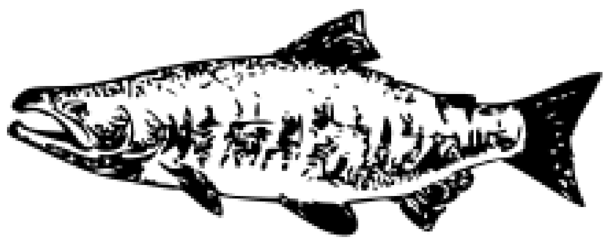
Mid-Hood Canal Juvenile Salmonid Evaluation: Duckabush River 2013



Josh Weinheimer

Washington Department of Fish and Wildlife

Fish Program, Science Division

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Acknowledgements

Measuring juvenile salmonid production from large systems like the Duckabush River involves a tremendous amount of work. The Duckabush River juvenile trap was operated by dedicated scientific technician Phil Aurdal from the Washington Department of Fish and Wildlife. Logistical support was provided by Wild Salmon Production Evaluation Unit biologist Pete Topping.

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Executive Summary

Juvenile salmonid monitoring on the Duckabush River, located in central Hood Canal, Washington, began in 2007. This work has been a collaborative project between the Washington Department of Fish and Wildlife (WDFW), Long Live the Kings (LLTK), and the Northwest Fisheries Science Center's (NWFSC) Manchester Research Station. This study measures the juvenile abundance and outmigration timing of Chinook salmon, chum salmon, pink salmon (even years only), coho salmon, and steelhead. We derive independent estimates for summer and fall chum salmon stocks in these watersheds via molecular genetic analysis. For those species with adult abundance surveys (chum, Chinook and pink salmon), we also estimate egg to migrant survival.

In 2013, a floating eight-foot screw trap was located at river mile 0.3 (0.48 rkm) and operated by WDFW from January 10 to July 2. The abundance of juvenile summer chum salmon was over six times larger than fall chum (Table 1). Egg-to-migrant survival was higher for summer than fall chum salmon. The peak of the summer chum outmigration occurred 4 weeks earlier than the peak of the fall chum outmigration. Chum salmon were by far the most abundant salmonid species emigrating from the Duckabush River in 2013 (Table 1).

TABLE 1.—Abundance, coefficient of variation (CV), egg-to-migrant survival, average fork length and median out-migration date for juvenile salmonids of natural origin leaving the Duckabush River, 2013.

	Abundance				
Species	**Estimate**	**CV**	**Survival**	**Median migration date**	**Average fork length**
Summer chum	285,468	5.1%	5.0%	9-Mar	-
Fall chum	42,213	14.6%	1.2%	7-Apr	-
Chinook	5,221	6.2%	52.2%	2-Apr	38.8 (±6.1)
Coho	6,732	22.1%	-	6-May	91.9 (±12.3)
Steelhead	1,908	15.3%	-	3-May	171.8 (±22.7)

Introduction

The Duckabush is a high-gradient watershed that drains into the western side of Hood Canal, Washington. Peak flow events in this watershed occur twice each year, during rain-on-snow events in the winter months and snow melt in the spring months. The Duckabush system originates in the Olympic Mountains within the Olympic National Park. Human development is minimal with the exception of light logging activity in the upper watershed and residential homes and dikes in the lower part of the river and estuary.

The Duckabush river supports a diverse salmonid community, including Chinook salmon (*Oncorhynchus tshawytscha),* chum salmon (*O. keta*), pink salmon (*O. gorbuscha*), coho salmon (*O. kisutch*), and steelhead trout (*Oncorhynchus mykiss*). Three of the salmonid species are federally protected under the Endangered Species Act. Chinook salmon are part of the Puget Sound Chinook Evolutionary Significant Unit (ESU), summer chum populations are part of the Hood Canal summer chum ESU, and steelhead are part of the Puget Sound steelhead ESU, as delineated by the National Marine Fisheries Service.

Chinook salmon in the Duckabush are part of the Puget Sound Chinook ESU listed as *threatened* in 1999 by the National Marine Fisheries Service under the Endangered Species Act (NOAA 1999b). Hood Canal has two genetically distinct Chinook salmon populations, one is the Skokomish River stock and the other is the Mid-Hood Canal stock that is composed of the Hamma Hamma, Duckabush, and Dosewallips subpopulations (Committee 2007).

Summer chum salmon in the Duckabush river are part of the Hood Canal summer chum ESU listed as *threatened* in 1999 by NMFS (NOAA 1999a). The Hood Canal summer chum ESU was historically composed of 16 independent populations (Ames et al. 2000). Summer chum are distinguished from fall and winter chum based on spawn timing and genetic differentiation (Ames et al. 2000; Crawford and Rumsey 2011). Historically, summer chum stocks in Hood Canal returned in the tens of thousands. By 1980, these returns plummeted to fewer than 5,000 adults and 8 of the 16 stocks were considered extinct. To promote conservation, harvest of Hood Canal summer chum was greatly reduced and hatchery supplementation was implemented in order to rebuild stocks to harvestable levels (Ames et al. 2000). The initiative also called for increased monitoring and improvements to freshwater habitat conditions. The Duckabush summer chum stock is one of the eight extant stocks within Hood Canal.

Under NMFS Listing Status Decision Framework, listing status of a species under the Endangered Species Act (ESA) will be evaluated based on biological criteria (abundance, productivity, spatial distribution and diversity) and threats to population viability (e.g., harvest, habitat) (McElhany et al. 2000). A statewide monitoring framework, termed "Fish-In Fish-Out", was developed by the Governor's Forum on Monitoring Salmon Recovery and Watershed Health and recommended the coupling of juvenile and adult monitoring for representative populations within each ESU (Crawford 2007). Guidelines for monitoring data needed to assess recovery status were recently published by the National Marine Fisheries Service (Crawford and Rumsey 2011). At the time of listing, little to no information was available on juvenile abundance or freshwater productivity of Chinook, summer chum, or steelhead in Hood Canal. Freshwater productivity (egg-to-migrant survival or smolts per spawner) is an important factor that contributes to population persistence and resilience (McElhany et al. 2000). Without information on juvenile migrants, managers are limited in their ability to assess the contributions of freshwater versus marine environment towards species recovery.

In response to these information needs, a juvenile monitoring study was initiated on the Duckabush River in 2007. The Duckabush River juvenile trapping project was initiated in 2007 by Long Live the Kings with a focus on wild steelhead production. In 2008, the Duckabush trapping season was expanded to include summer and fall chum, Chinook, and pink salmon and became a joint effort between Washington Department of Fish and Wildlife and Long Live the Kings. Steelhead smolt evaluations from both systems are part of the Hood Canal Steelhead Project led by the NWFSC Manchester Research Station.

This report summarizes results from both watersheds for the 2013 outmigration. Throughout this report, the number of juvenile migrants estimated for a given year will be referred to as "freshwater abundance" because they are the offspring of naturally spawning salmon in the Duckabush River. The combination of juvenile and spawner abundance for the Duckabush populations allows for brood-specific survival to be partitioned between the freshwater and marine environment. Spawner abundance is currently derived by staff from WDFW Region 6 and LLTK. Long-term combination of juvenile and adult abundance data over a range of spawner abundances and flow regimes should provide a measure of freshwater capacity as well as current ranges of freshwater and marine survival.

Objectives

In 2013, the primary objective of this study was to estimate the abundance, survival, and migration timing of juvenile migrants produced by Chinook and chum salmon spawning naturally in the Duckabush River. Additional objectives were to estimate the abundance of yearling coho and steelhead. The long-term goal for this study is to understand the factors that limit productivity of salmonid populations in the Duckabush River.

Methods

Trap Operation

On the Duckabush River, juvenile migrants were captured in a floating screw trap (8-foot or 1.5-m diameter) located on the right bank at river mile 0.3 (0.48 rkm), approximately 1,600 feet (490-m) upstream of the Highway 101 bridge (Figure 1). The trap consisted of two, four-foot wide tapered flights, wrapped 360 degrees around a nine-foot long shaft. These flights were housed inside a eight-foot diameter cone-shaped frame covered with perforated plating. The shaft was aligned parallel with the flow and was lowered to the water's surface via davits and winches mounted on two 20-ft aluminum pontoons. The trap fished half of an eight-foot diameter circle with a cross sectional area of 16*pi = 50.24 ft^2. Water current acting on the flights caused the trap to rotate, and with every 180 degrees of rotation, a flight entered the water while the other emerged. As the leading edge of a flight emerged from the water it prevented the escape of trapped fish. The fish were gently augured into a solid sided, baffled live box.

