazing of livestock are the dominant land-uses (Flitcroft et al. 2012; Morley et al. 2005; ODFW 2007; ODFW 2011).

3.2 Coho Salmon Life Cycle

Oregon Coast coho salmon live in streams connected to the Pacific Ocean with large enough drainage area to have year round streamflow (May et al. 2013). Salmon are anadromous, meaning they migrate from saltwater to reproduce in freshwater (Crozier et al. 2008). They have many stages of development which are depicted in Figure 2. The stages include: egg, alevin, fry, parr, smolt, and adult (Crozier et al. 2008).

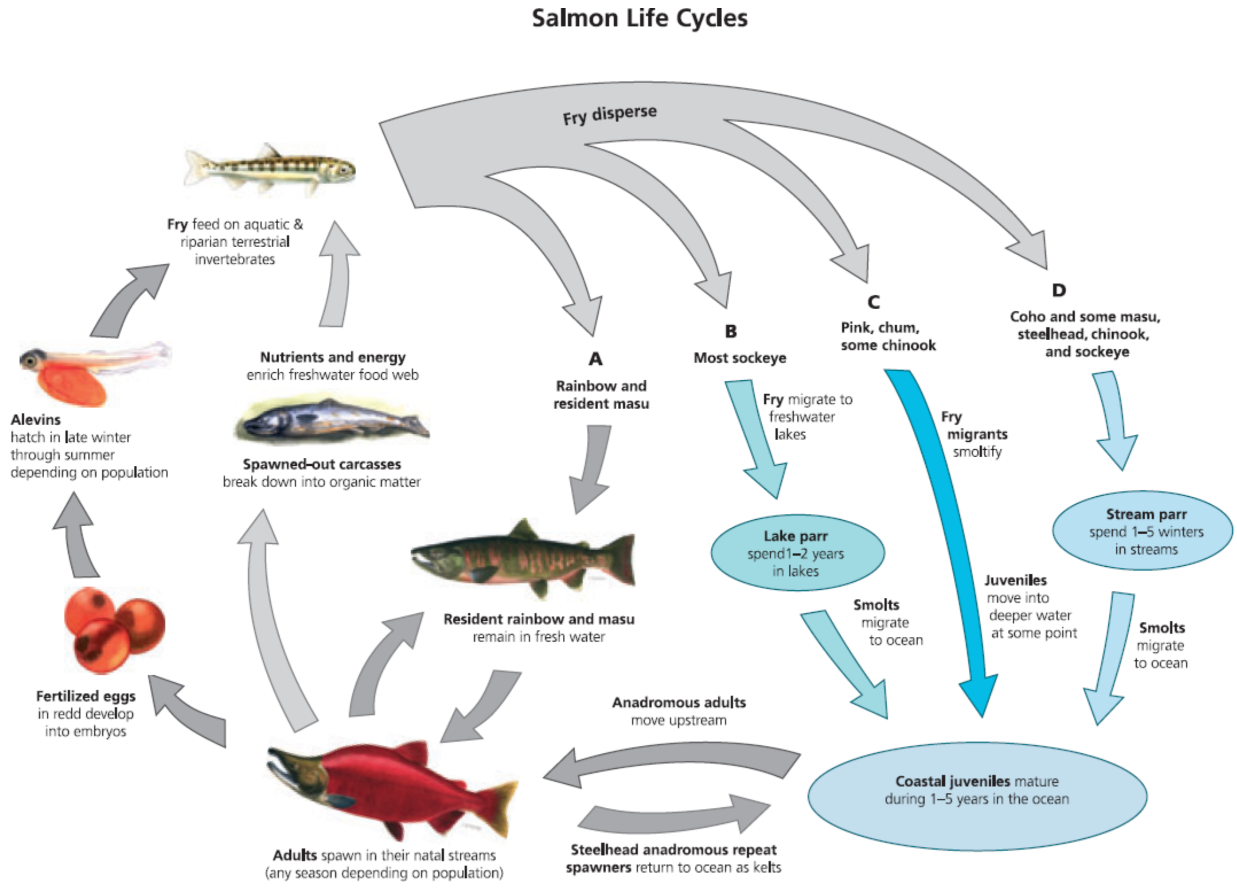

Figure 2. Anadromous life cycle of Pacific salmon species (Crozier et al. 2008).

Coho salmon go through the same developmental stages as other salmon species, but the timing and duration of the stages is unique. Sexually mature adult coho return from the Pacific Ocean and enter their natal coastal streams after the first fall rains increase river discharge, usually by mid-October (Lawson et al. 2004). The salmon move up the watershed to spawn in second to fourth order streams, preferring reaches with moderate to low gradients (Lawson et al. 2004; ODFW 2007). Spawning begins in November and lasts until March, with the peak occurring in December and January (Lawson et al. 2004). Female salmon build nests in the gravel (called redds), using their tail and fins to clear out fine sediment during construction (Jensen et al. 2009). Female coho build one redd where they release approximately 2,500 eggs (Lawson et al. 2004). Coho salmon spend an average of 11.3 days on their redd throughout the spawning process (Steel et al. 2012). Males fertilize the eggs and then guard the female and redd, although multiple males may fertilize a single redd (Anderson et al. 2013). All adult salmon die after reproduction is complete (Andrew and Wulder 2011).

The eggs incubate in the redd until March or April (Null and Lund 2012). Eggs hatch in the spring and the hatchlings remain in the gravel near their redds. Referred to as the alevin stage, the hatchlings rely on their yolk sack for food for the first 2-10 weeks. The next stage is the fry stage when the fish actively begin feeding on their own. Fry initially concentrate in shallow, slow moving water. Fry do not inhabit reaches with a gradient greater than 5% (May et al. 2013). As the fry develop they disperse from their nesting reach as they look for suitable foraging habitat (Koski 2009). Anderson et al. (2013) recorded juveniles as far as 6.3 km from their natal redd. They feed in daylight in the summer months (Rosenfeld and Raeburn 2009). Juvenile salmon predominantly feed up in the water column away from the bottom on drifting invertebrates being carried downstream by the current (Bellmore et al. 2012). Juveniles have also been observed actively swimming in search of prey (limnetic feeding) in back-channels, sloughs, and beaver ponds (Rosenfeld and Raeburn 2009). Throughout the summer, fry occupy reaches with lower water temperatures, lower predator density, increased woody protective structure, and increased in-stream diversity. Some individuals may even disperse and thrive upstream, if conditions outweigh energy demands (Anderson et al. 2013).

The fry feed and transition to the parr stage by fall. Parr are bigger than fry and have camouflage striping on their sides. A second period of dispersal occurs in the late fall when flow increases and parr seek more suitable winter habitat (Morley et al. 2005). Coho parr overwinter almost entirely in off-channel habitats such as sloughs, beaver ponds, side channels, and tributaries (Roni and Quinn 2001). The off-channel habitats provide relief from high winter flows (Anderson et al. 2013). Juvenile salmon are nocturnal in the winter, foraging at night (Morley et al. 2005).

The smolt stage is when juveniles begin their downstream migration. Smolting is usually triggered by a rise in water temperatures in the spring (Giannico and Hinch 2007). The 1.5 year old smolts begin to leave their freshwater systems for the Pacific Ocean in April and May (Bi et al. 2011). Smolting includes physiological, morphological, and behavioral changes that prepare juveniles for higher salinity concentrations (Spence and Hall 2010). The smolts may spend up to a month in the estuary environment during the downstream migration as the body adjusts (ODFW 2007).

Lawson et al. (2004) analyzed 14 datasets and found that an average of 42 coho smolts are produced per spawning female, with a maximum smolt production of 105 per spawner under highly productive conditions. Assuming 2,500 eggs are laid, the average egg-to-smolt survival is just 1.7%. Under the best conditions only 4.2% of eggs survive the initial 18 months in freshwater.

Smolts enter the Pacific Ocean to feed and continue developing for approximately 18 months (Bradford et al. 2005). At the time smolts enter the ocean they average 5-6 inches in length (Chittenden et al. 2010). Smolts feed on planktivorous fish such as smelt, herring, and anchovies while in the ocean (Bi et al. 2011). The Oregon Coast ESU smolt disperse from northern California to southern British Columbia during their time in the Pacific Ocean, although coho salmon migrate shorter distances than other salmon species (ODFW 2007). They return to their natal freshwater streams in autumn as three year old adults (Bradford et al. 2005). The average adult coho returns from the ocean 27-30 inches long, weighing 10.5 pounds (Meengs and Lackey 2005; Theriault et al. 2010). About 20% of males return the same year they left as smolts (Lawson et al. 2004). These two year old salmon are referred to as “jacks.” They are smaller than three-year old adults, averaging 16-18 inches in length (Theriault et al. 2010). Jacks are sexually mature and help maintain genetic diversity (Theriault et al. 2010).

3.3 Population History and Current Status

Salmon populations fluctuate in size (Bisson et al. 2009). Interannual variation of adult salmon abundance can be caused by natural changes in the freshwater environment (Lawson et al. 2004). For example, coho smolt production on the Oregon Coast is positively correlated with cooler than average ambient air temperatures, intermediate winter flows, and high spring flows

(Lawson et al. 2004). Productivity in the Pacific Ocean also causes significant variability in annual salmon returns (See section 3.5 Significance of Ocean Conditions for more detail).

Meengs and Lackey (2005) used cannery records to estimate historic coho salmon population size. They calculated that the historic coho salmon abundance of the Oregon Coast ESU populations was between 1.5 and 2.5 million adults annually. The Oregon Department of Fish and Wildlife (ODFW) uses the mean of 2 million as their historic population size estimate for Oregon Coast coho. Oregon salmon runs were likely highest around 1850, before major impacts of Euro-American activities, and after Native American populations had declined and were no longer harvesting at traditional rates (Meengs and Lackey 2005). By the late 1870s there was a noticeable reduction in Oregon salmon runs due to Euro-American trapping, logging, farming, mining, and canning activities (Meengs and Lackey 2005).

Adult abundance continued to fluctuate, but by the early 1950s annual adult population size was less than 300,000 (ODFW 2012). The ODFW has monitored adult abundance in Oregon Coast rivers since the 1950s. Figure 3 shows the native (non-hatchery origin) adult coho abundance from 1950 to 2012, compared with the estimated historic abundance (2 million). There are noticeable fluctuations in abundance, likely resulting from annual variation in ocean and freshwater conditions. While adult abundance observations over short periods are variable, the general trend of decline in coho populations becomes apparent over several decades. Average abundance decreased each decade from the 1950s through the 1990s (Figure 3). From 1950-1959 the ESU populations averaged 163,000 adults. By the 1970s the average abundance had dropped to just over 77,000 adults. The populations continued to decline, until measured abundance averaged just 46,000 adults from 1990-1999. Spawning surveys from 1993-1999 averaged 10 to 15 adults per mile, whereas there was an estimated more than 500 spawners per mile under historic conditions (ODFW 2007). The ODFW used historic estimates of population size (2 million adults) and available spawning habitat (4,000 stream miles) to calculate this estimate.

A period of good marine survival led to elevated abundance in the 2000s, which was highest since records began in the 1950s (ODFW 2007). Abundance peaked in 2011 when over 356,000 adult coho from Oregon Coast ESU returned to spawn. Even though abundance in 2011 was highest on record, it was drastically below historic population size (Figure 3). Overall, coho runs today are 5-20% of historic levels depending on good or poor ocean conditions (Meengs and Lackey 2005).

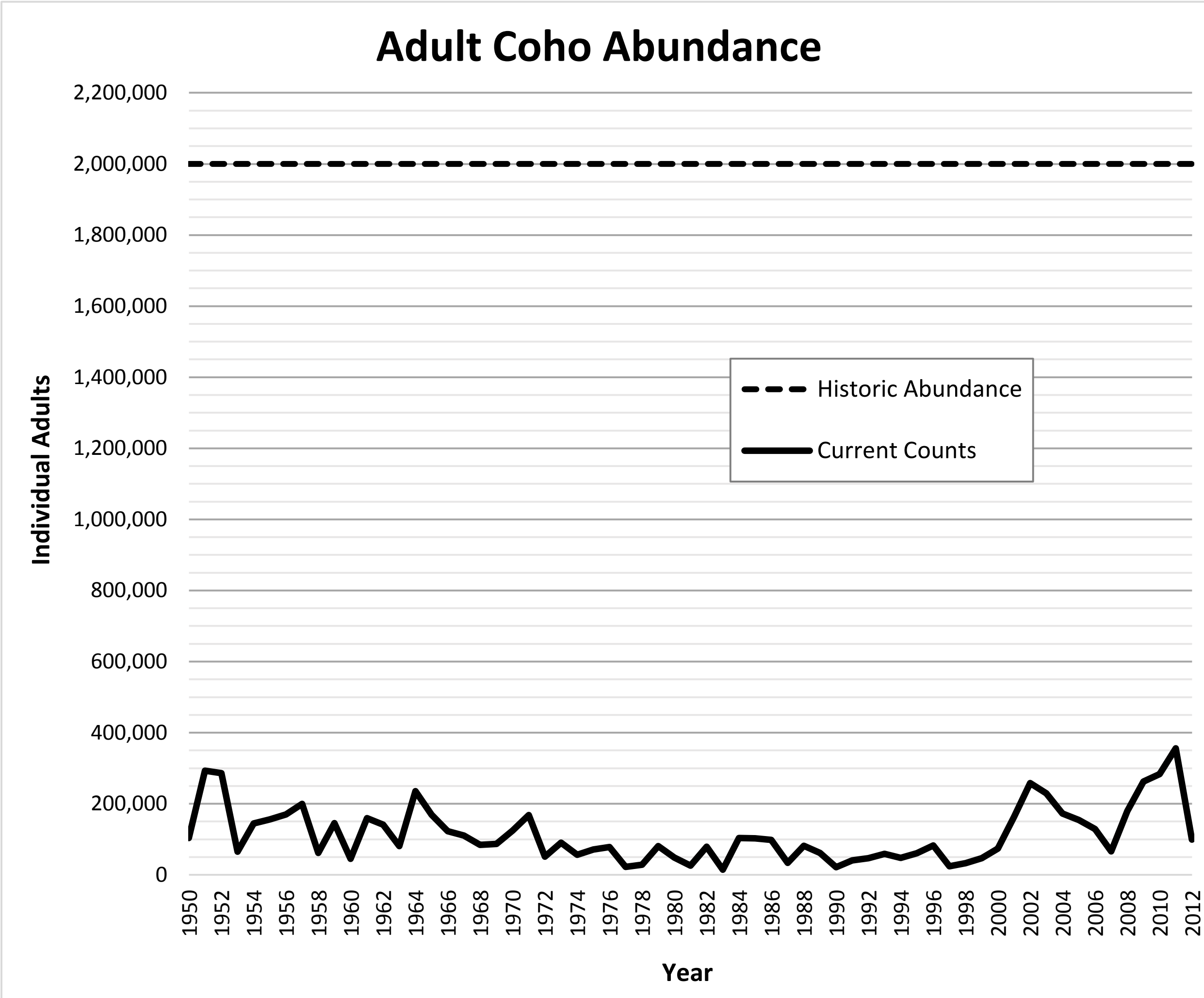

Figure 3. Adult abundance of Oregon Coast ESU populations from 1950-2012 (ODFW 2012).

<u>ESU Listed as Threatened</u>

Coho salmon on the Oregon Coast were first petitioned for listing under the ESA in 1993 (Stout et al. 2011). The National Marine Fisheries Service (NMFS), a division of the National Oceanic and Atmospheric Administration (NOAA), reviewed the status of coho salmon populations from Washington, Oregon, and California in 1995. NMFS listed Oregon Coast coho as threatened in 1997. Litigation over the status of Oregon Coast coho caused several changes back and forth between “not warranted for listing” and “threatened” (Stout et al. 2011). In 2001 the initial listing was deemed “unlawful” by the U.S. District Court. That ruling was appealed later that year, and the status was returned to threatened. In January of 2006, the NMFS determined that the Oregon Coast coho are not likely to become endangered, and should not be listed (ODFW 2007). The ruling was then challenged in federal court. The decision was overturned, and in February 2008 NMFS once again listed the ESU as threatened (Stout et al. 2011). The status of Oregon Coast coho salmon remains threatened today. The federal government is required to protect coho salmon and their habitat because of the ESA listing (Null and Lund 2012). A federal conservation plan is underway, but has not yet been completed. A federal ESA Recovery Plan states measurable criteria for the species to be delisted, the actions required for the recovery, and the expected time and monetary costs (ODFW 2007).

