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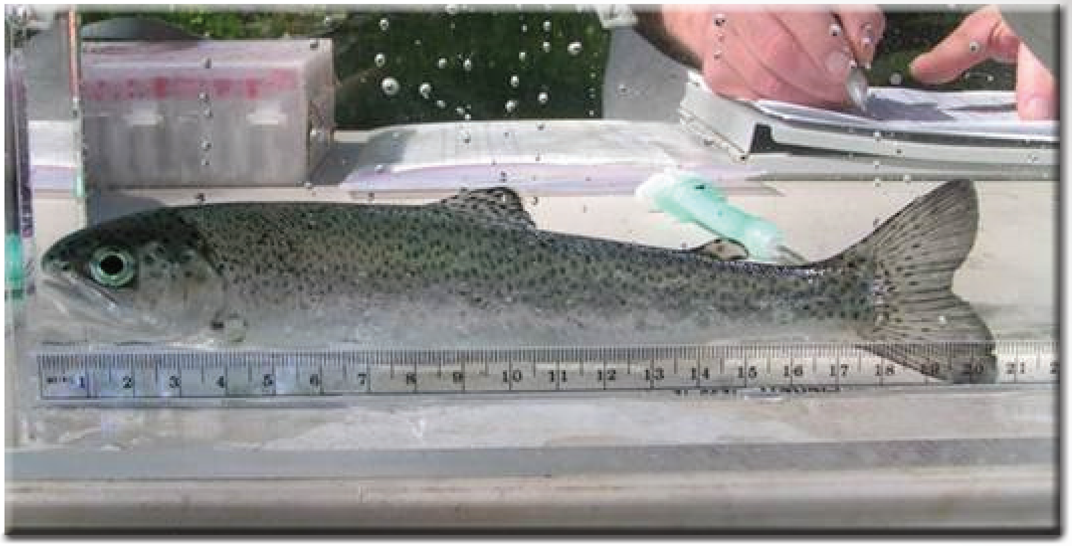
Nisqually River Juvenile Salmonid Monitoring Report: 2009 -2015



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Washington Department of Fish and Wildlife
Fish Program
Science Division

FPA 18-07

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Acknowledgements

This project would not be possible without the support and cooperation of the Centralia City Light Yelm Hydro staff for providing security, access and power during the trapping season and allowing us to store the trap on their grounds in the off-season. We thank the WDFW staff for collecting the field data: Justin Miller, Lars Swartling, Shannon Vincent, Chris Frazier and especially Devin West. Chinook escapement estimates used to calculate freshwater survival and productivity were provided by Larry Philips and James Losee (WDFW Region 6) and Craig Smith (Nisqually Indian Tribe). Steelhead scales were analyzed by the WDFW Ageing Laboratory under the direction of Lance Campbell. This research was funded through the U.S. Fish and Wildlife Service Federal Aid in Sport Fish Restoration (Dingell-Johnson Act) and Washington State General Fund.

Table of Contents

List of Tables

List of Figures

List of Appendices

Abstract

The Washington Department of Fish and Wildlife (WDFW) installed an eight-foot diameter rotary screw trap in the Nisqually River at river mile 12.8, near the Centralia City Light Yelm Hydro Powerhouse in 2009 to monitor outmigrating juvenile salmonids. The primary objectives of this study were to estimate abundance and document total catch, run timing, size and age composition of outmigrating juvenile Chinook salmon and steelhead. Our secondary objectives were to (a) estimate the abundance of juvenile Coho, Chum and Pink salmon; (b) document total catch, run timing, size and age composition of outmigrating of juvenile Coho, Chum, and Pink salmon; and (c) document species and total catch of non-target fish captured in the trap. Information collected at the Nisqually River rotary screw trap monitoring project provides critical abundance and life history information for the salmon and steelhead stocks within the river. These data coupled with adult return data can be used to measure key survival and productivity metrics to assess management practices and evaluate recovery efforts. This report describes the results of the monitoring efforts during the 2009-2015 field seasons.

We estimated that 34,745-408,158-Chinook sub-yearlings, 467-15,240 Chinook yearlings, 20,178-94,704 steelhead smolts, 80,048-254,456 Coho smolts, 17,197-862,328 Chum fry, and 2.1 million-27.5 million Pink fry outmigrated past the trap annually from 2009 to 2015. Smolt recruits per spawner time series data was too sparse to fit a formal stock-recruit curve (e.g., Ricker or Beverton-Holt) for all species. However, Chinook smolt recruits per spawner productivity shows positive linear relationships for fry (defined as sub-yearlings ≤ 45 mm), parr (subyearlings > 45 mm), and total juvenile outmigrations, indicating that there is no evidence that density dependence is limiting freshwater population productivity. These data suggest that the Nisqually River has ample high quality rearing habitat for the juvenile Chinook abundances we have observed thus far. However, in years of low abundance, outmigrations were dominated by parr outmigrants, with very few fry outmigrants, suggesting that the fry migration strategy was rare when rearing territories were likely occupied at low densities by juvenile Chinook. It was premature to discern any initial trends in productivity for Steelhead, Chum, and Pink and we were unable to calculate productivity for Coho because of uncertainty associated with estimates of spawner escapement.

Sub-yearling Chinook had a protracted outmigration timing relative to the other salmon and steelhead captured at the trap. Sub-yearling Chinook outmigrated continuously throughout the trapping season from January through August. We did not account for migration before and after the trapping period in the abundance estimate. The outmigration was typically bimodal and composed of recently emerged fry from January through mid-May followed by river reared parr from mid-May through August, a general pattern similar to other Puget Sound systems. However, in 2014 and 2015, when sub-yearling Chinook abundance was low, the migration-timing curve was unimodal, consisting entirely of parr outmigrants. Steelhead Coho, Chum and Pink all had distinct unimodal migration timings occurring within the trapping season. Steelhead and Coho outmigrated during the lull between the two modes of the sub-yearling Chinook from April through June. Chum and Pink outmigrated from late March through early June.

Lengths of salmon and steelhead were collected systematically though their outmigrations to accurately characterize size over time. The mean fork length of sub-yearling

Chinook fry ranged from 39.1 to 40.7 mm with little intra-annual variation. The mean fork length of sub-yearling Chinook parr ranged from 88.3 to 100.5 mm with greater intra-annual variation than the fry. Nisqually sub-yearling Chinook parr tended to migrate later and attain a larger body size than other populations monitored by WDFW in the Cedar, Green and Skagit rivers.. Yearling Coho mean fork length ranged from 105.6 to 116.4 mm. Chum and Pink mean fork lengths ranged from 35.3 to 42.9 mm and 33.7 to 34.2 mm, respectively. Similar to Chinook fry, pink and chum typically outmigrate as newly emerged fry with little river rearing.

Steelhead smolt scales were collected in conjunction with fork lengths from 2011 to 2015 to describe annual age composition of the outmigrants, reconstruct broods, and estimate productivity. Nisqually steelhead smolts were relatively young with the age composition made up of predominately age-1 (range, 10.9% to 41.9%), age-2 (43.0% to 78.2%), and age-3 (11.9% to 28.6%) smolts. Age-4 smolts were rarely observed: three in 2011 (1.4%), two in 2014 (0.5%), and one in 2015 (0.3%). One age-5 (1.1%) and one age-6 (1.1%) were present in 2012. Steelhead smolts were relatively large at a given age compared to other populations monitored by WDFW (Skagit, Green, Dungeness, Big Beef, Duckabush), with substantial overlap among size ranges; age-1 (range, 142 to 227 mm), age-2 (150 to 350 mm), age-3 (162 to 241 mm). Length ranges of age-4 (190 to 246 mm), age-5 (315 mm), and age-6 (196 mm) overlapped those of the younger age classes. However, sample sizes were too small to make any inferences about the population.

The trap was used to opportunistically collect samples to study estuary usage, document Pacific lamprey presence, assess early marine survival of outmigrating Chinook, steelhead and Coho, collect and archive tissue samples for future genetic mark-recapture estimates of Chinook escapement, monitor freshwater health of outmigrating steelhead and investigate resident rainbow contribution to anadromous steelhead outmigrants. We documented species and total catch of all non-target taxa collected at the trap.

Introduction

Declining trends in adult abundance of Puget Sound Chinook *Oncorhynchus tshawytscha* and steelhead *Oncorhynchus mykiss* beginning in the late 1980s prompted the National Marine Fisheries Service (NMFS) to list these populations as threatened under the Endangered Species Act (ESA) in 1999 and 2007, respectively. In response to these ESA listings, NMFS identified four key parameters for evaluating the conservations status of these populations: abundance, productivity, spatial distribution, and diversity (McElhany et al. 2000). Comprehensive evaluation of these key parameters requires the concurrent monitoring of both juvenile and adult life history stages (life cycle monitoring). Thus, increased attention has been given to monitoring outmigrating juvenile salmon and steelhead to complement ongoing adult monitoring efforts. In 2009, the WDFW Wild Salmon Production Evaluation Unit (WSPE) began operating a rotary screw trap in the Nisqually River to meet the NOAA guideline of monitoring adult and juvenile abundance in at least one population per major population group within each evolutionary significant unit (Crawford and Rumsey 2011). Since then, the estimates of abundance, freshwater productivity, marine survival and stock-recruitment relationships calculated with the paired juvenile and adult data have been integral to developing and adaptively managing recovery plans for Nisqually River fall Chinook and Nisqually River winter steelhead.

The goals of this monitoring study were to, when possible, estimate freshwater demographics of all anadromous Pacific salmon and steelhead that spawn in the watershed. Monitoring efforts were designed to provide precise and unbiased estimates. Specifically, the objectives for the Nisqually River rotary screw trap were to:

1) Estimate the abundance and productivity of juvenile Chinook and steelhead migrating out of the Nisqually River.

2) If possible, estimate the abundance and productivity of juvenile Coho *Oncorhynchus kisutch*, Chum *Oncorhynchus keta*, and Pink salmon *Oncorhynchus gorbuscha* migrating out of the Nisqually River.

3) Document total catch, run timing, size and age composition of outmigrating juvenile salmon and steelhead captured in the trap.

4) Document species and total catch of non-target fish captured in the trap.

This 6-year report summarizes the results of the juvenile salmon and steelhead monitoring conducted by WDFW in the Nisqually River among years 2009 to 2015.

Study Site

The Nisqually River originates from the Nisqually glacier on the south side of Mount Rainier, draining an area of about 761 mi^2. It generally flows west-northwest for about 81miles before flowing into South Puget Sound near Olympia, WA. The Alder Dam and La Grande Dam complex at river miles 44.5 and 42.5 respectively, regulate mainstem discharge. La Grande Dam is the upper extent of anadromous salmonid distribution. Streamflow into Alder Lake (Alder Dam impoundment) is primarily influenced by rainfall, snow, and glacial melt. Tributary flows are primarily influenced by rainfall and snow melt.

An 8 foot rotary screw trap was installed at river mile 12.8, about 100 yards above the Centralia City Light Yelm Hydro Powerhouse. This site was selected because a natural funnel within the river channel maximizes capture probability for juvenile salmonids of all age classes. The trap is located above all of the hatchery release sites to avoid unnecessary handling of the hatchery fish and interaction with naturally produced fish in the live box. This site also allows us to trap a smaller portion of the river because the mainstem flow is reduced by the quantity diverted into the Centralia City Light Yelm Hydro canal, improving trap performance and logistics. Additionally, this location provides secure and convenient access to the trap for installation and storage. There are an estimated 77.5 and 143.1 river miles used by Chinook and steelhead, respectively, for spawning and subsequent rearing habitat upstream from the trap (Nisqually Chinook Recovery Team 2001 and Nisqually Steelhead Recovery Team 2014).

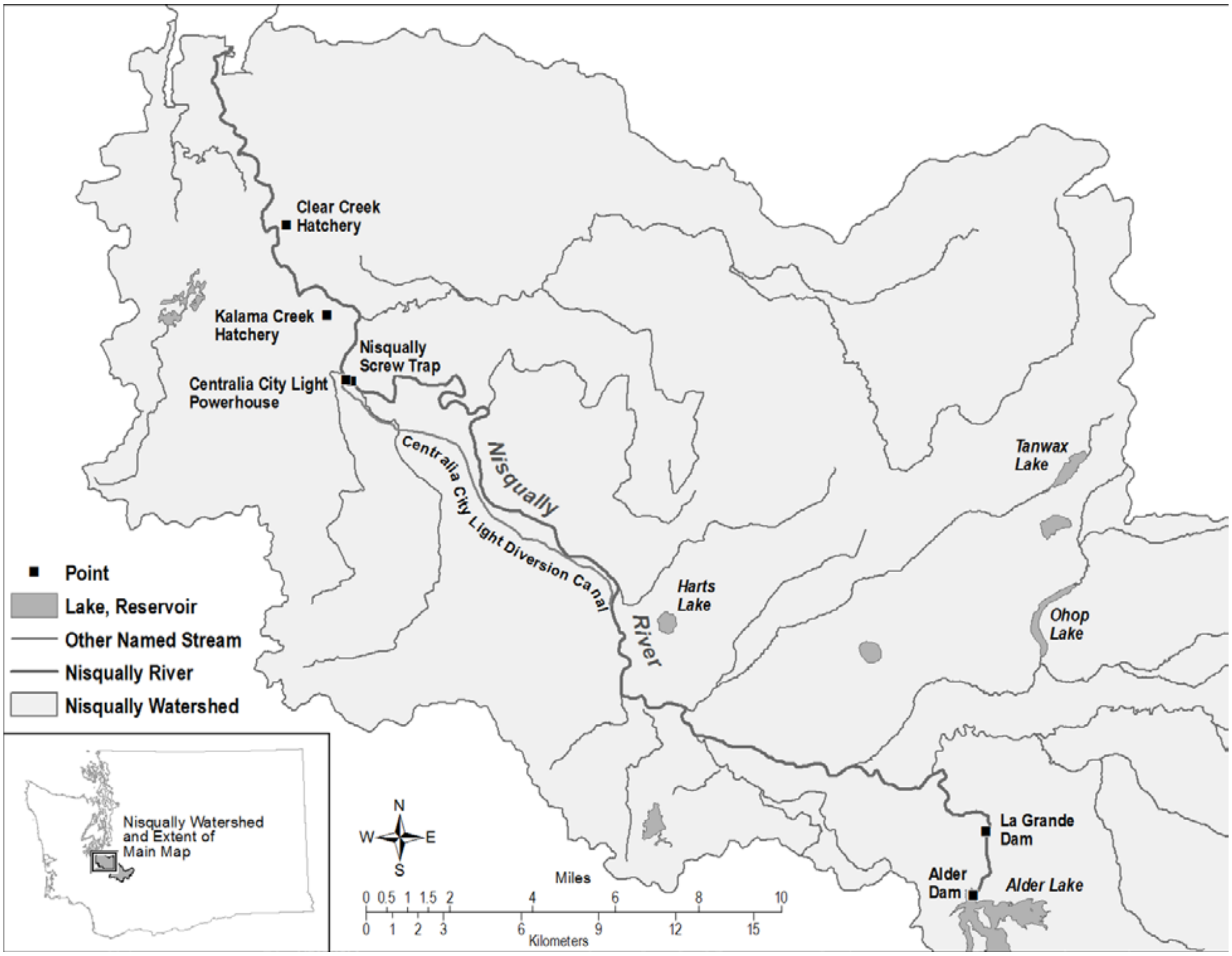

Figure 1. –Map of the Nisqually River basin with the screw trap, adult weir, Kalama and Clear Creek hatcheries, La Grande and Alder dams, Centralia Light powerhouse and diversion channel.

Methods

Trap operation

The trap was typically installed in mid-January and operated continuously through in mid-August in an attempt to sample the entire juvenile Chinook outmigration. This timeframe usually encompassed all other outmigrating anadromous salmonids as well. During certain periods, we are unable to operate the trap because of a variety of reasons including, but not limited to, political (e.g., furlough days), environmental (e.g., rapid increases in river discharge and debris) and mechanical (e.g., worn out bearings). Further, at times we only fished the trap at night to avoid interaction with recreational river users. Mean discharge during the 2009 to 2015 trapping seasons was 1,497 cfs with a range of 397 to 10,808 cfs (USGS gauge #12089500 near McKenna, WA).

Fish handling

The trap was emptied of fish once daily in the morning. During peak outmigrations and high flow events, the trap was checked periodically throughout the night and into the day to avoid overcrowding and excessive debris build-up in the live box. All captured salmonids were identified to species, noting the presence or absence of fin clips, dye marks, sutures or acoustic tagging scars. Chinook juveniles were classified as either sub-yearlings or yearlings. Sub-yearlings were further parsed into two categories: newly emerged fry with a fork length ≤ 45 mm or river-reared parr with a fork length > 45 mm (parr). Chinook yearlings had faint parr marks, silvery appearance and were typically larger than the sub-yearling conspecifics. Steelhead juveniles were classified as either trout parr or steelhead smolts. The criteria for trout parr included well-developed parr marks and heavy spotting across the dorsal surface; smolts had deciduous scales, silvery appearance, and a distinct dark banding on the outer margin of the caudal fin. Coho juveniles were classified as sub-yearlings and yearlings. The criteria for Coho sub-yearlings included well-developed parr marks, distinct black and white banding along leading edges of the dorsal and anal fins and pale orange caudal and anal fins; Coho yearlings were further classified into yearling parr and yearling smolts. Yearling parr are different from actively outmigrating smolts in that they still have distinct parr marks and their fins have an amber tinge whereas smolts had faint parr marks, clear caudal and anal fins and silvery appearance. We pooled catches of Coho smolts and yearling parr for the outmigration analysis. Catches of trout parr and Coho sub-yearling were not included in the analyses.

Yearling and smolt salmonids were anaesthetized about 10 at a time in an MS-222 solution (~ 60 mg/L) buffered with an equal parts sodium bicarbonate ($NaHCO_3$) solution. Sub-yearling salmonids were anaesthetized about 50 at a time in an MS-222 solution (~ 30 mg/L) buffered with an equal parts sodium bicarbonate ($NaHCO_3$) solution. Fork length (FL), measured to the nearest millimeter (mm), was collected systematically from every 10th fish marked for release in efficiency trials and all recaptured Chinook and steelhead. Steelhead scale samples were collected systematically from every 10th maiden capture and all recaptures for ageing. In all cases, fish were sampled as quickly as possible and were allowed to fully recover before being either released back into the river below the trap or marked and transported upstream of the trapping location for use in estimating trap efficiency (described below).

Trap calibration

The trapping season was stratified into statistical weeks, defined as seven-day weeks of Monday thru Sunday. Statistical weeks may be shorter than 7 days at the beginning and end of the calendar year (e.g., statistical week one in 2011 is Saturday thru Sunday). We used a stratified mark-recapture study design to calibrate species-specific trap efficiencies through the trapping season. Two types of marks were given to maiden captured outmigrants in good condition (e.g., no descaling, trap damage, or bite marks) to be released upstream of the trap. Sub-yearling Chinook less than 70 mm fork length, Chum, and Pink (when present) were batch marked by immersion in an aerated Bismarck Brown-Y dye solution (~ 10 mg/L) for 45 minutes. Sub-yearling Chinook greater than 70 mm fork length, steelhead smolts and yearling Coho were marked with a statistical week-specific fin clip. Mark groups of up to 200 sub-yearling Chinook and up to 100 steelhead and Coho smolts were released on a given day. Any newly marked fish found dead, moribund, or simply swimming erratically were removed from each release group. Due to the inability to differentiate Bismarck Brown-Y marks between statistical weeks, sub-yearlings were only marked Monday thru Thursday. This allowed all marked fish to be recaptured (recapture period of Tuesday thru Monday) within a statistical week. To assess delayed handling mortality, mark loss, and mark readability, periodically a portion of the marked fish were held in a live box for up to 5 days. To assess mark recognition by the field staff, a known number of marked and unmarked fish were placed in a bucket by one operator for the second operator to go through and compare their counts with the known numbers. These mark validation studies are essential to ensure that marked fish are representative of unmarked conspecifics. All other marked fish were broadcast released at least 0.5 river miles above the trap to maximize river channel complexity between the release site and the trap in an attempt to ensure complete mixing with outmigrants.

Missed catch

Missed catch during trap outages was estimated as:

Equation 1

$$\hat{C}_i = \overline{R}T_i;$$

Equation 2

$$\overline{R} = \frac{\sum_{p=1}^{n} R_p}{n};$$

Equation 3

$$R_p = \frac{C_p}{T_p};$$

and the associated variance was estimated as:

Equation 4

$$Var(\hat{C}_i) = Var(\overline{R})T_i^2;$$

Equation 5

$$Var(\overline{R}) = \frac{\sum_{p=1}^{n}(R_p - \overline{R})^2}{n(n-1)}$$

where:

i= trap outage index
$\hat{C}_i$ =Missed catch during trap outage i,
$\overline{R}$ = average catch rate prior and previous to trap outage i,
T_i = hours not fished during trap outage i,
p = intervals prior and previous to trap outage,
R_p = catch rate prior and previous intervals to the hours not fished,
C_p = catch during interval p,
T_p = hours during interval p,

n = number of intervals (p = 2, 3, …, n).

Because trap efficiency can be variable through the trapping season, we used a G-test (Sokal and Rohlf, 1981) to test capture probability homogeneity per statistical week to formally guide decisions regarding how to combined continuous homogeneous (stratify) efficiency trials and obtain a parsimonious estimator.

Abundance

We used a stratified 1-trap closed population mark-recapture study design to estimate abundance (Volkhardt et al. 2007). A modification of the Petersen method to estimate stratum specific abundance (Carlson et al. 1998):

Equation 6

$$\hat{U}_h = \frac{u_h(M_h + 1)}{m_h + 1}$$

and the associated variance was estimated as (Seiler et al. 2002):

Equation 7

$$Var(\hat{U}_h) = Var(\hat{C}_h)\left(\frac{(M_h+1)(M_h * m_h + 3M_h + 2)}{(m_h+1)^2(m_h+2)}\right) + \left(\frac{(M_h+1)(u_h+m_h+1)(M_h-m_h) * u_h}{(m_h+1)^2(m_h+2)}\right)$$

where:
h = stratum index (capture period and corresponding efficiency trial),
M_h = number of marked outmigrants released in stratum h (mortalities censored),
m_h = number of marked outmigrants captured in stratum h,
u_h = number of unmarked outmigrants captured plus $\hat{C}_h$ (if any) in stratum h, and
$\hat{U}_h$ = total outmigrant abundance in stratum h, excluding efficiency trail recaptured outmigrants and observed mortality.

The total outmigrant abundance was estimated as:

Equation 8

$$\hat{U} = \sum_{h=1}^{L} \hat{U}_h ,$$

where:
L= number of strata (h = 1, 2, …, L)

and total outmigrant variance was estimated as:

Equation 9

$$Var(\hat{U}) = \sum_{h=1}^{L} Var(\hat{U}_h)\,.$$

Approximate 95% confidence intervals were estimated as:

Equation 10

$$\pm 1.96\sqrt{Var(\hat{U})}\,.$$

The coefficient of variation was estimated as:

Equation 11

$$c.v. = \frac{\sqrt{Var(\hat{U})}}{\hat{U}}\,.$$

Abundance for species with no meaningful efficiency trials using a surrogate was estimated as:

Equation 12

$$\hat{N}_h = u_h \bar{e}_h$$

where:

$\hat{N}_h$ = total outmigrant abundance in stratum *h*, excluding observed mortality and

Equation 13

$$\bar{e}_h = \frac{m_h}{M_h}$$

where:

$\bar{e}_h$ = average trap efficiency for surrogate species in stratum *h*.

The associated variance was estimated as:

Equation 14

$$Var(\hat{N}_h) = \hat{N}_h^2 \left(\frac{Var(\bar{e}_h)}{\bar{e}_h^{\,2}} \right)$$

To minimize bias within the abundance estimates, the following critical assumptions common to closed population mark–recapture studies must be met: (1) the population is geographically closed, with no immigration or emigration; (2) the population is demographically closed, with no births or deaths; (3) no tags or marks are lost or missed; (4) marking does not change fish behavior or vulnerability to capture; (5) marked fish mix at random with unmarked fish; and (6) all fish have an equal probability of capture that does not change over time (Seber 1982; Hayes et al. 2007).

