DELTA AND NEARSHORE RESTORATION FOR THE RECOVERY OF WILD SKAGIT RIVER CHINOOK SALMON: LINKING ESTUARY RESTORATION TO WILD CHINOOK SALMON POPULATIONS

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This document has been prepared as a supplement to:

Skagit Chinook Recovery Plan

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ABSTRACT

In 1992 we set out on a research path to understand the role the Skagit estuary might play in recovering wild Skagit Chinook salmon. Now, over a decade of field research has informed our understanding of Skagit Chinook salmon populations and estuarine habitat. This document synthesizes studies of estuary habitat use, life history variation, estuary habitat loss, marine survival, and potential global warming scenarios, to predict the benefits of potential restoration projects for recovering Skagit Chinook salmon. In summary, our research leads to the following conclusions useful for Chinook population recovery planning:

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 indicates 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 delta rearing individuals.
5. Some fry migrant 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 demonstrate that wild Skagit Chinook salmon populations will benefit from estuarine habitat restoration (both delta estuary and pocket estuary habitat) and improved migration pathways within and between estuary habitats. From these results we have developed tools to predict benefits of candidate restoration sites thus linking potential estuary restoration with Skagit Chinook Salmon recovery goals.

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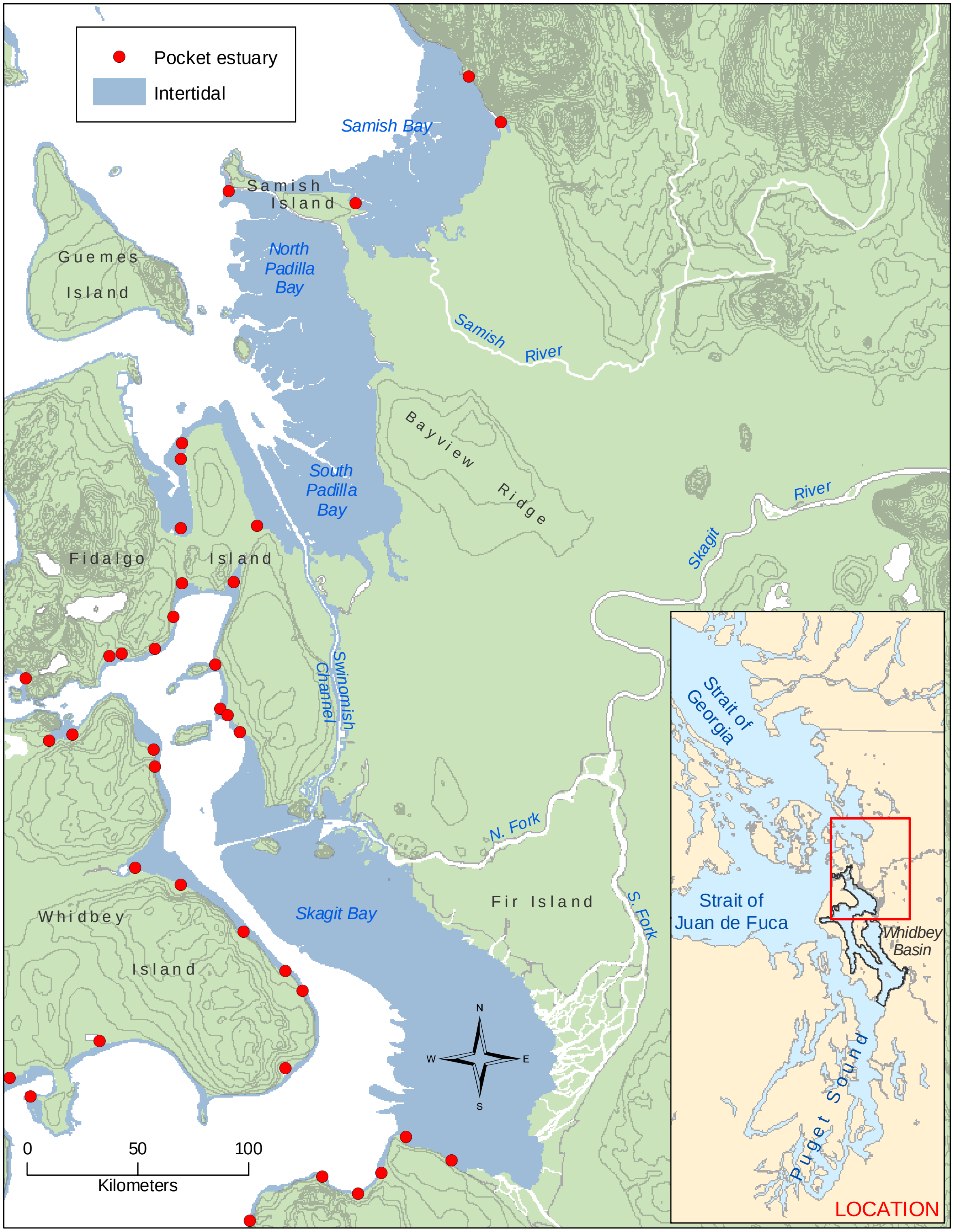


Figure 1.1. *Local and regional estuaries.* Puget Sound is a fjord estuary, containing several natal river estuaries, including the Skagit River delta, and hundreds of small, non-natal 'pocket' estuaries. The Whidbey Basin is a sub basin of Puget Sound, defined by bathymetry and water circulation patterns (Burns 1985). The Skagit River empties into Whidbey Basin.

1. INTRODUCTION

Our task is to recover the wild Skagit Chinook salmon populations listed under the Endangered Species Act, and restore fisheries. Nehlsen et al. (1991) exposed the scale of declining salmon populations for the Northwest and attributed habitat loss and degradation as major causes in the decline of stocks. This knowledge has led biologists and natural resource managers to ask comprehensive questions about what changes need to occur in order to recover salmon populations throughout the Northwest.

We have hypothesized that the Skagit estuary plays a critical role in the survival of wild Chinook salmon populations, but until recently we lacked a specific understanding of estuarine habitats and how fish use them. We were, therefore, unable to inform decision makers about what was needed to recover wild Skagit Chinook salmon populations. Specific information was needed to identify the critical actions needed for Skagit Chinook salmon recovery and to avoid ineffective actions. In 1992 we set out on a research path to understand the role the Skagit estuary might play in recovering wild Skagit Chinook salmon.

Now, over a decade of field research has informed our understanding of Skagit Chinook salmon populations and estuarine habitat. This document synthesizes studies of estuary habitat use by Chinook salmon, Chinook life history variation, estuary habitat loss, marine survival, and potential global warming scenarios, to predict the benefits of potential restoration projects for recovering Skagit Chinook salmon. It has been written as an appendix to a Co-manager's Skagit Chinook Recovery Plan, which describes actions (in addition to estuarine habitat restoration) necessary to recovery wild Skagit Chinook populations.

2. THE NEED FOR ESTUARY RESTORATION

The Puget Sound and Straits estuary are part of the continuum of habitats that salmon originating from the Skagit River use during their life cycle (Figure 1.1). As such, each salmon originating from the freshwater habitats of the Skagit River Basin must use some portion of the estuary and nearshore. Use of these habitats depends upon a variety of characteristics of the fish themselves and attributes of freshwater, estuarine, nearshore and ocean environments that the fish occupy or could potentially occupy.

Specifically, the estuarine ecosystem of the Skagit River consists of a diverse mix of habitats that salmon can potentially use. This habitat can be measured and defined by a variety of attributes at multiple scales of space and time. These attributes range from the millimeters to centimeters scale to the regional (hundreds of square kilometers). Traditionally, juvenile salmon habitat in nearshore ecosystems has been considered primarily at a site or patch scale. Examples of patch or site scale habitat attributes in a tidal marsh include area of the marsh, volume of the marsh, vegetation type and density, salinity and temperature patterns, and channel depth at the mouth of blind tidal channels. It has become increasingly apparent that simply relying on site or patch scale habitat attributes to study, manage, protect, and restore salmonid populations can lead to restoration approaches that are ineffectual.

The landscape context of habitat refers to the spatial arrangement of habitat, including size and shape; location of the habitat within the estuary (or the river ocean continuum); the composition of surrounding habitat; and connectivity with other habitats (Turner 1989). What this means in simple terms is that the function of any unit of habitat depends upon the context of that habitat within surrounding landscape. A landscape view of salmon habitat restoration incorporates the landscape context and function of specific habitats utilized by salmon throughout their life. At the landscape scale, the amount of estuarine habitat that is accessible to salmon affects the abundance and productivity of a population; the distribution, connectivity, abundance, size, and shape of estuarine habitat affect both the diversity and the spatial structure of a salmon population. At the site scale, attributes of estuarine habitats (e.g., temperature and salinity regimes, food web relationships) can affect diversity and productivity of populations.

The estuarine habitats of the Skagit River provide four main functions for juvenile salmon: 1) foraging and growth, 2) avoidance of predators, 3) physiological transition zone from freshwater to saltwater, and 4) migratory corridors to oceanic feeding grounds (Simenstad et al. 1982; Simenstad and Cordell 2000). These four functions are clearly interrelated. For example, growth and survival are interrelated as growth rate can affect survival as a result of how rapidly the fish can "outgrow" portions of their predator population. Estuarine habitats vary in their ability to support these four functions as a result of natural and anthropogenic variability in attributes of the habitat. The value of any unit of habitat to salmon, therefore, will reflect how well the habitat supports these four functions. Ultimately, how well estuarine habitats (and other habitats used by salmon) function for salmon will contribute to the viability and persistence of salmon populations.

