Skagit River Estuary Intensively Monitored Watershed Annual Report

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Introduction

Chinook salmon are well known for utilizing natal river tidal deltas, non-natal pocket estuaries (nearshore lagoons and marshes), and other estuarine habitats for rearing during outmigration (Reimers 1973, Healey 1980, Beamer et al. 2003). 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 juvenile Chinook salmon. However, these necessarily coarse-scale studies do not address the potential for large-scale estuarine habitat restoration to benefit salmon population productivity and life history diversity.

Rather than adopt hypotheses regarding the importance of estuarine habitat to Chinook salmon populations from the limited studies conducted in other river systems, the Skagit co-managers developed and implemented a research plan to determine the role the Skagit estuary might play in recovering wild Skagit Chinook salmon. Results from the Skagit studies are summarized in Beamer et al. (2005) and include elements relating to: estuary habitat use by juvenile Chinook salmon, juvenile Chinook life history variation, estuary habitat loss, and Chinook marine survival by life history type. In summary, the research led to the following conclusions:

1. All six wild Skagit Chinook salmon stocks include delta rearing and fry migrant life history types in their populations. These life history types currently rear in Skagit delta and pocket estuary habitats.

2. Skagit delta and pocket estuary habitats are much smaller and more fragmented than historically. Therefore, rearing opportunity of estuarine rearing Chinook salmon has been greatly reduced. Restoration opportunities exist at both historic delta and pocket estuary sites.

3. At contemporary Chinook salmon population levels, current delta habitat conditions are limiting the number and size of juvenile Chinook salmon rearing in delta habitat. Otolith data indicate that delta residence is important for the success of juvenile Chinook salmon surviving later in their life cycle. Restoration of delta habitat should increase capacity for delta rearing Chinook salmon.

4. At contemporary Chinook salmon population levels, limitations in current delta habitat conditions are displacing juvenile Chinook salmon from delta habitat to Skagit Bay habitat and forcing a change in their life history type from delta rearing to fry migrants. Literature values show that fry migrant survival is much lower than for delta rearing individuals.

5. Some fry migratory Chinook salmon rear and take refuge in pocket estuaries. Restoration of pocket estuary habitat can be a strategy to partially mitigate delta density dependence and improve survival of naturally occurring fry migrants.

6. Differences in habitat connectivity influence juvenile Chinook salmon abundance in both delta and pocket estuary habitats, indicating that habitat fragmentation, in addition to habitat loss, has been detrimental to Skagit Chinook populations. Restoration of connectivity should be a component of Skagit Chinook salmon population recovery planning.

7. Large-scale climatic processes influence marine survival. In the past 30 years we have observed two different climate regimes; average marine survival between regimes has varied by a factor of three. Skagit Chinook salmon population recovery planning must consider possible shifts in marine survival and ensure population recovery is achieved under a variety of conditions, including the worst-case scenario.
Collectively, these conclusions suggest that wild Skagit Chinook salmon populations should benefit from estuarine habitat restoration (both delta estuary and pocket estuary habitat) and improved migration pathways within and between estuary habitats. In response to these results predictive tools were developed to estimate benefits of candidate restoration sites, thus linking potential estuary restoration with Skagit Chinook Salmon recovery goals. The research findings were incorporated into actions of the Skagit Chinook Recovery Plan (SRSC and WDFW 2005).

Moving forward in time, with adoption of the Skagit Chinook Recovery Plan in 2005 and its implementation in subsequent years, the previous research results (i.e., summarized in Beamer et al. 2005) become a valuable “before restoration” dataset for monitoring the response of Skagit River Chinook salmon to estuary restoration. The goal of the Skagit River Intensively Monitored Watershed (IMW) Project is to understand changes in population characteristics (primarily abundance, productivity, and life history diversity) of wild Chinook salmon in response to reconnection and restoration of estuarine habitat. To accomplish this goal, we are monitoring the Skagit River Chinook salmon population at four stages of their migration: the mainstem Skagit River near estuary entry, the tidal delta, nearshore, and offshore. These monitoring programs allow us to examine changes in body size, abundance, and life history variation as fish migrate out of the estuary. The long time series of monitoring data allows us to examine the effects of large restoration projects in the tidal delta, which commenced in 2000 and will continue in future years. Additional status and trends monitoring of adults returning to the Skagit River provides a further reference to evaluate whether the cumulative amount of restoration can improve production.

Our study plan and summary of results highlights the hypotheses, restoration projects, methodologies, and results of the Skagit system-wide monitoring. In doing so, we address how our methodologies are answering two general questions relevant to monitoring the population response of Chinook salmon to estuary restoration:

1) do salmon exhibit limitations during estuarine life stages related to capacity and connectivity, and
2) has estuary restoration resulted in population- or system-level responses?

An additional question – do restoration projects increase utilization of estuary habitat by juvenile salmon – is encompassed in project effectiveness monitoring at smaller spatial scales. Effectiveness monitoring is not funded through the Skagit IMW and depends upon funding within restoration project budgets. These results were reported in the 2015 Study Plan.

The Skagit study team includes scientists from the Skagit River Systems Cooperative, NOAA’s Northwest Fisheries Science Center, Washington Department of Fish and Wildlife.

Study area
The Skagit River estuary is part of the larger Puget Sound fjord estuary, and consists of a mosaic of habitats with a tidal delta and its adjacent more marine bay, Skagit Bay (Fig. 1). Estuarine study sites consist of blind tidal channels within the Skagit River tidal delta, and shoreline and nearshore (subtidal neritic) areas of Skagit Bay.

The Skagit River tidal delta is a prograding fan with numerous distributary channels and estuarine wetland islands. Estuarine habitats within the tidal delta include two zones. The riverine tidal zone is the area of river channels and wetlands where freshwater is tidally pushed but not mixed with marine water. The tidal estuarine zone includes the channeled emergent and scrub-shrub marshes where freshwater mixes with salt water. Within these areas a diversity of estuarine habitats are formed and maintained by tidal and
riverine processes, creating a mosaic of wetlands and channels. These include blind tidal channels, which serve as our fish sampling units within the tidal delta.

