AN ABSTRACT OF THE THESIS OF

Katherine E. Nordholm for the degree of Master of Science in Fisheries Science
presented on March 17, 2014
Title: Contribution of Subyearling Estuarine Migrant Coho Salmon (*Oncorhynchus kisutch)* to Spawning Populations on the Southern Oregon Coast

Abstract approved:

Guillermo R. Giannico

The typical coho salmon life history has been characterized by juvenile fish that spend their entire first year in freshwater habitats before migrating into estuaries as smolts. However, reports of early migrating coho fry (age 0), including migration downstream to estuarine habitats, date back to the 1960s. Until a few years ago, these individuals were considered to be displaced surplus fish with low chances of survival. Recent studies have suggested that subyearling estuarine migrating coho salmon could be an alternative life history in coastal populations, but their return as jacks or mature adults needed to be documented for this life history to be considered a viable strategy. The goal of our study was to track the return of spawning coho salmon that had been individually tagged in either estuarine or riverine nursery habitats, and determine return percentages for each life history strategy as well as independently verify the presence of subyearling estuarine migrating coho salmon through otolith analysis on spawning populations. We used Passive Integrated Transponder (PIT) tags to identify individual fish as they passed through a series of antennas deployed in two coastal lowland streams on the southern Oregon coast. Percentage return of estuary tagged parr (fish ≥ 60 mm tagged in spring and summer of their first year) was variable between years and streams. For the 2010 return year, subyearling estuarine migrants was 2.5 times higher than stream residents in Palouse Creek. Fork length at estuary entrance was reconstructed for one return year of spawning fish based on otolith Sr:Ca and Br:Ca. Four main life history strategies were identified based on their fork length at time of estuary/ocean entrance: early migrating fry (< 60 mm fork length), early migrating parr (60 – 70 mm fork length), early migrating parr that returned to freshwater before migrating as yearlings ("nomads"), and yearling migrating smolts (> 70 mm fork length). Overall, 30% (Larson Creek) to 42% (Palouse Creek) of the 2009 spawning run was made up of fish that displayed evidence of estuarine residence during their first year. This study confirms that subyearling estuarine migrating coho salmon survive to reproductive age and contribute to subsequent generations. The survival of this life history type likely varies between years with changing ocean and stream conditions. It is hypothesized that their life history serves as a "bet hedging" strategy that supports coastal populations in years of poor stream conditions. In the face of rising sea levels, this life history may represent a key to the future viability of coho salmon stocks in coastal watersheds.

Contribution of Subyearling Estuarine Migrant Coho Salmon (*Oncorhynchus kisutch*) to Spawning Populations on the Southern Oregon Coast

by
Katherine E. Nordholm

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented March 17, 2014
Commencement June 2014

Master of Science thesis of Katherine E. Nordholm presented on March 17, 2014.

APPROVED:

Major Professor, representing Fisheries Science

Head of the Department of Fisheries and Wildlife

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Katherine E. Nordholm, Author

ACKNOWLEDGEMENTS

I sincerely appreciate the contributions of Guillermo Giannico in helping develop this project, for advice along the way, and the many edits he has contributed to this manuscript. I am grateful to Jon Souder for providing the opportunity to conduct this research as an employee with the Coos Watershed Association and simultaneously a student at Oregon State University. My committee members, Phil Roni and Jessica Miller provided essential guidance with the development of this project. I am especially grateful to Jessica, who opened her lab to me for the majority of the otolith work, shared a vast amount of knowledge during every meeting, and helped immensely with the interpretations of the results. I am grateful for Adam Weybright and Art Bass, whose work provided the foundation for my project. To the entire crew at the Coos Watershed office, especially Aimee, Dan, Dave, Freelin, and Nick, big thanks. I had four awesome field assistants: Hope Anderson (you are my number one peon), Samantha Bruno, Keeandra Rodriguez and Jenni Schmitt, they kept me mostly sane. Special thanks to Colleen Nordholm (who also happens to be my mom) for being my most dedicated volunteer, counting coho with me every single weekend, and filling in anytime I needed a substitute worker. Thanks to my dad, Arnold, for being my construction consultant and allowing me endless access to building materials and his fully stocked garage, sorry about all the tools I lost in the tide gates. Everyone that volunteered during this project deserves hearty thanks, but I don’t have room to list them here, I appreciate every single one of you. A special

thanks to TJ for going beyond being an awesome friend and always having my back. Props to Eric, for somehow deciding I was worth all this craziness, and sticking around. Very heartfelt thanks go to Bruce Miller, without his example and encouragement I would never have taken this step. Finally, undeniably, this thesis is dedicated to Tom Rumreich, for introducing me to my first salmon when I was eight-years-old, and for the countless experiences and opportunities he has provided in the many years since; his unbridled enthusiasm and love for all things fish related has truly been contagious.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF APPENDIX TABLES

Contribution of Subyearling Estuarine Migrant Coho Salmon (*Oncorhynchus kisutch*) to Spawning Populations on the Southern Oregon Coast

CHAPTER 1 INTRODUCTION

Pacific salmon are iconic along the western coast of North America because of their anadromous life cycles, which involve spawning in freshwater, migrating as juveniles to the ocean and returning as mature fish to spawn in their natal streams. This life-history pattern places juvenile fish in relatively safe freshwater environments but subsequently allows them to experience relatively higher growth rates in the productive waters of the north Pacific Ocean (Quinn 2005).

South of the central coast of British Columbia, coho salmon (*Oncorhynchus kisutch*) typically spend a year rearing in freshwater before migrating to the ocean. Timing for coho salmon smolt downstream migration varies among river systems and with stream flow. Most smolt migrations start in February and peak in mid-May (Quinn 2005). However, in many coastal streams, a large portion of coho salmon fry (age-0) migrate to the upper estuary in the spring shortly after they emerge from the gravel (Chapman 1962). These subyearling migrants can make up a sizable portion of juvenile populations (Miller and Sadro 2003, Koski 2009) and their movement has been associated with changes in discharge and water temperature during freshets (Hartman et al. 1982) as well as intra-specific competition for food resources (Mason and Chapman 1965). Chapman (1962) observed coho salmon fry moving downstream when rearing densities were high, and scale analyses reported by Mason (1976) and Wickett (1951) indicated that juvenile fish with such life history did not contribute to spawning populations. Because there was little evidence of survival, most fisheries managers thought that subyearling estuarine migrants did not survive until adulthood. This assumption was so prevalent that Hartman et al. (1982) proposed trapping early migrating fry and relocating them higher in the system to combat falling egg-smolt survival rates. Subsequently, Tschaplinski (1987) presented evidence that subyearling estuarine migrant coho salmon survived in the estuary through spring and summer , where they grew faster than their stream residing counterparts. Nonetheless, the notion that subyearling estuarine migrants were surplus fish displaced by competition prevailed for almost two more decades. This life history interpretation was eventually challenged and identified as in need of further research (Quinn 2005). It was Koski (2009) who presented a series of case studies and other evidence suggesting that the subyearling migratory life history of coho salmon was a viable one. He focused mostly on early migrating fish that returned upstream to overwinter before migrating to the ocean as smolts, and used the term "nomad" to distinguish fish with this movement pattern from other early migrating life history types.

Coho salmon fry migrating early into the estuary are using habitats not traditionally associated with this species. Both Oregon Coast and Southern Oregon coho salmon populations are listed as threatened by the National Marine Fisheries Service (NMFS), requiring that critical habitat be designated for them (NMFS 2011). One of the definitions of critical habitat includes "specific areas within the geographical area occupied by the species at the time of listing that contain physical or biological features essential to conservation and that may require special management consideration or protection" (NMFS 2011). Therefore, estuaries, including upper estuary salt marshes, should be considered critical habitats for coho salmon in populations that exhibit the early migratory life histories.

Ultimately, to determine the success or failure of subyearling estuarine migrants, individuals with this life history have to be observed in the spawning runs. There are two ways a fish's life history can be tracked; the first is using artificial tags, the second is with natural biological markers. Artificial tags include a variety of technologies from the most basic coded wire tags to electronic devices such as Passive Integrated Transponder (PIT) tags or acoustic and radio transmitters. Natural markers include the structural patterns and/or chemical composition that can be detected in scales and otoliths. Otoliths are small "ear stones" made of calcium carbonate, which deposits in concentric layers over time as the fish grows. They are located within jelly-filled sacks in the head of fish and primarily function in aiding the fish with hearing and orientation (Gauldie 1988). Because otoliths grow as concentric layers of calcium deposited while fish move among different environments, the elemental analysis of these structures can be used to reconstruct a fish's movement. In turn, the width of the otolith can be used to estimate the body size of the fish at the time of transition between fresh and estuarine/ocean waters (Campana 1990, Macdonald and Cook 2010, Walther and Limburg 2012).

In this study, I relied on PIT tags to track individual coho salmon from their juvenile stage until they returned to spawn and on otolith microchemistry to reconstruct the early life histories of spawners. Other studies have investigated the return of early migrating fish and documented multiple estuary life histories, but to my knowledge, this is the first study that documents the return of subyearling estuarine migrating coho salmon as spawners and estimates their proportion in a southern Oregon spawning run. The specific objectives of this study were to a) determine the percentage return, as spawners, of subyearling estuarine migrant coho salmon and b) estimate what proportion of a spawning run in lowland coastal streams of southern Oregon may consist of fish with an early migratory life history.

Given the generalized assumption that the subyearling estuarine migrant life history is unsuccessful in this species, the return and contribution of these fish needs to be documented in coastal estuaries and populations throughout the range of native coho salmon. Overlooking the early migrating aspect of coho salmon behavior could have negative consequences for the long-term recovery and stability of coho salmon populations where this life history is present.

CHAPTER 2 METHODS

Site Description

The study was conducted in Palouse and Larson Creeks, two third order streams that flow into Haynes Inlet, which is on the northeast end of Coos Bay, Oregon at approximately 18.5 km from its confluence with the ocean. Although several small coastal creeks drain directly into the bay, this body of water is primarily the estuary of the Coos River (Figure 1). The headwaters of both studied creeks are dominated primarily by second and third growth Douglas fir (*Pseudotsuga mensiezii*) forest in public lands (i.e. Elliott State Forest) and private timberlands. The area receives an average of 172 cm of precipitation annually.

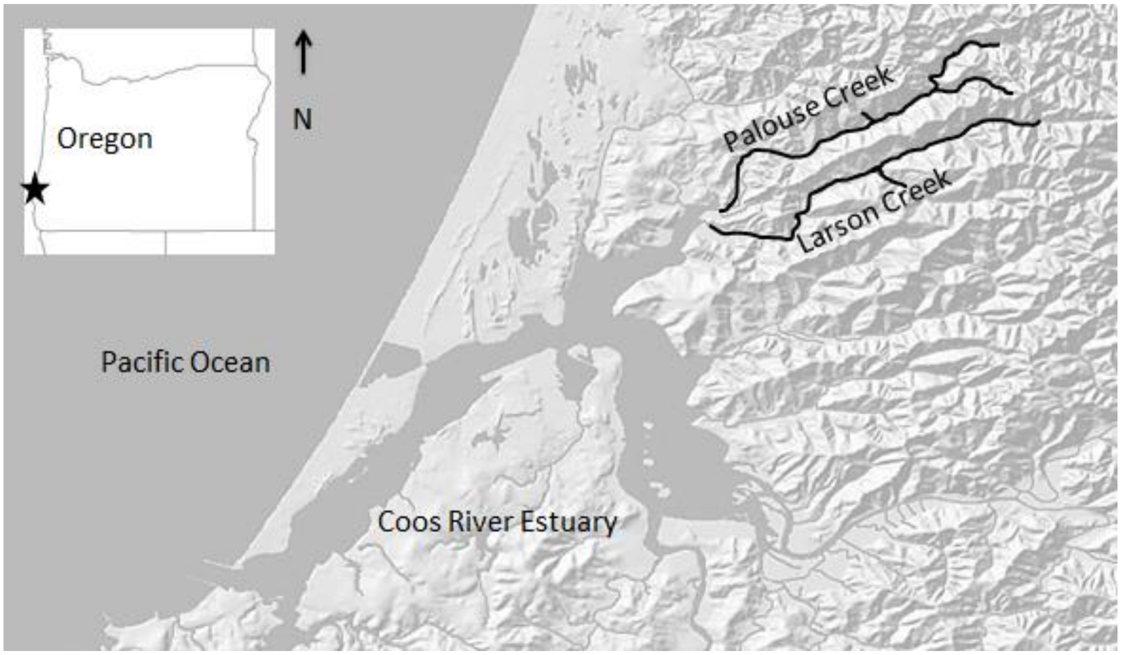


Figure 1. Coos River estuary, showing the location of study streams, Palouse and Larson Creeks. The insert map shows the location of Coos Bay on the Oregon Coast.

The valleys around the study streams were settled in the 1800s and their flood plains have been modified by diking and dredging to facilitate agricultural activities and reduce both the duration and frequency of flooding events. During the first half of last century tide gates were installed at the mouths of both creeks to prevent tidal flooding of the marshes that had been converted to farmlands. Major land uses on each creek include forestry (73% on Palouse Creek and 69% on Larson Creek) and agriculture (23% on Palouse Creek and 31% on Larson Creek).

Both Palouse and Larson Creeks sustain wild populations of coho salmon. Palouse Creek has a drainage area of approximately 17.5 km^2 and is 14.6 km long. Accessible habitat for coho salmon end at a 3 m falls at River Kilometer (Rkm) 12. The underlying geology of Palouse sub-basin is Tyee silt/sandstone (97%) and tuffaceous siltstone/sandstone (3%). Scouring has developed around the concrete tide gate box on Palouse Creek and has resulted in upstream intrusion of tidewater so that the reservoir created upstream is tidally influenced. This reservoir extends 2.4 to 3.7 km in length. As a result of tidal intrusion, salinities of up to 20 ppt have been observed 1.4 km upstream of the tide gate (Weybright 2011). Larson Creek has an area of approximately 17.2 km^2 and its main stem is 12.9 km long. Larson Creek's underlying geology is entirely Tyee silt/sandstone. Coho distribution ends at Rkm 9.6 due to a 2 meter-high waterfall. Sullivan Creek is a fourth order tributary that flows into Larson Creek's main stem at Rkm 5.9 and contains a large portion of the coho spawning habitat in that basin. The reservoir above the Larson Creek tide gates extends approximately 2.2 km. Reservoir lengths vary with stream discharge and tidal fluctuations, which drive the tide gate opening cycles. Estuarine water intrusion in the Larson Creek reservoir is very limited and the average salinity 0.5 km upstream of the tide gate is only 2.1 ppt (Bass 2010).

Percentage Return of Subyearling Estuarine Migrant Coho Salmon

Coho Salmon Life Histories

Tagging began in spring 2008 and coho salmon juveniles from brood years 2007-2010 were tagged and followed through their spawning returns for this study. Multiple capture methods were used to obtain fish for tagging. Rotary screw traps were located in both systems downstream of spawning habitat and positioned to capture coho salmon smolts; although fry were captured as well. The rotary screw trap in Palouse Creek was installed at Rkm 3.7 and in Larson Creek at Rkm 5.7. Both traps were operated from February through June. Juvenile coho salmon were also captured using three pass removal seining or electrofishing in pools and constricted channel sections, while single-pass beach seining was used to capture fish in wider channels, the upper estuary behind the tide gates, and the lower estuary. All smolts caught with rotary screw traps and a subsample of fish caught using seining nets and electrofishing equipment were PIT tagged. Individuals were classified by brood year, defined as the year when the eggs were laid in the gravel during the fall. Young of the year began to reach tagging length (>47 mm fork length) in April and were tagged through

December, smolts were tagged from January through the end of the smolt migration period in June.

Captured fish were quickly transferred to holding buckets with aerated water prior to being anesthetized with Tricaine Methanesulfonate (MS-222) in a buffer solution. Two sizes of full duplex PIT tags were used to mark fish. Juvenile coho salmon with fork lengths between 47 and 59 mm were tagged using Biomark’s TX148511B (8.5 x 2.12 mm - 0.067 g) tags. Fish with fork lengths of 60 mm and greater were tagged with Biomark’s TX1411SST (12.5 x 2.07 mm - 0.102 g) tags. The tags were implanted into the body cavity of fish using a 12 gauge hand-held syringe. At the smallest lengths of fish tagged for each size class, the tag size corresponded to 4% (8.4 mm tag) and 3% (12.5 mm tag) of the tag-to-body mass ratio. Tag number, fork length, mass, and brood year were recorded at time of tagging as well as notes on the condition of the fish, such as parasite load, deformed fins, or any unusual physical markings or reactions to tagging. Fish were allowed to recover equilibrium in holding buckets with fresh river water before being released back into the habitats in which they were captured.