During the outmigrant trapping season, we took steps to reduce the possibility of violating these assumptions. Although the system is physically open, the populations may be considered biologically closed because the trapping operation occurs over the majority of the outmigration, all outmigrants must pass a fixed point (i.e., the trap), and all outmigrants have a species-specific regimented age structure (assumption 1). Field staff were trained to properly apply and identify tags and marks to make sure that none were missed (assumption 3). Further, we assessed mark recognition by the field staff placing a known number of marked and unmarked fish in a bucket by one operator and testing the second operator by comparing their counts with the known numbers (assumption 3). To assess delayed handling mortality, mark loss, and mark readability a portion of the marked fish were held in a live box for up to 5 days (assumption 2 and 3). To satisfy the complete mixing assumption 5, fish were broadcast released at least 0.5 river miles above the trap in an effort to maximize the opportunity for complete mixing with unmarked conspecifics.

Survival and Productivity

Estimated survival for both the freshwater and marine environments as egg-to-smolt and smolt-to-adult return (SAR) respectively and productivity were reported as the number of smolts per spawner. Egg-to-smolt survival rate was calculated as the percent of a brood year's potential egg deposition surviving until ocean entry. Potential egg deposition (PED) was based on species-specific constant average fecundity from Quinn 2005.

Smolt-to-adult return (SAR) is the ratio of total number of returning adults from a given ocean entry year cohort of smolts. We tried to include estimates of terminal harvest in the number of returning adults to improve the accuracy of our SAR estimates where we could depending on available data. Chinook SAR's were calculated using adult returns that included the spawning escapement plus estimates of terminal harvest in the sport and tribal fisheries. Relative SAR's for steelhead were calculated using adult returns to the mainstem as spawning escapement plus any incidental harvest associated with sport and tribal salmon fisheries. Steelhead spawning escapement was limited to estimates of the mainstem because of concerns about changes in tributary survey methods and effort. Coho, Chum and Pink adult returns were limited to the spawning escapement. Coho and Pink escapement estimates are considered coarse because of uncertainty in the survey methods. We complied adult escapement, harvest and age composition data from a variety of sources to estimate SARs. For Chinook, we used Blair et al. 2014 and the In-season Implementation Tool (ISIT) Stock Monitoring Data Tracker 2017 (WDFW and Nisqually Indian Tribe unpublished data); for steelhead, WDFW, unpublished data and Madel and Losee 2016 and the ISIT Stock Monitoring Data Tracker 2017 (WDFW and Nisqually Indian Tribe unpublished data); for Chum, we used A. Dufault, WDFW, unpublished data; and for Pink, we used the WDFW Salmon Conservation Reporting Engine (SCoRE; https://fortress.wa.gov/dfw/score/score/)

Adult age data was assigned to a given ocean entry year cohort (i) based on the returning age composition. For example, adult escapement and catch in 2016 may be composed of returning juvenile outmigrants from ocean entry years 2015 (age 2), 2014 (age 3), 2013 (age 4), and 2012 (age 5). Cohort specific age composition was applied when available and an average age composition was used when not available. Steelhead adult abundance was restricted to estimates of mainstem spawners because the methods and effort have been consistent for the years of interest. Survey methods and effort for tributary spawners have been less consistent and are being evaluated and updated for inclusion in future estimates. We were unable to make cohort specific estimates of Coho survival and productivity because estimates of adult abundance were unreliable. Coho adult abundance (spawners) estimates in the Nisqually were based on an expansion of index reaches within the basin and these index reaches appear to no longer represent Coho spawning in the watershed. It is unclear when this relationship began to break down. However, it appears that adult abundance ranged between about 500 and 4,000 during the years of interest and thus we will report approximate estimates of survival and productivity based on this range.

Brood year specific egg-to-smolt survival estimates were calculated as:

Equation 15

$$\%Survival = \frac{\hat{U}_i}{PED_i} * 100$$

i = brood year,

$\hat{U}_i$ = estimated number of smolts from brood year i,

PED_i = potential egg deposition for brood year i.

Cohort specific SARs were estimated as:

Equation 16

$$SAR_j = \frac{\hat{N}_j + \hat{C}_j}{\hat{U}_j}$$

where:

j = ocean entry year,

$\hat{N}_j$ = estimated number of naturally spawning adults returning from ocean entry year i,

$\hat{C}_j$ =estimated number of adults from ocean entry year i captured in fisheries (sport and treaty),

$\hat{U}_j$ = estimated number of smolts outmigrating in ocean entry year i.

Results

Trap operation

The trap was in place for 201 to 219 days a year and operated 78.5% to 95.0% of the time among years 2009 to 2015 (Table 1).

Table 1. –Summary of the Nisqually River rotary screw trap operations, 2009-2015.

Year	Begin Date	End Date	Days	Percent Operation
2009	January 16	August 22	219	85.8%

2010	January 13	July 23	192	78.5%
2011	January 24	August 25	214	88.5%
2012	January 13	August 10	211	89.5%
2013	January 17	August 22	218	95.0%
2014	January 23	August 11	201	94.2%
2015	January 16	August 27	224	94.2%

Sub-Yearling Chinook

Catch

Total annual catch of natural origin sub-yearling Chinook outmigrants ranged from 1,523 to 31,862 among years 2009 to 2015. We estimated a missed catch of 248 to 3,538 outmigrants due to trap outages. Although the trapping effort included the majority of the outmigration, outmigrants were captured on the first and last day of each trapping year indicating that the outmigration began before trap installation and continued after trap removal. An unknown number of outmigrants moved past the trap site during this pre and post trapping period and were not estimated (Appendix A).

Trap calibration

From 13 to 32 weekly mark-recapture trails were conducted with sub-yearling Chinook outmigrants to calibrate the trap efficiency and were aggregated annually into three to ten strata among years 2009 to 2015. Trap efficiencies for the stratified data ranged between 1.5% and 35.4% (Appendix A).

Abundance estimates

Sub-yearling Chinook outmigrant abundance estimates ranged between 34,745 (CV = 14.5%) in 2014 and 408,158 (CV = 3.5%) in 2009 (Table 2).

Table 2. –Annual abundance estimates of sub-yearling Chinook outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Ocean Entry Year	Abundance Estimate	CV	95 % CI	
			Lower	Upper
2009	408,158	3.5%	380,182	436,134
2010	128,244	6.2%	112,612	143,876
2011	116,284	9.5%	94,610	137,958
2012	245,678	7.3%	210,599	280,757
2013	144,152	8.5%	120,367	168,037
2014	82,769	5.6%	73,623	91,915
2015	34,745	14.5%	24,854	44,636

Migration timing

The Chinook sub-yearling outmigration annually encompassed the entire trapping season. Timing was typically bimodal with an initial peak observed between the weeks of February 2 to February 23 of fry and a secondary peak observed between the weeks of June 1 to July 27 of parr

(Figure 2). In 2014 and 2015, very few fry outmigrants were observed and consequently did not display this bimodality but rather a single peak of parr outmigrants.

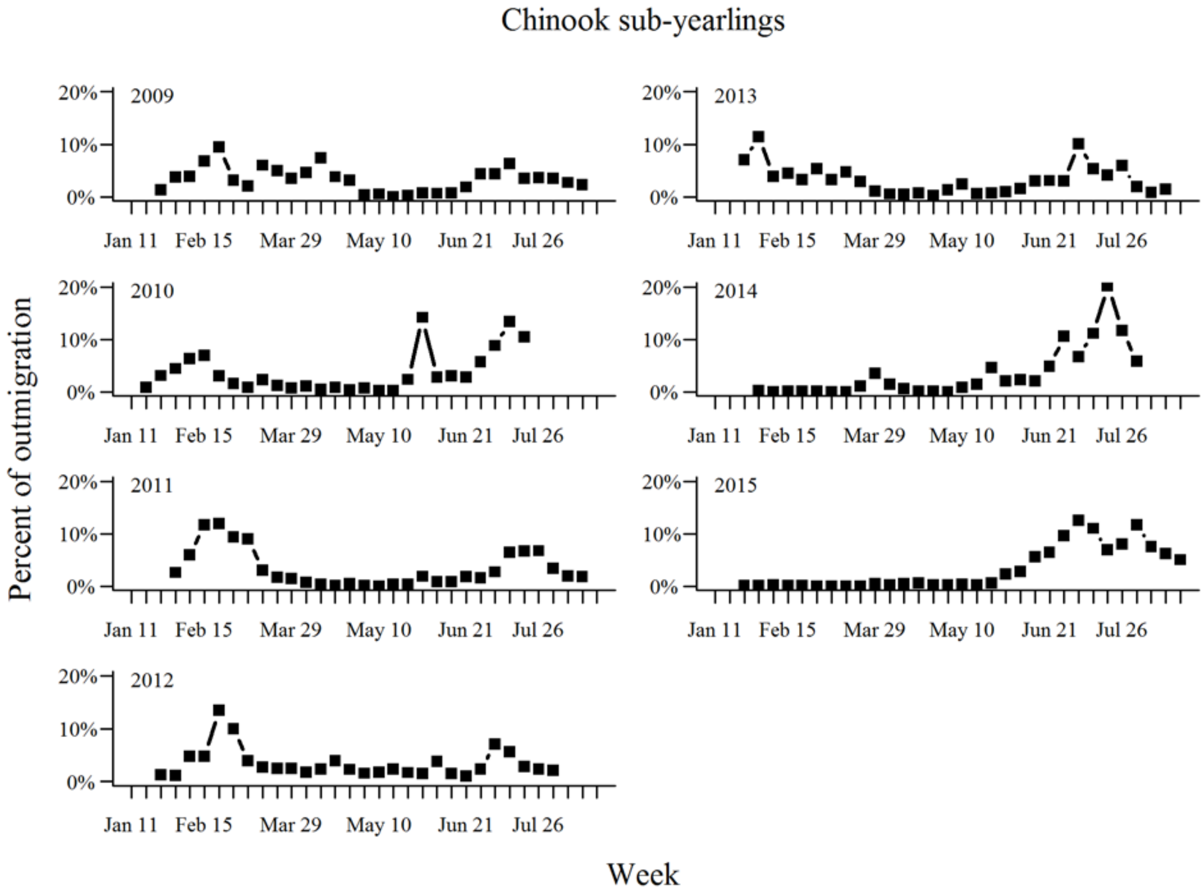

Figure 2. –Weekly outmigration timing of sub-yearling Chinook outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Length

Relative length frequency distributions reflect the bimodal outmigration pattern of fry and parr seen in the outmigration run timing. In 2009, there was a bimodal outmigration however; few fork lengths were collected from the fry outmigrants thus skewing the distribution. In 2014 and 2015, few fry outmigrants were observed and consequently the bimodality is not as clear as years 2009 to 2013 (Figure 3).

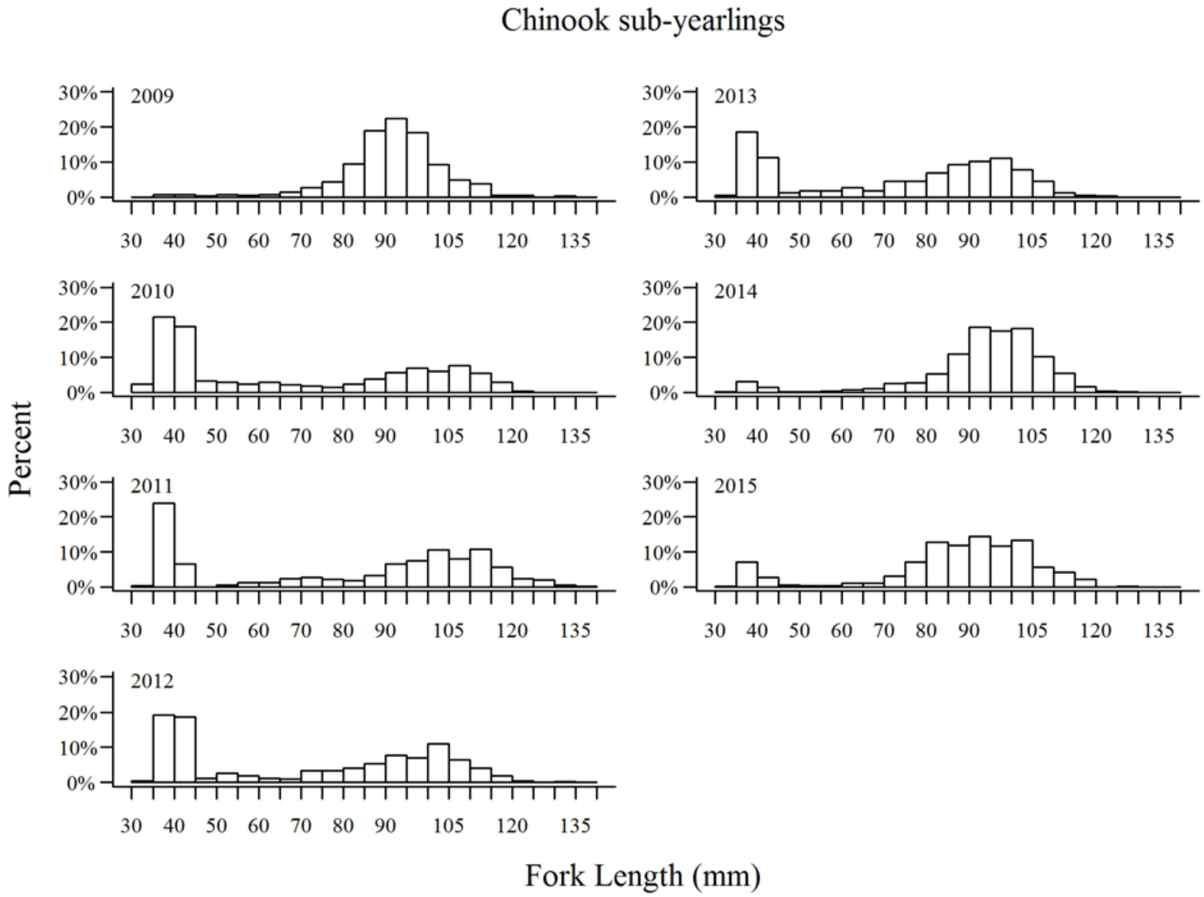

Figure 3. –Relative length frequency histograms of sub-yearling Chinook captured at the Nisqually River rotary screw trap, 2009-2015.

Forks lengths of maiden captured fry ranged from 30 to 45 mm and average length ranged from 39.1 to 40.7 mm whereas parr ranged from 46 to 137 and average length ranged from 88.3 to 100.5 mm during the trapping seasons, 2009 to 2015 (Figure 4, Table 3). From the start of the trapping season in January through March, mean fork lengths of recently emerged fry were consistent at about 40 mm, from April through June mean fork lengths increased steadily increased until plateauing out at about 90 mm in late June for the remainder of the trapping season (Figure 4).

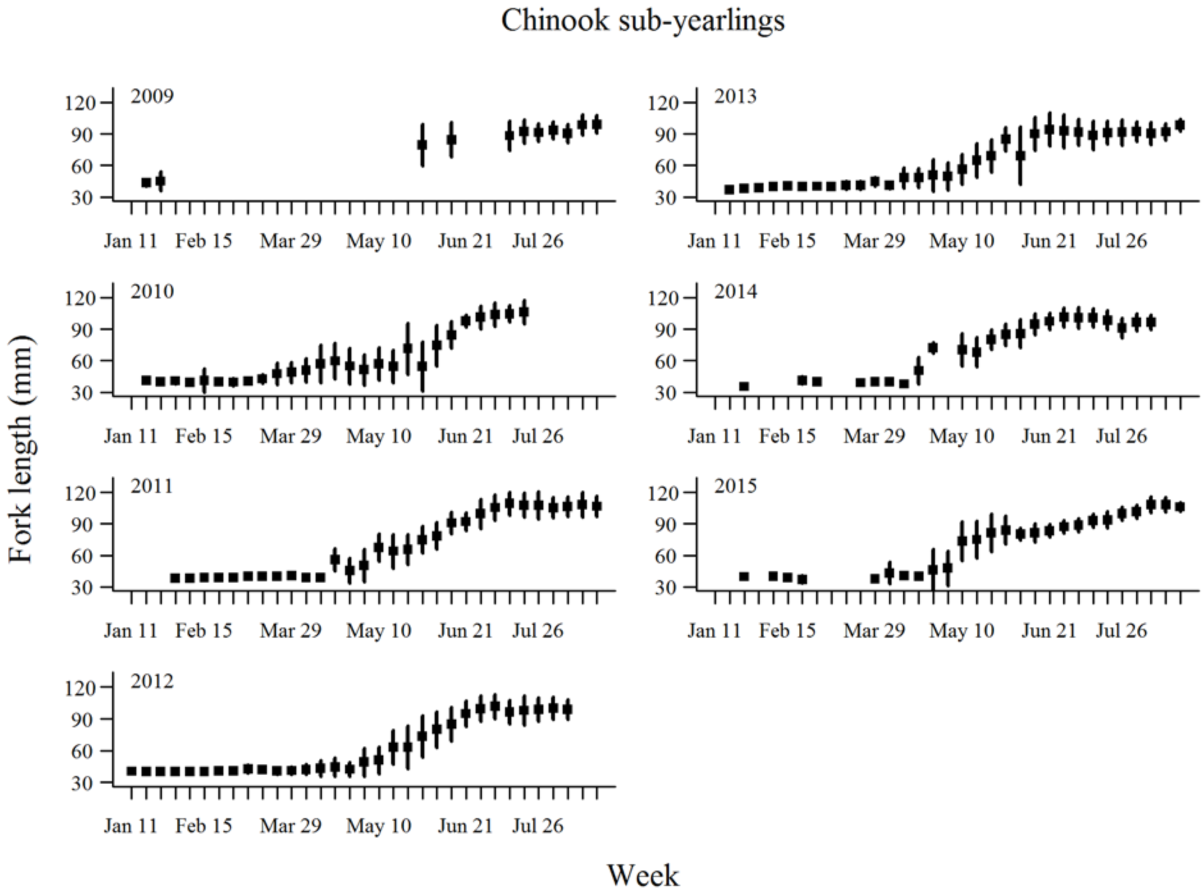

Figure 4. –Weekly mean fork lengths of sub-yearling Chinook captured at the Nisqually River rotary screw trap, 2009-2015. Error bars represent one standard deviation of the mean.

Table 3. –Annual sample size (n), minimum, maximum, mean and standard deviation (SD) of fork lengths in millimeters of fry and parr sub-yearling Chinook collected at the Nisqually River rotary screw trap, 2009-2015.

Ocean	Fry Fork Length (mm)					Parr Fork Length (mm)				
Entry Year	n	Min	Max	Mean	SD	n	Min	Max	Mean	SD
2009	6	36	45	40.7	3.6	428	46	133	92.3	11.1
2010	274	30	45	39.7	2.7	370	46	124	89.8	21.2
2011	170	35	45	39.1	1.8	382	52	137	100.5	16.9
2012	261	32	45	40.3	2.0	422	47	132	92.1	17.5
2013	215	34	45	39.9	2.2	494	46	124	88.3	15.3
2014	58	35	45	39.3	2.1	1,215	49	126	96.3	10.9
2015	51	34	44	39.2	2.1	455	46	127	92.6	12.7

Productivity

There were consistently more sub-yearling Chinook parr than fry outmigrating each year when the data were available. We were unable to parse the sub-yearlings in 2009 (brood year

2008) because we did not take lengths of Chinook fry in a systematic manner to accurately break down the sub-yearlings into fry and parr components. Years with larger numbers of spawners in the river tended to produce more outmigrants the next year (Figure 5).

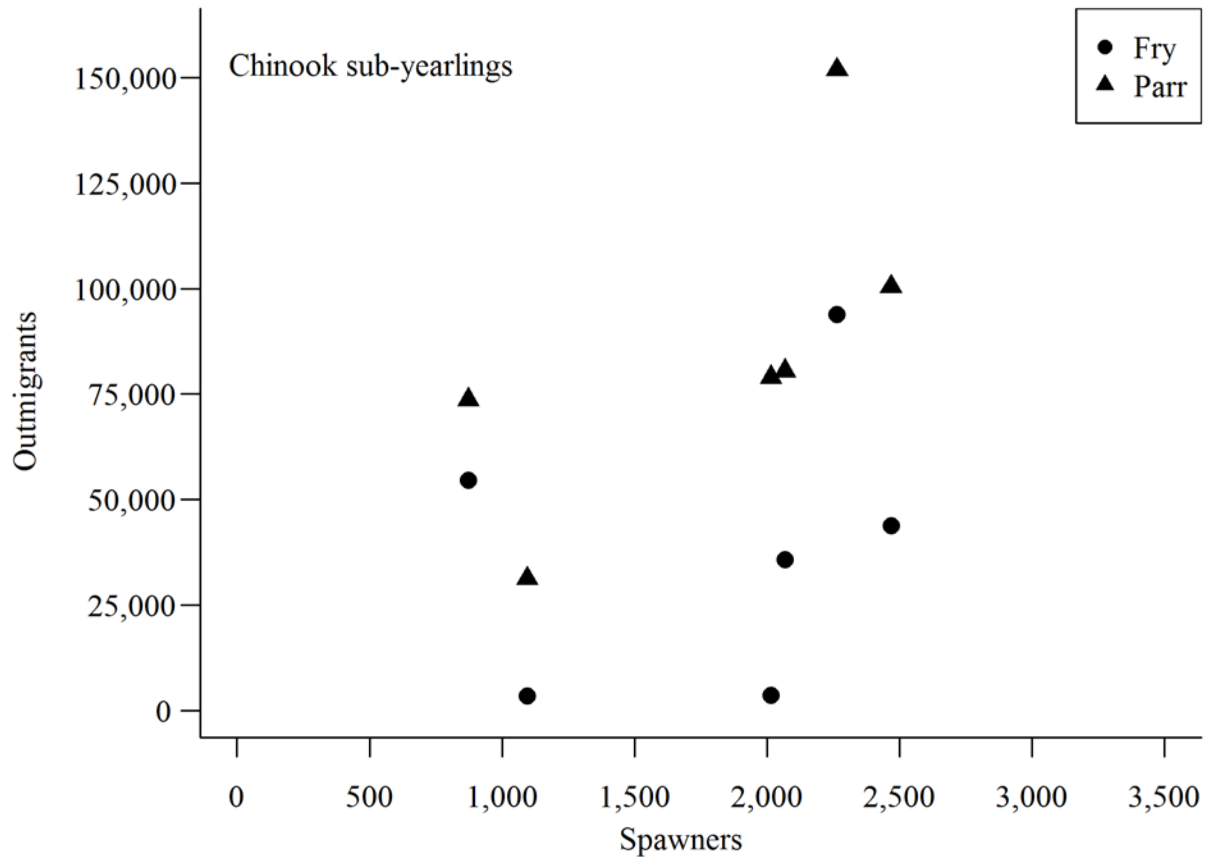

Figure 5. –Relationship between Chinook spawners and sub-yearling (fry and parr) outmigrants in the Nisqually River for brood years 2009-2014.

Yearling Chinook

Catch

Total annual catch of natural origin yearling Chinook outmigrants ranged from 37 to 880 among years 2009 to 2015. Missed catch of 0 to 89 outmigrants was estimated due to trap outages. The trapping effort included the majority of the outmigration. However, outmigrants were captured on the first day of some trapping years indicating that the outmigration began before trap installation. An unknown number of outmigrants moved past the trap site during this pre-trapping period and were not estimated (Appendix B).

Trap calibration

A range of 6 to 27 weekly mark-recapture trails were conducted with yearling Chinook outmigrants to calibrate the trap efficiency and were aggregated annually into one to three strata among years 2009 to 2015. Trap efficiencies for the stratified data ranged between 4.4% and 34.0% (Appendix B). Catches were too low and sporadic to calibrate the trap with meaningful efficiency trials in 2011, 2012 and 2015, thus we used the yearling Coho stratified efficiencies as surrogates.