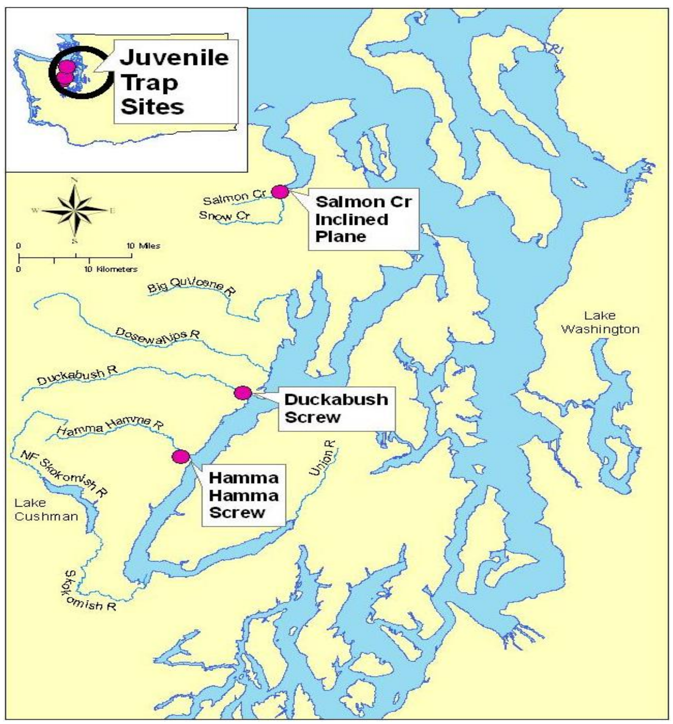

FIGURE 1.─Location of Duckabush screw trap.

Screw traps were fished 24 hours a day, seven days a week, except when flows or debris would not allow the trap to fish effectively (Table 2).

TABLE 2.— Summary of juvenile trap operations for the Duckabush River screw trap, 2013

Trap	Start Date	End Date	Hours Fished	Total Possible Hours	Percent Fished	Number of Outages	Avg Outage Hrs	St Dev.
Duckabush	1/10	7/2	3,845.50	4,125.50	93.21%	6	46.67	21.5

Fish Collection

The trap was checked for fish at dawn each day throughout the trapping season. At each trap check, all captured fish were identified to species and enumerated. A subsample of all captured migrants was measured each week (fork length in mm, FL). Juvenile steelhead were checked for hatchery marks or fin clips (adipose fin). Steelhead of natural origin were sampled for scales and DNA (fin clip).

Tissue was collected from the caudal fin of a subsample of the chum migrants throughout the season (10-40 samples per week). The genetic sampling protocol was designed to estimate a 90% confidence interval within ±10% of the observed value. This approach maximized sample size during the time intervals where summer and fall stocks were expected to overlap in outmigration timing.

Coho were enumerated as either fry or smolts (yearlings). Defining characteristics of coho fry were a bright orange-brown color, elongated white anal fin ray, small eye and small size (under 60-mm FL). Yearling coho were larger in size (approximately 90-160 mm FL), with silver sides, black tips on the caudal fin and large eye compared to the size of the head.

Trout were enumerated by three different age classes: fry, parr, and smolt. Fry were small in size (<40-mm FL), dark brown in color with orange fins, and caught late in the trapping season (after May 1). Parr were trout, other than fry, that were not “smolted” in appearance. Parr were typically between 50 and 150 mm fork length, dark in color (brown with spots on the tale), and caught throughout the trapping season. Smolts were chrome in appearance, larger in size (90 to 350-mm fork length) and with many spots along the dorsal surface and tail. Parr and smolts were assigned as either steelhead or cutthroat based on mouth size and presence or absence of red coloration on the ventral surface of the gill covers. Fry could not be assigned to species and were recorded as “trout”.

Trap efficiency trials were conducted with maiden-caught (i.e., fish captured for the first time) chum fry of natural origin throughout the season. No efficiency trials were conducted using Chinook due to very low catches of this species. Captured fish were anesthetized with tricaine methanesulfonate (MS-222) and marked with Bismark-brown dye. Marked fish were allowed to recover in freshwater. Marked fish were released at dusk into fast flowing water upstream of a bend in the river, approximately 75-m distance from the trap. The release site was selected to maximize mixing of marked and unmarked fish while minimizing in-river predation between release and recapture. Trials were conducted every few days to allow adequate time for all marked fish to reach the trap. Most marked fish were caught the day immediately following a release. Dyed fish captured in the trap were recorded as recaptures.

Genetic Identification of Juvenile Chum

Juvenile fish were assigned to a baseline consisting of summer- and fall-run chum salmon populations from Hood Canal based on genotypes from 16 microsatellite loci (Small et al. 2009). Baseline collections were combined into reporting groups composed of all summer-run and all fall-run chum salmon collections from Hood Canal. Assignment likelihoods were calculated per reporting group. For further details on genetic methods and assignments, see Small et al. (2009). Some of the juvenile samples, identified as chum in the field, produced anomalous genotypes (failed at some loci and alleles were out of range for chum salmon). These anomalies suggested that the samples may have been Chinook or pinks rather than chum salmon. The non-chum samples were not further analyzed to determine species.

Freshwater Production Estimate

Freshwater production was estimated using a single partial-capture trap design (Volkhardt et al. 2007). Maiden catch ($\hat{u}$) was expanded by the recapture rate of marked fish (*M*) released above the trap and subsequently recaptured (*m*). Data were stratified by week in order to accommodate for temporal changes in trap efficiency. The general approach was to estimate (1) missed catch, (2) efficiency strata, (3) time-stratified abundance, (4) proportion of summer versus fall migrants (for chum), and (5) total abundance.

<u>(1) Missed catch</u>. Total catch ($\hat{u}$) was the actual catch (n_i) for period *i* summed with missed catch ($\hat{n}_i$) during periods of trap outages.

Equation 1

$$\hat{u}_i = n_i + \hat{n}_i$$

Missed catch for a given period *i* was estimated as:

Equation 2

$$\hat{n}_i = \overline{R} * T_i$$

where:

$\overline{R}$ = Mean catch rate (fish/hour) from adjacent fished periods, and

T_i = time (hours) during the missed fishing period.

Variance associated with $\hat{u}_i$ was the sum of estimated catch variances for this period. Catch variance was:

Equation 3

$$Var(\hat{u}_i) = Var(\hat{n}_i) = Var(\overline{R}) * T_i^2$$

where:

Equation 4

$$V\left(\overline{R}\right)=\frac{\sum_{i=1}^{i=k}(R_i-\overline{R})^2}{k(k-1)}$$

(2) Efficiency strata. Chum data were organized into weekly strata (Monday – Sunday) in order to combine catch, efficiency trials, and genetic sampling data. Chinook and pink data were organized into time strata based on statistical pooling of the release and recapture data. Steelhead and coho data was combined into a single stratum that was representative of the entire trapping season. Pooling was performed using a *G*-test (Sokal and Rohlf 1981) to determine whether adjacent efficiency trials were statistically different. Of the marked fish released in each efficiency trial (M_1), a portion are recaptured (m) and a portion are not seen ($M - m$). If the *seen:unseen* [m:($M - m$)] ratio differed between trials, the trial periods were considered as separate strata. However, if the ratio did not differ between trials, the two trials were pooled into a single stratum. A *G*-test determined whether adjacent efficiency trials were statistically different ($\alpha = 0.05$). Trials that did not differ were pooled and the pooled group compared to the next adjacent efficiency trial. Trials that did differ were held separately. Pooling of time-adjacent efficiency trials continued iteratively until the *seen:unseen* ratio differed between time-adjacent trials. Once a significant difference is identified, the pooled trials are assigned to one strata and the significantly different trial is the beginning of the next stratum.

(3) Time-stratified abundance. Abundance for a given stratum (h) was calculated from maiden catch ($\hat{u}_h$), marked fish released (M_h), and marked fish recaptured (m_h). Abundance was estimated with an estimator appropriate for a single trap design (Carlson et al. 1998; Volkhardt et al. 2007).

Equation 5

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

Variance associated with the abundance estimator was modified to account for variance of the estimated catch during trap outages (see Appendix A in Weinheimer et al 2011):

Equation 6

$$V(\hat{U}_h)=V(\hat{u}_h)\left(\frac{(M_h+1)(M_h m_h+3M_h+2)}{(m_h+1)^2(m_i+2)}\right)+\left(\frac{(M_h+1)(M_h-m_h)\hat{u}_h(\hat{u}_h+m_h+1)}{(m_h+1)^2(m_h+2)}\right)$$

(4) Proportion of summer versus fall migrants. The number of summer chum migrants in a weekly strata ($\widehat{U}_h^{summer}$) was the juvenile abundance for that strata ($\widehat{U}_h$) multiplied by the proportion of stock-specific migrants (p_h^{summer}) as identified in the genetic analysis:

Equation 7

$$\hat{U}_h^{Summer} = \left(\hat{U}_h\right) \cdot p_u^{Summer}$$

Variance for the stock-specific estimate was:

Equation 8

$$Var\left(\hat{U}_h^{Summer}\right) = V\hat{a}r\left(\hat{U}_h\right) \cdot \left(\hat{p}^{Summer}\right)^2 + V\hat{a}r\left(\hat{p}^{Summer}\right)\hat{U}_h^2 - V\hat{a}r\left(\hat{U}_h\right) \cdot V\hat{a}r\left(\hat{p}^{Summer}\right)$$

$Var(p_h)$ was derived from the proportion of stock-specific migrants (p_h) and the number of fish sampled for genetics (n_h) in strata h, and the genetic assignment probability for each stock a:

Equation 9

$$Var(p_h) = \frac{p_h(1-p_h)}{n_h - 1} + \frac{a(1-a)}{n_h}$$

Error in the genetic assignment (a) was 0.99 for summer chum and 0.95 for fall chum based on Small et al. 2009.

