JUVENILE CHINOOK SALMON AND NEARSHORE FISH USE IN HABITAT ASSOCIATED WITH CRESCENT HARBOR SALT MARSH, 2011 THROUGH 2015

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Skagit River System Cooperative[1] Research Program

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Photo from Naval Air Station Whidbey Island

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Contents

Acknowledgements 3
Study area and purpose of report 4
Sampling methods, effort, and period 7
Results and discussion 11
Water quality 11
Temperature 11
Salinity 14
Dissolved oxygen 17
Fish assemblage 20
Juvenile pink and chum salmon timing and relative abundance 26
Wild juvenile Chinook salmon 28
Timing and relative abundance 28
Fish length 32
Origin of juvenile Chinook salmon caught at Crescent Harbor 34
Influence of Skagit River flow and juvenile Chinook outmigration population size 34
Juvenile Chinook density inside and adjacent to Crescent Harbor Salt Marsh 37
Comparison to other Skagit Bay pocket estuaries 40
Conclusions 41
References 42

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Study area and purpose of report

Crescent Harbor Salt Marsh and shoreline are part of the Puget Sound nearshore located within the Whidbey Basin (Figure 1). Crescent Harbor Salt Marsh is part of a group of nearshore habitats referred to as pocket estuaries. Pocket estuaries are partially enclosed bodies of marine water that are connected to a larger estuary (such as Puget Sound) at least part of the time, and are diluted by freshwater from the surrounding watershed upland at least part of the year (after Pritchard 1967).With respect to Puget Sound Chinook salmon, these small estuaries are differentiated from larger scale river estuaries because the watersheds they are associated with are too small to support spawning Chinook salmon populations; thus we call them non-natal estuaries with respect to juvenile salmon use (Beamer et al. 2003). Pocket estuaries are an important habitat for wild Chinook salmon fry early in the year once they leave their natal estuary and enter nearshore areas of Whidbey Basin (Beamer et al. 2003, Beamer et al. 2006).

Restoration and protection of Crescent Harbor Salt Marsh was identified as a priority in the Skagit Chinook Recovery Plan (page 204 in SRSC & WDFW 2005) because of its importance to early rearing of wild fry migrant Chinook salmon stocks. The restoration project area lies within the confines of Naval Air Station Whidbey Island (NASWI), and with the U.S. Navy as a willing land owner, restoration was completed by Skagit River System Cooperative (SRSC) and NASWI in 2009 through funding by the Salmon Recovery Funding Board (SRFB) and the Estuary and Salmon Restoration Program (ESRP). Restoration design built upon an initial assessment and restoration plan completed for NASWI and Island County Public Works (PWA and UW WET 2003). Restoration actions mainly consisted of: a) increasing tidal connectivity within the historic marsh area, and b) replacing the system's outlet channel tide gate with a Mabey-Johnson bridge, thus restoring tidal flooding and fish access to more than 200 acres of Crescent Harbor Salt Marsh (Figure 2). More information about the restoration actions can be found at: http://skagitcoop.org/programs/restoration/crescent-harbor-salt-marsh/.

In response to the completed restoration at Crescent Harbor Salt Marsh, we monitored fish use of the restored areas and its adjacent nearshore beaches from 2011 through 2015 over the juvenile Chinook salmon rearing period for pocket estuaries (January through June). The fish monitoring design for the Crescent Harbor Salt Marsh Restoration Project is a post-treatment (i.e., after restoration) stratified (lobes within the restored area) design. Limited pre-restoration project fish data for Crescent Harbor Salt Marsh are reported in PWA and UW WET (2003) for comparison.

Monitoring questions addressed in this report are:

1. How does local environment vary by year, season, and spatial strata within the Crescent Harbor Salt Marsh Restoration Project?
2. What fish species are present within the restored area?
3. How does juvenile Chinook salmon density vary by year, season, and spatial strata within the Crescent Harbor Salt Marsh Restoration Project?
4. How does seasonal juvenile Chinook salmon density in the restored Crescent Harbor Salt Marsh compare with nearby natural pocket estuaries?

Figure 1. Location of Crescent Harbor Salt Marsh area along the eastern shoreline of Whidbey Island, near the city of Oak Harbor.

Crescent Harbor Salt Marsh 2001 – before restoration (photo from WDOE shoreline oblique photos)


Crescent Harbor Salt Marsh 2009 – after restoration (photo from Naval Air Station Whidbey Island)

Figure 2. Pre- and immediately post-restoration at Crescent Harbor Salt Marsh.

Sampling methods, effort, and period

The Crescent Harbor Salt Marsh restoration area is divided into five distinct spatial strata: the adjacent nearshore outside the salt marsh (A); lobes B, C, and E within the salt marsh; and Crescent Creek (D), which flows into the salt marsh, all with varying degrees of connectivity to Crescent Harbor marine waters (Figure 3, top panel). Spatial strata were selected to coincide with restoration actions that opened up connectivity within the salt marsh. Because of the differing habitat types, two sampling methods were used: a small net beach seine in the restored salt marsh and adjacent nearshore; electrofishing in Crescent Creek. Four beach seine sites were chosen for each of lobes B, C, and E. In lobes B and C, two sites were selected on the larger, main channel, and two were selected in smaller side channels, representing two different flow regimes. Since lobe E is the furthest removed from marine waters of Crescent Harbor and has the least flow, sites were selected to represent the lobe spatially. Specific beach seine locations and Crescent Creek are shown in Figure 3, bottom panel.

Small net beach seine methodology uses an 80-foot (24.4 m) by 6-foot (1.8 m) by 1/8-inch (0.3 cm) mesh knotless nylon net. The net is set in a "round haul" fashion by fixing one end of the net on the beach while the other end is deployed by wading "upstream" against the water current (if present), hauling the net in a floating tote, and returning to the shoreline in a half circle. If water depth prohibits wading, the tote and net are towed in a half circle using a small skiff with an outboard engine. Both ends of the net are then retrieved, yielding a catch. One beach seine set was made at each site within the lagoon per sampling day. While we only have two "sites" shown in Figure 3 (bottom panel) for the adjacent nearshore, we did make two sets at each of the two sites for a total of four sets each sampling date. This corresponds to the four sets made in each lobe within the restored lagoon. Average beach seine area was 96 square meters. Photos of the methods and further descriptions are found within a methods paper published by Skagit System Cooperative (2003).

Crescent Creek was sampled using a Smith Root, Inc LR-24 electrofisher with the intent of sampling on the same days that beach seine sampling occurred in the adjacent nearshore and restored lagoon. Sampling in the creek was conducted in five accessible reaches extending from the upper edge of the marsh to the culvert at W. Crescent Harbor Road.

For both methods, we identified and counted the catch by species. We also recorded the time and date of each sampling and measured several associated water quality variables including water temperature, salinity, and dissolved oxygen using a YSI Professional Plus Model meter. Beach seine depths, velocity, vegetation and substrate types were also noted.

We beach seined or electrofished every two weeks, starting in February and ending in May. After 2011 we expanded the sampling period to include January and June each year thereafter (2012 through 2015). The sampling period was selected to encompass the period when juvenile Chinook salmon are known to be rearing in pocket estuaries and small independent streams entering the Whidbey Basin (Beamer et al. 2003, Beamer et al. 2006, Beamer et al. 2013). The limited electrofishing of Crescent Creek conducted in 2010 was included in an analysis related to juvenile Chinook salmon use of small independent streams draining into Whidbey Basin (Beamer et al. 2013). Summaries of the beach seine and electrofishing sampling effort is shown in Tables 1 and 2, respectively.

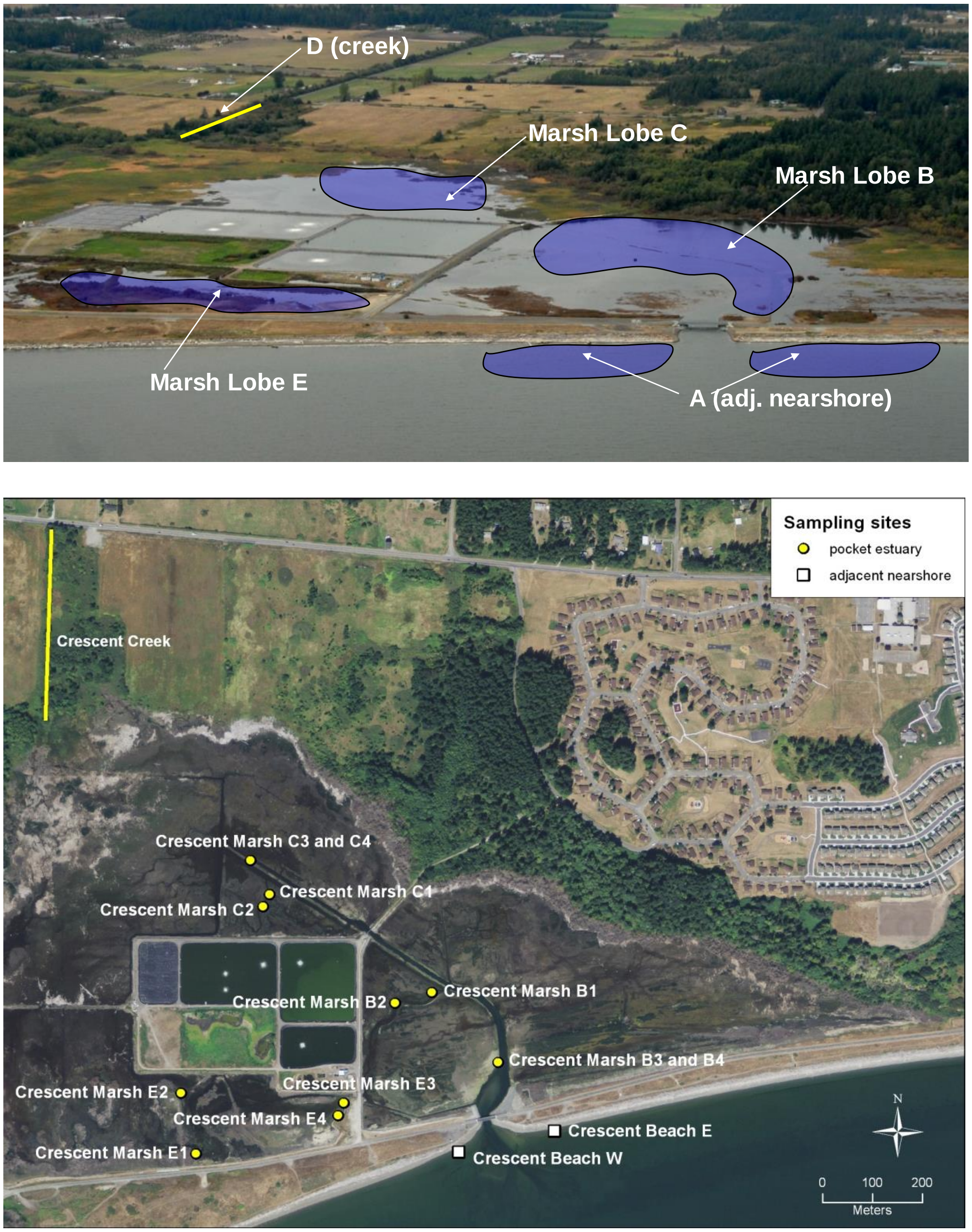


Figure 3. Location of sampling sites at Crescent Harbor Salt Marsh. Top panel shows five sampling strata (A-E) on oblique photo at high tide. Bottom panel shows beach seine and electrofishing sites. Yellow circles represent sites within the lagoon. White squares represent sites in the adjacent nearshore. Crescent Creek is shown as a yellow line, where electrofishing occurred. Beach seining was always done at the water's edge, regardless of tidal stage.

Table 1. Summary of beach seine effort (number of sets) at Crescent Harbor by strata, month, and year.

Year	Month	Beach (A)	Marsh (B)	Marsh (C)	Marsh (E)	Grand Total
2011	Feb	8	8	8	8	32
	Mar	8	8	8	8	32
	Apr	8	8	8	8	32
	May	8	8	8	8	32
	Total	**32**	**32**	**32**	**32**	**128**
2012	Jan	4	4	4	3	15
	Feb	8	8	8	8	32
	Mar	8	8	8	8	32
	Apr	8	8	8	8	32
	May	8	8	8	8	32
	Jun	4	4	4	4	16
	Total	**40**	**40**	**40**	**39**	**159**
2013	Jan	4	4	4	4	16
	Feb	8	8	8	8	32
	Mar	8	8	8	8	32
	Apr	4	4	3	4	15
	May	8	6	8	8	30
	Jun	8	8	8	8	32
	Total	**40**	**38**	**39**	**40**	**157**
2014	Jan	4	4	4	4	16
	Feb	8	8	8	8	32
	Mar	8	8	8	8	32
	Apr	8	8	8	8	32
	May	4	4	4	4	16
	Jun	8	8	8	8	32
	Total	**40**	**40**	**40**	**40**	**160**
2015	Jan	4	4	4	4	16
	Feb	8	8	8	8	32
	Mar	8	8	8	8	32
	Apr	8	8	8	8	32
	May	8	8	8	8	32
	Jun	4	4	4	4	16
	Total	**40**	**40**	**40**	**40**	**160**
Grand Total		**192**	**190**	**191**	**191**	**764**

Table 2. Summary of electrofishing effort (number of reaches shocked) at Crescent Harbor, by month and year.