Abundance estimates

Yearling Chinook outmigrant abundance estimates ranged between 240 (CV = 47.7%) in 2011 and 15,240 (CV = 27.1%) in 2010 (Table 4).

Table 4. –Annual abundance estimates of yearling Chinook outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Ocean Entry Year	Abundance Estimate	CV	95 % CI Lower	95 % CI Upper
2009	10,526	14.0%	7,646	13,406
2010	15,240	27.1%	7,142	23,338
2011	467[a]	68.0%	96[a]	1,090
2012	960[a]	224.8%	37[a]	5,189
2013	2,140	36.2%	621	3,659
2014	1,713	20.7%	1,018	2,408
2015	1,284[a]	139.1%	119[a]	4,784

[a] Denotes years when surrogate yearling Coho stratified efficiencies were used to estimate abundance. The lower limit of the 95% confidence interval would estimate a negative abundance thus the lower limit was reported as the actual catch during these years.

Migration timing

Timing of yearling Chinook was typically unimodal with a peak that ranged from the week of May 25 to June 8 (Figure 6). However, 2011 and 2012 did not exhibit a pronounced peak migration.

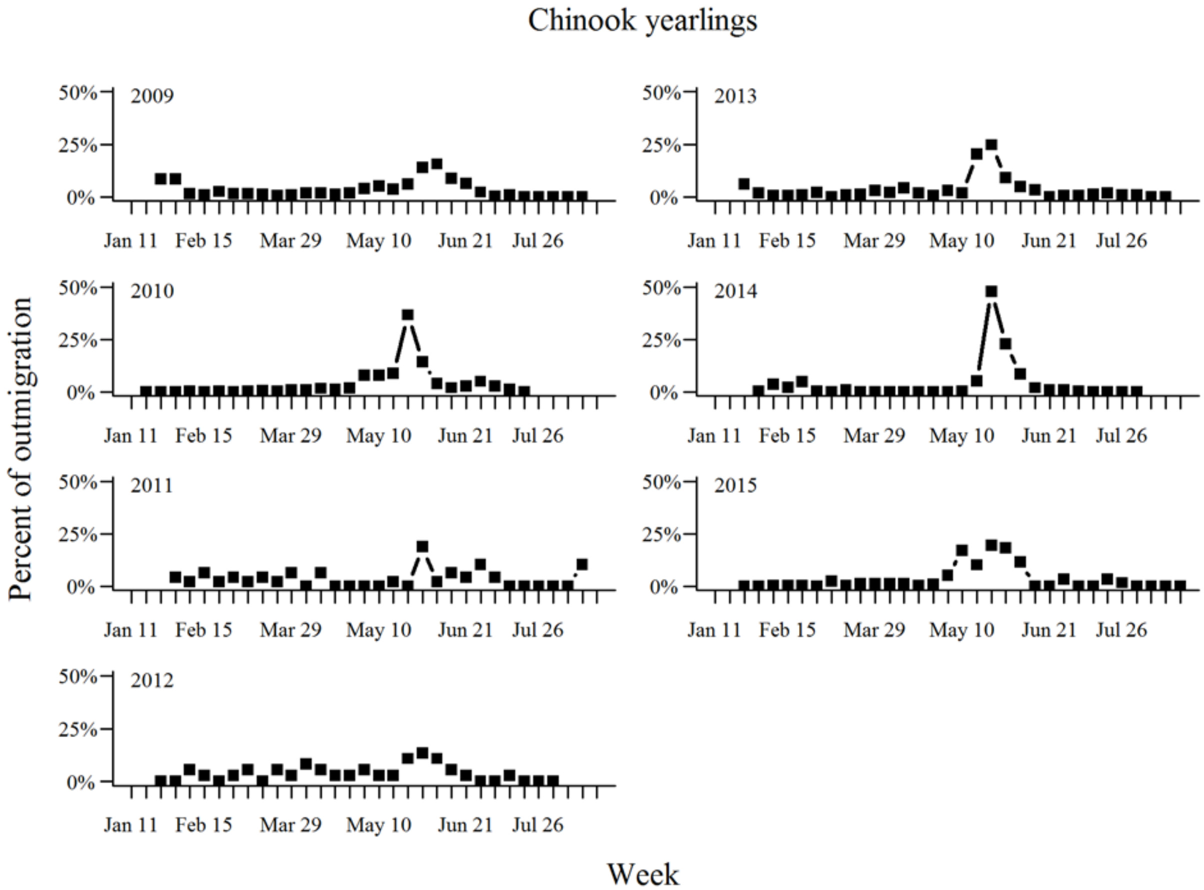

Figure 6. –Weekly outmigration timing of yearling Chinook outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Length

Yearling Chinook relative length frequency distributions were unimodal around 125 mm (Figure 7).

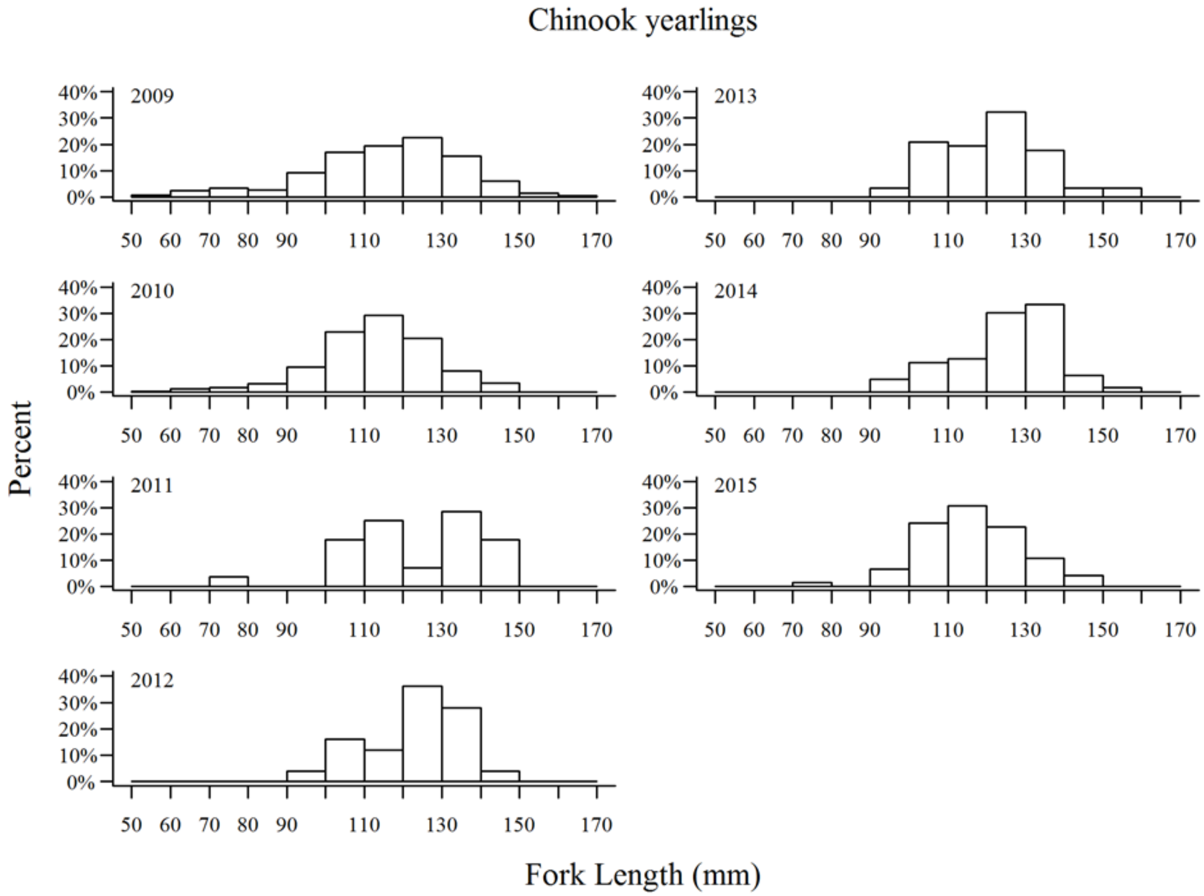

Figure 7. –Relative length frequency histograms of yearling Chinook captured at the Nisqually River rotary screw trap, 2009-2015.

Mean fork lengths were consistent through the season. Individual fork lengths of maiden captures ranged from 52 mm to 166 mm and average length ranged from 113.6 mm to 125.7 mm during the trapping seasons, 2009 to 2015 (Figure 8).

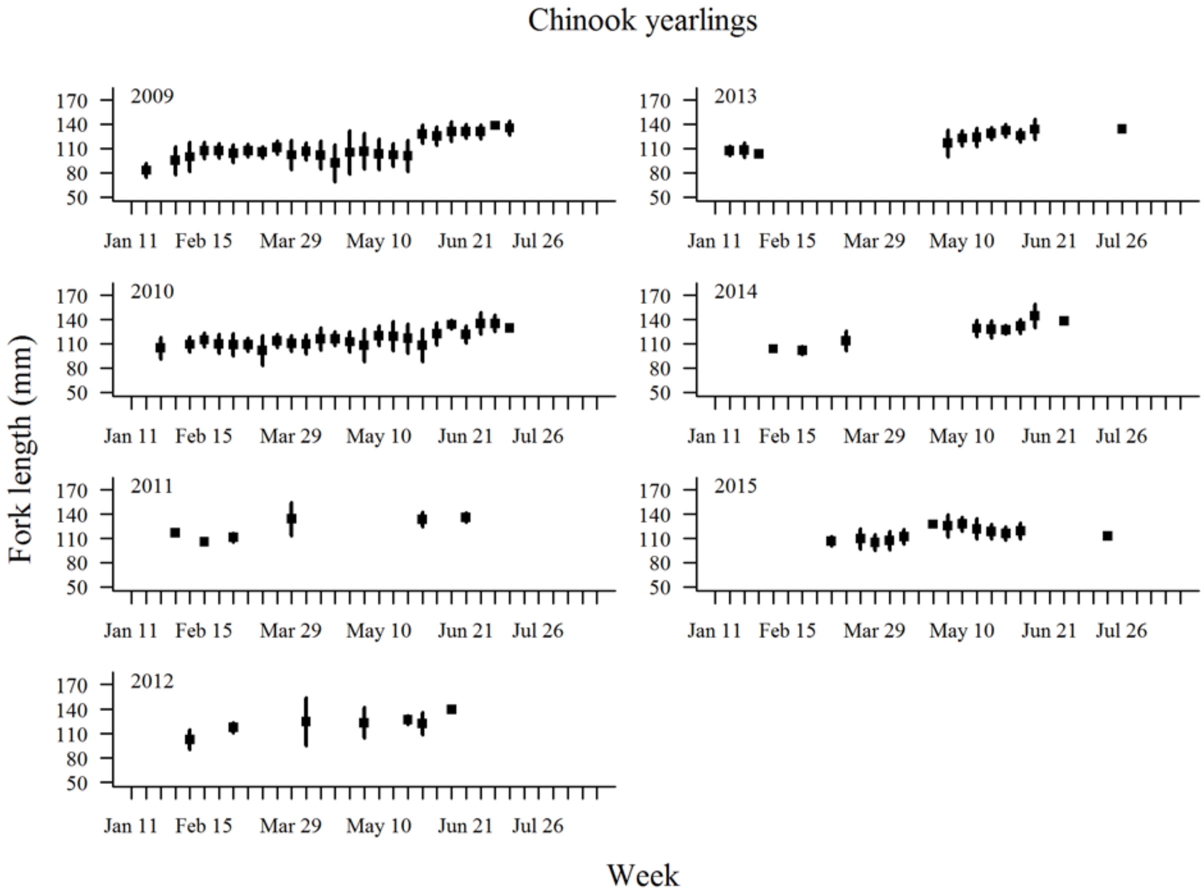

Figure 8. –Weekly mean fork lengths of yearling Chinook captured at the Nisqually River rotary screw trap, 2009-2015. Error bars represent one standard deviation of the mean.

Table 5. –Annual sample size (n), minimum, maximum, mean and standard deviation (SD) of fork lengths in millimeters of steelhead smolts collected at the Nisqually River rotary screw trap, 2009-2015.

Ocean	Fork Length (mm)				
Entry Year	n	Min	Max	Mean	SD
2009	622	76	380	195.9	24.3
2010	346	90	335	208.9	35.1
2011	28	142	278	195.7	25.3
2012	25	155	350	209.8	38.6
2013	62	145	285	199.7	24.9
2014	63	145	305	188.8	25.2
2015	75	140	357	191.8	25.3

Survival and Productivity

Freshwater survival ranged from 2.2% to 6.8% and productivity of Chinook ranged from 47 to 147 smolts per spawner among brood years 2008 to 2013 (Figure 9, Table 6). Marine survival ranged from 0.14% to 1.07% for the complete adult returns of ocean entry year cohorts 2009 to 2011 (Table 7).

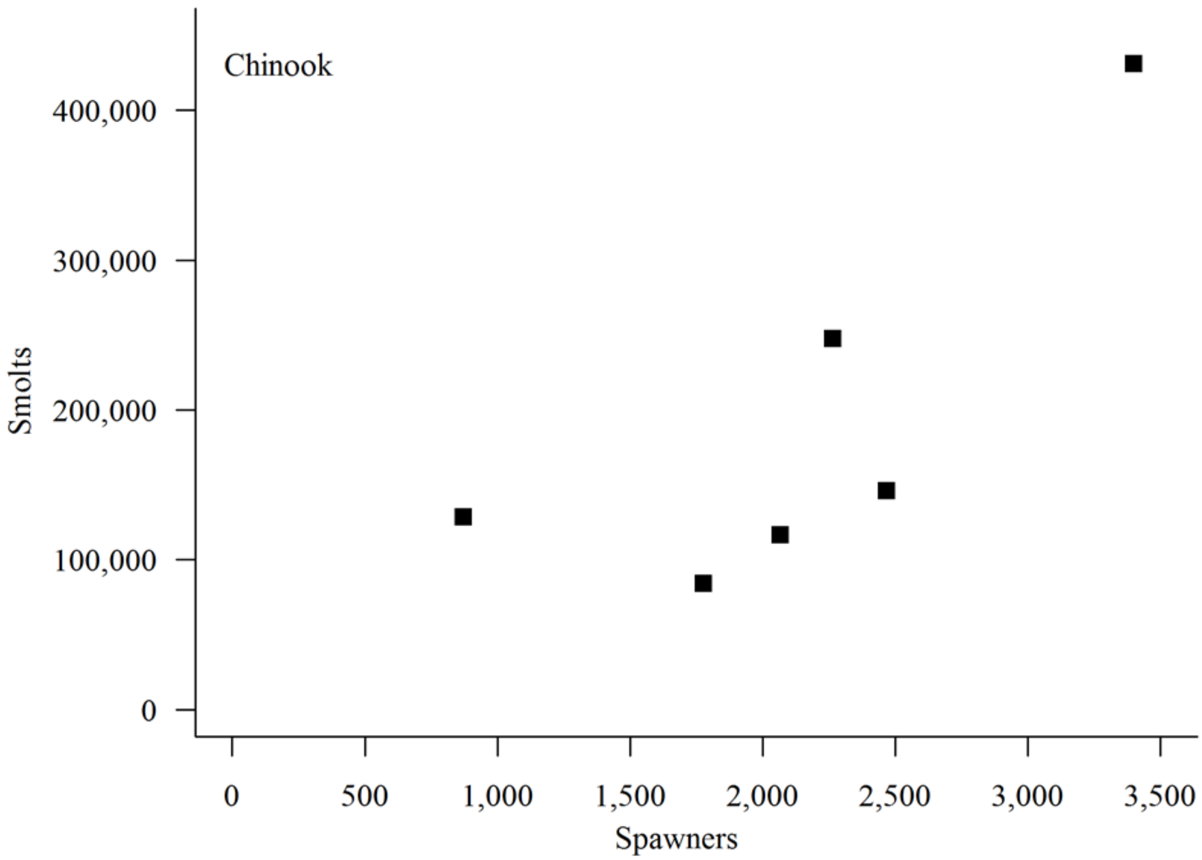

Figure 9. –Relationship between Chinook spawners and total juvenile abundance (sub-yearling plus yearling) in the Nisqually River for complete brood years 2008-2013.

Table 6. –Freshwater survival and productivity of Chinook in the Nisqually River for complete brood years 2008 – 2013.

	Adult		Smolt Abundance			Freshwater	Smolts per
BY	Spawners	PED	Age-0	Age-1	Total	Survival	Spawner
2008	3,399	7.3M	420,647	15,240	435,887	5.9%	128
2009	872	1.9M	140,206	240	140,446	7.5%	161
2010	2,067	4.5M	123,714	333	124,047	2.8%	60
2011	2,264	4.9M	260,212	2,140	262,352	5.4%	116
2012	2,467	5.3M	144,152	1,713	145,865	2.7%	59
2013	1,671	3.6M	82,769	1,284	84,053	2.3%	50

Table 7. –Marine survival of Chinook in the Nisqually River for complete adult returns of ocean entry year cohorts 2009-2011.

OEY	Outmigrant Abundance	Adult Return Age-2	Age-3	Age-4	Age-5	Total	SAR
2009	408,158	59	186	309	0	554	0.14%
2010	128,244	179	455	713	28	1,376	1.07%
2011	116,284	129	434	278	17	858	0.74%

Steelhead smolts

Catch

Total annual catch of wild origin steelhead outmigrants ranged from 530 to 4,772 among years 2009 to 2015. A missed catch of 1 to 322 outmigrants was estimated due to trap outages. The trapping effort appears to have included the entire outmigration (Figure 10).

Trap calibration

From 8 to 20 weekly mark-recapture trails were conducted with steelhead smolts to calibrate the trap efficiency and were aggregated annually into one to four strata among years 2009 to 2015. Trap efficiencies for the stratified data ranged between 2.1% and 18.5% (Appendix C).

Abundance estimates

Steelhead smolt abundance estimates ranged between 20,178 (CV = 26.7%) in 2012 and 94,704 (CV = 13.7%) in 2010 (Table 8).

Table 8. –Annual abundance estimates of steelhead smolts outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Ocean Entry Year	Abundance Estimate	CV	95 % CI Lower	95 % CI Upper
2009	54,063	10.2%	43,306	64,820
2010	94,704	13.7%	69,261	120,147
2011	60,740	9.6%	49,321	72,159
2012	20,178	26.7%	9,621	30,735
2013	88,212	9.5%	71,807	104,617
2014	52,204	9.5%	42,519	61,889
2015	54,572	10.3%	43,595	65,548

Migration timing

Annually, the steelhead smolt outmigration occurred within the trapping season. Timing was unimodal among years with a peak week that consistently ranged within a three week period from May 11 to June 1 (Figure 10, Table 9).

11).

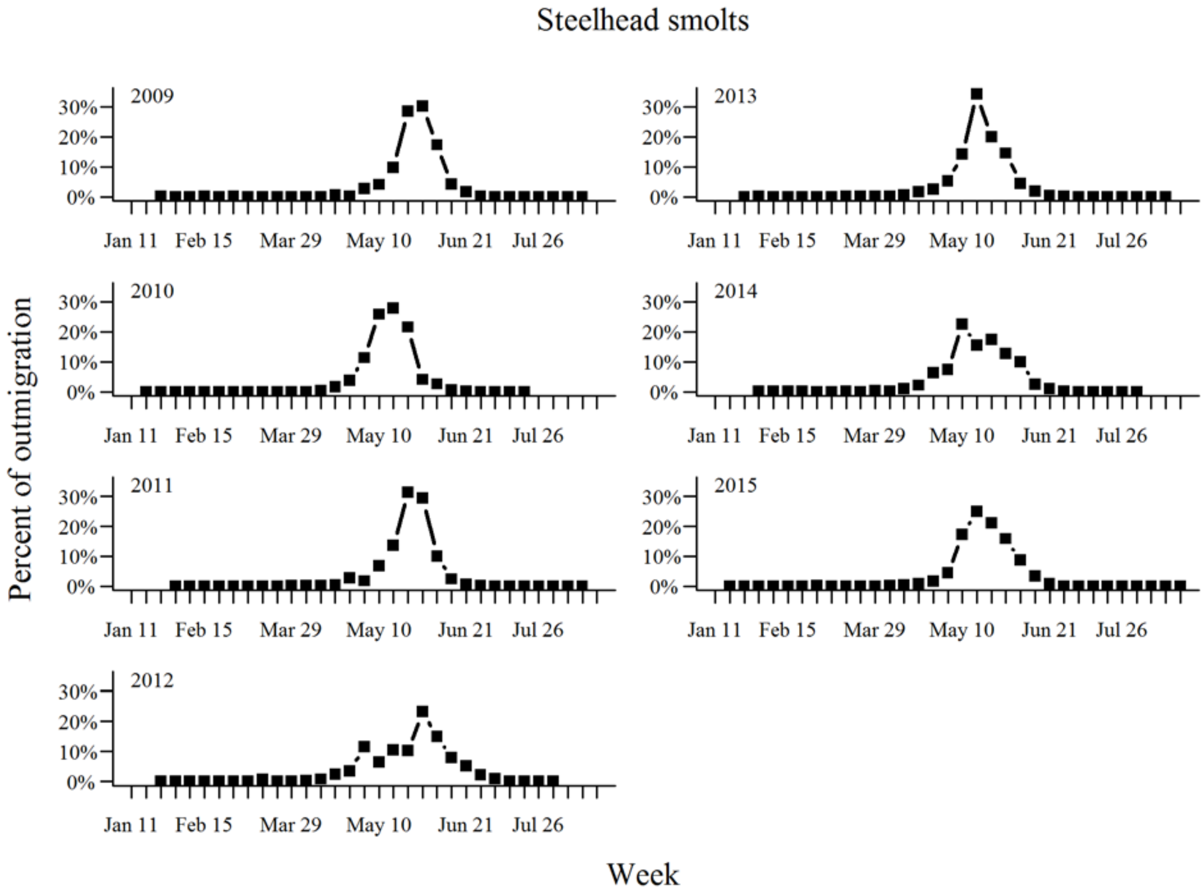

Figure 10. –Annual weekly outmigration timing of steelhead smolts outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Table 9. –Annual migration begin date, end date and median week of steelhead smolts outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Ocean Entry Year	Begin Date	End Date	Median
2009	January 26	July 6	June 1
2010	January 26	July 6	May 18
2011	March 2	July 20	May 25
2012	March 15	July 5	May 31
2013	February 2	June 29	May 18
2014	February 2	June 29	May 11
2015	February 2	June 29	May 18

Length

Relative length frequency distributions were typically unimodal around 185 mm (Figure 11).