Research on survival, growth, and tag retention following PIT tag injection in juvenile brown trout shows that fish with a tag-to-body weight ratio of less than 4.4% had a survival rate of 95% and a tag retention rate of 70% after four weeks. Fish tagged with a tag-to-body ratio of 3.4% or less had a survival rate above 99% and tag retention of 80% (Acolas 2007). Although no fish were held to determine tag retention rates during our study, it is assumed that tagging has little impact on the chosen life history of the fish and the fish had similar survival and retention rates. Female fish may lose tags at a higher rate than males during spawning (Prentice et al. 1993) which could negatively affect the ability to recover PIT tagged carcasses on spawning grounds.

Juvenile and adult coho salmon movements were monitored using Destron Fearing full duplex Biomark Multiplexing transceivers (Model FS1001M) connected to multiple antennas. Antennas detected tags when fish passed through or close to the structure. Each PIT tag’s unique number is decoded and downloaded to the receiver with a date-time stamp of the detection. Each set of antennas consisted of a downstream and an upstream row perpendicular to the bank; in turn, each row was made of one or two antenna panels depending on channel width at each monitoring location. The double row installation was needed to determine movement direction (Zydlewski 2001) Sets of antennas were located at four monitoring sites on Palouse Creek and two on Larson Creek (Figure 2).

Transceivers were powered by six 12-volt deep cycle marine batteries that were changed weekly to ensure adequate amperages to antennas. Antennas installed in freshwater were constructed of copper wire; antennas used in the brackish conditions that prevailed around the tide gates were built using coated litz wire (which consists of many small, individually insulated strands of wire woven together to provide greater inductance than standard copper wire) (Bass et al. 2012). All antennas were encased in rectangular frames put together with PVC pipes and attached to in stream wooden structures for support. Multiplexing transceivers had internal memories that stored information on tag numbers and detection times as well as antenna conditions, the buffer was downloaded and erased weekly when batteries were changed.

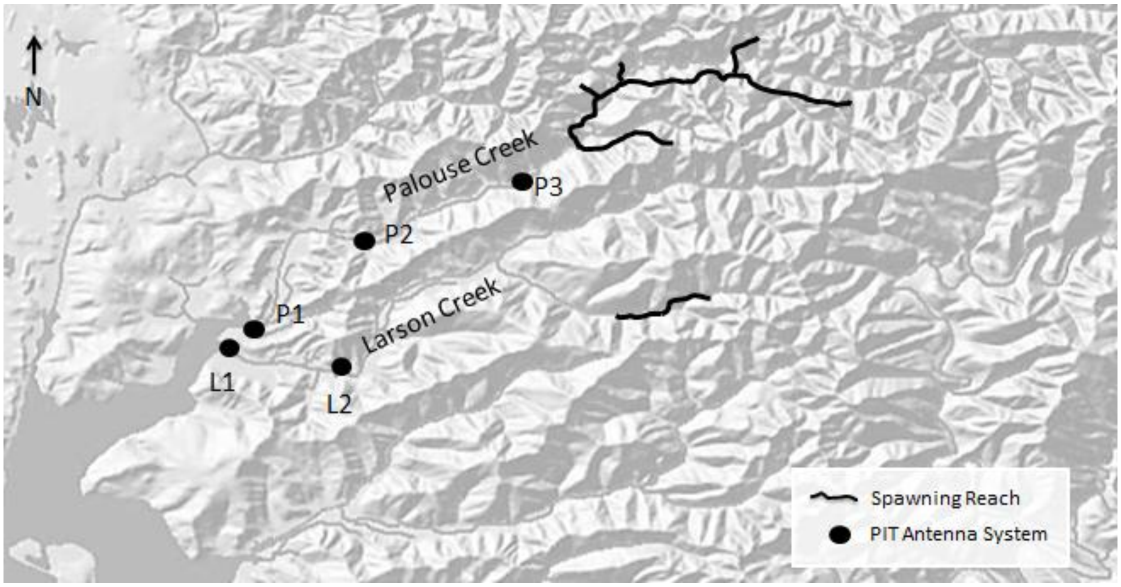


Figure 2. Coos River estuary, showing Palouse and Larson Creeks with location of spawning reaches and PIT antenna systems. Palouse Creek antenna systems were located at river kilometer (Rkm) 0.00 (P1), 3.17 (P2), and 7.27 (P3). Larson Creek antenna systems were located at Rkm 0.00 (L1) and 1.85 (L2).

Coho salmon returning spawners were determined from antenna detections starting in October and continuing through January. In addition to antenna detections, carcasses of spawned-out salmon recovered during spawning surveys were checked for the presence of PIT tags. Weekly spawning surveys were conducted on all spawning habitat where landowners allowed access (Figure 2). Surveys were conducted on 7-10 day rotations from the beginning of October until spawning ended and no live fish were seen for two consecutive surveys.

PIT tagged coho salmon that were detected returning as adults were matched to their early life history patterns. Tagging location (Rkm) and detection history at antenna systems throughout Larson and Palouse Creeks were used to classify returning spawners as either subyearling estuarine migrants, stream residents, or yearling smolts. Fish tagged as smolts had unknown early life histories and their percentage return was calculated separately from fish tagged in their first year. Coho salmon parr were classified into two life history types, 1) subyearling estuarine migrants and 2) stream residents. Coho salmon parr tagged either in the upper estuary or in the upper stream reaches, but subsequently detected in the upper estuary during their first spring/summer, were considered to be subyearling estuarine migrants. Parr tagged in the upper stream reaches and not detected in the upper estuary until the spring of the following year as yearling smolts were classified as stream residents. Any fish tagged when it was already a smolt was classified as of unknown early life history.

The upper estuary includes areas directly below the tide gates in both systems as well as the reservoirs behind the tide gates extending up 3.17 km in Palouse Creek, and 1.85 km in Larson Creek. The habitats included in these areas are the approximate extent of the tidal influence. Antennas located at P2 and L2 on each system were designed to detect fish at these locations as they transitioned between river and upper estuary habitats.

By using life stages and known location information at tagging as well as individual detection histories, fish were classified into various life history types. PIT tag fish return rates were based on how many individuals in each life history type were tagged as juveniles and how many were subsequently detected as returning spawners. Therefore, the return rate for smolts tagged in the spring as they were migrating into the estuary is only a measure of their ocean survival, while the return rate for parr tagged during their first spring and summer indicates both freshwater winter survival and ocean survival.

Percentage return and odds of returning were calculated for both study creeks. Odds ratios were used to determine if there was a significant difference between the return rate of subyearling estuarine migrants and stream resident coho salmon. The odds ratio and 95% confidence intervals were calculated for groups of fish with adequate numbers of returns using the following equations.

$OR = (A/C) / (B/D)$

Upper 95% CI = $e^{[\ln (OR) + 1.96 \sqrt{(1/A+1/B+1/C+1/D)}]}$

Lower 95% CI = $e^{[\ln (OR) - 1.96 \sqrt{(1/A+1/B+1/C+1/D)}]}$

Where, OR is the Odds Ratio, A is the number of subyearling estuarine migrants that returned, B is the number of subyearling estuarine migrants that did not return, C is the number of stream residents that returned, and D is the number of stream residents that did not return (Szumilas 2010). If the 95% confidence interval contains 1, then the odds between each group are not significantly different.

Antenna Efficiencies

The efficiencies of antennas to detect returning spawners were calculated using the ratio of fish detected at an antenna system to the number of fish that were known to have passed that system. Efficiencies (E) were calculated for each row of antennas at each location. Each fish was known to pass an antenna if it was detected at an antenna further upstream or if it was found as a carcass on the spawning grounds. Efficiencies for the entire basin were calculated using the following formula, where E is the ratio of the number of fish detected at each antenna to the number of fish known to pass (Zydlewski et al. 2006).

$$E_{\text{Combined}} = 1- [(1-E_{\text{system 1}}) \text{ x } (1-E_{\text{system 2}}) \text{ x } \ldots.(1- E_{\text{system n}})]$$

Antenna efficiency was calculated using the number of fish known to pass each row of antennas and the detections made at each location. Fish were known to pass if they had been detected above the row of antennas. For this reason the only fish known to pass the uppermost system on P3 were fish that were recovered on spawning surveys. Surveys above the antennas were conducted to recover PIT tagged fish on spawning grounds to further our ability to calculate antenna efficiency for all antennas.

Contribution of Subyearling Estuarine Migrant Life Histories to Spawning Runs

Water Chemistry

Water samples were collected from the ocean, the Coos River estuary, and the study streams and used to predict the elemental ratios expected to be seen in otoliths from fish originating in these waters. Strontium (Sr) and Barium (Ba) can substitute for Calcium (Ca) during the formation of the otolith in concentrations relative to the ratios in the environment (Kalish 1990). Changes in the ratios of Sr:Ca and Ba:Ca in otoliths can be linked to changes in salinity of the water where the fish resided. Otolith Sr:Ca ratios are positively correlated with water Sr:Ca ratios (Zimmerman 2005) and there are often higher concentration of Sr in ocean waters than in river water. Ba concentrations are usually much greater in freshwater systems than in ocean water (Elsdon and Gillanders 2005). Because of these difference in concentrations it is predicted that there is greater Sr:Ca ratios and lower Ba:Ca ratios concentration in the ocean than in freshwater and that this change in water chemistry is “recorded” in the chemical composition of otoliths as fish transitions from freshwater to saltwater.

To confirm that the water in our study system follows these predictions, water samples were collected on August 15, 2008 off the mouth of Coos Bay and in various estuarine locations and on May 14, 2012 in four locations on each stream (Figure 3). Samples were taken from the upstream spawning areas, just downstream of spawning habitat, at head of tidewater on each creek, and by the tide gates at the confluence of each creek with the estuary. Samples were filtered using 0.45 µm filter paper, acidified (Eaton et al. 2005), and refrigerated within 24 hours of collection. Samples were ran at Oregon State University W.M. Keck Collaboratory for Plasma Mass Spectrometry using atomic absorption spectroscopy with Teledyne Leeman Labs, Inc. Prodigy Inductively Coupled Plasma-Optical Emission Spectrometer. National Institute of

Standards and Technology (NIST 1643e) samples of known concentration were ran to provide a measure of accuracy.

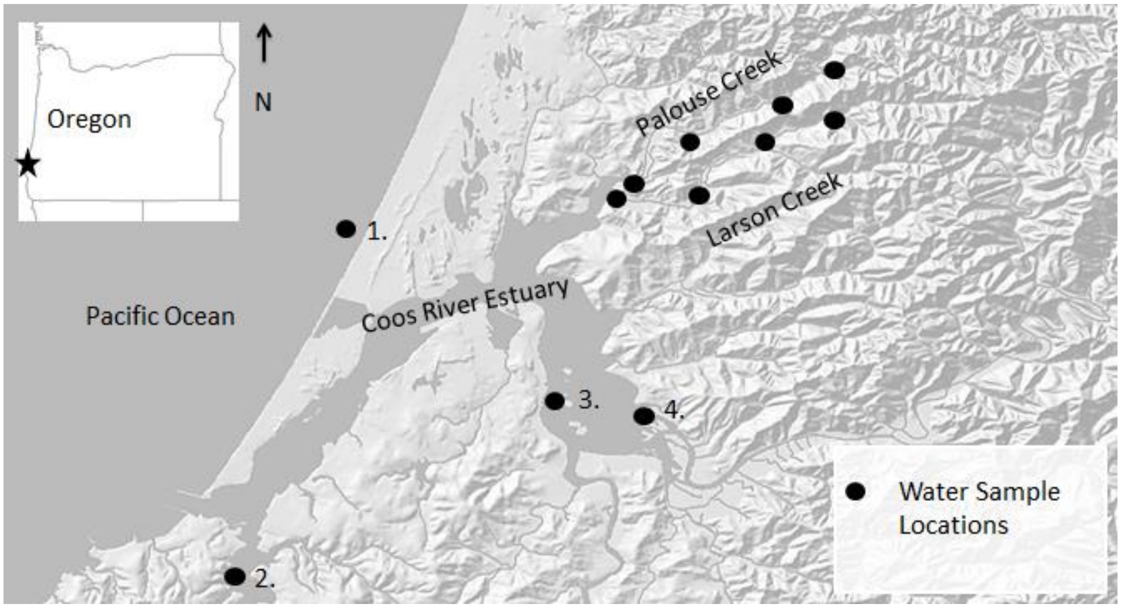


Figure 3. Location of water samples taken from the Coos Bay area and Palouse and Larson Creeks. Numbered locations show areas where estuary water samples were taken; 1) Horsefall Beach, 2) Charleston, 3) Coos Bay Dock, 4) Eastside Dock. Samples were taken from four location on each study stream; Rkm 0.0, 2.7, 5.8, and 8.1 on Larson Creek and Rkm 0.0, 3.4, 9.8, and 10.6 on Palouse Creek. Insert map shows location of the Coos River estuary in the state of Oregon.

Juvenile Regressions

Regression analysis was used to estimate the relationship between juvenile coho salmon otolith width (OW) (μm) and fork length (mm). The resulting equation was used to back-calculate the fork lengths spawners had when they entered estuary or ocean waters as juveniles. Juvenile coho salmon otoliths were obtained from fish that had died accidentally as a result of other monitoring and research activities in Coos

Bay and other basins in Oregon (n=178). Otoliths were measured (to the nearest micron) along the dorsal-ventral axis perpendicular to the anterior-posterior axis.

Fork lengths (to the nearest mm) were taken at the time of death and fish were frozen until otoliths were extracted. Pre-freezing fork length measurements (pre FL) were not available for 18 juvenile fish, and their post-freezing fork lengths (post FL) were corrected for changes that may have occurred during freezing using the pre-freezing and post-freezing fork lengths of the remaining 160 fish by the following equation ($R^2 = 0.995$) with 95% confidence intervals (CI) shown in parentheses:

$$\text{Pre FL} = 1.071\ (\pm\ 0.013)\cdot(\text{post FL}) - 3.593(\pm\ 0.933)$$

Two regression equations were developed to back-calculate the fork lengths spawners had when they entered the estuary or ocean as juveniles. The first regression was based on otoliths that had a width greater than 900 µm when the fish entered estuary or ocean waters ($r^2 = 0.925$, n=137, $P<0.001$).

$$\text{FL} = 0.095\ (\pm\ 0.005\ 95\%\ \text{CI}) \cdot \text{OW} - 43.995\ (\pm\ 6.158\ 95\%\ \text{CI})$$

The second regression was used if the otolith width at estuary or ocean entrance was between 530 and 675 µm, ($r^2 = 0.455$, n=41, $P<0.001$). In both equations, FL is the fork length and OW is the Otolith Width.

$$\text{FL} = 0.027\ (\pm\ 0.010\ 95\%\ \text{CI}) \cdot \text{OW} + 20.820\ (\pm\ 5.382\ 95\%\ \text{CI})$$

To establish length parameters for life history classifications, data from fork lengths of fish captured at rotary screw traps in both systems were compiled. Rotary screw traps were located below spawning habitats on each creek, and operated from

February to July as part of an ongoing coho salmon life-cycle monitoring program. The length distribution of juveniles that were caught during their downstream migrations in the springs of 2006 to 2012 were used to determine which fork lengths of fish were more likely to be smolts, parr, or fry. Fish that were less than 60 mm were considered fry, while individuals between 60 and 70 mm were classified as parr and those greater than 70 mm as smolts.

Otolith Analysis

Surveys were conducted in each study stream for spawning estimates, PIT tag retrieval, and otolith collection. To obtain a sample representative of the entire spawning populations otoliths were removed from all carcasses during spawning surveys carried out between December 1, 2009 and January 9, 2010. No PIT tagged fish were recovered during the 2009 run, therefore, the otoliths from PIT tagged fish used to compare otolith microchemistry to known life histories came from the 2010 spawning run.

Both sagittal otoliths were removed from each fish in the field, rinsed in clean river water and stored in plastic vials until preparation for microchemical analysis. Once in the laboratory, only one otolith per fish was mounted on a slide using thermoplastic resin. Otoliths were polished with the sulcus groove facing up, and they were polished with progressively smaller grits of jewelry polishing paper until the sulcus groove was no longer visible and the primordial core was showing. A final polish was conducted using 0.05-um alumina paste. The resin was then melted and each otolith flipped over and mounted onto a coverslip attached to a slide. The otolith's second side was polished in the same manner as the first. Cover slips were then transferred so that multiple polished otoliths were placed on a single slide, which were cleaned, air dried on a clean bench, and stored for subsequent analysis using laser ablation (Miller 2009).

Elemental analysis was performed at Oregon State University's W.M. Keck Collaboratory for Plasma Mass Spectrometry. A Thermo Scientific X-Series II inductively coupled mass spectrometer and a Photon Machines Analyte G2 193 excimer laser system were used. Analysis was conducted using a 30 µm diameter ablation and a 7-Hz pulse rate. The laser speed was set to travel across the otolith at 5 or 10 µm per second. Transects were set from ventral to the dorsal side across the widest part of the polished otoliths, through the center of the otolith.

Data were collected 30 seconds prior and post ablation, and the regions before the onset of ablation were used to calculate background values, which were then subtracted from measured values. National Institute of Standards and Technology (NIST) 612 glass standards were sampled repeatedly over the course of analysis and both known elemental concentrations and sampled values were used to create a correction factor to converted counts per second to elemental ratio and then to molar ratios using the elemental molar mass (Miller 2007). Measurements were presented in mmol mol $^{-1}$ for Sr:Ca ratios and µmol mol^{-1} for Ba:Ca ratios. Accuracy was measured using United States Geological Survey's calcium carbonate standard (MACS), with known elemental ratio compositions.