The shoreline of Skagit Bay is 127.4 kilometers in length and its intertidal area is 8,838 hectares. Skagit Bay shorelines include a variety of beach types based on differences in adjacent upland geologic materials (bedrock, glacial sediments, and recent coastal or river sediments), geomorphic processes within longshore drift cells, and the gradient of the shoreline. The beaches that dominate much of Skagit Bay are the sampling units for this study. In addition, subtidal surface (neritic) waters offshore of intertidal areas comprise the sampling locations for the final phase of population monitoring before fish migrate out of Skagit Bay.

Landscape analyses indicate that the Skagit River has lost much estuarine habitat to agricultural and residential development, despite a large amount of extant tidal delta and shoreline habitat. Under present day conditions, the contiguous habitat area of the Skagit tidal delta consists mostly of area in the vicinity of Fir Island, but it also includes a fringe of estuarine habitat extending from southern Padilla Bay to the north end of Camano Island. In 1991 the tidal delta footprint for this area was 3,118 hectares (Beamer et al. 2005). Prior to diking, dredging, and filling in the delta (circa 1860s) 11,483 hectares of tidal delta footprint existed in the same area (Collins et al. 2003), indicating that 73% of tidal delta has been disconnected from floodplain and tidal processes. These estimates of tidal delta habitat area account for gains in delta habitat caused by progradation occurring between the 1860s and 1991 (Beamer et al. 2005) and indirect losses of habitat occurring as a result of changed tidal processes and sediment deposition (Hood 2004). In Skagit Bay, 24% of the shoreline has been armored to protect land uses adjacent to accretion shoreforms or eroding sediment source bluffs (Mcbride et al. 2006).

Figure 1. The Skagit River estuary, showing potential restoration areas and actions (i.e., restoration projects) that were evaluated in the Skagit Chinook Recovery Plan (SRSC and WDFW 2005). Many of these actions have
occurred during the course of the Skagit IMW Project. The potential restoration area is the historic estuary footprint from Collins et al. (2003).
Skagit Chinook salmon juvenile life history types

Chinook salmon are described as the most estuarine-dependent of all the Pacific salmon and well-known for their life history variation (Reimers 1973, Healey 1980, Greene & Beechie 2004). These life history types can be distinguished based on differences in body size and the seasonal timing that fish transition from one habitat zone to another.

Existing research and long-term monitoring in the Skagit River suggests that five life history types comprise most of the juvenile life history variation of Chinook salmon (Table 1, Figure 2). The distinct juvenile life history types of Skagit Chinook salmon occur based on branching by juvenile Chinook patterns (i.e., does the fish remain or migrate) within three main ecological zones (freshwater, natal estuary, and marine nearshore). Branching occurs in each zone, resulting in five distinct juvenile life history types (Figure 2). The ecological zones correspond to distinct geographic areas: 1) freshwater = Skagit River and its tributaries; 2) natal estuary = Skagit tidal delta; and 3) marine nearshore = Whidbey Basin. Simply explained (and diagramed in Figure 2), each year cohorts of Chinook salmon fry emerge from their gravel egg pockets in the Skagit River and its tributaries during the winter and early spring months. Some fry migrate downstream without doing any appreciable rearing in the freshwater environment. Fry remaining in freshwater branch into two main life history types after an extended freshwater residence period. Some fish remain in freshwater for a few months and migrate downstream as parr, while others remain in the freshwater environment for over a year and migrate the following spring as yearlings. Of the fry that migrate downstream, some establish residence in the Skagit’s natal estuary for a period of time while others migrate into the more marine waters of Skagit Bay, part of the Whidbey Basin. Of the fry that end up in the Whidbey Basin, some establish residence in nearshore refuge habitats (e.g., non-natal estuaries and creek mouths) while others do not.

In recent years (brood years 1993 – 2008), one million to over seven million wild juvenile Chinook salmon have migrated from the Skagit River each year (Zimmerman et al. 2015). In each migration we observe all juvenile life history types. Below we describe the relationship of each life history type to the Skagit tidal delta.

**Fry Migrants:** Fry migrants move through the tidal delta without rearing there. Once in the marine nearshore environment, some fry migrants exhibit extensive rearing in non-natal estuaries (Beamer et al. 2003; Beamer et al. 2006a) and creek mouths (Beamer et al. 2013) in Skagit Bay and elsewhere in the Whidbey Basin while other fry migrants do not. Thus, we characterize fry migrants in the nearshore as two different life history types: a) those that use nearshore refuge habitats, and b) those that do not use nearshore refuge habitats. Baseline monitoring in the Skagit River and elsewhere (Reimers 1973) suggests that large fry migrant pulses are the outcome of density-dependent interactions in the tidal delta and river, and could be alleviated by restoration in the tidal delta (Beamer et al. 2005). While fry migrants are present in the Skagit’s outmigration population each year, their abundance appears to be a phenotypic response to density dependence occurring first in freshwater (Zimmerman et al. 2015) and later in estuarine habitat of the Skagit River system (Beamer et al. reviewed). Depending on the total outmigration population size, all fry migrants make up approximately 5% to over 40% of the juvenile Chinook salmon in Skagit Bay each year (Beamer et al. reviewed).

**Delta Fry:** Delta fry are by definition associated with the tidal delta, and rear there for a period of 0.5 – 2 months. The average tidal delta residence period for these Chinook salmon in 1995 and 1996 (combined) was 34.2 days (Beamer et al. 2000). Following the tidal delta rearing period, these fish migrate to Skagit Bay, usually starting in late May or June. We observe a tidal delta rearing region on their otolith. Beamer & Larsen (2004) further defined several life history sub-strategies for tidal delta rearing Chinook salmon based on movement patterns and overall residence period within the tidal delta. The number of tidal delta...
rearing migrants each year is a function of the river’s outmigration fry population size and density dependence occurring in estuary habitat (Beamer et al. reviewed). As tidal delta habitat fills up with migrating fry from upstream, the excess fry respond by moving downstream into the Skagit Bay. Beamer et al. (2005) estimated tidal delta rearing capacity at 2.25 million juvenile Chinook per year.