2.1. ESTUARIES AND JUVENILE CHINOOK SALMON

In this section we show that wild juvenile Chinook salmon utilize a variety of different estuarine habitats associated with the Skagit River over varying periods of time. Recognizing these patterns of habitat use is important for understanding the relationship between Chinook salmon and their habitats. This understanding is the foundation for developing a habitat restoration strategy to recovery endangered Chinook salmon populations.

Estuaries exist anywhere along the coast where geologic and hydrologic conditions can create a partially enclosed, diluted marine body of water. They vary in scale, depending on the size of the enclosure and the amount of freshwater dilution. A large estuary like Puget Sound and the Straits may itself contain river mouth estuaries and small-scale 'pocket' estuaries with more dilute marine water relative to the surrounding estuary[2] (Figure 1.1). The salinity, mixing, and geomorphology of estuaries vary almost infinitely. Add climate to the mix, and these habitat conditions determine the biotic community of an estuary. Juvenile Skagit Chinook salmon utilize the estuary of their native river—the tidally influenced part of the Skagit delta. Juvenile Skagit Chinook salmon also utilize nearshore habitats adjacent and distant from their natal river estuary. These habitats include shoreline and offshore areas as well as discontinuous pocket estuary habitat within the Whidbey Basin of Puget Sound.

[2] Estuaries can vary in scale and can be nested due to differences in the processes that form them. We define estuaries based on a geomorphic classification system described in Appendix D.IV of this document. See Table D.IV.1 for names and definitions of specific estuary or nearshore habitat types that exist in Puget Sound.

Congleton et al. (1981) first documented juvenile Chinook salmon rearing in the Skagit estuary and postulated that a high proportion of the total population depended on delta estuary habitat for an extended rearing period. More recent and comprehensive sampling of the Skagit estuary provides some context for the tidal delta rearing noted by Congleton et al. (1981). Wild (unmarked) juvenile Chinook salmon are consistently found in estuarine habitats from February through October (Figure 2.1). Conversely, juvenile hatchery Chinook salmon show a narrower temporal distribution in all four estuarine habitat types sampled compared to wild fish. This relationship is most pronounced in tidal delta and shallow intertidal nearshore habitats. Generally, wild Chinook salmon travel downstream and offshore over time, with declining densities presumably as a result of mortality, migration, and increased area of habitat. One exception to this is the pattern observed in pocket estuaries, where early seaward migrating fry begin to appear in winter, often in relatively high densities (Beamer et al. 2003).

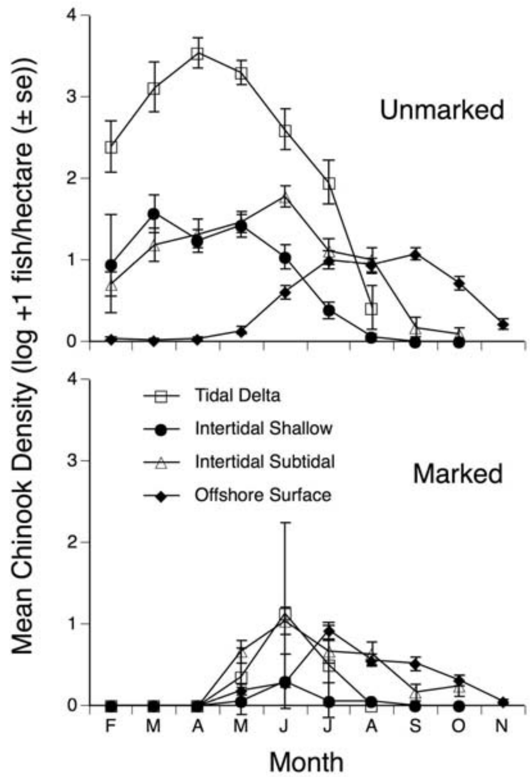


Figure 2.1. *Density of unmarked (top) and marked (bottom) juvenile Chinook salmon in four estuary habitat types within the Skagit estuary, 2002* (from Beamer and Rice 2005).

Together, these studies suggest that estuarine habitat use by juvenile Chinook salmon from the same brood year varies in use both in time and space resulting in different life history patterns. Because of this variation in habitat use, each life history type is potentially exposed to different levels of survival and growth within the freshwater or estuarine environment. Also, the different life history types can enter their ocean rearing phase at potentially different sizes and time, which would affect their survival during ocean residency. Life history variation is important to buffer populations against changes in survival at different life stages that may result from natural or human caused catastrophes (e.g., drought, flood, volcanic eruptions, tsunamis, oil spills). These types of conditions could severely impact or even eliminate entire populations or particular life stages of populations. Therefore, identifying specific juvenile life history types and their habitats is important for planning salmon population recovery.

2.2. JUVENILE CHINOOK SALMON LIFE HISTORY TYPES AND STRATEGIES

Chinook salmon populations are generally classified as one of two life history types: stream-type or ocean-type. The terms stream-type and ocean-type appear to have originated from Gilbert (1913) as a way to discriminate Chinook salmon based on their length of stream residence. Based upon banding patterns he observed on scales, Gilbert referred to stream-type fish as those fish having scales, with a banding pattern consistent with a period of poor growth in winter in cold freshwater habitats. Ocean-type scales (he used the term sea-type) did not show this poor winter growth, indicating the fish moved into warmer, more productive marine waters before winter. Subsequently, Healey (1991) proposed that ocean-types and stream-types were separate races that were independent and geographically isolated from one another except in the southern part of their range where they separated temporally in areas of sympatry. Recently, Healey's racial model explaining variability in Chinook salmon life history patterns at broad spatial scales has been challenged (Brannon et al. 2004,Waples et al. 2004).

In this report, we use the terms stream-type and ocean-type to separate Chinook salmon in the Skagit River into two groups based strictly upon certain characteristics exhibited by juveniles during their first year of life, including how long they rear in freshwater, when they outmigrate and how long they spend in estuarine habitats. Ocean-type Chinook salmon are those that migrate to sea early in their first year of life after spending only a short period (or no time) rearing in freshwater. A shorter period of freshwater rearing is usually correlated with more extensive use of estuarine habitats. In contrast, stream-type Chinook salmon spend one year or longer in freshwater and tend to pass quickly through estuaries.

Individual members of stream or ocean-type Chinook salmon exhibit a variety of alternative spatial and temporal life history strategies in their use of available habitat. We defined alternative life history strategies based solely upon the size at estuarine entry and arrival time in the estuary. Size at entrance into the estuary can be used to classify life history strategy because there is a linkage between fish size, habitat use, and residence time (Healey 1980, 1982, Levy and Northcote 1981, 1982, Simenstad et al. 1982, Levings et al. 1986, Tschaplinski 1987, Miller and Sadro 2003). In general, residence time in the estuary decreases as the size of the fish entering the estuary increases (with the exception of pink salmon). In addition, juvenile salmon are generally distributed based upon water depth, with the depth of the water occupied by the fish increasing as the size of the fish increases (McCabe et al. 1986). Larger fish can result from growth either in estuarine or freshwater habitats. The time the fish arrive in the estuary also varies within a general size class of individuals (Carl and Healey 1984, Bottom et al. 2001). Because available resources and habitats can be different depending on when a fish arrives in the estuary, arrival timing represents a reasonable way to define how the fish use habitats. As a result there can be a broad range in size and time of estuarine entry.

Although any one Chinook salmon population can potentially produce all life history strategies, some strategies will be more abundant or dominant than others within a population. All life history strategies are naturally occurring, however the distribution or proportion of members within a population associated with each life history strategy will depend upon the environmental conditions the fish are experiencing. The distribution of members within different strategies can vary in response to climate changes, freshwater habitat, stream flow, water temperature, predator populations, and ocean conditions. Chinook salmon populations with multiple life history types and strategies diversify their population and disperse the risk of mortality for progeny from the same brood year to different parts of the river-ocean rearing continuum.

Researchers have observed variations of life history types and strategies among Skagit Chinook salmon. Stream and ocean type Chinook salmon have been known to comprise the Skagit

Chinook salmon populations since the 1960s, when scales were used to identify the juvenile smolt ages from returning adults. More recent smolt trap work in the mainstem of the lower Skagit River suggests that ocean type populations dominate the juvenile outmigration (Seiler et al. 1995). Hayman et al. (1996) was the first to identify three different juvenile life history strategies for wild Skagit ocean type Chinook salmon. These were based purely on juvenile fish timing and size patterns observed in freshwater and estuarine habitats throughout the Skagit River and its estuary. Beamer et al. (2000b) later confirmed the presence of these same juvenile life history strategies based on otolith microstructure observations. In this report we use four life history strategies described in Table 2.1. Ocean-type and stream-type populations can each produce all four life history strategies as progeny.

