The influence of a naturally formed distributary channel on the distribution of juvenile Chinook salmon within the Skagit tidal delta

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North Fork Skagit River, 2006. Photo courtesy WA Department of Ecology.

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Abstract

In 2006 a new distributary channel began to form within the North Fork region of the Skagit tidal delta. This created a new fish migration pathway within and through the delta, potentially changing the distribution of juvenile Chinook rearing in the delta and influencing juvenile Chinook use of existing habitat and future restored habitat. This study used existing fish data to test whether the formation of a new distributary has changed the distribution of juvenile Chinook salmon within the Skagit tidal delta.

The long-term monitoring dataset provides an opportunity to retrospectively test spatially explicit hypotheses for juvenile Chinook densities before and after the new distributary formed at six sites in the Skagit tidal delta and Skagit Bay nearshore. We found the new distributary is not a viable pathway to move juvenile Chinook from the North Fork Skagit River to Fir Island's bayfront marsh habitat. Instead, juvenile Chinook that take the new distributary pathway are more likely to be exported to Skagit Bay nearshore than are juvenile Chinook taking the pathway along the North Fork Skagit River.

The new distributary has changed water flow and sediment deposition patterns within the North Fork tidal delta, which are further influenced by large scale processes also acting on tidal delta conditions, such as sea level rise and sediment inputs from the Skagit River. We identify areas within the North Fork tidal delta where habitat changes are rapidly occurring, including a) areas where distributary channel habitat is filling and changing to marsh / blind tidal channel habitat, and b) areas with less certain habitat change trajectories.

We recommend continued monitoring of fish and habitat in the Skagit tidal delta. The formation of the new distributary is a proxy for restoration actions being proposed in the Skagit (e.g., Fir Island Cross-Island Connector in the Skagit Chinook Recovery Plan) and other Puget Sound estuaries. It will be important to document how habitat in the North Fork tidal delta forms because of the new distributary and the surrounding larger scale processes, and how juvenile Chinook respond to changes.

Introduction

Chinook salmon are well known for utilizing natal river tidal delta habitats for rearing during outmigration (Reimers 1973, Healey 1980). Several studies have linked population responses to availability of estuary habitat, either by examining return rates of groups of fish given access to different habitat zones (Levings et al. 1989) or by comparing survival rates of fish from populations with varying levels of estuary habitat degradation (Magnuson & Hilborn 2003). These studies support the hypothesis that estuarine habitat is vital for Chinook salmon population health.

Studies of Skagit Chinook salmon indicate that tidal delta residence by juveniles is important for the population's success. Based on a study of otoliths, individual juvenile fish rear in their natal tidal delta for a period of 0.5 – 2 months (Larsen et al. 2009). The average tidal delta residence period for these Chinook salmon in 1995 and 1996 (combined) was 34.2 days (Beamer et al. 2000). Beamer et al. (2005) found that at contemporary Chinook salmon population levels, current Skagit tidal delta habitat conditions are limiting the number and size of juvenile Chinook salmon rearing in delta habitat as well as displacing juvenile Chinook salmon from tidal delta habitat to Skagit Bay habitat and forcing a change in their life history type from delta rearing to fry migrants. In fact, 5% to 40% of all the Chinook salmon fry outmigrating the Skagit River each year are fry migrants, ending up in Skagit Bay nearshore habitats in winter through early spring, largely due to density dependent processes occurring within the tidal delta (Greene et al 2016). Beamer et al. (2005) also found that differences in habitat connectivity influence juvenile Chinook salmon abundance in the Skagit tidal delta. Together these findings indicate that habitat fragmentation, in addition to habitat loss, has been detrimental to Skagit Chinook populations. Thus, restoration of tidal delta habitats and their connectivity are components of the Skagit Chinook Recovery Plan (SRSC and WDFW 2005).

In 2006 a new distributary channel began to form in the North Fork tidal delta well upstream of any pre-existing distributary channels (Hood 2010a). This new channel has widened each year since becoming a dominant flow path within the North Fork tidal delta (Eric Grossman of USGS, pers. comm.). The new distributary creates a new fish migration pathway within and through the Skagit tidal delta. Assuming the new pathway is used by outmigrating juvenile Chinook salmon, it could have changed the distribution of juvenile Chinook rearing in the tidal delta, having ramifications on juvenile Chinook use of existing habitat and future restored habitat. The new distributary could help improve connectivity of habitats within the tidal delta in a best case scenario for the Skagit Chinook Recovery Plan. The areas most influenced by the new distributary should be the North Fork tidal delta downstream of the bifurcation, and possibly bayfront habitat between the South Fork and North Fork tidal deltas.

This study used existing fish data from the Skagit Intensively Monitored Watershed (IMW) Program, a long-term juvenile Chinook salmon monitoring effort within the Skagit tidal delta and Skagit Bay (Greene et al. 2016), to retrospectively analyze whether the formation of a new distributary has changed the distribution of juvenile Chinook salmon within the Skagit tidal delta.

New distributary formation

This study used physical characteristics of the new distributary to retrospectively analyze whether the formation of a new distributary has changed the distribution of juvenile Chinook salmon within the Skagit tidal delta. In this section, we describe the new distributary's attributes measured by GIS.

Methods

We used GIS to measure on-screen three attributes of the new distributary on all available orthophotos from 2004 through 2015 (Figure 1). The distributary did not exist in 2004. It is first shown in the 2006 photo and has widened in each photo since. New distributary attributes measured are:

1. Channel width at the point of bifurcation with the North Fork Skagit River;
2. Narrowest channel width;
3. Length from point of bifurcation with the North Fork Skagit River to end of the vegetated tidal delta.

Results

Prior to 2006 the new distributary was not present in the North Fork Skagit tidal delta. However, a blind tidal channel was present, which ultimately became the alignment for the new distributary (Figure 1). Since the new distributary's formation, its channel width has increased exponentially (Figure 2, top and middle panels). Channel width at the point of bifurcation was 8 m in 2006 and increased to 108 m by 2015. The narrowest channel width was 2 m in 2006 and increased to 56 m by 2015. During the same period length of the new distributary through the vegetated tidal delta has decreased from 1,228 m in 2006 to 1,086 m in 2015 (Figure 2, bottom panel).

All three attributes of the new distributary are highly correlated with each other (Table 1), so we can only use one attribute in analyses testing whether the new distributary has influenced the distribution of juvenile Chinook salmon within the Skagit tidal delta. We used channel width at the point of bifurcation as an independent variable for the juvenile Chinook analyses described below, and distributary channel width as '0' meters for all years prior to 2006. For missing years in the orthophoto record we estimated channel width using linear regression methods.

Table 1. Pearson correlation R values for width and length results of the new distributary from 2006 through 2015.

	Channel width at bifurcation	Narrowest channel width	Length
Channel width at bifurcation	1		
Narrowest channel width	0.99	1	
Length	-0.98	-0.97	1