(5) Total abundance. Total abundance of juvenile migrants was the sum of in-season stratified estimates:

Equation 10

$$\hat{N}_T = \sum_{h=1}^{h=k} \hat{U}_h$$

Variance was the sum of variances associated with all in-season and extrapolated estimates:

Equation 11

$$V(\hat{N}_T) = \sum_{h=1}^{h=k} V(\hat{U}_h)$$

Coefficient of variation was:

Equation 12

$$CV = \frac{\sqrt{V(\hat{N}_T)}}{\hat{N}_T}$$

Egg-to-Migrant Survival

Egg-to-migrant survival was estimated for Chinook and chum. Egg-to-migrant survival was the number of female migrants divided by potential egg deposition (P.E.D.). Chum escapement was estimated using an Area-Under-the-Curve estimate based on live fish counts, an assumed stream life of 10 days and a 1.3 male:female ratio (M. Downen, WDFW Region 6, personal communication). Live chum counts were adjusted by a "percent seen" factor based on water clarity, calculated to account for fish not seen during individual surveys. Chinook escapement was estimated using an Area-Under-the-Curve estimate based on observed redds, 1 female per redd, and 1.5 male:female ratio. Potential egg deposition was based on estimated female spawners above the trap site and estimated fecundity of 2,500 for chum (Joy Lee Waltermire, Lilliwaup hatchery, LLTK, personal communication) and 5,000 for Chinook salmon (Healey 1991).

Migration Timing

Migration data was plotted according to statistical week (Monday – Sunday). A statistical week begins on a Monday and ends on a Sunday (Appendix A). The first and last week of the year are typically less than 7 days.

Freshwater Life History Diversity

In order to describe abundance and migration of the two sub yearling Chinook strategies, the sub yearling Chinook production was divided into fry and parr migrants. For a given statistical week, the proportion of Chinook within each size class (< 40-mm FL, > 40-mm FL) was applied to the migration estimate for that week.

Duckabush Results

Chum

Total estimated catch of natural-origin chum ($\hat{u}$ = 70,810) included 67,951 captures in the trap and 2,859 missed catch estimated for trap outages (Appendix B). A total of 3,105 natural-origin chum were marked and released over 30 efficiency trials, ranging between 87 and 105 fish per release group. Mark and recapture data were organized into 27 weekly strata for analysis. Trap efficiency of these strata ranged between 10.9% and 34.3%.

Chum fry were captured in extremely low numbers on the first day of trapping (January 10), and the last chum was observed on June 12, well before the trap was removed on July 2. Based on these observations, we assumed the trapping season encompassed the entire chum migration, and we made no abundance estimate for the period before trap installation or after trap removal.

Based on genetic analyses, the catch was predominantly (> 90%) summer chum until the end of March when the proportion of fall chum increased in the sample. From April 1 until the end of the trapping season, the sampled catch was mostly fall chum (Table 3). Four of the 400 samples had allele frequencies that did not meet the assignment threshold. Six of the samples could not be positively identified as chum or did not contain enough of a sample for analysis.

TABLE 3.─Genetic stock identification for juvenile chum salmon migrants caught in the Duckabush screw trap, 2013.

Date	Samples	Summer	Fall	Unassigned	Unknown	% Summer	% Fall
01/28/2013	10	10	0	0	0	100.00%	0.00%
02/04/2013	10	9	0	0	1	100.00%	0.00%
02/11/2013	10	8	0	0	2	100.00%	0.00%
02/18/2013	20	20	0	0	0	100.00%	0.00%
02/25/2013	30	30	0	0	0	100.00%	0.00%
03/04/2013	40	38	2	0	0	95.00%	5.00%
03/11/2013	40	38	2	0	0	95.00%	5.00%
03/18/2013	40	39	1	0	0	97.50%	2.50%
03/25/2013	40	30	10	0	0	75.00%	25.00%
04/01/2013	40	15	21	2	2	41.67%	58.33%
04/08/2013	40	6	33	1	0	15.38%	84.62%
04/15/2013	30	11	19	0	0	36.67%	63.33%
04/22/2013	20	2	18	0	0	10.00%	90.00%
04/29/2013	20	1	18	1	0	5.26%	94.74%
05/06/2013	10	0	9	0	1	0.00%	100.00%
Totals	400	257	133	4	6	66.07%	34.19%

A total of 285,468 ± 28,375 (95% C.I.) natural-origin summer chum fry are estimated to have migrated past the screw trap (Table 4). Coefficient of variation for this estimate was 5.1%.

A total of 42,213 ± 12,090 (95% C.I.) natural-origin fall chum fry are estimated to have migrated past the screw trap (Table 4). Coefficient of variation for this estimate was 14.6%. Details on the mark-recapture and genetic data used to derive these estimates are provided in Appendix B.

Egg-to-migrant survival was estimated to be 5.0% for summer chum and 1.2% for fall chum (Table 4).

TABLE 4.─Juvenile production and associated coefficient of variation, female spawning escapement, and egg-to-migrant survival for natural-origin chum salmon in the Duckabush River, outmigration year 2013.

Stock	Juvenile Production	Juvenile CV	Female Spawners	Egg to Migrant Survival
Summer	285,468	5.1%	2,279	5.0%
Fall	42,213	14.6%	1,417	1.2%
Total	327,680	4.8%	3,696	3.6%

The entire chum outmigration occurred over a 23 week period between early January and the middle of June (Figure 2). The median migration date for the summer component occurred on March 9, four weeks earlier than the median migration date of the fall component on April 7. The summer chum component of the migration was 95% complete by March 29. The fall chum component of the migration was 95% complete by May 7. Chum fry were not measured due to very low variation in total length.

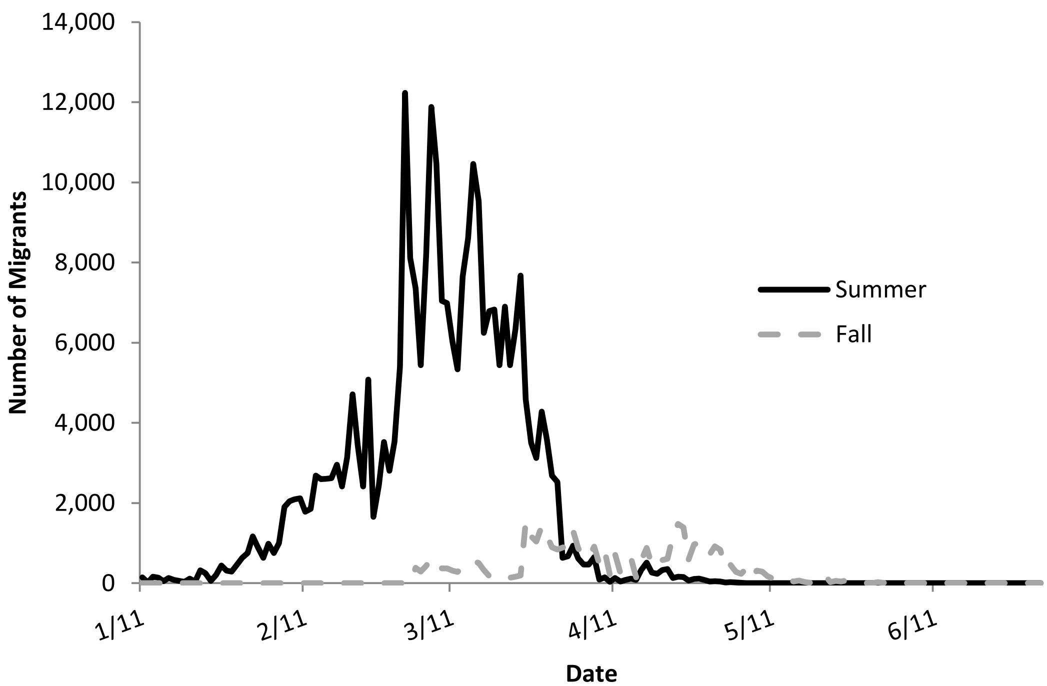

FIGURE 2.─Daily outmigration of natural-origin chum salmon fry in the Duckabush River, 2013 outmigration.