Year Month	2010	2011	2012	2013	2014	2015
Jan	0	5	5	4	5	5
Feb	0	9	5	8	10	10
Mar	4	10	10	10	10	10
Apr	5	10	5	5	10	10
May	5	10	10	10	5	10
Jun			5	9	9	5
Total	**14**	**44**	**40**	**46**	**49**	**50**

Beach seining at Crescent Beach E

An example of electrofishing

Results and discussion

Water quality

We used ANOVA methodology to determine factor and covariate influences on three different dependent variables for water quality measured just under the surface: 1) temperature, 2) salinity, and 3) dissolved oxygen (DO). We conducted separate analyses for each dependent variable, using the same factors and covariates for each model. Factors included in each ANOVA were strata (lobes A, B, C, and E; we did not include the creek - lobe D) and year. Covariates included in each ANOVA were month (seasonal effect) and the environmental measurements (temperature, salinity, DO) if they were not auto correlated with the tested dependent variable. Results are shown graphically and as ANOVA summary tables and pairwise comparison tables for significant results (i.e., $P < 0.05$) of tested factors.

Temperature

The final model uses 191 records of untransformed water surface temperature, has an R^2 of 0.89, retained month as the only significant covariate, and found significant Strata and Year differences in water temperature at Crescent Harbor Salt Marsh (Table 3). Salinity was not a significant covariate and DO was not included in the analysis because of its correlation with temperature.

The model coefficient for Month = 2.21. The positive coefficient associated with month for the period January through June is the expected seasonal increase in water temperature as winter turns to spring and early summer (Figure 4). Water surface temperature for all Crescent Harbor sites never exceeded the lethal limit for juvenile Chinook salmon of 24.8 °C (McCullough 1999) but commonly exceeded the 15 °C level thought to be stressful to juvenile salmon (Fresh 2006) by May or June each year.

The only significant difference in water temperature between strata was Beach (A) with Marsh (C) (Figure 5, Table 4). Marsh (C) is furthest from the colder marine waters and closest to creek water which is likely warmer than marine waters during late spring and early summer. The culvert between Marsh (B) and Marsh (E) failed over the first winter after construction and was filled in with quarry spalls. The culvert fix eliminated fish passage potential directly between Marsh (B) and Marsh (E) but not exchange of cooler marine waters to Marsh (E) via seepage through the coarse fill (Steve Hinton and Eric Mickelson, personal communication).

Annual differences in water temperature were detected (Table 5). Year 2011 was the coldest while Year 2013 was the warmest.

Table 3. ANOVA significance results for water surface temperature at Crescent Harbor Salt Marsh post restoration. P-values significant at the 0.05 level are bolded.

Variable Type	Variable	p-Value
Factors	STRATA	**0.002**
	YEAR	**0.000**
Interactions	STRATA*YEAR	0.506
Covariates	MONTH	**0.000**

Table 4. Pairwise results of water surface temperature by Strata at Crescent Harbor Salt Marsh using Tukey's Honestly Significant Difference Test. P-values significant at the 0.05 level are bolded.

STRATA (i)	STRATA (j)	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Beach (A)	Marsh (B)	-0.413	0.717	-1.415	0.589
Beach (A)	Marsh (C)	-1.391	**0.002**	-2.393	-0.389
Beach (A)	Marsh (E)	-1.008	0.051	-2.015	-0.001
Marsh (B)	Marsh (C)	-0.977	0.060	-1.979	0.024
Marsh (B)	Marsh (E)	-0.595	0.431	-1.602	0.412
Marsh (C)	Marsh (E)	0.383	0.765	-0.624	1.390

Table 5. Pairwise results of water surface temperature by Year at Crescent Harbor Salt Marsh using Tukey's Honestly Significant Difference Test. P-values significant at the 0.05 level are bolded.

YEAR(i)	YEAR(j)	Difference (degrees C)	p-Value	95% Confidence Interval	
				Lower	Upper
2011	2012	-0.653	0.601	-1.889	0.583
2011	2013	-3.109	**0.000**	-4.345	-1.873
2011	2014	-1.678	**0.002**	-2.921	-0.435
2011	2015	-3.085	**0.000**	-4.321	-1.849
2012	2013	-2.456	**0.000**	-3.621	-1.290
2012	2014	-1.025	0.120	-2.198	0.148
2012	2015	-2.432	**0.000**	-3.597	-1.267
2013	2014	1.431	**0.008**	0.258	2.604
2013	2015	0.024	1.000	-1.142	1.189
2014	2015	-1.407	**0.009**	-2.580	-0.234

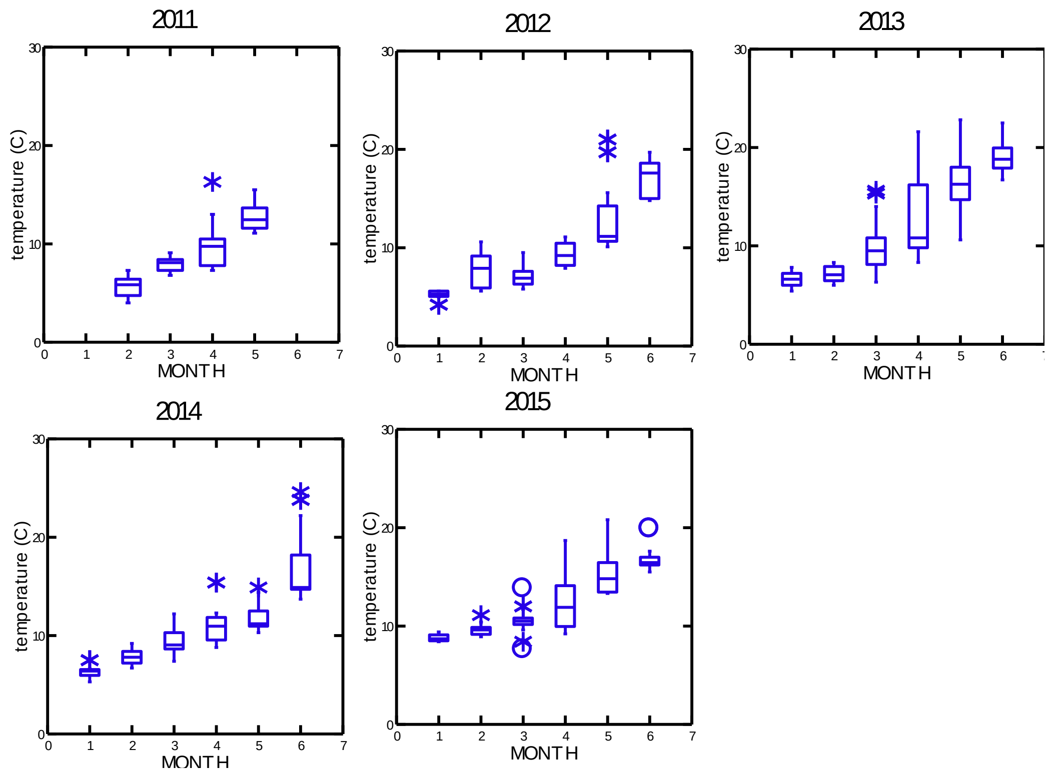


Figure 4. Boxplot of water surface temperature at Crescent Harbor by month and year. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

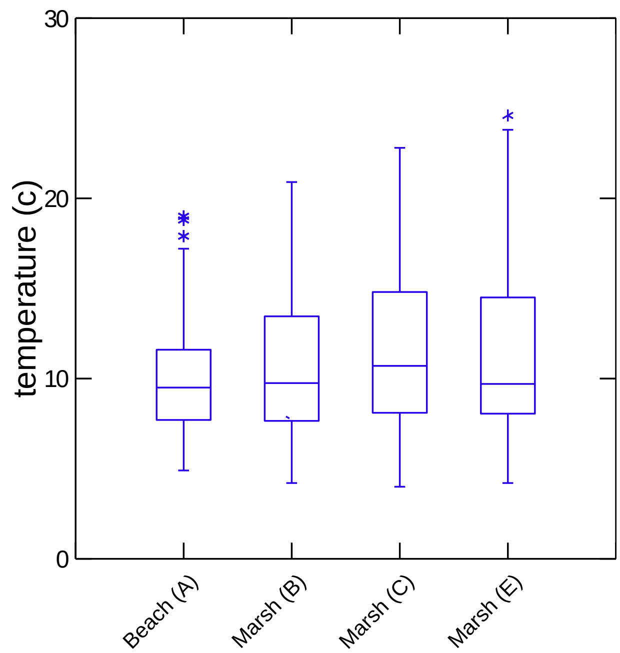


Figure 5. Boxplot of water surface temperature by sampling strata at Crescent Harbor. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

Salinity

The final model uses 191 records of untransformed water surface salinity, has an R^2 of 0.28, did not find any significant covariates, and found only significant Year differences in salinity at Crescent Harbor Salt Marsh (Table 6).

We observed monthly variability in salinity at Crescent Harbor (Figure 6), but there was no statistically significant seasonal pattern to the variability across all years. Salinity within pocket estuaries is a combination of the salinity of water in the surrounding marine basin as well as the pocket estuary's inflowing creek. In another pocket estuary located in northern Whidbey Basin – Lone Tree Lagoon – salinity variability is strongly influenced by the salinity of water in Skagit Bay (Beamer et al. 2004), which is influenced by Skagit River discharge (Lee et al. 2010). Thus, salinity within Crescent Harbor Salt Marsh is likely best predicted by Whidbey Basin salinity, which is influenced by river runoff into the Whidbey Basin, as well as localized effects of Crescent Creek's inflow during freshets. We did not include Skagit River or Crescent Creek discharge as covariates in our model. Based on monitoring from January through June, salinity within Crescent Creek Salt Marsh reflects a polyhaline (i.e., 18 – 30 ppt) or even mesohaline (i.e., 10 – 18 ppt) system, not the euhaline (i.e., 30 – 40 ppt) system suggested by PWA and UW WET (2003) (Figure 6).

There were no significant differences in salinity between strata within Crescent Harbor (Figure 7, Table 6), but annual differences in salinity were detected (Table 7). On average, Crescent Harbor Salt Marsh salinity in year 2013 was 2.3 ppt lower than in year 2015.

Table 6. ANOVA significance results for water surface salinity at Crescent Harbor Salt Marsh post restoration. P-values significant at the 0.05 level are bolded.

Variable Type	**Variable**	**p-Value**
Factors	STRATA	0.620
	YEAR	**0.040**
Interactions	STRATA*YEAR	0.997

Table 7. Pairwise results of water surface salinity by Year at Crescent Harbor Salt Marsh using Tukey's Honestly Significant Difference Test. P-values significant at the 0.05 level are bolded.

YEAR(i)	**YEAR(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
2011	2012	-0.982	0.760	-3.242	1.278
2011	2013	0.473	0.979	-1.787	2.733
2011	2014	-0.253	0.998	-2.525	2.020
2011	2015	-1.805	0.188	-4.065	0.455
2012	2013	1.455	0.339	-0.676	3.585
2012	2014	0.729	0.887	-1.415	2.873
2012	2015	-0.823	0.830	-2.954	1.307
2013	2014	-0.726	0.888	-2.870	1.418
2013	2015	-2.278	**0.029**	-4.409	-0.148
2014	2015	-1.552	0.279	-3.696	0.592

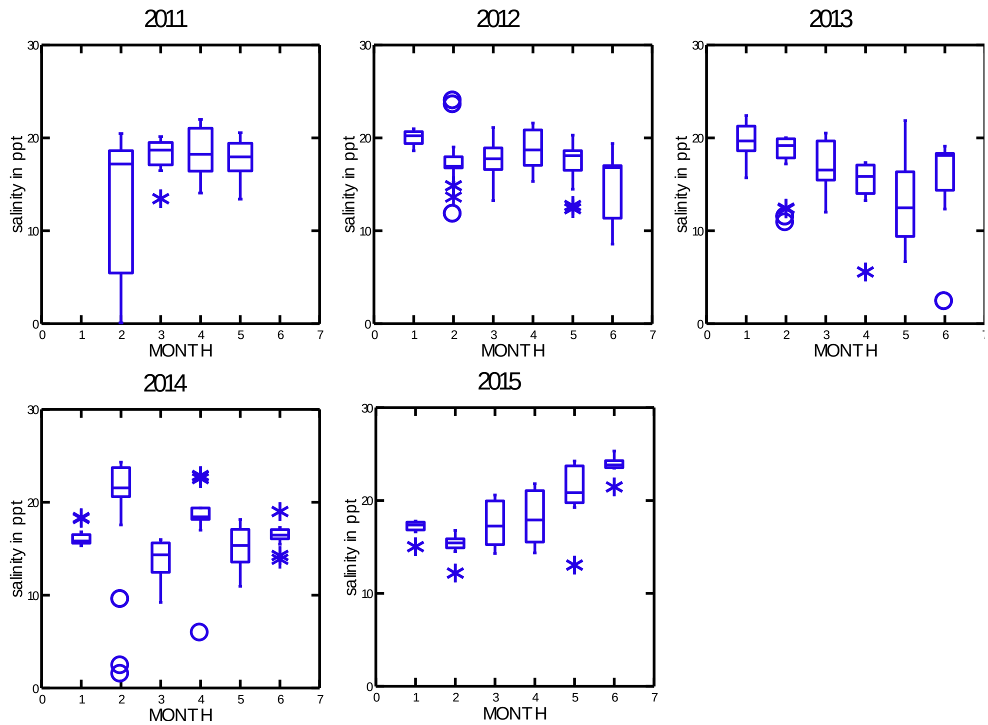


Figure 6. Boxplot of water surface salinity at Crescent Harbor by month and year. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

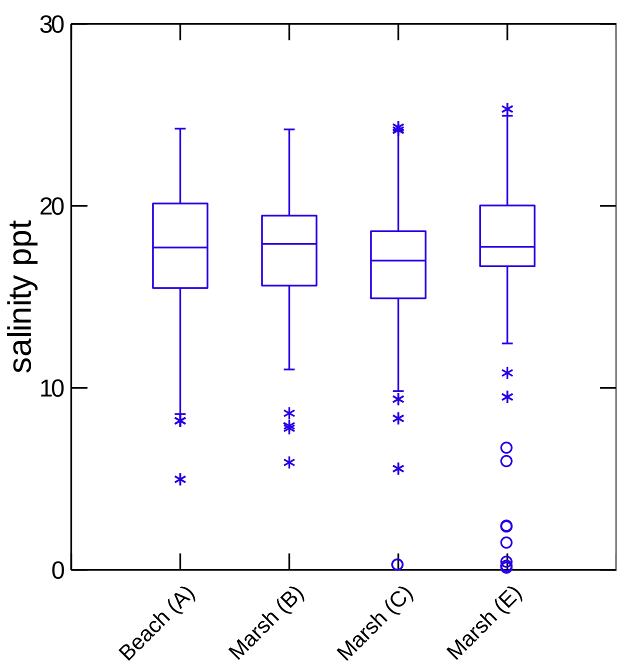


Figure 7. Boxplot of water surface salinity by sampling strata at Crescent Harbor. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

Dissolved oxygen

The final model uses 191 records of untransformed water surface dissolved oxygen, has an R^2 of 0.877, and did not find any significant covariates. We found significant Strata but not Year differences in DO levels at Crescent Harbor Salt Marsh (Table 8). Strong Strata/Month and Year/Month interactions in DO levels were detected, but were too numerous to be shown in this report.