Digital photographs were taken using a camera (Leica DC30) mounted on a compound microscope (Leica DM1000) and otoliths were measured using Image ProPlus ™ software (Media Cybernetics). Measured values for analytes were averaged every five data points to smooth the graph and aid in visual identifications of inflection points, which marked a habitat transition.

Graphs were used to visualize Ba:Ca and Sr:Ca ratios and the data were analyzed for each otolith to determine its width when the fish transitioned between freshwater and saltwater (Figure 4). The combination of Ba:Ca and Sr:Ca ratios have been used to distinguish between periods of freshwater residence and periods of estuarine/marine residence (Miller at al 2010). The central part of each graph corresponds to the core of the otolith, which carries a “marine signal” of maternal origin. Inflection points are areas of unstable elemental concentrations that indicate the fish transitioned between habitats. Areas of stable elemental concentration indicate periods of residence in habitats with relatively constant water chemical composition. Elemental thresholds were created for each habitat to aid in the classification of habitat transitions (Figure 4). If elemental concentration in the graph stabilized with a Ba:Ca ratio greater than 6.12 µmol mol^{-1} or a Sr:Ca ratio lower than 1.46 mmol mol^{-1} that area of the otolith corresponded to freshwater residence. If the elemental concentration in the graph stabilized with a Ba:Ca ratio lower than 4.6 µmol mol^{-1} or a Sr:Ca ratio between 1.80 and 2.26 mmol mol^{-1} that area of the otolith corresponded to ocean residence. Areas of the otolith developed when fish were in estuarine habitats had Ba:Ca ratios greater than 6.12 μmol mol^{-1} and Sr:Ca ratios were greater than 2.26 mmol mol^{-1}. The width of the otolith between inflection points was determined using the ablation laser travel time between them and the speed at which the laser traveled. Otolith widths were used in the regression equations to back-calculate the fork length of each fish at the time of first estuary and/or ocean entrance. Fork lengths for the widths of the otolith were calculated for both elements for each fish.

Fish were classified into life history groups according to their back-calculated fork lengths when entering the estuary or ocean. Otoliths widths with back-calculated fork lengths under 60 mm were classified as subyearling estuarine migrant fry. Similarly, otoliths with estuary or ocean back-calculated fork lengths between 60 to 70 mm length were classified as subyearling estuarine migrant. Finally, any otolith from fish with a back-calculated fork length over 70 mm at the time of estuary entrance was considered to be a yearling smolt. An additional life history classification, “nomad”, was added to refer to subyearling estuarine migrants fish that returned to freshwater for the winter before migrating to the ocean as yearling smolts the following spring. The otoliths of these fish showed two areas along their otolith transects that corresponded to an estuary residence.

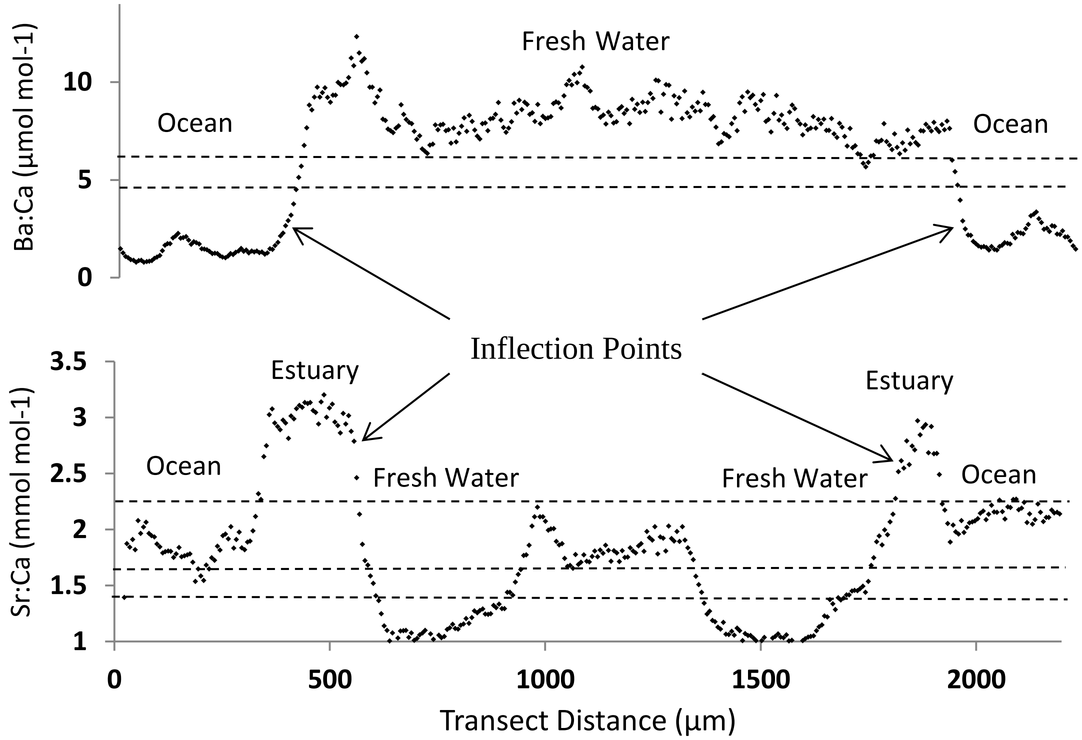


Figure 4. Ba:Ca and Sr:Ca ratios along the ablation transect line. Elemental thresholds for each habitat are shown by the dotted lines. These elemental composition graphs reveal the type of habitats (i.e., freshwater, estuarine, or marine) fish were in at the time concentric layers of the otoliths were formed.

CHAPTER 3 RESULTS

Percentage Return of Subyearling Estuarine Migrant Coho Salmon

Coho Salmon Life Histories

Subyearling estuarine migrant coho salmon were observed returning to Palouse and Larson Creeks to spawn. Over three years of monitoring, 143 PIT tagged coho salmon returned to spawn, 110 returned to Palouse Creek and 33 to Larson Creek. PIT tagged coho salmon began returning as jacks in 2006 and adults in 2007. The numbers of coho salmon tagged varied between creeks and years (Table 1). Percentage return for all PIT tagged fish from each brood year ranged from 0.25% to 3.93%. Combining all brood years of PIT tagged fish from both creeks, the percentage return for smolts was 2.81% and for parr the percentage return was 1.12%. Subyearling estuarine migrants had a combined percentage return of 1.01%, whereas stream resident parr had a percentage return of 0.87%. Subyearling estuarine migrant parr from brood year 2007 returning to Palouse Creek had the highest percentage return at 5.11% (Table 1). Subyearling estuarine migrants were statistically the most likely parr to return over all brood yeas and both creeks, these fish were 2.35 times more likely to return than stream resident fish (Table 2). Subyearling estuarine migrant coho salmon from Palouse Creek brood year 2007 had significantly higher return rates than stream resident fish of the same brood year (Table 2). In 2007, the subyearling migrants were 2.53 times more likely to return than stream residents tagged during the same life stage (Table 2). No other brood year showed a statistical difference in the percentage return between stream resident parr and subyearling estuarine migrating fish.

Table 1. The number of coho salmon tagged on Palouse and Larson Creeks for the 2007-2009 brood years and percent return for 2010-2012 spawning runs shown by life stage at tagging. “All Tagged” indicates the total number of fish PIT tagged for that brood year in each basin. “Smolts” are all the yearlings that were tagged in the spring. “Parr” are subyearlings tagged during their first summer or fall of life. Parr were classified as “Estuary Parr” if they were subyearling estuarine migrants and “Stream Parr” if they were stream resident fish.

Palouse Creek		Coho Life Stage When Tagged				
Brood Year		All Tagged	Smolts	All Parr	Estuary Parr	Stream Parr
2007	Numbers Tagged	1934	743	1191	567	624
	Returned in 2009	10	5	5	4	1
	Returned in 2010	66	29	37	25	12
	Percentage Return	3.93%	4.58%	3.53%	5.11%	2.08%
2008	Numbers Tagged	3390	544	2846	520	2326
	Return in 2010	9	6	3	1	2
	Return in 2011	12	6	6	0	6
	Percentage Return	0.62%	2.21%	0.32%	0.19%	0.34%
2009	Numbers Tagged	1113	145	968	255	713
	Return in 2011	4	1	3	0	3
	Return in 2012	6	1	5	0	5
	Percentage Return	0.90%	1.38%	0.83%	0.00%	1.12%
Larson Creek						
2007	Numbers Tagged	657	375	382	251	131
	Returned in 2009	4	2	2	2	0
	Returned in 2010	15	12	3	3	0
	Percentage Return	2.89%	3.73%	1.31%	1.99%	0.00%
2008	Numbers Tagged	620	125	495	335	160
	Return in 2010	0	0	0	0	0
	Return in 2011	3	0	3	1	2
	Percentage Return	0.48%	0.00%	0.61%	0.30%	1.25%
2009	Numbers Tagged	394	312	82	57	25
	Return in 2011	0	0	0	0	0
	Return in 2012	1	1	0	0	0
	Percentage Return	0.25%	0.32%	0.00%	0.00%	0.00%
All Fish						
	Numbers Tagged	8108	2244	5964	1985	3979
	Return in 2011	27	14	13	7	6
	Return in 2012	103	49	54	29	25
	Percentage Return	1.60%	2.81%	1.12%	1.81%	0.78%

Table 2. Odds ratios and 95% confidence intervals for subyearling estuarine parr migrants and stream resident parr from Palouse and Larson Creeks for the 2007-2009 brood years. Life history type with no PIT tagged fish detected returning is indicated by “na”. A 95% confidence interval that contains the number 1 is not statistically significant.

	Odds Ratios	Lower 95% CI	Upper 95% CI
Palouse Creek			
2007	2.53	1.30	4.92
2008	0.56	0.07	4.47
2009	na	na	na
Larson Creek			
2007	na	na	na
2008	0.24	0.02	2.63
2009	na	na	na
All	2.35	1.45	3.81

Antenna Efficiencies

Antenna efficiencies were only calculated for Palouse Creek due to the low numbers of PIT tagged fish detected returning to Larson Creek. Antenna efficiencies for adult fish tagged with 12.5 mm tags ranged from 20% to 100% for each across-stream system. The basin wide combined efficiency was essentially 100% for each year (Table 3). Tide gate antennas on Palouse Creek (P1) were removed during the 2012 run, so efficiency calculations were not applicable. Antennas in saltwater (P1) have a lower efficiency due to the water’s diminishing of the electromagnetic field of the antennas. The antennas used in saltwater worked in conditions up to 33 ‰ with a read range of 3-20 cm; smaller antennas had higher read ranges (Bass 2012).

Table 3. Palouse Creek antenna efficiency for returning spawning coho salmon during the 2010 - 2012 spawning runs. Efficiency is shown for returning fish tagged with 12.5 mm full duplex PIT tags. “Past” refers to the total number s of fish known to pass an antenna system. “Upstream” and “Downstream” denotes the location of each row in the antenna system.

Spawning Year	Location	P1 - Rkm 0.0		P2 - Rkm 3.17		P3- Rkm 7.27		Combined Efficiency
		Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	
2010	Passed	72	68	66	76	75	12	
	Detected	23	46	56	52	65	9	
	Efficiency	32%	68%	85%	68%	87%	75%	99.96%
2011	Passed	9	7	7	5	5	0	
	Detected	6	3	2	1	5	-	
	Efficiency	67%	43%	29%	20%	100%	-	100%
2012	Passed	-	-	5	6	6	0	
	Detected	-	-	3	4	6	-	
	Efficiency	-	-	60%	67%	100%	-	100%

Antenna efficiency decreases with the size of the tag being detected and such a small number of 8.4 mm tags were detected that calculations could not be made for fish retuning with these smaller tags. Eight of the 75 fish that returned to Palouse Creek had been tagged with 8.4 mm tags when they were between 47 mm and 60 mm in fork length. This smaller class is likely underreported in the final percent return calculations because of the low detection efficiency for the smaller tags used. Only fish returning tagged with 12.5 mm tags were used for efficiency calculations. These calculations used 70 fish for the 2010 run, 10 fish for the 2012 run and 6 fish for the 2012 run. During the 2010 spawning migration 20 spawners exhibited multiple upstream and downstream movements. The antenna system at Rkm 3.17 was the only location where downstream antenna efficiencies were calculated, the efficiency of the antenna system at that location when fish were moving downstream ranged from 83% to 99% with a combined efficiency of 100%; whereas the efficiency at that system for fish moving upstream ranged from 68% to 85% with a combined antenna efficiency of 95%. No efficiencies for downstream movement could be calculated for the 2011 and 2012 return years, because only one spawner was detected moving downstream in 2011 and none in 2012.

A total of 361 carcasses were scanned for PIT tags on Palouse Creek during the 2010 spawning surveys, 14 PIT tagged fish were recovered in that sample. These 14 fish were the only fish that were known to pass the uppermost row of antennas on Palouse Creek. No PIT tagged fish were recovered on Palouse Creek in 2011 or 2012, although 30 carcasses were checked in 2011 and 22 in 2012.

The efficiency calculations assume that fish pass through the read range of the antenna, but high flows may have allowed migrating coho salmon to swim around or over the antenna systems reducing their detection efficiency. Efficiency estimates include times where antennas were not functioning properly due to broken equipment, errors in the computer settings, or dead batteries. Over the three years of the study, there were a total of 26 days during the spawning runs when at least one location’s computer was malfunctioning and failed to record and save data.

Contribution of Subyearling Estuarine Migrant Life Histories to Spawning Runs

Water Chemistry

Water samples from around the Palouse and Larson Creek study sites, the estuary and the ocean, show that the elemental concentrations of Sr:Ca and Ba:Ca match generally observed patters, with Sr:Ca ratios being greater in the ocean, and decreasing as salinity decreases, and Ba:Ca ratios being higher in freshwater and decreasing as water becomes more saline. Samples of known elemental concentrations (NIST 1643e) were measured to estimate accuracy, and Sr, Ca, and Ba were within 8.08%, 0.55%, and 2.16% of known values, respectively (n=3). Repeat samples were taken to estimate precision and average percentage relative standard deviation (%RSD) for sampled Ba= 0.72%, Ca= 0.37%, and Sr =0.35% (n=8). Observed freshwater elemental ratios within the study tributaries ranged from 3.90 to 4.83 mmol mol^{-1} for Sr:Ca, and from 499.29 to 644.78 µmol mol^{-1} for Ba:Ca (Table 4). Observed marine elemental ratios from locations within the bay and ocean range from 8.58 - 8.67 mmol mol^{-1} for Sr:Ca ratios, and 4.36 to 34.57 µmol mol^{-1} for Ba:Ca (Table 4). The water samples from Palouse and Larson tide gates were from upper estuary brackish waters. The observed values in for these locations in the upper estuary were 5.15 and 7.77 mmol mol^{-1} for Sr:Ca and 500.20 and 139.49 µmol mol^{-1} for Ba:Ca. The Ba:Ca ratios were higher and Sr:Ca ratios were lower behind the Larson tide gate than the Palouse tide gate, this is likely due to the leaky nature of the Palouse gate, and the saline water seen upstream of the structure. Hence, subyearling estuarine migrant fish from Larson Creek could be harder to identify using otolith microchemistry.

Table 4. Mean Sr:Ca and Ba:Ca water ratios for marine (ocean and estuary) locations around Coos Bay and tributary locations on Palouse and Larson Creeks.

Location	Water Sr:Ca (mmol mol^{-1})	Water Ba:Ca (µmol mol^{-1})
Marine Locations		
Eastside Dock	8.64	28.44
Coos Bay Dock	8.58	34.57
Charleston	8.67	7.39
Ocean at Horsefall Beach	8.61	4.36
Tributary Locations		
Palouse Tide Gate (Rkm 0.0)	7.77	139.46
Larson Tide Gate (Rkm 0.0)	5.15	500.20
Larson (Rkm 2.7)	4.65	624.46
Palouse (Rkm 3.4)	4.44	644.78
Larson RST (Rkm 5.8)	4.75	528.68
Larson Upper (Rkm 8.1)	3.90	499.29
Palouse RST (Rkm 9.8)	4.54	551.89
Palouse Upper (Rkm 10.6)	4.83	590.68

Juvenile Regressions

Otoliths from 187 juvenile coho salmon collected in different Oregon streams (Table 5) were measured to determine the relationship between otolith width and fork length of the fish (fork lengths ranged from 32 to 124 mm (Figure 5). The otoliths removed from these fish were measured to create a regression of otolith width to fish fork length (Figure 5). Because the data showed two groupings of otolith widths, and the slopes and intercepts were different for each group, which means that the relationship changed as fish got bigger, two linear regression equations were created.

The first equation was used on otoliths widths larger than 900 µm (Figure 6). The second equation was used for otoliths widths between 450 and 700 µm (Figure 7).