Chinook

Total catch of natural-origin Chinook was 1,175 juveniles. Due to the low number of Chinook, chum efficiency trials involving chum were used to represent Chinook trap efficiency. The 27 chum efficiency trials were pooled into 11 strata using the *G*-test approach, with trap efficiencies ranging between 10.4% and 37.9%.

A total of 5,221 ± 637 (95% C.I.) natural-origin Chinook fry are estimated to have migrated past the screw trap (Table 5). Coefficient of variation for this estimate was 6.2%.

Egg-to-migrant survival was estimated to be 52.2% for Duckabush Chinook salmon in 2013 (Table 6).

TABLE 5.─Juvenile catch, marked and recaptured fish, and estimated abundance and associated variance for Chinook salmon in the Duckabush River, 2013. Release groups were pooled to form 11 strata. Missed catch and associated variance were calculated for periods the trap did not fish.

			Catch				Abundance	
Strata	**Date**	**Actual**	**Missed**	**Variance**	**Marks**	**Recaptures**	**Estimated**	**Variance**
1	1/11-3/1	43			1,023	167	262	1.67E+02
2	3/2-3/4	37			105	38	101	3.80E+01
3	3/5-3/8	24			105	24	102	2.40E+01
4	3/9-3/13	21			210	25	170	2.50E+01
5	3/14-3/18	79			210	70	235	7.00E+01
6	3/19-4/1	244	21	1.34E+02	418	76	1,442	7.60E+01
7	4/2-4/8	251	57	2.18E+02	105	36	882	3.60E+01
8	4/9-4/12	61			104	15	400	1.50E+01
9	4/13-4/22	284			311	118	745	1.18E+02
10	4/23-5/2	70			313	85	256	8.50E+01
11	5/3-7/2	61	10	2.86E+01	96	10	626	1.00E+01
	Season Total	1,175	88	3.81E+02	3,000	664	5,221	6.64E+02

TABLE 6.─Juvenile abundance and associated coefficient of variation, female spawning escapement, and egg-to-migrant survival for natural-origin Chinook salmon in the Duckabush River, outmigration year 2013.

Stock	**Juvenile Abundance**	**Juvenile CV**	**Female Spawners**	**Egg to Migrant Survival**
Chinook	5,221	6.2%	2	52.2%

The first Chinook fry was captured on February 4, 2013. Daily migration of Chinook was low and sporadic for most of the season (Figure 3). The median migration date occurred on April 2. The migration was 95% complete by June 4. One Chinook was captured on July 2, 2013, the last day of the trapping season. Based on the minimal catch of Chinook at the beginning and end of the trapping season, we assumed zero migration prior to trap installation and after trap removal.

Length of natural-origin Chinook fry ranged from 31-mm to 84-mm and averaged 39-mm throughout the trapping season (Figure 4). Average weekly fork lengths of juvenile Chinook began to increase during statistical week 19 (middle of May).

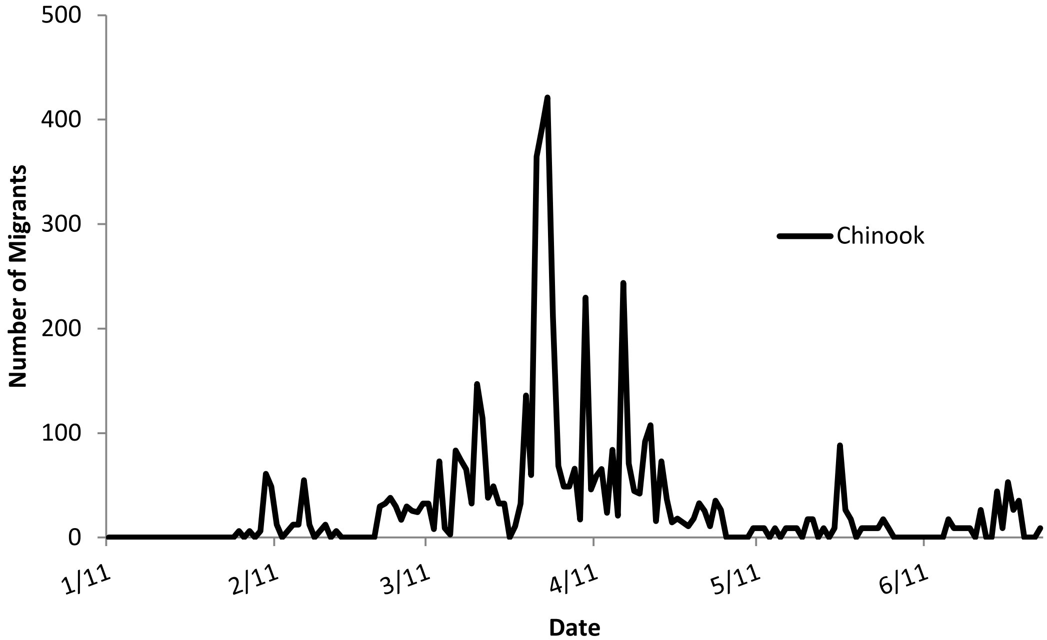

FIGURE 3.─Daily outmigration of natural-origin Chinook salmon fry in the Duckabush River, 2013 outmigration.

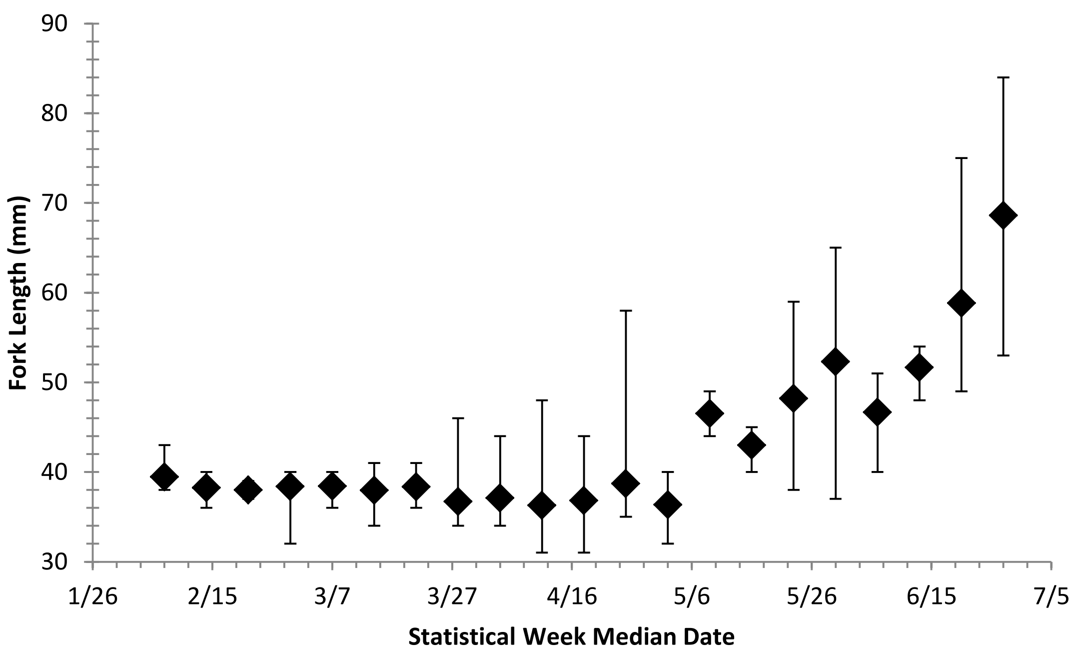

FIGURE 4.─Fork lengths (mm) of juvenile Chinook migrants of natural origin captured in the Duckabush River screw trap 2013. Data are mean, minimum, and maximum values by statistical median date.

Coho

Total catch of natural-origin Coho yearlings was 379 juveniles. coho captured after April 1 were marked and released upstream to estimate trap efficiency. All daily coho 1+ efficiency trials were pooled together to formulate a single stratum for the season.

A total of 6,732 ± 2,921 (95% C.I.) natural-origin coho yearlings are estimated to have migrated past the screw trap (Table 7). Coefficient of variation for this estimate was 22.1%.

TABLE 7.─Juvenile catch, marked and recaptured fish, and estimated abundance and associated variance for coho salmon in the Duckabush River, 2013. Release groups were pooled into one strata. Missed catch and associated variance were calculated for periods the trap did not fish.

	Catch					Abundance	
Date	**Actual**	**Missed**	**Variance**	**Marks**	**Recaptures**	**Estimated**	**Variance**
1/9-7/9	379	73	7.95E+01	282	18	6,732	2.22E+06

The first three coho yearlings were captured on January 11, 2013. The median migration date occurred on May 6 (Figure 5). The migration was 95% complete by May 27. The last coho was captured on June 15, 2013, seventeen days before the end of the trapping season.