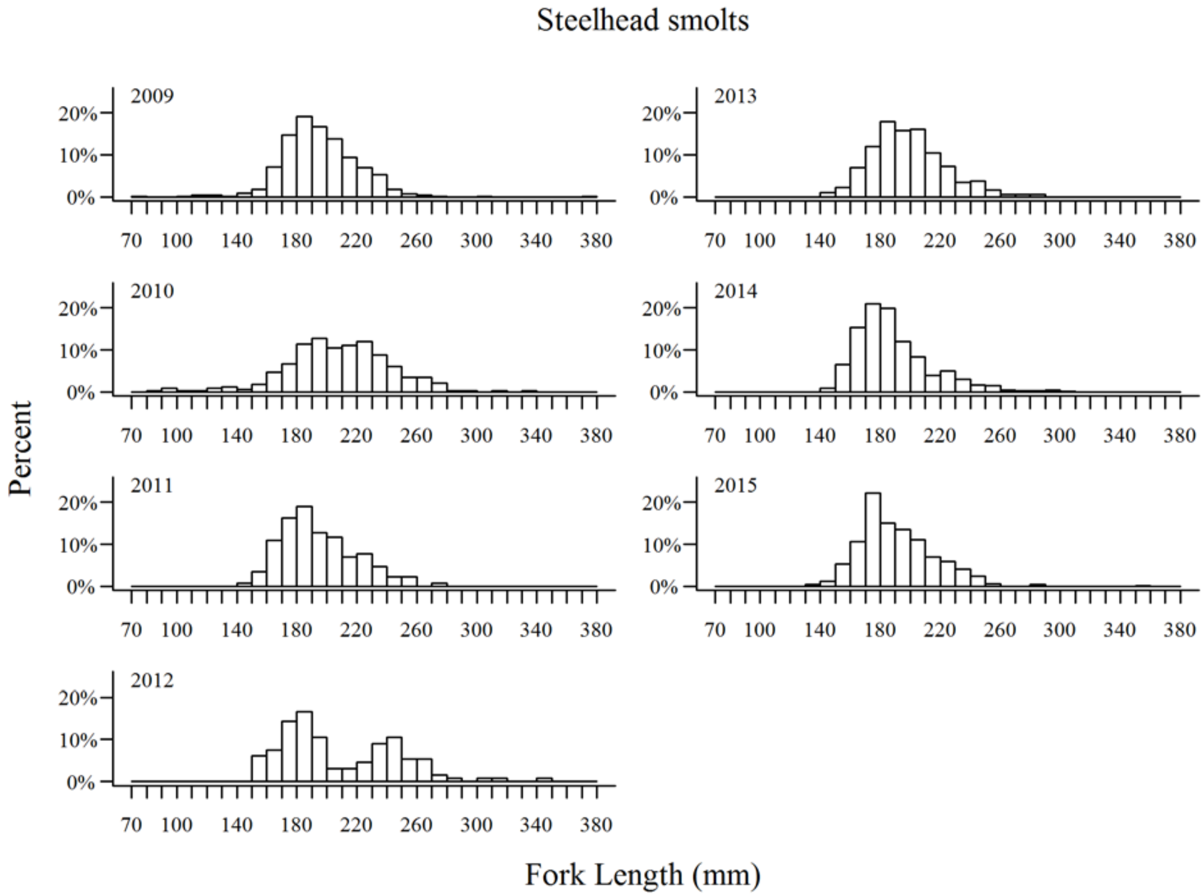

Figure 11. –Relative length frequency histograms of steelhead smolts captured at the Nisqually River rotary screw trap, 2009-2015.

Individual fork lengths of maiden captures ranged from 76 mm to 380 mm and average length ranged from 188.8 mm to 209.8 mm during the trapping seasons, 2009 to 2015 (Figure 11,Table 10). During the bulk of the outmigration, early outmigrants were the largest of the season, with a declining trend for the remainder of the migration (Figure 12).

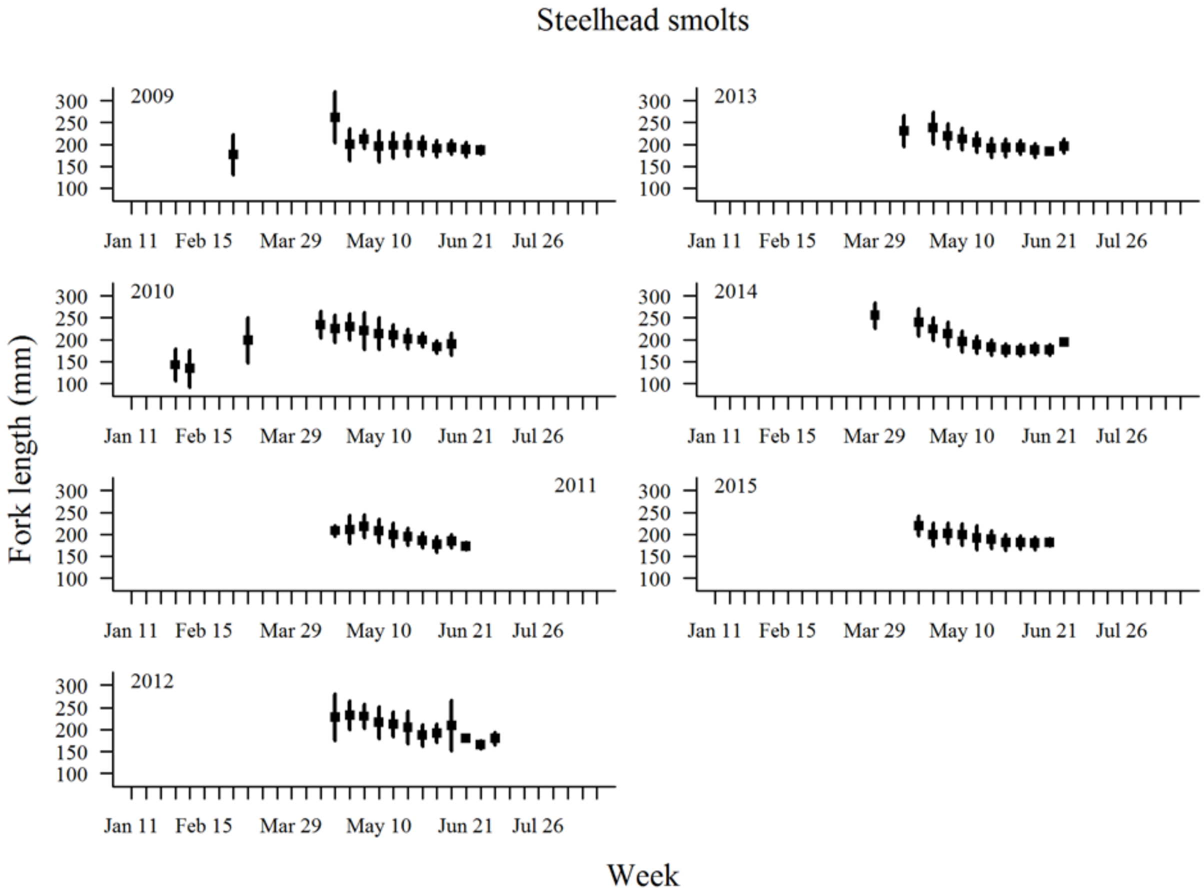

Figure 12. –Weekly mean fork lengths of steelhead smolts captured at the Nisqually River rotary screw trap, 2009-2015. Error bars represent one standard deviation of the mean.

Table 10. –Annual sample size (n), minimum, maximum, mean and standard deviation (SD) of fork lengths in millimeters of steelhead smolts collected at the Nisqually River rotary screw trap, 2009-2015.

Ocean	Fork Length (mm)				
Entry Year	n	Min	Max	Mean	SD
2009	1,201	76	380	195.9	24.3
2010	344	90	335	208.9	35.1
2011	257	142	278	195.7	25.3
2012	133	155	350	209.8	38.6
2013	318	145	285	199.7	24.9
2014	847	145	305	188.8	25.2
2015	490	140	357	191.8	25.3

Age

Age composition of steelhead smolts encountered at the trap was dominated by 1, 2, 3 and 4 year olds but also included 5 (N=1) and 6 year olds (N=1). Age-2 was typically the predominant age class except for 2014 when age-1 was the majority. Proportions of each age class were variable from year to year with the proportion of age 1 oscillating annually. Proportions of age 1 smolts ranged from 19.4% to 52.7%, age 2 smolts ranged from 41.8% to 78.2%, age 3 smolts ranged from 1.1% to 16.5%. Age 4 smolts, when present in the sample, ranged from 0.3% to 1.4% (Figure 13).

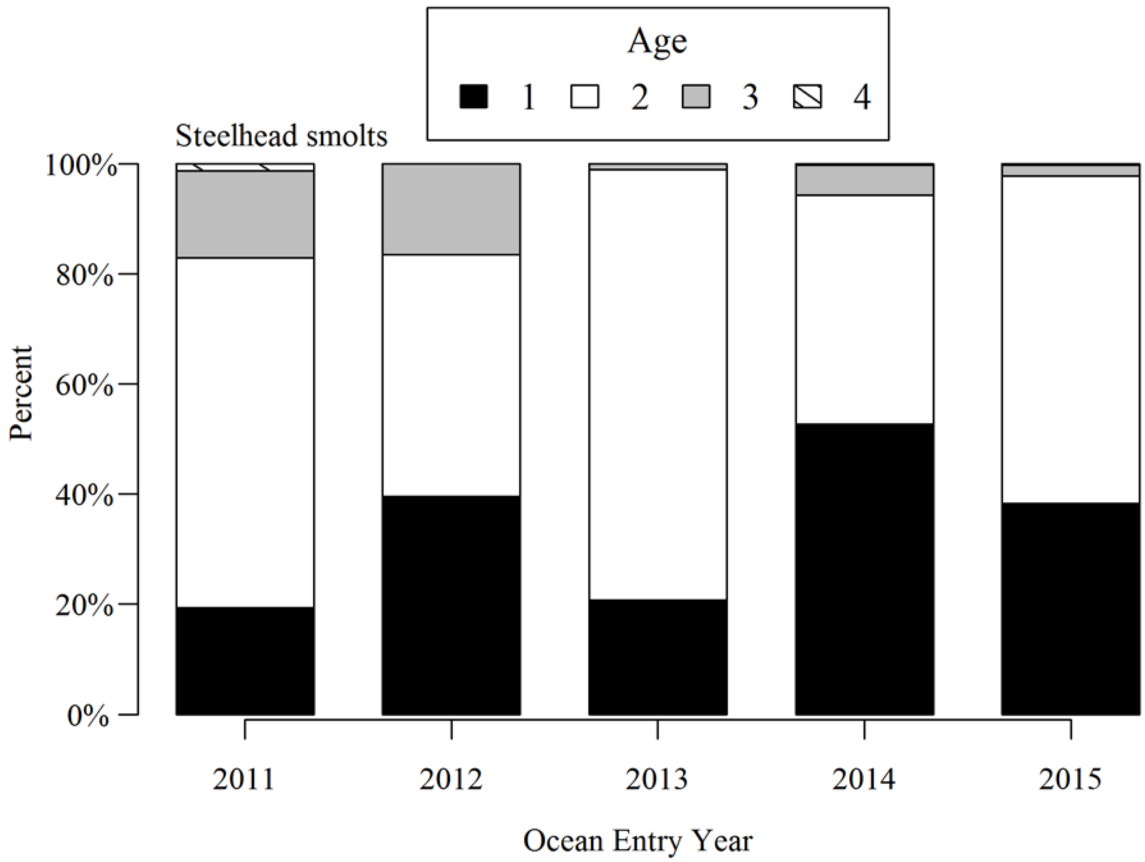

Figure 13. – Annual age composition of steelhead smolts captured at the Nisqually River rotary screw trap, 2009-2015.

Length at age

Length mean and range increased with age, except for some age-4 collections limited by small sample sizes (Figure 14). Minimum size at age was typically consistent suggesting a minimum size threshold for smoltification and outmigration.

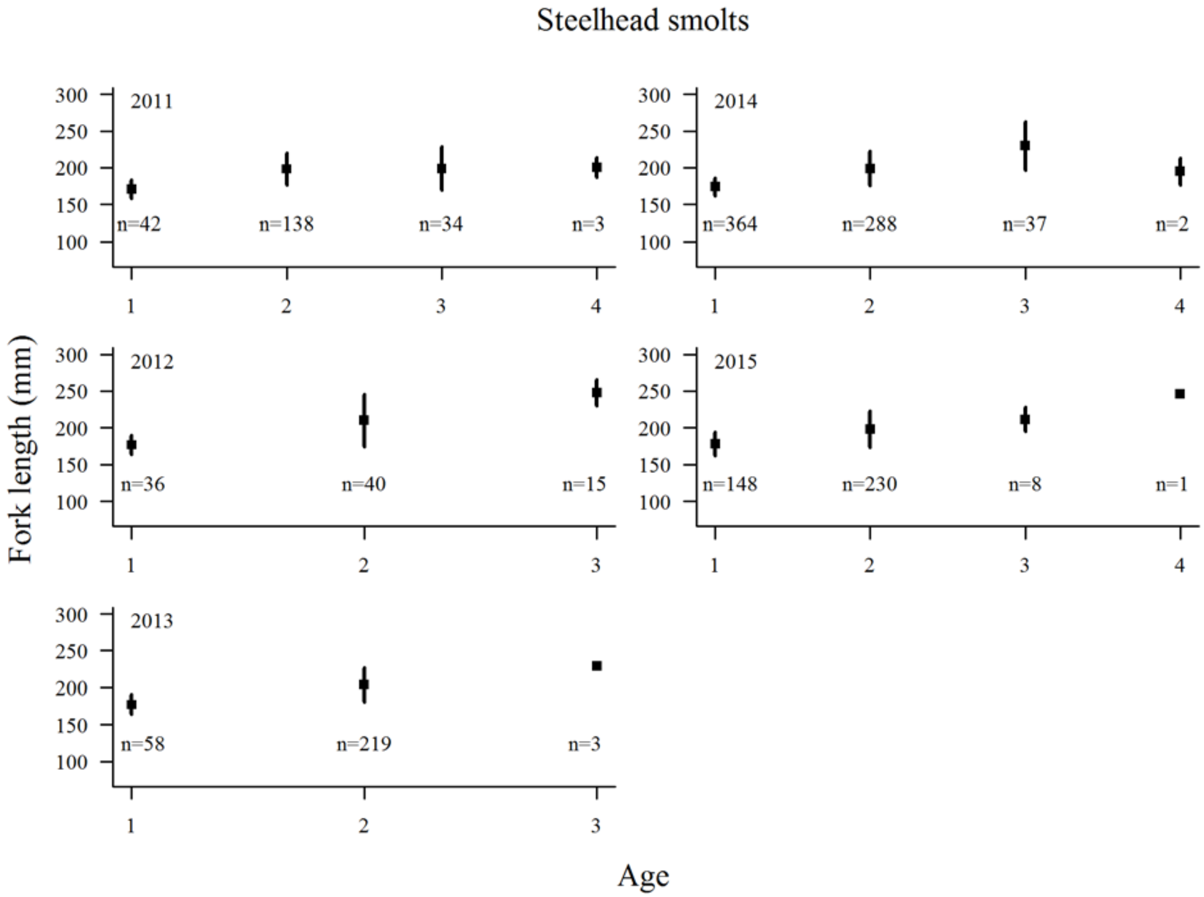

Figure 14. –Annual mean fork lengths at age of steelhead smolts captured at the Nisqually River rotary screw trap, 2009-2015. Error bars represent one standard deviation of the mean.

Survival and Productivity

Relative freshwater survival ranged from 1.3% to 12.9% and productivity of steelhead ranged from 31 to 304 smolt recruits per spawner among brood years 2008 to 2011 (Figure 15, Table 11). Marine survival ranged from 0.37% and 0.79% for the complete adult returns of ocean entry year cohorts 2009 to 2011 (Table 12).

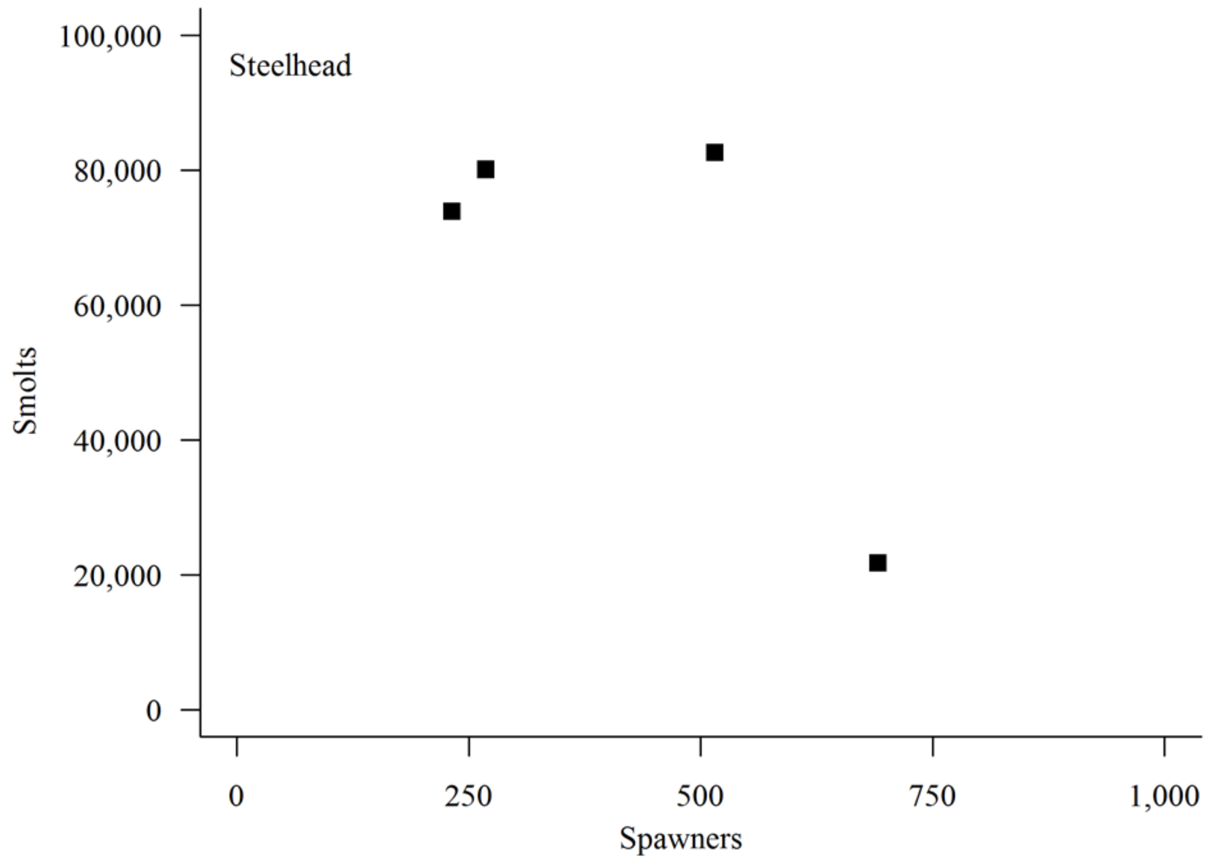

Figure 15. –Relationship between steelhead spawners and smolts in the Nisqually River for brood years 2008-2011.

Table 11. –Relative freshwater survival and productivity of steelhead smolts in the Nisqually River for complete brood years 2008 to 2011.

	Adult		Smolt Abundance					Freshwater	Smolts per
BY	Spawners[a]	PED	Age-1	Age-2	Age-3	Age-4	Total	Survival	Spawner
2008	515	1,268,165	16,762	56,430	9,517	0	82,708	6.5%	161
2009	232	571,068	29,362	38,627	3,255	0	71,244	12.5%	307
2010	704	1,732,896	11,756	8,679	945	252	21,632	1.2%	31
2011	284	699,066	7,811	68,994	3,774	178	80,757	11.6%	284

[a] Steelhead spawners were restricted to estimates of mainstem returns because the methods and effort have been consistent for the years of interest and less consistent for the tributaries.

Table 12. –Marine survival of steelhead in the Nisqually River for complete adult returns of ocean entry year cohorts 2009-2011.

	Outmigrant	Adult Returns[a]				
OEY	Abundance	Age-1	Age-2	Age-3	Total	SAR
2009	54,063	149	84	10	243	0.45%

2010	94,704	108	237	7	352	0.37%
2011	60,740	304	162	15	482	0.79%

[a] Steelhead adult returns were restricted to estimates of mainstem spawners and terminal catch (sport and tribal) because the methods and effort have been consistent for the years of interest and less consistent for the tributaries.

Yearling Coho

Catch

Total annual catch of natural origin Coho outmigrants ranged from 2,843 to 21,858 among years 2009 to 2015. Missed catch of 28 to 1,753 outmigrants was estimated due to trap outages. The trapping effort appears to have included the entire outmigration (Appendix D).

Trap calibration

From 11 to 26 weekly mark-recapture trails were conducted with yearling Coho outmigrants to calibrate the trap efficiency and were aggregated annually into four to eight strata among years 2009 to 2015. Trap efficiencies for the stratified data ranged between 2.9% and 31.67% (Appendix D).

Abundance estimates

Yearling Coho abundance estimates ranged between 80,048 (CV = 10.6%) in 2012 and 254,456 (CV = 8.6%) in 2011 (Table 13).

Table 13. –Annual abundance estimates of yearling Coho outmigrating past the Nisqually River rotary screw trap, 2009-2014.

Ocean Entry Year	Abundance Estimate	CV	95 % CI Lower	95 % CI Upper
2009	128,497	4.7%	116,767	140,227
2010	179,220	10.6%	141,969	216,471
2011	254,456	8.6%	211,744	297,168
2012	80,048	10.6%	63,373	96,723
2013	164,400	4.6%	149,604	179,196
2014	203,827	7.3%	174,724	232,930
2015	118,580	7.6%	100,867	136,294

Migration timing

The yearling Coho outmigration annually occurred within the trapping season. Timing was unimodal among years with a peak that ranged from May 10 to June 1 (Figure 16, Table 14).

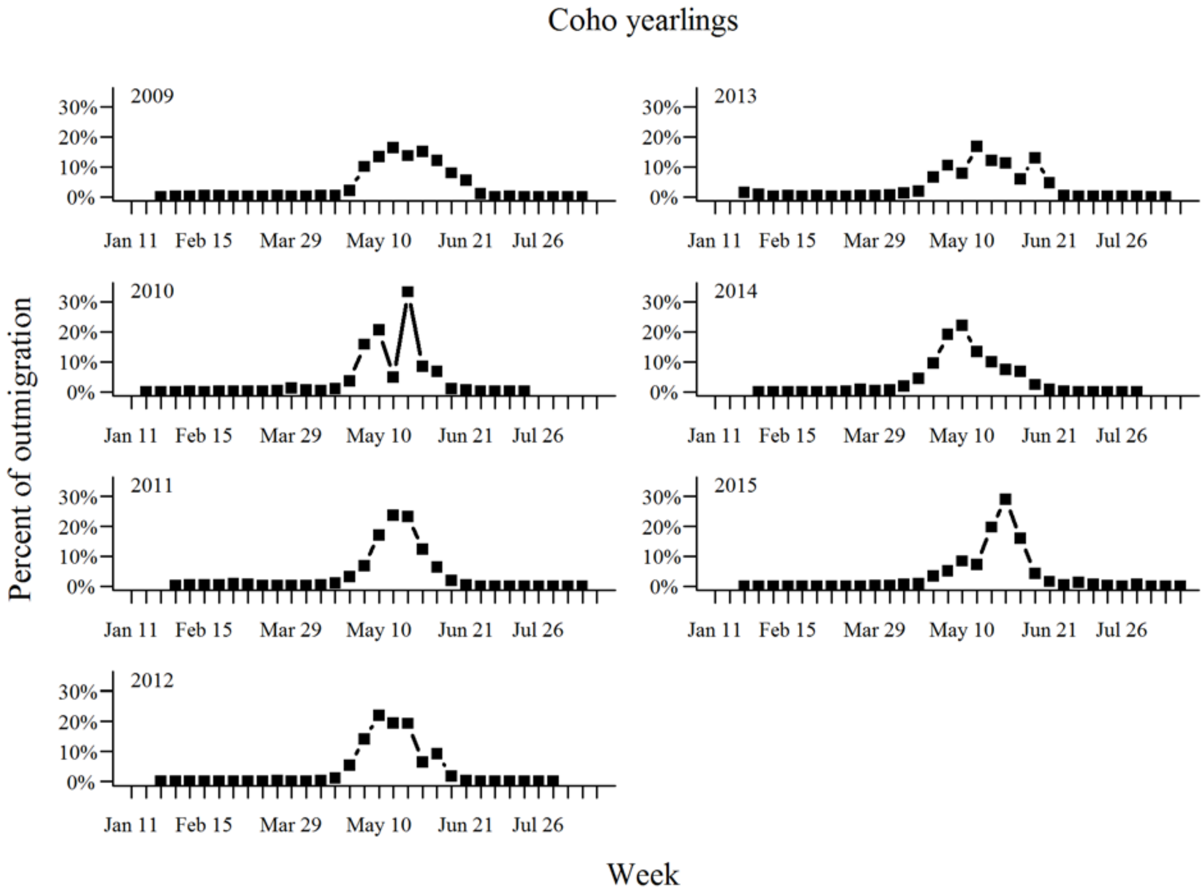

Figure 16. –Weekly outmigration timing of yearling Coho outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Table 14. –Annual migration begin, end and median dates of yearling Coho outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Ocean Entry Year	Begin Date	End Date	Median
2009	January 26	August 117	May 18
2010	January 19	July 20	May 25
2011	February 2	August 3	May 18
2012	February 9	July 26	May 10
2013	January 26	August 17	May 18
2014	February 2	August 3	May 11
2015	March 16	August 17	June 1

Length

Relative length frequency distributions were unimodal at about 105 mm except in 2012 and 2015 when the mode was at 115 mm (Figure 17).