Table 2.1. *Description of known juvenile life history strategies for wild Skagit Chinook salmon.*

Life History Type	Life History Strategy Description
Ocean Type	*Fry Migrants* – These fry emerge from egg pockets and migrate quickly downstream to Skagit Bay. Fry migrants do not rear extensively in tidal delta habitat so no tidal delta rearing structure is observed on their otolith. They enter Skagit Bay usually in February and March, at an average fork length of 39 mm (observed range from otoliths is 30-46 mm fork length). Some fry migrants take up residence in pocket estuary habitat (Beamer et al. 2003). These areas are thought to provide fry migrants with a survival or growth advantage over other nearshore habitats.
	Tidal Delta Rearing Migrants – Tidal delta rearing fry emerge from egg pockets and migrate downstream at the same time as fry migrants. Instead of directly entering Skagit Bay, they reside in tidal delta habitat for a period ranging from several weeks up to several months, reaching an average size of 74 mm fork length (observed range from otoliths is 49-126 mm fork length). The average tidal delta residence period for tidal delta rearing Chinook salmon in 1995 and 1996 (combined) was 34.2 days (Beamer et al. 2000b). 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 and 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
	Parr Migrants – These fry emerge from egg pockets and rear for a couple of months in freshwater to achieve a similar size as their tidal delta rearing cohorts over the same time period. Following freshwater residence, parr migrants move through the tidal delta and into Skagit Bay, usually starting in late May or June at the average size of 75 mm fork length (observed range from mainstem trapping is 57-92 mm fork length). Parr migrants do not reside in tidal delta habitats. We observe an extended freshwater rearing region and no tidal delta rearing region on their otolith. Some of these fish may reside in off channel habitat within the large river floodplain areas of the Skagit River (Hayman et al. 1996)
Stream Type	*Yearlings* – These fry emerge from egg pockets and rear in freshwater for a period over one year. Movement patterns and habitat preferences within freshwater are largely unknown. Yearlings migrate to the estuary generally from late March through May at the average size of 120 mm fork length (observed range is 92-154 mm fork length). Yearlings do not reside in tidal delta habitats for an extended period of time like tidal delta rearing migrants. Yearlings seem to pass through tidal delta habitats, possibly lingering briefly, on to nearshore areas. Yearlings are rarely found in shallow intertidal environments, but are most commonly detected in deeper subtidal or offshore habitats. Residence in nearshore areas of Skagit Bay by yearlings appears to be shorter than ocean type life histories

These life history strategy definitions continue to be tested and revised by on going research and monitoring efforts. Primary questions to answer include identifying all life history strategies and which stocks are represented by these different strategies. Otolith and genetic data collected from spawners throughout the basin, starting with the 1995 brood, could further refine these assumptions by identifying geographic locations of fish that exhibit specific life history strategies.

Fry migrants and tidal delta rearing fish depend upon estuarine habitats most sensitive to human disturbance. This is because they arrive in estuarine habitats early in the season at a small size and predominantly occupy shoreline or shallow water habitats. These habitats are at greatest risk of change by human land uses.

2.3. LIFE HISTORY STRATEGIES AND SKAGIT CHINOOK SALMON STOCKS

We have investigated the life history strategies of Skagit Chinook salmon by sampling otoliths (ear bones) of juvenile salmon caught in the Skagit Delta and Bay and of returning Skagit River spawners between 1995 and 2004. Otolith and genetic studies confirm that all six Skagit Chinook salmon stocks have multiple juvenile life history types and that all six stocks have juvenile life history strategies that depend on estuarine habitats.

Otolith patterns formed on Chinook salmon fry while in their intragravel life stage prior to emergence correspond to different locations within the Skagit River basin (SSC & WFRC 1999). These otolith patterns are defined as 'developmental checks'[3]. The four observed checks roughly corresponded to different Skagit Chinook salmon stock spawning ranges probably due to hydrologic and thermal differences within the Skagit River basin during the egg and alevin life stages of Chinook salmon. Developmental check type can therefore be used as a rough geographic marker for the origin of individual fish, assuming there is only downstream migration and negligible upstream migration by young of the year Chinook salmon fry during late winter and early spring.

Chinook salmon fry samples collected in the lower Sauk River mainstem were specific to developmental check pattern 'A'. This area is within the spawning range of Lower Sauk Summer Chinook salmon. Fry migrating downstream from the Suiattle River and upper Sauk River may also be included in these otolith samples. Therefore, developmental check 'A' may relate to Chinook salmon spawners originating throughout the Sauk River basin and its tributaries. Developmental check patterns 'B' and 'D' were specific to Chinook salmon fry collected in the Skagit River upstream of Marblemount. All the sites sampled upstream of Marblemount lie within the spawning range of the Upper Skagit Summers. Sample fry collected at Skagit River mainstem sites, downstream of its confluence with the Sauk River to Sedro Woolley, had one of the three developmental checks (A, B, and D) or a new pattern 'C'. By inference, the Lower Skagit mainstem is the source of fish with developmental check pattern 'C'. This area is the spawning range of Lower Skagit Falls. By examining development checks from juvenile Chinook salmon rearing in tidal delta blind channel habitat, we find all four patterns present (Figure 2.2).

Figure 2.3 shows the assignment of the different life history types by genetically determined stocks. This study shows that all six Skagit stocks depend on estuarine habitat because all stocks

[3] A developmental check is an area of an otolith located in close proximity to its core that has a distinctive series of increments. Developmental checks may be related to hatching, emergence, or other early life history events.

include tidal delta rearing and fry migrant juvenile life history strategies. The apparent life history diversity should help each stock be more resilient to a variety of environmental conditions. When examining habitat use and planning for restoration, we consider each life history type as essential to each stock's population recovery. With an understanding of Skagit Chinook salmon life history types dependent on tidal delta and nearshore estuarine habitats, we can begin inferring their biotic responses to estuarine habitat loss, both in the tidal delta and in pocket estuaries.

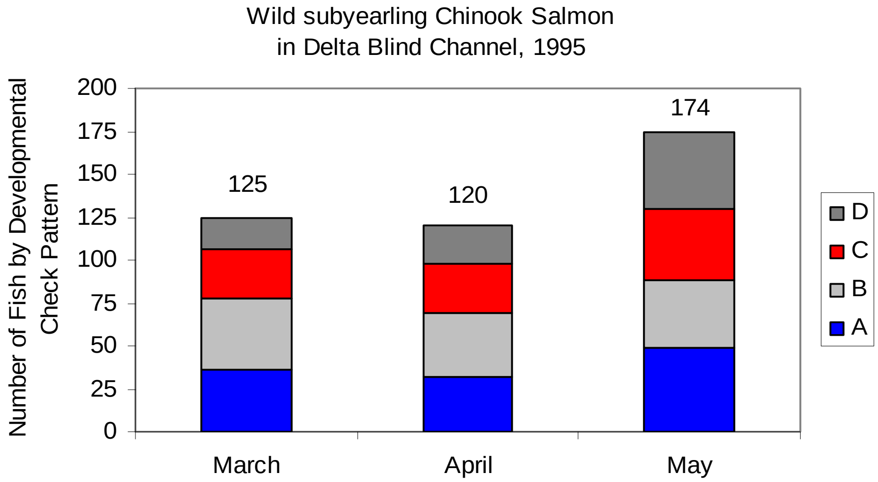


Figure 2.2. *Relationship between month and development check type for wild subyearling Chinook salmon caught in delta blind channel habitat, 1995.* A total of 419 juvenile Chinook were examined for developmental check pattern. The monthly sum is shown above bar in figure. All four developmental check patterns were present each month (from Skagit System Cooperative and Western Fisheries Research Center 1999).

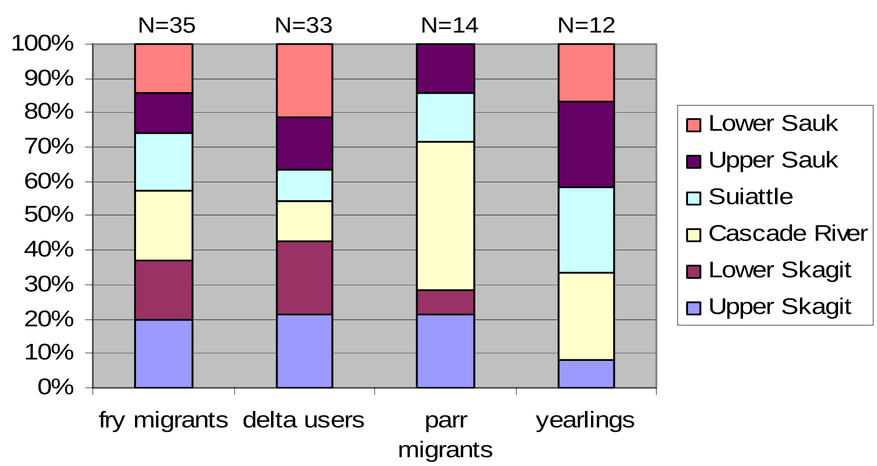


Figure 2.3. *Life history types of Skagit Chinook salmon stocks.* Percentage assignment of life history typed to the DNA baseline for each of the six Skagit Chinook stocks. The numbers of individuals of each life history strategy are noted above the corresponding column (from Heeg et al. 2004).

3. ESTUARINE HABITAT CONDITIONS

Knowing that all six Skagit Chinook stocks utilize estuarine habitat either as tidal delta rearing or fry migrant life history strategies, we next need to understand the extent to which human caused changes to estuarine habitats impact Skagit Chinook. We accomplish this by first documenting changes in the Skagit tidal delta and nearshore pocket estuaries in Whidbey Basin. We then identify biological responses to those habitat changes. Specific restoration actions are implied by the habitat needs of Chinook salmon and existing habitat conditions.

Natural landscape processes and human land use activities largely determine habitat conditions. In the Skagit tidal delta and Whidbey Basin pocket estuaries, human impacts have degraded or destroyed much of the estuarine habitat historically available to Chinook salmon. Understanding the change in estuarine habitat conditions can inform our salmon recovery efforts. Through mapping current habitat conditions and reconstructing historic conditions, we have established the magnitude of habitat loss and the extent of current habitat available for use by Skagit Chinook salmon.

3.1. HABITAT LOSS IN THE SKAGIT RIVER TIDAL DELTA

The Skagit River delta is a prograding to neutral fan delta with numerous distributary channels. When describing tidal delta habitat, we are referring to the tidal estuarine mixing zone and riverine tidal areas of the geomorphic delta landform (Day et al. 1989). 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 (tidal delta in the case of the Skagit) includes the channeled emergent and scrub-shrub marshes where freshwater mixes with salt water. Within these areas a diversity of estuarine habitats are (or were) formed and maintained by tidal and riverine processes, creating a mosaic of wetlands and channels (e.g., emergent or scrub-shrub wetlands, blind tidal or open ended distributary channels).