Month fit better in the final model as a factor than as a covariate because there is not a single direction in the seasonal effect over the sampled period (January through June) for all years. Temperature was not included in the analysis because of its correlation with DO. Salinity was not a significant covariate in the best model.

There were no significant differences in DO between years within Crescent Harbor (Table 8), but Strata differences in DO were detected (Figure 9, Table 9). On average, dissolved oxygen in water along the beach adjacent to Crescent Harbor Salt Marsh was higher than dissolved oxygen in any of the salt marsh lobes.

Of the water quality measurements taken during the 5-year sampling period, 10% of the water surface DO levels for all of the Crescent Harbor sites were less than the Washington State Department of Ecology's 'extraordinary' water quality standard of 7.0 mg/l (for salmonid and other fish migration and rearing in marine waters). Values below this water quality standard are considered unhealthy for juvenile salmon. The vast majority of low DO observations occurred in May or June (Figure 8) when juvenile Chinook salmon use was in decline. Low DO in summer is expected simply because the solubility of oxygen in water decreases as water temperature increases. All low DO occurrences were within the saltmarsh lobes and not on the beach outside of Crescent Harbor Salt Marsh (Figure 9).

Low DO levels may occur in estuarine habitats when plants or algae die. Bacteria and other decomposers reduce DO levels as they consume oxygen while breaking down dead organic matter. This phenomenon could have occurred when Crescent Harbor Salt Marsh was restored. In fact, vegetation monitoring showed that almost all of the pre-restoration vegetation (over 95%) died within the first year after the reintroduction of tidal influence (Clifton 2015). Thus, we expected to see a significant difference in DO between years with possibly increasing DO annually as the old vegetation worked its way out of the system and new vegetation colonized the area. However, we did not observe any significant year to year results. Possibly, any Crescent Harbor Salt Marsh vegetation transition effect on DO would have only been measurable in 2010, the year immediately following restoration and a year we did not monitor. Increasing DO levels are expected as vegetation continues to colonize the restored areas. Meanwhile, DO variability will likely respond to algae blooms and die offs that occur within Crescent Harbor Salt Marsh. Vegetation surveys from 2013 to 2015 show bare ground on 60% of the monitoring transects (Clifton 2015). The remaining 40% of transects consisted of mostly algae and only a small amount (3-6%) of salt marsh plants.

Table 8. ANOVA significance results for water surface dissolved oxygen at Crescent Harbor Salt Marsh post restoration. P-values significant at the 0.05 level are bolded.

Variable Type	**Variable**	**p-Value**
Factors	STRATA	**0.004**
	YEAR	0.997
	MONTH	0.075
Interactions	STRATA*YEAR	0.830
	STRATA*MONTH	**0.001**
	YEAR*MONTH	**0.001**
	STRATA*YEAR*MONTH	0.739

Table 9. Pairwise results of water surface dissolved oxygen by Strata at Crescent Harbor Salt Marsh using Tukey's Honestly Significant Difference Test. P-values significant at the 0.05 level are bolded.

STRATA(i)	**STRATA(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Beach (A)	Marsh (B)	1.326	**0.011**	0.230	2.422
Beach (A)	Marsh (C)	1.374	**0.007**	0.278	2.470
Beach (A)	Marsh (E)	1.849	**0.000**	0.747	2.951
Marsh (B)	Marsh (C)	0.048	0.999	-1.048	1.144
Marsh (B)	Marsh (E)	0.523	0.617	-0.579	1.625
Marsh (C)	Marsh (E)	0.475	0.690	-0.627	1.577

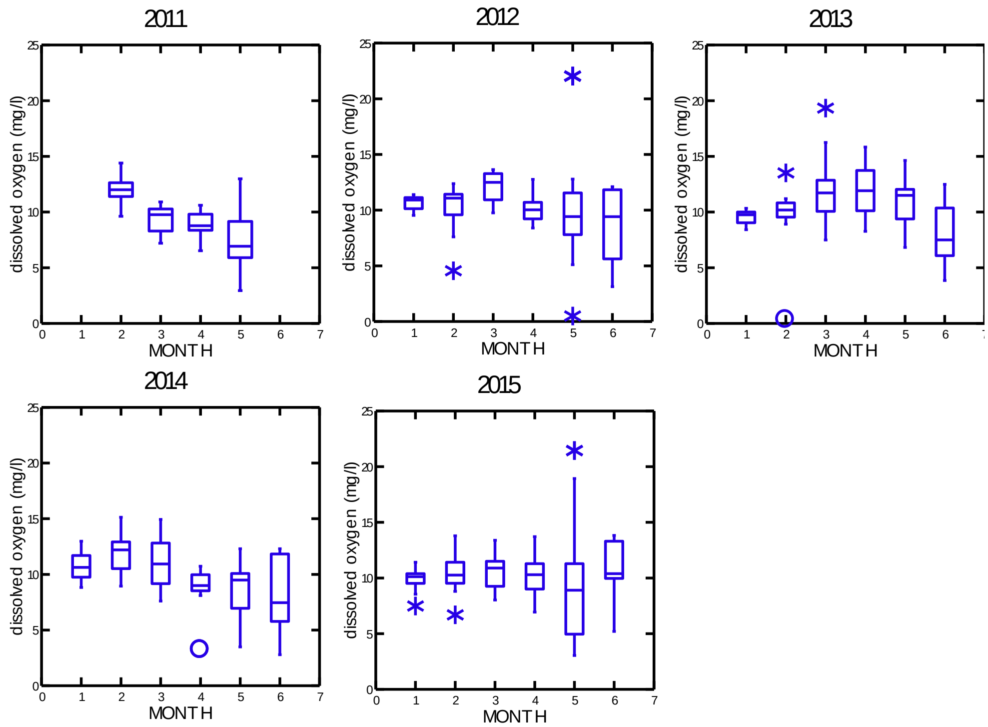


Figure 8. Boxplot of water surface dissolved oxygen at Crescent Harbor by month and year. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

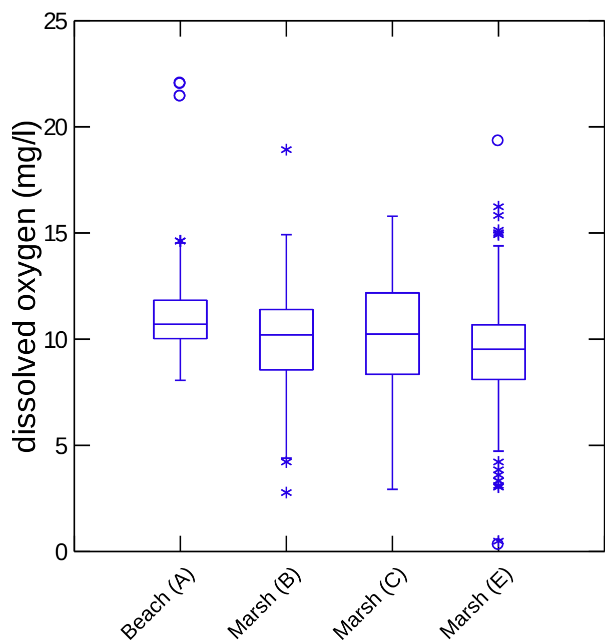


Figure 9. Boxplot of water surface dissolved oxygen by sampling strata at Crescent Harbor. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

Fish assemblage

The total number of fish caught during the sampling and the number of fish species represented in that catch was 18,959 with 13 species in 2011; 8,690 with 10 species in 2012; 5,842 with 13 species in 2013; 4,637 with 15 species in 2014; and 4,928 with 16 species in 2015 (Tables 10-14). Fish caught included juvenile salmon, sculpins (4 species), forage fish (2 species), and flatfish (2 species). All species of salmonids were caught except for steelhead (O. mykiss). Pacific staghorn and sharpnose sculpins were caught every year; padded sculpins were caught in 2011 and 2015; prickly sculpins were caught in 2013. Surf smelt were caught every year and Pacific sandlance were caught in 2013. Starry flounders were caught every year and English sole were caught in 2014.

The dominant fish in the catch other than juvenile salmon (which are discussed in detail later) were threespine stickleback, shiner perch, and Pacific staghorn sculpins.

> Threespine stickleback was the most abundant species caught: a total of 27,410 fish caught in all years combined, with the majority of these fish found in the combined marsh lobes. The percent distribution of sticklebacks from within the lobes ranged from 93.2% to 98.7% (2013 and 2011, respectively). They were found in the creek in all years, with the percent of stickleback catch ranging from 1.2% to 6.2% from that area (2011 and 2013, respectively). Very few were found in the adjacent nearshore habitat.
>
> Shiner perch were found in all years of sampling, although in 2015 there was only one fish caught. There was a total of 5,830 shiners caught in all years combined. Most of the shiners were caught inside the marsh lobes. The percent of the shiner catch from inside the lobes ranged from 93.5% to 98.1% (2011 and 2014, respectively). In 2013, 56.1% of the shiner catch came from the lobes while 43.9% were caught along the adjacent nearshore beach. Shiners were never caught in the creek.
>
> Pacific staghorn sculpins were also caught every year and were caught both in the combined marsh lobes and at the adjacent beach. There was a total of 2,752 staghorns caught in all years combined. The percent of the catch within in the combined lobes ranged from 72.2% to 87.2% (2013 and 2011, respectively). Staghorns were never caught in the creek.

Two non-native species of fish were documented, both caught in 2011: one shad (caught in Lobe C) and one bluegill sunfish (caught in the creek).

Table 10. Total fish catch (and mean catch per beach seine set [or mean catch per minute for electrofishing] in parentheses) by species at Crescent Harbor sites in 2011.

	Adjacent nearshore	Pocket estuary			
Strata & method	Spit beach	Lobe B	Lobe C	Lobe E	Crescent Creek
Species	Beach seine	Beach seine	Beach seine	Beach seine	Electro-fishing
Salmon:					
Chinook salmon, unmarked subyearling *Oncorhynchus tshawytscha*	1 (0.03)	27 (0.84)	67 (2.09)	3 (0.09)	10 (0.18)
Coho salmon, unmarked subyearling *Oncorhynchus kisutch*	0 (0.00)	0 (0.00)	1 (0.03)	0 (0.00)	0 (0.00)
Coho salmon, unmarked yearling *Oncorhynchus kisutch*	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (0.04)
Pink salmon, subyearling *Oncorhynchus gorbuscha*	0 (0.00)	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)
Chum salmon, subyearling *Oncorhynchus keta*	15 (0.47)	147 (4.59)	196 (6.13)	17 (0.53)	0 (0.00)
Cottids (sculpins):					
Pacific staghorn sculpin *Leptocottus armatus*	28 (0.88)	114 (3.56)	41 (1.28)	44 (1.38)	0 (0.00)
Padded sculpin *Artedius fenestralis*	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Sharpnose sculpin *Clinocottus acuticeps*	2 (0.06)	28 (0.88)	3 (0.09)	0 (0.00)	0 (0.00)
Flatfishes:					
Starry flounder *Platichthys stellatus*	25 (0.78)	1 (0.03)	5 (0.16)	1 (0.03)	0 (0.00)
Forage fish:					
Surf smelt *Hypomesus pretiosus*	2 (0.06)	8 (0.25)	0 (0.00)	0 (0.00)	0 (0.00)
Other nearshore or estuarine fishes:					
Shiner surf perch *Cymatogaster aggregate*	23 (0.72)	67 (2.09)	265 (8.28)	0 (0.00)	0 (0.00)
Threespine stickleback *Gasterosteus aculeatus*	14 (0.44)	363 (11.34)	9,821 (306.91)	7,393 (231.03)	221 (3.88)
American shad (non-native) *Alosa sapidissima*	0 (0.00)	0 (0.00)	1 (0.03)	0 (0.00)	0 (0.00)
Bluegill *Lepomis macrochirus*	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.02)
All fish	**111**	**756**	**10,400**	**7,458**	**234**

Table 11. Total fish catch (and mean catch per beach seine set [or mean catch per minute for electrofishing] in parentheses) by species at Crescent Harbor sites in 2012.