Table 5. Numbers of juvenile coho salmon that accidentally died during handling in various creeks throughout Oregon. These fish's otoliths were used to establish an otolith width/fish fork length relationship. Brood year (BY) is the year the cohort was laid in the gravel as eggs.

Location	Fork Length (mm)	BY 2009	BY 2010
Cascade Creek	77 - 105	7	0
East Fork Lobster	76	1	0
East Fork Trask	62-106	8	0
Larson Creek	34-106	6	32
Mill Creek Yaquina	80-118	2	0
Palouse Creek	32-94	1	71
Siletz Mill	66-124	7	0
Tenmile	82-120	34	0
West Fork Millicoma	59	0	1
West Fork Smith	89-112	9	0
Winchester Creek	70	1	0
Upper Lobster	37-108	5	1
Upper Nehalem	94	1	0

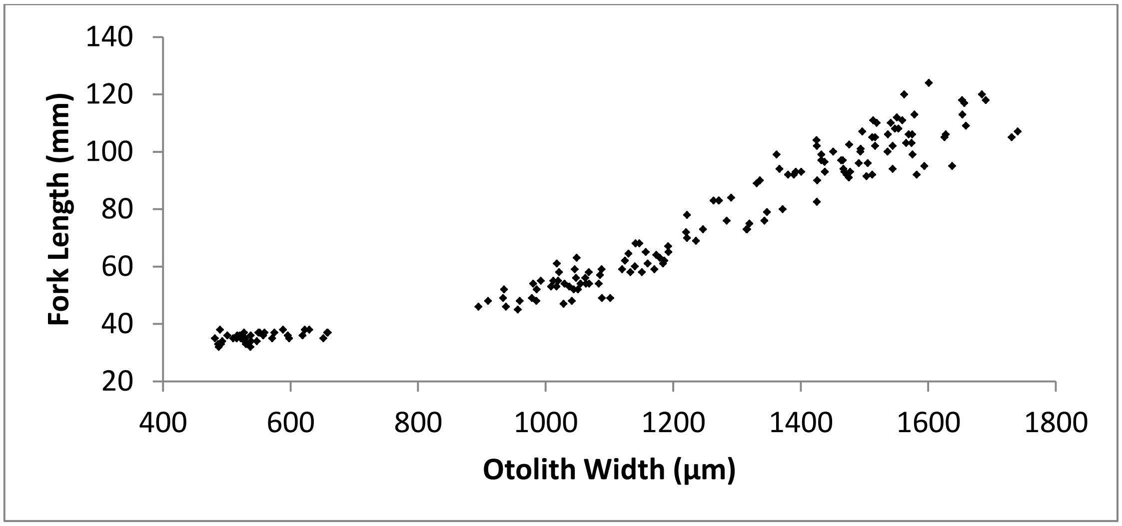


Figure 5. Scatter plot of juvenile coho salmon fork lengths and otolith widths from accidental handling mortalities from around the state (N=187). The cluster of data points closest to the intersection of both axes was fit its own regression equation separate from the one used for the rest of the data above 900 µm in otolith width.

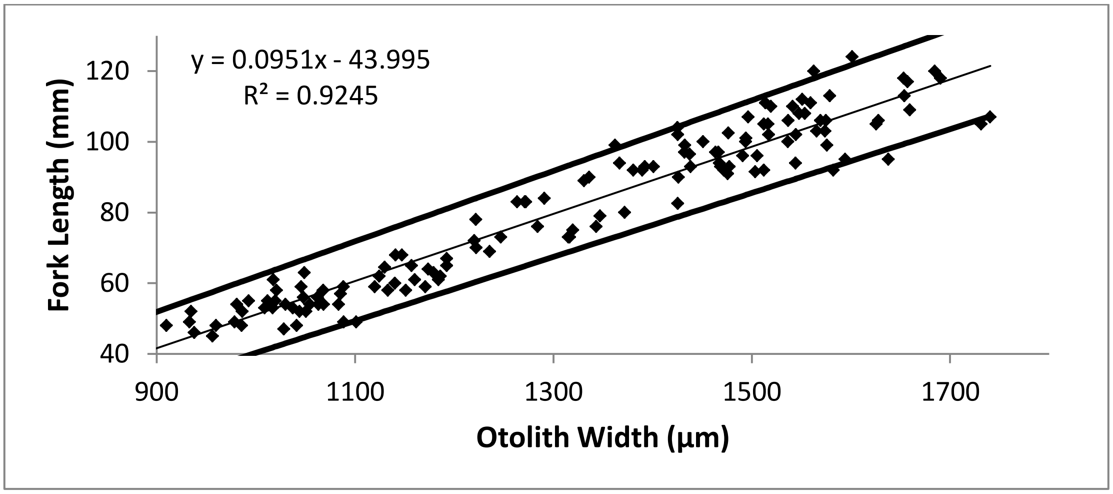


Figure 6. Linear regression between otolith width (with values > 900 µm) and juvenile coho salmon fork length (*P*-value <0.001; n=137). Bold lines represent 95% confidence intervals.

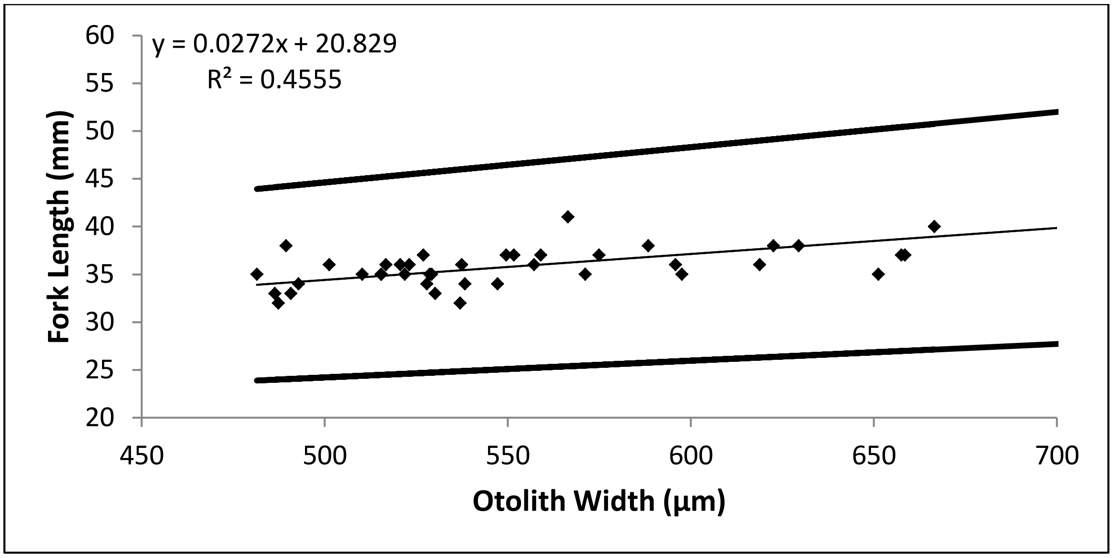


Figure 7. Linear regression between otolith width (between 450 and 700 µm) and coho salmon fry fork length (*P*-value <0.001; n=41). Bold lines represent 95% confidence intervals.

Otolith Analysis

In the fall of 2009, 136 otoliths were collected from spawner carcasses of coho salmon, 67 adult otoliths in Palouse Creek and 60 adult otoliths in Larson Creek. Otoliths from fish retuning to spawn a year earlier than their cohorts (jacks) were included as well. This identification was based on their mid-eye-to-posterior-scale (MEPS) length of ≤ 430 mm (Crawford et al. 2007). Otoliths from jacks were collected from three fish on Palouse Creek and six fish on Larson Creek. The MEPS length of the adults ranged from 440 mm to 675 mm, that of jacks ranged from 300 mm to 430 mm, and 16 incomplete carcasses had unknown length. Most otoliths found in fish are made of a calcium carbonate form called aragonite, but in salmon, there is a variation called vaterite that can form in varying degrees in one or both otolith of a fish. The chemistry of vateritic otoliths is significantly different form aragonite and does not capture the elemental ratios needed to interpret the life history of the fish (Gauldie et al. 1997). This form of carbonate is more common in hatchery fish (Sweeting et al. 2004); nonetheless, there were several vateritic otoliths in the study populations despite their wild-production origin. Because of vaterite and cracks, 39 of the 136 otoliths could not be interpreted.

Precision of the otolith microchemistry was estimated with a repeat sample of NIST 612 (n=17) mean percentage relative standard deviation (%RSD) were ^{86}Sr= 6.8%, ^{43}Ca= 6.5%, and ^{138}Ba= 4.7%. The calcium carbonate standard of known composition was used to provide an estimate of accuracy (MACS 1 and MACS 3). MACS 1 (n=4) had measured values that averaged with 12.1% of known Ba:Ca ratios and 9.7% for Sr:Ca ratios.

The back-calculated fork lengths derived from the Sr:Ca ratios were used to classify fish into various life history groups. In six of the 103 fish the Sr:Ca ratios remained constant over the entire otolith transect. These fish could have originated in a stream habitat that had high Sr:Ca ratios not observed in water samples from our study stream and may have been strays migrating into non-natal stream. In the cases where Sr:Ca values didn’t change along the otolith transect, I used the back-calculated fork lengths derived from Ba:Ca ratio instead. The back-calculated fork lengths from Ba:Ca ratios were usually similar to the back-calculated lengths from Sr:Ca ratios that indicated an ocean transition. There were some cases, however, when the back-calculated fork length from Ba:Ca ratios was more closely associated with the back-calculated length from Sr:Ca ratios, I considered that a signal of estuary residence. Therefore, the back-calculated length derived from Ba:Ca ratios only, was usually classified as the length of the fish entering the ocean, although it could have still been the length during estuary residence. The differences in the elemental patterns observed in the otoliths may be a reflection of the way the tide gates at the mouth of each system influence the natural salinity and salt wedges observed in the upper estuary (Giannico and Souder 2004). For instance, fish migrating downstream in Palouse Creek encounter a gradual increase of salinity as they migrate through the reservoir created upstream of the tide gate. This is because the concrete box holding the tide gate leaks and salt water intrudes upstream with each tidal cycle. The tide gate on Larson Creek prevents upstream intrusion of tidal waters, so fish migrating downstream transition rapidly from freshwater into full estuary salinity as they exit the tide gate. This abrupt change likely leaves a different pattern in the otolith elemental ratios.

Mean elemental ratios were calculated for freshwater, estuary, and marine habitats once areas of habitat transitions were located by visually identifying the inflection points on the Sr:Ca and Ba:Ca ablation transects (Table 6). The means of each habitat (Sr:Ca ratio in freshwater and the estuary, Sr:Ca ratio in the estuary and the ocean, and Ba:Ca ratio in freshwater and the ocean) were statistically different from each other (all *t*-test *P*-values < 0.001). In freshwater habitats, the mean observed Sr:Ca ratio was 1.37 ± 0.23 mmol mol^{-1}[mean ± SD] and the average for Ba:Ca ratio was 10.83 ± 5.14 µmol mol^{-1}(Table 6). In ocean habitats, the mean Sr:Ca ratio in otoliths was 1.86 ± 0.20 mmol mol^{-1} and the mean value of Ba:Ca ratio in the ocean was 2.58 ± 1.78 µmol mol^{-1}. Changes in Ba:Ca ratios were not identified during transitions from freshwater to estuarine waters and, therefore, the only mean ratio calculated for estuarine habitats was the mean Sr:Ca ratio. In estuary habitats the mean Sr:Ca ratio observed was 2.27 ± 0.34 mmol mol^{-1}.

Table 6. Range and mean values (± two standard deviations) for otolith Sr:Ca and Ba:Ca ratios corresponding to freshwater, estuary (Sr:Ca only), and ocean residence periods coho salmon for otoliths from the 2009 spawning year, and the otoliths from PIT tagged fish from the 2010 run year. Prediction intervals are ranges for 95% confidence intervals.

	Freshwater Sr:Ca (mmol mol^{-1})	Freshwater Ba:Ca (µmol mol^{-1})	Estuary Sr:Ca (mmol mol^{-1})	Ocean Sr:Ca (mmol mol^{-1})	Ocean Ba:Ca (µmol mol^{-1})
Mean	1.37 ± 0.23	10.83 ± 5.14	2.27 ± 0.34	1.86 ± 0.20	2.58 ± 1.78
Range	0.75 - 1.97	4.67 - 36.34	1.72 - 3.6	1.07 - 2.79	0.87 - 9.97
Prediction Interval	0.91 - 1.83	0.60 - 21.07	1.60 - 2.94	1.46 - 2.26	-0.95- 6.12
Sample Size	106	111	93	106	111

Although there was overlap in the range of observed elemental values in habitats, the majority of fish had elemental ratios that fell within the thresholds created to classify fish into life history groups. Two fish had freshwater residence ratios that fell out of the threshold range, seven fish had ocean elemental ratios that fell outside of the threshold range, and 44 of the otoliths had estuary elemental ratios that did not fit within the threshold range. In each one of these cases, identifications were based on inflection points that lead to the stabilization of elemental ratios at levels corresponding to habitat transitions. For example, fish with high elemental concentrations in freshwater also had high elemental concentrations in the ocean, so a transition between the habitats was still distinguishable on the elemental ratio graphs.

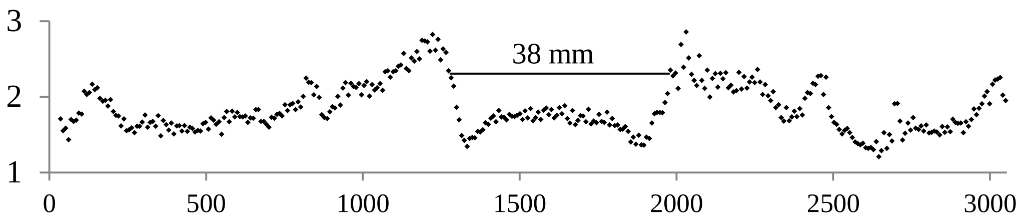
Water chemistry results showed Sr:Ca ratios reach marine levels in the lower estuary (Table 4), this means that areas of otoliths reflecting marine levels of Sr:Ca could be from times when a fish was still migrating through the estuary before reaching the ocean. There were no freshwater or estuary locations with significantly higher Sr:Ca ratios than those seen in the ocean, but higher values or Sr:Ca ratios were observed in the majority of the otoliths prior to reaching ocean elemental concentrations (Figure 4). These areas were interpreted as being estuarine signals and the otolith width at the increase in Sr:Ca was used to back-calculate the fork length of the fish when it entered the estuary. Fish without these estuary signals still migrated through estuarine habitats, but may have made it from freshwater to ocean too quickly for otoliths to capture that transition.

Three subyearling estuarine migrant life histories were identified from the elemental ratios in otoliths (Figure 8): 1) estuarine fry migrants (individuals that migrated into the estuary with a fork length under 60 mm); 2) estuarine parr migrants (juveniles that migrated into the estuary with a fork length between 60 mm and 70 mm); and, 3) estuarine nomads (estuary migrating fry that returned to freshwater as parr before migrating back into the estuary the following spring, this time as yearling smolts on their way to the ocean). Any fish migrating to the ocean or estuary with a fork length larger than 70 mm was considered a yearling smolt (Figure 8).

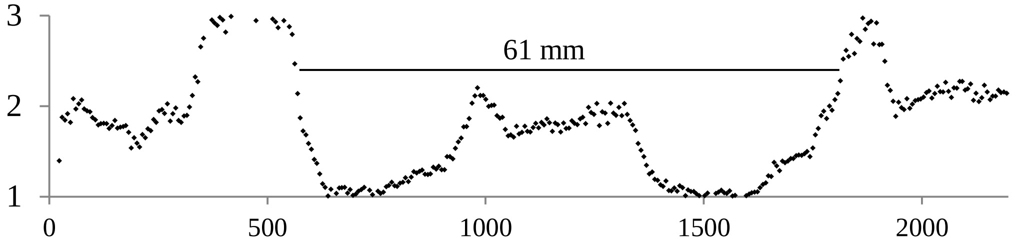
The otolith microchemistry of spawners that returned in 2009 revealed a wide range of juvenile fork lengths at time of their first estuary entrance (Figure 9). Back-calculated fork lengths show that fish entered the estuary or ocean at sizes ranging from 31.9 ± 9.7(95% CI) mm to 155.6 ± 16.0 (95% CI) mm (Figure 9). The average back-calculated fork length for all spawners combined was 70.0 ± 15.3 mm (95% CI) at estuary entrance and 105.5 ± 17.1 mm at ocean entrance. Subyearling estuarine migrants had an average back-calculated fork length of 56.5 ± 11.1 mm when they entered brackish waters, whereas the average estuarine entrance for yearling smolts was 80.8 ± 7.9 mm (Table 7).