3.4 Factors Contributing to Population Decline

Many factors have contributed to the decline of salmon populations. The major negative impacts have been referred to as the four Hs: harvest, hatcheries, hydroelectric dams (or other barriers to migration), and habitat loss (Ward et al. 2012). The first three are recognized in this paper but are not discussed in great detail. Coho salmon populations on the Oregon Coast have been negatively impacted by all four, but today are primarily limited by loss of habitat, particularly winter refuge habitat for smolts during high flows, cool water habitats during summer, and reduced food availability (ODFW 2007).

Over Harvest of Coho Salmon

Adult salmon harvest in both salt and freshwater reduces abundance of populations. By 1900, ten Oregon coastal streams had established canneries (Meengs and Lackey 2005). In 1911, the canneries produced 140,000 cases of salmon, weighing 40 pounds each on an annual basis (Meengs and Lackey 2005). During this time about 40% of adult salmon returns were harvested annually from commercial fishing in coastal estuaries and rivers (Meengs and Lackey 2005). The ODFW estimated that in some years coho harvest from ocean fisheries reached a maximum of 90% of returning adults (ODFW 2007). Coho salmon remained the most numerous commercially caught species up through the 1970s. Today, ocean harvest has been reduced to 15% or less of the returning adults, but the substantial harvest over the last century has contributed to the reduction of Oregon Coast ESU coho abundance (ODFW 2007).

Fish Hatcheries

Fish hatcheries can be operated as private, for-profit farms that raise fish for food (Nickelson 2003). Hatcheries can also be publically funded facilities used to enhance fish populations for commercial harvest, recreation, or for the recovery of endangered populations. Fish hatcheries on the Oregon Coast are the latter. They provide fish for harvest to take pressure off declining wild salmon populations. Hatcheries on the Oregon Coast began releasing fry in freshwater streams in the early 1900s (Nickelson 2003). In the 1960s hatcheries switched to releasing smolts. The smolts return to the exact stream they were released in after their ocean migration. The release of hatchery fish peaked in 1981 when 12 hatcheries on the Oregon Coast produced 10 million coho smolts that year.

While hatchery operations provide harvestable fish, they are detrimental to native fish (Nickelson 2003). Chase et al. (2012) found that in two California rivers the reaches with the lowest juvenile coho survival were both at the hatchery smolt release points. Nickelson (2003) analyzed 14 Oregon coastal coho salmon populations. There was a strong negative relationship between wild salmon productivity and the number of hatchery smolts released per stream (Figure 4).

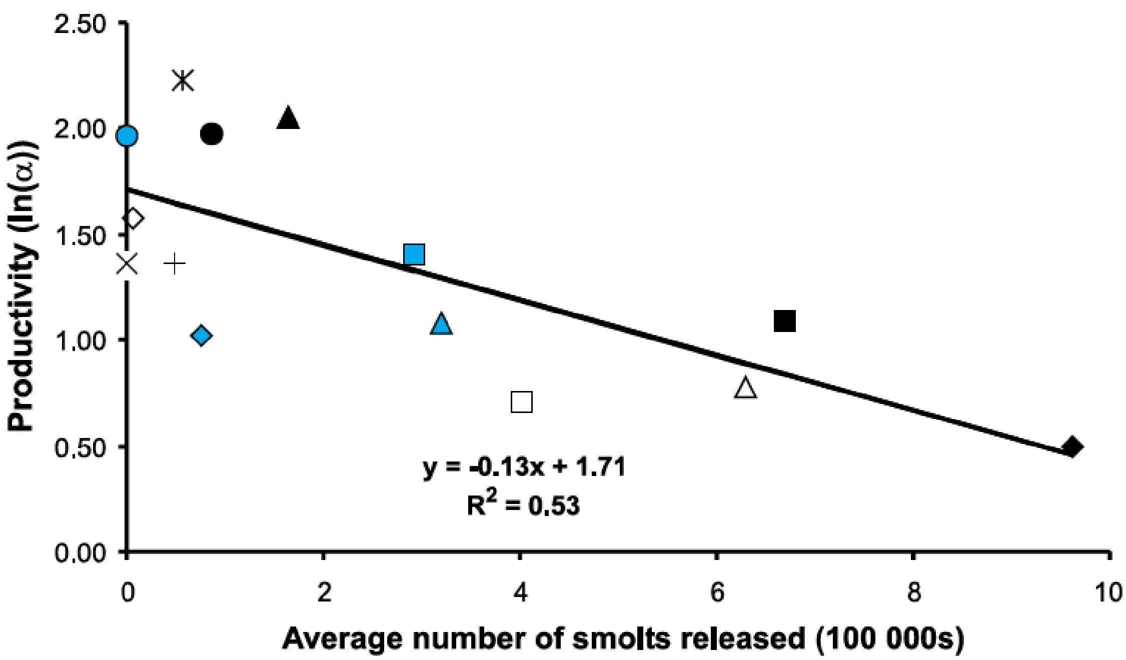

Figure 4. Productivity of native coho (mature offspring produced per adult spawner) against the number of hatchery smolts released for 14 Oregon Coast ESU streams. Each unique symbol represents one of the 14 streams (Nickelson 2003).

There are many possible explanations for the findings of Chase et al. (2012) and Nickelson (2003). The first explanation is density related, as lower densities of juveniles increases individual survival (Giannico and Hinch 2007). Releases of hatchery smolts increases competition for limited resources, notably prey abundance and foraging habitat. Insufficient food production has been recognized as a limiting factor in capacity of a watershed to sustain historic salmon runs (Bellmore et al. 2012; Giannico and Hinch 2007). In many streams nutrients are so limited that adult salmon carcasses are deposited to subsidize invertebrate productivity (Giannico and Hinch 2007). Hatcheries increase the overall smolt biomass in streams, intensifying the competition between juvenile salmon for limited foraging resources (Bellmore et al. 2012). Hatchery smolts are larger than wild smolts because of their development under controlled conditions, so they may have advantages in establishing foraging territory and capturing prey (Nickelson 2003). Resource competition is not only limited to juvenile fish. Hatchery fish returning from the ocean also compete with native adult salmon for spawning sites (Honea et al. 2009).

There is a second density-related consequence of hatchery releases. Large releases of hatchery smolts in the lower watershed and estuary attract predators (Nickelson 2003). Predation has been measured to kill 50% of smolts (Nickelson 2003). Hatcheries release smolts in groups of 100,000 or more and wild smolts join the schools of hatchery fish (Nickelson 2003). The high concentration of fish attracts a variety of predators including fish (spiny dogfish or northern pikeminnow), mammals (river otters and harbor seals), and birds (terns and cormorants) (Nickelson 2003).

Other concerns are that hatchery fish harm wild fish through the transmission of disease, and hatchery programs reduce fitness of native salmon populations by interbreeding (Honea et al. 2009; Nickelson 2003). The hatchery adults post migration also do not successfully reproduce and contribute to sustaining populations, so new releases are required annually (Nickelson 2003). The combination of all the negative impacts of hatcheries over the last century has contributed to the decline of Oregon Coast coho populations (Ward et al. 2012).

Dams and Migration Barriers

Dams and other barrier structures can reduce salmon survival (Anderson et al. 2013). The loss of habitat from impassable barriers is one of the primary causes for the decline of salmon (*Oncorhynchus* spp.) populations in Washington, Oregon, Idaho, and California (Anderson et al.

2013). Dams are constructed for irrigation, flood control, navigation, and hydropower (Honea et al. 2009). However, they act as barriers that prevent or hinder the ability of migratory fish such as salmon from accessing habitat. This is true for adults searching for spawning habitat, and for dispersing juveniles looking to find suitable foraging and refuge habitats (Anderson et al. 2013).

Dams also alter natural hydrologic regimes, which hinders the formation and maintenance of diverse and complex habitats (Waples et al. 2009). In addition, they suppress peak flows and subsidize low summer flows. High peak flows are important in the formation of new freshwater habitat, as they create new channels, recruit wood to the streambeds, and deposit sediment in the floodplain (Waples et al. 2009).

Large dams are uncommon on Oregon Coastal rivers, and are not a major source of coho salmon mortality (Oosterhout et al. 2005). However, small dams, dikes, and culverts are present in some streams and tributaries, creating migration barriers for Oregon Coast coho. An estimated 10-11% of Oregon Coast freshwater habitat is inaccessible due to barriers (Stout et al. 2011).

Loss of Freshwater Habitat

Habitat degradation on the Oregon Coast began in the early 1800s when Euro-American trappers drastically reduced the beaver populations. Beavers create structurally diverse habitats for salmon (Meengs and Lackey 2005). However, hydrologic and sediment processes were altered when hydraulic mining began on Oregon rivers in 1856 (Meengs and Lackey 2005; Morley et al. 2005). Hydraulic mining used pressurized water to collect gold-bearing sediment. The resulting erosion and sedimentation suffocated salmon and their redds. Diversion dams had to be constructed to collect the mining water. The dams blocked salmon passage, and reduced streamflow to lethal levels during the summer months.

Farming began on the Oregon coast in the 1860s. As upland areas were converted to plowed agricultural land, rivers were channelized and disconnected from their historic floodplains (Naiman et al. 2010). Development of uplands and floodplains significantly reduced the amount of available spawning and rearing habitat because levees and berms were constructed which cut off access to off-channel habitats (Honea et al. 2009). River ‘simplification’ was common where riparian vegetation and fallen wood were removed and replaced with riprap for erosion protection (Pess et al. 2012). Riparian vegetation contributes to wood accumulations, which create complex habitats and provides in-channel cover from predators (Honea et al. 2009; Pess et al. 2012).

Anthropogenic simplification of stream channels, in addition to restricting natural stream altering processes (landslides, wood deposits, floods), changed food production and availability. Invertebrate production is greatest in riffles (Rosenfeld and Raeburn 2009). Riffles, runs, and cascades then transport invertebrates downstream in the water column to drift-feeding juvenile salmon (Rosenfeld and Raeburn 2009). Historical, complex channels had sufficient riffles for invertebrate production and the pool frequency necessary for juvenile foraging habitat. A reach that can support 2,800 juvenile salmon per mile is considered high quality habitat (ODFW 2007). In 2007, the ODFW estimated 2,501 miles of high quality habitat within the Oregon Coast ESU streams needed to be restored.

Water usage for irrigation has led to potentially fatal low summer flows (Honea et al. 2009). These reduced water levels, combined with channelization and removal of riparian vegetation has increased water temperatures (Richter and Kolmes 2005). Salmon historically used thermal refuge habitat such as logjams, pools, and off-channel habitats during periods of elevated temperatures. Channel simplification has removed many of the thermal refuge habits, so salmon today are less able to cope with elevated stream temperatures (Richter and Kolmes 2005).

Heavy logging was occurring along coastal rivers by the 1870s (Meengs and Lackey 2005). Trees along rivers were harvested first because of ease of access and transportation downstream to mills. Riparian logging eroded stream banks, caused sedimentation in the channel, and increased water temperatures. “Splash dams” were constructed to control water levels for transporting logs. These dams allowed water to build up until the flow was sufficient to wash the logs downstream to the mills. The water was released in high-flow events that would erode the river banks, fill in pools, and wash away complex refuge and foraging habitats. By 1910, 160 splash dams had been constructed on Western Oregon rivers. Oregon coast systems were further degraded when the logs were milled and large quantities of sawdust was deposited into the streams.

Historically, about 4,000 miles of spawning habitat was available in the Oregon Coast ESU (ODFW 2007). Adult salmon need gravel to construct redds and deposit eggs. Riparian forests naturally regulate erosion and landslides that deposit fine sediment over spawning gravel (Wainwright and Weitkamp 2013). Logging continues today. Fifty percent of the riparian area within the ESU with potential to be high quality habitat is unforested or recently logged (Steel et al. 2012). Forests have other functions in addition to reducing sedimentation. They contribute wood structure to the stream channel that then creates a diversity of pools and other complex habitats (Balian and Naiman 2005; Honea et al. 2009). Forests also regulate water quality through reducing runoff, thermal heating, and nutrient erosion (Wainwright and Weitkamp 2013). Logging on tributaries can be as damaging as logging on main channels. Loss of wood recruitment, increased sedimentation, reduced complexity, and higher water temperatures in tributaries can impact both summer and winter survival of juvenile salmon (Wigington et al. 2006).

Habitat loss is most often cited as the primary reason for the decline of all salmon populations (Bisson et al. 2009; Ward et al. 2012). This is true for the Oregon Coast ESU where agriculture, timber harvest, floodplain development, and channel modifications over the last several hundred years has significantly reduced the presence of high quality habitat (Honea et al. 2009; Naiman et al. 2010). Currently only 30% to 55% of historic coho salmon habitat remains (Meengs and Lackey 2005).

Critical Habitat Functions and Disrupted Processes

River ecosystems are dynamic (Waples et al. 2008). Pacific Salmon evolved under shifting physical and climatic conditions, and human development over the last two centuries has disrupted natural disturbance regimes. Ecological processes create a variety of habitat conditions and combinations over time. Within the Oregon Coast ESU, wildfire, landslides, high water flood events, and vegetation succession have historically contributed to the development of habitat diversity (ODFW 2007). The productive capacity of the ESU depends on the continuation of the natural ecological processes (ODFW 2007).

Waples et al. (2009) identified six primary processes that shape freshwater salmon habitat but have been altered by anthropogenic influences. Stream-altering hydrologic regimes occur during extreme precipitation events (Waples et al. 2009). Annual high flow events cause lateral streambed migrations, shift locations of wood accumulations, and erode and deposit riparian material (Naiman et al 2010). Within the ESU boundary, urbanization, logging, agriculture, and climate change have increased winter flows and decreased summer flows. Human land use alterations have increased surface erosion and sediment supply to the stream channel which can limit availability of spawning and rearing habitat.

Sediment supply regimes are shaped by high precipitation and high streamflow events (Waples et al. 2009). Sediment supply events such as landslides, naturally play a part in shaping channel features (May et al. 2013). Oregon Coastal rivers are smaller streams with narrow valleys, and landslides can create areas with more broad valleys which typically have a lower gradient, more sinuous channel, allowing for the formation of off-channel habitats (May et al. 2013). Salmon are resilient to some flooding and erosion, however, the frequency of landslide events is increasing in the Pacific Northwest (Waples et al. 2009). Logging practices on the Oregon Coast has increased erosion, and the frequency of erosion events maybe past the threshold of what salmon can tolerate (Wainwright and Weitkamp 2013). Salmon are negatively impacted when eggs are scoured from redds, fine sediment is deposited, and fry are washed downstream (Schindler-Wildhaber et al. 2014; Waples et al. 2009).

Riparian vegetation disturbance regimes are driven by fire, channel migration, and bank erosion. The latter two are dominant drivers on the Oregon Coast (Waples et al. 2009). Riparian disturbance erodes the floodplain and contributes wood to the stream channel. Wood and sediment deposition in the floodplain then create new riparian habitat (Waples et al. 2009). Humans have developed the floodplains, isolating them from main channel, removed wood deposits, and reduced the frequency of riparian disturbances.

Nutrient regimes are perhaps the most severely altered. Adult spawners historically provided large deposits of ocean-derived nutrients which form the base of the freshwater food chain. When adult salmon spawn and die the carcass is carried by current or predators onto the stream bank. The carcasses decompose and enrich the soil. The current concentrations of marine derived nutrients adult salmon release to the stream is 6-7% of historic levels (Giannico and Hinch 2007).

Water temperature regimes have been altered and stream temperatures are frequently outside of the preferred range of salmon. Elevated water temperatures have multiple direct and indirect impacts on salmon productivity. Logging has decreased riparian shading of the main channels and shading of tributaries. Not all tributaries provide salmon habitat, but increased water temperatures in these tributaries will raise temperatures downstream in occupied reaches. Simplification of the stream channel has reduced the abundance of pools and other thermal refuge habitats.