**Parr Migrants:** Parr migrants do not extensively reside in tidal delta habitats. We observe an extended freshwater rearing region and no tidal delta rearing region on their otolith (Beamer et al. 2000). Depending on the total outmigration population size, parr migrants make up approximately 15% to over 60% of the subyearling outmigration each year (Zimmerman et al. 2015). Parr migrant abundance has averaged approximately 1.2 million per year and is a result of density dependence occurring in the freshwater rearing environment (Zimmerman et al. 2015).

**Yearlings:** Yearlings do not reside in tidal delta habitats for an extended period of time. Yearlings seem to pass through tidal delta habitats (possibly lingering briefly) and move on to nearshore areas. Yearlings are rarely found in shallow intertidal environments, but are most commonly detected in deeper subtidal or offshore habitats. Yearling outmigration abundance has ranged from 6,000 to 97,000 in recent years (Zimmerman et al. 2015).
Figure 2. Phenotypic branching of juvenile Skagit Chinook salmon by major ecological zones, resulting in five distinct juvenile life history types.

Table 1. Size and timing of juvenile Chinook salmon migrants by life history type at the transition from freshwater to estuary and estuary to nearshore. “na” = not applicable (i.e., the condition does not occur).

<table>
<thead>
<tr>
<th>Size characteristics</th>
<th>Subyearlings</th>
<th>Yearling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delta fry</td>
<td>Fry migrant</td>
</tr>
<tr>
<td>Size at outmigration from freshwater to (or through) estuary (mm)</td>
<td>&lt; 45</td>
<td>&lt; 45</td>
</tr>
<tr>
<td>Size at outmigration from estuary to nearshore (average and range in mm)</td>
<td>74 (46-124)</td>
<td>39 (30-46)</td>
</tr>
<tr>
<td>Size at outmigration from nearshore refuge habitat to open water (average and range in mm)</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Timing characteristics</td>
<td>Jan-Apr</td>
<td>Jan-Apr</td>
</tr>
<tr>
<td>Timing at outmigration from estuary to nearshore (months inclusive)</td>
<td>Apr-Aug</td>
<td>Jan-Apr</td>
</tr>
<tr>
<td>Timing at outmigration from nearshore refuge habitat to open water (months inclusive)</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>
Hypotheses about system-wide effects of estuary restoration

The research results (i.e., summarized in Beamer et al. 2005) are our “before restoration” dataset for monitoring the response of Skagit River Chinook salmon to estuary restoration. These results strongly suggest that restricted availability and connectivity of habitat in the tidal delta is limiting rearing opportunities for subyearling fry migrating downstream. We found four general patterns prior to restoration: an asymptoting level of population density in the tidal delta at high fry outmigration population sizes (Fig. 3A); negative relationships between tidal delta population and both body size (Fig. 3B) and the timing at which 50% of the tidal delta abundance is observed (Fig. 3C); and increases in abundance of fry migrants in the nearshore as a function of the number of fry migrants (Fig. 3D). If these patterns are the consequences of habitat limitations in the tidal delta, we predict that restoration should:

- reduce the rearing density at a given level of outmigration abundance (i.e., fish can spread out to a greater degree in estuarine habitats);
- increase size of outmigrants as they leave the tidal delta due to greater per capita resource availability;
- increase duration of individual residency in the tidal delta, thereby leading to a protracted pattern of cohort-level timing in the delta (e.g., the date that 50% of the cohort is observed);
- reduce the abundance of fry migrants in the nearshore due increased rearing capacity in the delta;
- increase marine survival and hence the rate of adult return as a consequence of better individual condition as predicted by previous hypotheses.

These predictions are expected to play out in spatially-predictable ways. We developed spatially-based hypotheses by considering how current delta habitat is being utilized by juvenile Chinook salmon (Fig. 4A) and then hypothesizing how juvenile Chinook salmon would respond to planned delta restoration (Fig. 4B). In these figures, the arrow directions depict how juvenile Chinook salmon move through delta habitat and into Skagit Bay. The pathways within the delta are based on where delta distributary channels are located or planned to be restored. The pathways for fish moving from delta habitat to Skagit Bay were derived from drift buoy data. Arrow thickness represents the number of juvenile Chinook salmon using each pathway based on the current or restored habitat amount and configuration. Figure 4B shows planned restoration areas in pink. Because of limitations in the migratory pathways that fish can take within delta habitat, we expect subsets of delta habitat to respond to delta restoration in similar ways. We do not expect the entire delta will respond to specific restoration projects in a homogeneous fashion. The sub-delta areas that we do expect to respond similarly are numbered and circled in Figure 4B.

Monitoring hypotheses are stated for each area in Table 2. All monitoring hypotheses are interpreted as functions to account for varying outmigration population sizes, habitat conditions (e.g. channels with deep areas with low tide impoundments v. channels without these features), and environment (e.g., floods, temperature, salinity).
Figure 3. Biological relationships pointing to rearing habitat limitations in the Skagit tidal delta prior to restoration: A) the cumulative density (summed density over multiple sampling weeks) of fry rearing in the tidal delta flattens as a function of fry migrating downstream; B) the size of fish rearing in the tidal delta in May declines as a function of cumulative density in the tidal delta; C) the proportion of fry migrants captured along the shoreline of Skagit Bay increases as a function of outmigrant fry; and D) the timing of residency in the tidal delta declines as a function of fish rearing in the tidal delta. From Beamer et al. reviewed.
Figure 4A. Current juvenile Chinook salmon pathways in the Skagit River estuary before restoration. The arrow directions depict how fish move through the tidal delta and into Skagit Bay. Arrow thickness represents the number of Chinook salmon following these pathways under current conditions.