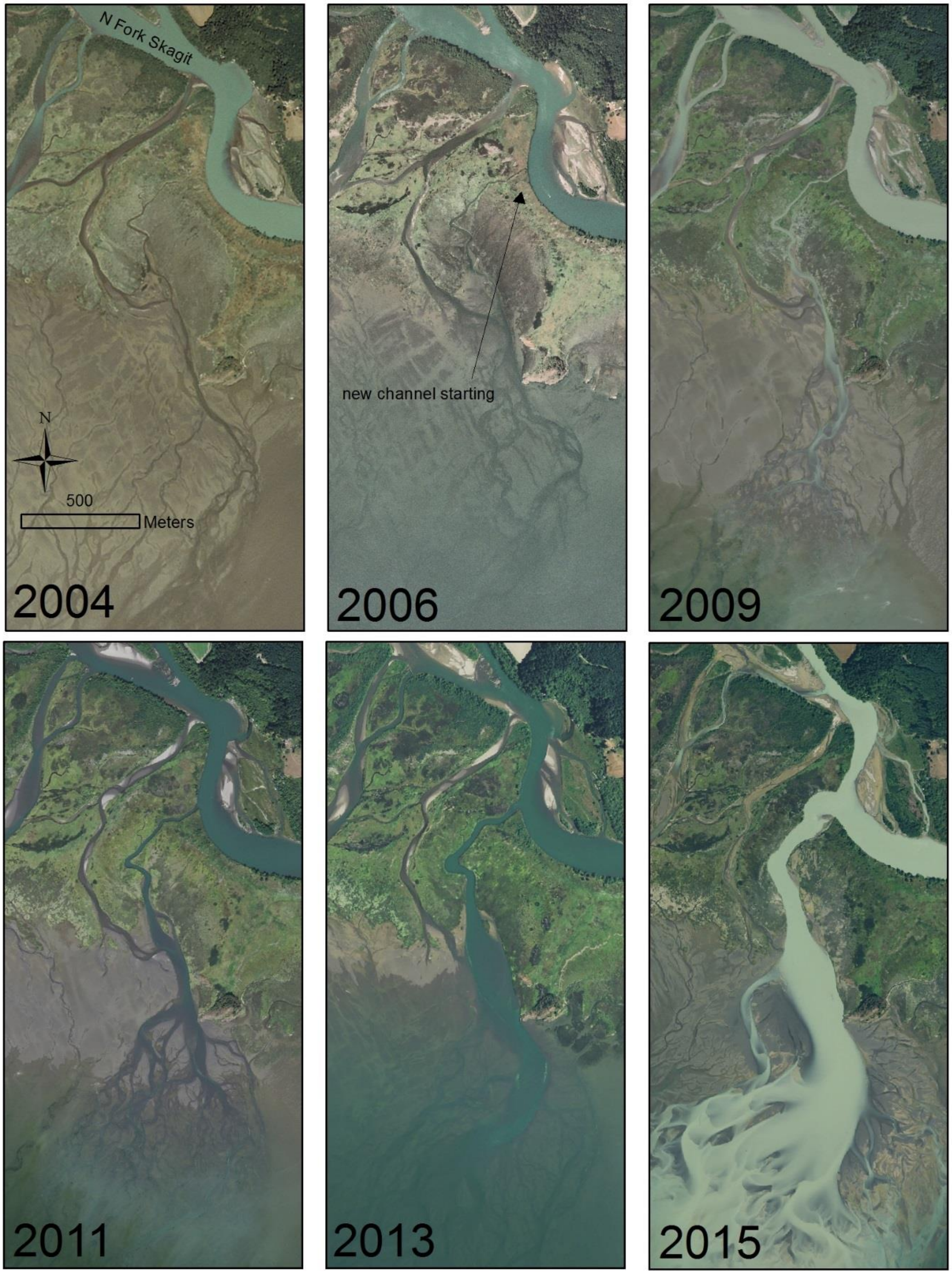


Figure 1. Photos showing progression of the new distributary. The distributary did not exist in 2004. It is first shown in the 2006 photo and has widened in each photo since.

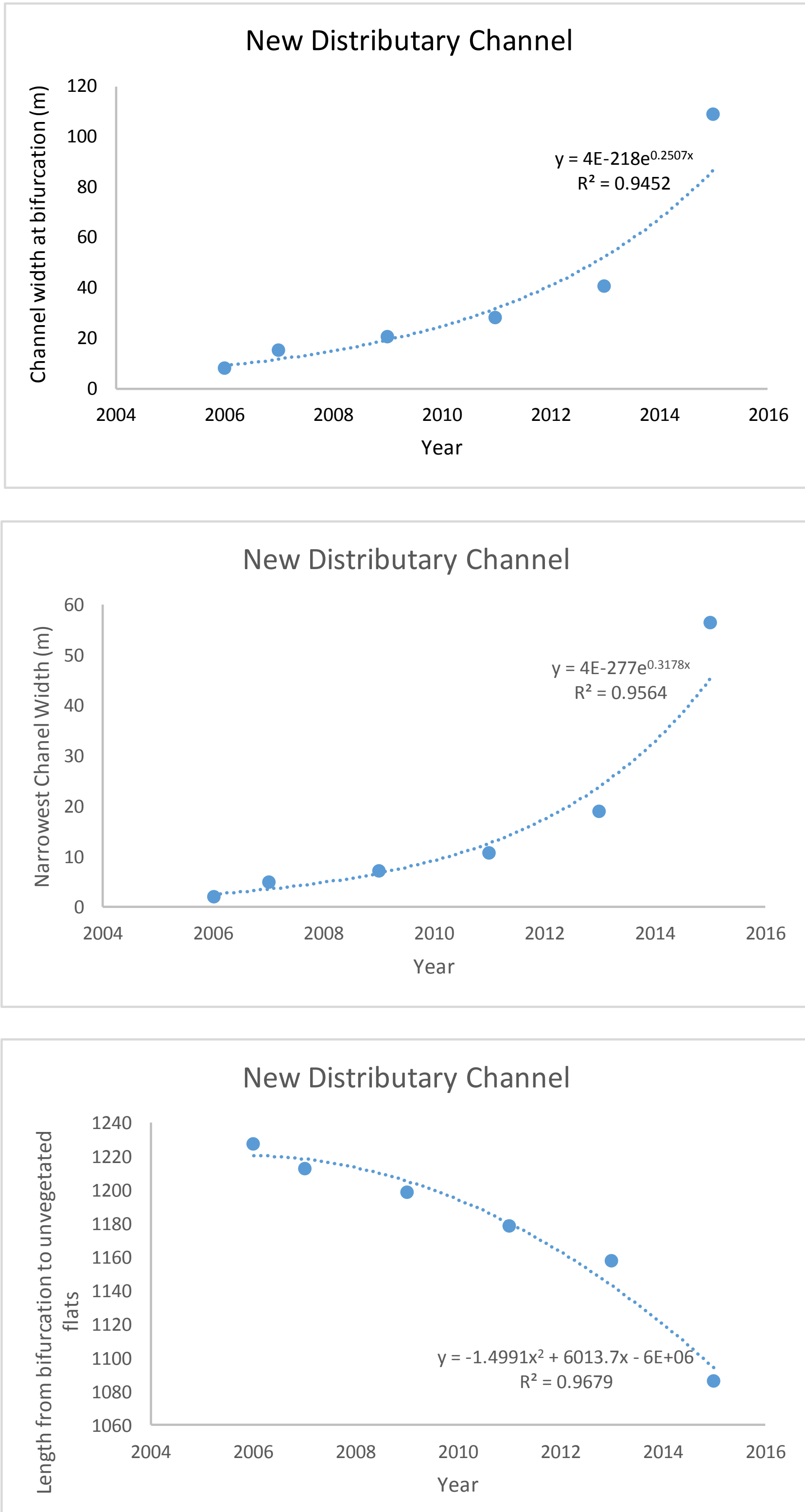


Figure 2. Width and length characteristics of the new distributary channel from its formation in 2006 through 2015.

Juvenile Chinook Response to New Distributary Formation

Methods

This study used existing fish data to retrospectively analyze whether the formation and widening of a new distributary has changed the distribution of juvenile Chinook salmon within the Skagit tidal delta.

Source of existing fish data

The Skagit IMW project (Greene et al. 2016) monitors Skagit River Chinook salmon via a long-term interagency program involving sampling of outmigrants at Mount Vernon (WDFW), fyke trapping of fish rearing in the tidal delta (SRSC), beach seining of nearshore habitats in Skagit Bay (SRSC), and townetting of offshore areas in Skagit Bay (Northwest Fisheries Science Center (NWFSC)). The Skagit IMW project provides data for a system-wide analysis of patterns of juvenile abundance and life history diversity across the juvenile outmigration season from late winter to fall of each year. From the Skagit IMW dataset we used natural origin juvenile Chinook density data spanning the years 2002 through 2015 from five tidal delta fyke traps and one nearshore beach seining site.

The Skagit IMW sampling effort is designed to encompass the entire juvenile Chinook outmigration period each year. Fyke trap sampling in the tidal delta occurs from February through August each year, while beach seining in the Skagit Bay nearshore occurs from February through October each year. For this analysis we used tidal delta data only from February through July. We excluded August data because the majority of values in the dataset were zero for this month at each site. For the nearshore beach seining we used data only representing the period when fry migrants move through the tidal delta and into Skagit bay, which is February through April. Methods for fish data collection are described in Greene et al. (2016) and not repeated here.

Sites used and hypotheses tested

We used data collected in 2002 through 2015 from five fyke trap sites within the Skagit tidal delta, including three sites located within the North Fork Skagit tidal delta (Grain of Sand, Cattail Saltmarsh, and Ika) and two sites located within the fringing tidal marshes along the Skagit Bay front (Browns Sl Barrow Ch, Browns Sl Diked Side). We also used data from one beach seine site along the eastern Whidbey Island shoreline (Strawberry Pt N) (Figure 3).