Post settlement diking, dredging, and filling in the delta have severely limited the historic extent of delta habitat. Collins (2000) created a historic reconstruction of the geomorphic Skagit delta showing the distribution of its estuarine habitats (Figure 3.1). Comparing Collins' reconstruction with mapping done by Skagit River System Cooperative (Beamer et al. 2000b) of the same estuarine zones using 1991 aerial photography, we find a net loss of 74.6% of tidal delta estuarine habitat area. The historic estuarine footprint was estimated at 13,373 hectares, and the 1991 footprint was 3,397 hectares. These estimates apply to the entire geomorphic Skagit delta, which extends from Camano Island northward and includes Samish Bay.

To understand changes in estuarine tidal delta habitat most directly relevant to Skagit Chinook salmon populations we looked at only that portion of the geomorphic delta extending from southern Padilla Bay to Camano Island. This portion of the geomorphic delta was historically contiguous and directly connected to the Skagit River, the primary source of Chinook salmon for this area (Figure 3.1). For this area, the historic estuarine footprint was estimated at 11,483 hectares and the 1991 footprint was 3,118 hectares, resulting in a 72.8% loss. Under present day conditions, the contiguous habitat area of the Skagit delta consists mostly of the delta area in the vicinity of Fir Island, but it also includes a fringe of estuarine habitat extending from the town of LaConner, to the north end of Camano Island. Natural formation of delta habitat outside of diked areas occurs by the deposition of riverine sediments. These estimates of delta habitat loss do account for gains in delta habitat caused by progradation occurring between the 1860s and 1991[4].

[4] Using remote sensing techniques, Hood (2005) estimates that the Skagit delta is prograding at a rate of approximately 1.66 hectares per year since 1956 in the North Fork region of the delta, and losing an average of 0.3 hectares per year over the same period in the South Fork. These numbers suggest a net addition of tidal delta habitat of 68.0 hectares over the last 50-year period. However, if only the last 15 years timeframe is analyzed, we see the North Fork region prograding at roughly the same rate (average of 1.4 hectares per year), and the South Fork region showing an average loss of 2.65 hectares per year — yielding a net loss of 18.75 hectares since 1991. The causes for this decline are not clear; however, projections for sea level rise in conjunction with global warming trends lead us to believe the South Fork will continue to lose ground for the foreseeable future.

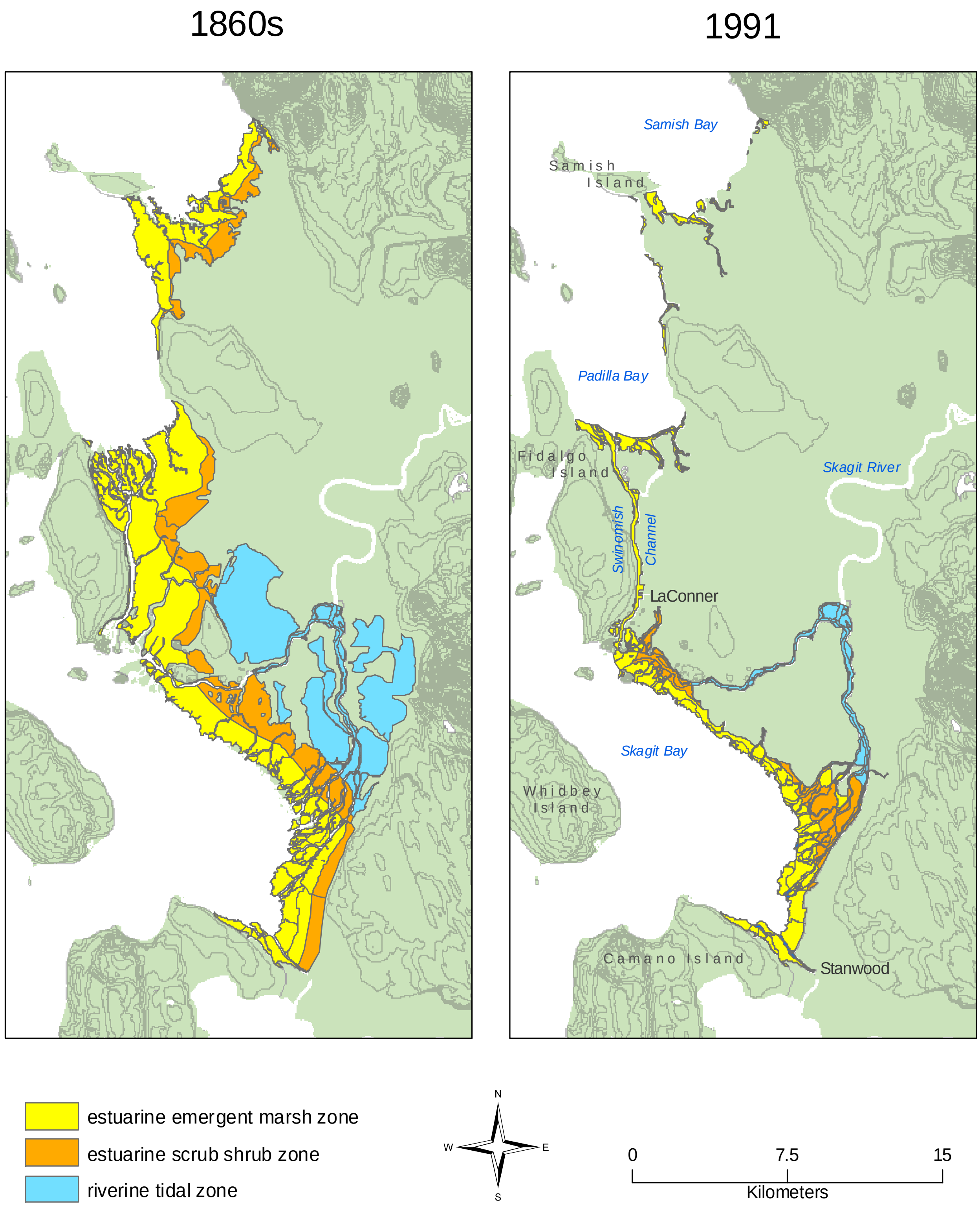


Figure 3.1. *Changes to the estuarine habitat zones within the geomorphic Skagit delta.* Historic (circa. 1860s) conditions were reconstructed by Collins (2000) using archival maps and survey notes. Current habitat zones were mapped by Beamer et al. (2000b) using 1991 orthophotos.

Not only is the contiguous tidal delta much smaller than historically, but it has also been fragmented, making movement of fish through its entirety more difficult. The former Swinomish Channel area once connected Skagit Bay with Padilla Bay via a wide estuarine emergent wetland and slough corridor. It is now a dredged navigation channel with only 14 small marsh patches along its entire length. Southern Padilla Bay has lost most of its emergent wetlands due to diking and/or isolation from river sediment sources. The emergent wetland zone along the bay front of Fir Island has narrowed and its distributaries have been cut off from the main river. There is no longer any remaining estuarine scrub-shrub habitat in this region of the tidal delta.

The change in the tidal delta estuary footprint is useful for understanding broad changes to the delta landscape, but it does not represent the loss of specific delta estuary habitats directly used by juvenile Chinook salmon. Juvenile ocean-type Chinook salmon that rear in delta estuarine habitats utilize specific habitats, namely blind channels and the margins of distributary channels, where low velocities and preferred depths exist (Appendix D.II). We estimated the change in these specific habitats in order to better understand the impact of tidal delta habitat loss on juvenile Chinook salmon rearing in (not just migrating through) tidal delta habitats (Figure 3.2).

Collins (2000) estimated the areas of several different channel types for the historic tidal delta. We did the same for current conditions. However, in our process of inventorying current tidal delta habitat channel conditions using high-resolution imagery (from 2000, 2002, and 2004), we found a significant difference between our ability to detect distributary and other non-blind channels using high-resolution imagery versus historic mapping using archival maps and notes. It is likely that the archival methodology used by Collins did not detect many smaller width distributary channels (Figure 3.2) resulting in possibly a three- to four-fold underestimate in their length for the historic period (Table 3.1). It is also likely that using a straight percentage of wetland area (6% for estuarine emergent marsh; 4% for estuarine scrub-shrub; and 2% for riverine tidal wetlands) to estimate the area of unmapped blind channels within historic wetlands does not compare well with estimates based on inventory using higher resolution photo imagery for current time periods.

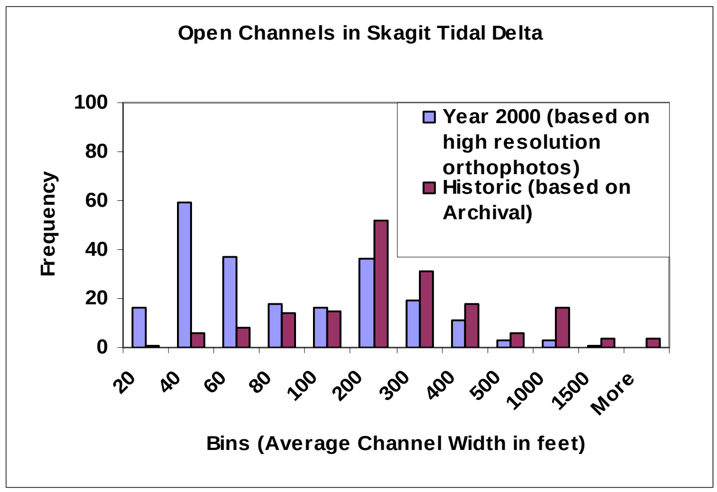


Figure 3.2: *Difference in detected distributary channels by inventory method.* The number of distributary channels detected using high resolution orthophotos is double compared to using archival data. Archival methods missed many of the narrower channels.