	Adjacent nearshore	Pocket estuary			
Strata & method	Spit beach	Lobe B	Lobe C	Lobe E	Crescent Creek
Species	Beach seine	Beach seine	Beach seine	Beach seine	Electro-fishing
Salmon:					
Chinook salmon, unmarked subyearling *Oncorhynchus tshawytscha*	6 (0.15)	3 (0.08)	3 (0.08)	1 (0.03)	3 (0.07)
Coho salmon, unmarked yearling *Oncorhynchus kisutch*	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (0.05)
Pink salmon, subyearling *Oncorhynchus gorbuscha*	2,283 (57.08)	1,197 (29.93)	6 (0.15)	69 (1.77)	0 (0.00)
Chum salmon, subyearling *Oncorhynchus keta*	35 (0.88)	39 (0.98)	4 (0.10)	85 (2.18)	0 (0.00)
Cottids (sculpins):					
Pacific staghorn sculpin *Leptocottus armatus*	90 (2.25)	148 (3.70)	205 (5.13)	279 (7.15)	0 (0.00)
Sharpnose sculpin *Clinocottus acuticeps*	8 (0.20)	31 (0.78)	4 (0.10)	0 (0.00)	0 (0.00)
Flatfishes:					
Starry flounder *Platichthys stellatus*	36 (0.90)	2 (0.05)	6 (0.15)	1 (0.03)	0 (0.00)
Forage fish:					
Surf smelt *Hypomesus pretiosus*	1 (0.03)	20 (0.50)	1 (0.03)	0 (0.00)	0 (0.00)
Other nearshore or estuarine fishes:					
Shiner surf perch *Cymatogaster aggregate*	45 (1.13)	1033 (25.83)	54 (1.35)	0 (0.00)	0 (0.00)
Threespine stickleback *Gasterosteus aculeatus*	5 (0.13)	19 (0.48)	167 (4.18)	2,737 (70.18)	62 (1.45)
All fish	**2,509**	**2,492**	**450**	**3,172**	**67**

Table 12. Total fish catch (and mean catch per beach seine set [or mean catch per minute for electrofishing] in parentheses) by species at Crescent Harbor sites in 2013.

	Adjacent nearshore	Pocket estuary			
Strata & method	Spit beach	Lobe B	Lobe C	Lobe E	Crescent Creek
Species	Beach seine	Beach seine	Beach seine	Beach seine	Electro-fishing
Salmon:					
Chinook salmon, unmarked subyearling *Oncorhynchus tshawytscha*	12 (0.30)	4 (0.11)	12 (0.31)	0 (0.00)	7 (0.14)
Coho salmon, unmarked subyearling *Oncorhynchus kisutch*	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (0.04)
Coho salmon, unmarked yearling *Oncorhynchus kisutch*	2 (0.05)	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)
Coho salmon, hatchery origin marked yearling *Oncorhynchus kisutch*	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Chum salmon, subyearling *Oncorhynchus keta*	28 (0.70)	7 (0.18)	59 (1.51)	3 (0.08)	1 (0.02)
Cutthroat trout, age 1+> *Oncorhynchus clarki*	0 (0.00)	2 (0.05)	0 (0.00)	0 (0.00)	0 (0.00)
Cottids (sculpins):					
Pacific staghorn sculpin *Leptocottus armatus*	113 (2.83)	82 (2.16)	107 (2.74)	104 (2.60)	0 (0.00)
Sharpnose sculpin *Clinocottus acuticeps*	9 (0.20)	26 (0.68)	3 (0.077)	0 (0.00)	0 (0.00)
Prickly sculpin *Cottus asper*	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Flatfishes:					
Starry flounder *Platichthys stellatus*	71 (1.78)	1 (0.03)	10 (0.26)	10 (0.25)	0 (0.00)
Forage fish:					
Surf smelt *Hypomesus pretiosus*	5 (0.13)	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)
Pacific sandlance *Ammodytes hexapterus*	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Other nearshore or estuarine fishes:					
Shiner surf perch *Cymatogaster aggregate*	1,394 (34.85)	737 (19.39)	750 (19.23)	290 (7.25)	0 (0.00)
Threespine stickleback *Gasterosteus aculeatus*	11 (0.28)	2 (0.05)	75 (1.92)	1,774 (44.35)	123 (2.52)
Arrow goby *Clevelandia ios*	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
All fish	**1,649**	**863**	**1,016**	**2,181**	**133**

Table 13. Total fish catch (and mean catch per beach seine set [or mean catch per minute for electrofishing] in parentheses) by species at Crescent Harbor sites in 2014.

	Adjacent nearshore	Pocket estuary			
Strata & method	Spit beach	Lobe B	Lobe C	Lobe E	Crescent Creek
Species	Beach seine	Beach seine	Beach seine	Beach seine	Electro-fishing
Salmon:					
Chinook salmon, unmarked subyearling *Oncorhynchus tshawytscha*	17 (0.43)	115 (2.88)	25 (0.63)	14 (0.35)	25 (0.72)
Chinook salmon, hatchery origin all marks, subyearling *Oncorhynchus tshawytscha*	3 (0.08)	8 (0.20)	0 (0.00)	0 (0.00)	0 (0.00)
Coho salmon, unmarked subyearling *Oncorhynchus kisutch*	15 (0.38)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Coho salmon, unmarked yearling *Oncorhynchus kisutch*	2 (0.05)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Pink salmon, subyearling *Oncorhynchus gorbuscha*	220 (5.50)	576 (14.40)	45 (1.13)	93 (2.33)	0 (0.00)
Chum salmon, subyearling *Oncorhynchus keta*	13 (0.33)	34 (0.85)	1 (0.03)	1 (0.03)	0 (0.00)
Sockeye salmon, wild yearling or older *Oncorhynchus nerka*	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Cutthroat trout, yearling or older *Oncorhynchus clarki*	0 (0.00)	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)
Cottids (sculpins):					
Pacific staghorn sculpin *Leptocottus armatus*	133 (3.33)	210 (5.25)	73 (1.83)	174 (4.35)	0 (0.00)
Sharpnose sculpin *Clinocottus acuticeps*	5 (0.13)	26 (0.65)	3 (0.08)	0 (0.00)	0 (0.00)
Flatfishes:					
Starry flounder *Platichthys stellatus*	29 (0.73)	0 (0)	4 (0.10)	0 (0.00)	0 (0.00)
English sole *Parophrys vetulus*	1 (0.03)	0 (0)	0 (0.00)	1 (0.03)	0 (0.00)
Forage fish:					
Surf smelt *Hypomesus pretiosus*	4 (0.1)	0 (0)	2 (0.05)	0 (0.00)	0 (0.00)
Other nearshore or estuarine fishes:					
Threespine stickleback *Gasterosteus aculeatus*	19 (0.48)	30 (0.75)	45 (1.13)	1,464 (36.60)	30 (0.87)
Shiner surf perch *Cymatogaster aggregate*	22 (0.55)	369 (9.23)	273 (6.83)	509 (12.73)	0 (0.87)
Pile perch *Rhacochilus vacca*	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Bay pipe fish *Syngnathus griseolineatus*	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00
All fish	**487**	**1,369**	**471**	**2,256**	**55**

Table 14. Total fish catch (and mean catch per beach seine set [or mean catch per minute for electrofishing] in parentheses) by species at Crescent Harbor sites in 2015.

	Adjacent nearshore	Pocket estuary			
Strata & method	Spit beach	Lobe B	Lobe C	Lobe E	Crescent Creek
Species	Beach seine	Beach seine	Beach seine	Beach seine	Electro-fishing
Salmon:					
Chinook salmon, unmarked subyearling *Oncorhynchus tshawytscha*	9 (0.23)	10 (0.25)	7 (0.18)	2 (0.05)	0 (0.00)
Chinook salmon, hatchery origin all marks, subyearling *Oncorhynchus tshawytscha*	0 (0.00)	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)
Coho salmon, unmarked subyearling *Oncorhynchus kisutch*	0 (0.00)	2 (0.05)	0 (0.00)	0 (0.00)	0 (0.00)
Coho salmon, unmarked yearling *Oncorhynchus kisutch*	1 (0.03)	0 (0)	0 (0.00)	0 (0.00)	0 (0.00)
Chum salmon, subyearling *Oncorhynchus keta*	21 (0.53)	19 (0.48)	4 (0.10)	1 (0.03)	0 (0.00)
Sockeye salmon, wild yearling or older *Oncorhynchus nerka*	0 (0.00)	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)
Cutthroat trout, yearling or older *Oncorhynchus clarki*	0 (0.00)	3 (0.08)	0 (0.00)	0 (0.00)	0 (0.00)
Native char all ages *Salvelinus* sp. (*malma* or c*onfluentus*)	2 (0.05)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Cottids (sculpins):					
Pacific staghorn sculpin *Leptocottus armatus*	166 (4.15)	110 (2.75)	36 (0.90)	495 (12.38)	0 (0.00)
Sharpnose sculpin *Clinocottus acuticeps*	4 (0.10)	13 (0.33)	9 (0.23)	0 (0.00)	0 (0.00)
Padded sculpin *Artedius fenestralis*	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Flatfishes:					
Starry flounder *Platichthys stellatus*	32 (0.80)	1 (0.03)	7 (0.18)	6 (0.15)	0 (0.00)
English sole *Parophrys vetulus*	1 (0.030)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Forage fish:					
Surf smelt *Hypomesus pretiosus*	32 (0.80)	5 (0.13)	10 (0.25)	0 (0.00)	0 (0.00)
Other nearshore or estuarine fishes:					
Threespine stickleback *Gasterosteus aculeatus*	83 (2.08)	2,165 (54.13)	181 (4.53)	533 (13.325)	72 (2.71)
Shiner surf perch *Cymatogaster aggregate*	0 (0.00)	1 (0.03)	0 (0.00)	0 (0.00)	0 (0.00)
Pile perch *Rhacochilus vacca*	2 (0.05)	16 (0.4)	6 (0.15)	743 (18.58)	0 (0.00)
Bay pipefish *Syngnathus griseolineatus*	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.025)	0 (0.00)
All fish	**362**	**2,386**	**293**	**1,815**	**72**

Juvenile pink and chum salmon timing and relative abundance

There are no differences in timing of pink salmon fry along beaches near Crescent Harbor Salt Marsh compared to within the salt marsh itself (Figure 10, top panels). In even numbered years, pink salmon fry are present, typically arriving and peaking in April and then disappearing as they migrate through on their way to the ocean. Mean pink salmon fry density in adjacent nearshore habitat in 2012 was nearly six times higher than in the salt marsh; however, due to the highly variable nature of pink fry catches, we found no significant difference between adjacent nearshore and the salt marsh lobes (ANOVA, $p = 0.102$), including models that included interactions with Year and Month (Figure 11, top panel). Pink salmon fry catches are highly variable due the fish's schooling behavior and quick migration through nearshore and pocket estuary systems.

There is a difference in timing of chum salmon fry along beaches near Crescent Harbor Salt Marsh compared to within the salt marsh itself (Figure 10, bottom panels). Chum salmon fry are found in higher relative abundance inside the salt marsh about a month earlier than in the adjacent nearshore, suggesting the early arriving chum fry may be rearing briefly in salt marsh habitat. Chum salmon fry typically peak in March within Crescent Harbor Salt Marsh and April along the adjacent nearshore. Mean chum salmon fry density in adjacent nearshore habitat in 2011 was eight times higher than in the salt marsh; however, due to the highly variable nature of chum fry catches, we found no significant difference between adjacent nearshore and the salt marsh lobes (ANOVA, $p = 0.169$), including models that included interactions with Year and Month. Overall, chum salmon fry densities are similar inside and outside of Crescent Harbor Salt Marsh (Figure 11, bottom panel).

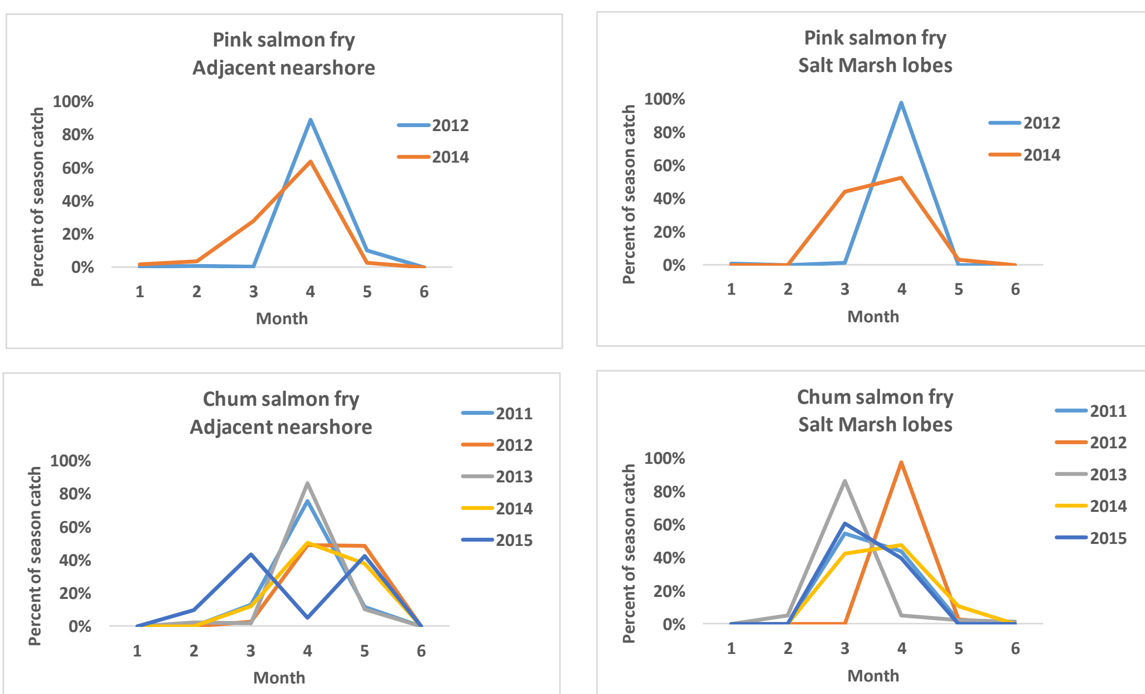


Figure 10. Average timing of pink (top panels) and chum (bottom panels) salmon fry within (left panels) and adjacent to (right panels) Crescent Harbor Salt Marsh 2011-2015.