The long-term monitoring dataset from the Skagit IMW provides an opportunity to retrospectively test the central idea because the dataset (a) spans the time period before and after the new distributary formed and (b) contains sites that are hypothesized to respond differently (i.e., increased fish density, decreased fish density, no change in fish density) to new distributary formation. Specifically, we tested the following four hypotheses based on the assumption that the new distributary channel is a migration pathway (as well as rearing habitat) for juvenile Chinook salmon:

Hypothesis 1: *Juvenile Chinook salmon densities are not influenced by the new distributary (before or after its formation) for habitat associated with the North Fork Skagit River upstream of the bifurcation.* The site representing this habitat is Grain of Sand.

Hypothesis 2: *Juvenile Chinook salmon densities are lower after new distributary formation for habitat associated with the North Fork Skagit River downstream of the bifurcation*. Sites representing habitat downstream of the bifurcation are Ika and Cattail Saltmarsh.

Hypothesis 3: *Juvenile Chinook salmon densities are higher after new distributary formation for habitat associated with the bayfront between the North and South Fork tidal deltas*. Sites representing bayfront habitat are Browns Sl Barrow Ch and Browns Sl Diked Side. This hypothesis would likely only be true if the new distributary provides a better pathway to bayfront habitat than the pathway via Freshwater Slough (in the South Fork tidal delta).

Hypothesis 4: *Juvenile Chinook salmon densities are higher after new distributary formation for nearshore habitat in Skagit Bay nearest to receiving flow of the new distributary*. The site representing this habitat is Strawberry Pt N beach seine site. This hypothesis would likely only be true if the new distributary is providing a better pathway out of the tidal delta than within the delta or across the delta's bayfront.

Independent variables

New distributary

For the Grain of Sand analysis, we used a continuously variable version of the new distributary influence called DistOpWidth(m). It is the annual estimate of new distributary's opening width (from Figure 2, top panel). Values range from 0 to 108 meters. For all remaining analyses, we used a categorical variable called: New Distributary (Not Present, Transitioning, or Fully Formed). In the fish density dataset, the new distributary was not present in years 2002-2005 (n=4), transitioning (i.e., forming) in years 2006-2012 (n=7), and fully formed (i.e., greatly widened) in years 2013-2015 (n=3).

Other covariates

We included six additional covariates that are hypothesized to influence variability in juvenile Chinook salmon density independent of the influence of the new distributary (Table 2).

Differences in juvenile Chinook density are expected by month simply because of the seasonal effect of juvenile salmon temporarily rearing in tidal delta habitat on their way to the marine environment. Peak Chinook density occurs in March or April at each site (Figure 4).

The number of fry outmigrants each year are hypothesized to have a positive influence on Chinook density. Large outmigration years result in higher Chinook densities in the tidal delta habitat than do low outmigration years.

Based on Before–After Control-Impact (BACI) results in Greene et al. (2015) and system level results in Greene et al. (2016), the amount of restoration (SF Chan Rest or SF Footprint Rest) negatively influences Chinook density (i.e., more habitat disperses fish, resulting in a lower density) for sites influenced by fish migration pathways through the South Fork tidal delta.

Annual river flow characteristics might influence Chinook fry migration. The period of January through April was selected to coincide with the period when Chinook fry are migrating out of the river into, or through, tidal delta habitats (Zimmerman et al. 2015). We included peak flow to account for possible effects of peak flow events triggering migration or displacement of Chinook fry out of the Skagit River. We included average flow based on the hypothesis that in years with lower flows during the fry outmigration period, proportionally more fish take the pathway into the South Fork tidal delta (and away from the North Fork tidal delta) than in higher flow years. The hypothesis is based on the presence of a large rightbank bar immediately upstream of the North Fork and South Fork Skagit River bifurcation. If Skagit River flows are low, then much more of the water in the mainstem is located on the east side of the river and would tend to flow more into the South Fork.

Variability in water temperature and dissolved oxygen (DO) can influence juvenile Chinook in estuarine environments. High temperature and low DO was found to influence juvenile Chinook presence/absence in the Skagit tidal delta (Beamer et al. 2016b). However, we did not include water temperature or DO as covariates because of their strong correlations with month. As previously described, the dataset did not use August observations when temperature is highest and DO the lowest.

Table 2. List of covariates and their description.

Covariate	Description
Month	Seasonal effect of juvenile Chinook migrating from river to marine environments.
fry outmigrants	Annual estimate of Skagit River Chinook fry outmigration size (from WDFW). Values range from 914,161 to 5,116,578 Chinook fry/year.
SF Chan Rest (ha)	Cumulative restoration extent occurring within the South Fork tidal delta (channel area only). Values range from 8.10 to 38.03 hectares. See Appendix 1 for details.
SF Footprint Rest (ha)	Cumulative restoration extent occurring within the South Fork tidal delta (tidal footprint). Values range from 93.7 to 183.4 hectares. See Appendix 1 for details.
peak Q Jan-Apr	Skagit River peak daily flow at Mt Vernon for the period January through April. Values range from 19,900 to 74,700 cfs.
ave Q Jan-Apr	Skagit River average daily flow at Mt Vernon for the period January through April. Values range from 12,585 to 21,182 cfs.

Data transformation

To reduce the effects of non-normal data distribution, zeros, and unequal variance, Chinook salmon densities were natural log (x+1) transformed. Normality in ANOVA test residuals from transformed and untransformed Chinook salmon density was tested. Residuals of untransformed data were not normally distributed, while the residuals of transformed data were normally distributed.

The predictable seasonal effect on juvenile Chinook density (Figure 5) was linearized using the best fit polynomial relationship for each site (Figure 5, Table 3). This allowed analysis of a maximum 84 observations (6 months x 15 years) instead of 15 (annual) observations per site.

Table 3. Month and transformed month values for Grain of Sand based on the conversion of month using the polynomial equation shown in the top panel of Figure 5.

Month	Transformed Month
2	8.6001
3	9.1906
4	8.9767
5	8.0436
6	6.4765
7	4.3606

Analysis approach

We used multiple regression and ANOVA methodology to determine factor and covariate influences on transformed juvenile Chinook density data from six different sites hypothesized to respond to the new distributary differently.

We conducted the analysis in two stages. First, we tested for new distributary and covariate influences on transformed juvenile Chinook density data from Grain of Sand, a site located upstream of the new distributary which should not be (and was not) influenced by the new distributary. Second, we standardized juvenile Chinook results from the five remaining sites to Grain of Sand's juvenile Chinook density results and then tested for new distributary and covariate effects. The main advantage of standardization is a gain in 2 residual degrees of freedom for each ANOVA or multiple regression analysis by eliminating the need to include the two predictable influences of Chinook density: seasonal (transformed month) and annual (fry outmigration).

We standardized transformed Chinook density results at each of the five other sites by dividing their Chinook density by Grain of Sand's Chinook density. The resultant dataset for each tidal delta site is reduced from 84 to 78 observations. We had to discard six of the 84 observations in the standardized version of the dataset because six Grain of Sand observations had Chinook densities of zero. The resultant dataset for the nearshore beach seine site is 42 observation because the period used was for fry outmigration (February through April).

Correlations between variables

Significant correlation exists between some of the continuous variables, which limits which independent variables can be included in each ANOVA test (Table 4). Specifically, we could only use one of the stream flow variables or South Fork restoration variables in any ANOVA test. We also could not use South Fork Restoration variable with New Distributary opening width, nor fry outmigration with average flow. The strong positive correlations between the South Fork Restoration variables and New Distributary opening width are because formation of the new distributary occurred at the same time as more restoration was completed in the South Fork tidal delta (compare results in Appendix 1 with Figure 2).