Table 3.1. *Comparison of distributary channel density.* Channel density is measured as channel length (m) per wetland area (ha).

Analysis Area	Open Channel Density (m/ha)
Historic (entire geomorphic delta)	11.8
Historic (Swinomish/S. Padilla only)	11.6
Historic (Skagit only)	15.1
Current (North Fork Skagit only)	41.2
Current (South Fork Skagit only)	39.0

We used allometric principles after Hood (2002a, 2002b, 2004) to empirically develop marsh to channel area regressions in order to estimate blind channel areas for both current and historic tidal delta areas. Specific regressions are described in Appendix D.III. We also used this method to account for the unmapped smaller distributaries for historic habitat. To account for distributary channel edge habitat, we measured water depth and velocity at sixteen distributary cross-sections and estimated the percent edge habitat for distributary channels of varying widths. We defined edge habitat as the physical habitat conditions preferred by age 0+ Chinook salmon rearing in tidal delta channels (Appendix D.II). We applied the percent edge relationships to both current and historic habitat inventories to estimate the amount of edge habitat in distributary channels (Table 3.2).

Table 3.2. *Current and historic tidal delta channel habitat areas for the contiguous Skagit delta from Camano Island to southern Padilla Bay.* Open channels include all types listed in Collins (2000) (main, connecting, distributary, tributary) and distributary channels truncated by diking.

Habitat Types	**Historic (~1860s)**	**Current (2000)**	**Change**
Area of all open channels (ha)	1,223.8	851.7	-30.4%
Edge area of all open channels (ha)	114.7	90.9	-20.7%
Blind tidal channel area (ha)	1,158.0	62.7	-94.6%
Area preferred by delta rearing Chinook salmon (ha)	**1,272.7**	**153.6**	**-87.9%**

Even with a 74.6% loss in the estuary footprint area, the loss in mapped open channel (distributary) area is only 30.4%, and the estimated loss in distributary edge habitat is only 20.7%. This possibly surprising result makes sense when we observe that both the North Fork and Swinomish Channel have widened, and the North Fork delta has prograded (Collins 1998), increasing its size and number of distributaries, thus increasing open channel and edge habitat area, for a lower net loss of these habitats relative to the total tidal delta area lost. However, even with the localized increase in North Fork delta area, there is a 94.6% overall loss in blind channel habitat, which is greater than the 74.6% delta estuary footprint loss. This disproportionate loss of blind channel habitat is due to a combination of direct and indirect dike impacts on blind tidal channels. The dikes along the delta front isolate and destroy tidal channels on their landward side, and reduce tidal prism and flushing power seaward, causing sediment infilling of blind channels in existing marsh immediately outside the dikes (Hood 2004). The net loss of the edge and blind channel habitats preferred by juvenile Chinook salmon for rearing is 87.9%.

3.2. LOSS OF WHIDBEY BASIN POCKET ESTUARIES

Pocket estuaries are small-scale estuaries within the larger Puget Sound estuary that form behind coastal accretion landforms, at embayments created by submerged valleys, or at small creek deltas (Appendix D.IV). Compared to adjacent intertidal habitat, pocket estuaries have: 1) substrates, intertidal gradients, and vegetation consistent with lower energy environments; and 2) local surface and/or groundwater freshwater inputs that depress salinity during some part of the year, usually winter and spring. Because pocket estuaries are not contiguous habitats, changes in fish migratory pathways between and into pocket estuaries are as much a part of the habitat loss as actual estuary area lost. Like estuarine habitat in the Skagit delta, much of the historic pocket estuary habitat and connections between those habitats have been lost or modified due to human land use. We have focused on pocket estuary habitat within Whidbey Basin, the sub-basin of Puget Sound into which Skagit Chinook salmon migrate after leaving their natal river delta (Figure 3.3).

To quantify the loss of pocket estuary habitat, we developed a process-based model that identifies segments of shoreline where pocket estuaries could have existed (McBride and Beamer, in prep.). We identified 113 pocket estuaries within the Whidbey Basin using the Nearshore Geomorphic Model (Figure 3.3). Field reconnaissance, geologic and topographic map data, and remote sensing by current and historic air photo interpretation were used to verify model-identified pocket estuaries. Verified sites include existing pocket estuaries and pocket estuaries for which there is a landscape signal indicating that habitat was present at the site prior to modification. At present we have verified 85 of the 113 predicted pocket estuaries, or 75%. Where the model predicts a pocket estuary, it is 100% accurate for verified sites thus far, though 2 of the predicted and verified pocket estuaries are and were historically probably too small to have included any fish habitat. One missed pocket estuary has been identified during field checking (error of omission). The number of model-predicted pocket estuaries can be considered a minimum number for the Whidbey Basin.

In validating the model, we have also been able to assess how many pocket estuary sites have been completely destroyed or made inaccessible to juvenile salmon by land use disturbances. Of our validated sample (85 of the 113 predicted pocket estuaries), 58 sites (68%) are no longer accessible for juvenile salmon habitat. Historically, the mapped pocket estuaries ranged from 0.6 hectares (1.5 ac) to 186 hectares (460 ac) of intertidal and subtidal habitat, with a median size of 9.7 hectares (24 ac). Currently these same pocket estuaries range from 0 to 93.5 hectares (231 ac), with a median size of 4.5 hectares (11 ac). The largest inventoried pocket estuary was, historically, Dugualla Bay. Triangle Cove is currently the largest.

The 27 accessible sites have all been modified. Modifications include dredging, filling, shoreline hardening, and diking. These modifications have resulted in loss of usable fish habitat. We have completed current and historic habitat inventories for those 27 pocket estuaries as the basis for estimating current and historic capacity of pocket estuary habitat for juvenile Chinook salmon within the Whidbey Basin. If our validated sub-sample of the 58 lost sites and the 27 modified pocket estuaries accurately represents all 113 Whidbey Basin pocket estuaries, we can then conclude that over two thirds of all Whidbey Basin pocket estuaries are completely lost to juvenile salmon use, and the remaining one third have been reduced in size by approximately 50%. This suggests an approximately 80% net reduction in pocket estuary area in the Whidbey Basin. For pocket estuaries in close proximity to the Skagit delta, the historic pocket estuary area was 340.7 hectares. Under present day conditions these same sites have only 47.5 hectares of intertidal or subtidal habitat, indicating an 86% loss.

The complete loss of individual pocket estuaries within the Whidbey Basin has adversely impacted the total area of this habitat type and has also further fragmented these habitats, decreasing the opportunity for fish to find pocket estuaries. Connectivity (the migratory pathways connecting the natal river delta to pocket estuaries, pocket estuaries to other pocket estuaries, and pocket estuaries to adjacent nearshore habitat) determines, in part, the opportunity

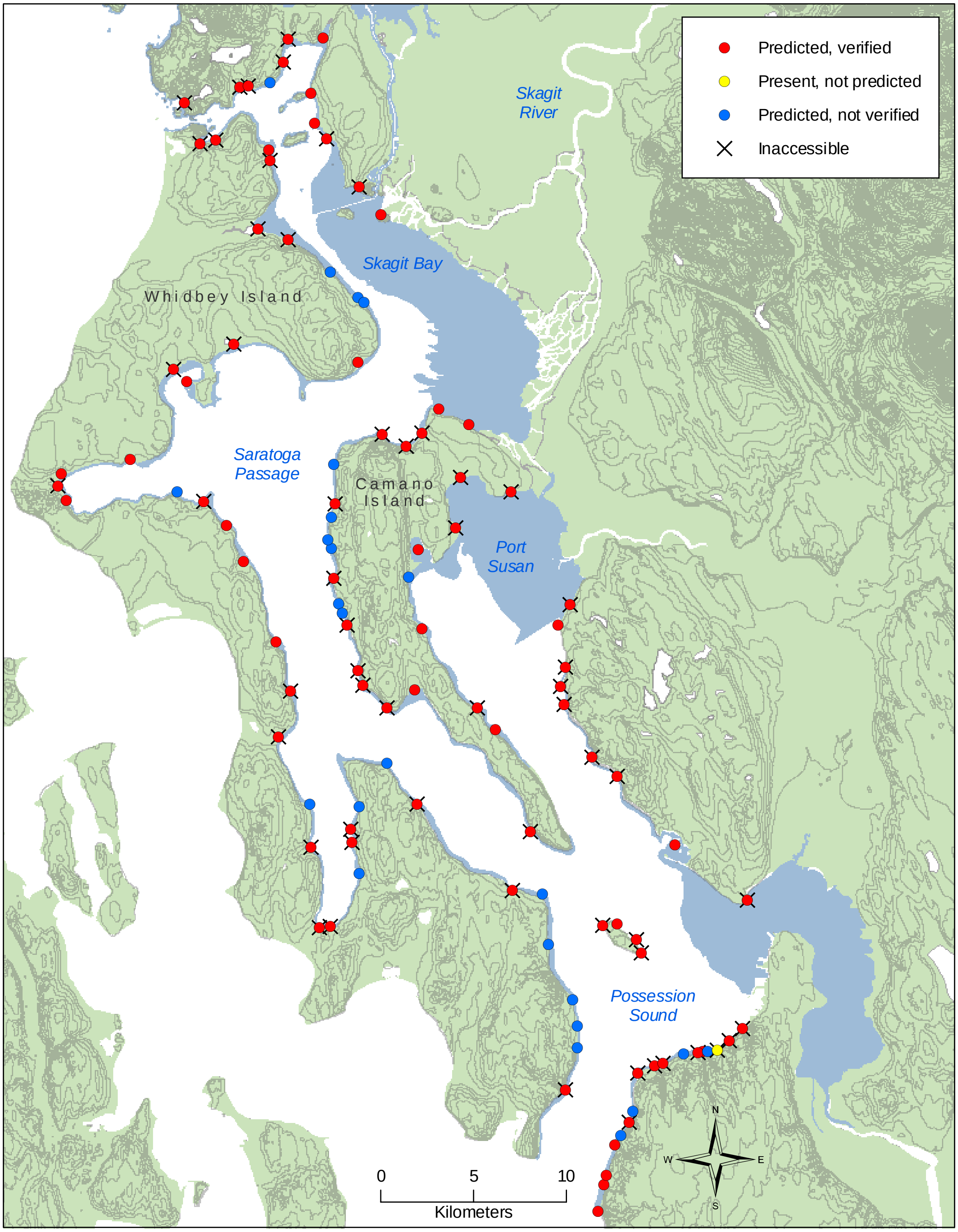
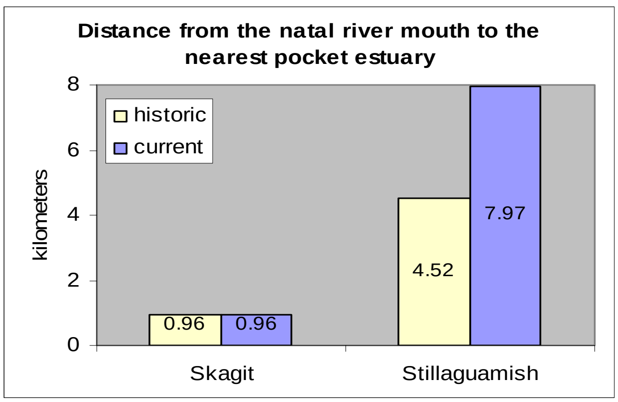


