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Duckabush Summer and Fall Chum Salmon 5 Year Review: Brood Year 2010-2014

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Washington Department of Fish and Wildlife
Fish Program Science

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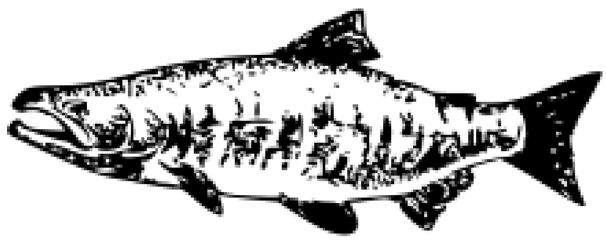

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Acknowledgements

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Mo Small (WDFW) conducted genetic analysis of juvenile chum samples. Kris Ryding (WDFW) consulted on the study design and estimator variance for the genetic sampling protocol.

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Executive Summary

This report summarizes the results from the juvenile monitoring study on the Duckabush River from 2011 to 2015. We evaluated freshwater productivity, juvenile outmigration timing, adult abundance and egg to migrant survival of summer and fall chum salmon. Abundance of adult summer chum was higher than fall chum four out of the 5 years of our study, and was composed almost entirely of natural-origin fish. Although we had no direct evidence, based on the exceedingly high survival rate needed to account for adult fall chum escapement from a single cohort monitored through the marine phase, we speculate that a significant number of fall chum spawners were stray hatchery origin fish from releases elsewhere within Hood Canal. Juvenile summer chum abundance ranged from three to twenty seven times larger than fall chum. Summer chum juveniles exhibited an earlier timed migration with peak outmigration occurring from late February to the middle of March. Egg to migrant survival for summer chum was higher than fall chum and was similar to values reported for other chum stocks on west coast. Fall chum egg to migrant survival was at the lower range of reported values for other fall chum stocks. Summer and fall chum freshwater survival appear to be negatively impacted by peak flow events and high spawning densities. Based on the results of this study, summer chum appear to be meeting the adult abundance and recruits per spawner recovery goals listed in the Summer Chum Salmon Conservation Initiative.

Introduction

The Duckabush River is located on the Olympic Peninsula in Washington State and drains east into Hood Canal. The river is home to a number of anadromous fish species, including Chinook salmon (*Oncorhynchus tshawytscha),* summer and fall timed chum salmon (*O. keta*), pink salmon (*O. gorbuscha*), coho salmon (*O. kisutch*), and steelhead trout (*Oncorhynchus mykiss*). Three of these salmonid species (Chinook, Summer Chum and Steelhead) are federally protected under the Endangered Species Act (ESA). For this report, we focus on summer and fall chum salmon.

Summer chum salmon in the Duckabush River are part of the Hood Canal Summer Chum Evolutionary Significant Unit (ESU) listed as *threatened* in 1999 by National Marine Fisheries Service (NMFS) (NOAA 1999). 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. Beginning in the 1980s, these returns plummeted to fewer than 5,000 adults and hit all-time lows in 1989 and 1990 with less than a 1,000 spawners in total. By 1991, 7 of the 16 stocks were considered extinct. In response to this decline, the Washington Department of Fish Wildlife and Point No Point Treaty (PNPT) Tribes developed the Summer Chum Salmon Conservation Initiative (SCSCI) which called for reductions in harvest of Hood Canal summer chum and hatchery supplementation 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 nine extant stocks within Hood Canal and has never been supplemented with hatchery summer chum. To achieve recovery, the SCSCI describes a series of stock-specific abundance, productivity and diversity goals. Duckabush summer chum must have a mean natural origin adult pre-harvest abundance of 3,290 and a mean post-harvest escapement of 2,060 natural origin adults over the most recent 12 year period. The abundance threshold for recovery of Duckabush summer chum was calculated using the mean of abundances from 1974-1980, a span of years prior to population decline. Mean escapement was calculated by dividing the abundance goal by a recruit per spawner ratio of 1.6 to account for harvest. Natural origin abundance and natural origin escapement must also not be lower than the stocks critical threshold of 700 adults in two of the most recent eight years and in no more than one of the most recent four years. In addition, natural recruits per spawner must average 1.6 over the eight most recent brood years and no more than two of these years can fall below 1.2 recruits per spawner (Washington Department of Fish and Wildlife and Point No Point Treaty Tribes 2003). Recovery for the entire ESU requires that no less than six extant Hood Canal stocks and 2 Strait of Juan de Fuca natural populations meet all the individual stock recovery criteria.

Productivity of the entire ESU must also meet or exceed 1.6 recruits per spawner (Washington Department of Fish and Wildlife and Point No Point Treaty Tribes 2003). We note, however, a recent effort to consider revising these recovery goals (Lestelle et al. 2014). To protect population diversity, agencies and local governments will plan and implement habitat restoration, rebuild individual stocks by natural or artificial means and reestablish extinct summer chum stocks where feasible (Washington Department of Fish and Wildlife and Point No Point Treaty Tribes 2003).

Hood Canal fall chum are part of the Puget Sound/Strait of Georgia ESU, which is currently considered healthy and includes all chum populations from the Strait of Georgia, Puget Sound, and Strait of Juan de Fuca (Johnson et al. 1997). Escapement estimates for Duckabush fall chum are available from 1986 to present and have ranged between 170 to 21,860 adult spawners. Historically, a small hatchery operated on the Duckabush from 1911 to 1942 and focused primarily on fall chum production to boost salmon available for the commercial fishing industry. Hatchery supplementation of fall chum resumed in Hood Canal in 1955 at the Washington Department of Fisheries Hoodsport Hatchery on Finch Creek (Fuss and Fuller 1993). Production was increased in 1974, when fall chum were released from WDFW's George Adams Hatchery on the Skokomish River. Beginning in 1979, Enetia Hatchery operated by the Skokomish Indian Tribe and McKernan Hatchery began releasing fall chum. In addition to these releases, egg box programs were started on numerous Hood Canal streams. Prior to 1974, Hood Canal was managed as a salmon preserve, where commercial fishing was not allowed to occur and releases totaled less than 10 million fish annually (Fuss and Fuller 1993). In 1974, following the Boldt decision, the status of salmon preserve was removed and commercial fishing was permitted within Hood Canal. Following this change in policy, releases of fall timed chum increased substantially and ranged between 20 and 60 million. Currently, releases average 30 million fall chum fry per year. The percentage of returning adults from these hatchery releases that stray into Hood Canal streams and rivers is unknown; the fall chum are not marked. The population goals for fall chum adult escapement in the Duckabush are 650 adults in odd years and 900 in even years. Escapement goals for Puget Sound fall chum were developed for both even and odd years due to lower run sizes observed during odd numbered years when pink salmon are present. These escapement goals are based on past escapement levels that resulted in large returns.