Figure 4B. Future juvenile Chinook salmon pathways in the Skagit River estuary after restoration. The arrow directions depict how fish move through the tidal delta and into Skagit Bay. Arrow thickness represents the number of Chinook salmon following these pathways, based on restored habitat area and connectivity. Conceptual habitat restoration areas are shown in pink. Subsets of delta habitat that are expected to respond in similar ways are circled and numbered. Monitoring hypotheses for each area are in Table 2.
Table 2. Draft monitoring hypotheses for juvenile Chinook salmon abundance in sub-delta polygons shown in Figure 4B.

<table>
<thead>
<tr>
<th>Sub-delta polygon #, name</th>
<th>Pre-restoration tidal footprint (acres)</th>
<th>Restoration potential (acres)</th>
<th>Juvenile Chinook response pre-restoration</th>
<th>Juvenile Chinook response post-restoration</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Swinomish Channel Corridor</td>
<td>520</td>
<td>770</td>
<td>Density lowest of all sub-delta polygons</td>
<td>Overall average density increases and between-site densities become less variable due to increased connectivity with the North Fork</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Population increases due to increased capacity along the Swinomish Channel Corridor</td>
</tr>
<tr>
<td>#2 North Fork Delta</td>
<td>1,926</td>
<td>980</td>
<td>Density highest of all sub-delta polygons</td>
<td>Overall average density decreases and between-site densities become less variable due to increased connectivity to other areas within the delta</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Population increases due to increased capacity within the North Fork Delta</td>
</tr>
<tr>
<td>#3 Central Fir Island Delta</td>
<td>928</td>
<td>470</td>
<td>Density is 3rd highest of all sub-delta polygons</td>
<td>Overall average density increases and between-site densities become less variable due to increased connectivity via a cross island corridor restoration project</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Population increases due to restored capacity within Central Fir Island</td>
</tr>
<tr>
<td>#4 South Fork Delta</td>
<td>3,902</td>
<td>630</td>
<td>Density is second highest of all sub-delta polygons</td>
<td>Density remains the same but between-site densities become less variable due to increased connectivity within the South Fork Delta</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Population increases due to increased capacity within the South Fork Delta</td>
</tr>
<tr>
<td>#5 Stanwood/English Boom Delta Fringe</td>
<td>1,056</td>
<td>None currently identified</td>
<td>Density lowest of all sub-delta polygons</td>
<td>Density and population increases due to increased source population increase originating from Stillaguamish and Skagit Rivers</td>
</tr>
</tbody>
</table>
Table 3. Restoration projects completed or planned in the Skagit River estuary, dates, benefit to salmon, and their acreage (area exposed to tidal inundation after restoration). Monitoring designs are: PT = post treatment design; BACI = before/after control impact design.

<table>
<thead>
<tr>
<th>Site</th>
<th>Year of completion</th>
<th>Benefit to salmon (connectivity, capacity, or both)</th>
<th>Area of estuary</th>
<th>Acres</th>
<th>Effectiveness monitoring design and years monitored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deepwater Slough</td>
<td>2000</td>
<td>Both</td>
<td>South Fork</td>
<td>221</td>
<td>PT, 2001-2003</td>
</tr>
<tr>
<td>Milltown Island</td>
<td>2006-7</td>
<td>Capacity</td>
<td>South Fork</td>
<td>212</td>
<td>PT, 2012-2013</td>
</tr>
<tr>
<td>South Fork Dike Setback</td>
<td>2007</td>
<td>Capacity</td>
<td>South Fork</td>
<td>40</td>
<td>PT, 2012, 2014</td>
</tr>
<tr>
<td>Swinomish Ch Fill Removal</td>
<td>2008</td>
<td>Capacity</td>
<td>Swinomish Channel</td>
<td>12</td>
<td>PT, 2009-2013</td>
</tr>
<tr>
<td>Cottonwood Island</td>
<td>&lt;5 years</td>
<td>Capacity</td>
<td>South Fork</td>
<td>169</td>
<td>Planned BACI, 2012</td>
</tr>
<tr>
<td>McGlinn Island Causeway</td>
<td>&lt;5 years</td>
<td>Connectivity</td>
<td>North Fork-Swinomish Channel</td>
<td>10</td>
<td>Planned BACI, 2005-present</td>
</tr>
<tr>
<td>Fir Island Farms</td>
<td>&lt;5 years</td>
<td>Capacity</td>
<td>Central Fir Island</td>
<td>130</td>
<td>Planned BACI, 2015-present</td>
</tr>
<tr>
<td>Deepwater Phase II</td>
<td>&lt;5 years</td>
<td>Capacity</td>
<td>South Fork</td>
<td>268</td>
<td>Not designed</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>1334</td>
<td></td>
</tr>
</tbody>
</table>

**Amount of estuary restoration**

Given the reliance of juvenile subyearling Chinook salmon on estuary habitat and the amount of historical habitat loss, we would expect estuary restoration to benefit Skagit River Chinook populations. Starting in 2000, there has been a systematic effort to restore estuary habitat (Table 3), resulting in seven completed projects and over 750 acres of habitat restored. Within the next five years, four additional restoration projects are anticipated to be completed, totaling 577 acres. Restoration includes improvements to capacity (amount of rearing habitat), connectivity (connection among rearing areas), or both. These efforts (i.e., constructed and anticipated projects) fulfill about 20% of the estuary restoration goal of increased juvenile Chinook carrying capacity described in the Skagit Chinook Recovery Plan (Beamer et al. 2005). Restoration in the estuary has been performed within the context of an overall portfolio of Chinook salmon recovery actions that also include habitat protection and restoration in tributary, floodplain, and nearshore habitats.