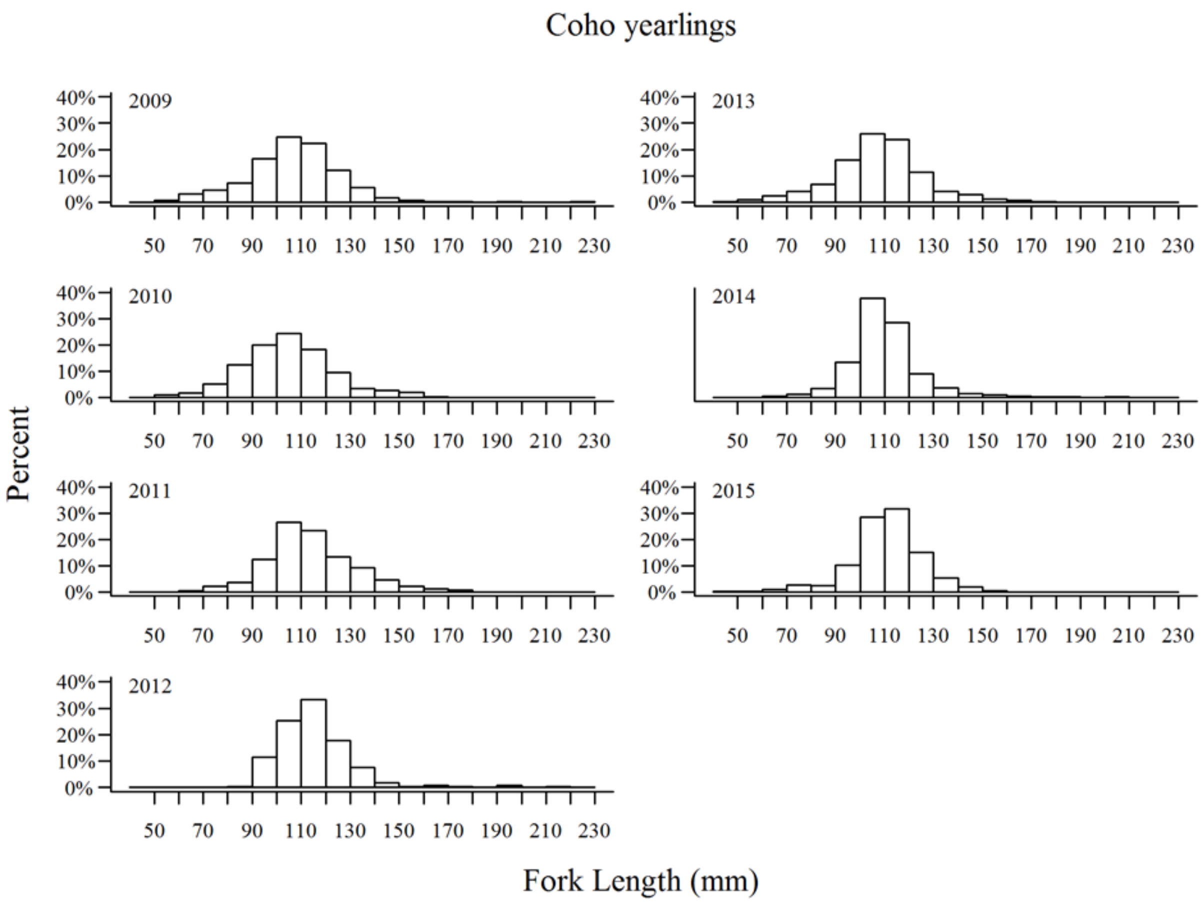

Figure 17. –Relative length frequency histograms of yearling Coho captured at the Nisqually River rotary screw trap, 2009-2015.

Mean fork length of Coho yearlings generally increased slightly and subsequently remained constant or gradually decreased through the outmigration. The subtle peak in size coincided with the beginning of the concerted outmigration of yearling Coho smolts, whereas earlier catches were yearling Coho parr (pre-smolts). Individual fork lengths of maiden captures ranged from 48 mm to 222 mm and average length ranged from 105.6 mm to 116.4 mm during the trapping seasons, 2009 to 2015 (Figure 18, Table 15).

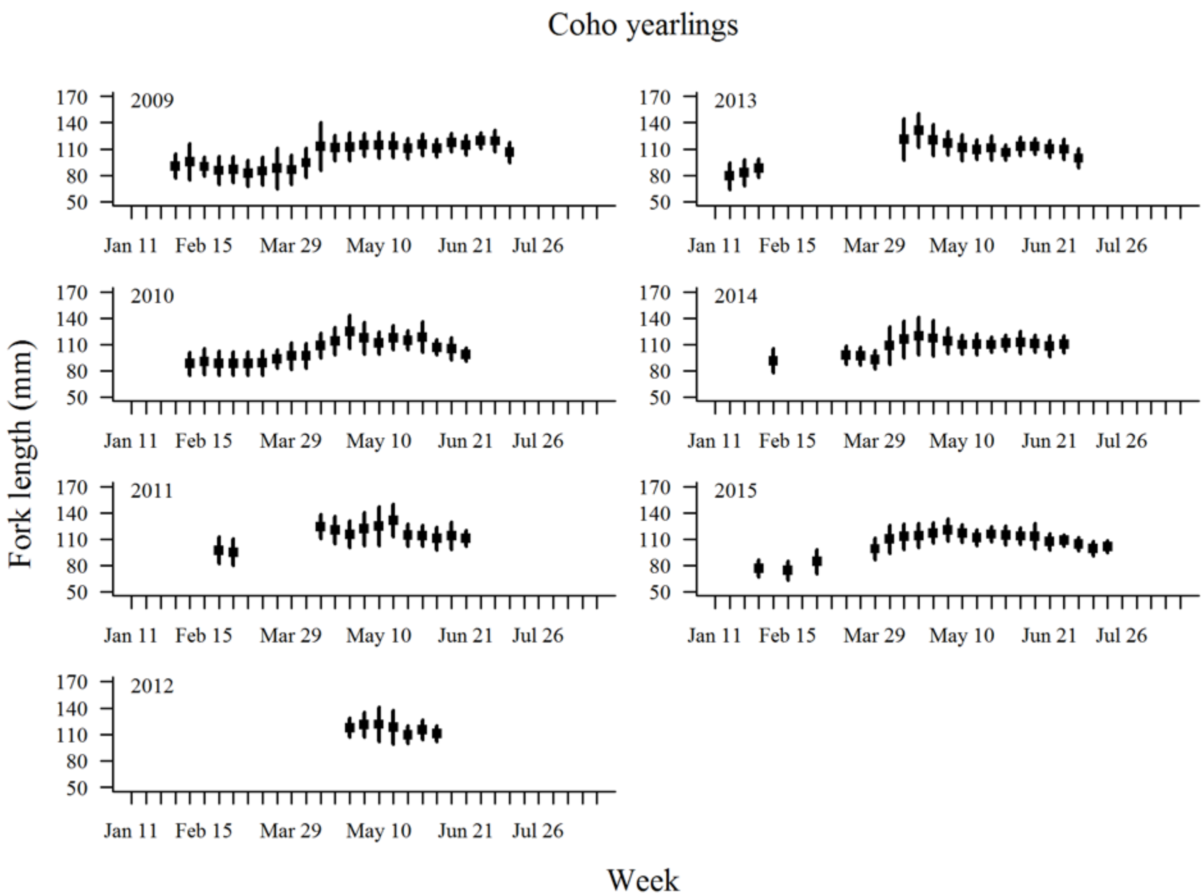

Figure 18. –Weekly mean fork lengths of yearling Coho captured at the Nisqually River rotary screw trap, 2009-2015. Error bars represent one standard deviation of the mean.

Table 15. –Annual sample size (n), minimum, maximum, mean and standard deviation (SD) of fork lengths in millimeters of yearling Coho collected at the Nisqually River rotary screw trap, 2009-2015.

Ocean	Fork Length (mm)				
Entry Year	n	Min	Max	Mean	SD
2009	1,567	51	222	107.2	18.4
2010	967	51	169	105.6	18.5
2011	482	62	176	114.6	18.2
2012	281	88	220	116.4	15.7
2013	659	50	175	108.0	18.3
2014	1,330	61	210	110.2	13.7
2015	1,203	48	198	111.7	14.9

Survival and Productivity

Coho Salmon freshwater survival ranged from 3.8% to 57.6%, productivity ranged from 29 to 271 smolts per spawner and marine survival ranged from 0.12% to 2.7% among years of trap operation. We emphasize that these are coarse estimates owing to the uncertainty in adult spawning escapement.

Chum fry

Catch

Total annual catch of wild origin Chum fry outmigrants ranged from 624 to 21,858 among years 2009 to 2015. We estimated missed catch of 0 to 2,799 outmigrants due to trap outages. The trapping effort appears to have included the entire outmigration (Appendix E).

Trap calibration

From 3 to 22 weekly mark-recapture trails were conducted with Chum fry outmigrants to calibrate the trap efficiency and were aggregated annually into one to five strata among years 2009 to 2015. Trap efficiencies for the stratified data ranged between 0.9% and 14.5% (Appendix E).

Abundance estimates

Chum fry estimates ranged between 17,197 (CV = 26.5%) in 2014 and 862,328 (CV = 16.0%) in 2011 (Table 16).

Table 16. –Annual abundance estimates of Chum fry outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Ocean Entry Year	Abundance Estimate	CV	95 % CI Lower	95 % CI Upper
2009	159,390	5.3%	142,939	175,841
2010	330,924	23.3%	179,528	482,320
2011	862,328	16.0%	591,631	1,133,025
2012	54,438	25.7%	27,039	81,837
2013	148,545	23.0%	81,567	215,523
2014	17,197	26.5%	8,252	26,142
2015	233,783	10.4%	186,290	281,275

Migration timing

The Chum fry outmigration annually occurred within the trapping season. Timing was unimodal among years with a peak that ranged from April 6 to April 27 (Figure 19, Table 17).

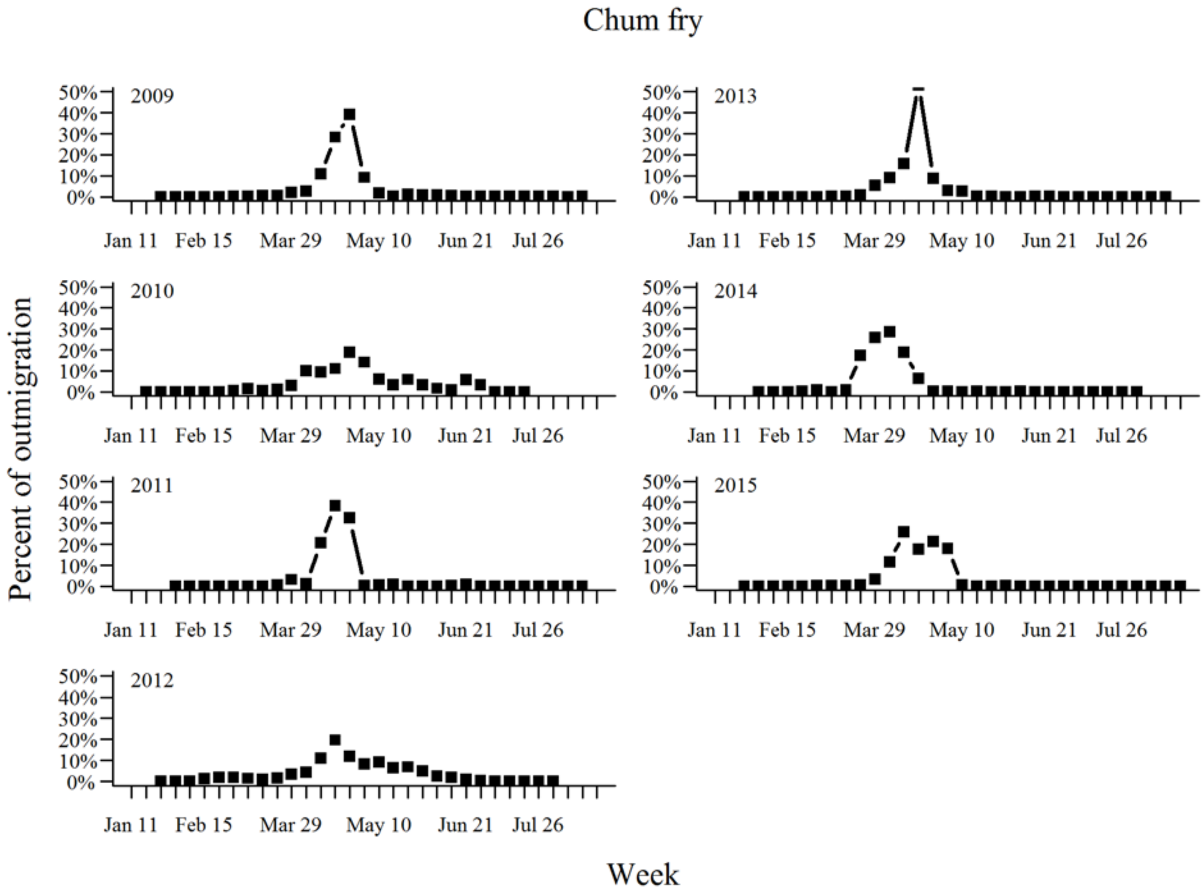

Figure 19. –Weekly outmigration timing of Chum fry outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Table 17. –Annual migration begin, end and median dates of Chum fry outmigrating past the Nisqually River rotary screw trap, 2009-2015.

Ocean Entry Year	Begin Date	End Date	Median
2009	February 16	August 17	April 27
2010	January 26	July 20	April 27
2011	February 16	July 6	April 20
2012	February 16	July 5	April 19
2013	February 16	June 22	April 20
2014	February 16	June 8	April 6
2015	February 23	June 22	April 13

Length
Relative length frequency distributions were unimodal at 35 mm (Figure 20).

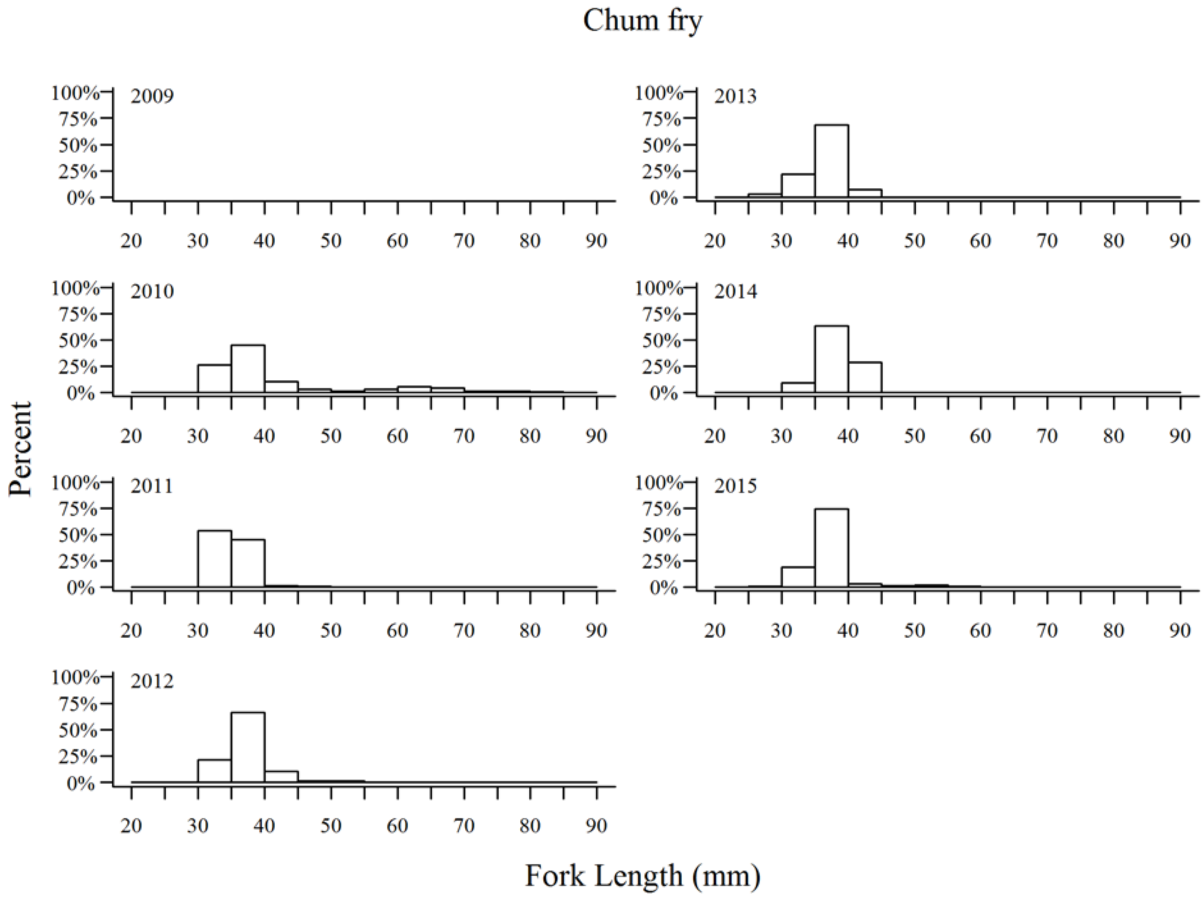

Figure 20. –Relative length frequency histograms of Chum fry captured at the Nisqually River rotary screw trap, 2010-2015. No lengths were collected in 2009

Mean fork length was generally consistent with little variability through the outmigration. However, in 2010 we observed some larger sizes suggestive of river-rearing parr, coinciding with the relatively protracted outmigration. Individual fork lengths of maiden captures ranged from 27 mm to 84 mm and average length ranged from 35.3 mm to 42.9 mm during the trapping seasons, 2009 to 2015 (Figure 21, Table 18).

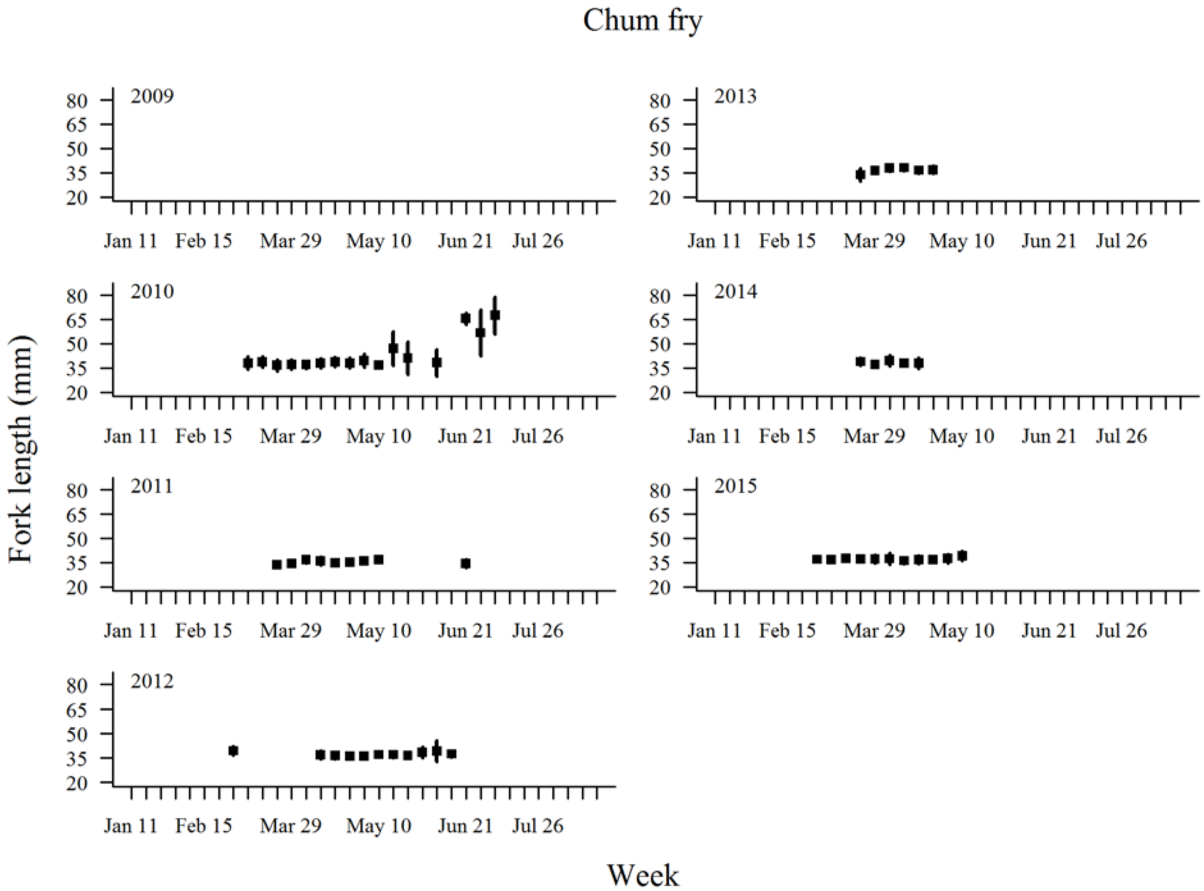

Figure 21. –Weekly mean fork lengths of Chum fry captured at the Nisqually River rotary screw trap, 2009-2015. Error bars represent one standard deviation of the mean.

Table 18. –Annual sample size (n), minimum, maximum, mean and standard deviation (SD) of fork lengths in millimeters of Chum fry collected at the Nisqually River rotary screw trap, 2010-2015. No lengths were collected in 2009.

Ocean	Fork Length (mm)				
Entry Year	n	Min	Max	Mean	SD
2009	-	-	-	-	-
2010	263	31	84	42.1	11.2
2011	161	31	47	35.3	2.3
2012	99	33	51	37.2	2.8
2013	111	27	42	36.9	2.7
2014	46	34	45	38.7	2.8
2015	468	28	58	42.9	3.2

Survival and Productivity

Chum Salmon freshwater survival ranged from 0.04% to 0.7% and productivity ranged from 1 to 10 fry per spawner among brood years 2008 to 2014 (Figure 22, Table 19). Marine survival of ocean entry year cohorts 2009 to 2011 was consistenly 4-5% but higher in ocean entry years 2012 and 2013 (Table 20).