Connectivity dynamics are events that block salmon from occupying habitats (Waples et al. 2009). Natural blockages are relatively short lived, examples include landslide dams, beaver dams, log jams, and isolation of old side channels. Anthropogenic impacts to connectivity regimes are permanent. Dams and culverts block salmon migration in-channel, while constructed dikes block off historic floodplains and off-channel habitats.

3.5 Significance of Ocean Conditions

Natural fluctuations in salmon population size are in part due to patterns of high and low ocean productivity (Bisson et al. 2009). Comparing salmon abundance with ocean productivity shows that ocean conditions are the dominant determinant for population size. For example, coastal coho salmon populations from 2001-2003 were the largest since the 1970s (Meengs and Lackey 2005). This increase in adult abundance occurred even though there were less available miles of high-quality freshwater habitat in 2001 than in the 1970s. A period of high ocean survival from 2001-2003 made up for the diminished freshwater conditions and caused the increase in abundance. Ocean conditions can actually explain up to 83% of adult recruitment for coho salmon that naturally spawn in Oregon (Lawson et al. 2004). The ocean conditions that influence salmon survival are highly variable, occurring at both annual and much longer scales (Bi et al. 2011).

Good and Poor Ocean Survival

High ocean survival for Oregon Coast coho occurs when over 12% smolts survive to adulthood (ODFW 2012). Medium ocean survival is when 4.5-12% of smolts survive to adulthood (ODFW 2012). Smolt survivorship of less than 4.5% is considered low (ODFW 2012). Ocean survival can drop below 1.5% during periods of poor conditions (Oosterhout et al. 2005). Coho survival less than 1.5% is classified as extremely low (ODFW 2012). Ocean conditions during the first few months of ocean residency are the most critical for determining smolt survival to adulthood (Steel et al. 2012).

Juvenile salmon grow in the ocean by eating planktivorous fish such as smelt, herring, and anchovies, therefore food production in the ocean is what determines smolt survival (Bi et al. 2011; ODFW 2007). Food production and smolt survival is related to ocean temperature, chlorophyll concentration, and zooplankton biomass (Bi et al. 2011). Zooplankton biomass is positively correlated with chlorophyll concentrations. Juvenile coho salmon feed in waters less than 130m deep. They are reliant on the presence of zooplankton to attract smelt, herring, and anchovies on the continental shelf (Bi et al. 2011). Ocean temperature plays a role because not all zooplankton species have the same nutritional value. Cold-water zooplankton are larger and have higher lipid concentrations than warm-water zooplankton (Bi et al. 2011). When reduced ocean temperatures bring cold-water zooplankton species on the continental shelf there is greater prey abundance resulting in higher salmon survival.

Natural Patterns and Cycles

Ocean conditions vary over seasonal as well as longer time scales (Lawson et al. 2004). Large-scale forcings such as El Nino Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) influence the near shore zooplankton community (Bi et al. 2011). ENSO events bring warm water and deep, warm-water zooplankton species onto the continental shelf. Similarly, warm PDO periods result in downwelling at the coast where near-shore water is replaced by warm off-shore water (Bi et al. 2011). Cold PDO periods bring cold subarctic waters to the Oregon coast (Bi et al. 2011). Periods of coastal upwelling, which brings cool water up to the surface, increases juvenile salmon survival (Bi et al. 2011). Cool water is rich in nutrients which are the basis of food production that supports coho salmon growth (ODFW 2007).

These marine cycles are related to atmospheric conditions. Periods of downwelling correspond with warm land surface temperatures and reduced precipitation and runoff (Lawson et al. 2004). Upwelling corresponds with cooler coastal air temperatures and increased precipitation (Lawson et al. 2004). Local fluctuations in upwelling winds can change ocean conditions on an annual basis (Bi et al. 2011). The annual variation of ocean conditions and salmon survival cannot easily be predicted (ODFW 2007).

Historic freshwater habit was productive enough that populations were maintained even through periods of low ocean survival. Poor ocean conditions would lead to reduced adult abundance and spawning output. Reduced spawning output led to decreased abundance of eggs and fry. The fewer fry would then have greater freshwater survival due to less density related mortality (Nickelson 2003). Habitat degradation over the last 150 years has reduced the productive capacity of streams such that smolt output cannot completely make up for poor ocean conditions of previous generations.

3.6 Management of Oregon Coast Coho Salmon

Primitive fisheries management for the Oregon Coast began in the late 1800s when commercial harvest rates were reexamined after noticeable declines in salmon abundance (ODFW 2007). These early conservation efforts continued into the 1900s with the goal increasing populations to maintain harvesting levels (ODFW 2007). There was no emphasis on protecting and restoring habitat, as the dominant strategy in the early 1900s was hatchery production (ODFW 2007). It became obvious that this simplistic management philosophy was ineffective. In 1982 the ODFW created a Coho Salmon Management Plan that incorporated scientific developments (ODFW 2007). This new type of modern era plan recognized the impacts that hatcheries, marine conditions, predation, and human land use had on every salmon life stage (ODFW 2007). The NMFS reviewed the status of all Pacific Coast coho populations in 1995 (Stout et al. 2011). The review led to the establishment of six coho ESUs, including the Oregon Coast ESU (Stout et al. 2011). Nine Basin Fish Management Plans were developed for conservation and recovery of individual Oregon Coast populations in the 1990s (ODFW 2007). In 2007 the Oregon Coast Coho Conservation Plan for the State of Oregon became the first region-wide recovery plan for Oregon coho salmon.

State Conservation Plan

The state of Oregon released the *Oregon Coast Coho Conservation Plan for the State of Oregon* (SCP) on March 16, 2007. At that time the Oregon Coast ESU status was viable (abundant, sustainable into the foreseeable future). The ESU has since been classified as threatened in February 2008 (Stout et al. 2011). The SCP, prepared by the Oregon Department of Fish and Wildlife, encompassed coho salmon conservation and recovery efforts at the regional scale. The SCP was scheduled to be updated in six years (by 2013) but has not been as of May 2014.

SCP Objectives

The SCP was created to "ensure the continued viability of the Oregon Coast (ESU) and to achieve a desired status that provides substantial ecological and societal benefits" (ODFW 2007). The overall goal is to improve the status of the ESU and get the population out of consideration for listing under the ESA (ODFW 2007). The classes and definitions of ESA listings are presented in Table 2.

At the time of release the status of the ESU was viable. The ESU has since been reclassified as threatened, a conclusion that the populations are likely to become endangered if no action is taken. The goal of the SCP remains the same even though the ESU has been reclassified as threatened. The ESU population goals are depicted in Table 2 as the "desired status." The populations under the desired status would be sufficiently abundant and self-sustaining, enough to allow recreational harvest. The SCP did state measurable indicators of "sufficiently abundant populations." The target number of returning adults is 101,000 in periods of extremely low marine survival (< 2%), 371,000 under low survival conditions (between about 2-4.5%), 715,000 during medium ocean survival (4.5-12%), and 800,000 in productive ocean conditions with high survival (>12%) (ODFW 2007; ODFW 2012).

Table 2. Oregon coho salmon classifications and definitions (ODFW 2007).

Classification	Definition
Pristine	All historical populations within the ESU are healthy and adverse impacts from human activities are insignificant at the population and ESU scale.
Desired status (*aka*: broad-sense recovery/Oregon Plan goal)	Populations of naturally produced fish comprising the ESU are sufficiently abundant, productive, and diverse (in terms of life histories and geographic distribution) that the ESU as a whole will: a) be self-sustaining, and b) provide environmental, cultural, and economic benefits.
Viable	Populations of naturally produced fish comprising the ESU are sufficiently abundant, productive, and diverse (in terms of life histories and geographic distribution) that the ESU as a whole is sustainable into the foreseeable future.
Threatened	The ESU is likely to become endangered within the foreseeable future throughout all or a significant portion of its range.
Endangered	The ESU is likely to become extinct within the foreseeable future throughout all or significant portion of its range.
Extinct	Means an ESU contains so few members that there is no chance their evolutionary legacy will ever re-establish itself within its native range.

SCP Methods for Recovery

The SCP calls for reductions in coho harvest, improvements to hatchery management, and substantial habitat restoration (ODFW 2007). Restoration that increases the productive capacity of the habitat is the primary action of the SCP. The SCP states that habitat management is the key to preservation and recovery of coastal coho (ODFW 2007). There will be no long-term loss of productive capacity of habitat across the ESU. The SCP also calls for conservation of ecological processes and modifications to land-use management to reestablish processes where needed.

The restoration goal is to double the available “high-quality” habitat in the ESU (ODFW 2007). High quality habitat has a capacity to produce 2,800 smolts per mile (ODFW 2007).The SCP states restoration of high quality habitat will be completed in mainstems, tributaries, estuaries, and wetland reaches of coastal rivers, but specifically identified winter refuge habitat and stream “complexity” as targets for restoration. Winter refuge habitat is a product of stream complexity. Complexity is described as various combinations of conditions that can be a benefit to all life stages. The indicators of high-quality winter refuge habitat are instream wood structures, pools, and off-channel habitats (ODFW 2007). Restoration of winter refuge habitat is most suited for low-gradient reaches at lower elevations of the watersheds (ODFW 2007). The lower elevations in watersheds are dominated by private land, so participation from landowners (residential, agricultural, and industrial forest owners) is important to improving habitat (ODFW 2007). From 1997-2003, $107 million was invested in restoration projects (ODFW 2007). About one third of that was voluntarily contributed by private landowners engaged in incentive-based partnerships promoting collaboration on restoration projects (ODFW 2007). It is hypothesized that cooperative restoration will result in more high quality habitat than developing stricter laws and regulations (ODFW 2007).

Public habitat restoration projects are guided by the Oregon Plan for Salmon and Watersheds, funded by the Oregon State Legislature (ODFW 2007). The SCP stated that state-level funding for restoration was expected to increase. Significant federal agencies involved in restoration include U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency (EPA), U.S. Forest Service, and Bureau of Land Management (ODFW 2007). State-level stakeholders involved in restoration include the ODFW, Oregon Department of Forestry, Oregon Water Resources Department, Oregon Department of Environmental Quality, and the Oregon Watershed Enhancement Board (OWEB) (ODFW 2007). OWEB maintains the Oregon Watershed Restoration Inventory (OWRI), a database of restoration projects in Oregon, which was used in this paper for analysis of restoration effectiveness within the ESU (See section 2.0 Methods). There are also community-based organizations such as water conservation districts, watershed councils, and local conservation groups that play a role in restoration funding and action (ODFW 2007).

3.7 The Effects of Management and Recovery Efforts

The SCP acknowledges management of coho salmon populations is constrained by economics, social values, and politics (ODFW 2007). However, the ODFW claims that adaptive management has eliminated significant threats to the ESU populations from harvest, hatchery programs, and habitat loss (ODFW 2007). The following sections briefly elaborate on the extent to which hatcheries and harvest threats have been reduced. Habitat restoration, the main focus of the SCP and this paper, is discussed in greater detail in Section 4.

Reductions in Hatchery Releases

Fish hatcheries were rejected as a strategy to achieve recovery goals (ODFW 2007). Supplemental hatchery programs on the Oregon Coast have failed to provide sustainable, long-term increases to salmon abundance and have had significant negative ecological impacts on wild fish (Oosterhout et al. 2005). The SCP concluded that hatcheries cannot make up for factors currently limiting production, namely habitat loss (ODFW 2007).

Hatchery smolt releases were reduced from a high of 35 million in 1981 to 260 thousand in 2010 (ODFW 2011). Hatchery releases were discontinued entirely in the Salmon and North Umpqua Rivers (ODFW 2007). The SCP stated that three hatcheries will remain active to support consumptive ocean fisheries and recreational needs not met by current wild populations. In 2009, only three remaining hatcheries release coho smolts in Oregon Coast (Stout et al. 2011). Figure 5 shows hatchery smolt releases on the Oregon Coast from 1960 to 2010. Note the significant decrease since 1994.

Research has been conducted to understand the impact of hatchery reductions on the Oregon Coast populations. Predation on smolts by birds and mammals was significantly reduced in the Alsea watershed from 1997 to 1998 when the number of hatchery smolts released dropped from 1,000,000 to 200,000 individuals (Nickelson 2003). Oosterhout et al. (2005) modeled scenarios of short-duration hatchery programs to increase abundance during times of poor ocean conditions or in rivers with poor habitat. Wild adult coho abundance and population fitness declined in all scenarios. The authors concluded that restoration has the greatest potential for salmon recovery and that hatchery programs are unlikely to produce long-term, sustainable effects.

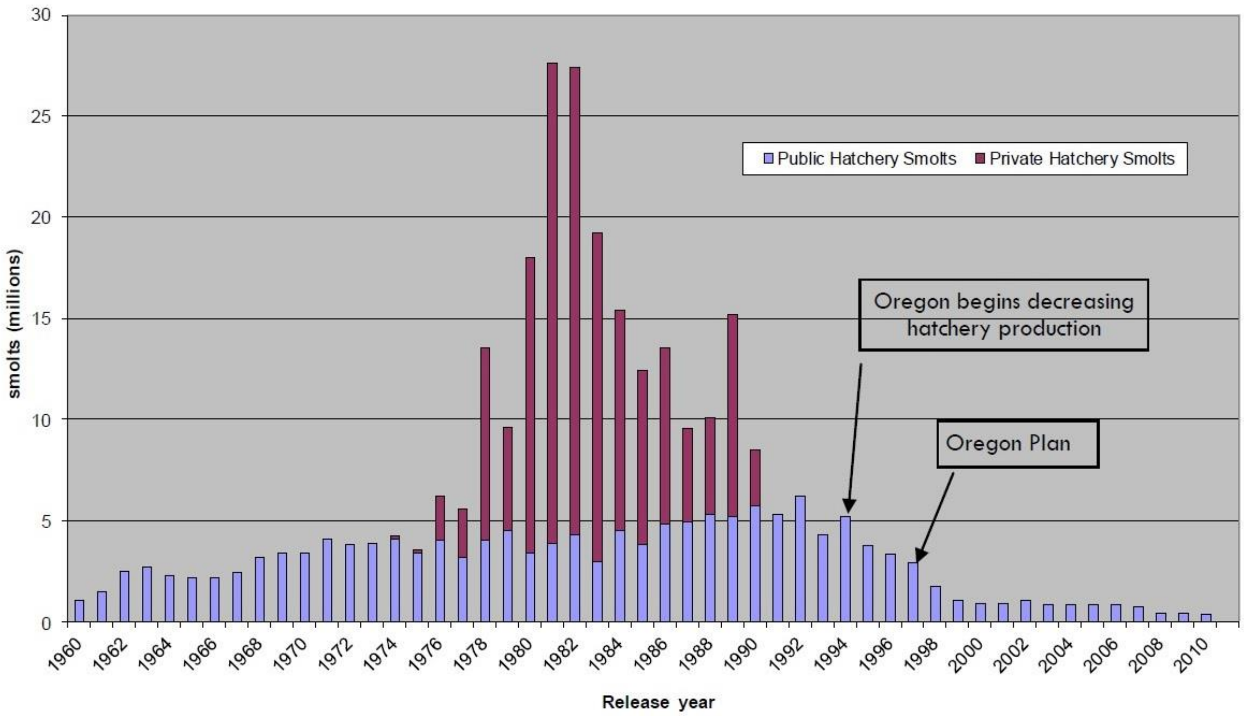

Figure 5. Oregon Coast hatchery smolt releases 1960-2010 (ODFW 2011).

<u>Reductions in Coho Salmon Harvest</u>

Historic harvest of coho salmon was almost always greater than 50% of returning adults (ODFW 2011). Harvest peaked in the 1970s when nearly 90% of the returning adults were harvested (Stout et al. 2011). Figure 6 illustrates harvest percentages from 1970 to 2010. The dramatic reduction in harvest beginning in 1994 is noticeable. Ocean harvest of coho salmon has been reduced to less than 15% of the adult runs per year (ODFW 2007). In addition, harvest limits are now set based on expected ocean survival (Stout et al. 2011).