Subyearling Estuarine Migrant Coho Salmon:

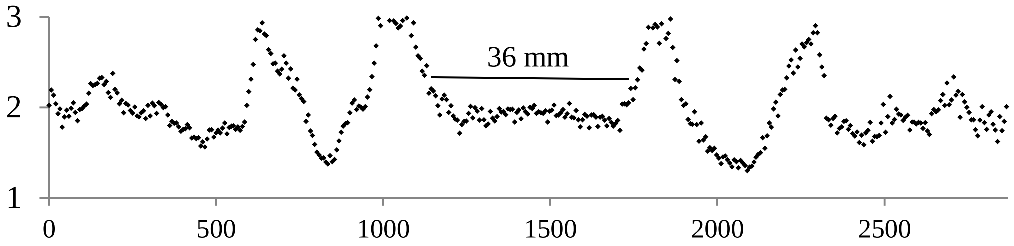
Estuarine Fry Migrant:



Estuarine Parr Migrant:



Estuarine Nomad:



Yearling Smolt:

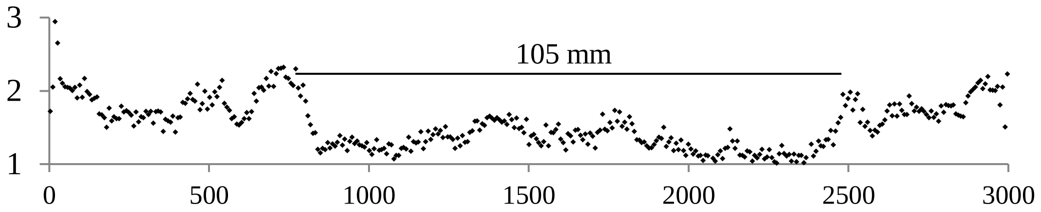


Figure 8. Otolith patterns for the three subyearling estuarine migrant and yearling smolt life history classifications from Sr:Ca graphs showing back-calculated fork lengths of the fish at time of estuarine or marine habitat entrance.

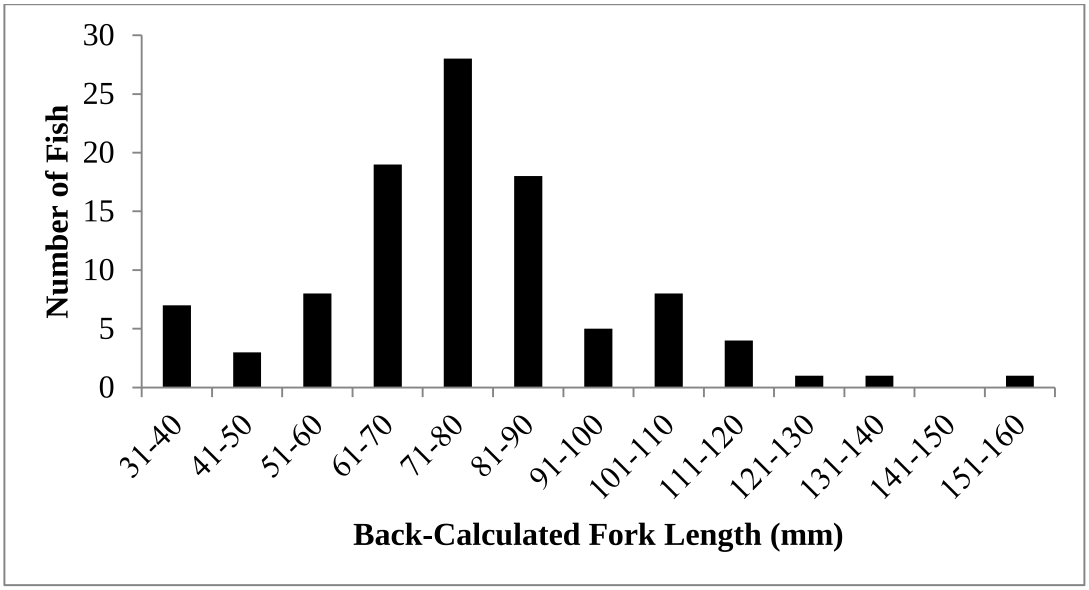


Figure 9. Back-calculated fork length of coho salmon at freshwater emigration for Palouse and Larson Creeks, Coos Bay, Or..

Table 7. The average back-calculated fork length (± 95% confidence interval) at estuary and ocean entrance for Palouse and Larson Creek coho salmon. "Population" is the average back-calculated length for all fish in both systems. "Yearling smolts" shows the average for all fish entering the estuary at a back-calculated fork length greater than 70 mm. "Subyearlings" were the averages for all fish entering the estuary at a back-calculated fork length less than 70 mm.

	Average Fork Length (mm)	
	Estuary Entrance	Ocean Entrance
Population	70.0 (15.3)	105.5 (17.1)
Yearling Smolts	80.8 (7.9)	108.0 (15.8)
Subyearlings	56.5 (11.1)	100.6 (18.2)

Larson Creek spawners that migrated as yearling smolts had a fork length when entering marine waters ranging from 70.7 ± 11.8 [mean ± 95% CI] mm to 131.2 ± 14.8 mm based on Sr:Ca ratios and from 71.1 ± 11.8 mm to 134.7 ± 13.3 mm based on Ba:Ca ratios. Palouse Creek spawners that migrated as yearling smolts entered the estuary at an estimated fork length of 71.0 ± 11.8 mm to 150.9 ± 15.8 mm based on Sr:Ca ratios, and at an estimated fork length of 76.3 ± 12.1 mm to 155.6 ± 16.0 mm based on Ba:Ca ratios. Larson Creek spawners with subyearling estuarine migrant life histories entered marine waters with a fork length of 31.9 ± 9.7 [estimate ± 95% CI] mm to 66.4 ± 11.6 mm and Palouse Creek spawners with the same early migrant life histories entered the ocean with fork lengths of 36.4 ± 10.9 mm to 69.9 ± 11.8 mm. Evidence of a “nomadic” life history was detected in the otoliths of only a few spawners: three in Palouse Creek and one in Larson Creek.

The results of the carcasses representative of the entire spawning run, indicate that 58% of the Palouse Creek spawners and 69% of the Larson Creek spawners had a yearling smolt life history and 31% of spawners in Larson Creek and 42% of the spawners in Palouse Creek exhibited a subyearling estuarine migrant life history (Figure 10). The most common variation within the subyearling migrant life history was estuary entrance at the parr stage, which was detected in 21% of the Palouse Creek and 16% of the Larson Creek carcasses. The subyearling nomadic life history, which involved a fall return to freshwater, was the least common, and was observed in the otoliths of only 6% of the Palouse Creek spawners and 2% of the Larson Creek spawners (Figure 10).

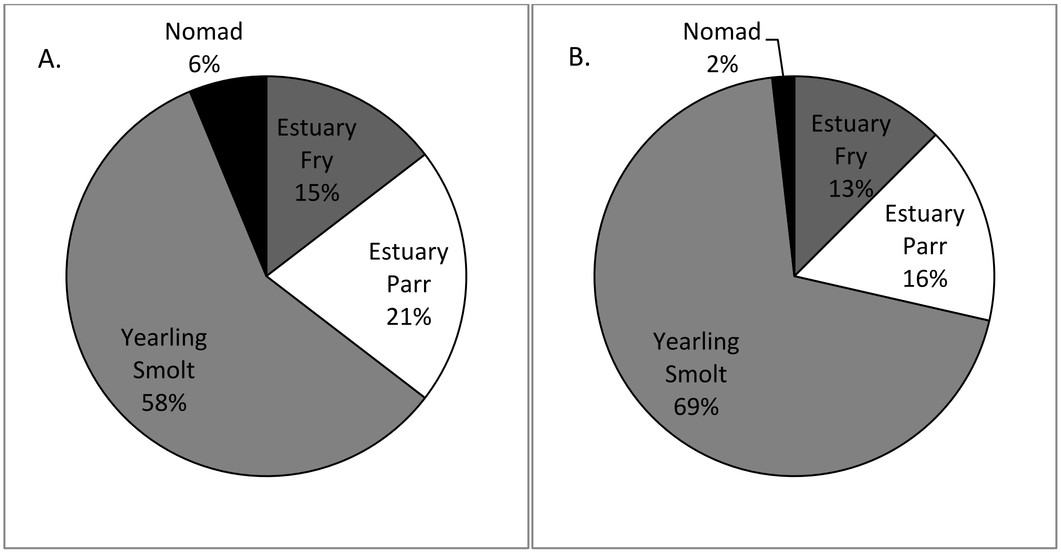


Figure 10. Proportional representation of different coho salmon early life histories based on otolith elemental analysis from returning spawners in 2009. A. Palouse Creek (n=48). B. Larson Creek (n=55).This includes three precocious males (jacks) that were recovered on Larson Creek and two from Palouse Creek. “Nomads”, “Estuary Fry”, and “Estuary Parr”, are types of subyearling estuarine migrants.

To estimate the percentages of fish that may have been misclassified based on the back-calculated fork lengths that I defined as characteristic of fry, parr, and smolt life stages, I used the records of the fork lengths of fish caught at the rotary screw traps in both creeks (February to June) of 2006 to 2012. For Palouse and Larson Creeks, 7.6% of fry that were caught at the trap had a fork length over 70 mm (n = 7,808) (Figure 11); these individuals were migrating to the estuary before their first June of life and would have be misclassified as yearling smolts based on back-calculated fork lengths. Among smolts, 6.9% had a fork length under 70 mm and 1.1% had a fork length of less than 60 mm (n = 4,148) (Figure 11). This percentages correspond to smolts that could have been misclassified as subyearling estuarine parr and fry migrants, respectively, based on their back-calculated fork lengths. Fish were also caught from June to September in the estuary. Among subyearling fish caught and tagged in the estuary, 28.7% were over 70 mm long and would have been classified as yearling smolts. However, this percentage does not represent the size of the fish when they first transitioned into the estuary. Many of these fish could have been residing in the estuary for an unknown amount of time before they were caught, measured and tagged. This indicates that subyearling estuarine migrant coho salmon may reach fork lengths similar to small yearling smolts and, therefore, there is risk of misclassifying them when one relies exclusively on back-calculated fork lengths based on otolith elemental analyses.

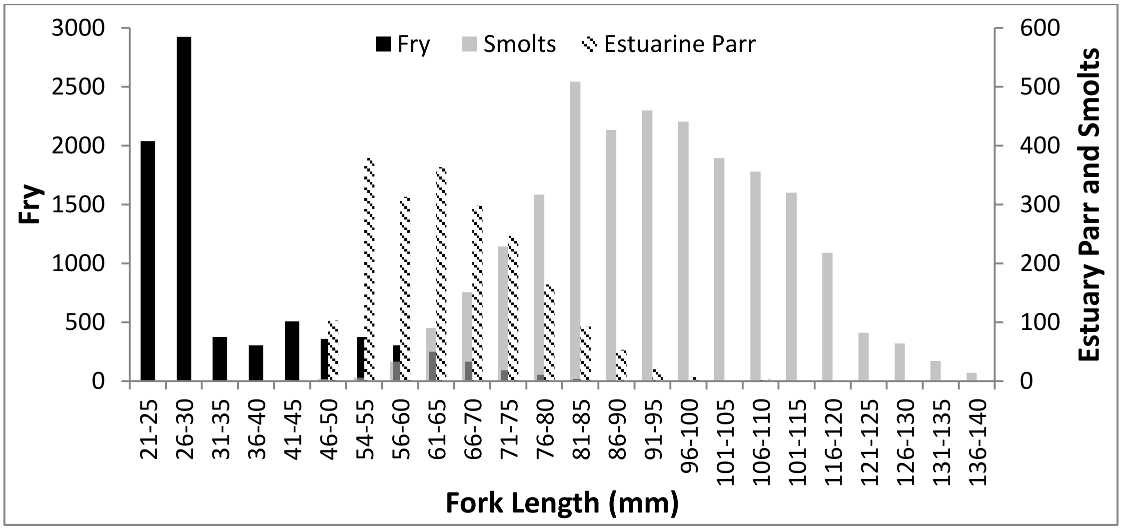


Figure 11. Fork length distributions of fry and yearling smolts caught in rotary screw traps in Palouse and Larson Creeks, and of estuarine parr (a subyearling migrant life history) caught and tagged in the estuary.

Fourteen otoliths were recovered from PIT tagged fish returning to spawn in 2010. Five could not be interpreted due to cracks or the presence of vaterite. The remaining nine otoliths were from three fish tagged as yearling smolts, one tagged as a stream resident parr and five tagged as subyearling estuarine migrants. Using PIT tagged fish to validate otoliths results is imprecise since the life history of the fish before tagging is unknown. The information from otoliths and fish tagged as stream resident parr or subyearling estuarine migrants were not comparable since the time between tagging and ocean and estuary entrance could not be determined. However, useful information can be gathered by comparing the yearling smolts fork length at tagging to their back-calculated fork lengths, since it is assumed that smolts on their spring migration are heading directly to the ocean. Using the three fish that were PIT tagged as smolts, I compared their known fork lengths at time of tagging to the back-calculated fork lengths from their otolith elemental analysis. The back-calculated fork lengths were, on average, 10.5% smaller than the known fork lengths at migration time (appendix B). Although, this is too small a sample to draw any conclusions it underlines the possible (although slight) underestimation of back-calculated fork lengths by my regression equation for individuals with otoliths widths > 900 µm.

A better evaluation of the reliability of back-calculated fish fork lengths based on otolith elemental analysis can be obtained by comparing the distributions of back-calculated fork lengths from 2009 spawners with the actual fork lengths of individuals from that same cohort that were captured in the screw traps as subyearling migrants (spring 2007) or yearling smolts (spring 2008). This comparison shows that both fork length distributions (observed and back-calculated) were very similar (Figure 12).

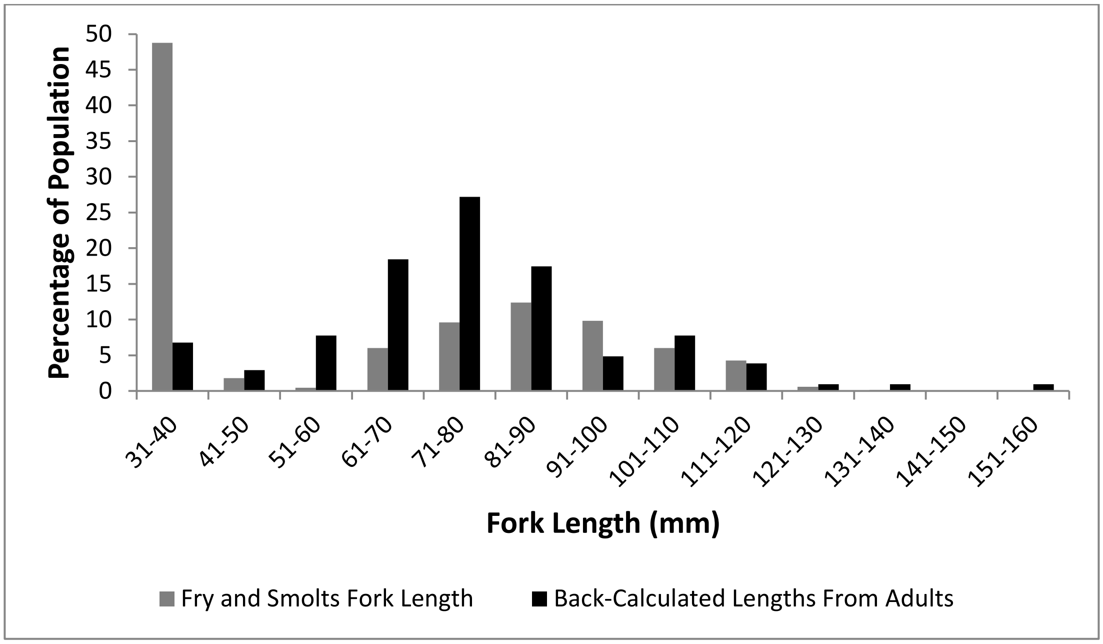


Figure 12. Observed fork lengths of coho salmon for brood year 2006 fish when they migrated as fry in 2007 or smolts in 2008 (grey bars) and back-calculated fork lengths at estuary entrance for the returning spawners in 2009 (black bars).

CHAPTER 4 DISCUSSION

This work expands the current understanding of the life history variation of coho salmon by determining the return rate of fish tagged as juveniles and the contribution of different life histories to spawning runs. It also shows that otolith microchemistry can be used to distinguish subyearling estuarine migrant coho salmon from stream residents and that back calculating fork length from otolith width where elemental ratios change can provide estimates of juvenile life history at salt-water entry. Most importantly, this work documents the survival and successful return of subyearling estuarine migrants. Although the odds of returning to spawn for parr with an estuarine migrant life history differ from year to year, it may be significantly higher than for stream rearing parr. In 2009, fish with subyearling estuarine migrant life histories made up 31% - 42% of the spawning runs.