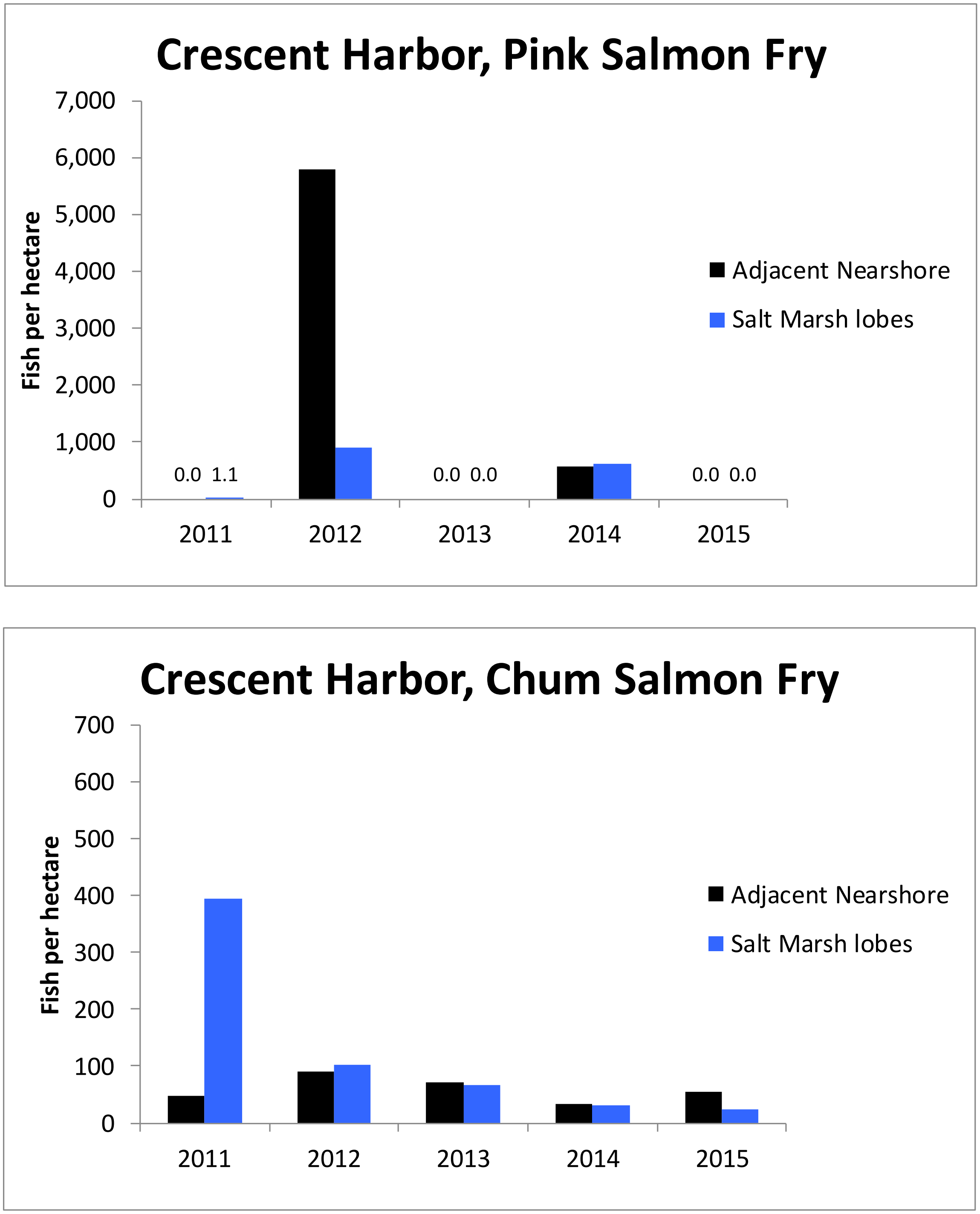


Figure 11. Average density of pink (top panel) and chum (bottom panel) salmon fry within and adjacent to Crescent Harbor Salt Marsh, 2011-2015.

Wild juvenile Chinook salmon

We use graphical analysis to illustrate the timing and relative abundance of wild juvenile Chinook salmon within and adjacent to Crescent Harbor Salt Marsh for all years of monitoring. Later in this section of the report we present results from statistical analyses quantifying whether there are differences in juvenile Chinook density within and adjacent to Crescent Harbor Salt Marsh. We also account for potential covariates in the statistical analyses that might influence the number of juvenile Chinook salmon using habitat at Crescent Harbor Salt Marsh. These covariates include: season, Skagit River discharge, and Skagit River subyearling Chinook salmon outmigration population size.

Timing and relative abundance

There are differences in the timing of wild juvenile Chinook salmon along beaches near Crescent Harbor Salt Marsh compared to within the salt marsh itself (Figure 12).

Adjacent nearshore: A bimodal distribution in the timing of wild juvenile Chinook salmon is observed in shallow nearshore habitat adjacent to Crescent Harbor Salt Marsh. An early peak occurs in March with a later peak in May. The early peak represents fry migrant Chinook salmon either displaced through density dependent process or environmental disturbances like floods or freshets from their natal large river estuary (Beamer et al. 2005). The pulse of early fry migrants may colonize pocket estuaries like Crescent Harbor Salt Marsh (Beamer et al. 2003, Beamer et al. 2006) or small independent streams within the Whidbey Basin (Beamer et al. 2013). The later peak (May) of wild juvenile Chinook found in nearshore habitat adjacent Crescent Harbor Salt Marsh can include fish that have migrated: a) from their natal river as parr migrants (Zimmerman et al. 2015); b) from their natal river estuary after rearing for a period of time; or c) after rearing in one or more pocket estuaries/small streams for a period of time.

Crescent Harbor Salt Marsh: Wild juvenile Chinook timing includes presence in January with steady increased relative abundance through April, followed by a drop in abundance in May and June (Figure 12). The timing curve of wild juvenile Chinook salmon within Crescent Harbor Salt Marsh reflects the timing expected for juvenile Chinook salmon rearing in pocket estuary habitat (Beamer et al. 2003, Beamer et al. 2006). Yearly and habitat type (within the salt marsh, adjacent nearshore) differences in wild juvenile Chinook salmon density are apparent over the five years of monitoring (Figure 13). Only in years 2011 and 2014 are densities of juvenile Chinook salmon higher in the salt marsh than in the adjacent nearshore. The year-to-year variability in juvenile Chinook salmon density may be driven by the number of juvenile Chinook salmon in the vicinity of Crescent Harbor, as well as by a fish preference for salt marsh habitat type. The number of juvenile Chinook salmon in the vicinity of Crescent Harbor each year is a function of how many fish outmigrate the nearby Chinook salmon-bearing rivers, and/or river flow patterns that trigger migration of Chinook fry into the nearshore. We quantify both variables in later sections of this report and include their potential effect on juvenile Chinook density differences by habitat type.

Crescent Creek: Wild juvenile Chinook salmon were present in Crescent Creek from February through June, with peak abundance occurring in April (Figure 14, top panel). The timing curve of wild juvenile Chinook salmon within Crescent Creek reflects the timing expected for juvenile Chinook salmon rearing in other Whidbey Basin small streams (Beamer et al. 2013). Most juvenile Chinook salmon had left the creek by June each year and we never caught juvenile Chinook salmon in the creek in January. In two years (2010 and 2015) of the six years monitored we did not catch any juvenile Chinook salmon in Crescent Creek (Figure 14, bottom panel). In 2010 the sampling effort was limited to three monthly sampling events (March, April, May); in 2015 we sampled the full period, January through June (Table 2). In both years we sampled over the months when juvenile Chinook salmon would be expected in small streams and would likely have detected their presence in the stream had they been there.

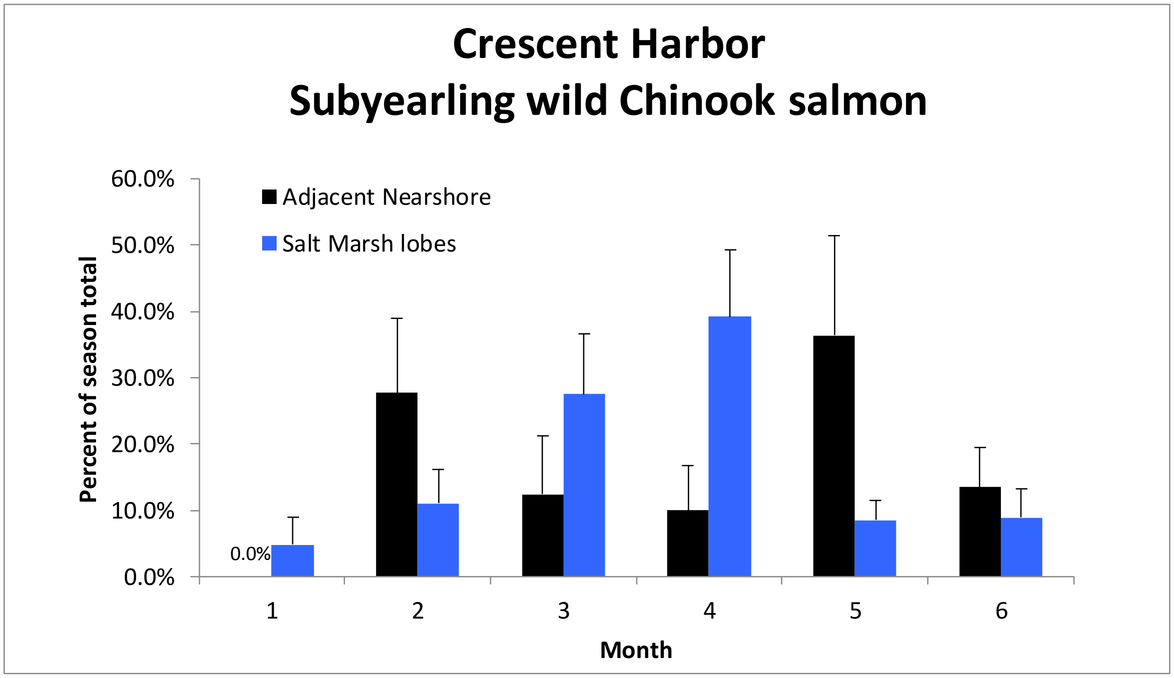


Figure 12. Average timing of juvenile Chinook salmon within and adjacent to Crescent Harbor Salt Marsh, 2011-2015. Error bars are standard error.

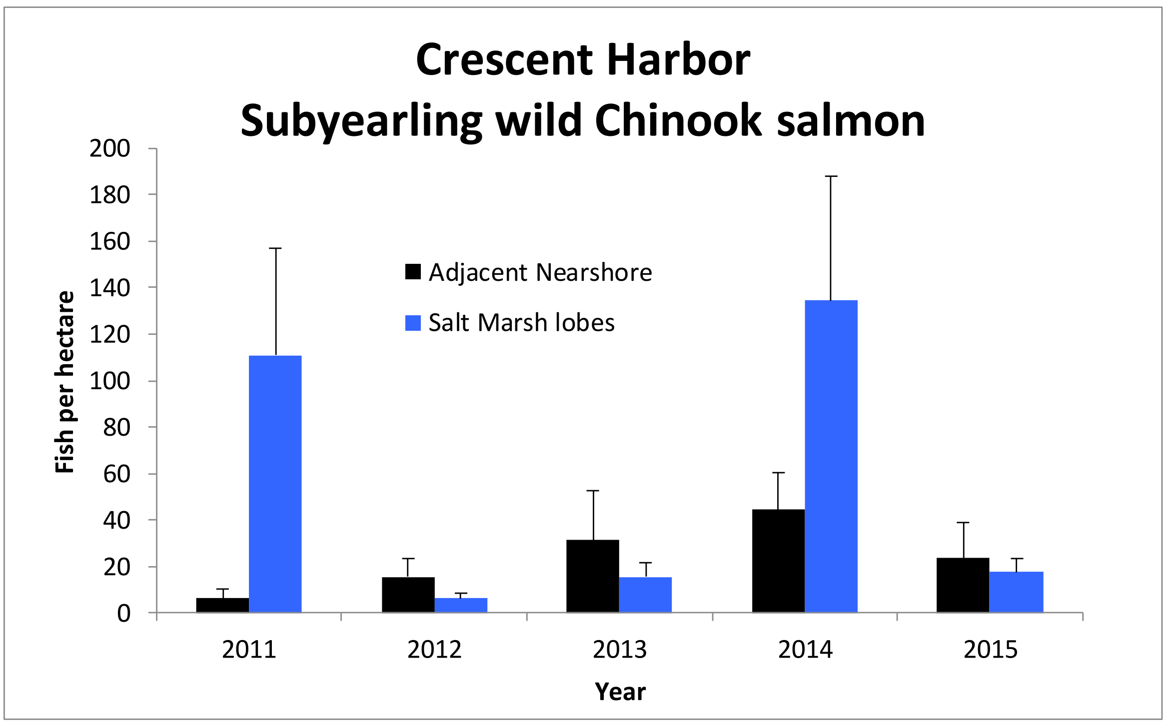
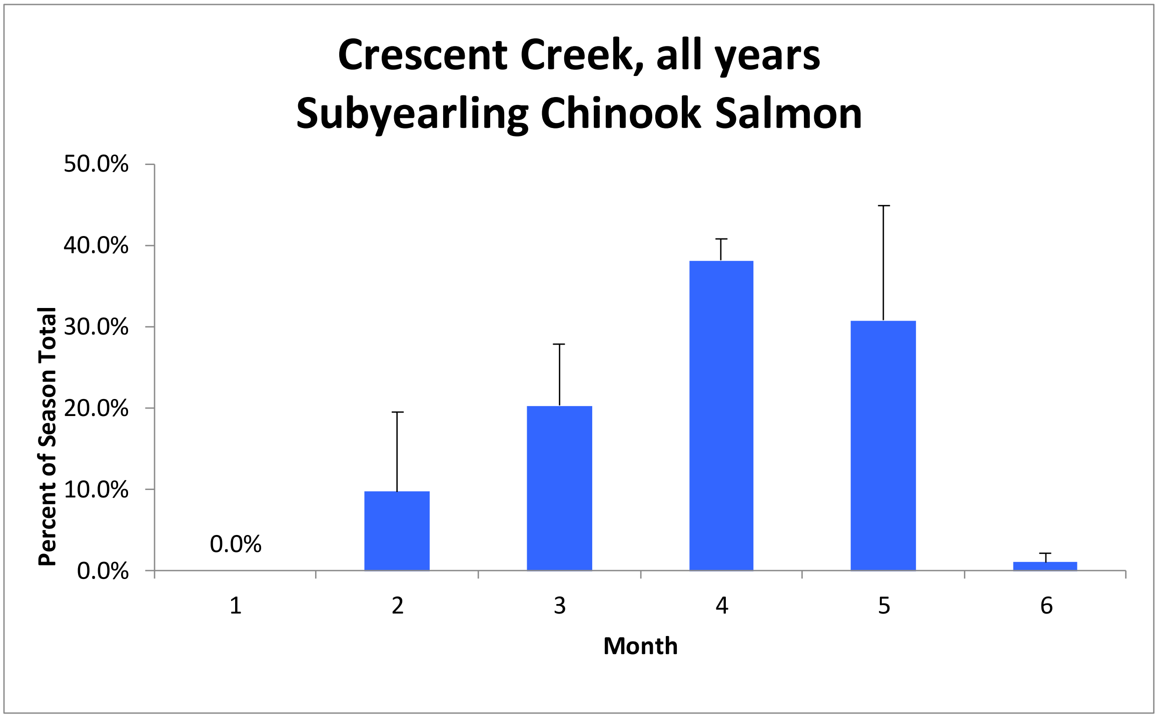