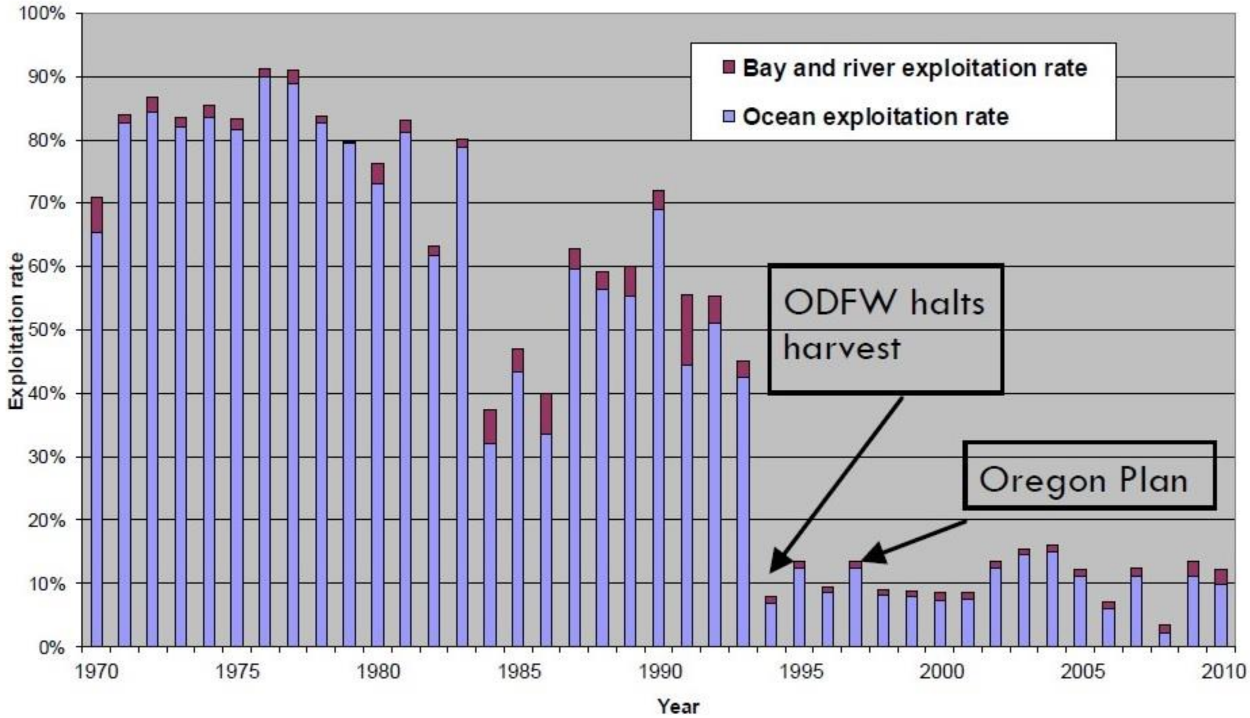

Figure 6. Oregon Coast coho salmon harvest 1970-2010 (ODFW 2011).

4.0 OREGON COAST COHO HABITAT AND POTENTIAL FOR RESTORATION

Available freshwater habitat is the limiting factor for long-term abundance of wild salmon (Meengs and Lackey 2005). To reduce anthropogenic sources of mortality, riverine restoration has been used to enhance salmon rearing, migrating, and spawning habitat (Katz et al. 2007). Federal, state, and local groups are investing time and money throughout the Pacific Northwest (PNW) to restore riverine habitat. The Clean Water Act (CWA) requires state to improve waters that do not meet water quality standards. However, the dominant driver of the PNW restoration effort has been the listing of all five salmon species under the ESA. An inventory of riverine restoration projects by Katz et al. (2007) showed that 80% of projects in Washington, Oregon, Idaho, and Montana occurred on rivers with anadromous salmon. That is substantial considering those rivers make up only 50% of the total land area of that region (Katz et al. 2007). Restoration treatments that can increase habitat quality to levels needed is available today, and the SCP identified restoration as the dominant action most needed to restore productivity of Oregon Coast coho salmon (ODFW 2007). The following sections discuss freshwater habitat conditions that reduce coho productivity, the status of Oregon Coast ESU habitat, and restoration actions that can improve habitat quality.

4.1 Habitat Characteristics that Limit Coho Salmon Survival

Over 50% of coho salmon egg-to-adult mortality occurs in freshwater (Wainwright and Weitkamp 2013). Because of their complex life-cycle, coho salmon require multiple freshwater habitats throughout their life, including habitats for egg incubation, juvenile rearing, and migrations (Bisson et al. 2009). Figure 7 shows the coho salmon life-cycle and the primary factor(s) that limit survival to the following stage of development.

The diversity of habitat available for coho salmon at each stage of development is also very important. Salmon of the PNW live in dynamic systems with region-wide variability in ocean conditions, climate, hydrology, and geomorphology (Flitcroft et al. 2012). Furthermore, there can be annual variation in local water temperature and food availability (Giannico and Hinch 2007). Salmon naturally cope with dynamic conditions by exploiting a diversity of habitats (Flitcroft et al. 2012).

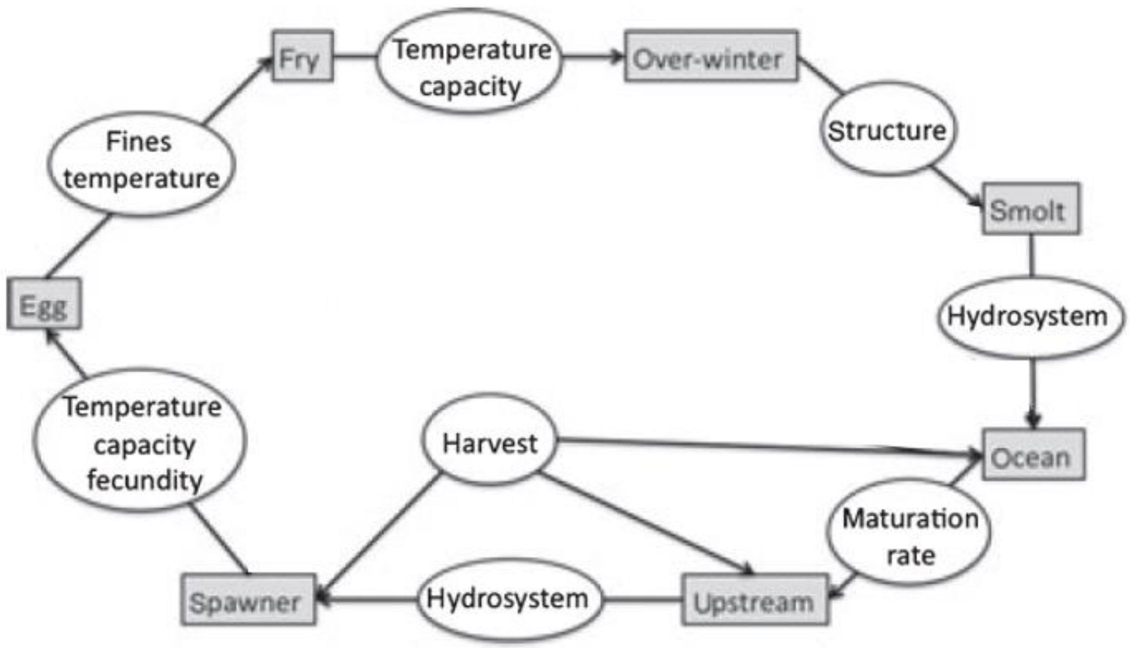

Figure 7. Salmon life cycle from egg to adult spawner (shaded rectangles), and primary factors influencing transition to next stage (ovals) (Honea et al. 2009).

The relationships between salmon survival and indicators of habitat such as water temperature, abundance of instream wood structure, pool depth, and percent fine sediment are due to complex and dynamic hydrologic, geomorphic, and biotic interactions. These interactions are explained below for each level of coho development.

Egg Survival to Fry Stage

Fertilized coho eggs are deposited in redds in December and January (Lawson et al. 2004). The eggs incubate amongst the gravel until they hatch in March and April (Null and Lund 2012). Egg to fry survival is dependent on water temperature where mortality can occur when temperatures are above or below the acceptable range (Honea et al. 2009). Coho egg survival is highest when temperatures are between 2.5- 6.5°C (Richter and Kolmes 2005). High winter water temperature can accelerate egg development, and offset natural timing of hatch and fry development with freshwater conditions (Lawson et al. 2004). Hatchlings in the first several weeks prefer water temperatures between 4-13°C (Null and Lund 2012). Temperatures greater than 15°C can result in egg mortality or poor fry development (Richter and Kolmes 2005).

Egg to fry survival can also be impacted by winter flows. Low flows can dewater redds. High winter flows can scour redds with moving gravel and reduce survival of eggs to emergence (Flitcroft et al. 2012; Lawson et al. 2004).

Fine sediment in the streambed is negatively correlated with egg to fry survival (Honea et al. 2009). Fine sediment has been characterized as particle size between 0.3-0.85 mm in diameter (Jensen et al. 2009). A meta-analysis of 14 egg to fry experiments by Jensen et al. (2009) showed coho salmon survival was reduced by 18.3% with a 1% increase in fine sediments less than 0.85 mm. Figure 8 shows results from the research of Jensen et al. (2009), in which coho salmon are represented by triangles and a dashed line. Once the percent fine sediment increased above 30%, the percent of egg survival was near zero.

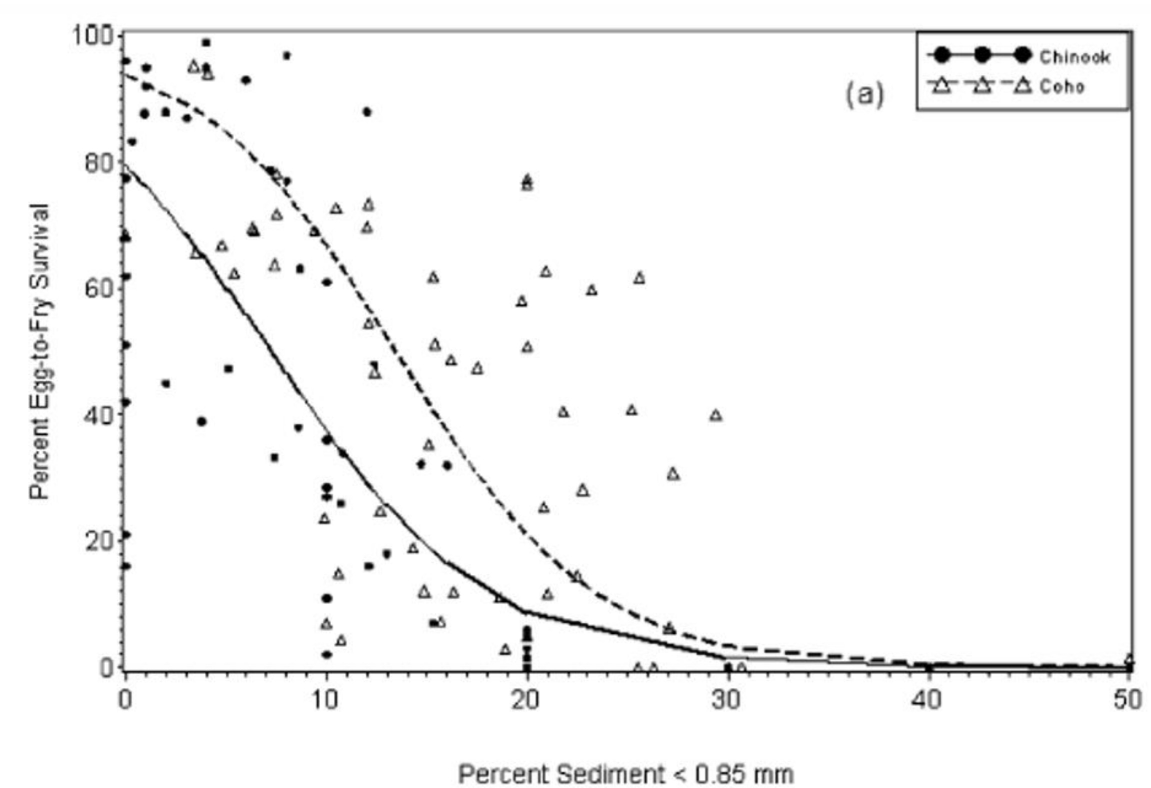

Figure 8. Chinook and coho salmon egg-to-fry survival against the percent of fine sediment in the streambed (Jensen et al. 2009).

Sedimentation problems in Oregon Coast streams are correlated with reduced forest cover, increased road density, and increased construction of anthropogenic impervious surfaces (Honea et al. 2009). It is not always clear how sedimentation reduces egg survival and fry emergence specifically. It is possible that fine sediment covers eggs and reduces dissolved oxygen flow during incubation and eggs die by suffocation (Schindler-Wildhaber et al. 2014). Another possibility is that sedimentation inhibits ventilation or removal of toxic metabolic wastes from the incubating eggs (Jensen et al. 2009). Even if the eggs survive they may be critically underdeveloped which would lead to increased mortality at a later life stage (Jensen et al. 2009). Sedimentation may also cover eggs to the point at which fry cannot emerge from the redd (Jensen et al. 2009). The direct cause may vary based on the unique conditions of each population and watershed.

Fry Survival to Overwintering Parr Stage

Oregon Coast coho fry begin feeding in April and May. Juveniles must survive the summer, fall, and winter before migrating out to the ocean as smolts the following spring. Juvenile coho salmon move throughout the watershed seasonally to find suitable habitat depending on conditions. Fry survival to overwintering parr stage is negatively correlated with streamflow and summer water temperatures (Honea et al. 2009). Fry can withstand temperatures up to 12°C but prefer a range between 4°C and 8°C (Richter and Kolmes 2005). Low summer flows can reduce fry survival, by increasing water temperature, and reducing availability of cool-water habitats (Lawson et al. 2004).

Summer thermal refuge habitat is identified as pools over 0.5 meters deep (Flitcroft et al. 2012). Coho salmon can survive summer even in intermittent streams with no streamflow if pools are present (Wigington et al. 2006). However, the quantity of available cool-water habitat can limit coho salmon survival, because coho avoid sharing habitats, and dominant fish outcompete smaller individuals (Giannico and Hinch 2007). Summer rearing density of coho salmon in Oregon coastal streams averages only 1.5 fish per square meter of pool surface area (Johnson et al. 2005).

Warmer summer temperatures increase metabolic rates and feeding requirements (Morley et al. 2005). This means that salmon predators will be consuming more as well (Richter and Kolmes 2005). Juvenile salmon need habitat specifically for foraging, as abundance of invertebrate prey is not equal throughout a reach (Rosenfeld and Raeburn 2009). Prey abundance is typically greater in riffles than in lower velocity habitats (Rosenfeld and Raeburn 2009). The greater abundance of food offsets the energy requirements of holding in the current. However, stream velocity can make it difficult for juvenile salmon to catch drifting invertebrates (Bellmore et al. 2012). Riffles with boulders or instream large wood complexes can provide relief from flows. High pool frequency will also increase salmon productivity because it slows down prey transport which increases consumption rates (Rosenfeld and Raeburn 2009). Rosenfeld and Raeburn (2009) reported that dominant juveniles can monopolize feeding habitats, showing that quantity of available foraging habitats can reduce coho productivity and survival as well.

Overwintering Parr Survival to Smolt Stage

In the fall, juvenile coho transition to the parr stage and disperse to winter habitats. Winter habitat consists of off-channel habitats such as sloughs, beaver ponds, side channels, and tributaries (Roni and Quinn 2001). Off-channel habitat is more important to coho than other species of salmon (Morley et al. 2005). Coho density in off-channel habitats is often greater than other salmon species which suggests that coho have a higher affinity for these habitats (Morley et al. 2005).

Parr to smolt survivorship is dependent on availability of winter rearing habitat (Giannico and Hinch 2007). Juvenile coho are less fit than adults for high winter streamflows, which increases energy expenditures and restricts dispersal (Flitcroft et al. 2012). High flows can displace parr, and even cause fatal injuries (Wigington et al. 2006). The off-channel habitats provide refuge from the high winter flows that negatively affect overwintering parr (Anderson et al. 2013). Productive streams must have abundant winter refuge habitat to avoid concentrating juveniles in the refuge habitats where survival is reduced through predation and or competitive interactions (Lawson et al. 2004). Some studies have shown that insufficient overwintering refuge habitat is the main factor limiting coho salmon productivity on the Oregon Coast (Morley et al. 2005).