Length of natural-origin coho fry ranged from 56-mm to 120-mm and averaged 92-mm throughout the trapping season (Figure 6). Average weekly fork lengths of juvenile coho began to consistently increase during statistical week 14 (early April).

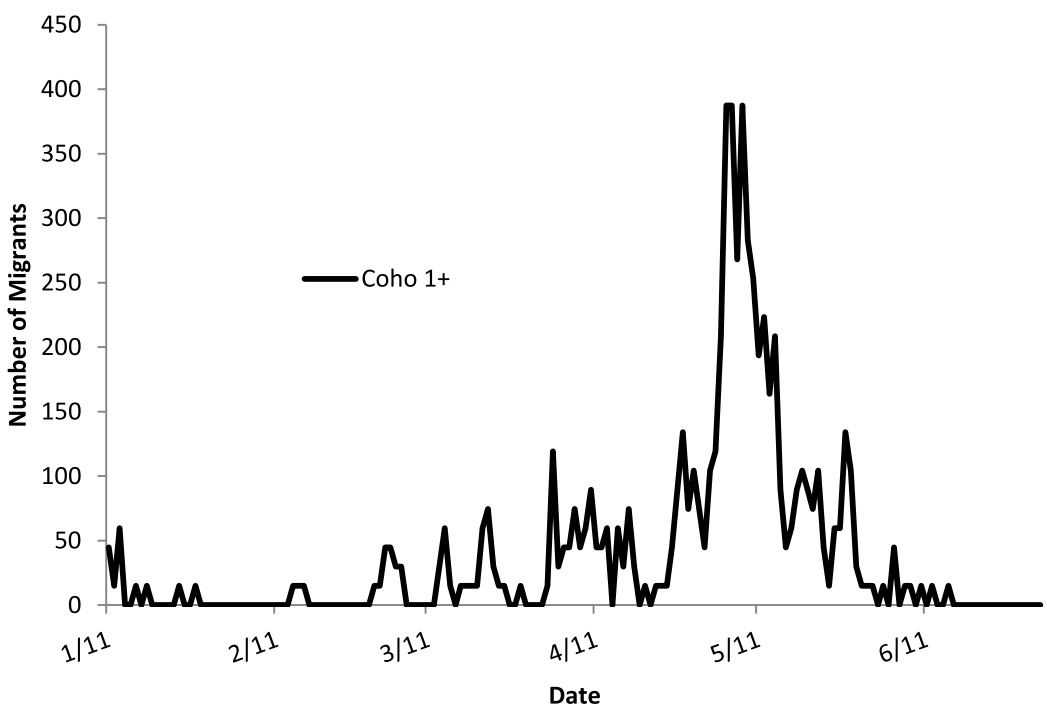

FIGURE 5.─Daily outmigration of natural-origin yearling Coho salmon in the Duckabush River, 2013 outmigration.

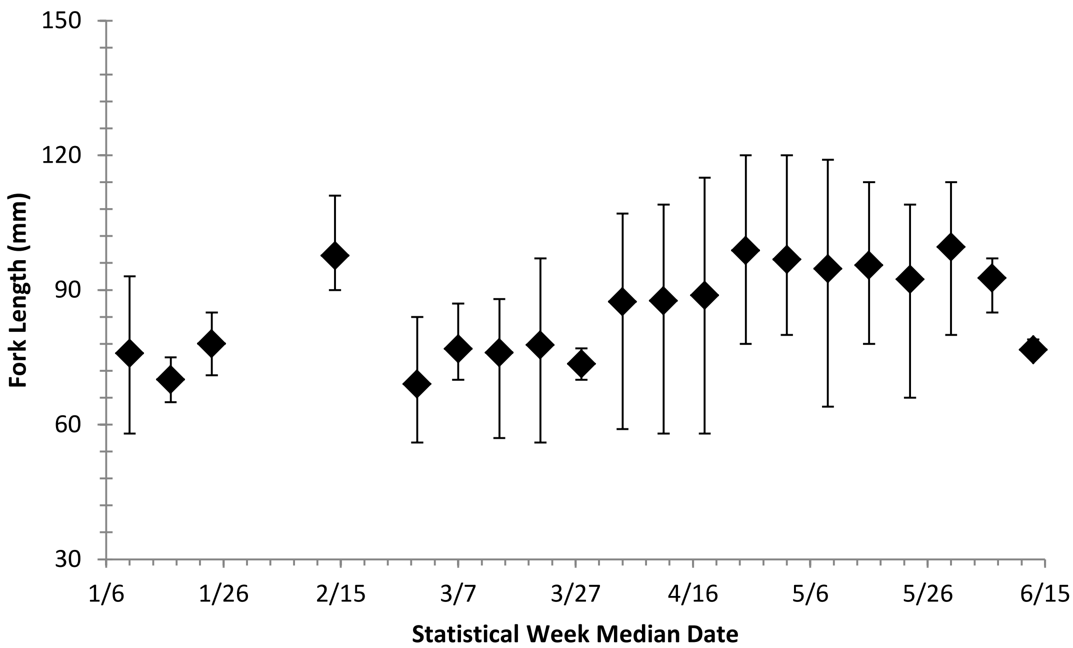

FIGURE 6.—Fork lengths (mm) of juvenile coho yearling migrants of natural origin captured in the Duckabush River screw trap 2013. Data are mean, minimum, and maximum values by statistical median date.

Steelhead

Total catch of natural-origin yearling steelhead was 55 juveniles. Due to the low number of natural-origin steelhead, catch of ad-marked hatchery steelhead released upstream from the trap were used to estimate steelhead smolt trap efficiency. The 10 hatchery steelhead efficiency trials were pooled together to formulate a single stratum for the season.

A total of 1,908 ± 572 (95% C.I.) natural-origin steelhead yearlings are estimated to have migrated past the screw trap (Table 8). Coefficient of variation for this estimate was 15.3%.

TABLE 8.—Juvenile catch, marked and recaptured fish, and estimated abundance and associated variance for steelhead in the Duckabush River, 2013. Release groups were pooled into one strata. Missed catch and associated variance were calculated for periods the trap did not fish.

	Catch					Abundance	
Date	**Actual**	**Missed**	**Variance**	**Marks**	**Recaptures**	**Estimated**	**Variance**
1/10-7/2	55	16	1.52E+01	3,707	137	1,908	8.53E+04

The first steelhead was captured on February 23, 2013. The median migration date occurred on May 3 (Figure 7). The migration was 95% complete by May 27. The last steelhead was captured on June 10, 2013, twenty two days before the end of the trapping season.

Length of natural-origin steelhead ranged from 127-mm to 230-mm and averaged 174-mm throughout the trapping season (Figure 9, Appendix C).

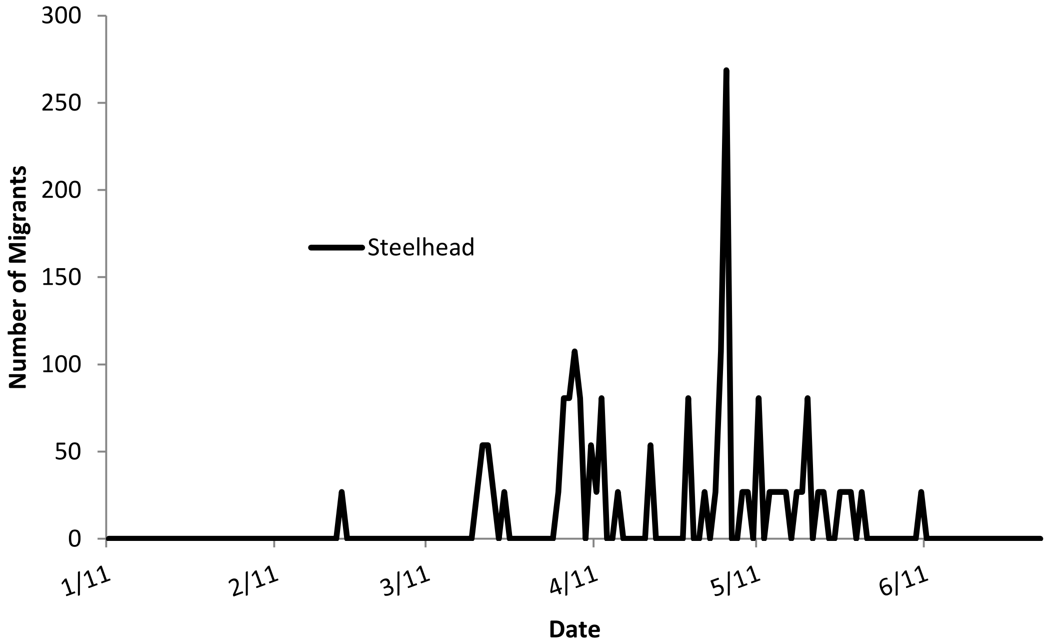

FIGURE 7.—Daily outmigration of natural-origin yearling steelhead in the Duckabush River, 2013 outmigration.