The Skagit IMW Project does not monitor the response of Chinook salmon to restoration projects occurring within freshwater habitats located upstream of the estuary, but it does account for their influence and natural environmental variation (e.g., floods) that influence juvenile Chinook migrants. This is done by maintaining the downstream migrant trap, which measures migrant population abundance, timing, and body size by life history type.
**Methods**

Survey methods and effort

We are currently monitoring Skagit River Chinook salmon via a long-term interagency program involving sampling of outmigrants at Mount Vernon (Washington Department of Fish and Wildlife, WDFW), fyke trapping of fish rearing in the tidal delta (Skagit River System Cooperative, SRSC), beach seining of nearshore habitats in Skagit Bay (SRSC), and townetting of offshore areas in Skagit Bay (Northwest Fisheries Science Center, NWFSC). This program provides us the capability for a system-wide analysis of patterns of juvenile abundance and life history diversity across the migration season. These data are collected within the overall framework of Skagit Chinook status and trends monitoring where over 60 indicators related to viable salmon population (VSP) parameters are measured (or estimated) for 12 different life stages of the Chinook salmon life cycle (Appendix 1). The Skagit IMW Project is responsible for measuring 27 indicators spanning five life stages from juveniles outmigrating the river to juveniles transitioning to offshore waters of the Salish Sea. We use differing levels of survey effort for the three main types of sampling in the Skagit River estuary. Table 4 summarizes the number of sites, frequency, and duration of sampling.

**Table 4.** Current monitoring programs for assessing effects of restoration in the Skagit River estuary.

<table>
<thead>
<tr>
<th>Method</th>
<th>Lead entity</th>
<th>Habitat</th>
<th>Sampling regime</th>
<th># of sites</th>
<th># of years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outmigrant trapping</td>
<td>WDFW</td>
<td>Mainstem</td>
<td>Daily, Feb-Jul</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>Fyke trapping*</td>
<td>SRSC</td>
<td>Tidal delta &amp; Swinomish Channel</td>
<td>Biweekly, Feb-July; monthly in August</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>Beach seining*</td>
<td>SRSC</td>
<td>Skagit Bay shore &amp; Swinomish Channel</td>
<td>Biweekly, Feb-Aug; monthly, Sept-Oct</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>Kodiak trawling*</td>
<td>NWFSC</td>
<td>Skagit Bay neritic</td>
<td>Monthly, Apr-Oct</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

*Partially supported by SRFB/IMW funding.

**Outmigrant trapping.** WDFW operates a juvenile fish trap on the Skagit River at river km 39.1 in the city of Mount Vernon. Operation of this trap began in 1990 for the purpose of estimating coho smolt production. The focus of this trapping operation has expanded over time and now provides an estimate of the number of juvenile wild Chinook salmon emigrating from the entire Skagit Basin (Zimmerman et al. 2015). The juvenile trap is operated each year from mid-January through July. This time frame was selected based on results from three extended trapping seasons conducted in the mid-1990s. The freshwater juvenile monitoring provides both abundance and life history data and includes juvenile migrant abundance by migrant type (fry, parr, yearling), juvenile body size, migration timing, and genetic sampling (details in Kinsel et al. 2007). The trap is actually two traps, an inclined plane and a screw trap. The rectangular inclined plane trap (1.8 x 4.9m) is fished by lowering the trap approximately a meter into the water at an oblique angle; the trap then catches fish swimming in a 2m² cross-sectional area near the surface of the water by forcing them onto the inclined plane and washing them into a collection box. The screw trap (2.5m circular diameter) is fished by lowering it partially into the water. Fish swim downstream into the 2.35m² cross-sectional entryway of the trap, and the rotation of plates within the trap forces fish into a collection box. The juvenile trap catches only a portion of the total juvenile Chinook emigrating from the Skagit River. Therefore, total abundance is estimated using a mark-recapture study design in order to expand the catch by a calibration factor (Zimmerman et al. 2015). Missed catch is estimated during trap outages and is included in the final estimate. During the emigration period, a known number of marked fish (dye or fin-clip) are released upstream of the trap and a portion of these are recaptured in the trap. Releases of marked fish are conducted throughout the outmigration period in order to account for differences in trap efficiencies due to river conditions. The resulting trap efficiency data is applied to catch data in order to estimate total migrant abundance (details in Zimmerman et al. 2015).
**Fyke trapping Skagit tidal delta.** To measure abundance of juvenile Chinook salmon rearing in the tidal delta, we sample habitat use of unmarked subyearling Chinook salmon in blind channels using fyke traps. Fyke trap methodology follows Levy & Northcote (1982) and uses nets constructed of 0.3cm mesh knotless nylon with a 0.6m by 2.7m diameter cone sewn into the net to collect fish draining out of the blind channel site. Nets feature a lead line that sinks the bottom of the net to the benthos and a float line that maintains the top of the net at the water surface. Overall net dimensions (length and depth) vary depending on the blind channel’s cross-sectional dimensions, but all nets are sized to completely block fish access at high tide.

We capture fish by setting a fyke trap across the mouth of the blind channel site at high tide and “fish” through the ebbing tide. Fish are captured as they move out of the dewatering channel. We sample twice a month over the period (February through August) during the spring tide series at index sites. The effort started with four index sites in 1992 and expanded to six in 1995. Index sites were selected to represent the three estuarine wetland zones (estuarine emergent, estuarine scrub-shrub, and riverine tidal) present within the Skagit delta and the two major delta rearing areas for subyearling Chinook associated with the Skagit River’s two dominant distributaries, the north and south forks.

Juvenile Chinook salmon catch are adjusted by trap recovery efficiency (RE) estimates derived from multiple mark-recapture experiments using a known number of marked fish released upstream of the trap at high tide. Recovery efficiency estimates are unique to each site and are related to hydraulic characteristics of the site during trapping (e.g., change in water surface elevation during trapping or water surface elevation at the end of trapping). We conduct five to eight different mark and recapture tests at each site to either calculate an average RE at the site or develop a regression model to convert the “raw” juvenile Chinook catch to an estimated population within the habitat upstream of the fyke trap on any sampling day. Average RE for the six fyke trap sites ranges from 29-57%. The RE adjusted Chinook catch is divided by the topwidth channel area of the blind channel network upstream of the trap to calculate a juvenile Chinook density for each fyke trap set. Topwidth channel area is measured in the field.