Figure 3.3. *Pocket Estuaries in Whidbey Basin.* Model-identified and verified. The model's prediction accuracy is 100% thus far. More than 75% of the predicted pocket estuaries have been validated. Of our validated sample, 68% of the pocket estuaries (58 sites) historically present are no longer usable fish habitat. One additional pocket estuary has been found during fieldwork (error of omission).

juvenile Chinook salmon have to utilize pocket estuary habitat. Multiple factors influence connectivity at specific sites. We summarize connectivity based on scale. Landscape scale connectivity describes how easily juvenile salmon can get to the vicinity of a pocket estuary from their source population area (e.g., Skagit River) and from one pocket estuary to another pocket estuary. Local scale connectivity describes pathways from immediately outside the pocket estuary (i.e., the adjacent nearshore waters) into the pocket estuary itself.

Using model-identified pocket estuaries in Whidbey Basin, we have made preliminary comparisons of landscape scale connectivity based on distance from rivers and distance between nearest neighbor pocket estuaries (Figures 3.4 and 3.5). Historically, there were 72 lagoon-type pocket estuaries with a median distance of 1.26 km to the nearest adjacent pocket estuary. Currently, there are only 21 lagoon type pocket estuaries still accessible to fish, with a median distance of 2.48 km to the nearest adjacent pocket estuary.



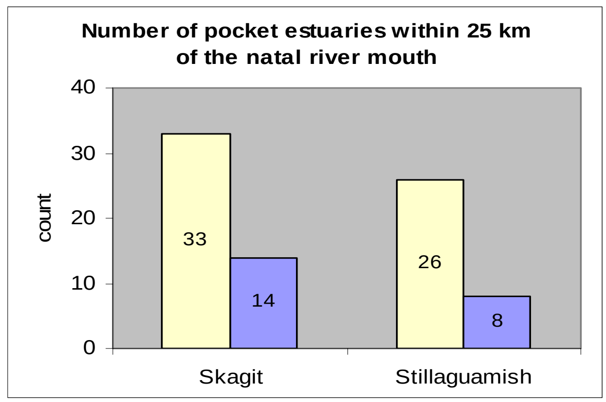


Figure 3.4. *Distance from natal rivers to nearest pocket estuary in the Whidbey Basin.* The number of pocket estuaries has decreased, thus the distance to the nearest pocket estuary from a river has increased. We have estimated that 9.5 km is a reasonable distance juvenile Chinook can travel from a delta during one ebb tide (Appendix F). Pocket estuaries within this range may be within an important threshold of connectivity between delta and nearshore habitats.

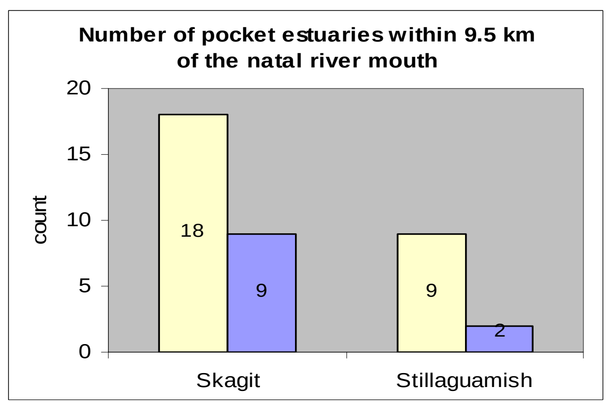
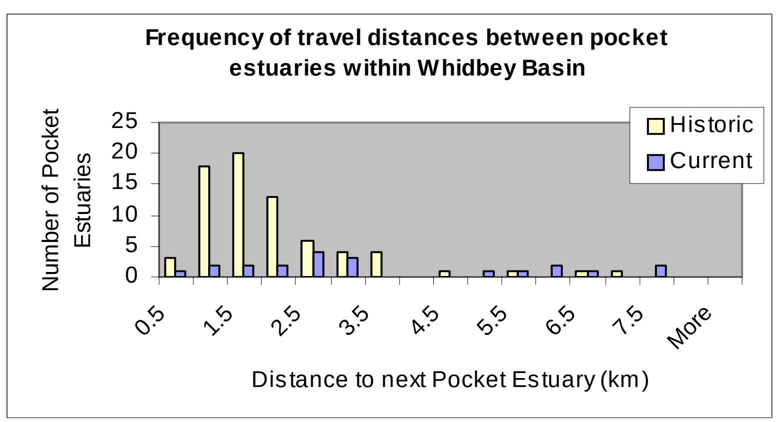


Figure 3.5. *Frequency distribution of the distance to nearest pocket estuary for lagoon type pocket estuaries in the Whidbey Basin.* Historic refers to pocket estuaries that were freely accessible to juvenile salmon. Current refers to pocket estuaries that are accessible to juvenile salmon today (including those with modified access or impacted habitat).



4. JUVENILE CHINOOK SALMON IN THE SKAGIT DELTA AND NEARSHORE

The loss of tidal delta and pocket estuary habitat and disruption of historic fish pathways, coupled with knowledge of juvenile Chinook life history strategies (tidal delta rearing migrants and fry migrants) that depend upon tidal delta and pocket estuary habitats have led us to hypothesize that the current habitat condition of Skagit estuarine habitat is limiting Chinook salmon population recovery. We have investigated potential responses of Chinook salmon to habitat conditions by sampling fish abundance, distribution, and growth throughout the tidal delta and nearshore, and by analyzing a sub-sample of juvenile salmon otoliths to determine life history strategies. The findings support our hypothesis and point toward specific priorities for estuarine habitat restoration.

4.1. CHINOOK RESPONSE TO TIDAL DELTA HABITAT LOSS WITH VARYING POPULATION SIZE

If tidal delta habitat used by juvenile Chinook salmon has been reduced by 88% (Table 3.2), then we would expect to observe a limitation on the number or size of juvenile Chinook salmon rearing in tidal delta habitat over varying freshwater smolt outmigration population sizes. If tidal delta habitat were limiting, then we would also expect the juvenile Chinook salmon population to experience lower survival in tidal delta habitats or displacement from tidal delta habitats. Displacement would likely result in proportionally more juvenile Chinook salmon in Skagit Bay earlier in the year (coinciding with the tidal delta rearing period). To test the density-dependent migration hypothesis, we initiated field studies in the tidal delta and Skagit Bay. In 1992 we started monitoring the juvenile Chinook salmon population rearing in tidal delta habitat and comparing it to freshwater smolt population estimates based on lower river mainstem trapping by WDFW. We monitor bi-weekly from February through July at six index blind channel sites (three sites each in the North and South Fork deltas) to represent the juvenile Chinook salmon population using tidal delta habitat each year. Methods are those described in Appendix D.I for fyke trapping. We also began monitoring the population of juvenile Chinook salmon in Skagit Bay in 1995, using large net beach seine methods described in Appendix D.I.

After monitoring population sizes ranging from 800,000 to 7,100,000 we found the relationship between freshwater wild juvenile Chinook salmon population size and wild juvenile Chinook salmon abundance in tidal delta habitat is density dependent (Figure 4.1A). We also found a mirror image when examining the average residence time of juvenile Chinook salmon in tidal delta habitat (Figure 4.1B). As the total freshwater smolt population increased, average residence time declined. These results support the idea that present day Skagit tidal delta habitat conditions are limiting the capacity of tidal delta-rearing Chinook salmon.

Additionally, the proportion of the total wild juvenile Chinook salmon population that bypasses rearing in tidal delta habitats and migrates directly to Skagit Bay (fry migrants) increases with wild smolt outmigration levels above 2,500,000 (Figure 4.1C). This finding indicates that at least some of the density dependence occurring in the tidal delta results in the displacement of juvenile Chinook salmon out of the rearing habitats in the tidal delta where they end up in Skagit Bay.

Model results by Greene and Beechie (2004) independently parallel our field results. By using a life cycle model that incorporates survival and area of spawning, stream, tidal delta, and nearshore habitat, Greene and Beechie (2004) determined that if density-dependent interactions result in higher migration downstream, the best opportunity for restoring capacity to the Skagit population would be to increase tidal delta habitat.