PIT tagging studies on the Olympic Peninsula in Washington also found that subyearling estuarine migrants return to spawn; 32 of the 86 PIT tagged fish that returned in the study systems were subyearling fish migrated to the ocean in the fall or winter (Bennett et al. in review). The common fall and winter early migrant life histories observed in Washington were almost entirely absent in my study, which revealed that subyearling migrants reached the estuary before fall, and encountered very little evidence of a fall migration. Coho salmon parr were tagged before their first winter of life, whereas smolts were tagged the following spring. Therefore, because the percentage return is calculated from time of tagging to detection, it is expected that the percentage return for subyearling estuarine migrants would be lower than that for yearling smolts. Higher percentage returns for yearling smolts were observed in two of the three years of my study, but for one year (2009) subyearling estuarine migrant fish had a higher percentage return than yearling smolts. Although the difference in the percentage return between yearling smolts and subyearling estuarine migrants was not significantly different for that year, it seems that in some years, the subyearling estuarine migrant life history may lead to higher than average survival. Higher survival of subyearling fish in the estuary starts in freshwater, where their survival has also been shown to be higher for fish tagged in the low reaches of the creek (Roni et al. 2012). Such relatively high survival rate could be related to the higher than average growth rate and the resulting large size going into winter (Tschaplinski 1987, Miller and Sadro 2008, Jones et al. 2011, Craig 2010, Kahler et al. 2011). Coho salmon parr that are larger than average at the beginning of winter, in general, have the highest winter survival rates in the population (Quinn and Peterson 1996, Zabel and Achord 2004). In addition to increased freshwater survival larger than average juvenile coho salmon experience increased marine survival in years when overall marine survival is poor (Holtby et al. 1990).

In this study, I relied on fish that had been tagged for life cycle monitoring purposes by the Coos Watershed Association and by other researchers. This tagging effort focused on Palouse Creek because this system sustains a larger coho salmon population than Larson Creek and access to the river through private land is easier.

The numbers of fish tagged was the highest in 2009, and for that reason the 2007 brood year (the 2010 spawning run) is much better represented in my data set than other years. Fewer fish were tagged in Larson Creek, and, therefore, the number of PIT tagged spawners returning, was comparatively small. Also during the periods of juvenile monitoring, I did not have an operating antenna system in the transition zone between the freshwater and upper estuarine habitats in Larson Creek (Rkm 1.85). This prevented the detection of fish that were tagged in the upper area of the stream and subsequently migrated downstream to the upper estuary during their first spring. As a result, some subyearling estuarine migrants could have been labeled as stream residents in Larson Creek. Although tagging was not evenly distributed between life history types or streams, it is assumed that percentage return of PIT tagged fish is representative of survival of non-tagged fish from corresponding life history types. Therefore, PIT tagged fish provide relative survival information for the different life history types, but they were not representative of the entire population.

Otolith microchemistry results provided a representative sample and allowed the determination of early life histories of salmon without the need to monitor fish from their earliest months of life. The life histories determined from otolith microchemistry included yearling smolts and subyearling migratory life histories. There were three types of subyearling migrants that returned to spawn: 1) fry that migrate to the estuary at < 60 mm fork length; 2) fry (< 60 mm fork length) that migrate down to the estuary during their first spring and then returned to freshwater to overwinter before migrating the following spring as yearling smolts (called “nomads” in this thesis); and 3) parr that migrate to the estuary during their first year of life at 60 - 70 mm fork length. The life histories observed in this study were similar to those in the Salmon River, where the percentage of fish with subyearling estuarine migrant life histories that returned to spawn, ranged from 21% to 47% of the run (Jones et al. 2011).

It is likely that not all subyearling migratory life histories can be identified by otolith methods. Some early migrants may “settle” in freshwater habitats before they even reach the upper estuary, in this case, their early migratory life history could not be determined based on otolith elemental analyses. Additionally, changes in the otolith microchemistry may take 1-2 days (Miller et al. 2011) so early migrating fish living in the upper reaches of the estuary may move temporarily into higher salinity waters and not deposit a distinguishable microchemical signal that can be used to detect such a movement pattern.

Although, the fork length classifications used to distinguish fry, parr, and yearling smolts were designed to be conservative, the regression equation used to estimate lengths based on otoliths widths might have underestimated fish fork length. Some studies have documented that faster than normal body growth can lead to proportionally smaller otoliths for a given fish fork length (Campana 1990, Wright et al. 1990). Therefore, it may be possible for an otolith-to-fork-length regression based on a group of relatively slower growing fish to end up underestimating fork lengths when it is applied to fish that experience higher growth rates in favorable habitats. The regression to estimate fork lengths for fish with otoliths ≥ 900-µm wide was calculated using over 50% of fish (72 of the 137) from outside the study area. These fish may have experienced rearing conditions that differed from fish in Palouse and Larson Creeks. The regression equation developed for fish with otoliths ≤ 700 µm reflects more accurately the fork length-to-otolith width relationship characteristic of the fish in this study because only specimens from Palouse and Larson Creeks were used in it.

The comparison of observed and estimated fork length distributions showed that the highest percentage of juvenile coho salmon caught in the traps corresponded to very young fry (49% of catch) and that only a small percentage (7%) of the spawners seemed to have migrated into the estuary at such a very early stage according to otolith elemental composition. High mortality rates among these very early migrating fry is not surprising, in fact it is what most earlier studies of coho life history expected (Chapman 1962). By contrast, the proportion of returning adult fish that had an estimated juvenile fork length at the time of estuary/ocean entrance of 51 mm to 80 mm is higher than would have been expected based on the proportional representation fish within this fork length range showed in the migrating population. This suggests a higher apparent survival among juvenile coho salmon of this size class than among those that were either smaller or larger at the time of transitioning into brackish habitats.

The use of otolith elemental composition to classify fish by fork length classes rather than age classes can lead to some misclassifications (e.g., small smolts may be considered to be parr or large parr grouped with smolts). These misclassifications could be alleviated in future studies by expanding the breath of information gleaned from otoliths. Width of the otoliths at ocean entrance and the width of the otolith at the first winter annuli could be compared to determine if the fish migrated before or after the first winter. Zinc may be of some use to determine the location of annuli as well, and could be added to the microchemical analysis (Halden et al. 2000). Knowledge of the location of winter annuli in comparison with the fork length of a fish at estuary/ocean transitions would allow the identification of larger than average early estuarine migrants. These methods could also help identify fall migrants and two-year old smolts, which cannot be identified with Sr:Ca and Ba:Ca ratios alone.

Early coho salmon migration reflects a biological drive rather than displacement and is common in many streams (Kahler et al. 2011). This drive to migrate could be influenced by genetically controlled circadian rhythms, which are expressions of internal changes triggered by day length, which can regulate cellular functions that ultimately elicit seasonal behaviors and even migrations (Schwassmann 1988). Circadian clock genes have been linked to differences in Chinook salmon spawning time as well as juvenile coho salmon growth rates and body lengths (O’Malley et al. 2007, O’Malley et al. 2010).

Biologically driven subyearling estuarine migration is not present in all coho salmon populations; but is more common in small coastal streams where the carrying capacity can be reached with small numbers of spawning fish (Hartman et al. 1996, Jones et al. 2011, Roni et al. 2012). In these types of stream habitats, estuaries act as additional rearing habitat that increase the resilience of the population and bolster their ability to absorb disturbances (Hilborn et al. 2003). Conditions between estuarine habitats and stream habitats differ in ways that lead to varied survival over years. These different interannual survival rates in multiple habitats provide basin-wide stability to smolt production (Hartman et al. 1996). Because survival of fish in each habitat differs with varying conditions, life history diversity buffers fluctuations in population size over long periods of time and, thus, improves its productivity (Greene et al. 2010).

As multiple populations face rapidly changing conditions, understanding coho salmon life histories, both adult and juvenile, is critical for the future conservation of the species. Large-scale climate change has affected salmon population production in the past (Hare and Francis 1995) and future climate change has been identified as a growing threat to coho salmon (NMFS 2011). Areas of transition in a salmon’s life, such as migration through the estuary, are points where they are most susceptible to environmental changes**.** Because salmon migration timing is highly adapted to local environments (Spence 1995), and coastal areas and estuary habitats are projected to be some of the first areas to experience climate-change related alterations (Nicholls et al.

1999), future changes will have the greatest impact on coho salmon that use estuarine habitats to rear. Possible impacts to coastal salmonids from forecasted climatic changes are primarily associated with: a) increases in water temperature; and b) sea level rise. Higher freshwater temperatures are expected to cause salmonid eggs to hatch earlier, as observed in streams where water temperatures increased after riparian forests were logged. Earlier hatching means earlier fry emergence, and this may induce a greater tendency to be passively displaced downstream with early spring flows (Hartman et al. 1982). In turn, the rise in sea levels, which are forecasted to increase by 50 to 80 cm towards the end of the century (USGCRP 2002), will change the current extent and conditions of the estuaries these fish rely upon. Coho salmon and other related species might benefit from the anticipated estuarine habitat expansion if it leads to an increase in feeding opportunities and growth (NMFS 2011). But good quality nursery habitats may not become abundant or easily accessible if humans tendencies to dike coastal streams, drain floodplains, and protect coastal infrastructure are not informed by the needs of this and other commercially important species. In Coos Bay alone, almost 90 percent of upper estuarine habitats have been lost due to dikes and landfill (Schultz 1990). To protect against the negative consequences of sea level rise current estuarine habitats utilized by coho salmon needs to be preserved and restoration of historic estuarine habitats should become a priority in areas where managers are seeking to stabilize or preserve threatened populations.

In addition to having diverse juvenile life histories, coho salmon are widely dissimilar in their ocean migrations, having as many as 12 ocean distribution patterns (Weitkamp and Neely 2002). Among the returning spawners sampled for this study approximately 47% of the otoliths examined had one or two sets of Ba:Ca ratio peaks above the average ocean values during their ocean life history. Investigation into the cause of these Ba:Ca signals could offer insight into the ocean conditions where coho salmon are dwelling. Future work on coho salmon ecology combine juvenile life history with their ocean distribution patterns and provide a more complete picture of the diversity of coho salmon adaptive strategies.

Additional research documenting coho salmon life history diversity, survival, and contribution to populations will help determine which life history types are in need of the most protection to maintain the resilience of their populations in light of changing ecosystems. Understanding the interactions between habitat availability and usage for differing life history types will help generate predictions of the effects climate change could have on populations in the future. Future research into the behavior, habitat, and diets preferred by subyearling estuarine migrants would help prioritize and direct restoration projects. Habitat restoration for the purpose of protecting coho salmon should include estuary and salt marshes (NMFS 2011) as well as areas where subyearling estuarine migrant coho salmon aggregate, such as off-channel rearing areas in both freshwater and estuaries (Craig 2010), and channels with vegetative cover, undercut banks and large debris (Tschaplinski 1987).

Restoration of estuarine habitats has increased the numbers of Chinook salmon early life histories observed in the Salmon River, Oregon in just a few years (Bottom et al. 2005). To preserve life history diversity of coho salmon the habitats used by each life history type need identification and protection. Any habitat loss that affects one life history type could affect the genetic make up of salmon populations if differences in life histories have a genetic basis (McClure et al. 2007). By preserving life history diversity the resiliency of coho salmon populations over long periods can also be preserved.

BIBLIOGRAPHY

Acolas, M.L., J.M. Roussel, J.M. Lebel, and J.L. Bagliniere. 2007. Laboratory experiments on survival, growth and tag retention following PIT injection into the body cavity of juvenile brown trout (*Salmo trutta*). Fisheries Research 86(2): 280-284.

Bass, A.L. 2010. Juvenile coho salmon movement and migration through tide gates. Master's Thesis, Oregon State University, Corvallis

Bass, A.L., G.R. Giannico, and G.T. Brooks. 2012. Performance of a full-duplex passive integrated transponder (PIT) antenna system in estuarine channels. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4:145-155.

Botton, D.L., K.K. Jones, T.J. Cornwell, A. Gray, and C.A. Simenstad. 2005. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). Estuarine, Coastal and Shelf Science, 64, 79–93.

Chapman, D. W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. *Journal of the Fisheries Research Board of Canada*, 19: 1047-1080.

Campana, S.E. 1990. How reliable are growth back-calculations based on otoliths? Canadian Journal of Fisheries and Aquatic Sciences 47: 2219-2227.

Craig, B.E. 2010. Life history patterns and ecology of juvenile coho salmon (*Oncorhynchus kisutch*) within a tidal freshwater estuary. Master's Thesis. University of Washington.

Crawford, B., T.R. Mosey, and D.H. Johnson. 2007. Carcass counts. Pages 59-86 in D.H. Johnson, B.M. Shrier, J.S. O'Neal, J.A. Knutzen, X. Augerot, T.A. O'Neil, and T.N. Pearson, editors. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Eaton, A.D., L.S. Clesceri, E.W. Rice, A.E. Greenberg (Eds.). 2005. Standard methods for the examination of water and wastewater. Port City Press, Baltimore, MD.

Elsdon, T.S., and B.M. Gillanders. 2005. Alternative life-history patterns of estuarine fish; barium in otoliths elucidates freshwater residence. Canadian Journal of Fisheries and Aquatic Science 62: 1143 - 1152.

Gauldie, R.W. 1988. Function, form and time-keeping properties of fish otoliths. Comparative Biochemistry and Physiology Part A: Physiology 91(2): 395-402.

Gauldie, R.W., S.K. Sharma, and E. Volk. 1997. Micro-Raman Spectral Study of Vaterite and Argonite Otoliths of the Coho Salmon, Oncorhynchus kisutch. Comparative Biochemistry and Physiology 118: 753-757.

Giannico, G., and J. Souder. 2004. The effects of tide gates on estuarine habitat and migratory fishes. Oregon Sea Grant, Oregon State University, Corvallis, OR

Green. C.M., Hall, J.E., Guilbault, K.R., and Quinn, T.P. 2010. Improved viability of populations with diverse life-history portfolios. Biology Letters 6(3), 382-6

Halden, N. M., S.R. Mejia, J.A. Babaluk, J.D. Reist, A.H. Kristofferson, J.L. Campbell, and W.J. Teesdale. 2000. Oscillatory zinc distribution in Arctic char (*Salvelinus alpinus*) otoliths: The result of biology or environment? Fisheries Research 46: 289–298.

Hare, S. R., and R.C. Francis. 1995. Climate change and salmon production in the Northeast Pacific Ocean. In R. J. Beamish (Ed.), Ocean climate and northern fish populations (pp. 357–372). Canadian Special Publication of Fisheries and Aquatic Science, 121.

Hartman, G. F., B. C. Anderson, and J. C. Scrivener. 1982. Seaward migration of salmon (*Oncorhynchus kisutch*) fry in Carnation Creek, an unstable coastal stream in British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 39:588-597.

Hartman, G.F., J.C. Scrivener, and M.J. Milles. 1996. Impacts of logging in Carnation Creek, a high-energy coastal stream in British Columbia, and their implication for restoring fish habitat. Canadian journal of Fisheries and Aquatic Sciences (suppl.) 53:237-251.

Hilborn, R., T.P. Quinn, D.E. Schindler, and D.E. Rogers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences of the United States of America 100: 6564-6568.

Holtby, L.B., B.C. Andersen, R.K. Kadowaki. 1990. Importance of smolt size and early Ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 47 (11): 2181-2194.

Jones, K.K., T.J. Cornwell, D.L. Bottom, S. Stein, H.W. Kelly, and L.A. Campbell. 2011. Recovery of wild coho salmon in Salmon River basin, 2008-2010. Oregon Plan for Salmon and Watersheds Annual Monitoring Report No. OPSW-ODFW-2011-10.

Kahler T.H., R. Philip, T.P. Quinn. 2011. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58(10): 1947-1956.

Kalish, J.M. 1990. Use of otolith microchemistry to distinguish the progeny of sympatric anadromous and non-anadromous salmonids. U. S. National Marine Fisheries Service Fishery Bulletin 88:657-666.

Koski, K.V. 2009. The fate of coho salmon nomads: the story of an estuarine-rearing strategy promoting resilience. Ecology and Society, 14(1): 4. Available: ecologyandsociety.org/vol14/iss1/art4/.

Macdonald, J.I., D.A. Cook. 2010. Variability in Sr:Ca and Ba:Ca ratios in water and fish otoliths across an estuarine salinity gradient. Marine Ecology Progress Series 413: 147-161.

Mason, J. C. 1976. Response of underyearling coho salmon to supplemental feeding in a natural stream. Journal of Wildlife Management 40:775-788.

Mason, J. C., and D. W. Chapman. 1965. Significance of early emergence, environmental rearing capacity, and behavioral ecology of juvenile coho salmon in stream channels. Journal of the Fisheries Research Board of Canada 22:173-190.

McClure, M. M., S.M. Carlson, T.J. Beechie, G.R. Pess, J.C. Jorgensen, S.M. Sogard, S.E. Sultan, D.M. Holzer, J. Travis, B.L. Sanderson, M.E. Pawer, and R.W. Carmichael. 2008. Evolutionary consequences of habitat loss for Pacific anadromous salmonids. Evolutionary Applications 1(2): 300-318.

Miller, B. A., and S. Sadro. 2003. Residence time and seasonal movements of juvenile coho salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon. Transactions of the American Fisheries Society 132(3): 546-559.