In an effort to help measure the success of the Hood Canal summer chum recovery plan, a juvenile monitoring study was initiated on the Duckabush River in 2007. The main goal of the study is to better understand the factors that govern freshwater productivity and marine survival of summer and fall chum in the Duckabush River. Prior to our study, no freshwater productivity data were available for mid-Hood Canal summer and fall chum. 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). One of challenges discovered when juvenile trapping began was that sympatric summer and fall chum exhibit overlapping juvenile outmigration timing curves without clear separation despite stark differences in adult spawn timing and genetic makeup. Beginning in 2011, we collected DNA samples from chum on a weekly basis throughout the trapping season, allowing us to partition the entire juvenile chum outmigration into summer and fall components. The ability to differentiate the proportion of summer vs fall fish is critical to evaluating how the freshwater and marine environment affects survival of each stock. To our knowledge, this is the only study in the Hood Canal region that collects genetic samples from chum to partition and evaluate the two sympatric stocks independently.

In addition to monitoring the recovery of summer chum, this study also serves as a baseline for productivity prior to future habitat restoration projects. The Puget Sound Nearshore Estuary Restoration Program has proposed a major restoration project for the Duckabush Estuary, currently one of three projects in the top tier (J. Krienitz, WDFW, personal communication). The proposal calls for removing the existing road and associated causeway crossing the mouth of the Duckabush River and installing an estuary-spanning bridge, opening up the entire estuary to natural hydrologic processes. Our work will provide an excellent "before" dataset to evaluate the effectiveness of estuary restoration as it relates to juvenile salmon. Given the importance of estuarine habitats to summer chum salmon ecology, we hypothesize that the proposed restoration project would provide a significant long term benefit to summer chum salmon early marine survival.

This report is a five year review that covers juvenile migration years 2011 to 2015. We investigate the differences in timing of juvenile outmigration, freshwater productivity, adult abundance and egg to migrant survival for summer and fall chum salmon in the Duckabush River. We compare Duckabush productivity to freshwater production of Salmon Creek, WA summer chum, and several British Columbia fall chum populations. In addition, we discuss whether summer chum salmon are meeting the recovery goals defined in SCSCI, including an initial assessment of marine survival afforded by the complete adult return of the first monitored juvenile migration in 2011.

Methods

Study Site

The Duckabush is a high-gradient watershed that drains into the western side of Hood Canal, Washington. The Duckabush system originates in the Olympic Mountains within the Olympic National Park. The river is classified as a transitional watershed with peak flow events occurring twice each year, during rain events in the winter months and snow melt in the spring months. Human development is minimal relative to much of the Puget Sound region 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. Anadromous fish can only access the lower reach of the Duckabush due to an impassable waterfall at river mile 8. In addition to chum salmon, steelhead trout, Chinook salmon, coho salmon, pink salmon and cutthroat trout are present in the Duckabush River. Juvenile trap catches are described in previous reports (Weinheimer 2015).

Trap Operation

On the Duckabush River, juvenile migrants were captured in a floating rotary screw trap 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 an eight-foot (1.5 m) 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 foot 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.

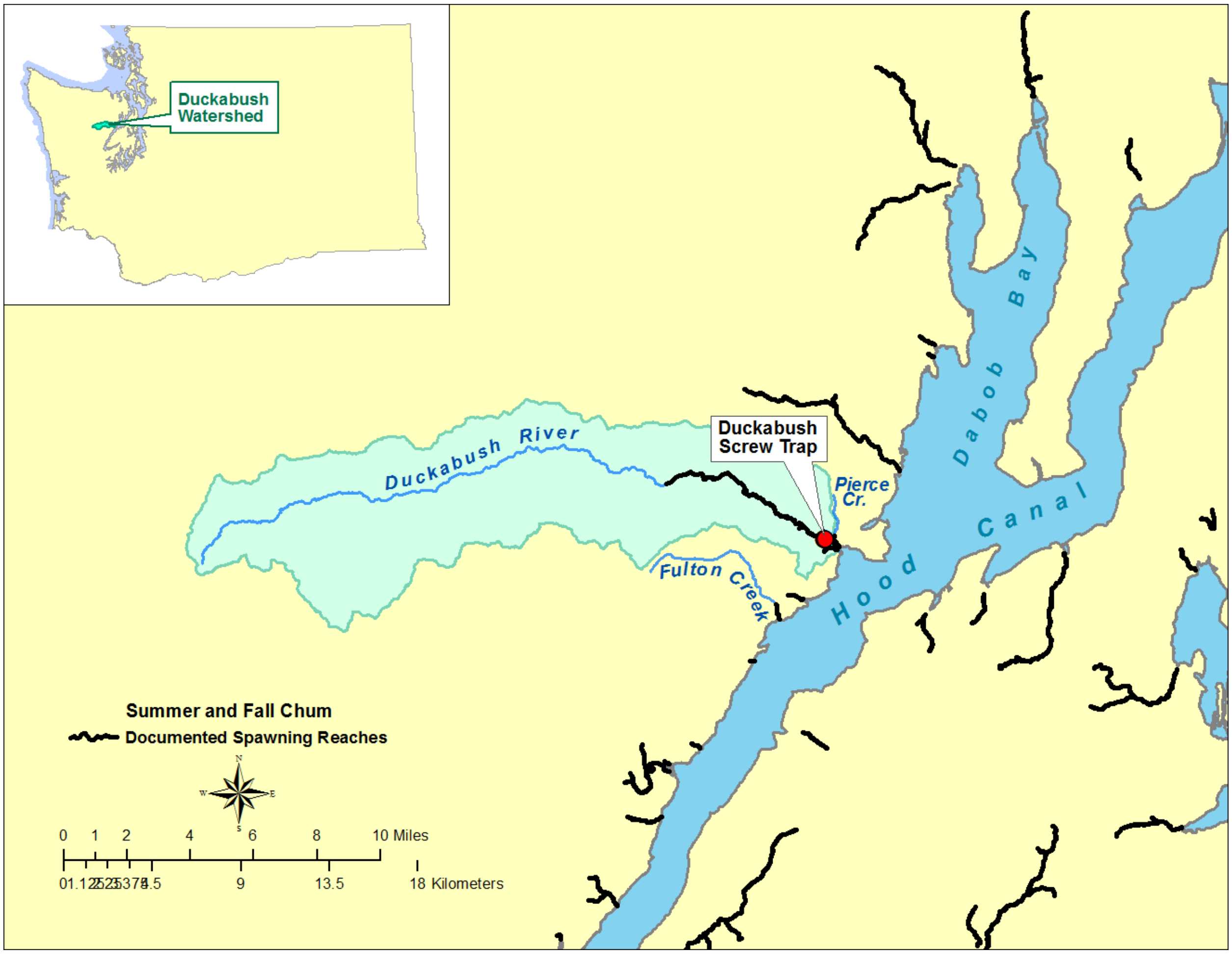


Figure 1. Location of Duckabush screw trap.

The screw trap was fished 24 hours a day, seven days a week, except when flows or debris would not allow the trap to fish effectively (Table 1).