Juvenile use of refuge sites has been shown to increase survival over those that remain in main-channel (Anderson et al. 2013). Wigington et al. (2006) measured higher winter survival for juvenile coho in intermittent tributaries than in the main channel (Table 3). Parr winter survival was greater in tributaries off of the main channel for all three years of the study. Additionally, parr that overwinter in off-channel habitats often have higher growth rates than individuals that remain in the main channel (Morley et al. 2005). This is significant because larger smolt size increases ocean survival rate (Wigington et al. 2006).

Table 3. Juvenile coho salmon percent survival while overwintering in tributaries and mainstem of the West Fork Smith River watershed, OR (Wigington et al. 2006).

Stream type	*Winter 2002-03*	*Winter 2003-04*	*Winter 2004-05*
Intermittent streams	13	21	41
Perennial streams	12	25	38
Mainstem	9	14	14

Survival of coho parr is also thought to be influenced by complex interactions between the size, density, and quantity of woody debris (Chase et al. 2012). Juvenile density increases when large wood debris is present (Flitcroft et al. 2012). The relationship between coho presence and wood structure has several possible explanations. Woody debris in streams can lower water velocity, reducing energy expenditures, and provides refuge from predators (Giannico and Hinch 2007). Wood can also trap and retain salmon carcasses from being flushed downstream, and juvenile salmon have been observed feeding directly on carcasses. Survival rates of overwintering coho in a control pen without wood structure and adult carcasses were found to be lowest (out of four pens) in both years of a study by Giannico and Hinch (2007) (Figure 9).

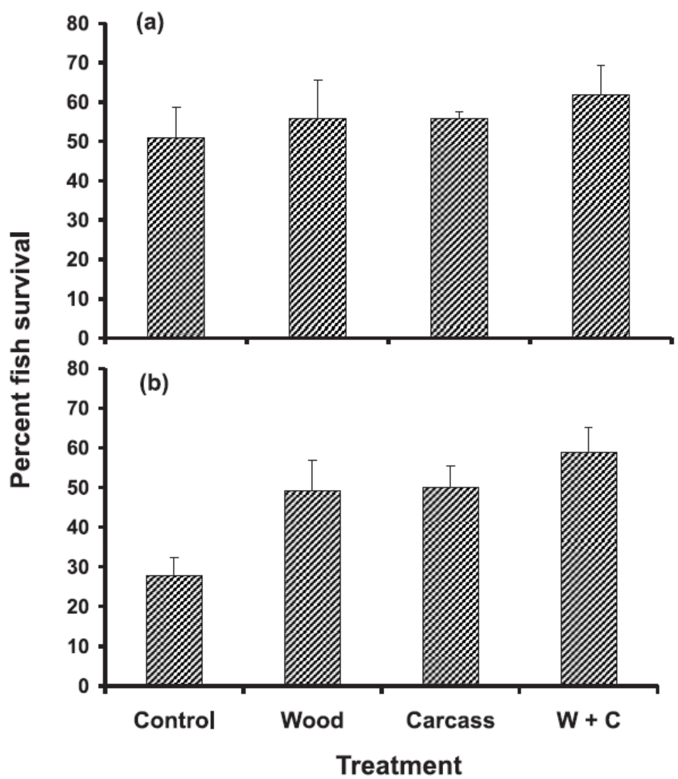

Figure 9. The survival percentage of juvenile coho salmon in four pens in the Mamquam River, British Columbia, during winters 1996-1997 (a), and 1997-1998 (b) (Giannico and Hinch 2007).

Smolt Survival to Ocean Migration

Smolts prefer temperatures between 12°C and 14°C while in freshwater (Null and Lund 2012). High temperatures can trigger smolts to migrate to the ocean prematurely (Richter and Kolmes 2005). Spring water flows can aid smolts migrating downstream (Lawson et al. 2004). Lawson et al. (2004) showed that high spring flows are positively correlated with smolt production on the Oregon Coast. The smolts benefit from a shorter outmigration and less time being exposed to predators. Also, elevated flows are usually associated with increased turbidity which may hide smolts from predators.

Migratory Adult Survival to Spawn

Adult coho salmon cannot live in waters for an extended period of time with temperatures above 23.4°C (Lawson et al. 2004). Migratory adults can move well through waters up to 15.6°C (Richter and Kolmes 2005). However, temperatures above 13°C just prior to spawning results in reduced fertility (Richter and Kolmes 2005).

Adult salmon require gravel to spawn. Spawning habitat has been identified as riffles with bottom greater than 50% gravel, and less than 8% silt (Flitcroft et al. 2012). Reductions in fine sediment increase egg survival and adult spawner abundance (Honea et al. 2009).

Nutrient Limitations in Oregon Coast Rivers

The survival of coho fry, parr, and smolt have all been impacted by the reduction in nutrients and aquatic productivity in Oregon Coast watersheds (Giannico and Hinch 2007). Decreased abundance of spawning adult salmon has reduced the nutrients and organic matter available, limiting the food available to juveniles (Bellmore et al. 2012). The concentration of marine derived nutrients from adult salmon released to Oregon Coast streams each year is 6-7% of historic levels (Giannico and Hinch 2007). Increased salmon carcass presence causes increased growth rates and body mass of juvenile coho salmon (Giannico and Hinch 2007). There are multiple advantages of body mass relating to winter survival. In the experiment by Giannico and Hinch (2007), the juveniles that survived the winter were statistically larger than juveniles that died. Greater body mass increases metabolic efficiency in cold water temperatures (Giannico and Hinch 2007).

Water Temperature

Temperature related mortality can occur in all coho life stages (Huang et al. 2011). Temperature tolerance varies for different watersheds and can be dependent on duration, availability of refuge habitat, acclimation, body size, food availability, and competition (Null and Lund 2012). Dissolved oxygen decreases when water temperature increases (Richter and Kolmes 2005). Salmon essentially have to breathe harder, which moves more water than normal over the gills (Richter and Kolmes 2005). This process has been shown to increase the rate of uptake of toxins in the water (Richter and Kolmes 2005).

Salmon are more susceptible to parasites and disease at higher water temperatures (Lawson et al. 2004). The temperature for many bacterial infections and diseases is above 16°C (Richter and Kolmes 2005).

Elevated temperatures can cause weight loss (Richter and Kolmes 2005). Water temperature has indirect effects on coho salmon through altering primary and secondary productivity (Morley et al. 2005). Other ways in which salmon can be impacted by temperature are direct physiological stress, territoriality, and aggressiveness (Morley et al. 2005; Richter and Kolmes 2005). The presence of thermal refuge habitats (deep pools, reaches shaded by riparian vegetation, and smaller tributaries) are important for coho salmon survival in many Oregon Coast watersheds (Richter and Kolmes 2005).

Cumulative Impacts of Poor Habitat Conditions

Individual stressors do not have to be lethal to negatively impact salmon populations. Multiple stressors can cumulatively reduce salmon survival, as stressed fish are less able to deal with additional stressors (Richter and Kolmes 2005). Studies that quantify single stressors often underestimate impacts (Wainwright and Weitkamp 2013). For example, many streams in the ESU boundary have water temperatures slightly greater than historic conditions. They also have reduced riparian vegetation and lower frequency of pools and other thermal refuge habitats (Richter and Kolmes 2005). Each condition in and of itself would not have significant impacts on salmon productivity. It is often the cumulative effects of multiple stressors that limit salmon survival. There are also indirect impacts to salmon that are not easily detected, but manifest over time, often through trophic interactions (Richter and Kolmes 2005). An example would be elevated water temperatures that do not directly cause salmon mortality, but promotes a range expansion of a non-native species which then preys on juvenile salmon.

4.2 Oregon Coast ESU Habitat Assessment

The EPA temperature standard for salmon bearing streams is 12.8°C. That is problematic on the Oregon Coast where 43% of the streams are listed on the EPA 303(d) list for high temperatures (Lawson et al. 2004). Table 4 quantifies the stream miles of the Oregon Coast ESU in excedence of the EPA standard. Nearly 3 thousand miles of habitat has water temperatures higher than the range preferred by coho salmon.

Table 4. The stream miles that exceed summer water temperature standards in the five Oregon Coast ESU stratum (Wainwright and Weitkamp 2013).

Stratum	Total Habitat Miles	Impaired Miles	Impaired Percent
Lakes	239	14	6%
Mid-Coast	2017	607	30%
Mid-South Coast	1193	426	36%
North Coast	1466	471	32%
Umpqua	2009	1430	71%
TOTAL	6924	2948	43%

Freshwater habitat in the ESU is limiting coho productivity. Table 5 shows the primary and secondary factors limiting coho productivity of the 21 independent populations. Nearly all limiting factors are habitat related. Only the North Umpqua and Salmon Rivers are limited by non-habitat related factors (hatchery production).Water quality and or stream complexity is listed as a limiting factor for all populations (water quality includes water temperature). The extent to which habitat quality is limiting Oregon Coast coho populations is the reason why the SCP selected restoration as the best method of recovery (ODFW 2007).

In 2007, the ODFW estimated 2,501 miles of high quality habitat needed to be restored to reach Oregon Coast coho salmon recovery goals of the SCP (ODFW 2007). High quality habitat has a capacity to produce 2,800 smolts per mile (ODFW 2007). Table 6 shows the total stream miles of high-quality habit needed for each independent population of the ESU, and the estimated dollar amount needed for restoration. The amount of habitat restoration varied throughout watersheds. Beaver Creek needs just 11 miles of habitat restored, while the Siuslaw River requires restoration of 381 stream miles. The column farthest to the right of Table 6 is the estimated cost of restoration. The total cost of restoration of the Oregon Coast watersheds is over 62 million dollars. The average cost of restoring each stream mile is $25,000.

Table 5. The independent populations of the Oregon Coast ESU with primary and secondary factors limiting coho productivity (ODFW 2007).

Population	Primary Limiting Factor	Secondary Limiting factor
Necanicum	Stream Complexity	--
Nehalem	Stream Complexity	Water Quality
Tillamook	Stream Complexity	Water Quality
Nestucca	Stream Complexity	--
Salmon	Hatchery Impacts	Stream Complexity
Siletz	Stream Complexity	--
Yaquina	Stream Complexity	Water Quality
Beaver	Spawning Gravel	Stream Complexity
Alsea	Stream Complexity	Water Quality
Siuslaw	Stream Complexity	Water Quality
Lower Umpqua	Stream Complexity	Water Quality
Middle Umpqua	Water Quantity	Stream Complexity Water Quality
North Umpqua	Hatchery Impacts	Stream Complexity
South Umpqua	Water Quantity	Stream Complexity Water Quality
Siltcoos	Exotic Fish Species	Stream Complexity Water Quality
Tahkenitch	Exotic Fish Species	Stream Complexity Water Quality
Tenmile	Exotic Fish Species	Stream Complexity Water Quality
Coos	Stream Complexity	Water Quality
Coquille	Stream Complexity	Water Quality
Floras	Stream Complexity	Water Quality
Sixes	Stream Complexity	Water Quality

Table 6. Cost of creating enough high quality habitat to reach recovery goals. Scenario 1 is meeting restoration goals in 17 years, 33 years for scenario 2, and 50 years for scenario 3 (ODFW 2007).

Population	New Miles HQH Needed	Scenario 1		Scenario 2		Scenario 3		Total Cost
		Miles/ year	Cost per Bienium	Miles/ year	Cost per Biennium	Miles/ year	Cost per Bienium	
Necanicum	41	2.4	$120,179	1.2	$61,910	0.8	$40,861	$1,021,518
Nehalem	311	18.3	$915,880	9.4	$471,817	6.2	$311,399	$7,784,982
Tilllamook	126	7.4	$371,276	3.8	$191,263	2.5	$126,234	$3,155,844
Nestucca	45	2.6	$131,510	1.4	$67,748	0.9	$44,714	$1,117,838
Salmon	16	0.9	$46,821	0.5	$24,120	0.3	$15,919	$397,982
Siletz	79	4.6	$231,714	2.4	$119,368	1.6	$78,783	$1,969,570
Yaquina	136	8.0	$400,122	4.1	$206,123	2.7	$136,042	$3,401,038
Beaver	11	0.7	$33,647	0.3	$17,333	0.2	$11,440	$286,001
Alsea	129	7.6	$378,881	3.9	$195,181	2.6	$128,820	$3,220,493
Siuslaw	381	22.4	$1,120,602	11.5	$577,280	7.6	$381,005	$9,525,115
Lower Umpqua	195	11.5	$574,484	5.9	$295,946	3.9	$195,325	$4,883,117
Middle Umpqua	301	17.7	$886,116	9.1	$456,484	6.0	$301,280	$7,531,990
North Umpqua	51	3.0	$150,635	1.6	$77,600	1.0	$51,216	$1,280,399
South Umpqua	349	20.5	$1,025,551	10.6	$528,314	7.0	$348,687	$8,717,182
Coos	58	3.4	$169,318	1.7	$87,224	1.2	$57,568	$1,439,203
Coquille	213	12.5	$626,301	6.5	$322,640	4.3	$212,942	$5,323,561
Floras	42	2.5	$123,481	1.3	$63,612	0.8	$41,984	$1,049,593
Sixes	16	1.0	$48,387	0.5	$24,926	0.3	$16,451	$411,287
Total	2,501	147.1	$7,354,907	75.8	$3,788,892	50.0	$2,500,668	$62,516,711

4.3 Salmon Habitat Restoration

Tables 5 and 6 show the extent to which restoration is needed on Oregon Coast streams to recover coho populations. Restoration science that can increase habitat quality to levels needed is available today (ODFW 2007). Within the Oregon Coast ESU, restoration on federal land and state forest land is most feasible (ODFW 2007). Private industrial forests are the next most feasible. Restoration is least feasible on agricultural and urban lands. Agricultural and urban lands dominate the lower elevations of watersheds, which are typically the most degraded habitats (ODFW 2007). The SCP recognized that while it may be more difficult, cooperative restoration on private land at lower elevations poses the greatest potential to improve the habitat.

There are many types of projects to restor coho salmon freshwater habitat relating to: barrier removal, instream flow, nutrient enhancement, riparian function, sediment reduction, stream complexity, upland, and water quality (Katz et al. 2007). Stream complexity and water quality are the two primary factors limiting Oregon Coast coho populations. Many of the restoration types have been documented in scientific literature showing positive impacts on PNW salmon. Table 7 lists the eight main forms of salmon restoration modified from Katz et al. (2007). To the right of each of the eight main restoration categories are examples of that type of restoration. The eight types of restoration projects are explained in greater detail in the following sections of this report.

Table 7. Types of restoration projects for improving coho salmon habitat.

Project Type	Examples	Project Type	Examples
Barrier Removal	Dam Removal	Sediment Reduction	Erosion Control
	Fish Ladder Installation		Bank Stability
	Fish Ladder Improvement		Gavel Inputs
	Culvert Removal	Stream Complexity	Instream Structure
	Culvert Improvement		Channel Reconfiguration
Instream Flow	Water Rights		Refuge Habitat
	Regulate Flows		Off-channel Creation
	Reduce Withdrawals		Off-channel Connectivity
Nutrient Enhancement	Carcass Deposits	Upland	Land-Use Management
Riparian Function	Plantings		Run-off Control
	Plant Removal		Road Decommission
	Physical Structure		Forestry Regulations
	Livestock Fencing	Water Quality	Temperature Reduction
			Pollutant Removal

Barrier Removal

Barrier removal and fish passage improvements have become increasingly popular methods for salmon conservation (Anderson et al. 2013). Examples of barrier removal projects include dam removal, passage improvements through fish ladders, and culvert removal. Large-scale dams and the need for fish ladders are not common on Oregon Coast streams (Oosterhout et al. 2005). Some tributaries have small dams, water diversions, culverts, and road crossings that block coho passage (Stout et al. 2011). An estimated 6-11% of previously unavailable habitat has been restored through barrier removal projects on Oregon Coast rivers (Stout et al. 2011).

Barrier removal can restore the ecosystem processes typical of natural streams such as extreme hydrologic events, and transportation of sediment and nutrients (Bisson et al. 2009). The most significant impact of barrier removal projects is that adult salmon can access habitat previously unavailable. Barriers to juvenile salmon can limit a stream's population capacity as well, and should also be considered for removal (Anderson et al. 2013).