Miller, J.A. 2007. Scales of variation in otolith elemental chemistry of juvenile staghorn sculpin (*Leptocottus armatus*) in three Pacific Northwest estuaries, Marine Biology 151:483-494.

Miller, J.A. 2009. The effects of temperature and water concentration on the otolith incorporation of barium and manganese in black rockfish *Sebastes melanops*. Journal of Fish Biology 75:39-60.

Miller, J. A. 2011. Effects of water temperature and barium concentration on otolith composition along a salinity gradient: Implications for migratory reconstructions. Journal of Experimental Marine Biology and Ecology 405(1): 42-52.

Miller, J., A. Gray, and J. Merz. 2010. Quantifying the contribution of juvenile migratory phenotypes in a population of Chinook salmon (*Oncorhynchus tshawytscha*). Marine Ecology Progress Series 408: 227-240.

NMFS (National Marine Fisheries Services). 2011. Southern Oregon/Northern California Coast recovery domain 5-year review: summary and evaluation of Southern Oregon/Northern California Coast coho salmon ESU. Southwest Region, Long Beach , CA.

Nicholls, R., F. Hoozemans, and M. Marchand. 1999. Increasing flood risk and wetland losses due to global sea-level rise: regional and global analysis. Global Environmental Change, 9 (suppl.): 69-87.

O’Malley, K.G., M.D. Camara, and M.A. Banks. 2007. Candidate loci reveal genetic differentiation between temporally divergent migratory runs of Chinook salmon (*Onchrhynchus tshawytscha*). Molecular Ecology 16: 4930-4941.

O’Malley, K.G., M.J. Ford, and J.J. Hard. 2010. Clock polymorphism in Pacific salmon: evidence for variable selection along a latitudinal gradient. Proceedings of the royal society B 277: 3703-3714.

Prentice, E., F. Waknitz, D. Maynard, P. Sparks-McConkey, C. McCutcheon, W. Steffens, A. Jensen, L. Stuehrenberg, S. Downing, B. Sandford, T. Newcomb, and D. Neff. 1993. Study to determine the biological feasibility of a new fish tagging system. Bonneville Power Administration Annual Report 1989, Project No. 1983-31900, BPA Report DOE/BP-11982-4, Portland, Oregon.

Quinn, T. P. 2005. *The behavior and ecology of Pacific salmon and trout.* American Fisheries Society, Bethesda, Maryland and the University of Washington Press, Seattle, Washington, USA.

Quinn, T.P., and N.P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of Individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53(7): 1555-1564.

Roni, P., T. Bennett, R. Holland, G. Pess, K. Hanson, R. Moses, M. McHenry, W. Ehinger, and J. Walter. 2012. Factors affecting migration timing, growth and survival of juvenile coho salmon in two coastal Washington watersheds. Transactions of the American Fisheries Society 141: 890-906.

Schultz, S.T. 1990. The Northwest coast: a natural history. Timber Press, Portland, Oregon.

Schwassman H.O. 1988. Biological rhythms. In: Hoar W,S,, Randall D.J. editors. Fish physiology. New York: Academic Press. P. 371-416.

Spenc, B. 1995. Geographic variation in timing of fry emergence and smolt migration of coho salmon (*Oncorhynchus kisutch*). PhD Thesis, Oregon State University, Corvalis.

Sweeting R.M., R.J. Beamish and C.M. Neville. 2004. Crystalline otoliths in teleosts: comparisons between hatchery and wild coho salmon (*Oncorhynchus kisutch*) in the Strait of Georgia. Reviews in Fish Biology and Fisheries 14: 361–369.

Szumilas, M. 2010. Explaining odds ratios. Journal of the Canadian Academy of Child and Adolescent Psychiatry 19(3): 227-229.

Tschaplinski, P. J. 1987. Comparative ecology of stream-dwelling and estuarine juvenile coho salmon (*Oncorhynchus kisutch*) in Carnation Creek, Vancouver Island, British Columbia. Dissertation. University of Victoria, Victoria, British Columbia, Canada.

United States Global Change Research Program (USGCRP). 2002. Climate Action Report. Chapter 6: Impacts and Adaptation. 32 p.

Walther, B.D., and K.E. Limburg. 2012. The use of otolith chemistry to characterize diadromous migrations. Journal of Fish Biology 81: 796-825.

Weitkamp, L., and K. Neely. 2002. Coho salmon (Oncorhynchus kisutch) ocean migration patterns: insight from marine coded-wire tag recoveries. Canadian Journal of Fisheries and Aquatic Sciences 59: 1100-1115.

Weybright, A.D. 2011. Juvenile Coho Salmon Movement, Growth and Survival in a Coastal Basin of Southern Oregon. Master's Thesis, Oregon State University, Corvallis.

Wickett, W.P. 1951. The coho salmon population of Nile Creek. Fisheries Research Board of Canada, Pacific Progress Report No. 89, pp. 88-89.

Write, P.J., N.B. Metcalfe, and J.E. Thorpe. 1990. Otolith and somatic growth rates in Atlantic salmon parr, *Solmo salar* L: evidence against coupling. Journal of Fish Biology 36: 241-249.

Zabel R.W., and S. Achord. 2004. Relating size of juveniles to survival within and among populations of Chinook salmon. Ecology 85: 795-806.

Zimmerman, C.E. 2005. Relationship of otolith strontium-to-calcium ratios and salinity: experimental validation for juvenile salmonids. Canadian Journal of Fisheries and Aquatic Sciences, 62(1): 88- 97.

Zydlewski, G., G. Horton, T. Dubreuil, B. Letcher, S. Casey, and J. Zydlewski. 2006. Remote monitoring of fish in small streams: A unified approach using PIT tags. Fisheries, 31 (10):492-502.

APPENDICES

Appendix A. Average Values of Sr:Ca and Ba:Ca for Each Otolith from Adult Coho Salmon in Palouse and Larson Creeks

Table A1. Average values of Sr:Ca and Ba:Ca for otolith areas corresponding to freshwater residence, estuarine residence and ocean residence. Standard errors are shown in parenthesis. All otoliths are from spawners found on Larson Creek, Coos Bay, and include three Jacks (Lo-041, Lo-073, Lo-081).

Otolith ID	Freshwater Sr:Ca (mmol mol^{-1})	Freshwater Ba:Ca (µmol mol^{-1})	Estuary Sr:Ca (mmol mol^{-1})	Ocean Sr:Ca (mmol mol^{-1})	Ocean Ba:Ca (µmol mol-1)	Otolith ID	Freshwater Sr:Ca (mmol mol^{-1})	Freshwater Br:Ca (µmol mol^{-1})	Estuary Sr:Ca (mmol mol^{-1})	Ocean Sr:Ca (mmol mol^{-1})	OceanBa:Ca (µmol mol-1)
Lo-037	1.18 (0.02)	9.39 (0.57)	2.86 (0.08)	1.89 (0.03)	1.92 (0.47)	Lo-067	1.40 (0.02)	6.50 (0.31)	2.79 (0.17)	1.90 (0.04)	1.07 (0.15)
Lo-038	1.08 (0.04)	9.91 (0.80)	na	1.64 (0.02)	1.35 (0.26)	Lo-068	1.66 (0.04)	7.53 (0.25)	2.07 (0.05)	1.88 (0.02)	0.87 (0.06)
Lo-039	1.29 (0.02)	14.02 (1.81)	na	1.71 (0.03)	1.44 (0.28)	Lo-069	0.75 (0.02)	10.35 (0.42)	na	2.11 (0.04)	1.27 (0.09)
Lo-040	1.64 (0.04)	7.70 (1.82)	na	1.72 (0.04)	1.83 (0.12)	Lo-070	1.22 (0.03)	12.61 (0.93)	1.95 (0.03)	1.74 (0.02)	3.20 (1.27)
Lo-041	1.37 (0.02)	8.75 (1.01)	2.01 (0.13)	1.89 (0.04)	1.35 (0.56)	Lo-071	1.18 (0.04)	7.17 (0.30)	1.72 (0.05)	1.69 (0.030	2.23 (0.40)
Lo-042	1.11 (0.03)	5.61 (0.13)	na	1.97 (0.03)	2.28 (0.18)	Lo-072	1.58 (0.04)	36.34 (1.90)	2.14 (0.05)	1.80 (0.02)	9.97 (2.91)
Lo-044	1.24 (0.05)	10.84 (0.19)	na	1.81 (0.05)	1.64 (0.11)	Lo-073	1.56 (0.02)	9.85 (0.74)	2.06 (0.05)	1.93 (0.03)	3.61 (0.32)
Lo-045	1.26 (0.03)	8.02 (0.40)	2.03 (0.06)	2.06 (0.04)	1.39 (0.28)	Lo-074	1.37 (0.02)	8.41 (0.45)	2.40 (0.14)	2.12 (0.03)	1.13 (0.11)
Lo-046	1.03 (0.02)	5.69 (0.41)	3.26 (0.20)	1.87 (0.04)	1.91 (0.48)	Lo-075	1.22 (0.08)	11.70 (0.43)	2.10 (0.05)	1.77 (0.02)	1.99 (0.12)
Lo-047	1.09 (0.03)	7.63 (0.31)	3.01 (0.04)	1.79 (0.04)	1.67 (0.30)	Lo-076	1.20 (0.05)	8.95 (0.64)	2.08 (0.08)	1.07 (0.03)	2.71 (0.82)
Lo-048	1.16 (0.03)	8.21 (0.53)	2.46 (0.04)	2.18 (0.07)	2.20 (0.14)	Lo-077	1.06 (0.02)	7.13 (0.25)	na	1.97 (0.02)	1.24 (0.08)
Lo-049	1.04 (0.03)	10.02 (0.73)	2.10 (0.05)	1.72 (0.03)	1.40 (0.12)	Lo-078	1.82 (0.02)	8.76 (0.23)	2.78 (0.04)	2.11 (0.03)	1.20 (0.12)
Lo-052	1.67 (0.04)	12.32 (0.90)	2.16 (0.03)	1.91 (0.04)	2.22 (0.83)	Lo-079	1.20 (0.03)	8.61 (1.51)	1.92 (0.04)	1.65 (0.03)	1.08 (0.08)
Lo-053	1.19 (0.04)	8.23 (0.43)	2.20 (0.90)	1.95 (0.05)	1.68 (0.36)	Lo-080	1.08 (0.02)	7.08 (0.38)	2.10 (0.06)	1.80 (0.02)	2.28 (0.21)
Lo-054	1.00 (0.01)	8.45 (0.62)	1.73 (0.05)	1.67 (0.03)	2.22 (0.24)	Lo-081	1.69 (0.03)	16.32 (1.44)	2.40 (0.09)	2.02 (0.04)	2.16 (0.29)
Lo-055	1.02 (0.03)	8.39 (1.07)	2.21 (0.73)	1.70 (0.03)	2.13 (0.21)	Lo-082	na	16.36 (1.10)	na	na	7.52 (1.39)
Lo-056	1.18 (0.02)	6.59 (0.92)	na	1.78 (0.02)	3.67 (0.13)	Lo-087	na	5.59 (0.05)	na	na	1.11 (0.20)
Lo-057	1.30 (0.02)	7.36 (0.37)	2.19 (0.02)	1.83 (0.04)	1.65 (0.24)	Lo-090	1.23 (0.04)	8.78 (1.28)	2.27 (0.04)	1.87 (0.05)	1.87 (0.744)
Lo-058	1.03 (0.02)	4.67 (0.57)	1.92 (0.05)	1.54 (0.030	1.57 (0.30)	Lo-091	1.25 (0.03)	9.63 (0.16)	na	1.66 (0.02)	1.11 (0.08)
Lo-059	1.44 (0.09)	6.49 (0.66)	2.17 (0.02)	1.98 (0.01)	1.87 (0.41)	Lo-092	1.37 (0.02)	17.34 (0.05)	na	2.01 (0.040	2.75 (0.13)
Lo-060	1.07 (0.03)	9.02 (0.36)	2.08 (0.07)	1.76 (0.04)	1.47 (1.30)	Lo-093	1.16 (0.02)	7.69 (0.11)	na	1.82 (0.02)	2.97 (0.11)
Lo-061	0.95 (0.02)	7.37 (0.59)	na	1.64 (0.03)	1.10 (0.14)	Lo-094	1.26 (0.03)	8.86 (0.03)	1.90 (0.06)	1.77 (0.02)	1.82 (0.16)
Lo-062	1.36 (0.03)	25.05 (1.44)	1.86 (0.06)	1.78 (0.03)	4.84 (1.37)	Lo-095	na	11.84 (0.05)	na	na	1.80 (0.12)
Lo-063	1.41 (0.04)	22.21 (1.19)	2.45 (0.02)	2.19 (0.02)	5.40 (0.46)	Lo-096	1.45 (0.06)	26.40 (2.79)	2.33 (0.08)	1.67 (0.03)	4.19 (0.96)
Lo-064	1.31 (0.02)	7.51 (0.25)	na	1.73 (0.03)	3.16 (0.41)	Lo-098	1.35 (0.03)	11.53 (2.45)	1.99 (0.02)	1.72 (0.02)	1.79 (0.10)
Lo-065	1.12 (0.03)	13.33 (2.05)	2.07 (0.07)	1.72 (0.07)	1.19 (0.27)	Lo-099	1.17 (0.04)	12.69 (0.07)	2.17 (0.05)	1.71 (0.03)	2.42 (0.12)
Lo-066	1.12 (0.03)	8.64 (0.52)	na	1.51 (0.03)	1.26 (0.24)	Lo-100	1.16 (0.03)	11.10 (0.51)	2.28 (0.05)	1.74 (0.03)	3.42 (0.95)
						Total Average	1.26 (0.03)	10.68 (0.71)	2.22 (0.08)	1.81 (0.03)	2.38 (0.41)

Table A2. Average values of Sr:Ca and Ba:Ca for otolith areas corresponding to freshwater residence, estuarine residence and ocean residence. Standard errors are shown in parenthesis. All otoliths are from spawners found on Palouse Creek, Coos Bay, and include one Jack (Po-079).