Table 1. Summary of juvenile trap operations for the Duckabush River screw trap, 2011-2015.

Trap Year	Start Date	End Date	Hours Fished	Total Possible Hours	Percent Fished	Number of Outages	Avg Outage Hrs	Standard Deviation
2011	1/10	7/26	4,388.25	4,725.50	91.81%	6	64.54	36.1
2012	1/9	7/9	3,873.92	4,366.00	88.73%	10	49.21	38.1
2013	1/10	7/2	3,845.50	4,125.50	93.21%	6	46.67	21.5
2014	1/8	6/25	3,586.83	4,027.00	89.07%	7	62.88	47.9
2015	1/9	6/28	3,613.75	4,075.75	88.66%	8	57.75	41.9

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).

Tissue was collected from the caudal fin of a subsample of the chum migrants throughout the season (10-40 samples per week). A 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.

Trap efficiency trials were conducted with maiden-caught (i.e., fish captured for the first time) chum fry throughout the season. 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 meters 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 Salmon

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, 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

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

<u>(2) Efficiency strata.</u> Chum data were organized into weekly strata (Monday – Sunday) in order to combine catch, efficiency trials, and genetic sampling data.

<u>(3) Time-stratified abundance</u>. 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

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

<u>(4) Proportion of summer versus fall migrants (chum salmon only).</u> The number of summer chum migrants in a weekly strata ($\hat{U}_h^{summer}$) was the juvenile abundance for that strata ($\hat{U}_h$) 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

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

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

<u>(5) Total abundance</u>. 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

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

Adult Escapement

Chum salmon escapement was estimated using an Area-Under-the-Curve estimate based on live fish counts, an assumed stream life of 10 days and an assumed sex ratio of 1.3 male:female (M. Downen, WDFW Region 6, personal communication). Live chum counts were adjusted by a visibility factor based on water clarity in order to account for fish not seen during individual surveys. Surveys were performed every 7 to 10 days. This method was used for both summer and fall chum salmon. On the Duckabush, the survey reach encompassed river mile 2.3 to the mouth, which covers approximately 90% of the available chum spawning habitat. In addition to fish counted in the mainstem, escapement estimates for summer chum in Fulton Creek, a small independent tributary located 2.6 miles south, are included in the total Duckabush escapement estimate. Similarly, fall chum escapement estimates include estimates from Fulton Creek and Pierce Creek, a small tributary just north of the river mouth. Summer chum escapement is reported as the total number of natural and hatchery produced spawners. Although there were no hatchery summer chum salmon released in the Duckbush River, several river systems in the region were supplemented, and used thermal otolith marks. We collected approximately 100 and 200 otoliths per year from adult summer chum to identify hatchery origin spawners. In order to calculate natural-origin abundance, the proportion of hatchery vs natural origin during a given year was applied to the total escapement for that season.

Egg-to-Migrant Survival

Egg-to-migrant survival was the number of female migrants divided by potential egg deposition (P.E.D.). In an attempt to accurately estimate survival within the Duckabush itself, we only include the fish estimated to have spawned above the smolt trap site. We did not include fish that escaped into Fulton or Pierce Creek. We did not extrapolate for the number of fish that spawned above our survey section. Reported egg to migrant survivals are most likely biased high but still serve as an index when comparing among different years. During the 2010 fall chum survey season, we were only able to perform one spawning ground survey due to high water. As a result, the escapement estimate is likely biased low, so we have omitted it from our egg to migrant survival analysis. Potential egg deposition was based on estimated female spawners above the trap site and estimated fecundity of 2,460 per female chum salmon (Joy Lee Waltermire, Lilliwaup hatchery, LLTK, personal communication). The estimated fecundity was the four-year average of N = 172 female summer chum collected from the Lilliwaup River from 2007-2010. We assumed that summer and fall chum salmon shared similar fecundity.

Marine Survival

Marine survival was the outmigrating fry abundance divided by total returning adult escapement across all age classes of a given brood. Beginning in fall of 2013, scale samples were collected from returning adults to determine the age class distribution for a given return. Within each return year, the percentage of each age class was multiplied by the total escapement to calculate the number of adults in each brood year. The number of returning adults for each brood year was summed across return years to estimate the total number of adult returns from a single outmigration year. Our estimates do not account for any harvest and represent marine survival back to the spawning grounds.

Juvenile and Adult Migration Timing

Juvenile migration was plotted by the percentage of the total migration each year that migrated past the trap site on a given day. Adult data is plotted by the adjusted live count of adult spawners seen on a given survey day.

Results

Adult Abundance

Historical spawning escapement data for Duckabush summer chum dates back to 1968. Similar to other Hood Canal summer stocks, steep declines in abundance began to occur in 1980, when fewer than 1,000 adults returned to the Duckabush (Figure 2). Between 1980 and 2002 only one year (1996) saw more than 950 adults return. Since 2003, escapement has averaged 3,640 adults and shows an upward trend in adult abundance. Escapement averaged 4,289 adults prior to the collapse.

Spawning escapement data for Duckabush fall chum is only available back to 1986. In contrast to summer chum, fall chum abundance remained relatively stable during the 1990s and early 2000s (Figure 2). Adult escapement between 1986 and 2007 averaged 5,869 fish, with peaks of more than 15,000 fish in 1994, 1996 and 2002. Fall chum experienced dramatic declines from 2008-2010 when less than 1,000 total fish returned over that 3 year period.

Adult summer chum salmon were more abundant than fall chum salmon in 3 out of the 4 years in our juvenile monitoring study (Table 2). Escapement of summer chum has averaged 4,525 total and 4,485 adults above the trap (brood years 2010-2014). Fall chum have been less abundant, averaging 2,557 total and 2,721 adults above the trap during the same time frame. Over 95% of the summer chum escapement was natural origin and spawned above our trap site. The percentage of the fall chum escapement above our trap fluctuated between 77-92%.