Figure 13. Average density of juvenile Chinook salmon within and adjacent to Crescent Harbor Salt Marsh, 2011-2015. Error bars are standard error.



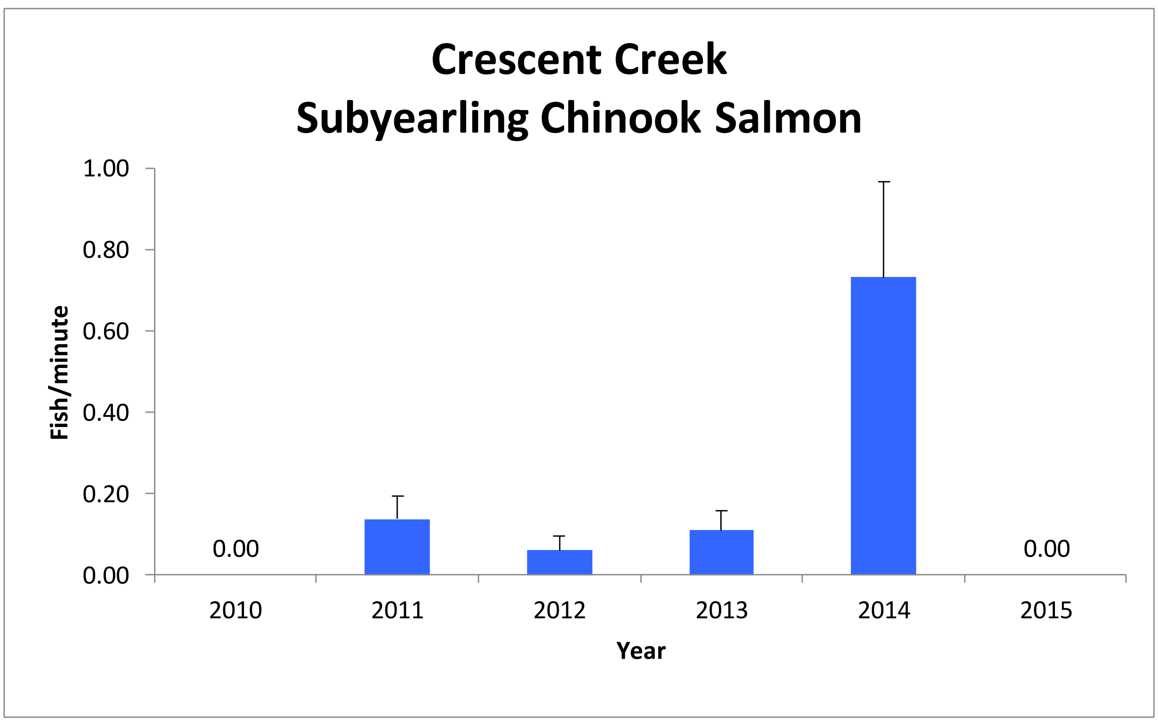


Figure 14. Average timing (top panel) and relative abundance (bottom panel) of wild juvenile Chinook salmon in Crescent Creek, 2011-2015. Error bars are standard error.

Fish length

There are inadequate numbers of wild juvenile Chinook salmon length samples to make statistical comparisons of Chinook length between habitats (salt marsh verses adjacent nearshore, or between lobes of salt marsh) by year. However, there are adequate samples collected within Crescent Harbor Salt Marsh to compare seasonal and annual patterns of wild juvenile Chinook salmon length.

The final model uses 271 records of untransformed measurements of fork length (in millimeters), has an R^2 of 0.70, retained Month as a significant covariate, and found significant Year differences in wild juvenile Chinook salmon length (Table 14). The model coefficient for Month = 9.5. The positive coefficient associated with month is an expected seasonal pattern. Juvenile Chinook salmon increase in length as they grow in productive habitats on their way to the ocean. On average, juvenile Chinook salmon within Crescent Harbor Salt Marsh habitats increased in length by 9.5 mm per month (Figure 15). The fish within restored habitat of Crescent Harbor Salt Marsh exhibited growth. Annual differences in wild juvenile Chinook length were detected (Table 15). On average, when controlling for the seasonal effect and differences in sample size between years: 1) fish in 2011 were 3.5 mm larger than fish in 2014; 2) fish in 2013 were 8.2 mm smaller than fish in 2015; and 3) fish in 2014 were 7.7 mm smaller than fish in 2015. The overall pattern of juvenile Chinook salmon size is influenced by how many fish are outmigrating the Chinook salmon-bearing rivers each year (Figure 16), suggesting there are smaller fish in big outmigration years.

Table 15. ANOVA significance results for wild juvenile Chinook salmon length at Crescent Harbor Salt Marsh post restoration. P-values significant at the 0.05 level are bolded.

Variable Type	Variable	p-Value
Factor	YEAR	**0.002**
Covariate	MONTH	**0.000**

Table 16. Pairwise results of wild juvenile Chinook salmon length within Crescent Harbor Salt Marsh by year using Tukey's Honestly Significant Difference Test. P-values significant at the 0.05 level are bolded.

YEAR(i)	YEAR(j)	Difference (mm)	p-Value	95% Confidence Interval	
				Lower	Upper
2011	2012	6.477	0.397	-3.547	16.500
2011	2013	4.149	0.367	-2.058	10.356
2011	2014	3.551	**0.045**	0.053	7.050
2011	2015	-4.035	0.467	-10.645	2.575
2012	2013	-2.328	0.980	-13.457	8.802
2012	2014	-2.925	0.929	-12.804	6.953
2012	2015	-10.511	0.089	-21.870	0.848
2013	2014	-0.598	0.999	-6.568	5.373
2013	2015	-8.184	**0.051**	-16.375	0.008
2014	2015	-7.586	**0.012**	-13.974	-1.198

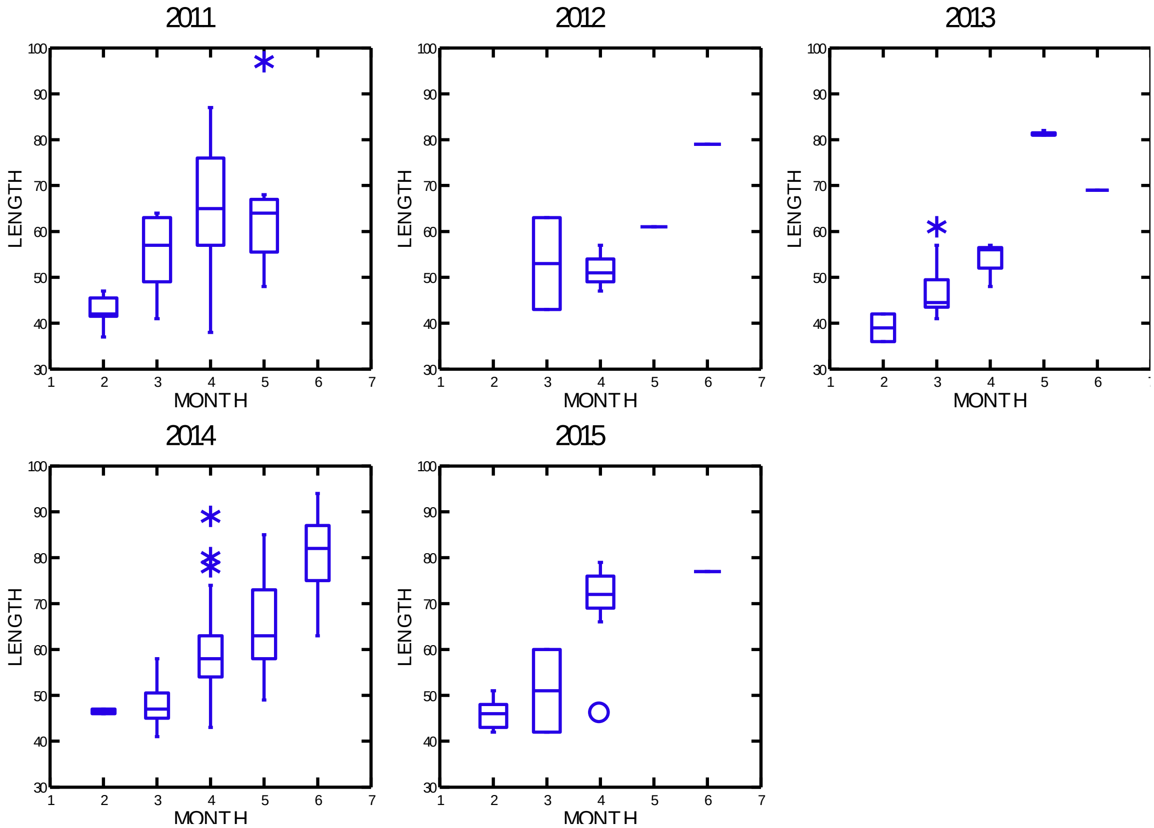


Figure 15. Boxplot of wild juvenile Chinook fork length (in millimeters) within Crescent Harbor Salt Marsh by month and year. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

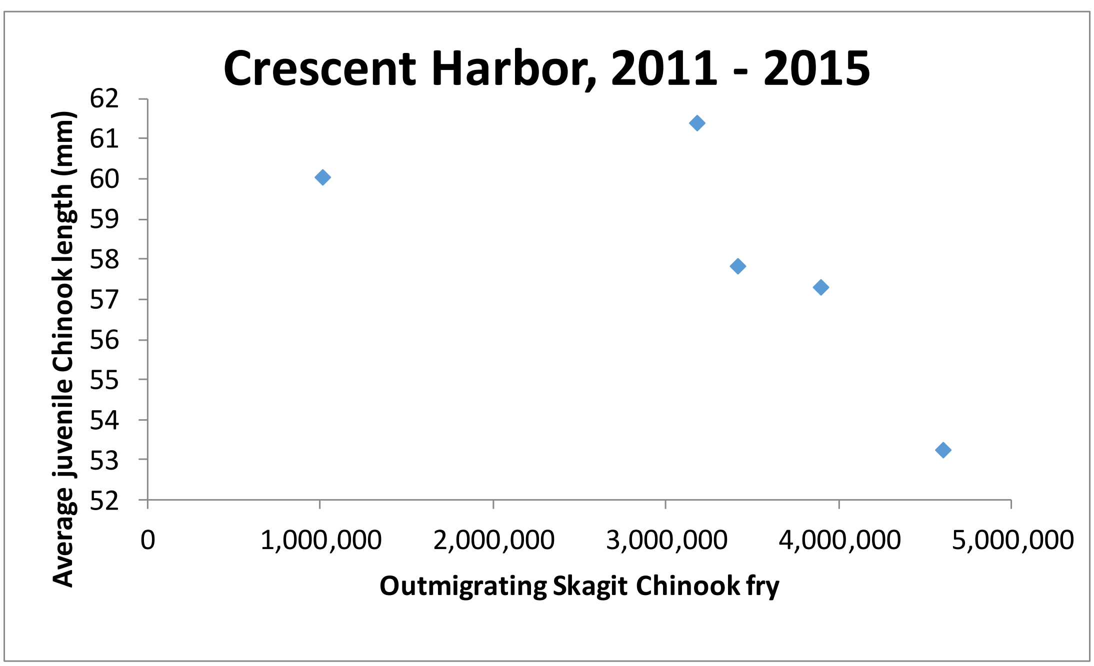


Figure 16. Relationship of average wild juvenile Chinook salmon size as a function of Skagit River juvenile Chinook salmon outmigration.