Otolith ID	Freshwater Sr:Ca (mmol mol^{-1})	Freshwater Ba:Ca (µmol mol^{-1})	Estuary Sr:Ca (mmol mol^{-1})	Ocean Sr:Ca (mmol mol^{-1})	Ocean Ba:Ca (µmol mol-1)	Otolith ID	Freshwater Sr:Ca (mmol mol^{-1})	Freshwater Br:Ca (µmol mol^{-1})	Estuary Sr:Ca (mmol mol^{-1})	Ocean Sr:Ca (mmol mol^{-1})	Ocean Ba:Ca (µmol mol-1)
Po-073	1.61 (0.02)	10.54 (0.05)	na	2.32 (0.02)	6.28 (0.35)	Po-106	1.59 (0.04)	8.13 (0.15)	2.63 (0.15)	1.86 (0.04)	1.36 (0.08)
Po-074	1.49 (0.01)	12.77 (1.19)	2.15 (0.04)	1.83 (0.020	3.15 (1.31)	Po-107	na	9.33 (0.37)	na	na	1.96 (0.10)
Po-075	1.58 (0.02)	8.23 (0.25)	2.37 (0.09)	2.04 (0.03)	1.87 (0.66)	Po-108	1.42 (0.040	14.30 (0.66)	2.20 (0.06)	1.72 (0.05)	2.23 (0.18)
Po-077	1.19 (0.03)	10.08 (0.71)	na	1.91 (0.02)	2.36 (0.18)	Po-109	1.63 (0.04)	11.08 (0.40)	2.06 (0.03)	1.79 (0.02)	1.24 (0.38)
Po-078	1.70 (0.04)	15.10 (0.73)	na	2.14 (0.03)	2.17 (0.08)	Po-113	1.50 (0.03)	8.15 (0.36)	2.29 (0.03)	1.98 (0.03)	2.06 (0.21)
Po-079	1.27 (0.03)	13.65 (0.07)	1.91 (0.04)	1.64 (0.03)	2.35 (0.09)	Po-114	1.18 (0.02)	11.38 (0.53)	2.28 (0.07)	1.60 (0.03)	2.17 (0.27)
Po-080	1.44 (0.03)	9.46 (0.07)	1.81 (0.02)	1.65 (0.04)	1.58 (0.11)	Po-115	1.39 (0.02)	11.84 (4.04)	2.95 (0.02)	1.94 (0.05)	1.39 (0.11)
Po-081	1.31 (0.02)	9.26 (0.02)	2.74 (0.18)	1.73 (0.03)	2.24 (0.11)	Po-116	1.43 (0.03)	11.95 (0.47)	na	1.74 (0.03)	1.30 (.10)
Po-082	1.61 (0.05)	9.20 (0.41)	2.46 (0.07)	2.11 (0.04)	1.89 (0.33)	Po-118	1.34 (0.04)	12.35 (0.50)	1.85 (0.05)	1.62 (0.03)	3.51 (0.45)
Po-083	1.30 (0.04)	13.87 (1.44)	2.31 (0.18)	2.08 (0.03)	3.93 (0.38)	Po-121	1.97 (0.04)	14.70 (1.17)	2.38 (0.10)	2.03 (0.08)	2.91 (0.26)
Po-084	1.80 (0.05)	14.93 (0.85)	2.29 (0.04)	1.91 (0.04)	5.51 (0.95)	Po-123	1.13 (0.03)	5.86 (0.38)	1.88 (0.07)	1.78 (0.05)	2.84 (0.79)
Po-085	1.71 (0.06)	5.37 (0.19)	2.31 (0.04)	2.00 (0.03)	1.77 (0.12)	Po-125	1.37 (0.08)	27.57 (1.60)	2.90 (0.21)	1.93 (0.09)	8.83 (0.22)
Po-086	1.41 (0.05)	8.69 (0.71)	2.03 (0.08)	1.81 (0.03)	2.36 (0.43)	Po-128	1.60 (0.08)	14.89 (1.21)	2.43 (0.05)	2.03 (0.42)	9.47 (0.67)
Po-088	1.53 (0.03)	7.53 (0.39)	2.37 (0.02)	1.99 (0.03)	1.88 (0.22)	Po-132	1.61 (0.03)	9.80 (0.43)	na	2.79 (0.05)	1.46 (0.03)
Po-089	1.82 (0.06)	9.68 (0.57)	2.37 (0.06)	2.08 (0.04)	1.90 (0.10)	Po-134	1.87 (0.04)	11.66 (0.78)	2.11 (0.03)	1.88 (0.02)	2.33 (0.56)
Po-090	1.51 (0.06)	8.80 (0.92)	2.31 (0.10)	2.06 (0.05)	3.65 (0.31)	Po-138	1.16 (0.02)	10.70 (0.46)	2.23 (0.07)	1.95 (0.02)	3.30 (1.4)
Po-091	1.17 (0.09)	6.02 (0.23)	2.05 (0.05)	1.73 (0.04)	1.56 (0.29)	Po-140	1.55 (0.01)	8.78 (0.74)	2.38 (0.07)	2.02 (0.03)	4.82 (0.10)
Po-092	1.40 (0.04)	9.52 (0.29)	1.86 (0.09)	1.81 (0.03)	1.48 (0.15)	Po-141	1.52 (0.02)	10.65 (0.57)	2.26 (0.04)	1.97 (0.03)	2.20 (0.21)
Po-093	1.79 (0.06)	8.64 (0.36)	2.19 (0.05)	2.03 (0.04)	1.49 (0.18)	Po-143	1.59 (0.03)	16.30 (0.42)	2.75 (0.11)	1.94 (0.03)	2.47 (0.15)
Po-094	1.41 (0.06)	10.22 (0.71)	2.53 (0.11)	2.13 (0.04)	2.87 (3.65)	Po-166	1.40 (0.03)	9.74 (0.08)	1.92 (0.17)	1.69 (0.03)	2.63 (0.11)
Po-095	1.71 (0.06)	9.40 (0.30)	2.28 (0.05)	1.95 (0.05)	1.93 (0.20)	Po-171	1.59 (0.06)	9.70 (0.07)	2.07 (0.06)	1.84 (0.04)	3.42 (0.10)
Po-096	1.47 (0.06)	10.64 (1.06)	2.32 (0.84)	1.95 (0.05)	1.55 (0.10)	Po-172	1.45 (0.03)	11.13 (0.06)	2.45 (0.08)	1.60 (0.04)	1.92 (0.17)
Po-097	1.41 (0.05)	7.04 (0.28)	2.89 (0.18)	1.95 (0.04)	0.87 (1.29)	Po-174	1.47 (0.03)	10.17 (0.09)	2.12 (0.05)	1.79 (0.02)	2.52 (0.09)
Po-098	1.55 (0.05)	10.57 (0.58)	2.45 (0.11)	1.86 (0.04)	2.40 (0.36)	Po-176	1.45 (0.03)	8.29 (0.05)	2.09 (0.08)	1.75 (0.04)	1.41 (0.09)
Po-100	na	8.65 (0.58)	na	na	4.17 (0.36)	Po-177	1.23 (0.02)	9.04 (0.07)	1.91 (0.04)	1.76 (0.04)	4.81 (0.12)
Po-102	1.59 (0.06)	8.41 (2.86)	2.16 (0.05)	2.00 (0.05)	5.54 (0.92)	Po-178	1.35 (0.03)	8.02 (0.04)	2.07 (0.05)	1.87 (0.03)	3.06 (0.12)
Po-103	1.25 (0.03)	32.80 (1.31)	2.76 (0.15)	1.63 (0.03)	9.17 (2.73)	Po-180	1.31 (0.03)	7.00 (0.07)	2.09 (0.37)	1.71 (0.03)	1.71 (0.08)
Po-104	1.60 (0.04)	9.97 (0.65)	2.43 (0.08)	1.97 (0.03)	1.81 (0.136)	Po-181	1.05 (0.04)	6.04 (0.05)	2.32 (0.05)	1.76 (0.03)	1.72 (0.07)
Po-105	1.57 (0.04)	18.27 (1.50)	3.60 (0.12)	1.91 (0.04)	1.56 (0.11)	Total Average	1.48 (0.04)	10.98 (0.62)	2.31 (0.10)	1.90 (0.04)	2.85 (0.41)

Appendix B. Spawner back-calculated fork lengths at time of habitat transition as juveniles from otolith widths beased on Sr:Ca and Ba:Ca ratios.

Table B1. Estimated juvenile coho salmon fork lengths (± 95% CI) from otolith widths based on Sr:Ca and Ba:Ca ratios from Larson Creek spawners that were classified as having a yearling smolt life history. Lo-041, Lo-073, Lo-081, Lo-087, Lo-095 were five precocious males (jacks).

Otolith ID	Estuary Fork Length (Sr:Ca)	Ocean Fork Length (Sr:Ca)	Fork Length (Ba:Ca)
Lo-037	89.6 (12.8)	114.5 (14.0)	114.5 (14.0)
Lo-038		102.6 (13.4)	101.3 (13.3)
Lo-039		89.48 (12.8)	88.9 (12.7)
Lo-040		117.5 (14.1)	115.8 (14.1)
Lo-041	76.5 (12.1)	109.2 (13.7)	101.6 (13.4)
Lo-042		128.5 (14.7)	114.5 (14.0)
Lo-044		105.6 (13.6)	102.9 (13.4)
Lo-045	79.7 (12.3)	112.7 (13.9)	93.6 (13.0)
Lo-048	73.1 (11.9)	133.4 (14.9)	123.3 (14.4)
Lo-049	71.4 (11.9)	113.9 (14.0)	98.4 (13.2)
Lo-052	81.0 (12.3)	103.5 (13.4)	92.0 (12.9)
Lo-056		131.2 (14.8)	128.8 (14.7)
Lo-057	75.5 (12.1)	117.6 (14.1)	112.2 (13.9)
Lo-059	81.0 (12.3)	125.5 (14.5)	114.9 (14.0)
Lo-060	81.0 (12.3)	110.3 (13.8)	101.3 (13.3)
Lo-061		84.6 (12.5)	84.6 (12.5)
Lo-062	77.8 (12.2)	134.0 (15.0)	134.7 (15.0)
Lo-064		116.9 (14.1)	101.5 (13.3)
Lo-065	104.8 (13.5)	131.1 (14.8)	113.5 (13.9)
Lo-066		75.0 (12.0)	76.4 (12.1)
Lo-067	85.3 (12.6)	108.2 (13.7)	103.5 (13.5)
Lo-068	81.3 (12.4)	96.3 (13.1)	91.3 (12.8)
Lo-069		78.3 (12.2)	
Lo-070	80.9 (12.3)	122.1 (14.4)	112.6 (13.9)
Lo-071	70.7 (11.8)	124.4 (14.5)	110.8 (13.8)
Lo-073	89.6 (12.8)	114.5 (14.0)	114.5 (14.0)
Lo-077		92.0 (12.9)	
Lo-081	79.8 (12.3)	135.2 (15.0)	128.0 (14.7)
Lo-087		112.9 (13.9)	113.6 (13.9)
Lo-091		90.0 (12.8)	83.8 (12.5)
Lo-092		96.1 (13.08)	95.4 (13.1)
Lo-093		74.5 (12.0)	71.1 (11.8)
Lo-094	72.7 (11.9)	89.2 (12.7)	87.9 (12.7)
Lo-095			108.5 (13.7)
Lo-098	91.4 (12.9)	117.5 (14.1)	106.8 (13.6)
Lo-099	77.3 (12.2)	98.5 (13.2)	
Lo-100	81.1 (12.3)	122.5 (14.4)	114.1 (14.0)
Lo-102	70.9 (11.8)	99.6 (13.3)	110.4 (13.8)

Table B2. Estimated juvenile coho salmon fork lengths (± 95% CI) from otolith widths based on Sr:Ca and Ba:Ca ratios from Palouse Creek spawners that were classified as having a yearling smolt life history. Po-079 was a jack.

Otolith ID	Estuary Fork Length (Sr:Ca)	Ocean Fork Length (Sr:Ca)	Fork Length (Ba:Ca)
Po-075		102.2 (13.4)	89.7 (12.8)
Po-079	99.5 (13.3)	134.7 (15.0)	125.1 (14.5)
Po-080	74.8 (12.0)	105.3 (13.5)	97.8 (13.2)
Po-081	101.1 (13.3)	112.1 (13.9)	104.7 (13.5)
Po-083	80.7 (12.3)	91.7 (12.9)	82.3 (12.4)
Po-085		150.9 (15.8)	155.6 (16.0)
Po-095			108.7 (13.7)
Po-096	80.8 (12.3)	91.3 (12.8)	80.8 (12.3)
Po-097	81.7 (12.4)	104.0 (13.5)	100.0 (13.3)
Po-098	78.2 (12.2)	110.6 (13.8)	99.4 (13.2)
Po-100			78.7 (12.2)
Po-102	71.3 (11.9)	124.0 (14.5)	124.0 (14.5)
Po-103	89.0 (12.7)	104.0 913.5)	89.0 (12.7)
Po-104	77.0 (12.1)	102.9 (13.4)	77.8 (12.2)
Po-105	75.9 (12.1)	121.0 (14.3)	109.4 (13.7)
Po-106	77.3 (12.2)	101.6 (13.4)	92.6 (12.9)
Po-107			113.8 (14.0)
Po-108	77.8 (12.2)	102.3 (13.4)	106.7 (13.6)
Po-109	71.6 (11.9)	99.3 (13.2)	91.7 (12.9)
Po-116		95.1 (13.0)	91.7 (12.9)
Po-118	71.0 (11.8)	95.7 (13.1)	85.8 (12.6)
Po-121	79.7 (12.3)	104.0 (13.5)	97.5 (13.2)
Po-123	85.0 (12.5)	112.1 (13.9)	94.3 (13.0)
Po-125	77.8 (12.2)	90.1 (12.8)	89.5 (12.8)
Po-132		102.5 (13.4)	97.1 (13.1)
Po-138	78.4 (12.2)	90.1 (12.8)	83.7 (12.5)
Po-140	76.9 (12.1)	100.8 (13.3)	95.4 (13.1)
Po-143	86.0 (12.6)	104.9 (13.5)	88.4 (12.7)

Table B3. Palouse and Larson Creek coho salmon spawners classified as subyearling estuarine migrants from the widths of their otoliths based on Ba:Ca and Sr:Ca ratios. * = estimates made with the regression equation for otoliths under 675 µm in width. Lo-082 was a jack. Fry migrants have estimated estuary or ocean entrances at fork length ≤ 60 mm, whereas parr migrants have estimated estuary or ocean fork lengths at > 60 ≤ 70 mm.

Otolith ID	Estuary Fork Length (Sr:Ca)	Ocean Fork Length (Sr:Ca)	Fork Length (Ba:Ca)	Life History
Lo-046	66.4 (11.6)	103.6 (13.5)	98.6 (13.2)	Parr
Lo-047	60.9 (11.3)	102.5 (13.4)	90.5 (13.8)	Parr
Lo-053	64.6 (11.5)	92.3 (12.9)	108.8 (13.7)	Parr
Lo-054	54.2 (11.0)	76.4 (12.1)	67.1 (11.7)	Fry
Lo-055	63.6 (11.5)	102.2 (13.4)	94.9 (13.0)	Parr
Lo-058	43.6 (10.5)	94.8 (13.0)	100.4 (13.3)	Fry
Lo-063	62.8 (11.4)	98.2 (13.2)	87.6 (12.7)	Parr
Lo-072	63.3 (11.5)	105.3 (13.5)	106.8 (13.6)	Parr
Lo-074	44.6 (11.5)	118.9 (14.2)	107.8 (13.7)	Fry
Lo-075	53.5 (11.0)	107.7 (13.7)	107.7 (13.7)	Fry
Lo-076	55.0 (11.1)	100.1 (13.3)	93.2 (12.9)	Fry
Lo-079	68.7 (11.7)	108.9 (13.7)	106.6 (13.6)	Parr
Lo-080	66.0 (11.6)	97.9 (13.2)	96.5 (13.1)	Parr
Lo-082			43.3 (13.4) *	Fry
Lo-090	60.5 (11.3)	93.4 (12.9)	92.5 (12.9)	Parr
Lo-096	37.5 (11.3) *	113.6 (13.9)	117.6 (14.1)	Fry
Po-073	64.0 (11.5)			Parr
Po-074	68.5 (11.7)	113.6 (13.9)	108.4 (13.7)	Parr
Po-077	62.7 (11.4)			Parr
Po-078	65.0 (11.5)	104.9 (13.5)	100.9 (13.3)	Parr
Po-082	61.9 (11.4)	120.9 (14.3)	121.6 (14.3)	Parr
Po-088	68.1 (11.7)	116.7 (14.1)	115.0 (14.0)	Parr
Po-089	59.5 (11.3)	106.9 (13.6)	98.8 (13.2)	Fry
Po-090	68.7 (11.7)	123.8 (14.5)	102.4 (13.4)	Parr
Po-091	39.2 (10.3)	96.2 (13.1)	87.2 (12.6)	Fry
Po-092	69.9 (11.8)	95.2 (13.0)	82.5 (12.4)	Parr
Po-093	52.7 (10.9)	114.2 (14.0)	108.9 (13.7)	Fry
Po-094			39.5 (12.0) *	Fry
Po-113	52.3 (10.9)	96.6 (13.1)	83.1 (12.4)	Fry
Po-114	56.9 (11.1)	100.0 (13.3)	91.9 (12.9)	Fry
Po-128	50.6 (10.8)		46.8 (10.6)	Fry
Po-134	65.9 (11.6)	91.1 (12.8)	86.5 (12.6)	Parr
Po-141	62.4 (11.4)	80.0 (12.3)	77.6 (12.2)	Parr

Table B4. Palouse and Larson Creek coho salmon spawners classified as having a "nomadic" early life history from the otoliths widths based on Ba:Ca and Sr:Ca ratios. * = estimates made with the regression equation for fish with otoliths under 675 µm in width.

Otolith ID	1st Estuary Fork Length (Sr:Ca)	2nd Estuary Fork Length (Sr:Ca)	Ocean Fork Length (Sr:Ca)	Fork Length (Ba:Ca)
Lo-078	31.9 (9.7) *	93.8 (13.0)	121.5 (14.3)	117.4 (14.1)
Po-084	36.4 (10.9)	109.3 (13.7)	117.8 (14.2)	118.5 (14.2)
Po-086	39.2 (11.9)	77.0 (12.1)	95.1 (13.0)	88.4 (12.7)
Po-115	36.2 (20.8) *	79.0 (12.2)	113.9 (14.0)	109.6 (13.7)

Table B5. Back-calculated fork length for estuary and ocean entrances based on otolith microchemistry and recorded fork length at time of tagging for nine coho salmon that retuned to spawn in 2010. Figures in parentheses are 95% confident intervals. "Otolith Life History" is the classification given the fish based on the otolith microchemistry, and "Life History at Tagging" is the life history classification given to the fish based on the information available at the time it was tagged.

Otolith ID	1st Estuary Fork Length (Sr:Ca Inflection)	2nd Estuary Fork Length (Sr:Ca Inflection)	Ocean Fork Length	Otolith Life History	Life History at Tagging	Fork Length at Tagging
Po-166	79.4 (12.3)		87.9 (12.7)	Smolt	Smolt	101
Po-171	74.0 (12.0)		105.2 (13.5)	Smolt	Smolt	115
Po-172	56.8 (11.1)		123.2 (14.4)	Estuary Fry	Estuary Fry	51
Po-174	80.0 (12.3)		128.4 (14.7)	Smolt	Estuary Parr	80
Po-176	70.9 (11.8)		108.4 (13.7)	Smolt	Estuary Parr	90
Po-177	36.2 (10.1)		66.1 (11.6)	Estuary Fry	Estuary Parr	75
Po-178	93.6 (13.0)		132.3 (14.9)	Smolt	Stream Parr	70
Po-180	67.0 (11.6)	94.7 (13.0)	114.0 (14.0)	Nomad	Estuary Parr	85
Po-181	35.4 (10.5) *	64.3 (11.5)	102.7 (13.4)	Nomad	Smolt	112