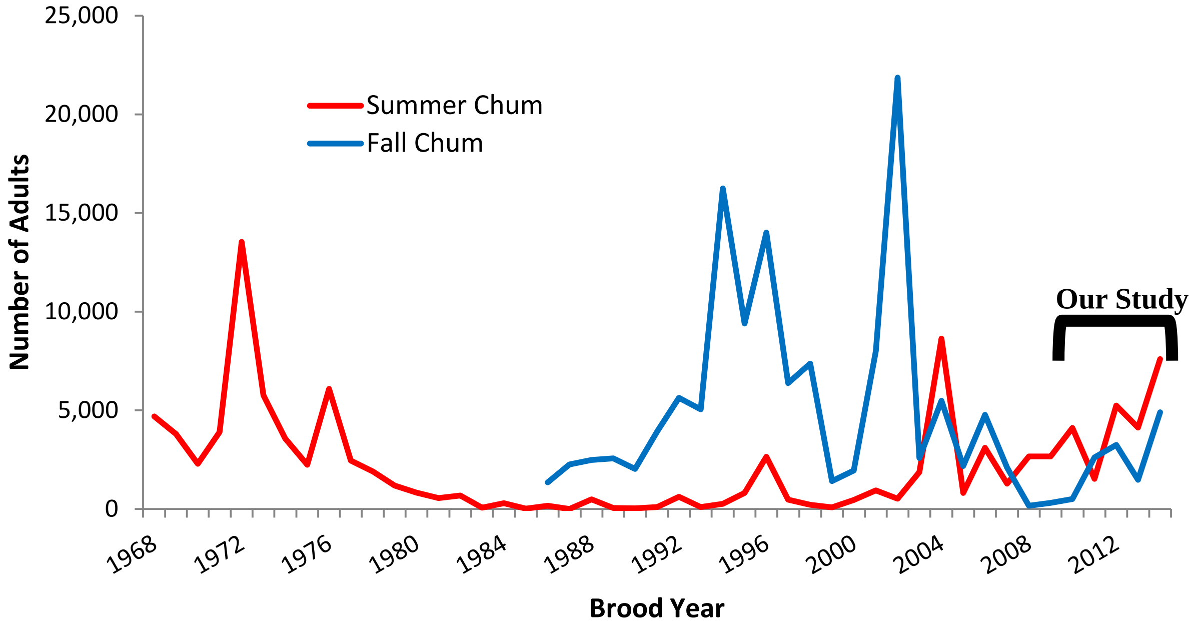


Figure 2. Adult escapement estimates for Duckabush summer and fall chum, brood year 1968-2014.

Table 2. Adult escapement of Duckabush summer and fall chum, return year 2010-2014. Summer chum total includes Fulton Creek escapement and fall chum total includes Fulton and Pierce Creek escapement. Above trap estimates for both stocks only include adult escapement for Duckabush mainstem. Otolith samples were used to identify hatchery marks.

Return Year	Summer					Fall	
	Otolith samples	Hatchery	Natural	Total	Above Trap	Total	Above Trap
2010	194	234	3,876	4,110	4,110	512	373*
2011	137	23	1,515	1,538	1,529	2,626	2,234
2012	119	85	5,156	5,241	5,241	3,259	2,973
2013	191	66	4,063	4,129	3,939	1,487	1,144
2014	24	0	7,607	7,607	7,607	4,902	4,531

*Only one survey completed in the fall of 2010.

Productivity and Egg to Migrant Survival

Summer chum fry were more abundant than fall chum during the past 5 trapping seasons (Table 3). Summer chum juvenile estimates were more precise than fall chum estimates (Table 3). The greatest outmigration abundance of summer chum (2014) corresponded with the lowest outmigration of fall chum (Table 3). Egg to migrant survival of summer chum was more variable from year to year than fall chum (Table 3). Fall chum survival was less than 2% for all years (Table 3).

Table 3. Fry abundance and egg to migrant survival of Duckabush summer and fall chum, outmigration year 2011-2015. CV is the coefficient of variation for the juvenile abundance estimate.

Stock	Juvenile Migration Year	Estimated Juvenile Abundance	Estimated Juvenile Abundance CV	Egg to Migrant Survival
Summer	2011	347,597	9.8%	7.91%
	2012	290,891	5.4%	17.79%
	2013	285,468	5.1%	5.09%
	2014	480,202	5.7%	11.40%
	2015	130,126	7.2%	1.60%
Fall	2011	32,656	23.2%	*
	2012	43,053	12.6%	1.80%
	2013	42,213	14.6%	1.33%
	2014	17,676	48.5%	1.44%
	2015	44,595	13.8%	0.92%

*Only one survey completed in fall of 2010, likely an over estimate of survival and was not included

Marine Survival

The 2010 brood year is the only cohort for which we have estimated adult returns for all age classes. The 2012 summer chum brood had twice as many 3 year olds returns as the 2010 and 2011 broods (Table 4). Fall chum survival for 2010 was estimated to be over six times higher than summer chum. A majority of summer and fall chum returning are 3 and 4 year olds (Table 4, Table 5). Nearly half of the 2012 fall chum escapement was composed of age-5 year fish (Table 5).

Table 4. Estimated marine survival of Duckabush summer and fall chum, brood years 2010-2012.

Stock	**Brood Year**	**Freshwater Production**	**Adult Return by Age Class**				**Total Adults**	**Marine Survival**
			2	**3**	**4**	**5**		
Summer	2010	347,597	66	1,057	6,460	314	7,897	2.27%
	2011	290,891	0	1,070	2,167		3,237	1.11%*
	2012	285,468	0	2,424			2,424	0.85%*
	2013	480,202	0				0	0.00%*
Fall	2010	32,656	0	192	4,131	302	4,625	14.16%
	2011	43,053	0	267	1,511		1,778	4.13%*
	2012	42,213	0	181			181	0.43%*
	2013	17,676	0				0	0.00%*

*Does not include all returning adult age classes

Table 5. Age data for Duckabush summer and fall chum, return years 2012-2015.

Stock	Return Year	Escapement	Number of Samples	Percentage of Return			
				2	3	4	5
Summer	2012	5,241	240	1.3%	51.7%	40.8%	6.3%
	2013	3,939	328	0.0%	26.8%	65.5%	7.6%
	2014	7,607	199	0.0%	14.1%	84.9%	1.0%
	2015	4,905	172	0.0%	49.4%	44.2%	6.4%
Fall	2012	2,973	55	0.0%	32.7%	20.0%	47.3%
	2013	1,144	167	0.0%	16.8%	80.2%	3.0%
	2014	4,531	68	0.0%	5.9%	91.2%	2.9%
	2015	1,995	33	0.0%	9.1%	75.8%	15.2%

Adult Spawn Timing

The peak spawning date for summer chum varied by 13 days between brood years 2011 and 2014 (Figure 3). Fall chum salmon were more variable than summer chum salmon, with the peak spawning date ranging from mid-November to mid-December. Only one survey was conducted in 2010 for fall chum salmon.