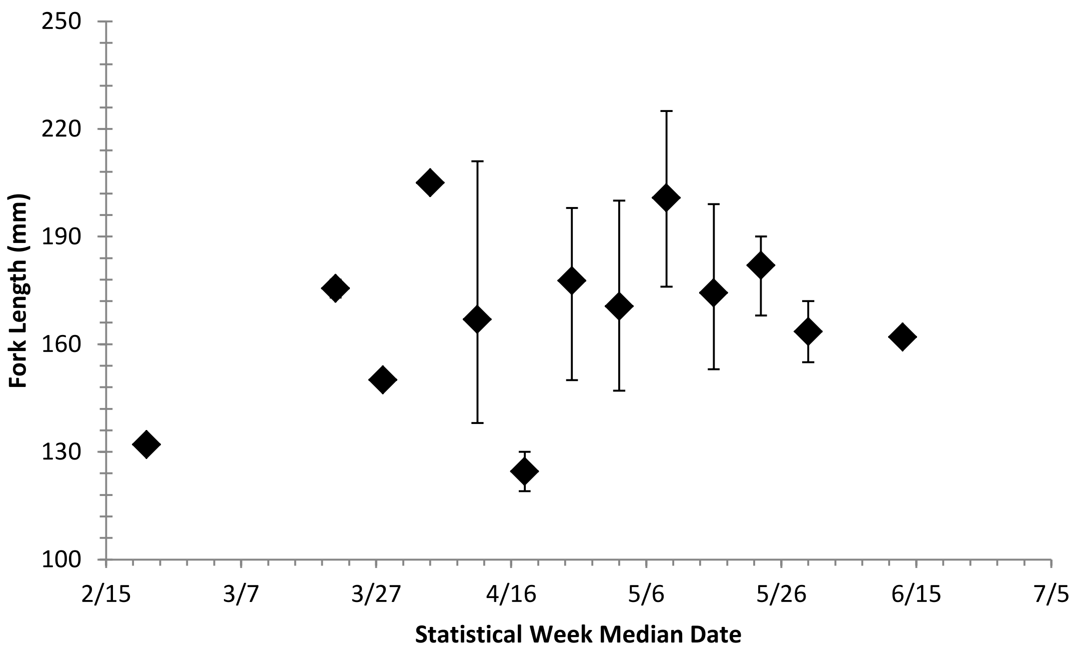

FIGURE 8.—Fork lengths (mm) of juvenile steelhead yearling migrants of natural origin captured in the Duckabush River screw trap 2013. Data are mean, minimum, and maximum values by statistical median date.

Other Species

In addition to the species listed above, catch during the trapping season included 6,148 coho fry, 1 cutthroat smolt, 1 cutthroat adult, 259 trout parr, and 137 ad-marked steelhead smolt. Non-salmonid species captured included sculpin (*Cottus* spp.) and lamprey ammocoetes.

Discussion

This report provides the freshwater production, survival and out-migration timing for chum and Chinook salmon populations in Hood Canal in 2013. The 2013 trapping season marked the third year that genetic samples were collected to distinguish between summer and fall timed chum salmon in the Duckabush and Hamma Hamma Rivers. Based on this study design, we were able to compare juvenile out-migration timing between the two sympatric stocks of chum salmon.

Precision and Accuracy of Mark-Recapture Estimates

Precision of the juvenile abundance estimates provided in this report were within or slightly higher than the NMFS guidelines recommended for monitoring of ESA-listed species (Crawford and Rumsey 2011) . Precision, represented by the coefficient of variation (*CV*), represents the ability of a value to be consistently reproduced. The precision of a mark-recapture estimate is a function of both catch and recapture rates (i.e., trap efficiency; Robson and Regier 1964) as well as the uncertainty in the proportions attributed to each sample. The uncertainty of the genetic proportions in a given time period is influenced by the proportion value and the number of fish sampled. Now that the migration timing for each stock is better understood, we should be able to further improve precision of the estimate by maximizing tissue sampling during periods of overlap between summer and fall chum salmon.

The accuracy of the juvenile abundance estimates provided in this report were assessed with respect to five assumptions of the mark-recapture estimator (Hayes et al. 2007; Seber 1973). Accuracy represents how well the derived estimate matches the true value. An estimate derived from a mark-recapture study design is considered to be accurate (i.e., unbiased) when the estimator assumptions are met. Therefore, the Duckabush River juvenile monitoring study was designed to minimize violation of these assumptions.

<u>Assumption 1. Population is closed with no immigration or emigration and no births or deaths.</u> The emigration assumption is technically violated because the trap catches downstream migrants that are emigrating from the river. However, we assume that the entire cohort is leaving the system within a defined period and that the abundance of juveniles can be estimated at a fixed station during this migration. This assumption is supported by the modality of downstream movement.

Two potential sources of deaths are mark-related mortality and in-river predation. Stress associated with handling or marking is minimized by gentle handling and dying by trained staff. Mortalities in response to handling or marking was minimal based on periodic evaluations of fish held for 24-hour periods after the marking process. Mortality between release and recapture due to in-river predation or live box predation is expected to be an important issue for the small fry migrants (Chinook, chum). The release site above the trap was selected to be close enough to the trap to minimize in-river predation but far enough from the trap to maximize mixing of marked and unmarked fish (assumption #4 below). Predation within the live box is a potential source of mortality, especially later in the season when catch of yearling migrants increase.

Assumption 2. All animals have the same probability of being caught. This assumption would be violated if trap efficiency changes over time, if capture rates within a species are different for small and large fish, or if a portion of the presumed "migrants" are not moving in a downstream direction. Temporal changes in trap efficiency are accommodated by stratifying the migration estimate into different time periods. Size-biased capture rates are unlikely for chum and Chinook salmon that migrate at relatively small sizes (30-45 mm fork length). It is possible that larger (>45mm) Chinook could evade capture better than smaller sized migrants. Due to low catches of Chinook, we are unable at this time to have mark-recapture tests using larger Chinook migrants to test this hypothesis. Equal probability of capture would also be violated if a portion of the juvenile fish were caught because they were redistributing in the river rather than in process of a downstream migration. The location of the traps near the mouth of each river, the recapture of marked sub-yearlings within one day of release, and the modality of the outmigration do not support the idea that the fry migrants caught in this study were simply redistributing in the river.

Assumption 3. Marking does not affect catchability. This assumption would be violated if marked fish were better able to avoid the trap or were more prone to capture than maiden-caught fish. Trap avoidance of marked fish was more likely for coho or steelhead than the smaller sub-yearling Chinook or chum salmon. However, behavioral differences between maiden captures and recaptured fish are currently unknown. Handling and marking the fish may also make them more prone to capture if the stress of handling compromises fish health. To minimize this effect, fish held for release were monitored for the 10+ hours between initial capture and release. During this period, fish are held in a perforated bucket that allows water to be exchanged between bucket and stream. Fish that do not appear to be healthy or swimming naturally were not included in the release group.

Assumption 4. Marked fish mix at random with unmarked fish. This assumption would be violated if marked and unmarked fish were spatially or temporally distinct in their downstream movements. The locations of the trap and release sites were selected to minimize violations of this assumption. The traps are located in the fast-moving thalweg used by juvenile fish (marked and unmarked) to ease downstream transport. The release sites were selected at the outset of study on both rivers and have been consistent over time. Release locations in both watersheds were selected in order to maximize mixing of marked and unmarked sub yearlings while minimizing in-river predation. The assumption of equal mixing can be tested by pairing releases from different locations upstream of the trap (Tynan 1997). This type of comparison will be planned for future evaluation of this assumption.

Assumption 5. No marks are lost and all marks are detected. This assumption would be violated if dye or fin clips were not retained or recognized on recaptured fish. This assumption was likely met. Bismark Brown dye is known to retain its coloration of fish throughout the recapture period of several days (unpublished data). The frequency of undetected marks should also have been low given the highly-trained staff performing both the marking procedure and collecting the recapture data.

Assumptions for Missed Catch

The accuracy of each abundance estimate depends, in part, on accurate estimates of missed catch during periods that the trap did not fish. The linear interpolation method used to estimate in-season missed catch assumed that no major changes occurred in fish migration during the outage period. Drops or spikes in migration rates during high flows would violate this assumption but are nearly impossible to verify.

A second type of missed catch occurred prior to or after the trapping season. Chum salmon have the most extended migration of any species in the Duckabush juvenile evaluations and low levels of catch were occurring at the beginning of the trapping season. Emergence timing of summer and fall chum is expected to vary as a function of adult spawn timing, incubation temperatures, and total days in the gravel (NOAA 1999a; NOAA 1999b). The combination of these factors changes from year to year and leads to some variability in the timing of emergence for all species in a system. This variability in emergence made migration prior to trap installation difficult to estimate. Althoughs the onset of the chum migration is unknown, the extremely low catches observed during the first few days of trapping suggest a longer trapping season would not substantially alter our estimates.