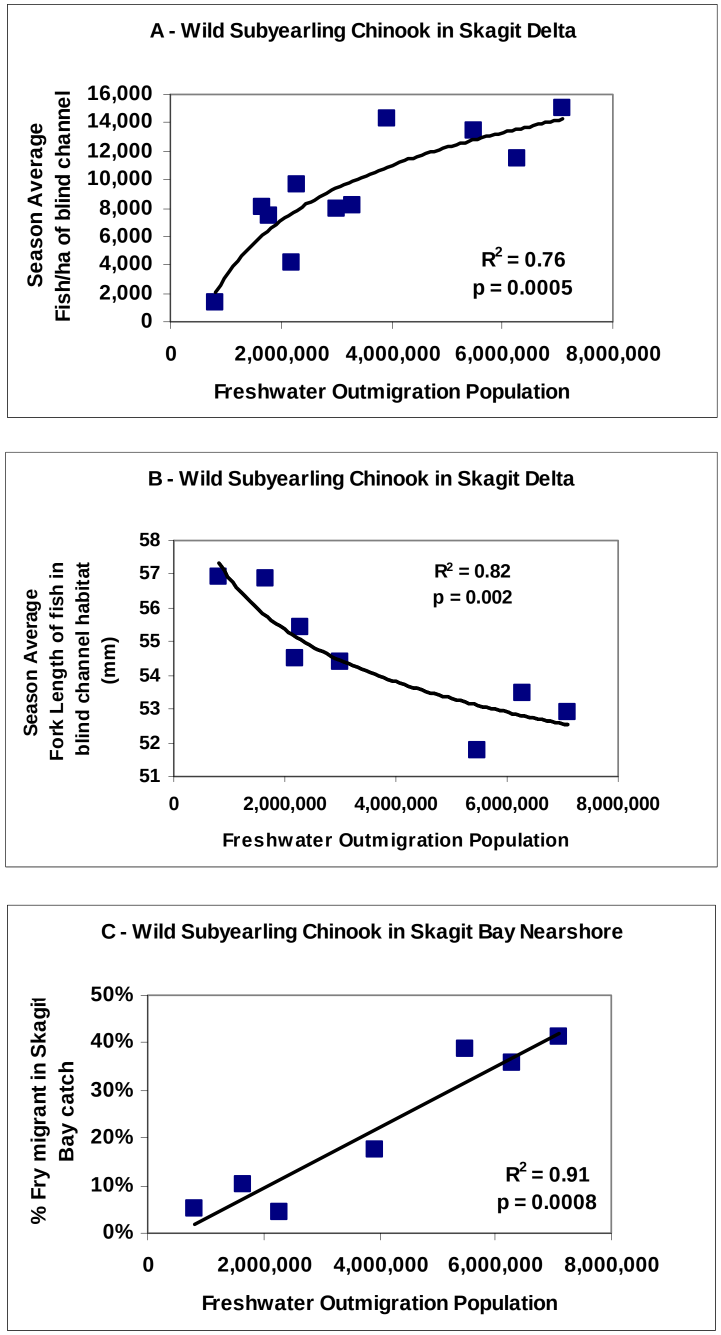


Figure 4.1. *Density dependence in the Skagit delta.*

(A) Relationship between juvenile Chinook abundance in delta habitat and total outmigration population size. The number of wild juvenile Chinook per unit area within delta blind channel habitat levels off as the total number of outmigrating Chinook salmon increases, indicating that delta habitats are filling up.

(B) Relationship between juvenile Chinook size and total outmigration population size. The size of wild juvenile Chinook salmon rearing in delta blind channel habitat declines as total juvenile Chinook population increases.

(C) Relationship between fry migrant and total outmigration population size. The proportion of the juvenile Chinook population in Skagit Bay that are fry migrants (those migrating directly to Skagit Bay without residing in the delta) increases as the total outmigrating population increases, indicating delta density dependence results in displacement of fish from delta to bay habitats.

Juvenile Chinook density estimates in the delta are 1992-2002 seasonal averages derived from 6 index sites using fyke trapping methods. The proportion of the Skagit Bay juvenile Chinook population that are fry migrants is derived from 6 Skagit Bay index beach seine sites, 1996-2002. Freshwater Chinook smolt population estimates are from WDFW, Olympia, WA.

4.2. TIDAL DELTA HABITAT AND GROWTH OF JUVENILE CHINOOK SALMON IN SKAGIT BAY

In this section we show that loss of tidal delta habitat has impacted the growth and survival of juvenile Chinook salmon in addition to delta habitat capacity.

Considering the tidal delta density dependent relationship exhibited by wild Chinook salmon and the fry migrant response, we examined some potential relationships between tidal delta and bay residence and growth using juvenile Chinook salmon otolith microstructure (Beamer and Larsen 2004). For these analyses only juvenile life history types potentially affected by tidal delta density dependence were examined. These include tidal delta rearing life history types and fry migrants.

All growth relationships support the idea that a tidal delta rearing period improves growth of wild juvenile Chinook salmon after they reach Skagit Bay. Increased time of residence equates to a larger size before entering bay habitat. If faster growth is important to later survival, and we know that there is some form of density dependence occurring in the Skagit tidal delta, then it would make good restoration sense to increase tidal delta habitat capacity (and quality) in order to increase fish residence in the tidal delta habitat.

High survival rates have not been conclusively linked to high growth rates in young juvenile salmon (<110mm forklength), however this linkage has been demonstrated for both yearling and sub-yearling salmon. Studies in yearling spring Chinook salmon have demonstrated that faster growth prior to seawater entry in the spring improves smolt physiology (seawater adaptability) and smolt-to-adult survival (Wagner et al. 1969; Beckman et al. 1999). Bilton (1984) found that larger sub-yearling Chinook salmon survived to adulthood at a much higher rate than smaller fish. Clarke and Shelbourne (1985) showed that larger sub-yearling Chinook salmon have greater seawater tolerance than smaller fish. Parker (1971) showed that smaller fish in juvenile salmon populations were eaten at a higher rate than larger fish. Together, these studies strongly support the idea that faster growing and larger juvenile Chinook salmon have a survival advantage over smaller individuals.

A modeling study by Greene et al. (2005) found that conditions in Skagit Bay are a strong determinant of overall mortality across the life cycle of wild Skagit Chinook salmon. Skagit Bay residence is the beginning of the more marine rearing phase of the Chinook salmon life cycle. The otolith study links juvenile Chinook salmon survival potential in Skagit Bay to rearing time in the Skagit tidal delta. This means that the consequences of poor or limited habitat in an earlier life stage (e.g., a limitation in tidal delta capacity for tidal delta rearing juvenile Chinook salmon) may be observed later in the Chinook salmon's life cycle. Together, both studies provide strong evidence that tidal delta restoration will have a large benefit for the Skagit Chinook salmon population by alleviating capacity constraints in the tidal delta and also improving growth (and therefore survival) of fish after they reach Skagit Bay.

4.3. JUVENILE CHINOOK SALMON IN POCKET ESTUARIES

In this section we show that Chinook salmon naturally adopting the fry migrant life history strategy and fish displaced from tidal delta habitats to nearshore habitats (thus becoming fry migrants) utilize pocket estuaries during the early period of nearshore rearing. We propose that this use of pocket estuaries allows them to grow faster and avoid predation by other fish. Pocket estuaries are also important to maintain the diversity of life strategies and partially relieve delta overcrowding. It therefore follows that pocket estuary restoration is also important for Skagit Chinook salmon population recovery.

Juvenile Chinook salmon accumulate in pocket estuaries during late winter and early spring (Beamer et al. 2003). Juvenile Chinook salmon use of pocket estuaries is described as “non-natal” use because juvenile Chinook salmon do not originate from the watersheds draining into the pocket estuaries. All Chinook salmon utilizing pocket estuaries must find them via migration pathways through Skagit Bay. Skagit River-origin Chinook salmon can migrate from the Skagit River and delta into nearshore areas of Skagit Bay, and then into pocket estuary habitats associated with Skagit Bay.

Abundance of wild Chinook salmon fry migrants in pocket estuary habitat more closely mimics wild juvenile Chinook salmon use in the tidal delta habitats of the Skagit River than in adjacent nearshore or offshore areas (Beamer et al. 2003). Juvenile Chinook salmon are over 100 times and 10 times more abundant in pocket estuary habitat than in offshore or nearshore habitat, respectively, during the period from February through May[5]. There is a seasonal shift in habitat occupancy by juvenile Chinook salmon from shallow, more protected habitats (like pocket estuaries and tidal delta blind channels) to offshore areas later in the year.

While the accumulation of juvenile Chinook salmon in winter and early spring in Skagit Bay pocket estuaries is clear, we do not yet fully understand what aspects of pocket estuaries affect habitat functions for fry migrants. Later in this document (section 4.4) we propose that the complexity and distance of the pathway salmon must follow to reach the pocket estuary are important, but it is likely that such attributes as amount of freshwater inflow, size, shape, amount of vegetation present, as well as anthropogenic factors also affect pocket estuary habitat functions.

The increased size of juvenile Chinook salmon in pocket estuaries compared to fish found outside pocket estuaries suggests that productivity of these systems may be greater than nearshore areas in winter and early spring (Beamer et al. 2003). These systems are also somewhat warmer at this time of year than surrounding nearshore waters. If this productivity hypothesis is true, pocket estuary habitats may provide the “best” feeding area available to the fish at this time of the year and allow fish to outgrow their potential predator population as rapidly as possible.