**Beach seining Skagit Bay shoreline.** To measure density of unmarked Chinook salmon rearing along shoreline habitats, we use beach seining techniques. Our beach seine is a 37m by 3.7m by 0.3cm mesh knotless nylon net. The net is deployed by fixing one end of the net on the beach and the other on a boat, which sets the net across the current and returns the net to the beach at a distance of approximately 60% of the net’s length. After the set is held open against the tidal current for a period of a few minutes, the boat end is brought to the shoreline edge and both ends are retrieved, yielding a catch in the net’s bunt section. We make three sets per site on each sampling day. Beach seine set area varies by site and sample day because tow times, set widths, and tidal current velocities moving past the site all vary dynamically. Tow time, set width and water surface velocity are measured for each beach seine set in order to calculate a set area. The juvenile Chinook catch for each set is adjusted by set area to calculate a Chinook density for each beach seine set. Average set area for the six large net beach seine sites in Skagit Bay is 486 square meters.

We conducted 34 mark-recapture tests to estimate RE for beach seine methods. Marked fish were introduced to the seined area in 2 groups: 1) just before setting the net, and 2) just prior to closing the net and retrieving it to shore. Overall RE for the six beach seine sites was consistently high, averaging 84.5% (±10.1% C.I.).

**Kodiak trawling Skagit Bay subtidal neritic areas.** We sample subtidal neritic (surface and subsurface) areas of Skagit Bay using a 3.1m high x 6.1m wide Kodiak surface trawl, or “townet,” deployed between two boats, each with a 15.2m towline connected to a bridle on the net (see Rice et al. 2011). Mesh sizes
in the net were 7.6 cm stretch in the forward section, 3.8 cm and 1.9 cm in the middle sections, and 0.6 cm in the codend. The primary vessel (13.7 m long, 174 hp inboard diesel) tows the left side of the net while trawling, and the second vessel (5.5 m long, 225 hp gasoline outboard) tows the right side. The net is towed at the surface for 10 minutes per tow, at 900-1000 rotations per minute (RPM) on the engine of the primary vessel and a typical towing speed of 2-3 knots through the water. Distance through the water is recorded with a mechanical flow meter deployed by the larger vessel. Area swept is calculated as the distance traveled through the water multiplied by the width of the net opening.

Adult returns. The long duration of status monitoring in the Skagit watershed will provide opportunities to relate various outmigrant metrics to adult returns of Chinook salmon (Greene et al. 2005), measured at index sites on spawning grounds by tribes and WDFW. Age data, derived from scales collected from carcasses on the spawning grounds and test fisheries, allow the reconstruction of annual abundance estimates into productivity ratios (recruits per spawner) organized by spawning cohort (i.e., brood year). These rates of return include estimates of terminal harvest. We currently have 18 complete cohorts with which to examine whether the benefits of estuary restoration can be detected at adult stages, but only 10 of these spawned after the initiation of restoration in 2000.

Indicators measured

Fish abundance and density. Measures of abundance vary for each life stage. WDFW estimates the total number of juvenile outmigrants. In the Skagit tidal delta, Skagit Bay shoreline, and Skagit Bay neritic habitats, we use two indices of abundance: density and cumulative density. Both measures encompass the entire utilization curves of juvenile Chinook salmon in each habitat. Density is measured as the average density of juvenile Chinook salmon across index sites and rearing months. Cumulative density is a measure of the abundance of juvenile Chinook salmon that occupy a per unit area of either tidal delta or shoreline habitat over the entire rearing period. Cumulative Chinook salmon density is estimated for the period February through August for tidal delta blind channel habitat (a period of over 200 days), and February through October for shoreline habitat (a period of over 270 days). Cumulative density (fish*days*ha^{-1}) is calculated as

\[
C = \sum_{m=F}^{L} D_m n_m 
\]

Eq. 1

where \( D_m \) is the average monthly density, \( n_m \) is the number of days in the month, and \( F \) and \( L \) is the first and last month (\( m \)) sampled, respectively.

Fish length. Outmigrants are measured at all stages for body size (fork length in mm), which is used in combination with capture date and region to describe and enumerate life history types. Change in size is also a potential outcome of restoration, and we used cohort-level estimates of size calculated by averages of log-transformed data and weighted by the abundance of fish captured in sampling events.

Migrant timing. We produce an annual measure of migrant timing at each stage of sampling by calculating the Julian day at which 50% of the cumulative abundance is reached.

Results to date

Local effects of restoration

All seven built restoration projects (Table 3) have been monitored for juvenile Chinook use within the restored area for at least two seasons. The effectiveness monitoring results offer some important insights into which restoration strategies offer the greatest potential for improving utilization of restored estuarine habitat by juvenile Chinook salmon. Below we summarize the findings:
If you build it, they will come. All monitored projects in all years after restoration found juvenile Chinook using the restored habitat consistent with the timing curve of juvenile Chinook salmon in reference sites (See Study Plan).

Some restoration designs work better than others for fish. Projects using dike setback, dike breach, or fill removal had juvenile Chinook densities within the restored area consistent with the levels in nearby reference sites. Projects using self-regulating tidegates (SRTs) had much lower juvenile Chinook densities than nearby reference sites (Greene et al 2012). Self-regulating tidegates were better for juvenile Chinook salmon than the traditional flapgate they often replace (by approximately double), but SRTs averaged an order of magnitude lower in juvenile Chinook density compared to nearby reference sites. One combination project, at Fisher Slough (dike setback with floodgate replacement) performed well (Beamer et al 2014). We detected an order of magnitude (10-fold) increase in habitat use by juvenile Chinook salmon in Fisher Slough upstream of the floodgate, consistent with habitat use observed at other reference sites throughout the Skagit tidal delta. This increase is predominantly associated with the dike setback and current operation of the floodgate to allow fish passage during both slack and flood stages of the tide cycle.