Anderson et al. (2013) recorded coho passage upstream after a barrier had been removed on Cedar River in Washington. Rock Creek is a tributary that was previously behind the impassable barrier. Post-restoration, adult coho began spawning in Rock Creek, with the number of individuals increasing each year of their five-year study, showing that adult coho salmon can recolonize previously unavailable habitats. Juveniles in the study also were shown to further disperse to locations where there was no adult reproduction.

Instream Flow

Restoration of instream flow means to reestablish natural streamflow regimes that are more representative of historic conditions. Natural flows are important in the formation of freshwater habitat through the creation of new channels, wood recruitment to the streambed, and sediment movement and deposition (Waples et al. 2009). Low flows can be caused by groundwater pumping and surface water diversions (Null and Lund 2012). Low flows cause increased water temperatures, reduced connectivity to riparian and off-channel habitat, and reduced gravel recruitment (Null and Lund 2012). Examples of instream flow restoration projects include reducing water usage by reallocating water rights, regulating water releases from reservoirs, and reducing water pumping from rivers. Low flows are not a major factor limiting Oregon Coast coho salmon populations (ODFW 2007).

Nutrient Enhancement

The nutrient concentration of Oregon Coast rivers is significantly reduced because of poor adult salmon returns (Giannico and Hinch 2007). Placing salmon carcasses in streams can provide marine derived nutrients, replacing the nutrients lost from diminished adult salmon runs (Bisson et al. 2009). Carcass deposits reestablish aquatic and riparian food webs (Bisson et al. 2009). The nitrogen and carbon deposited from salmon carcasses supports aquatic invertebrate productivity and is indirectly passed to juvenile salmon feeding on invertebrates (Giannico and Hinch 2007). Invertebrates are the dominant food source for juvenile coho salmon (Morley et al. 2005). Nutrient enhancement restoration through salmon carcass deposition has been shown to increase juvenile muscle mass and lipid reserves (Giannico and Hinch 2007).

Riparian Function

Riparian logging and development has contributed to a reduction in riparian habitat function throughout many of the Oregon Coast watersheds (Meengs and Lackey 2005; Pess et al. 2012). Riparian vegetation has many functions that are important to salmon survival (Balian and Naiman 2005). Examples of restoring riparian function include projects that remove non-native vegetation, or planting of native vegetation. Riparian vegetation stabilizes the stream bank, reducing erosion and sedimentation in the channel (Meengs and Lackey 2005).

Restoration of riparian forests is common (Bisson et al. 2009). Riparian forests contribute to wood accumulations, which creates complex habitats and provides in-channel cover from predators (Honea et al. 2009; Pess et al. 2012). Forests provide shading to the stream, which has been shown to be effective at cooling water temperatures (Bisson et al. 2009; Null and Lund 2012). Forests can also moderate instream flows and subsurface groundwater contributions from the adjacent water table (Bisson et al. 2009).

Another example of restoring riparian function is installing livestock fencing. Agricultural and grazing of livestock are the dominant land-uses in the lowland regions of the Oregon Coast (Flitcroft et al. 2012). Installation of livestock fencing keeps animals out of the riparian corridor. The results are more riparian plant biomass from reductions in grazing, less compaction of riparian soils, and reduced erosion of the streambanks.

Sediment Reduction

Sedimentation in the streambed is one of the greatest contributing factors in freshwater salmon mortality (Jensen et al. 2009; Schindler-Wildhaber et al. 2014). Sediment reduction restoration projects include erosion control and bank stability measures through enhancing riparian vegetation. Riparian vegetation regulates erosion and deposition of fine sediment over spawning gravel (Wainwright and Weitkamp 2013). Logging and development in the riparian corridor of Oregon Coastal streams has removed riparian vegetation and caused sedimentation of the streambed ((Meengs and Lackey 2005; Steel et al. 2012).

Another form of sediment reduction restoration is actual gravel inputs (Utz et al. 2012). This technique augments the streambed with suitably sized sediments for spawning and egg incubation (Utz et al. 2012). Restoration via gravel inputs has been shown to be effective at restoring salmon habitat. Albertson et al. (2013) measured habitat quality characteristics of a restoration site on the Merced River, California with 19 other reference streams. The restored site had percent fine sediment and streambed substrate compactedness measurements lower than the mean of the reference streams (Albertson et al. 2013).

Stream Complexity

Stream complexity restoration is a broad category. Habitat complexity is described by the ODFW as various combinations of conditions that can be a benefit to all life stages. Examples of stream complexity restoration projects are: installing engineered physical structure in the stream channel, reconfiguring the channel properties, creating refuge habitat for high flows, predators, and elevated water temperatures, creating off-channel habitats, and reconnecting the stream channel to off-channel habitats. Stream complexity restoration is needed in Oregon Coast streams, as it is either the primary or secondary factor limiting coho productivity for all 21 independent ESU populations (ODFW 2007).

The placement of woody debris instream has multiple benefits. Ecologically, large wood slows bedload movement and deposits and sorts gravels (Johnson et al. 2005). The placement of large wood within the stream channel has been shown to increase abundance of pools and increase pool depth (Johnson et al. 2005). In a study by Johnson et al. (2005), the placement of large wood increased then amount of side-channel habitat. Engineered logjams on the Elwha River in Washington State scoured pools (Pess et al. 2012). In addition, there was a 60% increase in sediment storage in gravel bars near the logjams. The streambed sediment characteristics changed from large coble dominant to gravel.

Pess et al. (2012) found that the process of wood dispersing and accumulating is the dominant factor in the distribution of juvenile coho salmon. Instream woody debris placement has been shown to increase fry to smolt survival (Johnson et al. 2005). Woody structure is preferred by juvenile salmon because it provides refuge from current and predators (Giannico and Hinch 2007). Large wood and complex structure within pools often increases densities of rearing juvenile salmon (Johnson et al. 2005). Juvenile coho salmon abundance was significantly higher near engineered log jams than surrounding reaches on the Elwha River due to slower water speeds and increased cover from predators (Pess et al. 2012).

Reconfiguring the stream channel properties often includes adding sinuosity, pools, and riffles to the streambed. High velocity riffles can produce invertebrates, but provide little opportunity for consumption (Rosenfeld and Raeburn 2009). Pools can be created to make up to 40-50% of the total channel area (Rosenfeld and Raeburn 2009). Invertebrate prey are consumed at a higher rate in pools with little transport downstream. (Rosenfeld and Raeburn 2009).

Off-channel habitats are used by juvenile salmon for refuge from high winter flows (Morley et al. 2005). In addition, off-channel habitats have a more consistent water temperature and invertebrate productivity (Morley et al. 2005). Restoring tributaries can influence juvenile salmon abundance. Sub-basins of watersheds can have high annual variation of juvenile abundance due to dynamic conditions (Flitcroft et al. 2012). In stressful years juvenile abundance increases in tributaries where seasonal refuge habitat has high connectivity and proximity to one another (Flitcroft et al. 2012). Tributaries with broad valleys have more potential to develop complex habitats because the stream channel is less constrained (May et al. 2013).

Reconnecting the stream channel to off-channel habitats such as floodplains, sloughs, and tidal marshes can restore hydrologic connectivity (Waples et al. 2009). Floodplains are a dynamic habitat for both aquatic and terrestrial organisms including rearing juvenile salmon (Honea et al. 2009). Juvenile coho abundance is often greater in side channels, tributaries, backwaters, and other off-channel habitats than the main channel (Chase et al. 2012). Floodplains have been shown to increase organic matter recruitment leading to elevated invertebrate productivity (Bellmore et al. 2012).

Upland

Upland conditions can affect freshwater salmon habitat. Upland restoration includes, but is not limited to, land-use management, run-off control, road decommissioning, and forestry regulation. Road decommissioning is common on the Oregon Coast, where the logging industry has resulted in high road density (DellaSala et al. 2013). Decommissioning non-paved roads decreases surface runoff that contributes sediment to the stream channel (Fullerton et al. 2010). Land-use on the Oregon Coast is comprised of industrial forestry, agriculture, livestock grazing, and urban development (Flitcroft et al. 2012; Morley et al. 2005; ODFW 2007). Industrial forestry is the dominate land use in the headwaters of Oregon Coast streams (Morley et al. 2005). Managing forestry regulations is important for the maintenance of coho freshwater habitat (Meengs and Lackey 2005). The SCP called for modification of land-use management if needed to improve coho habitat and reestablish ecological processes (ODFW 2007).

Water Quality

Water quality is the primary or secondary limiting factor of coho salmon productivity for 15 of the 21 independent populations (ODFW 2007). Indicators of water quality are: temperature, dissolved oxygen, nutrient load, chemical composition, and pollutants. Water temperature exceeds the EPA standard (12.8°C) for salmon bearing streams in 43% of stream miles that Oregon Coast coho inhabit (Wainwright and Weitkamp 2013). Water quality restoration can be the removal or reduction of temperature and pollution sources. Water quality restoration can also be a side effect of other restoration projects such as those that increase shading, reduce runoff, and enhance nutrient concentrations.

5.0 ANALYSIS

There were three statistical analysis components of this research. First, the OWRI database was used to quantify the number of projects, the treatments, and the cost of habitat restoration actions on Oregon Coast streams from 1997 to 2012. Second, the SRT database was used to determine if ESU was recovering, stable, or declining. This was done analyzing trends in adult abundance goals, and measured adult abundance from 1994 to 2012. The third component was to evaluate the impact that habitat restoration had on coho population size for the ESU. The results of the statistical analysis are documented in the next three sections.

5.1 Restoration in Oregon Coast Watersheds

There were 4,173 restoration projects on the Oregon Coast streams with independent coho populations from 1997-2012 that were documented in the OWRI database (OWEB 2012). The total cost of the restoration projects was $145,620,716 (OWEB 2012). Multiple treatments were reported for some projects in the OWRI database. Figure 10 shows the relative percentage of each restoration treatment. The most common restoration treatment was sediment reduction which was 29% of all treatments. The least common restoration treatments were instream flow and nutrient enhancement, which accounted for only 1% of treatments each.

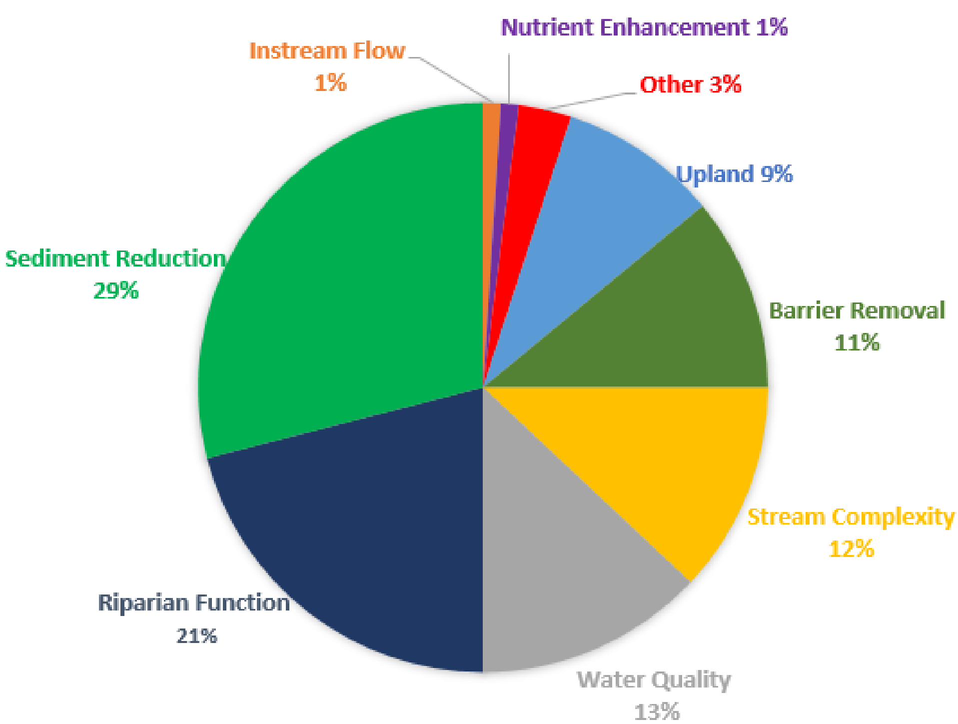

Figure 10. Restoration treatments in the ESU by percent (OWRI 2012).

Restoration projects were not evenly located throughout the ESU streams. The Coquille watershed had 507 projects, while Tahkenitch Lake only had 7 (OWRI 2012). There were no records of restoration in the Beaver Creek watershed. Tillamook Bay watershed had the most money spent on restoration ($24,102,054) even though it had the sixth highest number of projects. Table 8 shows the number of restoration projects, the dollars spent, and the most common and second most common treatments for watersheds. The OWRI database did not distinguish between the Lower and Middle Umpqua watersheds, although they both have individual independent populations within the ESU. In Table 8 projects from the Lower and Middle Umpqua are combined in one entry.

Table 8. The number of projects, dollars spent, and common treatments for ESU watersheds (OWRI 2012).

Watershed	Number of Projects	Total Dollars Spent	Most Common Treatment	Next Most Common Treatment
Coquille	507	10,930,542	Sediment Reduction	Riparian Function
Nehalem	423	17,004,278	Sediment Reduction	Riparian Function
Siuslaw	416	10,475,029	Riparian Function	Sediment Reduction
Lower and Middle Umpqua	415	16,069,297	Sediment Reduction	Riparian Function
Coos	404	10,798,360	Sediment Reduction	Riparian Function
Tillamook Bay	369	24,102,054	Sediment Reduction	Water Quality
Alsea	251	8,911,179	Sediment Reduction	Riparian Function
Sixes	250	4,580,705	Sediment Reduction	Water Quality
Siletz	224	4,622,289	Sediment Reduction	Water Quality
South Umpqua	195	10,562,678	Sediment Reduction	Riparian Function
Necanicum	190	5,165,651	Sediment Reduction	Riparian Function
Yaquina	153	4,118,186	Sediment Reduction	Stream Complexity
Nestucca	119	4,497,813	Sediment Reduction	Riparian Function
Tenmile Lakes	104	2,305,959	Sediment Reduction	Barrier Removal
Floras Creek	54	2,007,682	Sediment Reduction	Riparian Function
North Umpqua	39	7,588,979	Sediment Reduction	Barrier Removal
Salmon	32	990,105	Stream Complexity	Sediment Reduction
Siltcoos	22	643,771	Riparian Function	Barrier Removal
Tahkenitch Lake	6	246,159	Sediment Reduction	Stream Complexity
Total:	**4,173**	**145,620,716**		

Sediment reduction was the most common restoration treatment in 16 of the 19 watersheds. The Siltcoos was the only watershed where sediment reduction was neither the most common nor second most common treatment. Riparian function was the second most common treatment in the ESU watersheds. Riparian function was either the most common or second most common treatment in 11 of the 19 watersheds.

Cost Comparisons

Instream flow was the most expensive restoration treatment. Of the 121 projects that listed instream flow as a treatment, the average cost was $105,016. The next most expensive treatment was barrier removal with an average cost of $62,100. Riparian function was the least expensive treatment with an average cost of $19,166. Sediment reduction was also comparatively inexpensive, averaging $36,103 per project.