Duckabush Chum Salmon

The 2013 season marked the highest spawning abundance for both summer and fall chum since genetic identification of juveniles began in 2011. In contrast, the resulting juvenile production of summer chum was the lowest observed during the same 3 year period (Table 9). Production of fall chum was nearly identical to 2012 estimate despite having nearly 20% more spawners. This resulted in both stocks having their lowest egg-to-migrant survivals to date.

TABLE 9. Juvenile production and associated adult escapement and egg-to-migrant survival survival for summer and fall chum in the Duckabush River, 2011-2013.

Stock	Adult Return Year	Adult Escapement	Juvenile Migration Year	Estimated Juvenile Migration	Egg to Migrant Survival
Summer	2010	4,110	2011	347,597	7.78%
	2011	1,529	2012	290,891	17.50%
	2012	5,241	2013	285,468	5.01%
Fall	2010	512	2011	32,656	5.87%
	2011	2626	2012	43,053	1.51%
	2012	3259	2013	42,213	1.19%

Over the past three years of the study, abundance of juvenile summer and fall chum appears to have been to a certain degree constant despite changes in adult abundance. The number of summer spawners has varied by more than 2,000 adults between seasons and has resulted in abundance estimates that range between 285,000 to 347,000 juveniles (Figure 9). Fall chum spawner abundance has risen each season despite fairly flat juvenile abundances estimates between 32,000 - 43,000 outmigrants (Figure 10). This trend suggests that production of Duckabush summer and fall chum could be constrained by density-dependent factors.

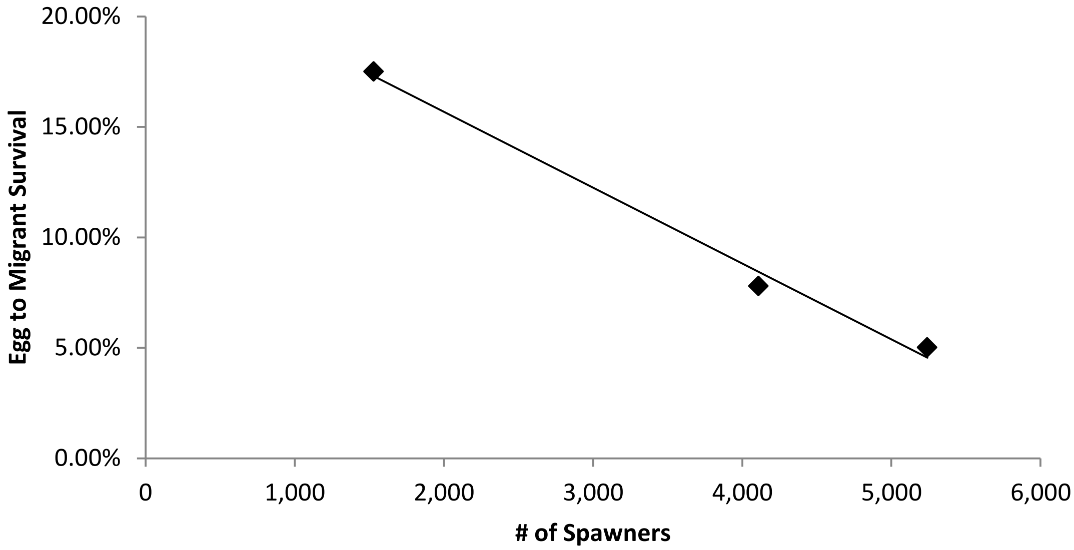

FIGURE 9.—Egg-to-migrant survival vs number of spawners of Duckabush summer chum, 2011-2013.

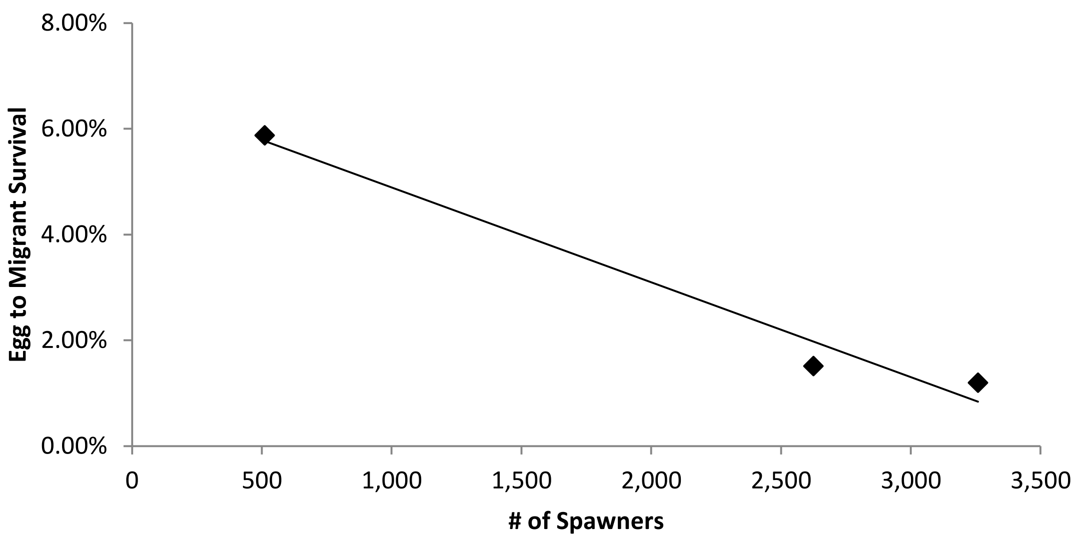

FIGURE 10. — Egg-to-migrant survival vs number of spawners of Duckabush fall chum, 2011-2013.

The outmigration timing of Duckabush summer chum peaked six weeks earlier than Duckabush fall chum in 2013. Summer chum dominated the chum out-migration for 14 of the 25 trapping weeks with a transition to fall chum migrants near the middle of April. Differences in outmigration timing and the variation in timing of marine entry for these stocks will continue to be tracked and compared in future years of study.

Duckabush Chinook Salmon

Freshwater production of Chinook salmon has nearly doubled each season since this study began in 2011 (Table 10). Adult abundance has remained very low, and hence estimated egg to migrant survival has continued to increase each season. The past two seasons have estimated egg to migrant survival rates that are higher than the range of values observed in other Pacific Northwest river systems (Kinsel et al. 2007; Lister and Walker 1966). It seems unlikely that Duckabush Chinook continue to survive at higher rates than other salmonid species in the system (Weinheimer and Zimmerman 2012). On the contrary, we suspect that adult Chinook surveys consistently underestimate spawning escapement. Possible explanations include unseen spawners during surveys or entry of adult Chinook into the system after spawning surveys were complete for the year. Low abundance populations are difficult to survey, and in this case, a small number of missed adults would substantially alter our estimates of egg to migrant survival.

TABLE 10.—Fry abundance, observed spawning escapement, estimated spawning escapement and egg-to-migrant survival for natural-origin Chinook salmon in the Duckabush River, outmigration year 2011, 2012 and 2013.

Out-Migration Year	Fry Abundance	Observed Spawning Escapement	Estimated Spawning Escapement	Egg-to-Migrant Survival
2011	1,219	0	5	-
2012	2,788	5	-	22%
2013	5,221	6	-	52%

We quantified two migration subyearling strategies employed by juvenile Chinook. Fry migrants, which migrate downstream immediately following emergence, were approximately 87% of the freshwater production that migrated past the Duckabush screw trap in 2013. Parr migrants, which spend some time growing and rearing in freshwater prior to migration, decreased as a proportion of the total subyealring migration each of the last three years (Table 11) despite increases in the number of adult Chinook salmon over this time frame. As data accumulate in future years, we will explore possible mechanisms that limit parr production such as density dependent competition for rearing habitat or or cold stream temperatures reducing freshwater growth potential.

TABLE 11. ─Migration timing and abundance of two life history strategies (fry and parr) of natural-origin Chinook outmigrants, 2011-2013.

Out Migration Year	Date 10%	50%	90%	Number of Fry	Number of Parr	Percent Fry	Percent Parr	Total Outmigration
2011	4/5	4/13	6/17	755	464	61.9%	38.1%	1,219
2012	4/15	4/23	5/9	1,890	898	67.8%	32.2%	2,788
2013	3/11	4/2	5/16	4,535	686	86.9%	13.1%	5,221

Duckabush Coho Salmon and Steelhead

The 2013 season marked the second year since trapping began that we were able to estimate yearling coho and steelhead production in the Duckabush River. Yearling production of both species has remained fairly constant for the past two seasons (Table 12, Table 13). As data accumulate in future years, we will plan to use these data to evaluate the carrying capacity for freshwater production of yearling coho and steelhead outmigrants in the Duckabush River.