Individual projects are contributing to estuary restoration goal. Where juvenile Chinook abundance has been quantified and compared to habitat-based juvenile Chinook carrying capacity estimates for restored areas (Fisher Slough, Wiley Slough), the built restoration projects have performed better than the conceptual projects described in the Skagit Chinook Recovery Plan. At Fisher Slough, the combination of dike setback and current floodgate operation translated to an increase in the smolt carrying capacity of Fisher Slough by nearly 22,000 estuary rearing Chinook salmon smolts per year based on two years of monitoring after dike setback (Beamer et al. 2014). The Skagit Chinook Recovery Plan estimate for the Fisher Slough Restoration Project was slightly over 16,400 smolts per year. At Wiley Slough, dike setback restoration translated to an increase in the smolt carrying capacity of over 70,000 estuary rearing Chinook salmon smolts per year based on two years of monitoring after dike setback (Beamer et al. 2015). The Skagit Chinook Recovery Plan estimate for the Wiley Slough Restoration Project was under 39,000 smolts per year.

System-level effects of restoration
Between 2000 and 2012, nearly 290 hectares were restored to tidal inundation in the Skagit River South Fork but no restoration occurred in the North Fork, providing the basis to rigorously test for restoration effects using a paired BACI study design. We have examined three juvenile Chinook salmon metrics measured within the tidal delta: average density, timing of residence within the tidal delta (relative to timing at WDFW’s trap), and average body length (Figure 5). To visualize effects of restoration, we graphed annual measurements as detected in the North Fork and South Fork, and focused first on the relationship of these characteristics before restoration. As restoration has accumulated over time, we would expect measurements to depart farther from the pre-restoration relationship. Hence, the effects of restoration can be represented as the difference between the post-restoration data and the pre-restoration regression line.

Following our prediction that added habitat from restoration should allow fish to redistribute at lower densities, average density in the South Fork of the tidal delta dropped relative to density in the North Fork after restoration was initiated (Figure 5A). Successive restoration efforts had a cumulative effect on reducing density ($R^2 = 0.26$, $p < 0.05$), which is understated in Figure 5B due to the log-transformation.
The added capacity translated into approximately 690 daily residents per restored hectare at high outmigrations.

We also predicted that added capacity would result in longer individual residency, which would increase the timing of abundance. We calculated a cohort-based index of residency within the tidal delta by subtracting the Julian day at which 50% of the cumulative catch was observed within the tidal delta from that day observed at WDFW’s trap at Mount Vernon. Prior to restoration, this value was not highly correlated in the North and South Forks, and successive restoration efforts increased residency in the South Fork relative to that measured in the North Fork (Figure 5C). Residency significantly increased as a function of restoration (R^2 = 0.25, p < 0.05, Figure 5D), such that a 200ha restoration effort would result in an average increase in cohort residency of 15 days within the tidal delta.

We found little support that habitat restoration resulted in increases in the average length of tidal delta residents measured over the course of the rearing season. Average length was highly correlated between North and South Forks, and it appeared to decline in post-restoration years (Figure 5E) by 2-5mm. However, overall declines did not strongly depend upon the amount of restoration (Figure 5F), suggesting other possible causes for declines in size (e.g. environmental covariates not incorporated into analysis of size, reduced growth at earlier life stages).

We tested three additional predictions of restoration benefits occurring subsequent to residence in the tidal delta. Because mobile fish captured outside of the tidal delta could not be tracked to a North or South Fork pathway, these comparisons could not benefit from the paired study design. We examined effects of cumulative restoration in a regression context, but note that any patterns we observed could be explained by other temporally varying factors in addition to cumulative restoration.

The first prediction, that tidal delta restoration results in protracted residency in estuary and nearshore habitats because fish have more opportunities to rear in the tidal delta, was strongly supported. To calculate effects of restoration, we first regressed pre-restoration estuary/nearshore residency (Julian day at which 50% of cumulative catch was observed in the nearshore relative to that measured at the Mount Vernon trap) as a function of fry captured in the river because residency is strongly density-dependent (Figure 8A). Post-restoration residuals correlated with cumulative amount of restoration even more strongly than tidal delta residency data (R^2 = 0.37, p < 0.05, Figure 6B), and resulted in about the same magnitude of effect, i.e., an increase in cohort residency of about 15 days would track 200ha of habitat restoration.