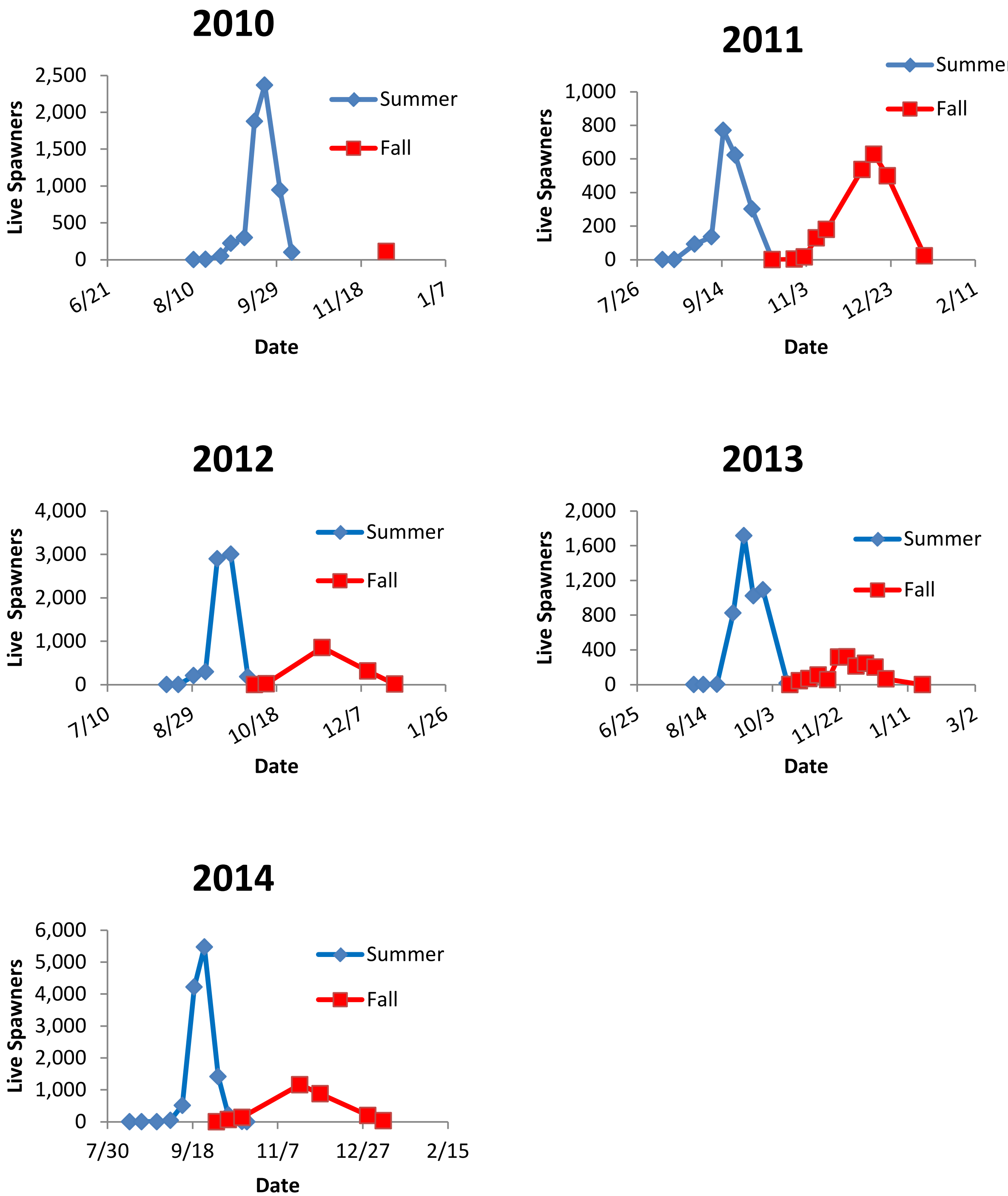


Figure 3. Adult live counts of spawning summer and fall chum, 2010-2014.

Juvenile Outmigration Timing

Peak outmigration of summer chum occurred between the last week of February and the middle of March (Figure 4). Juvenile fall chum migrated over a more protracted time period than summer chum (Figure 4). A large majority of the outmigration was complete for both stocks by May 1 during all years (Figure 4).

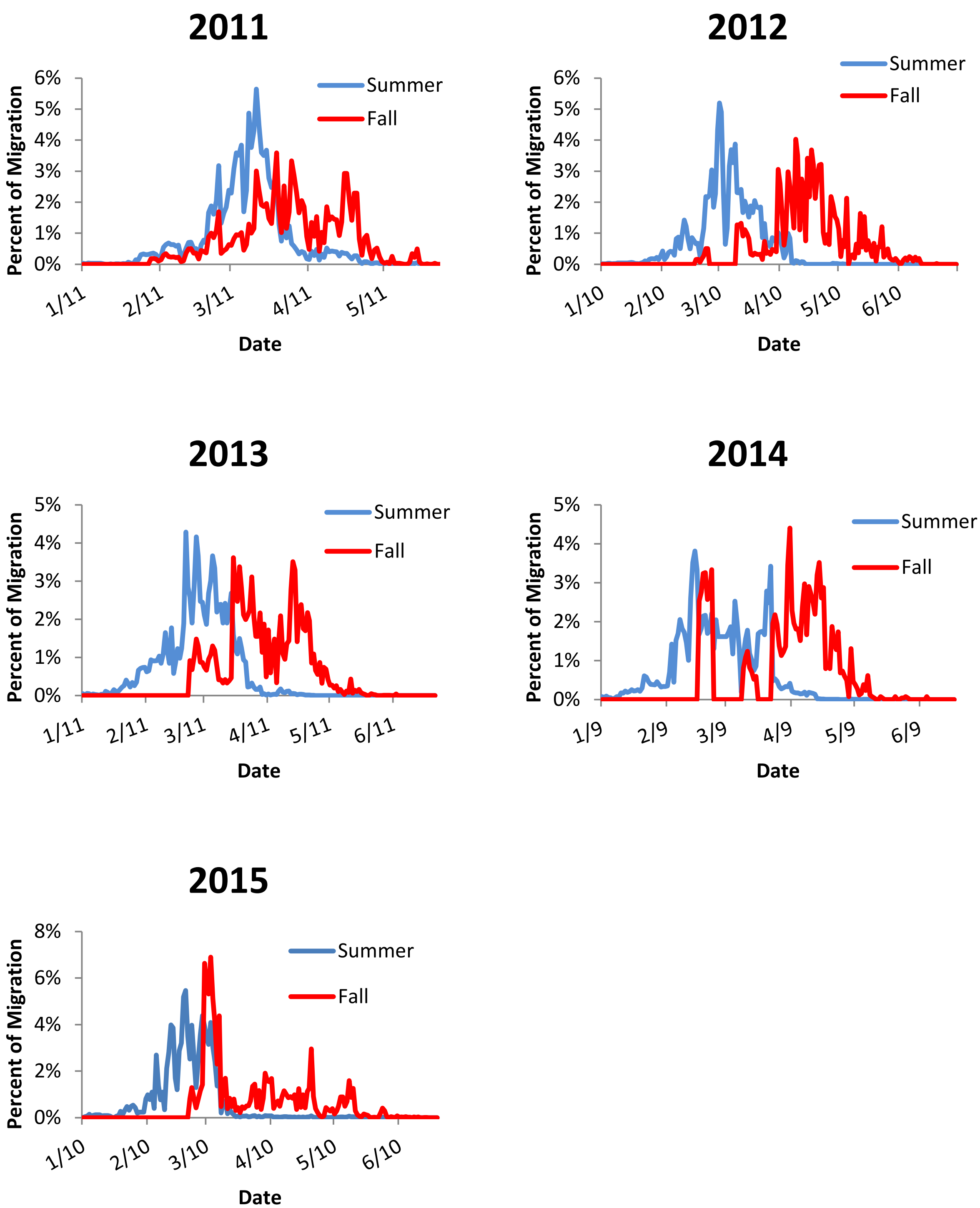


Figure 4. Outmigration timing of juvenile summer and fall chum, outmigration years 2011-2015.