Table 4. Pearson correlation R values for continuous variables. Bold font denotes a significant correlation between variables at the 0.05 level.

	fry outmigrants	DistOpWidth(m)	SF Chan Rest (ha)	SF Footprint Rest (ha)	peak Q Jan-Apr	ave Q Jan-Apr
fry outmigrants	1					
DistOpWidth(m)	-0.22	1				
SF Chan Rest (ha)	-0.01	**0.73**	1			
SF Footprint Rest (ha)	-0.01	**0.78**	**0.99**	1		
peak Q Jan-Apr	0.19	-0.05	-0.17	-0.20	1	
ave Q Jan-Apr	**0.45**	0.18	-0.03	0.02	**0.40**	1

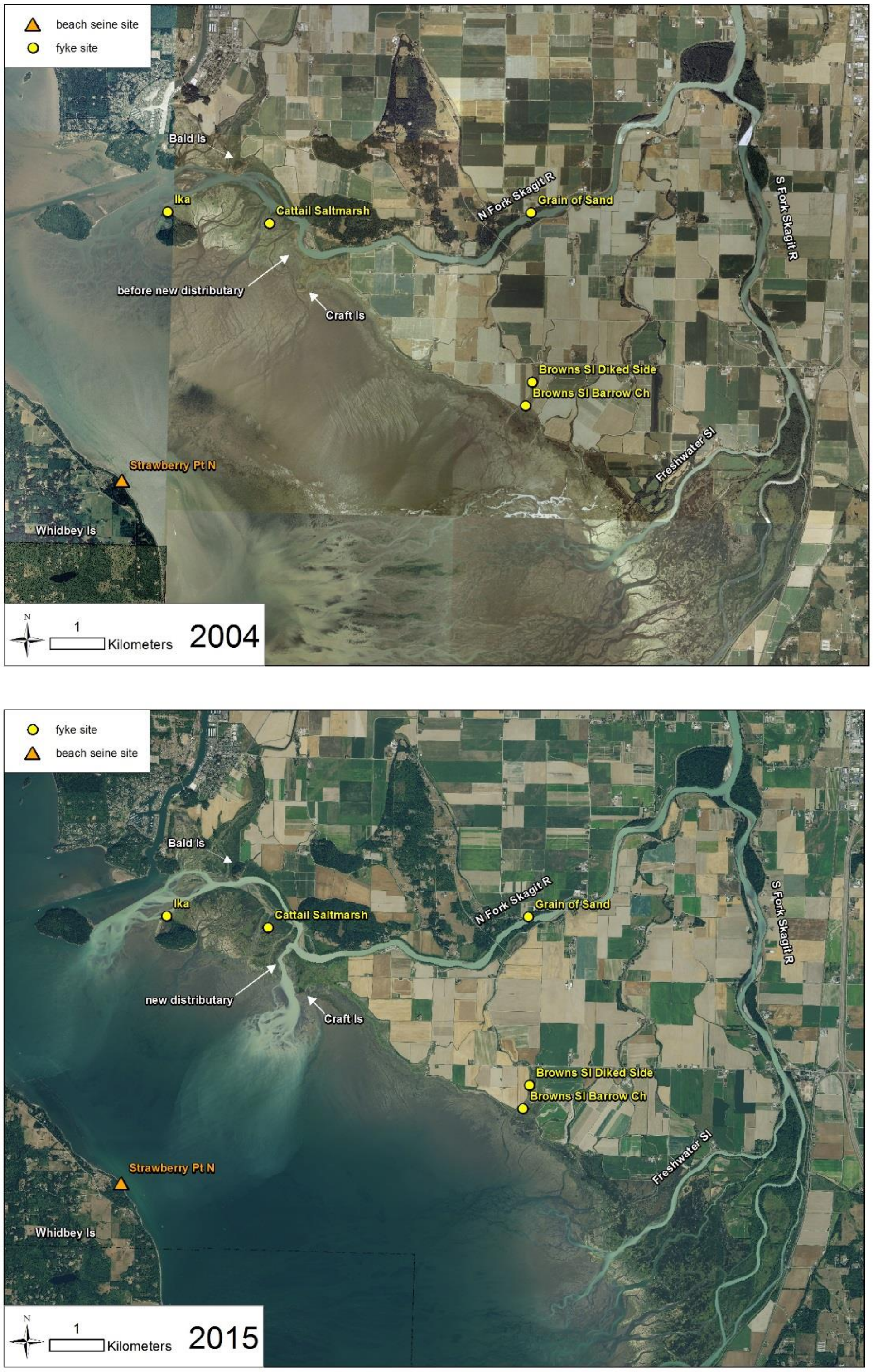


Figure 3. Location of fyke trap and beach seine sites in relation to North and South Fork channels and new distributary for the year immediately before distributary formation (top panel) and in 2015 (bottom panel).

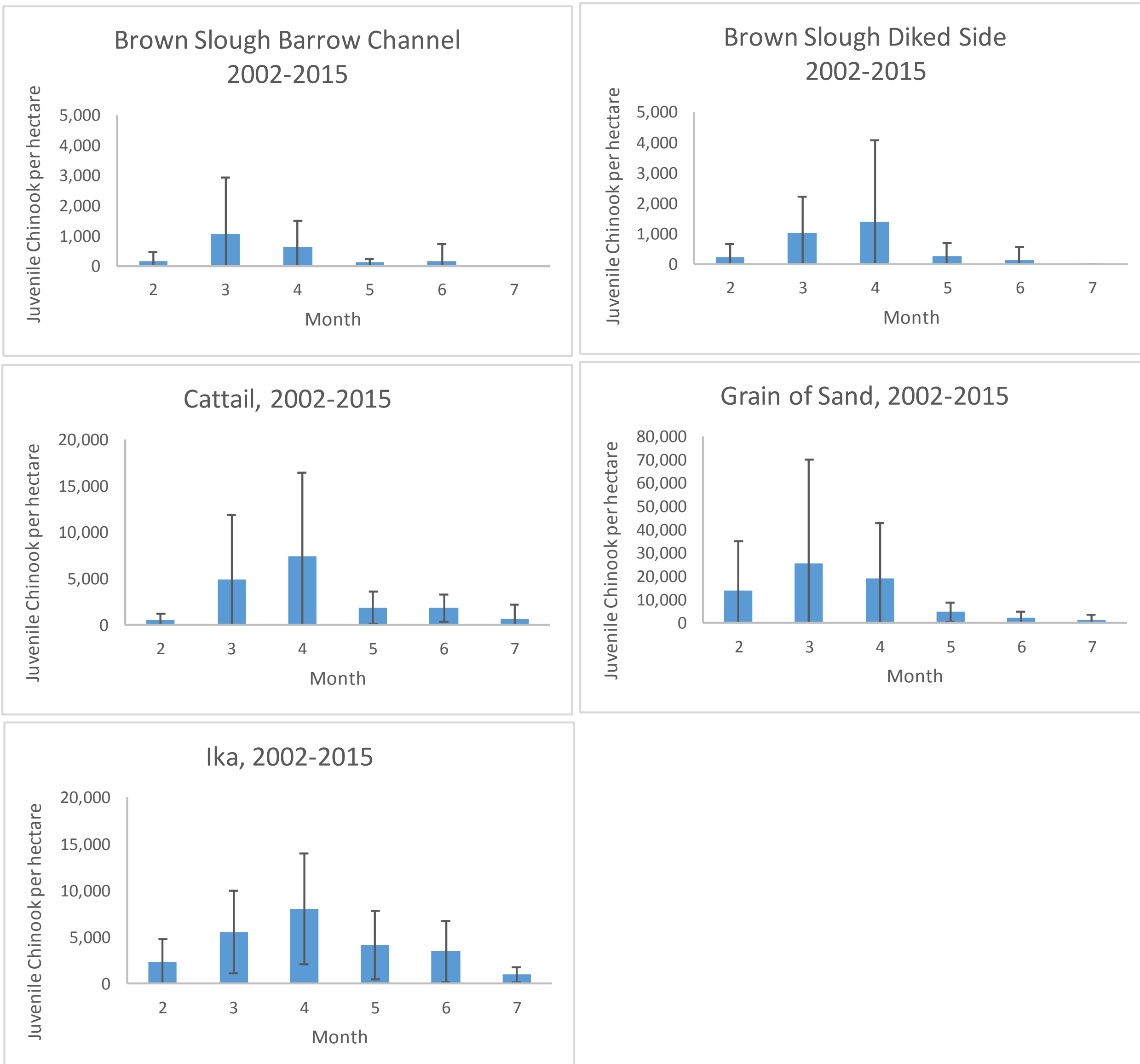
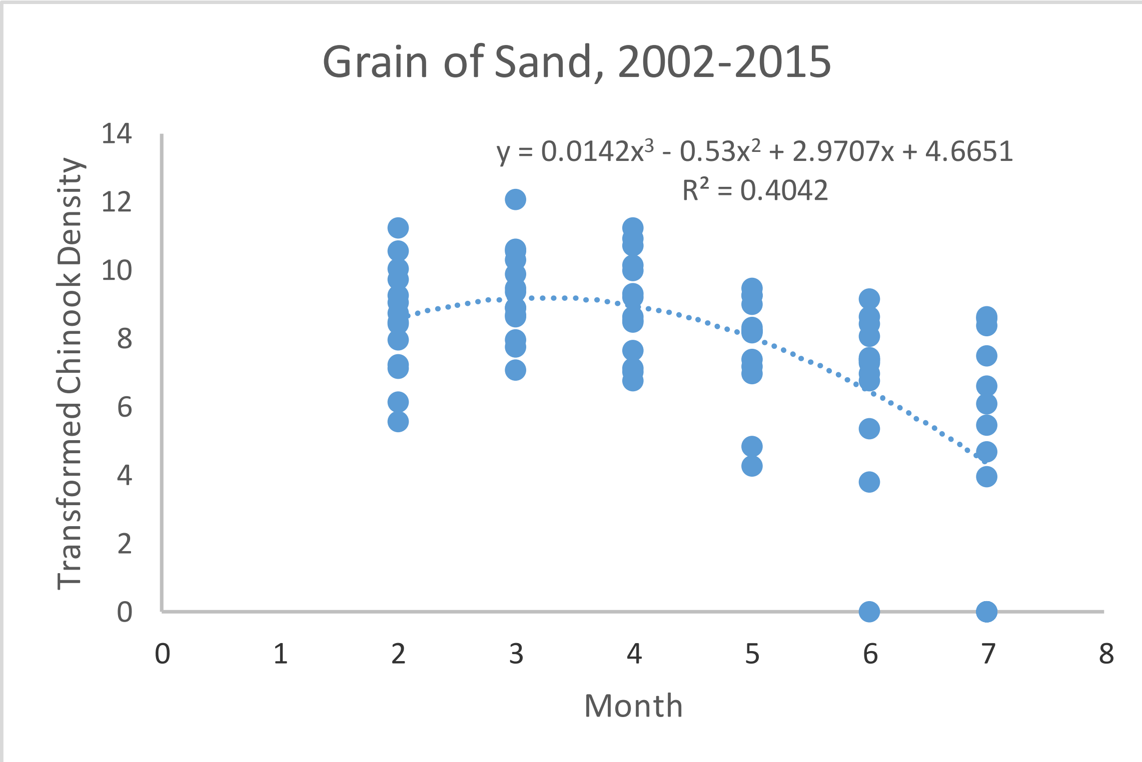