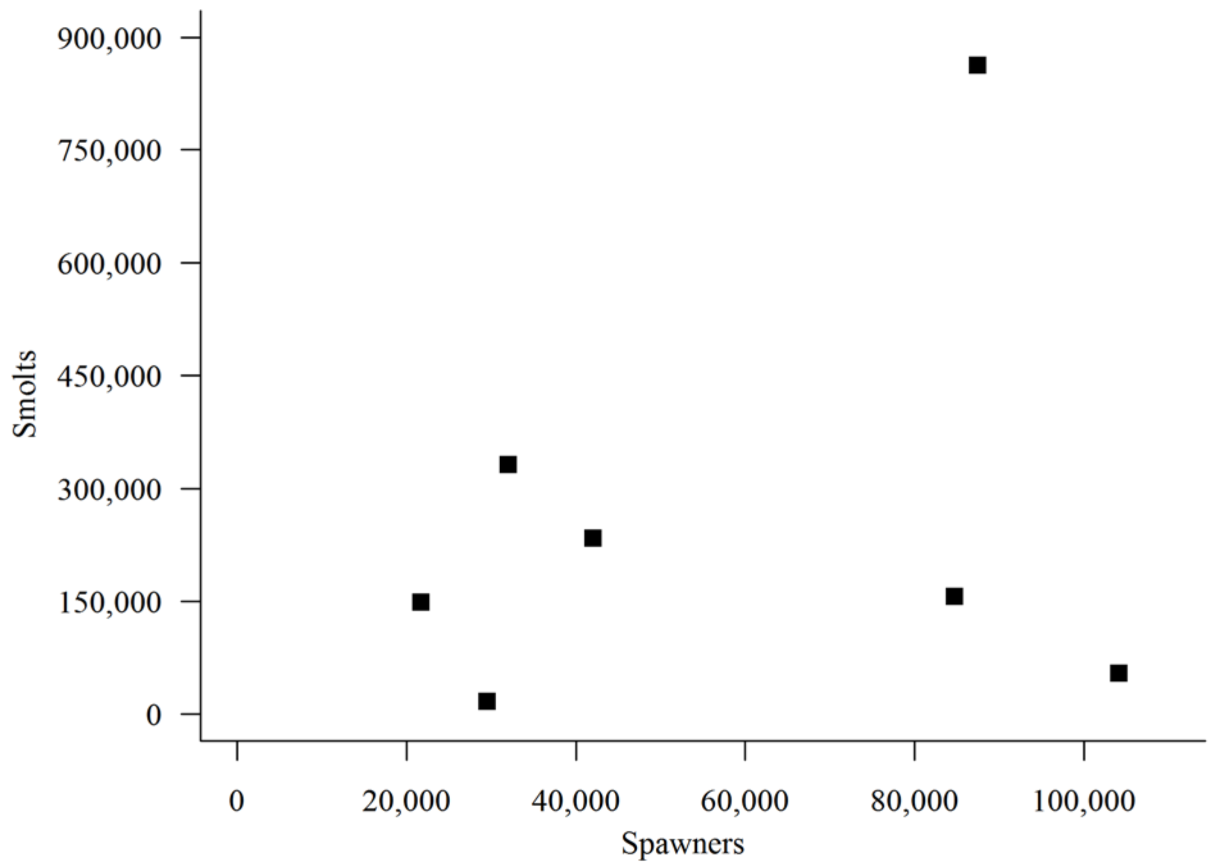

Figure 22. –Relationship between Chum spawners and smolts in the Nisqually River for brood years 2008-2014.

Table 19. – Freshwater survival and productivity of Chum in the Nisqually River for complete brood years 2008 – 2014.

BY	Adult Spawners	PED	Smolt Abundance	Freshwater Survival	Smolts per Spawner
2008	24,733	35.6 M	156,070	0.4%	6
2009	11,066	15.9 M	330,924	2.1%	30
2010	54,482	78.3 M	862,328	1.1%	16
2011	46,096	66.3 M	54,438	0.1%	1
2012	14,806	21.3 M	148,545	0.7%	10
2013	15,570	22.4 M	17,197	0.1%	1
2014	37,930	54.5 M	233,783	0.4%	6

Table 20. –Marine survival of Chum in the Nisqually River for complete adult returns of ocean entry year cohorts 2009-2013.

OEY	Outmigrant Abundance	Adult Return Age-3	Age-4	Age-5	Total	SAR
2009	159,390	1,039	5,695	217	6,951	4.36%
2010	330,924	7,053	6,496	127	13,676	4.13%
2011	862,328	8,858	36,018	2,462	47,337	5.49%
2012	54,438	1,785	10,804	186	12,775	23.47%
2013	148,545	6,610	5,580	725	12,915	8.69%

Pink fry

Catch

Total annual catch of wild origin Pink fry outmigrants ranged from 94,394 to 1,314,910 among years 2010, 2012 and 2014. Two off year Pink Salmon were captured during the 2011 trapping season. Missed catch of 4,436 to 28,522 outmigrants was estimated annually due to trap outages. The trapping effort appears to have included the entire outmigration (Appendix F).

Trap calibration

From 8 to 18 weekly mark-recapture trails were conducted with Pink fry outmigrants to calibrate the trap efficiency and were aggregated annually into three to nine strata among years 2010, 2012 and 2014.Trap efficiencies for the stratified data ranged between 0.4% and 16.0% (Appendix F).

Abundance estimates

Pink Fry estimates ranged between 27,543,984 (CV = 8.6%) in 2014 and 8,586,354 (CV = 8.7%) in 2012 (Table 21).

Table 21. –Annual abundance estimates of Pink fry outmigrating past the Nisqually River rotary screw trap; 2010, 2012 and 2014.

Ocean Entry Year	Abundance Estimate	CV	95 % CI Lower	95 % CI Upper
2010	17,699,963	14.0%	12,831,424	22,568,502
2012	8,586,354	8.7%	7,115,701	10,057,007
2014	27,543,984	8.6%	22,880,996	32,206,972

Migration timing

The Pink fry outmigration annually occurred within the trapping season. Timing was unimodal among years with a peak that ranged from March 30 to April 13 (Figure 23, Table 22).

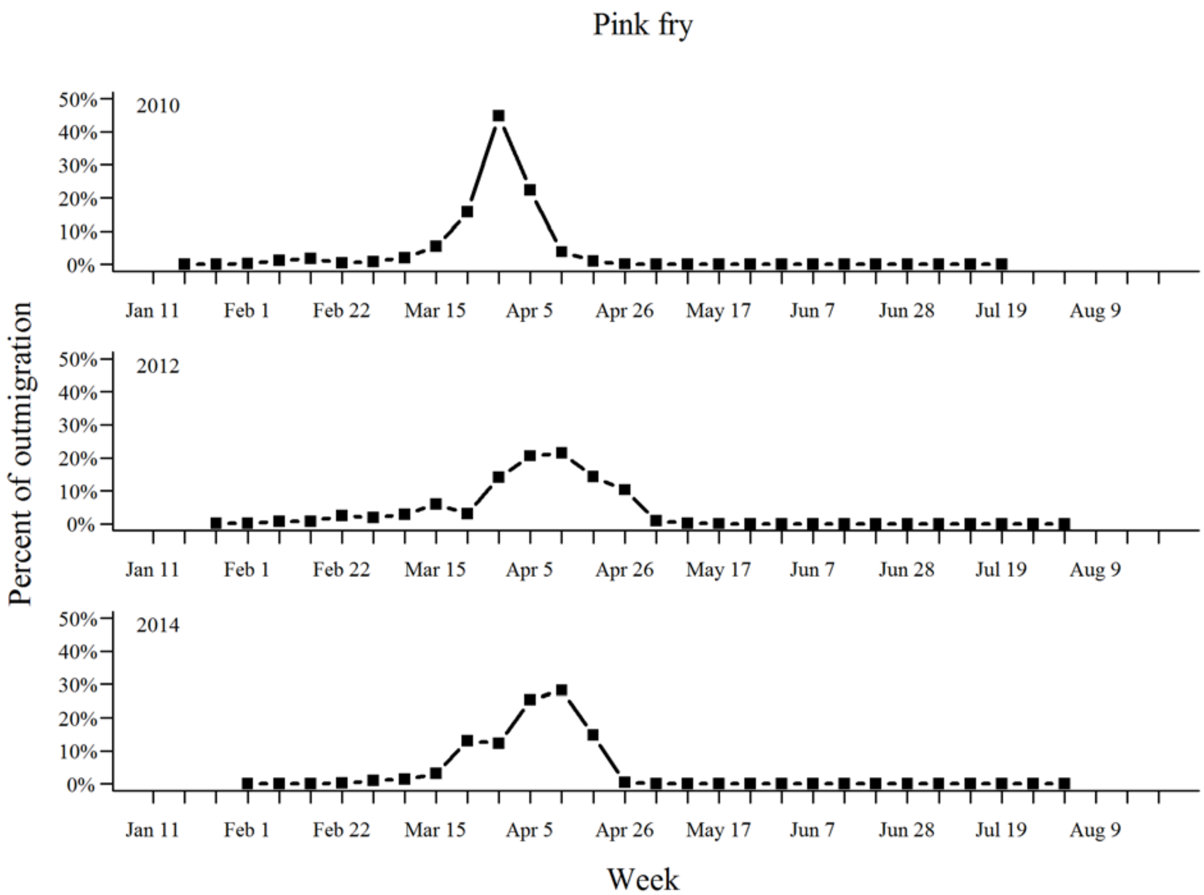

Figure 23. –Weekly outmigration timing of Pink fry outmigrating past the Nisqually River rotary screw trap, 2010, 2012 and 2014.

Table 22. –Annual migration begin, end and median dates of Pink fry outmigrating past the Nisqually River rotary screw trap; 2010, 2012 and 2014.

Ocean Entry Year	Begin Date	End Date	Median
2010	January 19	June 29	March 30
2012	January 26	June 14	April 12
2014	February 2	July 13	April 13

Length

Relative length frequency distributions were unimodal at 35 mm (Figure 24). Mean fork length generally consistent with little variability through the outmigration. However, in 2010, similar to chum salmon, we observed some larger sizes suggestive of river-rearing parr, coinciding with the relatively protracted outmigration. Individual fork lengths of maiden captures ranged from 27 mm to 65 mm and average length ranged from 33.7 mm to 34.7 mm during the trapping seasons, 2009 to 2014 (Figure 25, Table 23).

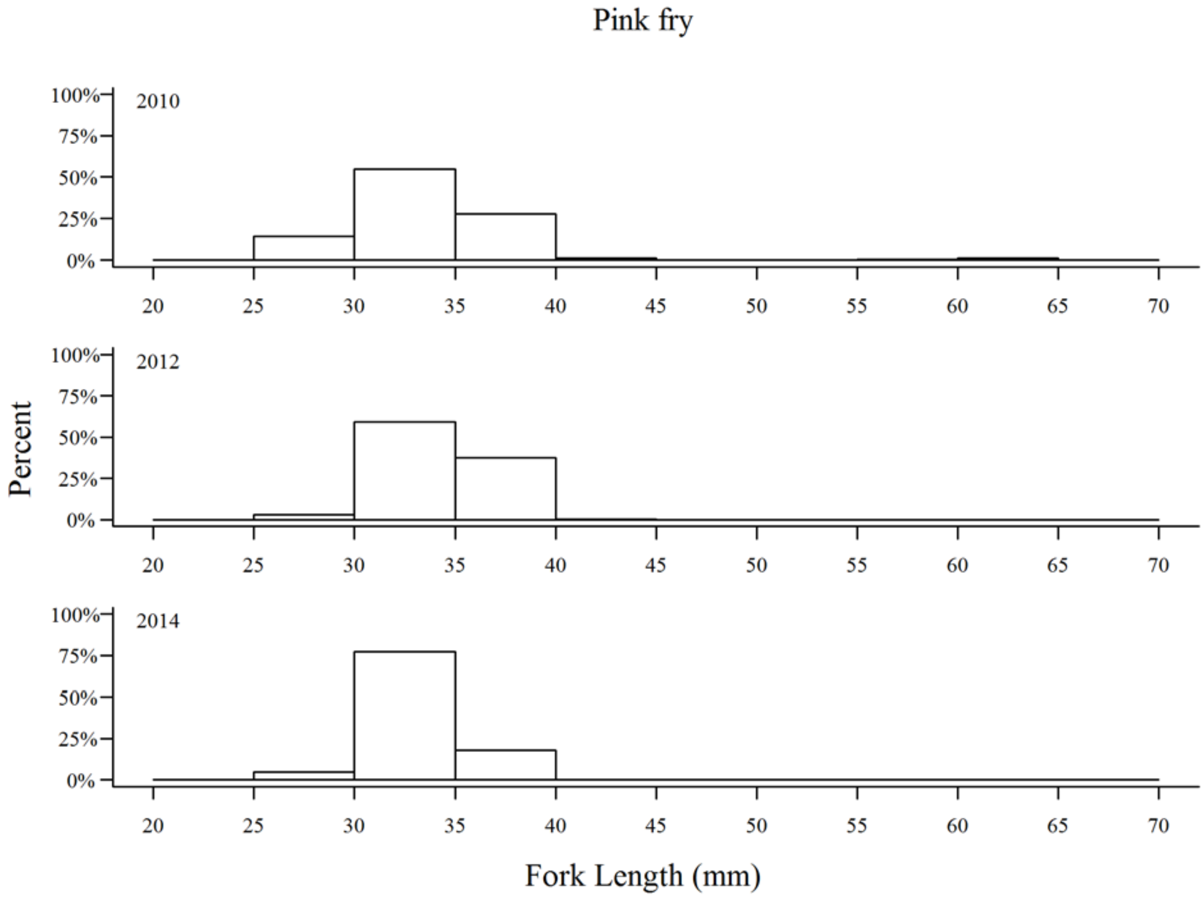

Figure 24. –Relative length frequency histograms of Pink fry captured at the Nisqually River rotary screw trap; 2010, 2012 and 2014.

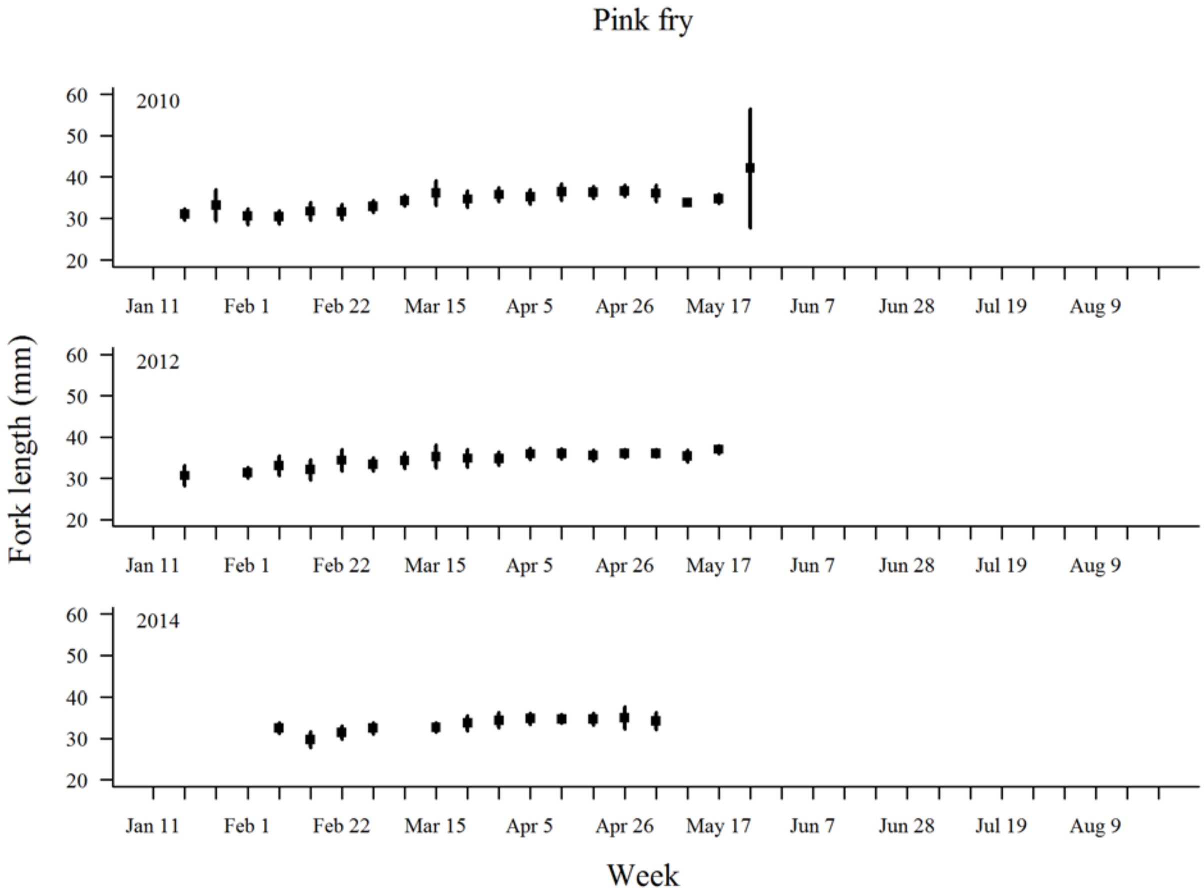

Figure 25. –Weekly mean fork lengths of Pink fry captured at the Nisqually River rotary screw trap; 2010, 2012 and 2014. Error bars represent one standard deviation of the mean.

Table 23. –Annual sample size (n), minimum, maximum, mean and standard deviation (SD) of fork lengths in millimeters of Pink fry collected at the Nisqually River rotary screw trap; 2010, 2012 and 2014.

Ocean	Fork Length (mm)				
Entry Year	n	Min	Max	Mean	SD
2010	366	27	65	34.2	4.7
2012	242	28	41	34.7	2.2
2014	479	27	45	33.7	2.0

Survival and Productivity

Freshwater survival ranged from 1.3% to 4.1% and productivity of Pink salmon ranged from 11 to 34 smolt recruits per spawner among brood years 2009 to 2013 (Figure 25, Table 24). Marine survival was 0.59% to 9.5% for the complete adult returns of ocean entry year cohorts 2010 to 2014 (Table 25).

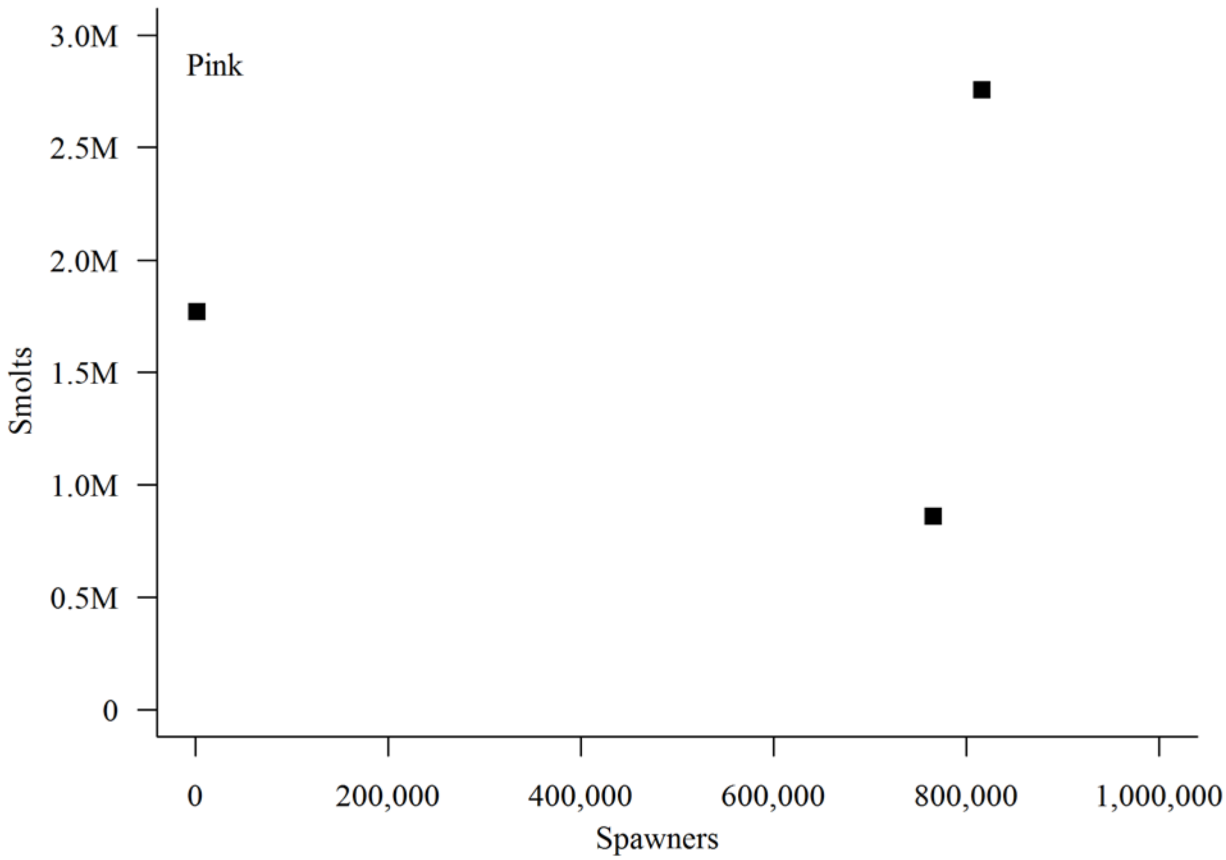

Figure 26. –Relationship between Pink spawners and smolts in the Nisqually River for brood years 2009-2013.

Table 24. –Freshwater survival and productivity of Pink fry in the Nisqually River for complete brood years 2009 – 2013.

BY	Adult Spawners	PED	Smolt Abundance	Freshwater Survival	Smolts per Spawner
2009	2,000[a]	1.6M	17.7M	NA	NA
2011	765,447	630.7M	8.6M	1.3%	11
2013	815,887	672.3M	27.5M	4.1%	34

[a] Pink spawners for this year are likely an underestimate because the unexpanded raw catch for this brood was 1.3M, almost equal to egg deposition resulting in freshwater survival >100% and productivity greater than a reasonable fecundity.

Table 25. –Marine survival of Pink in the Nisqually River for complete adult returns of ocean entry year cohorts 2010-2014.

OEY	Outmigrant Abundance	Adult Return	Marine Survival
2010	17,699,963	765,447	4.3%
2012	8,586,354	815,887	9.5%

2014	27,543,984	162,148	0.59%

Other species

O. nerka

Two distinct forms of *O. nerka* were captured at the trap; fry and fingerling sized parr. A portion of the fingerlings were ad-marked (adipose fin removed) as hatchery origin. Total annual catch of *O. nerka* juveniles ranged from 0 to 587 among years 2009 to 2015 (Table 26). Abundance was not estimated because catches were too low, too sporadic or both to calibrate the trap with meaningful efficiency trials. Fry were captured from April 9 to August 25 and parr were captured through the entire trapping season among years. Individual lengths for fry ranged from 29 mm to 89 mm and 117 mm to 215 mm for parr**.**

Table 26. –Total annual catch of *O. nerka* juveniles among years 2009 to 2015.

Trap	*O. nerka* fry	*O. nerka* parr	
Year	Unmarked	Unmarked	Ad-marked
2009	0	1	0
2010	0	0	0
2011	587	7	2
2012	64	4	3
2013	114	39	13
2014	25	31	35
2015	227	6	10

Cutthroat trout

Total annual catch of cutthroat ranged from 53 to 96 among years 2009 to 2015 (Figure 27, Table 27). Like Sockeye fry, abundance was not estimated because catches were too low and sporadic to calibrate the trap with meaningful efficiency trials. Among years, there is no distinct peak in the timing of catches to suggest a coordinated outmigration. Thus we are unsure if cutthroat trout captured at the trap are milling residents or anadromous outmigrants.