TABLE 12. ─Yearling coho production and corresponding upper and lower cofindence intervals for the Duckabush River 2012 and 2013.

		Abundance		
Migration Year	Estimate	Lower CI	Upper CI	CV
2012	7,082	5,186	8,977	13.7%
2013	6,732	3,811	9,654	22.1%

TABLE 13.─steelhead production and corresponding upper and lower cofindence intervals for the Duckabush River 2012 and 2013.

		Abundance		
Migration Year	Estimate	Lower CI	Upper CI	CV
2012	2,299	1,529	3,068	17.1%
2013	1,908	1,335	2,480	15.3%

Recommendations

The following recommendations should improve future assessments of juvenile production and survival in the Duckabush River:

(1) Record length upon recapture and compare with maiden catch to assesstrap size selectivity.
(2) Increase trapping efficiency for yearling migrants to estimate juvenile coho and steelhead smolt production.

Appendix A

Statistical Weeks for 2013

APPENDIX A1.–Statistical Weeks for 2013.

Stat Week	2013
1	Jan 1- Jan 6
2	Jan 7 - Jan 13
3	Jan 14 - Jan 20
4	Jan 21 - Jan 27
5	Jan 28 - Feb 3
6	Feb 4 - Feb 10
7	Feb 11 - Feb 17
8	Feb 18 - Feb 24
9	Feb 25 - Mar 3
10	Mar 4 - Mar 10
11	Mar 11 - Mar 17
12	Mar 18 - Mar 24
13	Mar 25 - Mar 31
14	Apr 1 - Apr 7
15	Apr 8 - Apr 14
16	Apr 15 - Apr 21
17	Apr 22 - Apr 28
18	Apr 29 - May 5
19	May 6 - May 12
20	May 13 - May 19
21	May 20 - May 26
22	May 27 - Jun 2
23	Jun 3 - Jun 9
24	Jun 10 - Jun 16
25	Jun 17 - Jun 23
26	Jun 24 - Jun 30
27	Jul 1 - Jul 7

Appendix B

Duckabush River catches, trap efficiencies, and abundance estimates for 2013

APPENDIX B1.–Actual catch (*n*), Estimated catch ($\hat{u}$), marked (*M*) and recaptured (*m*) fish, and estimated abundance (U) of chum fry migrants at the Duckabush River screw trap in 2013. Release groups were pooled by statistical week. An asterisk (*) indicates periods with insufficient catch for efficiency trials, so mark-recapture data from outside the given date range were used to estimate abundance. Missed catch and associated variance were calculated for periods that the trap did not fish.

Week	Dates	n	$\hat{n}$	$\hat{u}$	$V(\hat{u})$	M	m	$\hat{U}$	$V(\hat{U})$
2*	1/11-1/13	53		53		192	30	330	4.53E+03
3*	1/14-1/20	96		96		192	30	598	1.24E+04
4	1/21/1/27	263		263		192	30	1,637	7.86E+04
5	1/28-2/3	549		549		202	22	4,846	9.04E+05
6	2/4-2/10	1,446		1,446		210	27	10,897	3.62E+06
7	2/11-2/17	3,324		3,324		210	40	17,106	5.68E+06
8	2/18-2/24	4,117		4,117		210	37	22,860	1.11E+07
9	2/25-3/3	9,962		9,962		209	54	38,037	1.92E+07
10	3/4-3/10	10,589		10,589		210	36	60,386	7.94E+07
11	3/11-3/17	15,070		15,070		315	83	56,692	2.79E+07
12	3/18-3/24	7,899	1,415	9,314	5.17E+03	209	41	46,570	4.07E+07
13	3/25-3/31	5,551		5,551		209	35	32,381	2.36E+07
14	4/1-4/7	2,405	1,331	3,736	6.49E+04	105	36	10,703	2.52E+06
15	4/8-4/14	1,284		1,284		208	63	4,193	1.97E+05
16	4/15-4/21	1,962		1,962		207	70	5,748	3.13E+05
17	4/22-4/28	2,075		2,075		208	52	8,183	9.49E+05
18	4/29-5/5	874		874		201	43	4,012	2.94E+05
19*	5/6-5/12	262	68	330	1.08E+03	201	43	1,515	6.84E+04
20*	5/13-5/19	47	42	89	8.80E+01	201	43	409	6.22E+03
21*	5/20-5/26	99		99		201	43	455	5.19E+03
22*	5/27-6/2	16	3	19	9.69E+00	201	43	87	6.46E+02
23*	6/3-6/9	4		4		201	43	18	7.03E+01
24*	6/10-6/16	4		4		201	43	18	7.03E+01
25*	6/17-6/23	0		0		201	43	0	0.00E+00
26*	6/24-6/30	0		0		201	43	0	0.00E+00
27*	7/1-7/7	0		0		201	43	0	0.00E+00
Totals		67,951	2,859	70,810	7.12E+04	3,105	669	327,680	2.17E+08

APPENDIX B2.—Estimated abundance of summer (U_s) and fall chum (U_f) fry migrants at the Duckabush River screw trap in 2013. Total chum migrants (U) were stratified by statistical week. The proportion of summer (P_s) and fall chum (P_f) were based on *n* genetic samples collected during each weekly strata.

Week	U	V(U)	n	Ps	v(Ps)	n	Pf	v(Pf)	Us	V(Us)	Uf	V(Uf)
2*	330	4.53E+03	10	1.00	9.90E-04	10	0.00	4.75E-03	330	4.63E+03	0	4.96E+02
3*	598	1.24E+04	10	1.00	9.90E-04	10	0.00	4.75E-03	598	1.27E+04	0	1.64E+03
4	1,637	7.86E+04	10	1.00	9.90E-04	10	0.00	4.75E-03	1,637	8.12E+04	0	1.24E+04
5	4,846	9.04E+05	10	1.00	9.90E-04	10	0.00	4.75E-03	4,846	9.26E+05	0	1.07E+05
6	10,897	3.62E+06	9	1.00	1.10E-03	9	0.00	5.28E-03	10,897	3.75E+06	0	6.08E+05
7	17,106	5.68E+06	8	1.00	1.24E-03	8	0.00	5.94E-03	17,106	6.04E+06	0	1.70E+06
8	22,860	1.11E+07	20	1.00	4.95E-04	20	0.00	2.38E-03	22,860	1.13E+07	0	1.21E+06
9	38,037	1.92E+07	30	1.00	3.30E-04	30	0.00	1.58E-03	38,037	1.96E+07	0	2.26E+06
10	60,386	7.94E+07	40	0.95	1.47E-03	40	0.05	2.41E-03	57,367	7.69E+07	3,019	8.78E+06
11	56,692	2.79E+07	40	0.95	1.47E-03	40	0.05	2.41E-03	53,857	2.99E+07	2,835	7.73E+06
12	46,570	4.07E+07	40	0.98	8.73E-04	40	0.03	1.81E-03	45,406	4.05E+07	1,164	3.88E+06
13	32,381	2.36E+07	40	0.75	5.06E-03	40	0.25	6.00E-03	24,286	1.85E+07	8,095	7.62E+06
14	10,703	2.52E+06	36	0.42	7.22E-03	36	0.58	8.26E-03	4,460	1.25E+06	6,243	1.78E+06
15	4,193	1.97E+05	39	0.15	3.68E-03	39	0.85	4.64E-03	645	6.86E+04	3,548	2.22E+05
16	5,748	3.13E+05	30	0.37	8.34E-03	30	0.63	9.59E-03	2,108	3.15E+05	3,640	4.39E+05
17	8,183	9.49E+05	20	0.10	5.23E-03	20	0.90	7.11E-03	818	3.55E+05	7,364	1.24E+06
18	4,012	2.94E+05	19	0.05	3.29E-03	19	0.95	5.27E-03	211	5.28E+04	3,801	3.47E+05
19*	1,515	6.84E+04	9	0.00	1.10E-03	9	1.00	5.28E-03	0	2.45E+03	1,515	8.01E+04
20*	409	6.22E+03	9	0.00	1.10E-03	9	1.00	5.28E-03	0	1.77E+02	409	7.07E+03
21*	455	5.19E+03	9	0.00	1.10E-03	9	1.00	5.28E-03	0	2.22E+02	455	6.25E+03
22*	87	6.46E+02	9	0.00	1.10E-03	9	1.00	5.28E-03	0	7.66E+00	87	6.83E+02
23*	18	7.03E+01	9	0.00	1.10E-03	9	1.00	5.28E-03	0	2.94E-01	18	7.17E+01
24*	18	7.03E+01	9	0.00	1.10E-03	9	1.00	5.28E-03	0	2.94E-01	18	7.17E+01
Totals	327,680	2.17E+08	-	-	5.03E-02	-	-	1.13E-01	285,468	2.10E+08	42,213	3.81E+07

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