Figure 4. Monthly average juvenile Chinook salmon density by five sites within the Skagit tidal delta. Error bars are one standard deviation.



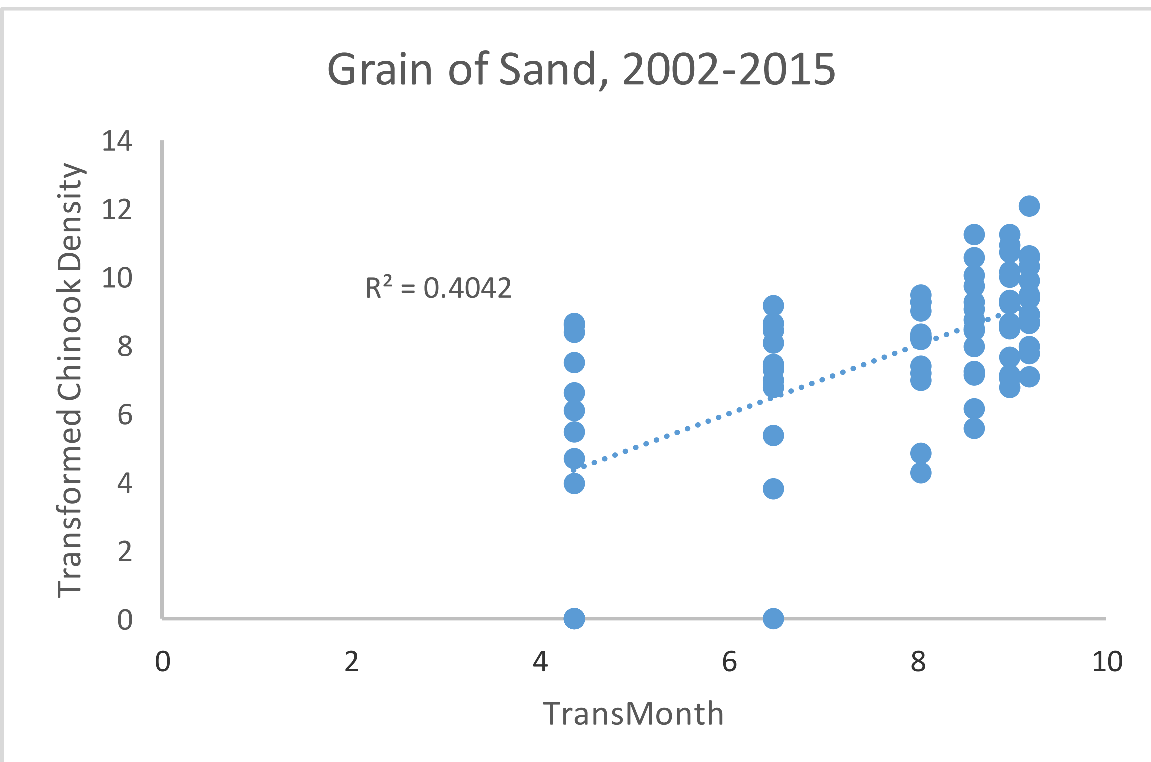


Figure 5. Example of log transformed juvenile Chinook density results for Grain of Sand as a function of months (top panel) and transformed months (bottom panel).

Results

Hypothesis 1 (Grain of Sand)

We did not detect a significant influence of the new distributary on transformed Chinook density at Grain of Sand (Table 5). The best model for Grain of Sand includes 84 observations and has an R^2 of 0.48 but only retained fry outmigration and transformed month as significant variables (Table 6). No flow variables were significant in any model runs.

This is the expected result because Grain of Sand is located upstream of the new distributary channel. Juvenile Chinook salmon using Grain of Sand should not be influenced by the new distributary either positively or negatively. Hypothesis 1 is supported by the Grain of Sand results.

Based on the Grain of Sand results we can compare juvenile Chinook density results from all other sites to Grain of Sand, thereby eliminating the need to account for two important covariates (transformed month and fry outmigration) in statistical tests because their effects are already accounted for by standardizing to Grain of Sand.

Table 5. Multiple regression significance results for transformed juvenile Chinook density at Grain of Sand using all variables. P-values significant at the 0.05 level are bolded.

Independent variable	p-Value
fry outmigrants	**0.006**
transformed month	**0.000**
DistOpWidth(m)	0.291
peak Q Jan-Apr	0.312

Table 6. Best fit multiple regression significance results for transformed juvenile Chinook density at Grain of Sand. P-values significant at the 0.05 level are bolded.

Independent variable	Coefficient	p-Value
fry outmigrants	0.0000005	**0.001**
transformed month	1.0003341	**0.000**

Hypothesis 2 (Cattail Saltmarsh and Ika)

We did not detect a significant influence of the new distributary on standardized Chinook density at Cattail Saltmarsh or Ika (Table 7, Figure 6). The models for these sites include 78 observations for each site and have an R^2 of 0.04 and 0.01, respectively. No flow variables were significant in any model runs.

There is no effect of the new distributary on juvenile Chinook densities at Cattail Saltmarsh and Ika. This is an unexpected result. We expected fewer juvenile Chinook at these sites after the new distributary formed (or widened) because fish that could otherwise find Cattail Saltmarsh or Ika are expected to go through the new distributary upstream.

Hypothesis 3 (Browns Slough sites)

We did not detect a significant influence of the new distributary on standardized Chinook density at Browns Sl Barrow Ch or Browns Sl Diked Side (Table 7, Figure 6). The models for the Browns Slough sites include 78 observations for each site and have an R^2 of 0.04 and 0.05, respectively. No flow variables were significant in any model runs. There is a hint of a South Fork restoration influence on the diked side site ($p = 0.107$).

There is no effect of the new distributary on juvenile Chinook densities at Browns Sl Barrow Ch or Browns Sl Diked Side. This is an unexpected result assuming the new distributary provides a better pathway to bayfront habitat than the pathway via Freshwater Slough in the South Fork tidal delta. If the new distributary provides a better pathway to bayfront habitat, then we expected more juvenile Chinook at Browns Slough after the new distributary formed (or widened).

Hypothesis 4 (Strawberry Pt N)

We did detect a significant influence of the new distributary on standardized Chinook density at Strawberry Pt N (Table 7, Figure 6). The overall model for this site includes 42 observations and has an R^2 of 0.20. Standardized Chinook densities were higher at Strawberry Pt N after the new distributary was fully formed compared to the period when it was not present or transitioning (Table 8). We also found a significant positive influence of peak flow on standardized juvenile Chinook density at Strawberry Pt N (Table 8). Higher peak flows during the fry outmigration period results in more juvenile Chinook at Strawberry Pt N.

There is an effect of the new distributary on juvenile Chinook densities at Strawberry Pt N. This is an expected result. The new distributary allows more fish to migrate through the North Fork tidal delta and over to the Whidbey Island shoreline near Strawberry Point. Years with higher peak flows during fry outmigration exacerbate the effect.