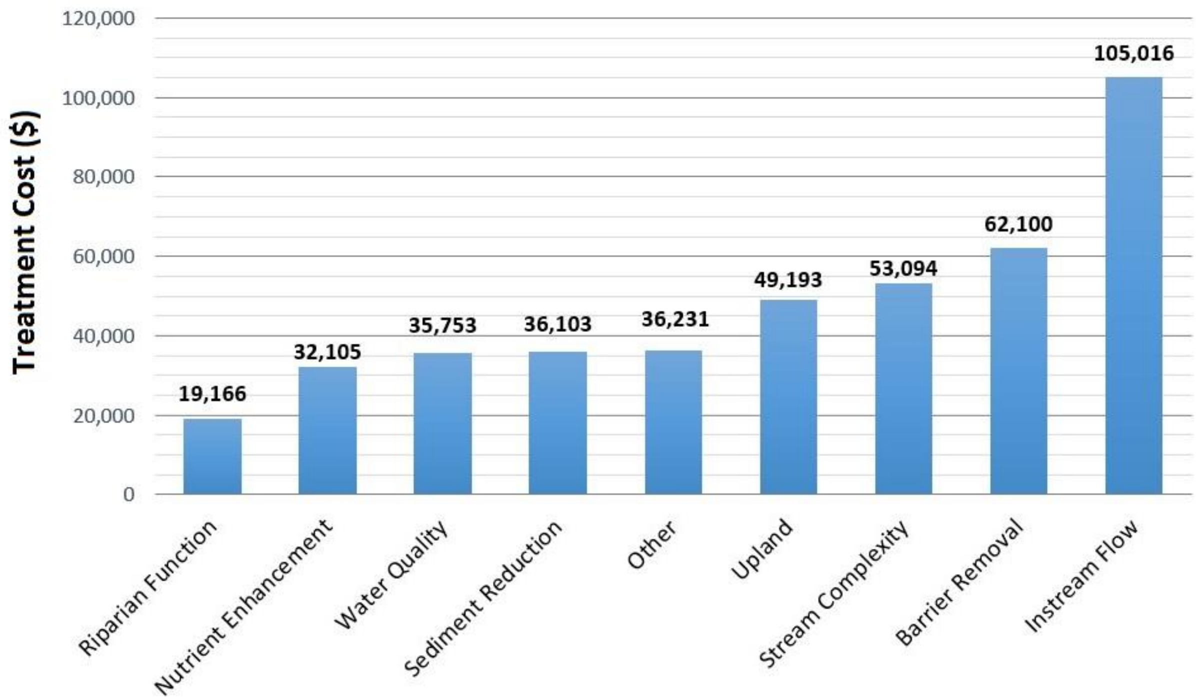

Figure 11. Average cost of restoration treatments (OWRI 2012).

5.2 Recovery of ESU Populations

Adult coho populations are naturally variable on an interannual basis. Beginning in 1994, the ODFW has calculated a yearly abundance goal for the ESU based on ocean conditions. For the entire ESU the abundance goal is 101,000 adults for years with extremely low marine survival, 371,000 adults for low survival years, and 715,000 adults for medium survival years (ODFW 2012). Abundance goals were also calculated for each of the 21 independent populations individually. Abundance goals are rarely met right now, but the purpose of the SCP is to have the abundance goals met by 2057 (ODFW 2007). From 1994 to 2012 the average percent of abundance goal was 48.7% for the whole ESU.

I used measured abundance to calculate the percent of the abundance goal that was achieved each year. Population recovery would mean the percent of the goal reached would increase over time until at least 100 percent of the goal was met annually. I used a linear regression to evaluate whether or not the percent of abundance goal had increased for the ESU since 1994. The slope of the linear regression was a positive 1.7 for the whole ESU. This means that the percent of the abundance goal met was increased on average 1.7% per year. However, the strength of the regression ($p = 0.36$) was not statistically strong enough to conclude that the ESU is recovering. Figure 12 shows the linear regression with percent of abundance goal plotted on the y-axis, and year plotted on the x-axis. The two dark curved lines on either side of the linear regression represent the 95% confidence interval on the estimate mean. The lighter grey lines represent the 95% prediction interval.

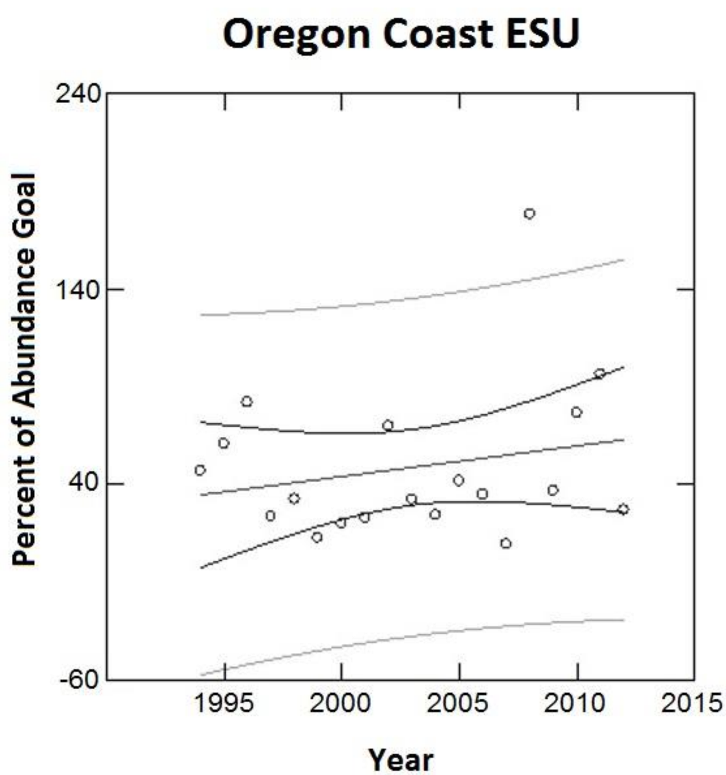

Figure 12. Linear regression of the percent of abundance goal met from 1994 to 2012 (ODFW 2012).

I ran the same linear regression analysis for each of the 21 independent populations to evaluate if they were recovering. Table 9 lists the average percent of abundance goal, the recovery rate, and the strength of the regression for the 21 independent populations. The Coos population met the greatest percent of its goal, averaging 89.7% of the abundance goal from

1994 to 2012. The Middle Umpqua population only averaged 23.5% of its abundance goal over the time period. In total, 11 of the populations average less than half of their abundance goals.

Table 9. The average percent of abundance goal, the rate of recovery, and the strength of the regression for the 21 independent Oregon Coast coho populations (ODFW 2012).

Population	Average Percent of Abundance Goal	Rate of Recovery	P-value of Regression
Coos	89.73	-3.67	0.25
Siletz	86.91	12.91	0.06
Tenmile	83.55	0.00	1.00
Beaver	74.21	0.00	1.00
Tahkenitch	65.72	0.51	0.80
Sixes	60.26	-2.17	**0.04**
Floras	60.26	-0.04	0.99
Coquille	57.57	1.06	0.64
Siltcoos	56.53	-2.73	0.12
North Umpqua	51.74	2.73	0.13
Yaquina	49.97	1.44	0.55
Alsea	49.28	6.28	**0.03**
Lower Umpqua	46.40	-1.07	0.51
Nestucca	45.47	1.00	0.67
Tillamook	39.86	4.04	**0.02**
South Umpqua	37.24	3.01	0.14
Nehalem	35.47	2.55	0.10
Siuslaw	35.23	1.42	0.36
Salmon	34.38	4.57	**0.03**
Necanicum	31.68	1.72	0.09
Middle Umpqua	23.49	0.51	0.51
Entire ESU	48.74	1.57	0.36

Fourteen of the populations had a positive slope for the linear regression. This means that the percent of abundance goals increased over time for the 14 populations. However, only the Alsea, Salmon and Tillamook populations had statistically significant recovery. Figure 13 shows the linear regressions for the three populations with statistically significant abundance recovery from 1994 to 2012. The Coos, Lower Umpqua, Siltcoos, and Sixes populations had negative slopes, with the Sixes population being statistically significant. Three populations, Beaver, Floras, and Tenmile had a slop of zero, indicating no change in abundance.

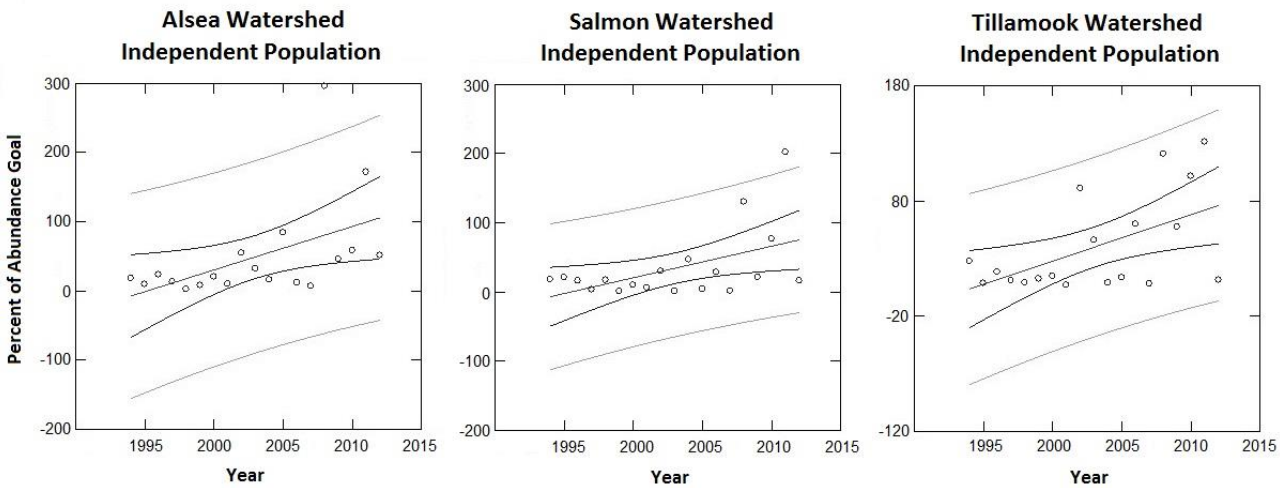

Figure 13. Linear regression for the three populations, Alsea, Salmon, and Tillamook, with statistically significant recovery from 1994-2012 (ODFW 2012).

5.3 Restoration Effects on Recovery

My hypothesis was that habitat restoration since 1997 has increased coho abundance. I tested my hypothesis using a correlation between the rate of recovery and dollars spent on restoration for the independent populations of the ESU. The rate of recovery did increase as total dollars spent increased but it was a very weak relationship (correlation coefficient = 0.15). Figure 14 depicts the correlation between recovery and restoration for the Oregon Coast ESU.

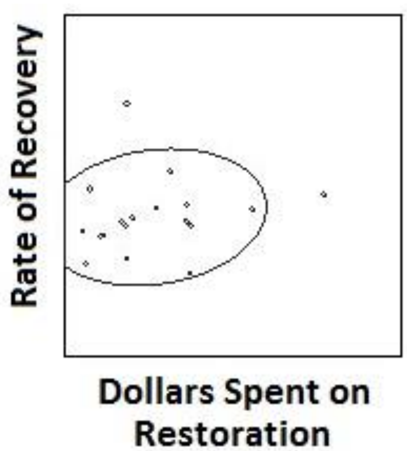

Figure 14. The correlation between population recovery and dollars spend on habitat restoration.

I also ran correlations to analyze whether any one restoration treatment was related to rate of recovery. Barrier removal, riparian function, sediment reduction, stream complexity, and upland treatments occurred in all ESU watersheds with restoration data. None of the treatments had a statistically significant relationship with rate of recovery.

6.0 DISCUSSION

The cumulative effectiveness of restoration in recovering salmon populations is unknown (Bradford et al. 2005). The uncertainty comes from difficulties isolating the response to restoration from other variables that influence salmon abundance (Bradford et al. 2005). Salmon abundance naturally fluctuates due to the influence of many factors, and isolating only the restoration effects can be challenging.

The results of my analyses on Oregon Coast coho salmon populations were inconclusive. A total of $145,620,716 was invested in habitat restoration on ESU streams from 1997 to 2012, however, my analyses showed that habitat restoration has not yet resulted in increased coho abundance. The ESU as a whole showed a positive trend but the increase in abundance was not statistically significant. Overall, there was almost no correlation between dollars invested in habitat restoration and the abundance of coho salmon on the Oregon Coast. My results reflect similar findings in the literature (Katz et al. 2007).

It is important to note that while restoration was not proven to increase salmon abundance, it may be offsetting further habitat loss, climatic factors, and hatchery influences that negatively impact salmon. Models developed and ran by Honea et al. (2009) found that current rates of degradation may further diminish salmon abundance by over 50%. Restoration may be necessary just to make up for future habitat loss to maintain current abundance levels.

6.1 Possible Explanations

There are four possible explanations for the lack of response to restoration efforts. They are not mutually exclusive, and may all be true to some degree. First, restoration may not be improving habitat quality to conditions necessary for coho recovery. The SCP concluded that $62.5 million was needed to restore enough miles of high quality habitat for the ESU to reach desired abundance goals. Since the SCP was written in 2007, $54.5 million has been invested but abundance has averaged less than 49% of the goal. Restoration projects should be evaluated to see if habitat quality is improving, and to understand which treatments are most effective.

A second explanation could be that restoration is improving habitat, but the quantity of restored habitat is not yet sufficient for noticeable recovery. There are many examples of successful restoration projects spanning a variety of geographic locations, habitats, and treatments. An example is constructed side channels in Washington State that provided deeper pools, slower flows, cooler summer water temperatures, and greater invertebrate productivity than the main channel. The restored channels resulted in coho density increasing by nearly two fold in summer, and four times greater in the winter than coho density in the main channel (Morley et al. 2005). It is possible that restoration is working but the SCP underestimated the amount of restoration needed, and the surrounding habitat may be limiting the benefit of improved conditions from isolated projects. Under this scenario continued restoration in ESU watersheds should be encouraged until recovery goals are met.

A third explanation also assumes that restoration is improving habitat, but that it may take salmon many generations to reach abundance levels in equilibrium with the improved habitat (Bradford et al. 2005). The SCP estimated that a 50-year timeline (year 2057) would be realistic to achieve desired recovery results (ODFW 2007). I only analyzed 19 years of population data so it is possible that recovery trends were not measurable over such a short period of time.

A final alternate explanation is that other population drivers such as climate, weather events, marine conditions, and hatchery competition are masking the benefits of restoration. Coho abundance showed high variability on a year to year basis. Over 356,000 adult coho returned to spawn on the Oregon Coast in 2011. The next year there was less than 100,000. Freshwater habitat cannot explain all that variation, and it is possible that the positive effects of restoration have not been accurately quantified.

6.2 Critique of Restoration in Oregon Coast ESU

The SCP estimated $62,516,711 was needed to restore 2,501 miles of high quality habitat for coho abundance to reach the goal by 2057. Since the SCP was written in 2007, 83.8% of the estimate has been invested in restoration projects. Table 10 shows the estimated cost of restoring 17 Oregon Coast watersheds and the amount already spent on restoration. Analysis of these watersheds showed that spending was unequally distributed throughout the ESU. There are seven watersheds where the amount spent on restoration exceeded the estimate. On the North Umpqua the amount spent on restoration is nearly five times as much as estimated. At the same time no restoration was completed on Beaver Creek or Flores Creek. Restoration on the Oregon Coast should be occurring where it is most needed. My analysis found that some watersheds in need of restoration have gone without, while other watersheds have received excess funding.

Table 10. Dollars spent on restoration in Oregon Coast watersheds (OWRI 2012).

Watershed	Estimated	Completed	Percent
Necanicum	$1,021,518	$1,127,191	110.3
Nehalem	$7,784,982	$3,785,089	48.6
Tillamook Bay	$3,155,844	$3,909,949	123.9
Nestucca	$1,117,838	$3,263,767	292.0
Salmon River	$397,982	$830,049	208.6
Siletz	$1,969,570	$942,689	47.9
Yaquina	$3,401,038	$1,187,936	34.9
Beaver	$286,001	$0	0.0
Alsea	$3,220,493	$2,844,739	88.3
Siuslaw	$9,525,115	$3,205,930	33.7
Lower and Middle Umpqua	$12,415,107	$9,079,331	73.1
North Umpqua	$1,280,399	$6,149,750	480.3
South Umpqua	$8,717,182	$5,697,643	65.4
Coos	$1,439,203	$5,413,084	376.1
Coquille	$5,323,561	$3,390,377	63.7
Floras	$1,049,593	$0	0.0
Sixes	$411,287	$1,553,619	377.7
Total	$62,516,711	$52,381,143	83.8

Restoration on the Oregon Coast should also use treatments that address the habitat factors critical to coho survival. Table 11 shows the habitat factor limiting survival for each population, and the percent of restoration that was addressing the limiting factor. It does not include watersheds where non-habitat related factors (exotic species and hatchery impacts) were the primary factors limiting survival. My analysis found that restoration is not using treatments designed to improve habitat conditions that limit survival. Twelve of the 14 watersheds are limited by insufficient stream complexity, but stream complexity was not a dominant treatment for those watersheds. The Siletz watershed was the best with 34.2% of restoration funding going to stream complexity treatments. The worst was the Nehalem watershed where only 14% of the $3.78 million spent on restoration treated stream complexity issues. Similarly, the South Umpqua population is limited by water quality, specifically high temperatures, but only 7% of restoration funding went to water treatments. Treating limiting factors should be a priority.