Origin of juvenile Chinook salmon caught at Crescent Harbor

Wild juvenile Chinook salmon are not marked with coded wire tags so there is no way to know, without doing genetic analysis, the origin of wild Chinook caught at the Crescent Harbor Salt Marsh monitoring sites. Because of Crescent Harbor's geographic proximity to the Skagit and Stillaguamish Rivers, we assume juvenile Chinook salmon from both river systems most likely could use habitat at Crescent Harbor Salt Marsh compared to any other Puget Sound Chinook salmon bearing rivers. Our assumption is supported by four coded wire-tagged hatchery Chinook salmon caught at Crescent Harbor sites on June 19, 2014. Three fish were from the Skagit River, one from the Stillaguamish River.

Due to the difference in juvenile Chinook salmon outmigration from the Skagit River (millions of fish/year) compared to the Stillaguamish River (10s to 100s of thousands of fish/year), and the fact that the Skagit River is the closest Chinook-producing river to Crescent Harbor, we expect most juvenile Chinook salmon using Crescent Harbor Salt Marsh to be of Skagit River origin. Previous genetic analysis of juvenile Chinook salmon within Whidbey Basin supports the idea that most (up to 70%) juvenile Chinook found in pocket estuaries and small independent streams entering Whidbey Basin are from the Skagit River, even in areas distant from Skagit Bay (Beamer et al. 2010, Beamer et al. 2013).

Influence of Skagit River flow and juvenile Chinook outmigration population size

As noted in the previous section, we hypothesize that Skagit River origin Chinook salmon most likely drive abundance patterns of juvenile Chinook salmon at Crescent Harbor Salt Marsh. Thus, we only included Skagit River variables in statistical analysis of density by spatial strata.

The number of Chinook salmon fry outmigrating from the Skagit River logically should influence the number of fish available to colonize Crescent Harbor habitat. This number varied from a low of 1 million to a high of 4.6 million over the five years of monitoring at Crescent Harbor (Table 17).

Juvenile salmon migration can be triggered by changes in river flow, so we hypothesize that peak Skagit River flow timing and magnitude might have an influence on the number of fry migrant Chinook salmon available to colonize Crescent Harbor habitat. Skagit River flows varied within and across the years we monitored at Crescent Harbor (Figure 17). We identified the peak flow magnitude (daily average discharge in cfs) that occurred during the Chinook salmon fry outmigration period (i.e., January through April, from Zimmerman et al. 2015) and standardized the peak flow by dividing it by the 7-day average flow before the peak. Standardized peak flow is called *delta Q*. Flow statistics for each year of monitoring at Crescent Harbor are shown in Table 17. Of the three variables (outmigrants, peak flow, and standardized peak flow), only standardized peak flow seems to explain the patterns of juvenile Chinook salmon density at Crescent Harbor (Figure 18).

Table 17. Summary of Skagit River juvenile Chinook salmon outmigration and flow variables used for statistical analysis. Skagit River juvenile Chinook outmigration results are from Anderson and Kinsel 2016.

Year	Skagit River juvenile Chinook outmigrants (fry only)	Skagit River flow at Mount Vernon			
		Date of peak flow	Peak flow magnitude (cfs)	7-day average flow prior to peak flow event	Standardized change in flow (*delta Q*)
2011	3,177,656	4/1/2011	33900	8331	4.07
2012	3,900,019	1/5/2012	34500	17869	1.93
2013	4,603,262	1/10/2013	28500	13257	2.15
2014	3,416,943	3/10/2014	48800	11563	4.22
2015	1,016,166	2/8/2015	63700	19350	3.29

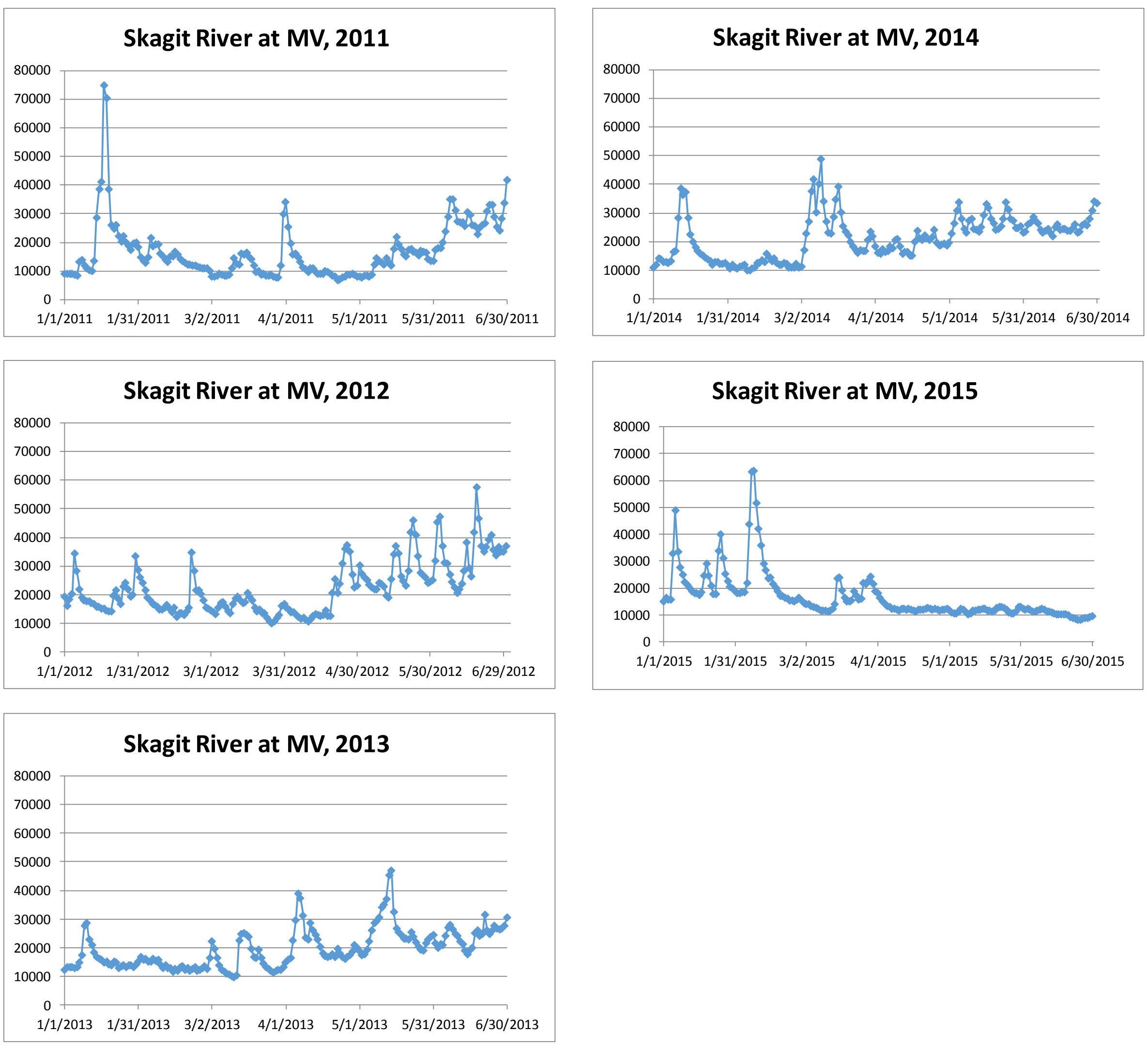


Figure 17. Year-by-year comparison of Skagit River peak flows at Mount Vernon, WA (during the fry migration period of each year).

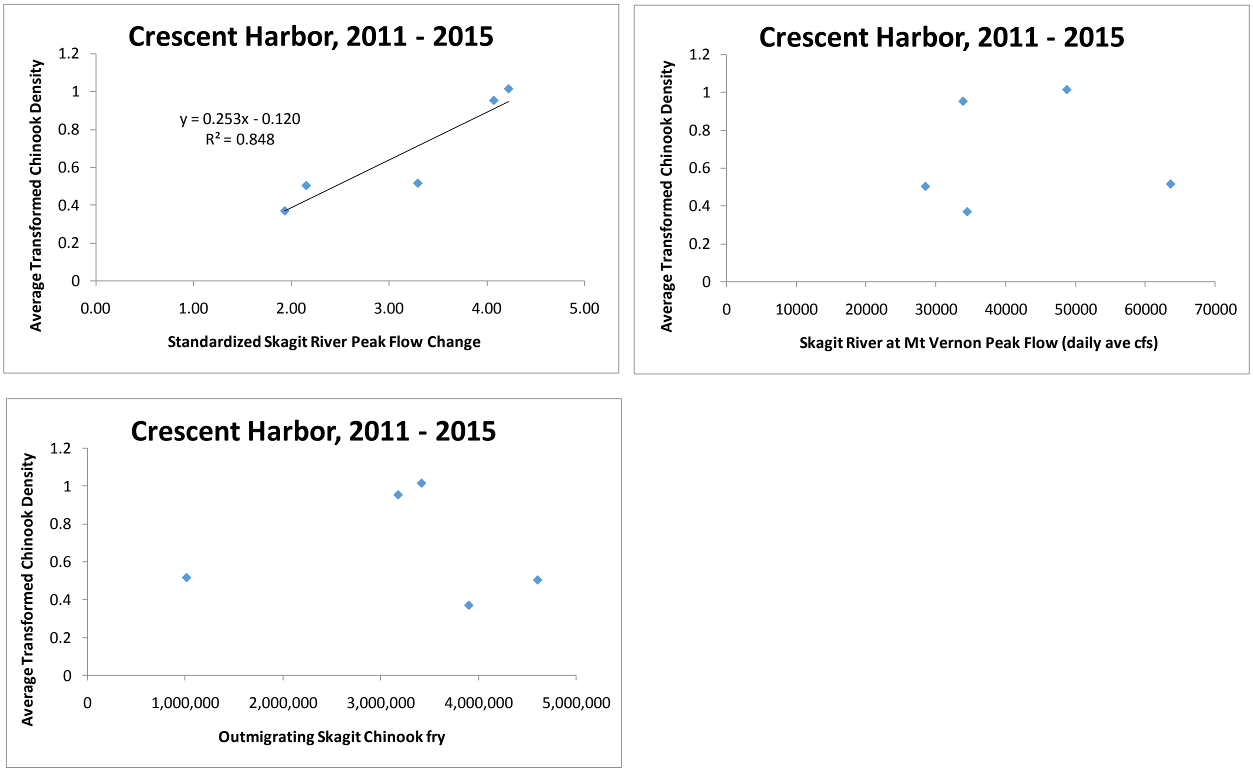


Figure 18. Relationship between Standardized Skagit River Peak Flow (top left panel), Skagit River Peak Flow (top right panel), and Skagit River Chinook fry outmigration size (bottom left panel) with average juvenile Chinook salmon density at Crescent Harbor.

Juvenile Chinook density inside and adjacent to Crescent Harbor Salt Marsh

To test whether oberved densities of Chinook fry were significantly higher inside the Crescent Harbor Salt Marsh relative to the adjacent nearshore beaches, we developed a generalized linear model (GLM) using the following equation:

$$Y_{i,j} \sim Pois\ (\alpha_{i,j} e^{\beta_{i,j} x})$$

Where:

- p is the prediction of juvenile Chinook salmon density in fish/hectare
- α is the model's intercept
- β is the model's slope
- *i* factor level for sampling period (Jan/Feb, March/Apr, and May/June), and *j* is the factor level for sample location (Beach (A), Marsh (B), Marsh (C), and Marsh (E)).

The model was fit using quasi-poisson errors to account for overdispersion in Chinook fry density data relative to model predicted values. We ran a step-wise model selection process to determine which covariates, if any, significantly influenced the slope of the GLM. Covariates included: Skagit River Chinook fry outmigrants, peak flow, and delta Q (from Table 17). Temporal strata (Jan/Feb, Mar/Apr, May/June) were based on the apparent differences in timing of juvenile Chinook salmon over the monitored period (Figure 12) and the expectation that juvenile Chinook salmon would utilize pocket estuary habitat at higher densities early in the year compared to adjacent nearshore habitat (Beamer et al 2003, Beamer et al 2006).

We found significant seasonal and spatial effects on juvenile Chinook salmon denstiy at Crescent Harbor Salt Marsh, but only one covariate was retained as significant (Table 18). A significant postive relationship between relative change in peak flow (i.e., *delta q*) and density of Chinook fry was observed at all sites. Skagit River Chinook fry outmigrants and peak flow were not significant in any model.

Using the model outputs to isolate the temporal and spatial effects from covariate driven variability we made predictions of juvenile Chinook salmon density for all spatial and temporal strata with two standardized peak flow senarios (delta Q = 2; delta Q = 4) (Table 19, Figure 19). Juvenile Chinook salmon densities within Crescent Harbor Salt Marsh strata are more than 5 times higher during the March/April rearing period compared to the earlier (Jan/Feb) and later (May/Jun) periods. Juvenile Chinook salmon densities during the March/April rearing period are more than three times than higher in Marsh B than adjacent nearshore beaches (Beach A). Juvenile Chinook salmon densities for all sites and time periods are eight times higher when delta Q = 4 than when delta Q = 2. There is declining juvenile Chinook salmon density within Crescent Harbor Salt Marsh as a function of distance from Marsh B.