Table 7 Significance results for standardized transformed juvenile Chinook density by site. NA = not applicable. Bold values are p-values significant at the 0.05 level. The direction of influence (+ or -) are shown in parentheses for covariates with p-values less than 0.11.

Model type	**Variable type**	**Variable**	**Site**				
			Cattail Saltmarsh	**Ika**	**Browns Sl Barrow Ch**	**Browns Sl Diked Side**	**Strawberry Pt N**
ANOVA	Factor	New distributary	0.296	0.770	0.809	0.271	**0.043**
	Covariate	Peak Q Jan-Apr	0.500	0.591	0.681	0.380	**0.047 (+)**
		South Fork restoration	NA	NA	0.501	0.107 (-)	NA

Table 8. Pairwise results of standardized transformed juvenile Chinook density at Strawberry Pt N by New Distributary using Tukey's Honestly Significant Difference Test.

New Distributary comparisons		**Difference**	**p-Value**
Fully Formed	Not Present	0.205	0.047**
Fully Formed	Transitioning	0.168	0.076*
Not Present	Transitioning	-0.037	0.850

** significant at the 0.05 level; * significant at the 0.1 level

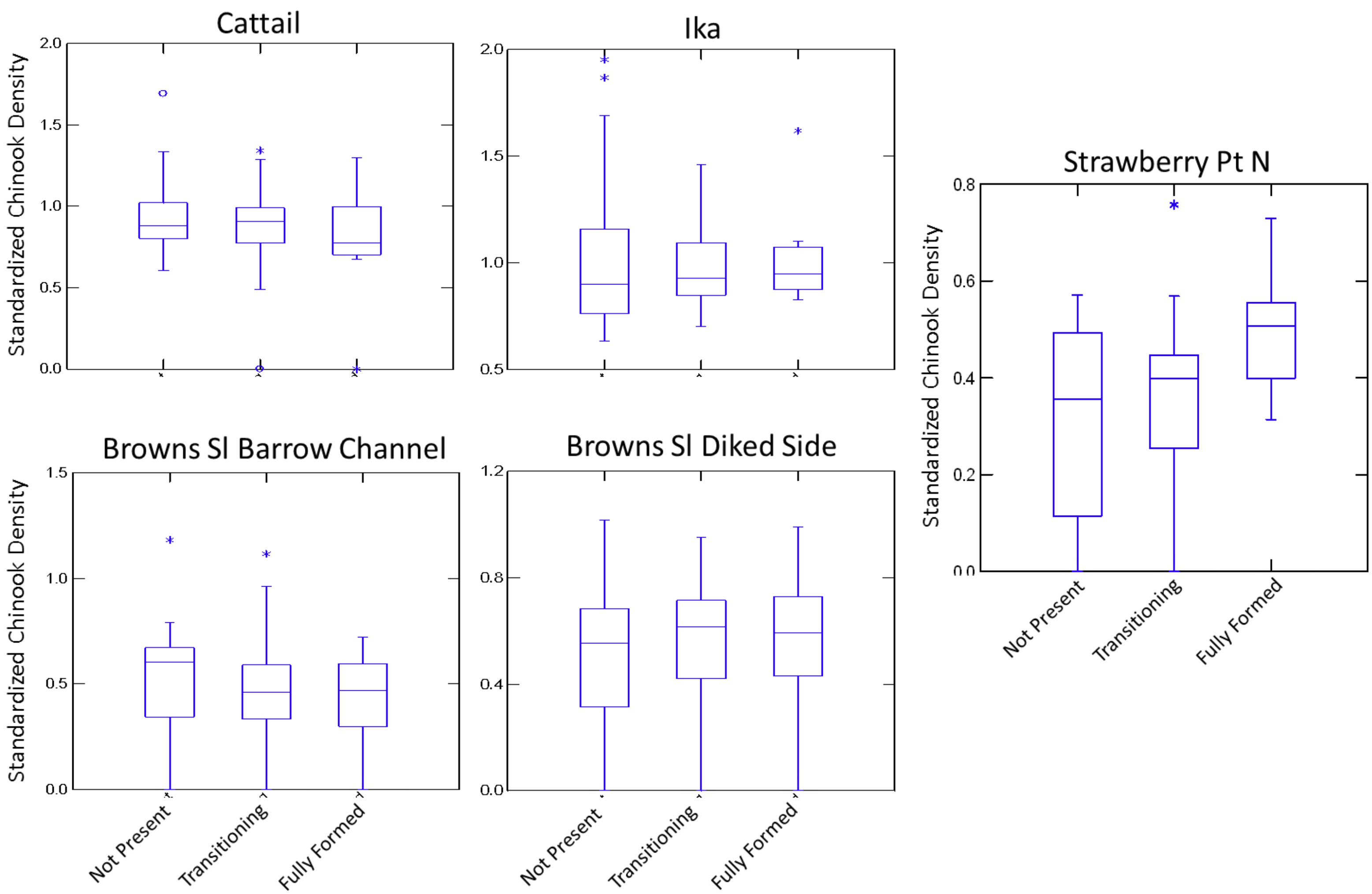


Figure 6. Boxplots of standardized transformed juvenile Chinook density by time periods of the new distributary (not present, transitioning, and fully formed) by site. Chinook densities are standardized to densities observed at Grain of Sand.

Discussion

Juvenile Chinook density

Hypothesis 1

Hypothesis 1 was supported by our analysis. Grain of Sand is located upstream of the new distributary channel. Juvenile Chinook salmon using Grain of Sand should not be influenced by the new distributary either positively or negatively because they are migrating downstream from the Skagit River and encounter Grain of Sand before having the choice to take the new distributary pathway or remain in the North Fork Skagit River.

Hypothesis 2

Hypothesis 2 was not supported by our analysis. We found no evidence of the new distributary decreasing juvenile Chinook density in North Fork tidal delta habitat downstream of the bifurcation point of the new distributary. This is an unexpected result especially when all other hypotheses make sense. Possibly the unbalanced fish data used for this study contribute to the unexpected result. The fish dataset is not balanced in terms of the new distributary effect. Out of the 14 years of data, only three years are from the period when the new distributary is fully formed and likely to be influencing juvenile Chinook distribution the most. More years of monitoring with the distributary fully formed will likely improve our ability to detect the influence of the new distributary on juvenile Chinook distribution.

Hypothesis 3

Hypothesis 3 was not supported by our analysis. We found no evidence of the new distributary increasing juvenile Chinook density in bayfront habitat, at least not in the Browns Slough area. Upon further examination, we believe it was not reasonable to expect the new distributary to improve juvenile Chinook access to the Browns Slough area. Fish migration pathway data suggests the better pathway to these areas is via the Freshwater Slough route, so expecting the new distributary to improve juvenile Chinook access to this area is not likely correct. The distance along the bayfront from the mouth of Freshwater Slough (3.25 km) is shorter than the mouth of the new distributary (5.55 km) to Browns Slough. Additionally, the low tide channel signature of the new distributary suggests flow travels southwesterly across the unvegetated flats toward the Whidbey Island shoreline near Strawberry Point. This southwesterly flow direction is the same pattern observed by drift buoy trials in 2004 for the nearby Cattail and Ika Sloughs of the North Fork delta (see Figure D.VI.3 on page 84 in Beamer et al. 2005). Conversely, drift buoy trials in 2004 at the mouth of Freshwater Slough showed water flowing northwesterly toward bayfront habitats (see Figure D.VI.4 on page 85 in Beamer et al. 2005).

Hypothesis 4

Hypothesis 4 was supported by our analysis. We found evidence of the new distributary exporting juvenile Chinook out of the North Fork tidal delta and over to the Whidbey Island shoreline in the area of Strawberry Point. This is the strongest statistical inference and most worrisome from the standpoint of getting Chinook fry migrants to find rearing habitat within the tidal delta. However, the fish results are logical for at least three reasons. First, by 2015 the width of the new distributary and North Fork Skagit River downstream of the new distributary are approximately equal, making the new distributary a very significant pathway for fish migration. Second, the new distributary pathway is shorter and has less opportunity for fish to disperse into rearing habitat compared to the North Fork Skagit River route downstream of the new distributary. From the bifurcation of the new distributary and North Fork Skagit River it is 3.4 km to the end of the tidal marshes along the North Fork (at Ika Island) and only 1.05 km along the new distributary to the end of the tidal marshes (at Craft Island). Third, tidal flow direction (discussed above in Hypothesis 3) suggests fish that take the new distributary pathway – and do not find tidal delta habitat along its corridor – would be pushed in the direction of Strawberry Point once they leave the tidal delta. The 2015 image shown in Figure 3 shows a large plume of turbid river water flowing directly from the mouth of the new distributary toward Strawberry Point.