Table 11. Primary factors limiting coho survival in ESU watersheds and amount spent on restoration addressing limiting habitat factors (OWRI 2012).

Watershed	Primary Factor Limiting Coho Survival	Percent of Restoration Addressing Limiting Factor
Necanicum	Stream Complexity	20.2
Nehalem	Stream Complexity	14.0
Tillamook Bay	Stream Complexity	18.5
Nestucca	Stream Complexity	23.5
Siletz	Stream Complexity	34.2
Yaquina	Stream Complexity	24.0
Beaver	Spawning Gravel	0.0
Alsea	Stream Complexity	26.1
Siuslaw	Stream Complexity	18.1
South Umpqua	Water Quality	7.0
Coos	Stream Complexity	16.0
Coquille	Stream Complexity	24.2
Floras	Stream Complexity	0.0
Sixes	Stream Complexity	15.4

6.3 Future Restoration Challenges

The SCP identified five challenges associated with improving coho habitat specifically for the Oregon Coast ESU. First, there is already built infrastructure among ESU watersheds, and population growth will lead to continued impacts on rivers (Null and Lund 2012). Second, the quality of habitat conditions varies across the ESU. Some watersheds need extensive restoration while others are in a less degraded state. Third, goals, decision making, and management differs with land ownership. Restoration can be constrained by the lack of cooperation of landowners (Fullerton et al. 2010). Coastal Oregon is a mosaic of state, federal, industrial, agricultural, and private land ownership (Bisson et al. 2009). This makes it difficult to address issues and plan restoration at a regional scale. Fourth, the existing practice of natural resource use remains strong in Oregon, and it will be difficult to maintain environmental protection with increasing demand for natural resources (Null and Lund 2012). Lastly, there are differences in public values of salmon conservation (ODFW 2007). Public values are tied with funding, and funding can limit the overall impact of restoration projects (Fullerton et al. 2010). Low funding leads to fewer projects, and the cost constraints limit the potential of projects that do get funded (Fullerton et al. 2010).

Climate Change

The SCP did not mention climate change, but the challenges associated with climate change were well documented in scientific literature. Climate change will alter salmon habitat, and anthropogenic impacts have reduced the capacity of salmon streams to cope with weather and climatic stressors (Richter and Kolmes 2005). Air temperatures in the Pacific Northwest have already increased 0.8°C over the last century (Wainwright and Weitkamp 2013). Higher than average air temperatures on the Oregon Coast have corresponded to lower summer flows (Lawson et al. 2004). Air temperatures are predicted to rise 1°C to 3°C over the next 50 years, and this will impact water temperatures (Honea et al. 2009; Wainwright and Weitkamp 2013). It will be critical to restore and preserve ecological functions that regulate stream temperatures (Bisson et al. 2009).

It is predicted that more precipitation will fall as rain instead of snow. Spring snowpack has already declined 16-40% in western Oregon over the last 75 years (Wainwright and Weitkamp 2013). Summer rainfall is predicted to decrease, while winter rainfall will increase (Wainwright and Weitkamp 2013). This will alter timing and magnitude of peak flows (Bisson et al. 2009). The frequency of high precipitation and corresponding flood events are expected to increase spring runoff, and may change when smolts migrate out to the ocean. There is potential that downstream migration of smolts will occur earlier when productivity in ocean is not optimal (Lawson et al. 2004).

Climate change will also change sea level, ocean temperature, wind-driven upwelling, and ocean acidity (Wainwright and Weitkamp 2013). The Pacific Ocean has become more acidic and continued acidification is expected. Acidification can negatively impact coho salmon food sources by decreasing carbonate concentrations. Sea level on the Oregon Coast is predicted to increase between 15 cm to 1.25 m by 2100. This may reduce the amount of tidal flats and estuary habitats available to juvenile salmon. Sea surface temperature is predicted to rise 0.3°C to 0.8°C by 2040. Sea surface temperature increases may contribute to greater ocean stratification. Stratified conditions restrict upwelling of cold, nutrient-rich water. Wind-driven upwelling has intensified but with the onset date shifted later in the spring. Coho salmon productivity is correlated with weak stratification and early upwelling it is still unclear if increased wind intensity can overcome the expected increased stratification.

The vast majority of climate change impacts on salmon are expected to be negative (Wainwright and Weitkamp 2013). Figure 15 shows the effects, from strong negative to strong positive, that climate change impacts will have on salmon. Twenty-two of the 40 measured impacts of climate change are predicted to have a negative or strong negative effect on coho salmon. Only 10 of the 40 impacts are predicted to have a positive or strong positive effect on coho salmon. Wainwright and Weitkamp (2013) predicted an overall reduction in Oregon Coast coho abundance due to climate change.

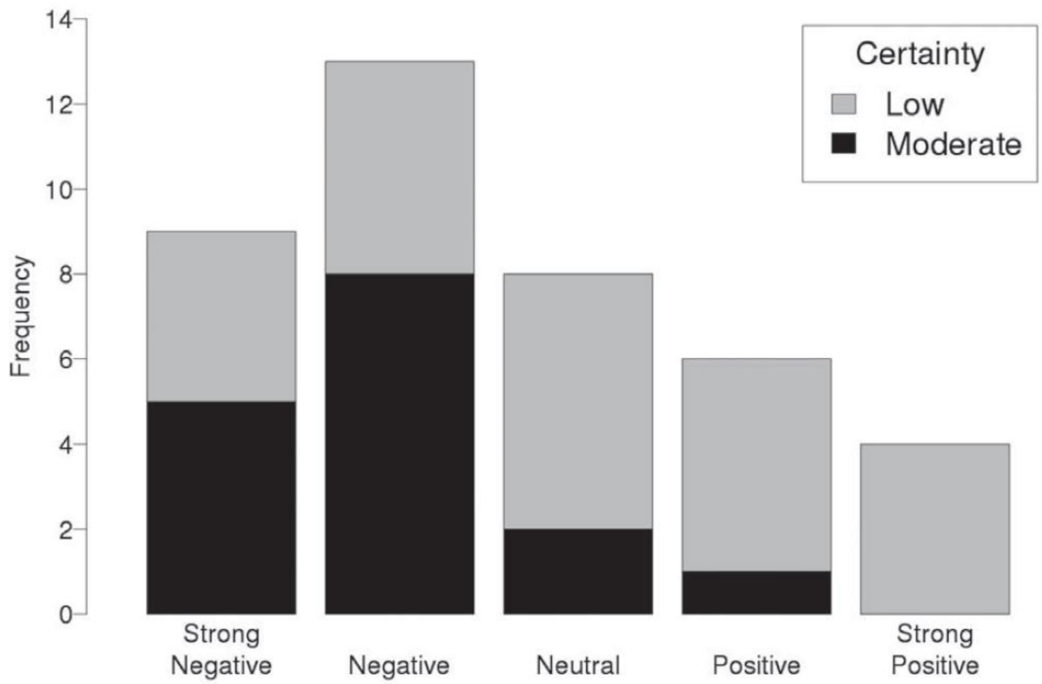

Figure 15. The frequency of positive and negative climate change impacts on Pacific Salmon (Wainwright and Weitkamp 2013).

7.0 RECOMMENDATIONS

Since the 1990s there have been reductions in commercial harvest, reductions in hatchery production, and extensive restoration on the Oregon Coast. My analysis shows that the decline in anthropogenic sources of mortality has stabilized coho populations and possibly led to increased abundance. The ESU remains below recovery goals, but there are additional population management and habitat restoration measures that have the potential to increase abundance to the desired status.

7.1 Management Recommendations for Coho Salmon

The ESU populations showed a slight increase in attainment of the abundance goal from 1994 to 2007. The increase was not statistically significant but may become so over a longer time period. The following four sections detail management recommendations that will accelerate coho recovery on the Oregon Coast so that abundance goals stated in the SCP will be met by 2057.

Maintain Levels of Harvest

Commercial harvest was a contributor to the decline in coho salmon populations on the Oregon Coast until harvest rates were drastically cut in 1994 (Meengs and Lackey 2005). The SCP stated that increasing harvest rates is desirable once population goals are met. However, coho abundance from 1994 to 2012 averaged less than 49% of the goal. I recommend that harvest rates remain at current reduced levels until the ESU achieves abundance goals for ten years.

Reduce Hatchery Production

Scientific literature overwhelmingly states that hatchery production is ineffective at recovering coho populations (Chase et al. 2012; Giannico and Hinch 2007; Ward et al. 2012). In addition, hatcheries reduce survival rates of coho that naturally reproduce (Nickelson 2003). Oosterhout et al. (2005) explored hatchery reform and possible actions to improve hatchery effectiveness, but could find no scenario with long-term benefits. Hatchery production on the Oregon Coast has declined since 1994, but there are still three hatcheries in operation. I recommend the discontinuation of the three remaining hatchery operations to reduce sources of coho mortality.

Create Individual Plan for Each Independent Population

Salmon response to habitat conditions vary depending on individual watershed characteristics. There were five different factors (lack of stream complexity, hatchery impacts, lack of spawning gravel, poor water quality, and non-native fish species) that limited coho survival of the 21 independent populations. Furthermore, great variability existed in the number of stream miles that needed to be restored per watershed. The SCP recommended that the Beaver Creek watershed needed only 11 miles restored, while the Siuslaw River watershed needed 381 miles restored. I recommend that a unique recovery plan is created for each independent population because of the great differences in coho abundance, habitat quality, hydrologic characteristics, and sources of mortality across the ESU. Each individual recovery plan should identify what unique factors are limiting survival, what habitat types must be conserved, what habitat types must be restored, and methods for generating funding. The same recovery strategy will not work for all the independent populations. Populations have a better chance to recover if management is adapted to their unique characteristics.

Continued Analysis

Due to the preliminary nature of my analysis, there is still uncertainty as to the effect that restoration has had on coho abundance. I used a simple correlation between dollars spent on restoration and adult coho abundance. A more in-depth, multi-variate analysis may provide more definitive conclusions. I recommend additional analysis to assess Oregon Coast coho recovery. Research should focus on the quality and quantity of freshwater habitat in ESU watersheds, coho survival rates at other life stages (egg, fry, parr, and smolt) in response to restoration, and adult recovery trends over a longer time period.

7.2 Habitat Restoration Recommendations for Oregon Coast

The success of habitat restoration for Pacific salmon population recovery has been variable and largely ineffective (Katz et al. 2007). My analysis of Oregon Coast coho salmon has shown that restoration did not result in significant increased salmon abundance from 1994 to 2012. Based on my research, I developed recommendations related to restoration project location, treatment, monitoring, and habitat forming processes to improve the effectiveness of future restoration actions on the Oregon Coast.

Restoration Locations

Most restoration sites are chosen because of land availability, but when restoration is opportunity based it can lead to ineffectiveness (Palmer 2009). Restoration locations should be chosen strategically. However, restoration locations on the Oregon Coast have not been distributed well enough. Some watersheds have had no restoration, whereas others have had an abundance. For restoration location at the ESU-scale I recommend prioritizing watersheds with the poorest habitat quality. Location at the watershed-scale should prioritize reaches with the greatest potential to improve habitat. Restoration managers must also consider the distribution and interconnectedness of habitats throughout the entire watershed (Flitcroft et al. 2012). I recommend that restoration on the Oregon Coast shift away from individual, opportunistic projects, to a watershed-scale strategy with an emphasis on availability, diversity, and connectivity of habitat.

Restoration Treatments

Successful restoration must consider the most important factors limiting coho survival (Bellmore et al. 2012). The ODFW identified the primary and secondary factors limiting survival for all the independent populations of the Oregon Coast ESU. To date, restoration treatments known to improve critical habitats have not been used on the Oregon Coast. I recommend that future restoration projects prioritize treatments based on ability to improve critical habitat. At the same time, restoration managers must be proactive in combating the negative impacts expected from climate change, as water temperatures may become the primary factor limiting coho survival in the ESU. Restoration on reaches or rivers with water temperature above optimal range should be a priority. Treatments that create cool water habitats, thermal refuge habitats, and restore temperature regulating processes should be used as much as possible.

There is not one optimum habitat that will maximize a stream's capacity to support salmon populations (Bisson et al. 2009). A diversity of habitat types is also important to consider (Bisson et al. 2009). Complex and diverse habitats are commonly indicated by the abundance of coarse sediment and large wood complexes (Bisson et al. 2009). Habitat diversity increases coho resilience to variation and disturbances of habitat conditions (Flitcroft et al. 2012). Some habitats may not be used all the time, but when available they provide refuge from warm temperatures, strong currents, predators, and pollution (Bisson et al. 2009).

It is important to note that coho salmon are not the only anadromous fish within the Oregon Coast watersheds. Coho salmon share freshwater habitat with four other salmonid species: Chinook salmon, chum salmon, steelhead trout (*Oncorhynchus mykiss*), and coastal cutthroat trout (*Oncorhynchus clarkii*) (Steel et al. 2012). Restoration managers must consider impacts to the whole ecosystem and not simply the target species. Restoration treatments that improve conditions for one species may worsen conditions for another. For example, optimizing streambed characteristics for coho salmon through the creation of riffle, cascades, and pools may negatively impact steelhead trout (*Oncorhynchus mykiss*) which have different foraging behaviors (Rosenfeld and Raeburn 2009). Similarly, restoring a reach for optimum overwinter habitat can decrease the productive capacity of the reach during low-flow summer conditions (Rosenfeld and Raeburn 2009).

Restoration of Ecological Processes

The productive capacity of the ESU depends on maintaining and re-establishing natural and dynamic ecological processes (ODFW 2007). It is critical that we understand how processes have been altered and how the impacts can be reversed (Bisson et al. 2009). Waples et al. (2009) proposed three types of actions that can be taken to promote and conserve habitat-shaping processes. First, managers can reduce the anthropogenic constraints on beneficial existing processes. An example is removing human development such as riprap and levees from the riparian corridor and floodplain. This will allow hydrologic, sediment, and riparian vegetation dynamics to naturally create habitat. Other actions can reduce the negative anthropogenic alterations of processes. Water temperature regulating regimes have been worsened through human development. Actions that contribute to elevated water temperatures, such as riparian logging, can be prevented. Lastly, ecological processes can be restored. Examples include planting riparian trees, engineered log jams, and implementing other measures that increase riparian wood recruitment into the stream channel. I recommend that there be a greater emphasis placed on the restoration of ecological processes. Restoring static conditions cannot provide salmon with the full range of diverse and complex habitats that can be formed through physical, chemical, and biological processes (Waples et al. 2009).

Monitoring

Monitoring is critical to restoration success (Palmer 2009). The riverine restoration project database compiled by Katz et al. (2007) showed that only 6.7% of the 23,123 projects in Washington, Oregon, Idaho, and Montana included monitoring. The vast majority of the monitoring that was identified only confirmed that the project succeeded in establishing the proposed conditions (Katz et al. 2007). Similarly, the OWEB only checks that state funded restoration on the Oregon Coast meets the agreement (ODFW 2007). Monitoring should do more than just verify that restoration has been completed. Monitoring is needed to test uncertainties about restoration. Which restoration treatments have been better at establishing desired habitat conditions (higher invertebrate productivity, lower water temperatures, and reduced fine sediment in streambed)? Is restoration increasing salmon abundance or freshwater survival? Monitoring can also detect unanticipated effects of restoration. A project may benefit salmon but harm another species. Or restoration can potentially benefit juveniles but reduce survival at a later life stage.

There is limited time, funding, and other resources to use for recovering Oregon Coast coho salmon, and those resources must be used efficiently. The data collected from monitoring can be used to adaptively manage current projects and plan more efficient restoration projects in the future. At least 4 or 5 years of post-treatment sampling is necessary at a minimum to understand salmon response to restoration (Johnson et al. 2005). I recommend that funding should be set aside for 10 years of monitoring after restoration on the Oregon Coast. Ten years of monitoring requires continuity in funding, methods, and personnel (Johnson et al. 2005). A region-wide monitoring protocol should be established to maintain continuity. Lastly, I recommend that the monitoring data be compiled into one location that is accessible for future use. The OWRI database is a useful resource, but it would be strengthened by the addition of monitoring data.

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