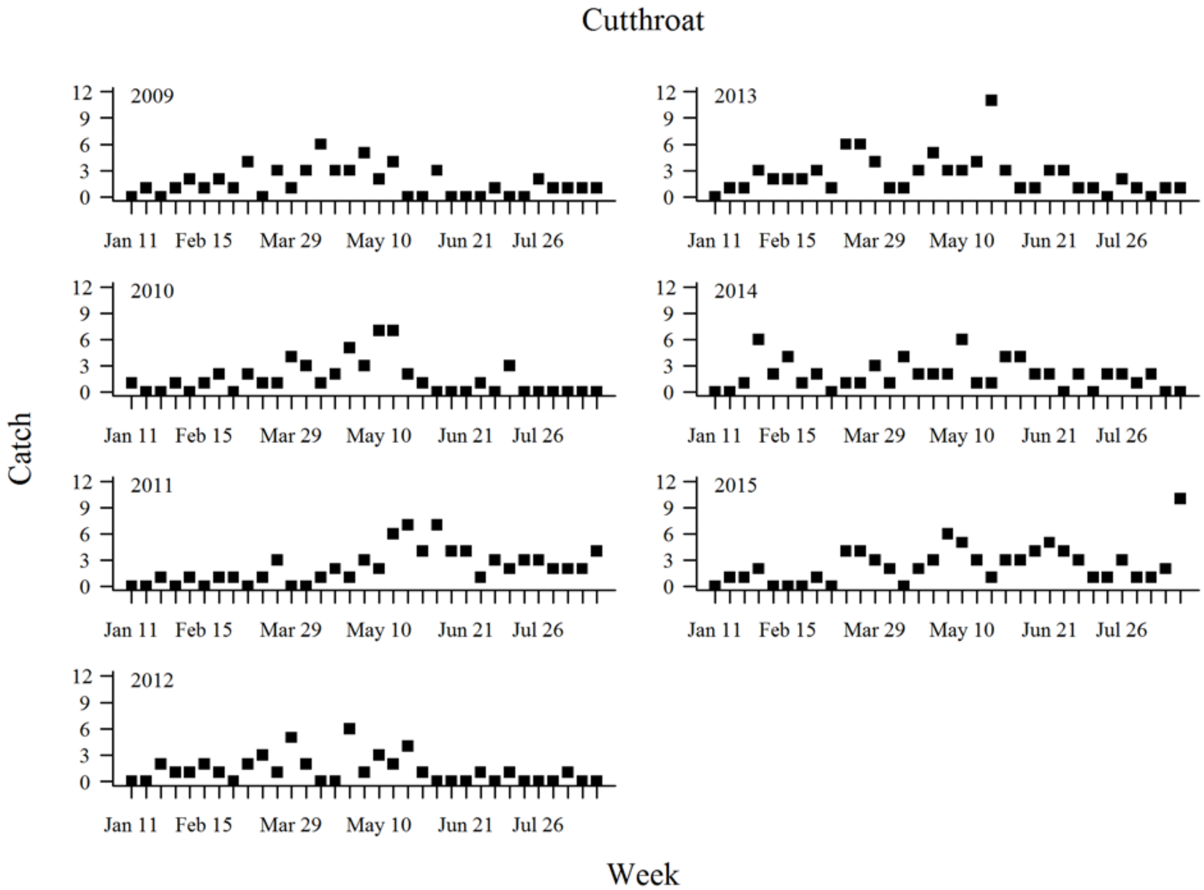

Figure 27. –Weekly catch of Cutthroat in the Nisqually River rotary screw trap, 2009-2015.

Table 27. –Total annual catch of Cutthroat in the Nisqually River rotary screw trap, 2009-2015.

Trap Year	Catch
2009	53
2010	50
2011	72
2012	40
2013	96
2014	61
2015	79

Relative length frequency distributions of cutthroat trout had no clear mode among years (Figure 28). Individual fork length of cutthroat trout ranged from 64 mm to 380 mm and average length ranged from 1146.0 mm to 287.7 mm during the trapping seasons, 2009 to 2015 (Figure 29, Table 28).

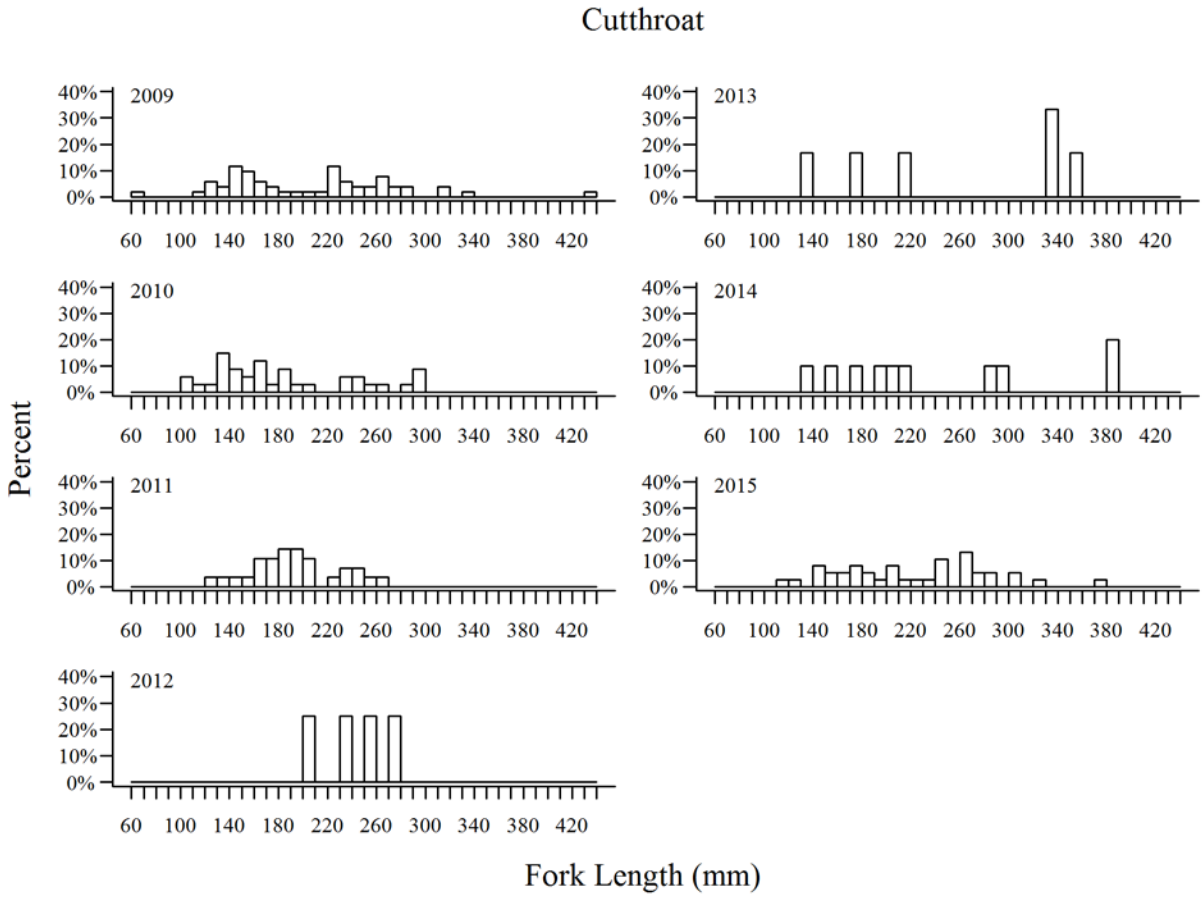

Figure 28. –Relative length frequency histograms of Cutthroat captured at the Nisqually River rotary screw trap, 2009-2015.

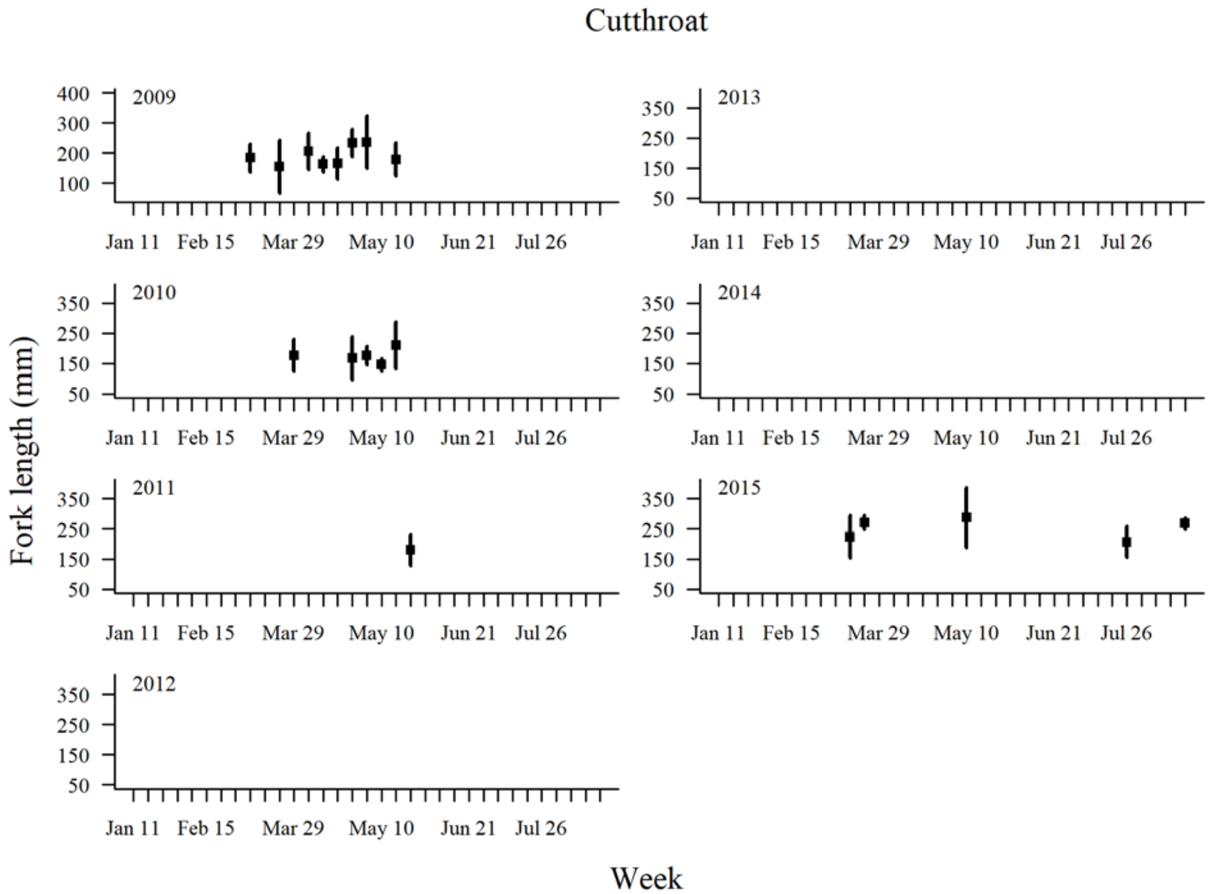

Figure 29. –Weekly mean fork lengths of Cutthroat captured at the Nisqually River rotary screw trap, 2009-2015. Error bars represent one standard deviation of the mean.

Table 28. –Annual sample size (n), minimum, maximum, mean and standard deviation (SD) of fork lengths in millimeters of Cutthroat trout collected at the Nisqually River rotary screw trap; 2009-2015.

Trap	Fork Length (mm)				
Year	n	Min	Max	Mean	SD
2009	52	64	440	208.1	69.3
2010	34	103	300	186.5	59.0
2011	28	124	266	193.5	36.4
2012	4	206	274	244.8	29.3
2013	6	138	360	259.0	96.0
2014	10	138	390	245.9	91.1
2015	38	113	380	223.3	60.9

Hatchery origin salmon and trout

Hatchery origin juvenile salmon and trout were routinely captured in the Nisqually River rotary screw trap (Table 29). Adipose clipped Chinook and Coho were likely strays that swam upstream after release from Kalama Creek or Clear Creek hatcheries. Hatchery origin Kokanee were stocked into Alder Lake and the hatchery origin Rainbow trout were likely stocked into Harts, Ohop or Tanwax lakes. Efficiency trial were not conducted on any hatchery origin juvenile salmon or trout captured in the Nisqually River rotary screw trap because catches were too low, too sporadic or both to conduct meaningful efficiency trials

Table 29. –Hatchery origin juvenile salmon and trout captured in the Nisqually River rotary screw trap, 2009-2015.

Trap	Chinook	Coho	Kokanee		Rainbow trout	
Year	Ad-marked	Ad-marked	Unmarked	Ad-marked	Unmarked	Ad-marked
2009	0	1	1	0	799	0
2010	28	0	0	0	289	0
2011	3	0	7	2	331	664
2012	0	0	4	3	35	6
2013	0	105	39	13	2	4
2014	0	0	31	35	110	15
2015	0	0	6	10	41	0

Adult salmon and steelhead

Adult Chinook, steelhead, Chum and Coho have been captured at the trap annually among years 2009 to 2015 (Table 30).

Table 30. –Adult salmon and steelhead captured in the Nisqually River rotary screw trap, 2009-2015.

Trap Year	Chinook	steelhead	Chum	Coho
2009	1	0	11	0
2010	0	0	7	0
2011	0	1	0	0
2012	0	0	24	0
2013	0	0	1	0
2014	0	1	0	1
2015	0	4	11	6

Other

In addition to the bycatch described above the following were captured and noted: lamprey ammocetes (family *Petromyzontidae*), sculpin (*Cottus* spp.), dace (*Rhynichthys* spp.), Three-spine Sticklebacks (*Gasterosteus aculeatus*), sunfish (*Lepomis* spp.), Yellow Perch (*Perca flavescens*), Black Crappie (*Pomoxis nigromaculatus*), Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*Micropterus salmoides*), Mountain Whitefish (*Prosopium williamsoni*), suckers (*Catostomus* spp.), Fathead Minnow (*Pimephales* promelas) and Brown Bullhead (*Ameiurus nebulosus*).

Discussion

Prior to 2009, little was known about the freshwater demographics or life history patterns of juvenile salmon and steelhead in the Nisqually River. From 2009 to 2015, biological data was collected from outmigrating juvenile salmon and steelhead captured in the Nisqually River using a screw trap. We estimated abundance, productivity and life history diversity for the ESA listed fall Chinook salmon and winter steelhead in this watershed. The Nisqually screw trap monitoring study was able to complete all of the proposed goals and objectives. The trap was also used to accommodate outside studies to address pertinent monitoring and resource management questions.

Abundance estimates were calculated annually for the two target species, Chinook salmon and steelhead trout within the precision guidelines recommended by Crawford and Rumsey (2011). Abundance estimates were also calculated for Coho and Chum salmon in all years and for Pink salmon during their even year outmigrations. All of these abundance estimates should be considered minimums for the entire system because an unknown number of the juvenile salmon and steelhead emerge or rear in the 12.8 river miles downstream from the juvenile trap site. Further, an unknown number of Chinook outmigrants move past the trap site prior to trap installation and after trap removal and are not accounted for in the abundance estimates.

Chinook

The smolt recruits per spawner time series was too sparse to fit a formal stock-recruit curve (e.g., Ricker or Beverton-Holt). However, the productivity time series shows positive linear relationships for both fry and parr life history as well as complete brood (sub-yearling plus yearling) outmigrations. Further, the protracted run timing coupled with the relatively large proportions of river-reared sub-yearling parr, the annual presence of yearling outmigrants and the large size obtained by sub-yearling parr all suggest that there that the Nisqually River has ample high quality rearing habitat for the juvenile Chinook at the abundances we have typically observed thus far. However, at low abundances, outmigrations were dominated by parr outmigrants, with very few fry outmigrants, suggesting fry migration is more common when rearing densities are higher. For watersheds with longer time series and higher spawning abundances than the Nisqually River, previous work has demonstrated that parr production was density dependent whereas fry production is density independent (Zimmerman et al. 2015, Anderson and Topping 2018). As the Nisqually outmigrant time series accumulates, we plan to directly test for density dependent freshwater productivity.

Estimates of sub-yearling Chinook outmigrant abundance and productivity were consistently lower than the average smolt abundance of 500,000 outmigrants and intrinsic productivity of 260 migrants per spawner predicted by the Ecosystem Diagnosis and Treatment (EDT) model (Blair 2017). These predictions are based on the assumption of a fully fit population that fully seeds the available habitat. The large difference between the EDT predictions and the empirical estimates presented here suggest that these assumptions are not met. Furthermore, the empirical time series may help inform the model through benchmarking model predictions against measured data, incorporating the measured data into model parameters, and using the measured data to better understand the ecological processes being modeled.

Estimates of marine survival are still limited due to the variable age at maturity (age-2 to age-5) for Chinook salmon. Three complete broods have returned from the six years of trapping presented here. Marine survival estimates for both natural-origin and hatchery-origin Chinook from the Nisqually had a similar pattern of relatively low followed by high and then moderate survival rates for the three available years. This pattern was generally consistent among South Puget Sound hatcheries suggesting that all of these fish are experiencing similar conditions during the marine phase of their life history (Table 7 and Table 31).

Table 31. –Marine survival of South Puget Sound hatchery sub-yearling Chinook for complete brood years 2008-2010. Table provided by J. Losee, WDFW.

	River				
Brood Year	Chambers	Nisqually	Puyallup	Deschutes	Minter
2008	0.26%	0.35%	0.52%	0.05%	0.14%
2009	0.38%	0.99%	0.51%	0.29%	0.53%
2010	0.34%	0.53%	0.25%	0.15%	0.19%

The sub-yearling Chinook outmigration consistently encompassed the entire trapping season and was typically bimodal, composed of recently emerged fry during the first mode followed by river reared parr during the second mode. This pattern was similar to that of other Puget Sound systems (Topping et al. 2006, Topping et al. 2008, Zimmerman et al. 2015, Kiyohara 2016, Anderson and Topping 2018). However, in 2014 and 2015 when sub-yearling Chinook abundance was low, the migration timing curve was unimodal and composed of parr.

Within these general life history patterns, we observed some important differences between the Nisqually population and other Puget Sound Chinook populations. Specifically, parr outmigrated later and were larger in body size compared to other Puget Sound populations. The increase in size over time, from fry to parr, plateaus at about 90 mm in mid-July for the remainder of the trapping season suggesting an upper size (fork length) limit in the Nisqually. This is different from other Puget Sound outmigrant trapping operations where this asymptote in size is not observed and average size of sub-yearling Chinook consistently increases to about 80 mm at the end of the trapping season when daily catches are at or near zero (Topping et al. 2006, Topping et al. 2008, Zimmerman et al. 2015, Kiyohara 2016, Anderson and Topping 2018). We speculate that the relatively cold temperatures and stable flows provided by the large bottom draw dams in the system contribute to the apparently extended rearing and growing season in the Nisqually River.

Finally, Nisqually fall-run Chinook consistently produced yearling outmigrants, which is a migration strategy commonly associated with spring-run Chinook salmon populations (Beechie 2006). These observations emphasize the role environmental conditions have in shaping life history patterns migration timing and size of juvenile Chinook salmon. The Nisqually spawning population was predominately a fall-run stock derived from the Green River (out of basin), where yearling migrants are rarely encountered (Anderson and Topping 2018). If migration patterns were entirely shaped by genetic lineage rather than river conditions, we would expect more similar patterns, and few yearling outmigrants, to the Green River population.

Steelhead smolts

Steelhead smolts are often more difficult to capture in partial capture traps such as rotary screw traps because they tend to be older and larger than sympatric salmon smolts. Therefore, basic metrics of steelhead abundance, productivity, and survival have typically been limited to small streams with census counts at barrier traps that may not be representative of the large rivers found within Puget Sound. The Nisqually trap is one of two large river rotary screw traps in Puget Sound where WDFW annually estimates steelhead smolt abundance (Dungeness is the other). Thus, the combined juvenile and adult abundance estimates provide a relatively unique opportunity in this region to assess steelhead population dynamics in a large river.

The smolt recruits per spawner time series was too sparse to detect any initial trends or fit a formal stock-recruit curve. However, estimates of freshwater productivity appear to be high. Losee et al. (*in prep*) recently reviewed the estimates of productivity and how various sources of error associated with the escapement estimate, smolt abundance estimate and alternative sources of production, e.g., resident *O.mykiss* and leakage of catchable-size trout stocked in area lowland lakes may bias these estimates. To address these potential biases, escapement estimates for steelhead were restricted to mainstem adult returns because methods and effort have been consistent. Veteran crews surveyed the entire mainstem Nisqually to get accurate unbiased counts of the total number of redds. Tributary data was not used because of inconsistencies in tributary survey methods during our years of interest. Smolt abundance estimates were stratified to account for temporal changes in trap efficiency during the outmigration and to minimize bias. Abundance estimates were relatively precise with a coefficient of variation typically under 15%. Resident *O. mykiss* contribution was low with about 10% of steelhead smolts captured in the Nisqually trap. Field identification of steelhead smolts and hatchery rainbow trout were validated by assessing growth patterns in scale samples. After addressing these potential sources of bias, Losee et al. (*in prep*) supported the smolts per spawner estimates presented here and concluded that this is a productive population of steelhead

Nisqually River steelhead appear to be a rather productive population relative to others across the range. In a comprehensive analysis of smolt and spawner data for western Washington steelhead the Nisqually population had the highest estimates of intrinsic productivity among 15 populations (Buehrens *in prep*). For most years, abundance estimates were consistent with the EDT prediction of 57,536 outmigrants, based on current habitat conditions (Nisqually Steelhead Recovery Team 2014). The agreement between the model predictions and the outmigration estimates suggests that marine survival, and not freshwater productivity, is currently limiting adult abundance.

Steelhead have a diverse suite of life history traits. This diversity in life history traits provides a buffer against variable environmental conditions and tends to keep steelhead populations more stable and less vulnerable to large swings in abundance. The Nisqually River appears to have a number of unique life history traits. Nisqually steelhead smolts were relatively large, young, and therefore their size at age was large. Average fork length of smolts was consistently larger than steelhead in the Skagit, Green, Dungeness, Duckabush or Big Beef watersheds (WDFW unpublished data). Nisqually steelhead smolts were also younger on average than the Skagit and Dungeness rivers, which tend to have an age structure made up of predominately age-2 and age-3 smolts (WDFW unpublished data). Similar to the Green River, in Central Puget Sound, age-1 smolts were a significant component of the Nisqually outmigration (WDFW unpublished data). Maintaining and promoting the life history traits that are unique to the Nisqually is critical to maintaining a robust and sustainable population.

Steelhead smolts length, age composition, and productivity displayed considerable variation among years. Within this annual variability, there were distinct repetitive patterns. Mean fork lengths of outmigrating cohorts alternated annually between being larger and smaller, fluctuating up to 13 mm among years. Relative freshwater survival fluctuated annually as well, with an alternating pattern of high and low survival rates. This variability in freshwater survival is reflected in the age structure of ocean entry year cohorts. For example, steelhead smolts from brood year 2010 had a relatively low freshwater survival rate that aligned with relatively small proportions of age-1, age-2 and age-3 smolts outmigrating in the successive cohorts. By contrast, brood year 2011 had a relatively high freshwater survival and subsequently appears to have had relatively large proportions of age-1, age-2 and age-3 smolts outmigrating in the successive cohorts. These alternating patterns of size and age appear to coincide with patterns of even-year pink abundance. Specifically, steelhead smolts were larger in years that coincided with Pink fry outmigrations and broods with higher relative freshwater survival occurred in years with Pink adult returns. It appears that steelhead smolts benefit from the pulsed nutrient subsidy provided by even-year Pink salmon.

Yearling Coho

The average Coho yearling production above the trap for these six years of trapping was 161,209 outmigrants, consistent with 147,197 production potential predicted by Zillges (1977). The Zillges (1977) prediction was based on the average quantity of summer rearing habitat and assumes that summer low flows are the major factor limiting Coho smolt production. While there is some variability in annual production, on average the Nisqually appears to be producing at or near capacity based on the Zillges method.

Yearling Coho were consistently captured prior to the concerted yearling smolt migration and it was unclear if they are actively outmigrating or simply redistributing. Estuary sampling by the Nisqually Indian Tribe (NIT) show catches of Coho in the Nisqually nearshore in March and April suggesting that these early catches of yearling Coho are active outmigrants (Hodgson et al. 2016).

Chum fry

Similar to the other species the smolt recruits per spawner time series is too sparse to fit a formal stock-recruit curve. Though it is premature to draw any conclusions, productivity was variable; with high and low levels of outmigrants produced from similar levels of escapement, suggesting environmental factors may have a strong influence on survival. Interannual variation in estimates of salmon productivity can be influenced by flow when eggs are in the gravel in other Puget Sound rivers (Weinheimer et al. 2017; Zimmerman et al. 2015; Anderson and Topping 2018). Consequently, it may be worth exploring correlations between flow and Chum salmon productivity in the Nisqually.

Marine survival appears to be rather high compared to the other sub-yearling outmigrants (Chinook and Pink) as well as Chum in the Duckabush River (Weinheimer 2016). This may be a result of spawning below the trap in the mainstem Nisqually River as well as Muck Creek, a known spawning tributary for Chum that enters the Nisqually about 2 river miles below the trap (C. Smith, NIT, personal communication). We likely did not catch any fry produced below the trap and consequently they are not accounted for in the abundance estimate. As a result, we have likely underestimated the total fry abundance and outmigrants per spawner, while overestimating smolt to adult return survival.