Importance of covariates

Month and annual Chinook fry outmigration size:

We hypothesized juvenile Chinook salmon density at all our sites would be strongly influenced by two predictable variables: month and fry outmigrants. Month is the logical seasonal effect because juvenile salmon are temporarily rearing in tidal delta habitat on their way to the marine environment. The number of Chinook fry that outmigrate the Skagit River each year should have a positive influence on Chinook density at sites downstream. Large outmigration years result in higher Chinook densities in rearing habitat than do low outmigration years. In fact, preliminary analysis revealed a strong seasonal and/or fry outmigration influence on juvenile Chinook density at all six sites. Overall, 33-67% of the variation in juvenile Chinook density was accounted for by these two variables. The preliminary analysis was done to figure out a way to analyze our fish data and maximize its statistical power. The preliminary analyses resulted in the two-stage analysis procedure (described in methods above).

Peak and Average Skagit River flow:

We did not find peak flow during the fry outmigration period to influence juvenile Chinook density at any tidal delta site. Peak flow did positively influence juvenile Chinook density at Strawberry Pt N, our nearshore beach seine site. Peak flow statistics have been shown to influence the number Chinook fry at Crescent Harbor Saltmarsh, a pocket estuary located about 7 miles south of Strawberry Pt N along the Whidbey Island shoreline (Beamer et al. 2016a).

We included average flow during the Chinook fry outmigration period as a possible covariate. Average flow was thought to potentially influence how many fish would use the North Fork compared to the South Fork. In years with lower flows, proportionally more fish might take the pathway into the South Fork tidal delta (and away from the North Fork tidal delta) than in higher flow years. We found no statistical support for the average flow hypothesis in any ANOVA test.

South Fork Restoration extent:

We included the cumulative extent of restoration in the South Fork tidal delta based on its known influence on juvenile Chinook density within the South Fork tidal delta (Greene et al. 2015; Greene et al. 2016). We thought the South Fork Restoration covariate might help elucidate results at the two Browns Slough sites because fish using Browns Slough habitats might be coming from South Fork migration pathways rather than through the new distributary. We found weak evidence for the South Fork restoration influence at Browns Sl Diked Side. Larger amounts of restored habitat within the South Fork Skagit delta coincided with decreased juvenile Chinook densities at Browns Sl Diked Side. This is a logical result especially since the large Wiley Slough Restoration Project that came online for fish use in 2010 is located along the Freshwater Slough fish migration pathway and is known to be used by large numbers of juvenile Chinook (Beamer et al. 2015), some of which may have found their way to the Browns Slough area had Wiley Slough habitat not been available for rearing.

Future habitat trajectory of North Fork Tidal Delta

Water flow and sediment deposition patterns have been changing within the North Fork tidal delta due to the formation and widening of the new distributary (Figure 1). However, large scale processes also influence North Fork tidal delta conditions, such as sea level rise and sediment inputs from the Skagit River. In fact, Skagit tidal delta progradation rate was found to decline even during a period of increasing timber harvest, subsequent landslides, and sediment delivery (Hood et al. 2016). This suggests that relative sea level rise and sediment routing within the tidal delta are responsible for the decline in the formation of tidal delta habitat. Hood et al. (2016) calculated progradation rate for three areas of the Skagit tidal delta. Over the aerial photo period of record, Skagit tidal delta progradation rates for all areas within the vegetated tidal delta have been in decline. For two of the three areas (bayfront, South Fork) progradation rate is currently negative, which means marsh habitat is being lost faster than it can form. North Fork tidal delta progradation rate was last measured at zero, but the trend is negative, suggesting that soon the North Fork tidal delta will be losing marsh habitat faster than it forms. In this section we discuss possible future trajectories of marsh and channel habitat within the North Fork tidal delta considering the direct influence of the new distributary and larger-scale processes.

In Figure 7 we show areas where North Fork tidal delta habitat change is likely to occur within the next 5-15 years if the new distributary continues to capture much of the North Fork Skagit River flow resulting in new tidal marsh areas being formed by the depositional processes described by Hood (2010b):

1. The 17.9 ha polygon labeled ‘A’ has been filling in with sediment and becoming progressively less and less a distributary channel. We believe within the next five years (~2020) this area will become tidal marsh and blind channel habitat. When this happens, the four smaller distributary channels breaking off the old North Fork channel (shown as white arrows in Figure 7) will become blind channels. Juvenile salmon access to these blind channels will come from the bayfront, likely through a pathway taken via the new distributary and then westerly along the bayfront toward Ika Island.
2. The three polygons labeled ‘B’ are also filling in with sediment, though not as fast as area ‘A.’ These ‘B’ areas (96.7 ha total) are likely to become tidal marsh and blind channel habitat within the next 10-15 years (~2025-2030).

In Figure 7 we also show three areas within the North Fork tidal delta where the direction of habitat trajectory is less certain.

1. The 6.2 ha polygon labeled ‘C’ is currently a barrier acting to turn a distributary channel’s flow westerly toward Ika Island. This area may become established marsh if adequate sedimentation

is maintained. However, future sedimentation to this area may be reduced due to the formation of the new distributary. The polygons labeled ‘C’ and ‘D’ (13.8 ha) are at risk of erosion due to sea level rise.

2. The 33.0 ha polygon labeled ‘E’ is new sediment deposition and is currently the high point at the mouth of the new distributary. It acts as a barrier by deflecting the new distributary’s flow south and slightly west – away from the bayfront. The sustainability of this barrier is uncertain. New sediment deposition may continue via the new distributary. If this is the case, the new distributary should lengthen and narrow while developing fringing marsh habitat along its flow path. Conversely, this barrier is exposed to longshore sediment transport processes in Skagit Bay, which may act to redistribute it down-drift (i.e., westerly) thereby deflecting the new distributary flow even more westerly. With this idea in mind, we looked at past North Fork tidal delta distributary patterns in the context of past marsh progradation (Figure 8). There appears a theme of distributaries making a right hand (westerly) turn at the marsh edge, possibly due to dominant longshore sediment movement patterns caused by strong winter southeast winds and/or prevailing tidal currents when water surface elevation is suitable for sediment transport. While we are uncertain of the new distributary’s future flow direction it seems unlikely – based on how other North Fork tidal delta distributaries evolved – to think the new distributary would ever flow easterly toward the bayfront.
3. The 14.6 ha polygon labeled ‘F’ (in Figure 7) is in the erosional path of the new distributary. It is along the ‘outside’ bend of the new distributary and may continue to erode if the new distributary continues to widen or as it ‘scrolls’ westward along its outside bend. The smaller distributary (Fishtown Slough, shown as black arrows in Figure 7) would be captured by the new distributary if erosion continues. Conversely, Fishtown Slough will become a blind channel system if erosion to this area stops.