Discussion

Adult Abundance

The mean escapement of natural origin summer chum during our 5 year study exceeded the recovery escapement thresholds described in the SCSCI for the Duckabush River (Table 2). Our study did not attempt to estimate the number of fish encountered in fisheries, limiting our ability to estimate abundance prior to harvest. Rates of harvest on Hood Canal summer chum has ranged between 2 and 21 percent from 2000-2013 (Washington Department of Fish and Wildlife and Point No Point Treaty Tribes 2014). Despite the fact that some harvest likely occurred during our study, average escapement was still well above the recovery threshold. The 2014 brood year was the third largest escapement observed in the Duckabush since 1968.

Fall chum have also exceeded their escapement population goals for all but one year (2010, Figure 2). A series of large flow events limited surveys during the fall chum spawning period in 2010. Surveyors were only able to complete one survey that season and likely missed a portion of the escapement. It remains unknown what percentage of the fall timed chum escapement is of hatchery origin. Hood Canal has received large (>30 million) plantings of hatchery fall chum fry since the mid 1970s. Given the size of the hatchery program, even a low rate of straying into the Duckabush River could account for a considerable number of hatchery-origin adults.

Productivity and Egg to Migrant Survival

The Duckabush River is one of eight rivers (Big and Little Quilcene, Dewatto, Dosewallips, Hamma Hamma, Skokomish, Tahuya and Union Rivers) in the Hood Canal region home to both summer and fall timed chum. This study provides the first production estimates of both stocks in sympatry. Summer chum dominated total fry abundance during all five years of our research. Total abundance of summer chum ranged between 130,000 and 480,000, with only one season falling below 285,000 fry. In contrast, fall chum ranged between 17,000 and 45,000. Even during the spring of 2011, when more adult fall chum were counted on the spawning grounds than summer chum, summer juveniles were over six times more abundant at the trap. The difference in juvenile abundance between the two stocks was an unexpected outcome from our study.

Similar to juvenile abundance, egg to migrant survivals were much higher and had a wider range for summer fish than fall fish. The survival rates we observed for both stocks were within the ranges reported by other studies (Table 6). The only other estimate of egg to migrant for Hood Canal/Strait of Juan de Fuca summer chum was on Salmon Creek, a tributary located 23 miles north of the Duckabush River that flows into Discovery Bay. Salmon Creek is a small stream with a transitional rain/snow hydrograph that originates in the Olympic National Forest and is home to summer chum salmon, coho salmon and steelhead. Our observed egg to migrant survival rates for summer fish tend to be at the lower range of those observed at Salmon Creek.

Similar to summer chum, our fall chum egg to migrant survival rates are at the low end of the reported ranges and had the lowest average survival of all the studies listed. All of the fall timed egg to migrant survival rates listed are from rivers and streams in southern British Columbia, Canada.

Prior to trapping, we expected to observe similar egg to migrant survival rates between summer and fall fish. In contrast, we observed significant differences in freshwater survival between summer and fall fish. We evaluated three possible hypotheses to explain the variation in survival observed for Duckabush summer and fall chum. These included exposure to high flows during incubation, density dependence, and the proportion of hatchery-origin spawners.

One environmental variable that has been shown to impact freshwater survival is peak flow events experienced during incubation. High flow events generally correspond with increased fine sediment and bed load transport and scour that can negatively impact salmon embryo survival (Lisle and Lewis 1992; McNeil 1966; Montgomery et al. 1996). To evaluate the impact of increased flows on survival of Duckabush chum, we examined the peak flow events experienced between September 1 and January 31 for summer chum and October 15 to March 31 for fall chum. This time frame encompasses a majority of the incubation period prior to emergence. Both stocks showed a negative correlation between peak flow events and egg to migrant survival (Figure 5). A similar relationship between flow and chum egg to migrant survival was observed by Lister and Walker (1966) in the Big Qualicum River, British Columbia. Peak stream discharge appears to adversely affect freshwater survival of chum in the Duckabush River.

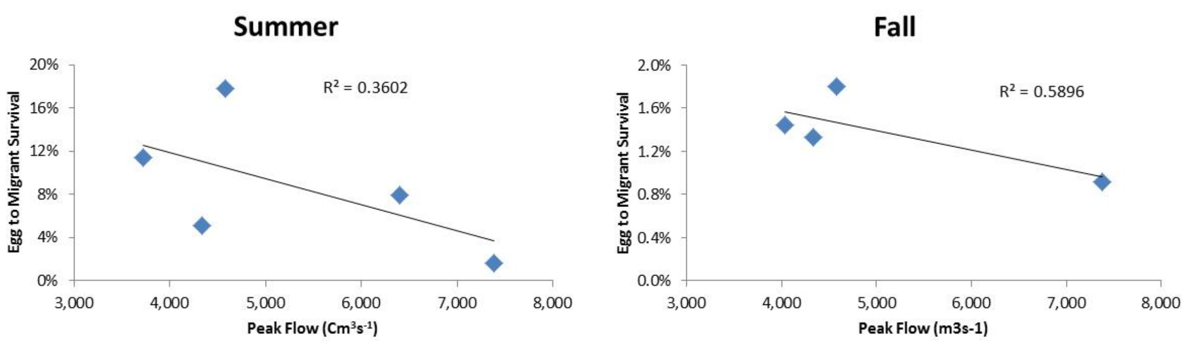
Another variable we investigated was the influence of adult abundance on survival. High densities of spawners in a limited stream environment can saturate the available spawning habitat and increase mortality due to redd superimposition. Fukushima (1998) observed density-dependent mortality in pink salmon in Auke Creek, Alaska. The Duckabush River has a limited amount of river accessible to anadromous fish due to a waterfall at approximately river mile 8. Downstream from this cascade, the river has only a couple small tributaries and side channels that are only accessible at higher flows. This limits a large portion of the spawning to the mainstem section, with a majority of spawning occurring from river mile 2.3 to the mouth. We plotted egg to migrant survival vs the estimated adult escapement for each season. Both summer and fall chum were negatively correlated with increasing adult abundance (Figure 6). These trends suggest that Duckabush summer and fall chum could be constrained by density-dependence factors.

One other factor we hypothesize could be influencing freshwater productivity is the proportion of hatchery origin spawners. We directly estimated that the proportion of summer chum salmon hatchery origin spawners (i.e., pHOS) over the 5 year study via thermal otolith marks, and it ranged between 0–5.7%. In contrast, although we had no direct measurement of pHOS for fall chum salmon, a simple demographic calculation for the brood year 2010 outmigration suggests many of the fall chum salmon spawners were hatchery origin (82 – 98%, see marine survival section below for details).