The results at Crescent Harbor Salt Marsh are consistent with observations of juvenile Chinook salmon use of other Whidbey Basin pocket estuaries (Beamer et al 2003; Beamer et al 2006). Juvenile Chinook were expected to occupy the pocket estuary early in the year at higher densities than adjacent nearshore habitat. However, the declining density of juvenile Chinook salmon within Crescent Harbor Salt Marsh as a function of distance from Marsh B suggests connectivity between marsh lobes may not be uniform. Also, the rearing period when juvenile Chinook are in higher densities than adjacent nearshore habitat is more abreviated than some other pocket estuaries within the Whidbey Basin. The shorter period may be related to environmental conditions, especially the low dissolved oxygen and higher temperature observations that coincide with the time period when juvenile Chinook salmon densities begin to decline in May or June.

The statistical analysis also reveals the importance of an environmental factor influencing the number of juvenile Chinook salmon in the vicinity of Crescent Harbor. In the five years we monitored at Crescent Harbor Salt Marsh, the standardized peak Skagit River flow occurring during the fry migration period was positively correlated with numbers of Chinook salmon fry to in the area (Figure 18) and was a highly significant covariate in the model (Table 18). Standardized peak flow was more important to determining the number of juvenile Chinook found in and around Crescent Harbor than the number Skagit River Chinook salmon fry that out-migrated in those same years. Specifically standardized peak flow was a significantly better predictor of observed subyearling Chinook density in the Crescent Harbor area than the observed Chinook salmon fry outmigration sizes ranging from 1.0 and 4.6 million. This illustrates the importance of external environmental factors that influence actual fish use at restoration sites. In this case, connectivity between a restoration site and a source river of juvenile Chinook salmon is not only a function of distance from the river and the total number of fish outmigrating the river, but also environmental conditions of the source river.

Table 18. Summary table of GLM fit to relationship between Chinook fry density and rearing period, spatial strata, and relative change in flow. Significance results are relative to Mar/Apr for sampling period and Beach (A) for spatial strata.

Coefficient	**Estimate**	**Std. Error**	**t value**	**p**
Intercept	0.14	1.05	0.13	0.89
Sampling period: Jan/Feb	-1.63	0.54	-3.04	**0.00**
Sampling period: May/June	-1.07	0.42	-2.54	**0.01**
Spatial strata: Marsh (B)	1.29	0.49	2.64	**0.01**
Spatial strata: Marsh (C)	0.95	0.51	1.88	0.06
Spatial strata: Marsh (E)	-1.00	0.83	-1.20	0.23
delta q	1.03	0.25	4.17	**0.00**

Table 19. Least squares predictions of juvenile Chinook salmon density (fish/ha) with standard errors in parentheses, across seasons (Jan/Feb, March/Apr, May/June) and location (adjacent nearshore and sampled sites within Crescent Harbor Salt Marsh), under high and low scenarios of relative change in Skagit River flow (delta Q = 4, and delta Q = 2).

Season	delta Q	Beach (A)	Marsh (B)	Marsh (C)	Marsh (E)
Jan/Feb	4	14 (9.1)	50.8 (27.1)	36.4(20.1)	5.1(4.4)
	2	1.8 (1.4)	6.4 (4.5)	4.6 (3.3)	0.7 (0.6)
March/Apr	4	71.8 (31.7)	259.8 (64.5)	186 (53.2)	26.6 (19.0)
	2	9.1 (5.8)	32.9 (17.1)	23.5 (12.7)	3.4 (2.9)
May/June	4	41 (13.7)	50.8 (37.2)	36.3 (28.1)	5.2 (7.2)
	2	1.8 (2.2)	6.4 (6.8)	4.6 (5.0)	0.7 (1.0)

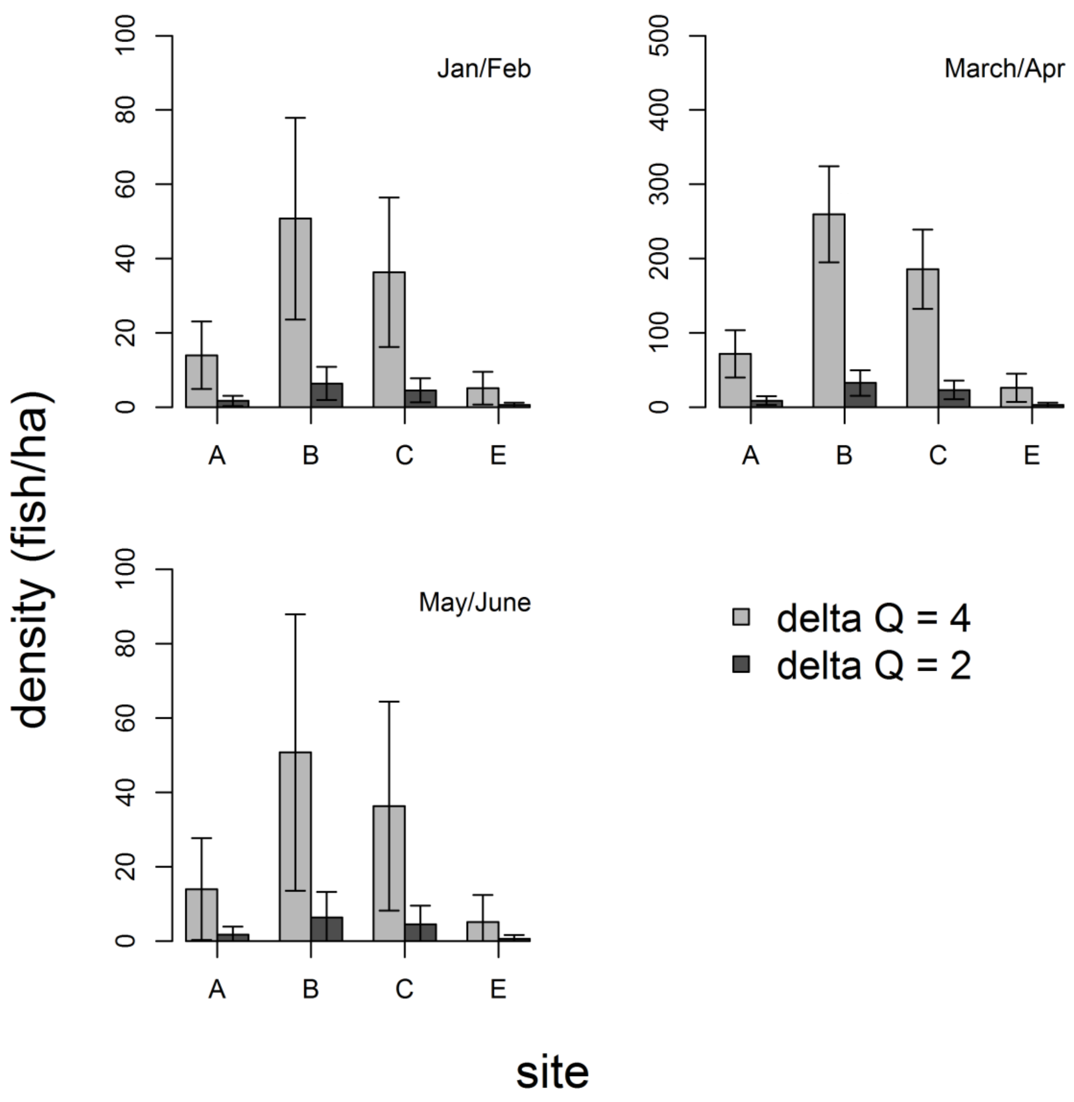


Figure 19**.** Model least squares predictions of seasonal changes in Chinook fry density between the adjacent nearshore beach (A) and sites within the pocket estuary (B, C, and E) under high (delta Q = 4) and low (delta Q = 2) relative change in peak flow. Note differing Y axes between figure panels.

Comparison to other Skagit Bay pocket estuaries

Pocket estuaries with natural outlet conditions in Skagit Bay consistently have much higher densities of wild juvenile Chinook salmon inside their lagoon or marsh habitat than in adjacent nearshore habitat (Figure 20). Over the six-year period of studying five different pocket estuaries, we found the cumulative density of wild juvenile Chinook salmon inside the pocket estuary to be on average 6.79 times higher than in adjacent nearshore habitat for the early rearing period of fry migrant Chinook salmon. Average Crescent Harbor Salt Marsh results are somewhat less than the average of Skagit Bay pocket estuaries with natural outlet channels. Over the five-year monitoring period at Crescent Harbor Salt Marsh, we found the cumulative density of wild juvenile Chinook salmon inside the salt marsh to be on average 4.6 times higher than in adjacent nearshore habitat.

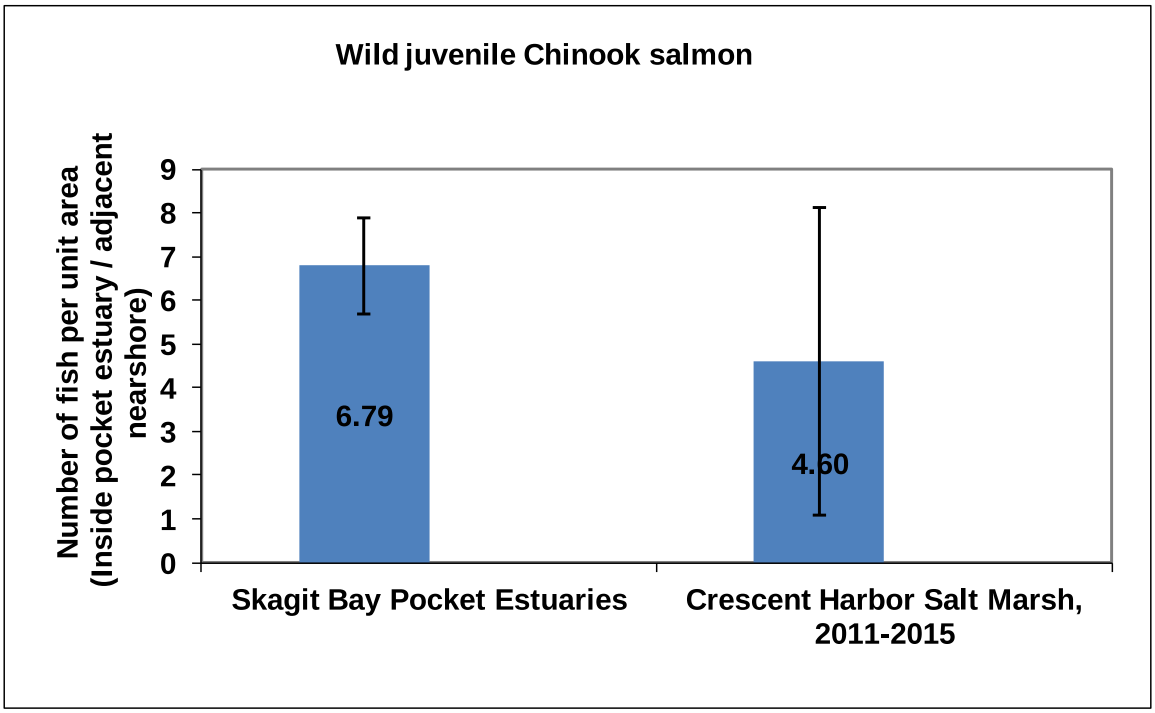


Figure 20. Relative difference in cumulative seasonal (January through May) wild juvenile Chinook salmon density in pocket estuary habitat compared to adjacent nearshore habitat for pocket estuaries with natural outlet conditions in Skagit Bay. Error bars are standard error. Results are shown for five pocket estuaries (Arrowhead Lagoon, Kiket Lagoon, Lone Tree Lagoon, Old Bridge Saltmarsh, and Turners Bay) over 6 years (2003 – 2007, and 2009) in Skagit Bay. The total number of wild juvenile Chinook observations is 15 for Skagit Bay pocket estuaries with natural outlet conditions. Data are from SRSC Research program (Beamer et al. 2003, Beamer et al. 2006).

Conclusions

1. Up to 16 species of fish are present in restored habitat of the Crescent Harbor Salt Marsh system. Only one species of fish (threespine stickleback) were caught in Crescent Harbor Salt Marsh prior to restoration (PWA & UW WET 2003), demonstrating that fish have accessed restored areas of Crescent Harbor Salt Marsh restored and Crescent Creek.
2. Juvenile Chinook salmon are utilizing the restored habitat of the Crescent Harbor Salt Marsh system, including Crescent Creek. Juvenile Chinook salmon were present in all years of monitoring within Crescent Harbor Salt Marsh. In four of six years monitored, juvenile Chinook salmon were caught in Crescent Creek, a non-natal stream.
3. Timing of wild juvenile Chinook salmon in Crescent Harbor Salt Marsh and Crescent Creek is generally consistent with other Whidbey Basin pocket estuaries and small streams.
4. Wild juvenile Chinook salmon using Crescent Harbor Salt Marsh habitat exhibited growth, on average a 9.5 mm increase in fork length per month.
5. There are more wild juvenile Chinook salmon inside Crescent Harbor Salt Marsh (Lobe B) than in adjacent nearshore habitat in March and April, consistent with the expectation of juvenile Chinook salmon seeking out and utilizing pocket estuary habitat for rearing during the early part of the year.
6. However, within Crescent Harbor Salt Marsh, there is a declining order of wild juvenile Chinook salmon density associated with connectivity of marsh lobes. Water quality data collaborate with the juvenile Chinook results to suggest that restrictions in hydraulic connectivity between marsh lobes may be the driver influencing this observation.
7. Hydraulic connectivity improvements within Crescent Harbor Salt Marsh (i.e., between marsh lobes) would likely allow for improved water quality, and for better use of Crescent Harbor Salt Marsh habitat by fish.

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