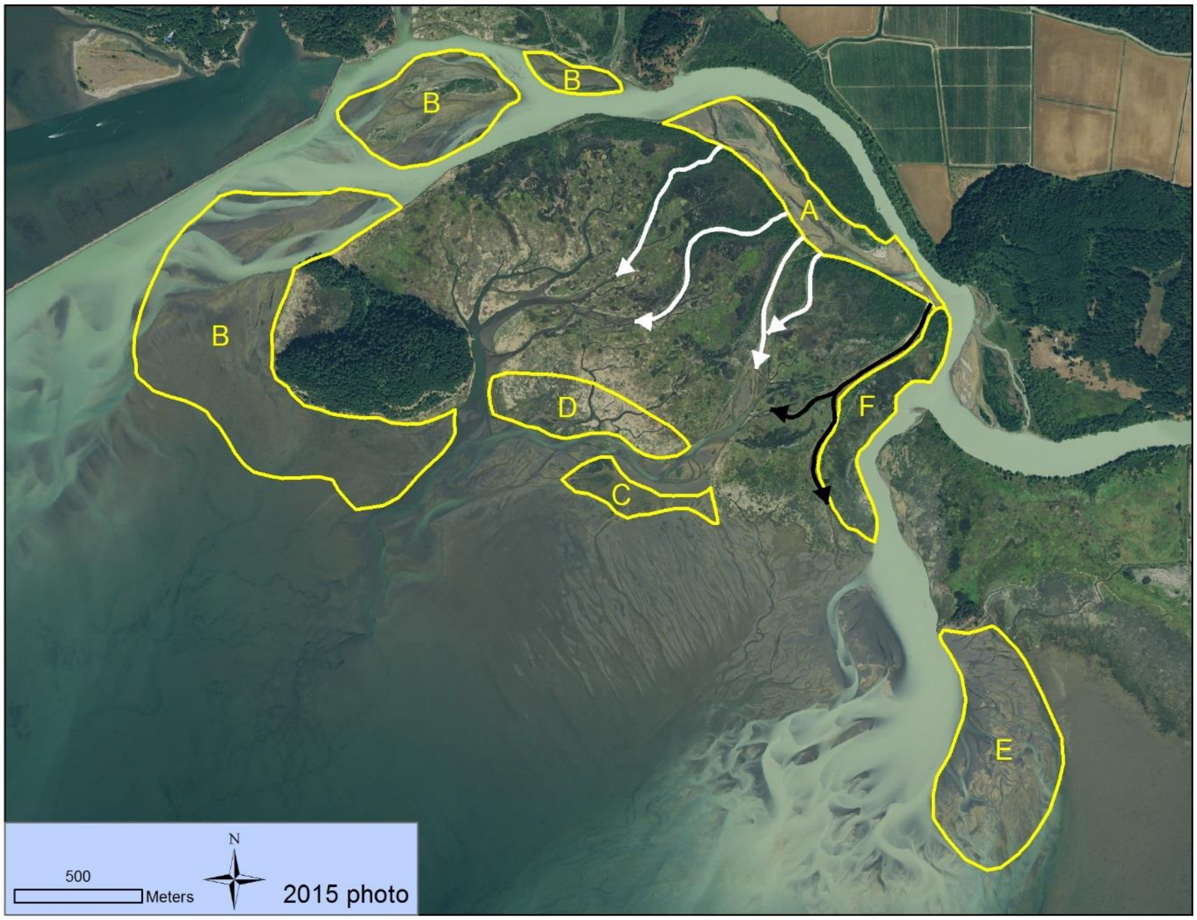


Figure 7. Locations in the North Fork tidal delta likely to change within the next 5-15 years. See text above for details.

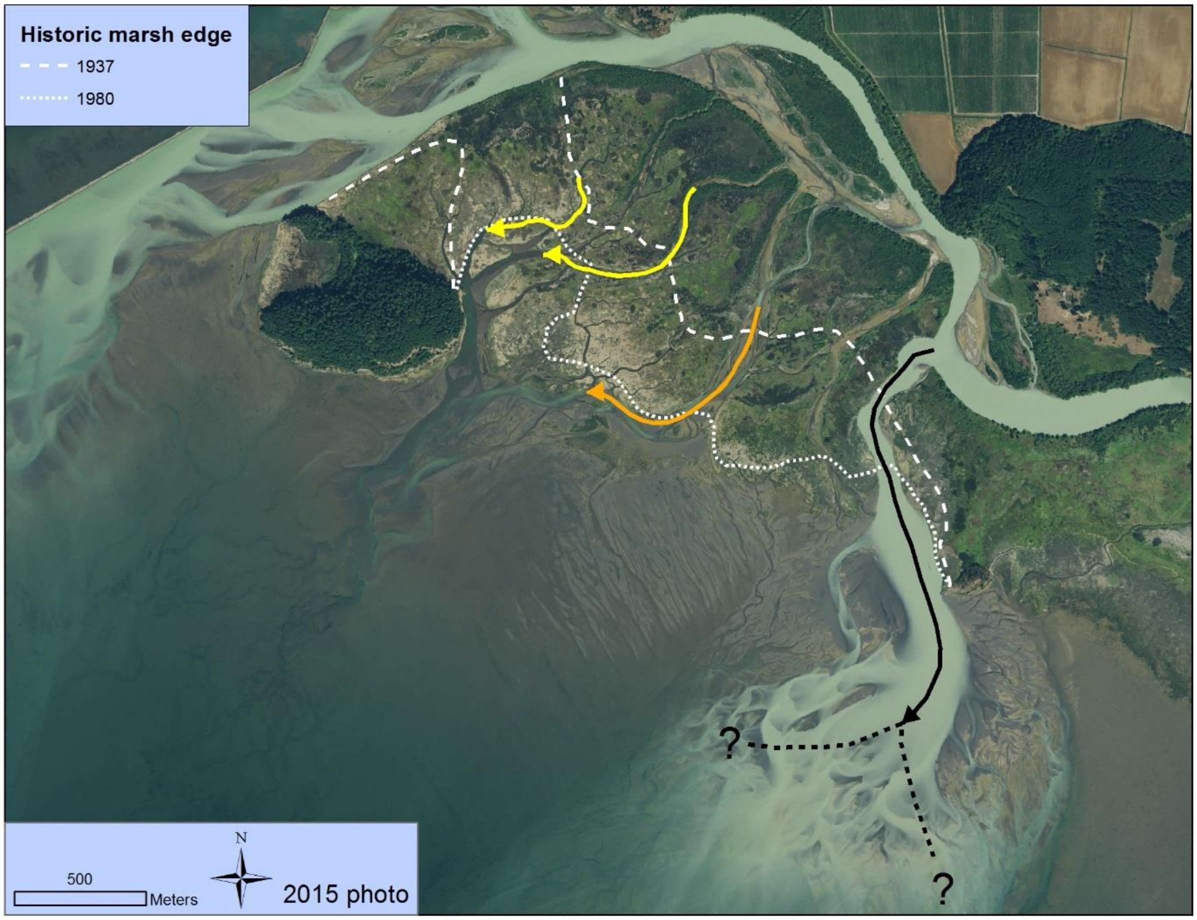


Figure 8. Past and current tidal marsh edge and distributary channel patterns in the North Fork tidal delta. The yellow and orange arrows show the right hand (westerly) turn of distributaries. The location of the right hand turns coincide with the lower edge of marshes during earlier periods. The yellow arrows represent distributaries where the right hand turns formed as marshes prograded between 1937 – 1980. The orange arrow represents a distributary where the right hand turn coincides with the 1980 marsh edge. The black arrow is the new distributary.

Conclusions

1. The new distributary is not a viable pathway to move juvenile Chinook from the North Fork Skagit River to bayfront habitat, at least not as far away as the Browns Slough area.
2. Because of the large width of the new distributary and its short length, juvenile Chinook that take the new distributary pathway are more likely to be exported to Skagit Bay nearshore compared to juvenile Chinook taking the pathway along the North Fork Skagit River.

Recommendation

We recommend continued monitoring of fish and habitat in the Skagit tidal delta. The formation of the new distributary is a proxy for restoration actions being proposed in the Skagit (e.g., Fir Island Cross-Island Connector in the Skagit Chinook Recovery Plan) and other Puget Sound estuaries. It will be important to document how habitat in the North Fork tidal delta forms because of the new distributary and the surrounding larger scale processes, and how juvenile Chinook respond to those changes.

The formation of the new distributary coincident to the ongoing Skagit IMW Program has provided a unique opportunity for a natural experiment using a very powerful BACI design. Ongoing Skagit IMW fish data collection and biannual orthophotos provide available data for continued monitoring. For a BACI design we are limited to data from sites before the new distributary formed. These are represented by the six sites used in this study. More years of data will likely be beneficial, especially for testing whether the new distributary is linked to decreased juvenile Chinook use for areas of the North Fork tidal delta downstream of the bifurcation of the new distributary.

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Appendix 1. Restoration extent within the South Fork Skagit tidal delta, 2002 – 2015

Appendix Table 1. Restoration extent in the South Fork Skagit tidal delta by project and year.

Restoration project	Year of first juvenile Chinook use	Channel & impoundment (ha)	Tidal wetland footprint (ha)	Reference/comments
Deepwater Sl	2001	8.100	93.659	from 2004 GIS
SF Dike Setback	2007	0.336	8.094	Beamer 2015 (habitat measured in 2011)
Milltown Is	2007	0.000	0.000	no net gain in channel or tidal wetland area per GIS layers for 2004 and 2011 (connectivity to existing habitat was improved)
Wiley Sl	2010	29.030	63.110	Beamer et al. 2015 (measured in 2011)
Fisher Sl	2012	0.567	18.575	Beamer et al. 2014

Appendix Table 2. Cumulative restoration extent in the South Fork Skagit tidal delta by year.

Year	channel & impoundment (ha)	tidal wetland footprint (ha)
2002	8.100	93.659
2003	8.100	93.659
2004	8.100	93.659
2005	8.100	93.659
2006	8.100	93.659
2007	8.436	101.753
2008	8.436	101.753
2009	8.436	101.753
2010	37.466	164.863
2011	37.466	164.863
2012	38.033	183.438
2013	38.033	183.438
2014	38.033	183.438
2015	38.033	183.438

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