Although based on indirect evidence from a single outmigrant cohort, fall chum appear to have a much higher proportion of hatchery spawners than summer chum salmon. We hypothesize that this difference may contribute to their lower egg to migrant survival. Several studies have demonstrated fitness loss in hatchery-origin fish compared to natural origin fish when both groups spawn naturally in the river (Araki et al. 2008; Berejikian and Ford 2004) and depressed productivity of wild fish when interbreeding with hatchery origin fish (Araki et al. 2009). Berejikian and Ford (2004) hypothesized that species that have minimal freshwater portions of their life histories, (e.g., chum, pink and ocean-type Chinook) would be less likely to change phenotypically and genetically due hatchery propagation than species with longer freshwater life histories (e.g., coho, steelhead, stream-type Chinook). A recent study by Berejikian (2009) found that the relative reproductive success of hatchery origin and natural origin summer chum at Big Beef creek were not significantly different. When comparing Berejikian's study to our work on the Duckabush, one key difference is the number of generations each stock has been in the hatchery. Berejikian collected summer chum fish that originated from the Quilcene River, a Hood Canal tributary located 13 miles north of the Duckabush River. The Quilcene River was the first river in Hood Canal to implement a supplementation program beginning in 1992. His study involved collecting adults that returned in 2004 and 2005. The ancestry of adults prior to the parental generation was unknown but the number of generations in the hatchery likely ranged between 1 to 3 generations. In contrast, Hood Canal has been supplemented with hatchery origin fall chum since the early 1900s with large releases (>20 million fry) beginning in the mid-1970s. It is possible that hatchery origin fall chum that strayed to the Duckabush could have spent upwards of 10 plus generations in the hatchery. We might expect that as the number of generations in the hatchery increases, the chances for selection and loss of fitness also increase, even for species with minimal freshwater life history (Berejikian and Ford 2004). As more research involving relative fitness of hatchery populations such as chum becomes available, we hope to further refine our understanding of how hatchery origin fall chum may be affecting freshwater productivity in the Duckabush.

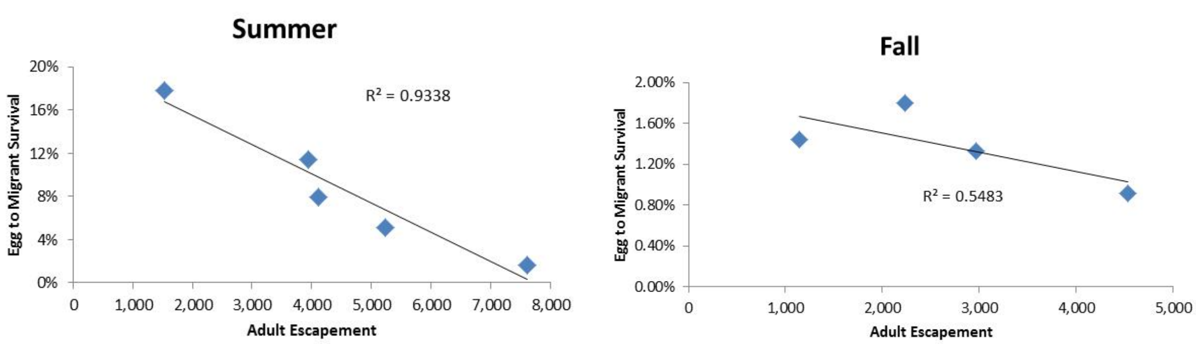
Table 6. Egg to migrant survival of summer and fall chum in Washington and British Columbia.

Location	Stock	Years Sampled	Range (percent)	Mean (percent)	Source
Duckabush	Summer	5	1.6 - 17.5	8.6	This Study
Salmon Creek	Summer	8	3.76 - 67.6	25.3	WDFW (unpublished)
Duckabush	Fall	4	0.8 - 1.8	1.3	This Study
Fraser River BC	Fall	19	5.7 - 35.4	14.2	(Beacham and Starr 1982)
Big Qualicum River BC	Fall	4	5.0 - 17.0	11.2	(Lister and Walker 1966)
Hooknose Creek BC	Fall	14	1.0 - 22.0	8.5	(Neave 1966)
Nile Creek BC	Fall	4	0.1 - 7.0	1.5	(Wickett 1952)
Inches Creek BC	Fall	4	1.6 - 9.3	5.5	(Fedorenko and Bailey 1980)
Barnes Creek BC	Fall	4	4.6 - 18.8	7.0	(Fedorenko and Bailey 1980)



*Fall analysis does not include brood year 2010

Figure 5. Duckabush summer and fall chum egg to migrant survival vs peak flow (m^3s^{-1}), brood year 2011-2015.



*Fall analysis does not include brood year 2010

Figure 6. Duckabush summer and fall chum egg to migrant survival vs adult escapement, brood year 2011-2015.

Marine Survival

Following the adult returns of 2015, we were able to estimate marine survival for the 2011 outmigration. This marks the first time that an approximation of marine survival has been estimated for Duckabush summer and fall chum. Only two other summer chum stocks have been evaluated for marine survival: Big Beef Creek, a small stream located on the east side of Hood Canal just north of the Duckabush, and Salmon Creek, in Discovery Bay (Table 7). Survival rates for fall chum within Hood Canal are limited to two years (1968 and 1969) at Big Beef Creek.

The brood year 2010 estimated marine survival rate for summer chum was slightly higher than has been observed for other summer stocks in the ESU (Table 7). In contrast, we estimated marine survival for fall chum to be over 5 times higher than any other study as observed in Washington or British Columbia. It seems unlikely that Duckabush fall chum would outperform similar stocks by such a wide margin.

One hypothesis is that a large number of the returning fall chum are strays from the large hatchery releases in Hood Canal. If we apply the range of survivals observed from other fall stocks (0.3 – 2.6%) to the brood year 2010 fall chum freshwater outmigrants, we would expect somewhere between 98 and 849 natural origin adults to return in return years 2013 through 2015, a small fraction of the total estimated spawning recruitment from this same cohort (4,625, Table 4). Assuming the difference is composed of hatchery-origin fish spawning in the Duckabush River, these estimates correspond to a hatchery fraction ranging between 82 and 98 percent. Given the relatively low observed productivity from fall chum during our study (Table 6), it seems plausible that hatchery origin fall fish are far outnumber naturally produced fish on the spawning grounds.

Although complete marine survival estimates were not available for brood years 2011 - 2014, we calculated the marine survival value needed to have to achieve the 1.6 adult recruits per spawner summer chum recovery goal (Figure 7, Table 8). The 2010 brood year, the only year we have adult returns for all age classes, exceeded the recovery objective with a recruits per spawner ratio of 1.9. The 2011 brood year is also above the productivity recovery goal (2.1 R/S) even prior to the return of 5 year old adults. The 2012 brood year has only had its age 2 and 3 year olds returns and will need to have a 3% marine survival rate to meet the recovery goal. Brood year 2013 was the second highest fry per spawner ratio we observed during our study and needs a marine survival of 1.3% to meet recovery productivity. The 2014 brood was by far our lowest fry per spawner ratio and will need marine survival levels of 6% just to meet replacement.