Pink fry

The smolt recruits per spawner time series is too sparse to fit a formal stock-recruit curve. The productivity estimate for the 2009 brood was greater than a reasonable fecundity for a female Pink salmon. This estimate was likely inflated because of combination of apparent high freshwater survival coupled with an underestimated escapement.

The Nisqually had substantial increases of adult Pink returns during the years of trap operation compared to the prior 50 years and the ecological implications have yet to be determined. There appears to be a Pink salmon effect signal with younger steelhead smolts in the years following an odd-year adult pink return. However, we did not observe a clear effect of pinks on Coho salmon or Chinook salmon, both of which have at least some extended river rearing and overlap in spawning spatial distribution.

O. nerka

All *O. nerka* captured in the trap were originally assumed to be sockeye salmon outmigrants. However, Alder Lake is annually stocked with kokanee fry in late spring and fingerlings (a portion of which are ad-marked) in the autumn (L. Phillips, WDFW, personal communication). In 2011, we captured two ad-marked fingerling sized *O. nerka* that could be attributed to the Alder Lake plantings, and many fry sized *O. nerka* that had not been observed in the previous years. The WDFW Ageing Lab assessed otolith annuli patterns from a small subsample (N = 4) to determine whether they reared in a riverine or lacustrine environment. Results from the otolith analysis revealed that samples displayed annuli spacing consistent with either a lacustrine environment or hatchery rearing. These results coupled with the fry showing up in the trap within a week of the spring kokanee stocking event suggested their hatchery origin. As there are few accessible natural lakes in the Nisqually system, these *O. nerka* juveniles were likely kokanee that had been stocked in Alder Lake and subsequently moved into the river.

Rainbow trout

During the first two years of operation, we captured a large number of hatchery rainbow trout. These unmarked trout were identified as hatchery origin by their catch timing in the trap and phenotypic characteristics. Similar to the kokanee fry, we began capturing these trout within a week of the annual lowlands lakes stocking and they displayed a number of characteristics associated with hatchery rearing such as stubbed dorsal fins, stubbed snouts and eroded pectoral fins. Harts, Ohop and Tanwax lakes, within the Nisqually River basin, were stocked annually with “catchable” sized (200 to 280 mm total length) rainbow trout to provide a valuable sport fishery for the region. Washington Department of Fish and Wildlife staff suspected that the source of rainbow trout moving into the river was Ohop Lake. Consequently, in 2011, two-thirds of the fish stocked in Ohop Lake were ad-marked prior to stocking. This marking rate matched the ad-marked to unmarked ratio observed at the trap thus suggesting that a portion of the rainbow trout stocked in Ohop Lake were leaving the lake. Because of these findings, the stocking practices and management of Ohop Lake has changed to limit possibility of escape into the river (J. Losee, WDFW Region 6, personal communication). The number of hatchery Rainbows captured in the trap initially dropped substantially (six were captured in 2013) with the revised stocking practices. However, in 2014 and 2015 we observed an increase in catches suggesting escape from Harts or Tanwax lakes. Beginning in 2015 WDFW began stocking triploid trout in Ohop and Hart's lakes to reduce the risk of genetic introgression with native Nisqually River *O.mykiss*.

Independent studies

The effectiveness of the Nisqually trap provided the opportunity to accommodate independent studies to address pertinent resource management questions while maintaining the goals and objectives of the monitoring study. The Nisqually screw trap monitoring study provided data, physical samples, and logistical support in collaboration with other entities to produce the following technical reports and peer review publications.

Hayes et al. (2013) used lamprey collected from the Nisqually trap to help determine the current distribution of Pacific lamprey in major watersheds flowing into Puget Sound.

Lind-Null and Larsen (2011) analyzed the microstructure of juvenile Chinook otoliths collected at the Nisqually trap to confirm a Nisqually-specific freshwater microstructure pattern observed in Chinook otoliths collected in the Nisqually River delta.

Nisqually Steelhead Recovery Team (2014) included a section that summarized trap operations and described life history characteristics based on biological information collected at the Nisqually trap to describe the steelhead population in the Nisqually River.

The Nisqually is the southernmost steelhead population within Puget Sound and faces the challenge of a long distance migration through this changing ecosystem. . For this reason, coupled with the consistent catches of juvenile steelhead, the Nisqually juvenile monitoring study has been an integral part of the early marine survival and fish health assessment components of the Salish Sea Marine Survival Project (http://marinesurvivalproject.com, Moore et al. 2015, Moore and Berejikian 2017, and Chen et al. 2018.)

Losee et al. (*in prep*), conducted a formal investigation to validate the estimates of productivity by attempting to account for the variance associated with the escapement estimate as well as evaluating resident *O. mykiss* contribution with otolith microchemistry. This investigation concluded that the estimates of productivity are likely accurate and that this is a productive population of steelhead.

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Appendices

Appendix A. –Summary of maiden catch (recaptures censored), estimated missed catch, number of marked fish released for efficiency trials, number of subsequent recaptures, abundance estimate and associated variance by strata for sub-yearling Chinook outmigrating past the Nisqually River rotary screw trap (river mile 12.8), 2009-2015.

	Dates		Catch				Abundance	
Strata	Begin	End	Actual	Missed	Marked	Recaptured	Estimate	Variance
1	01/16/09	02/21/09	2,893	220	2,873	96	92,234	90,457,206.9
2	02/22/09	03/14/09	4,219	0	3,861	430	37,804	3,239,344.8
3	03/15/09	03/28/09	2,432	0	2,217	111	48,162	20,388,538.6
4	03/29/09	04/04/09	896	0	645	67	8,512	1,010,830.8
5	04/05/09	04/18/09	2,824	8	1,824	99	51,684	25,890,775.2
6	04/19/09	06/13/09	2,370	4	1,121	76	34,592	14,752,757.8
7	06/14/09	07/25/09	13,105	0	2,737	393	91,069	18,515,700.0
8	07/26/09	08/01/09	1,303	13	400	34	15,077	5,925,127.5
9	08/02/09	08/15/09	1,282	0	546	26	25,972	23,384,752.7
10	08/16/09	08/22/09	538	7	279	49	3,052	164,050.5
		Total:	**31,862**	**252**	**16,503**	**1,381**	**408,158**	**203,729,084.8**
1	01/13/10	07/04/10	6,171	992	2,846	229	88,665	46,469,062.1
2	07/05/10	07/11/10	925	29	540	35	14,336	5,383,849.0
3	07/12/10	07/23/10	2,059	0	612	49	25,243	11,754,160.4
		Total:	**9,155**	**1,021**	**3,998**	**313**	**128,244**	**63,607,071.4**
1	01/24/11	04/10/11	2,439	194	1,116	41	70,025	116,780,037.4
2	04/11/11	07/03/11	2,038	86	474	96	10,401	951,898.1
3	07/04/11	07/24/11	2,982	0	1,033	149	20,555	2,512,712.1
4	07/25/11	08/25/11	1,684	137	915	108	15,303	2,033,285.6
		Total:	**9,143**	**417**	**3,538**	**394**	**116,284**	**122,277,933.2**
1	01/13/12	02/19/12	2,003	160	1,198	54	45,498	37,645,568.4
2	02/20/12	06/17/12	3,599	297	2,983	83	141,776	270,103,712.7
3	06/18/12	07/01/12	1,047	0	901	113	8,284	578,101.5
4	07/02/12	07/15/12	1,798	94	1,655	98	31,648	10,363,665.8
5	07/16/12	08/10/12	1,942	0	1,968	206	18,472	1,624,550.6
		Total:	**10,389**	**551**	**8,705**	**554**	**245,678**	**320,315,598.9**
1	01/17/13	02/03/13	539	9	463	7	31,784	111,937,585.9
2	02/04/13	05/19/13	2,727	19	1,802	95	51,573	26,904,181.4
3	05/20/13	05/26/13	226	0	73	18	880	31,212.7
4	05/27/13	06/16/13	663	11	497	42	7,805	1,353,331.2

5	06/17/13	06/30/13	1,087	0	843	114	7,977	524,023.0
6	07/01/13	07/21/13	3,335	0	1,979	229	28,710	3,371,250.0
7	07/22/13	07/28/13	891	110	341	42	7,961	1,333,078.4
8	07/29/13	08/22/13	857	131	422	55	7,462	3,049,821.2
		Total:	**10,325**	**280**	**6,420**	**602**	**144,152**	**148,504,483.8**
1	01/23/14	05/25/14	705	11	456	26	12,118	5,172,934.8
2	05/26/14	06/08/14	522	50	351	47	4,194	410,133.2
3	06/09/14	06/15/14	233	50	175	62	790	18,312.1
4	06/16/14	06/22/14	728	151	521	107	4,248	162,186.2
5	06/23/14	07/13/14	2,528	321	1,666	227	20,830	2,045,730.2
6	07/14/14	07/27/14	2,042	0	1,072	76	28,455	9,999,302.4
7	07/28/14	08/11/14	1,183	649	615	92	12,134	3,965,945.1
		Total:	**7,941**	**1,232**	**4,856**	**637**	**82,769**	**21,774,544.0**
1	01/16/15	06/28/15	694	9	421	33	8,725	2,104,847.20
2	06/29/15	08/27/15	829	239	803	32	26,020	23,361,938.40
		Total:	**1,523**	**248**	**1,224**	**65**	**34,745**	**25,466,785.6**

Appendix B–Summary of maiden catch (recaptures censored), estimated missed catch, number of marked fish released for efficiency trials, number of subsequent recaptures, abundance estimate and associated variance by strata for yearling Chinook outmigrating past the Nisqually River rotary screw trap (river mile 12.8), 2009-2015.

	Dates		Catch				Abundance	
Strata	Begin	End	Actual	Missed	Marked	Recaptured	Estimate	Variance
1	01/16/09	08/22/09	880	89	553	50	10,526	2,159,544.4
		Total:	**880**	**89**	**553**	**50**	**10,526**	**2,159,544.4**
1	01/13/10	03/28/10	97	0	47	16	273	3,164.4
2	03/29/10	05/02/10	162	2	92	13	1,089	73,499.0
3	05/03/10	07/23/10	605	72	204	9	13,878	16,995,466.3
		Total:	**864**	**74**	**343**	**38**	**15,240**	**17,072,129.7**
1	01/24/11	05/29/11	20	0	N/A	N/A	318	93,803.4
2	05/30/11	06/05/11	10	0	N/A	N/A	70	0.0
3	06/06/11	06/12/11	0	0	N/A	N/A	0	0.0
4	06/13/11	08/25/11	17	1	N/A	N/A	79	7,242.9
		Total[a]:	**47**	**1**	**N/A**	**N/A**	**467**	**101,046.3**
1	01/13/12	05/27/12	25	0	N/A	N/A	764	4,306,176.7
2	05/28/12	06/03/12	7	0	N/A	N/A	80	0.0
3	06/04/12	06/17/12	3	0	N/A	N/A	103	350,177.0
4	06/18/12	08/10/12	2	0	N/A	N/A	13	224.3
		Total[a]:	**37**	**0**	**N/A**	**N/A**	**960**	**4,656,578.0**
1	01/17/13	08/22/13	242	5	51	5	2,140	600,529.0
		Total:	**242**	**5**	**51**	**5**	**2,140**	**600,529.0**
1	01/23/14	08/11/14	249	11	144	21	1,713	125,608.0
		Total:	**249**	**11**	**144**	**21**	**1,713**	**125,608.0**
1	01/16/15	04/26/15	25	0	N/A	N/A	124	60,750.2
2	04/27/15	05/17/15	47	0	N/A	N/A	352	401,814.5
3	05/18/15	05/24/15	17	0	N/A	N/A	1712	0.0
4	05/25/15	08/27/15	30	0	N/A	N/A	636	2,725,494.9
		Total[a]:	**119**	**0**	**N/A**	**N/A**	**1,284**	**3,188,060.6**

[a] Denotes year when yearling Coho stratified efficiencies were used as a surrogate to estimate abundance. The lower limit of the 95% confidence interval would estimate a negative abundance thus the lower limit was reported as the actual catch during these years.

Appendix C –Summary of maiden catch (recaptures censored), estimated missed catch, number of marked fish released for efficiency trials, number of subsequent recaptures, abundance estimate and associated variance by strata for steelhead smolts outmigrating past the Nisqually River rotary screw trap (river mile 12.8), 2009-2015.

	Dates		Catch				Abundance	
Strata	Begin	End	Actual	Missed	Marked	Recaptured	Estimate	Variance
1	01/16/09	06/06/09	2,070	8	1,860	78	48,951	29,797,272.6
2	06/07/09	08/22/09	658	0	605	77	5,112	322,399.2
		Total:	**2,728**	**8**	**2,465**	**155**	**54,063**	**30,119,671.8**
1	01/13/10	04/11/10	35	0	27	5	163	3,523.1
2	04/12/10	05/16/10	1,156	64	917	19	55,998	148,605,147.6
3	05/17/10	07/23/10	2,298	171	1,123	71	38,543	19,898,767.4
		Total:	**3,489**	**235**	**2,067**	**95**	**94,704**	**168,507,438.1**
1	01/24/11	06/12/11	2,982	200	2,032	108	59,348	33,861,923.5
2	06/13/11	08/25/11	193	0	165	22	1,392	77,945.0
		Total:	**3,175**	**200**	**2,197**	**130**	**60,740**	**33,939,868.5**
1	01/13/12	08/10/12	530	1	493	12	20,178	29,012,559.7
		Total:	**530**	**1**	**493**	**12**	**20,178**	**29,012,559.7**
1	01/17/13	05/19/13	1,595	12	1,241	40	48,680	56,093,908.0
2	05/20/13	08/22/13	2,584	2	1,650	107	39,532	13,959,488.0
		Total:	**4,179**	**14**	**2,891**	**147**	**88,212**	**70,053,396.0**
1	01/23/14	05/18/14	1,712	229	851	56	29,012	20,933,960.8
2	05/19/14	06/01/14	2,262	0	1,424	201	15,957	1,172,670.1
3	06/02/14	06/08/14	566	43	498	41	7,235	2,309,985.1
4	06/09/14	08/11/14	232	50	204	18	3,042	1,390,172.6
		Total:	**4,772**	**322**	**2,977**	**316**	**55,246**	**25,806,788.6**
1	01/16/15	08/27/15	2,500	15	2,017	92	54,572	31,363,815.2
		Total:	**2,500**	**15**	**2,017**	**92**	**54,572**	**31,363,815.2**

Appendix D –Summary of maiden catch (recaptures censored), estimated missed catch, number of marked fish released for efficiency trials, number of subsequent recaptures, abundance estimate and associated variance by strata for yearling Coho outmigrating past the Nisqually River rotary screw trap (river mile 12.8), 2009-2015.

	Dates		Catch				Abundance	
Strata	Begin	End	Actual	Missed	Marked	Recaptured	Estimated	Variance
1	01/16/09	03/07/09	255	3	253	35	1,820	88,938.7
2	03/08/09	03/14/09	52	0	38	12	156	1,448.6
3	03/15/09	04/18/09	192	0	143	16	1,626	141,074.2
4	04/19/09	04/25/09	207	0	63	17	736	22,273.7
5	04/26/09	05/23/09	5,745	0	1,933	174	63,490	21,465,711.3
6	05/24/09	06/13/09	7,130	37	1,094	174	44,844	9,838,201.3
7	06/14/09	06/20/09	1,093	0	400	34	12,522	4,103,138.1
8	06/21/09	08/22/09	576	0	366	63	3,303	153,970.6
		Total:	**15,250**	**40**	**4,290**	**525**	**128,497**	**35,814,756.5**
1	01/13/10	03/28/10	323	0	155	23	2,099	160,282.7
2	03/29/10	04/11/10	210	16	139	8	3,515	1,508,933.0
3	04/12/10	04/18/10	147	0	65	15	606	18,169.0
4	04/19/10	05/02/10	1,558	0	463	55	12,909	2,663,165.9
5	05/03/10	05/09/10	1,375	331	197	6	48,255	296,260,265.1
6	05/10/10	05/30/10	11,876	298	1,052	141	90,276	49,958,577.6
7	05/31/10	06/20/10	905	770	504	41	20,139	10,570,977.0
8	06/21/10	07/23/10	227	2	148	23	1,421	75,056.6
		Total:	**16,621**	**1,417**	**2,723**	**312**	**179,220**	**361,215,426.8**
1	01/24/11	05/29/11	12,283	1,236	2,112	133	213,176	455,661,260.4
2	05/30/11	06/05/11	3,268	0	399	57	22,537	7,491,734.7
3	06/06/11	06/12/11	695	219	296	17	15,081	11,635,656.3
4	06/13/11	08/25/11	833	0	531	120	3,662	97,278.4
		Total:	**17,079**	**1,455**	**3,338**	**327**	**254,456**	**474,885,929.8**
1	01/13/12	05/27/12	2,216	27	2,138	70	68,026	65,704,812.9
2	05/28/12	06/03/12	310	0	311	27	3,454	408,354.4
3	06/04/12	06/17/12	267	1	308	9	8,281	6,257,971.6
4	06/18/12	08/10/12	50	0	45	7	287	8,800.7
		Total:	**2,843**	**28**	**2,802**	**113**	**80,048**	**72,379,939.6**
1	01/17/13	04/21/13	801	147	344	19	17,213	16,194,815.0
2	04/22/13	05/05/13	2,728	0	1,366	138	26,828	4,853,794.0
3	05/06/13	05/19/13	7,279	0	1,400	263	38,194	4,567,540.0

4	05/20/13	05/26/13	5,562	0	600	142	21,566	2,274,157.0
5	05/27/13	06/09/13	3,731	0	1,293	192	25,015	2,886,420.0
6	06/10/13	06/23/13	1,541	23	939	42	34,189	26,055,372.0
7	06/24/13	08/22/13	216	2	63	9	1,395	156,381.4
		Total:	**21,858**	**172**	**6,005**	**805**	**164,400**	**56,988,479.4**
1	01/23/14	05/04/14	3,412	134	1,347	72	65,479	55,941,581.3
2	05/05/14	05/18/14	7,462	1,230	997	110	78,149	139,860,810.7
3	05/19/14	06/01/14	7,453	0	1,400	305	34,123	3,086,085.1
4	06/02/14	06/15/14	2,097	352	1,065	114	22,701	21,403,721.1
5	06/16/14	08/11/14	551	37	332	57	3,375	179,241.3
		Total:	**20,975**	**1,753**	**5,141**	**658**	**203,827**	**220,471,439.5**
1	1/16/2015	4/25/2015	573	1	342	69	2,812	99,498.4
2	4/26/2015	5/17/2015	3,332	0	1,887	252	24,864	2,267,979.6
3	5/18/2015	5/24/2015	829	0	627	62	8,263	1,032,919.3
4	5/25/2015	8/27/2015	3,859	83	1,760	83	82,641	78,276,198.7
		Total:	**8,593**	84	**4,616**	**466**	**118,580**	**81,676,596.0**

Appendix E–Summary of maiden catch (recaptures censored), estimated missed catch, number of marked fish released for efficiency trials, number of subsequent recaptures, abundance estimate and associated variance by strata for Chum fry outmigrating past the Nisqually River rotary screw trap (river mile 12.8), 2009-2015.

	Dates		Catch				Abundance	
Strata	Begin	End	Actual	Missed	Marked	Recaptured	Estimated	Variance
1	01/16/09	04/25/09	9,938	14	2,414	256	93,517	31,079,144.7
2	04/26/09	08/22/09	4,532	2	1,510	103	65,873	39,365,905.6
		Total:	**14,470**	**16**	**3,924**	**359**	**159,390**	**70,445,050.3**
1	01/13/10	02/28/10	229	0	55	8	1,424	177,097.9
2	03/01/10	03/28/10	1,289	0	389	27	17,953	10,541,388.3
3	03/29/10	04/11/10	1,469	16	667	18	52,209	134,623,947.9
4	04/12/10	04/25/10	4,322	0	1,974	148	57,288	20,926,351.2
5	04/26/10	07/23/10	2,120	125	539	5	202,050	5,800,182,737.9
		Total:	**9,429**	**141**	**3,624**	**206**	**330,924**	**5,966,451,523.1**
1	01/24/11	04/10/11	1,943	117	703	23	60,426	151,410,866.4
2	04/11/11	04/17/11	2,661	285	951	9	280,459	7,177,958,318.3
3	04/18/11	04/24/11	5,652	2,372	597	17	266,575	3,672,321,106.4
4	04/25/11	08/25/11	2,622	25	673	6	254,868	8,072,846,408.3
		Total:	**12,878**	**2,799**	**2,924**	**55**	**862,328**	**19,074,536,699.4**
1	01/13/12	08/10/12	1241	25	601	13	54,438	195,415,269.5
		Total:	**1,241**	**25**	**601**	**13**	**54,438**	**195,415,269.5**
1	01/17/13	04/07/13	1,986	276	1,669	185	20,318	7,224,753.0
2	04/08/13	08/22/13	1,728	125	1,037	14	128,227	1,160,543,072.0
		Total:	**3,714**	**401**	**2,706**	**199**	**148,545**	**1,167,767,825.0**
1	01/23/14	08/11/14	625	3	355	12	17,197.0	20,825,943.0
		Total:	**625**	**3**	**355**	**12**	**17,197**	**20,825,943.0**
1	01/16/15	04/12/15	1,485	0	1,086	29	53,806	92,648,718.1
2	04/13/15	04/26/15	2,002	0	1,723	31	107,857	351,510,858.6
3	04/27/15	08/27/15	1,986	0	1,270	34	72,120	142,978,687.7
		Total:	**5,473**	**0**	**4,079**	**94**	**233,783**	**587,138,264.4**

Appendix F–Summary of maiden catch (recaptures censored), estimated missed catch, number of marked fish released for efficiency trials, number of subsequent recaptures, abundance estimate and associated variance by strata for Pink fry outmigrating past the Nisqually River rotary screw trap (river mile 12.8) during even years, 2009-2015.

	Dates		Catch				Abundance	
Strata	Begin	End	Actual	Missed	Marked	Recaptured	Estimated	Variance
1	01/13/10	01/31/10	619	10	272	12	13,209	1.21E+07
2	02/01/10	02/14/10	5,632	0	1,495	16	495,616	1.35E+10
3	02/15/10	02/21/10	6,731	0	768	36	139,895	4.93E+08
4	02/22/10	03/21/10	367,292	0	2,979	490	2,229,185	8.45E+09
5	03/22/10	03/28/10	536,853	0	798	96	4,422,119	1.75E+11
6	03/29/10	04/04/10	212,820	28,531	600	16	8,532,467	5.94E+12
7	04/05/10	04/11/10	117,027	0	800	65	1,420,282	2.76E+10
8	04/12/10	04/25/10	66,848	0	1,385	222	415,476	6.49E+08
9	04/26/10	07/23/10	1,088	11	403	13	31,714	6.56E+07
		Total:	**1,314,910**	**28,552**	**9,500**	**966**	**17,699,963**	**6.17E+12**
1	01/13/12	03/18/12	4,495	1,814	2,493	11	1,311,220	1.56E+11
2	03/19/12	04/22/12	86,508	2,396	14,856	205	6,411,877	2.19E+11
3	04/23/12	08/05/12	3,391	226	715	2	863,257	1.88E+11
		Total:	**94,394**	**4,436**	**18,064**	**218**	**8,586,354**	**5.63E+11**
1	01/23/14	03/09/14	16,038	8,848.1	185	8	514,313	3.10E+10
2	03/10/14	03/23/14	53,362	9,457.9	1381	21	3,946,230	7.96E+11
3	03/24/14	04/06/14	250,738	0.0	2737	96	7,077,532	4.93E+11
4	04/07/14	08/11/14	289,817	182.0	3145	56	16,005,909	4.34E+12
		Total:	**609,955**	**18,488**	**7,448**	**181**	**27,543,984**	**5.66E+12**