Despite exhibiting strong evidence for density dependence tied to juvenile stages, both the frequency of fry migrants in Skagit Bay (Figure 6C) and smolt-adult-return rate (SAR, Figure 6E) showed little evidence of being influenced by the cumulative amount of restoration (Figures 6D and 6F). However, regressions of pre- and post- restoration data suggest that their density-dependent relationships with in-river fry are trending in the expected direction: post-restoration frequency of fry migrants is increasing less, and SAR is declining less strongly, as a function of in-river fry. Based on the relatively small change pre- and post-restoration, detecting future changes to these metrics might be expected to require years of high abundance when the benefits of restoration are most fully realized. Alternately, scenario testing using various life cycle modeling techniques may be able to test the consequences of cumulative restoration when large outmigrations occurred. These efforts are currently under development.
Figure 5. Correspondence of biological metrics (measured annually) expected to be sensitive to restoration measured in the two forks of the Skagit tidal delta, and the change from pre-restoration levels as a function of cumulative restoration. Average population density (Panel A), cohort residency in the tidal delta (C), and average body length (E) were measured in the North Fork (NF, reference) and South Fork (SF, restoration treatments) before (filled circles, solid regression lines) and after restoration (open circles, dashed lines). Residuals from the pre-restoration regression were then plotted as a function of amount of restoration (Panels B, D, and F) to examine population response to cumulative restoration.
Figure 6. Density-dependent biological metrics measured in Skagit Bay in years before (filled circles, solid regression lines) and after restoration (open circles, dashed lines) as functions of the abundance of in-river fry captured by WDFW at Mount Vernon. Panel A shows annual cohort-level timing in the nearshore, adjusted by timing of outmigrants at the trap. Panel C shows the proportion of catch in shoreline monitoring composed of fry migrants in each year. Panel E graphs the annual smolt-adult return rate (age-corrected pre-harvest adults from a given cohort, adjusted by the number of migrants estimated at the Mount Vernon trap). Residuals from the pre-restoration regression were then plotted as a function of amount of restoration (Panels B, D, and F) to examine population response to cumulative restoration.
Future efforts
The above results provide a solid basis for concluding that restoration in the tidal delta is having beneficial effects beyond a project-by-project level. Where possible, effectiveness monitoring has shed light on which project designs are most beneficial to juvenile Chinook salmon. Yet several questions remain that we plan to address in future years. While the long-term monitoring has provided good evidence for system-level effects during juvenile rearing stages, we have as yet not documented whether restoration is in fact resulting in population benefits (i.e., higher returns of adults). The hypotheses of density dependent interactions by fry entering the Skagit tidal delta is strongly supported, as is the reduced SARs resulting from large fry migrations. Why does the now significant amount of restoration not produce higher SARs? Possible reasons include: 1) SAR exhibits high inherent variability from multiple causes at several spatial scales, 2) incomplete adult cohorts that experienced the highest levels of cumulative restoration need to return over the next two years before the benefits can be fully realized, 3) the greatest benefits of restoration are observable during large outmigrations, which have been lacking in the most recent years, and 4) migrating fry do not behave uniformly to typical habitat targets of estuary restoration. The first three possibilities can be addressed by additional years of monitoring and/or via additional large restoration projects, and additional analyses that better take into account variability in marine mortality and/or life cycle dynamics under scenarios of high cohort abundance.

The fourth possibility deserves additional attention and additional approaches. If migrant fry are not solely the losers of density-dependent interactions, but seek habitat types fringing tidal deltas that have greater bioenergetic opportunities than river dominated habitats, up-river restoration actions may have a muted benefit for this life history type. This hypothesis could explain why both the frequency of fry migrants in the nearshore and SAR do not exhibit much response to restoration. To address this possibility, continued monitoring will need to be paired with other types of restoration. Significantly, the upcoming McGlinn Island Causeway restoration should provide an opportunity to test this hypothesis, as this reconnection of the North Fork with Swinomish Channel to the north will provide more marine-influenced estuarine rearing opportunities along Swinomish Channel and in Padilla Bay. Testing this hypothesis will require additional monitoring in Swinomish and Padilla Bay habitats before and after the restoration event.

Reporting
Timely data analysis and reporting is critical if we are to adaptively manage the monitoring efforts in order to respond to unforeseen events and provide regular feedback to other restoration efforts and funding agencies. Currently, SRFB funding of the Skagit IMW supports only data collection (including database entry and QA/QC) by field staff and not data analysis or reporting by senior scientists. Predictable reporting, both in scope and timing is necessary to efficiently manage budgets and staff time. Below (Table 5) we propose a schedule of analysis and reporting for each polygon-level hypothesis (Table 2) that takes into account the expected impact and timing of restoration actions, expected time for juvenile Chinook density to respond, and the time needed to process and analyze the field data and report the results. We will 1) provide a summary of data collection efforts (sampling effort in each polygon) annually, and 2) calculate the metrics used in the analyses bi-annually to ensure consistency in collection and processing.
Table 5. Proposed reporting schedule for each testable hypothesis.

<table>
<thead>
<tr>
<th>Sub-delta polygon #, name</th>
<th>Restoration potential (acres)</th>
<th>Juvenile Chinook response post-restoration</th>
<th>Analysis and report</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Swinomish Channel Corridor</td>
<td>770</td>
<td>Overall average density increases and between-site densities become less variable due to increased connectivity with the North Fork. Population increases due to increased capacity along the Swinomish Channel Corridor.</td>
<td>BACI design underway with index sites being sampled since 2004. The post treatment period is expected to start within 5 years (McGlinn Island Causeway, see Table 3). Ongoing analyses (Fig 6). Existing restoration within this area is part of the system level response.</td>
</tr>
<tr>
<td>#2 North Fork Delta</td>
<td>980</td>
<td>Overall average density decreases and between-site densities become less variable due to increased connectivity to other areas within the delta. Population increases due to increased capacity within the North Fork Delta.</td>
<td>Ongoing BACI with the South Fork. Analyses shown in Figure 5 can be updated periodically. New BACI with the Swinomish Channel Corridor within 5 years (McGlinn Island Causeway, see Table 3). Ongoing analyses (Fig 6). The Cottonwood project will add to the system level response within 5 years.</td>
</tr>
<tr>
<td>#3 Central Fir Island Delta</td>
<td>470</td>
<td>Overall average density increases and between-site densities become less variable due to increased connectivity via a cross island corridor restoration project. Population increases due to restored capacity within Central Fir Island.</td>
<td>No cross island connectivity restoration expected within 5 years. Ongoing analyses (Fig 6). The Fir Island Farm project will add to the system level response starting in 2017.</td>
</tr>
<tr>
<td>#4 South Fork Delta</td>
<td>630</td>
<td>Density remains the same but between-site densities become less variable due to increased connectivity within the South Fork Delta. Population increases due to increased capacity within the South Fork Delta.</td>
<td>Ongoing BACI with the South Fork until new BACI with the Swinomish Channel Corridor expected to begin within 5 years. Ongoing analyses (Fig 6). Existing and near future restoration (Deepwater Phase 2) within this area is part of the system level response.</td>
</tr>
<tr>
<td>#5 Stanwood/English Boom Delta Fringe</td>
<td>None currently identified</td>
<td>Density and population increases due to increased source population increase originating from Stillaguamish and Skagit Rivers.</td>
<td>No analysis planned.</td>
</tr>
</tbody>
</table>
Literature Cited