Table 7. Marine survival of summer and fall chum in Washington and British Columbia.

Location	Stock	Brood Years	Marine Survival		Source
			Mean (%)	Range (%)	
Duckabush, WA	Summer	2011	2.27[1]	-	This Study
Salmon Creek, WA	Summer	2007 - 2011	1.14[1]	0.52 - 2.16[1]	WDFW (unpublished)
Big Beef Creek, WA	Summer	1968 - 1969	0.66[1]	0.53 - 0.79[1]	Koski (1975)
Duckabush, WA	Fall	2011	14.16[1]	-	This Study
Big Beef Creek, WA	Fall	1968 - 1969	1.84[1]	1.1 - 2.58[1]	Koski (1975)
Fraser River, BC	Fall	1961 - 1979	1.2[2]	0.3 - 2.7[2]	Beacham and Starr (1982)
Inches Creek, BC	Fall	1970 - 1975	1.27[1]	0.88 - 1.82[1]	Fedorenko and Bailey (1980)

[1] Includes fishing mortality

[2] Does not include fishing mortality

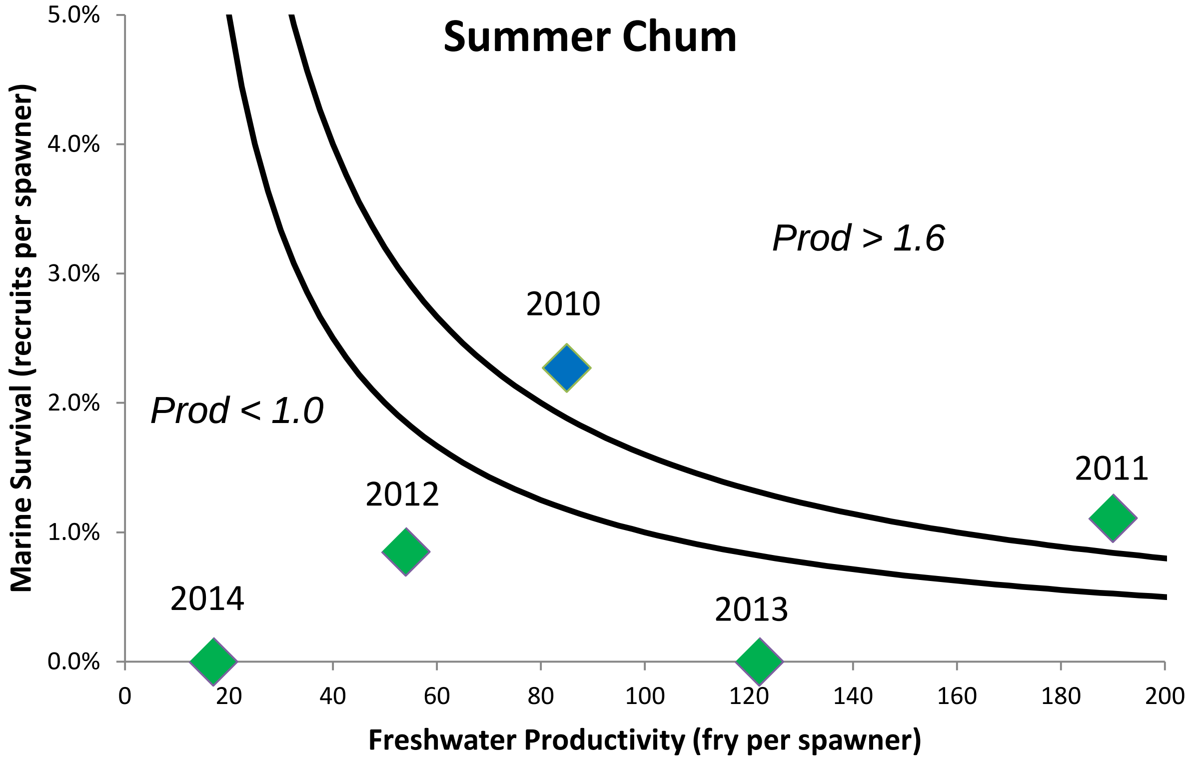


Figure 7. Duckabush summer chum freshwater productivity vs marine survival, brood year 2010-2014. The blue dots represent years we have adult returns for all age classes and green dots represent incomplete returns and represent the current marine survival to date.

Table 8. Duckabush summer chum marine survival levels needed to achieve replacement (R/S 1.0) and recovery productivity (R/S 1.6), brood year 2010-2014.

Brood Year	Fry Per Spawner	Marine Survival	
		R/S 1.0	R/S 1.6
2010	85	1.18%	1.90%
2011	190	0.53%	0.80%
2012	54	1.86%	3.00%
2013	122	0.83%	1.30%
2014	17	5.97%	9.60%

Migration timing

The Duckabush provided a unique opportunity to evaluate two ecotypes of the same species that have distinctly different adult spawn timing, yet spawn in the same location. During our study, peak summer adult abundance occurred between 54 and 89 days earlier than fall chum (Table 9). Peak summer adult abundance occurred within a two week period in mid-September during all 5 seasons. Fall timed chum had a wider range of peak dates than summers. Our adult timing results appear to be within the ranges observed for other summer and fall chum stocks within Puget Sound.

The juvenile outmigration of the two stocks also exhibited different timing, but the separation of peak dates was less than that observed for the adults (Table 9). The difference in outmigration timing ranged from 18 to 39 days. Fall timed chum may develop at a faster rate during colder temperatures than summer chum, in an attempt to synchronize entry into the marine environment despite later spawn timing. Koski (1975) and Tallman and Healey (1991) observed similar synchronous fry emigration relationships with chum salmon that spawned during different seasons. This phenomenon of synchronous emigration is likely due to the availability of prey in the marine environment. Chum fry depend on zooplankton as a primary food source and would benefit from timing their arrival to the estuary with peaks in prey productivity. Zooplankton availability is dependent on phytoplankton blooms which occur during increased spring photoperiod and warming sea surface temperatures. Timing marine entry with peaks in prey increases initial growth and limits the amount of time for size selective mortality (Walters et al. 1978).

Table 9. Dates of peak adult and juvenile abundance for summer and fall chum, brood year 2010-2014.

Brood Year	Adults			Juveniles		
	Summer	Fall	**Difference**	Summer	Fall	**Difference**
2010	9/22	Unk	**-**	3/13	4/8	**26**
2011	9/15	12/13	**89**	3/10	4/18	**39**
2012	9/21	11/14	**54**	3/2	3/25	**23**
2013	9/12	11/27	**76**	2/22	4/8	**45**
2014	9/25	11/20	**56**	3/1	3/19	**18**

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