Pocket estuaries also appear to provide fry migrant Chinook salmon refuge from larger predatory fish compared to the adjacent nearshore environment (Beamer et al. 2003). We found relatively few large predators such as cutthroat trout, bull trout, and yearling salmon in pocket estuaries. While we found many staghorn sculpins in pocket estuaries, they tended to be not large enough

[5] These differences in density assume no difference in catch efficiency between the different methods used to capture fish. This assumption is likely not entirely true. However, our beach seine capture efficiency is approximately 80% and our fyke trapping methods already account for efficiency (see Appendix A) so townet efficiency (the method used to capture fish in offshore habitat) would need to approach 8% or 0.8% respectively to negate our density conclusion (Bax 1983).

in pocket estuaries to be predators on juvenile salmon. The importance of bird predation on fish rearing in pocket estuaries is unknown but it could be significant. We have observed Great Blue Herons feeding on unknown prey species at the mouths of outlet channels as the tide ebbs; salmon could be one of their target prey species.

Pocket estuaries may benefit displaced tidal delta rearing life history strategies as well as intrinsic fry migrant life history strategies. We have discussed how the current constraining tidal delta conditions "export" some juvenile Chinook salmon to Skagit Bay where they are less well suited to survive (sections 4.1 and 4.2). If exported fish find pocket estuary habitat within Skagit Bay, they may be able to mitigate, to some degree, the effects of tidal delta density dependence by rearing in pocket estuaries. Pocket estuary habitat appears to be not only preferred nearshore habitat early in the year, but also a safer and more productive habitat compared to other nearshore habitats. Thus, we advocate restoring pocket estuary habitat, especially sites in close proximity to the delta, where juvenile Chinook salmon can easily find them. Restoration of pocket estuary habitat should benefit intrinsically occurring fry migrant Chinook salmon and "exported" fry migrants regardless of the reasons that these fish are in the nearshore (e.g., tidal delta density dependence or environmental events that move juvenile salmon, such as floods). Restoration of pocket estuary habitat helps diversify our estuarine restoration portfolio but it won't replace tidal delta restoration. Though pocket estuary habitat was historically more abundant than at present around Skagit Bay, its restoration potential, while significant, is not sufficient to completely solve the effects of tidal delta density dependence.

4.4. BIOLOGICAL RESPONSE TO CONNECTIVITY

In this section we show that habitat connectivity influences juvenile salmon abundance in estuarine habitats. Therefore improving connectivity in the delta and between pocket estuaries must be part of an estuary restoration strategy.

4.4.1 Landscape Connectivity

One of the important emerging aspects of salmon recovery is the application of landscape ecology principles and concepts to the restoration and protection of salmonid ecosystems (Simenstad 2000, Simenstad and Cordell 2000, Roni et al. 2002, Hood 2002a and 2002b). Landscape context refers to the spatial arrangement of habitat, including its size and shape; location of the habitat within the estuary; the composition of surrounding habitat; and connectivity with other habitats (Turner 1989). In short, a landscape view of salmon habitat proposes that the function of any unit of habitat depends upon the context of that habitat within the "bigger picture" of the surrounding habitat.

Applying landscape concepts to the Skagit estuary, Congleton et al. (1981) speculated that much of the habitat along the central Fir Island delta was not used by juvenile salmon because there were no direct delta channel pathways to it. Yates (2001) found a northward decline in juvenile Chinook salmon abundance along Swinomish Channel that he attributed to a physical blockage between the North Fork and Swinomish Channel and a sudden increase in salinity located at the southern end of Swinomish Channel at Hole-in-the-Wall. While these authors did not specifically use a landscape variable such as habitat connectivity to interpret their results, they do show that juvenile salmon abundance is not homogeneous across the Skagit River estuary, implying that pathways to habitat likely influence fish use.

Within the delta and nearshore ecosystems of the Skagit River, we explicitly use habitat connectivity as an attribute to help value specific habitat types. We consider connectivity at two different scales. First, we refer to landscape or large scale connectivity as the relative distances and pathways that salmon must travel to find habitat. As we use it, landscape connectivity is a function of both the distance and complexity of the pathway that salmon must follow to certain types of habitats (e.g., blind tidal channels and pocket estuaries). Habitat connectivity decreases as complexity of the route the fish must swim increases and the distance the fish must swim increases. Within the delta, the complexity of the route fish must take to find key habitat is measured by the distributary bifurcation order (Figure 4.2, methods described in Appendix D.V) and distance traveled. After the fish leave the delta, we add distance traveled in the bay following surface current patterns mapped by drift buoy trials (Appendix D.VI). Thus, a pocket estuary located within 10 km of the delta is of higher value (other factors being equal) than a pocket estuary located 20 km from the delta.

Landscape connectivity (C) is calculated:

$$C = \frac{1}{\sum_{j=1}^{j_{end}} (O_j * D_j)}$$

Where:

O_j = distributary channel order for channel segment j

D_j = distance along segment j of order O_j

j = count ($1...j_{end}$) of distributary channel segments

j_{end} = total number of channel segments at destination or sample point

4.4.2 Local Connectivity

In addition to landscape scale connectivity, we also use local scale connectivity to help value specific units of habitat. As we use it, local connectivity refers to the accessibility of habitat to juvenile salmon and is defined by channel depth at high tide of either the entrance to a pocket estuary or blind tidal channel network (Figure 4.3). A deeper channel will have higher connectivity than a shallower channel. We recognize that other factors, such as local temperature and velocity, may define accessibility; however we believe that depth is a reasonable surrogate for connectivity at this scale. Our definition of local connectivity is synonymous with the concept of habitat opportunity proposed by Simenstad (2000), Simenstad and Cordell (2000), and then applied in studies of the Columbia River Estuary (Bottom et al. 2001). They defined *opportunity* as the ability of juvenile salmon to "access and benefit from the habitat's capacity" and included tidal elevation, velocity, and temperature as measures of opportunity. The above authors distinguished habitat *quality* or *capacity* from opportunity. They define quality as habitat attributes that encourage production for juvenile salmon via things such as feeding, growth and reduced mortality. Examples include predation population sizes, prey production and availability, and the maintenance of prey communities.

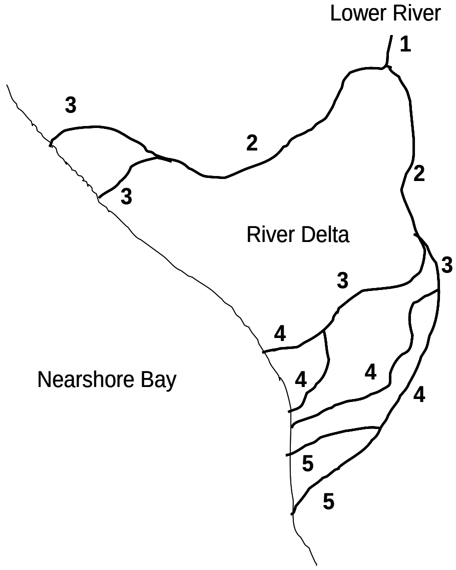


Figure 4.2. *Delta distributary channel bifurcation ordering.*

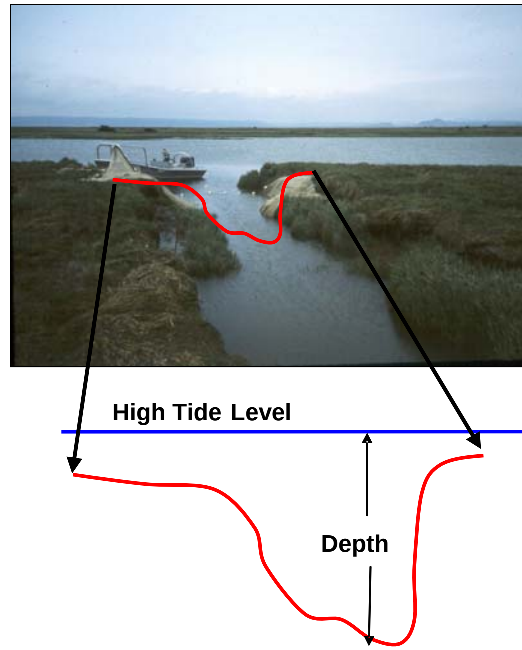


Figure 4.3. *Local scale connectivity.* Measured as depth of water at high tide at the channel entrance for a delta channel or pocket estuary.

4.4.3 Juvenile Chinook Density and Connectivity

Our results show differences in connectivity influence juvenile Chinook salmon abundance in both tidal delta and pocket estuary habitats. We illustrate the influence of landscape scale connectivity using data collected at 18 sites throughout the Skagit estuary (Figure 4.4). Daily average juvenile Chinook salmon density[6] increases as a function of landscape connectivity until a connectivity value of approximately 0.035, where the relationship may level off (Figure 4.5A). Sites with landscape connectivity values greater than 0.035 average 11,200 juvenile Chinook salmon per hectare of tidal delta blind channel over the season. This fish density may approach carrying capacity of those sites, although this idea should be tested with data from additional sites with high connectivity and other years. Increasing local connectivity corresponds to increasing juvenile Chinook salmon abundance in pocket estuary habitats (Figure 4.5B).

We propose that Chinook salmon population recovery planning should consider restoration of connectivity within the delta as a primary goal because of the historic loss in connectivity due to blocking distributary channels. Restoration planning should also apply the concepts of connectivity to prioritize and predict outcomes of specific delta and pocket estuary restoration sites.

[6] Daily average Chinook salmon density is estimated for the period February through June, a period of 150 days where we observe the use curve of juvenile Chinook salmon in pocket estuaries and tidal delta habitat. We conduct bi-weekly sampling during this period and estimate a density (fish/ha) for each sampling event. We average these data by month and calculate a cumulative seasonal density by multiplying the monthly average by the number of days in each month and summing the value for each month. The cumulative seasonal density is divided by 150 (days) to yield a daily density averaged over the season.

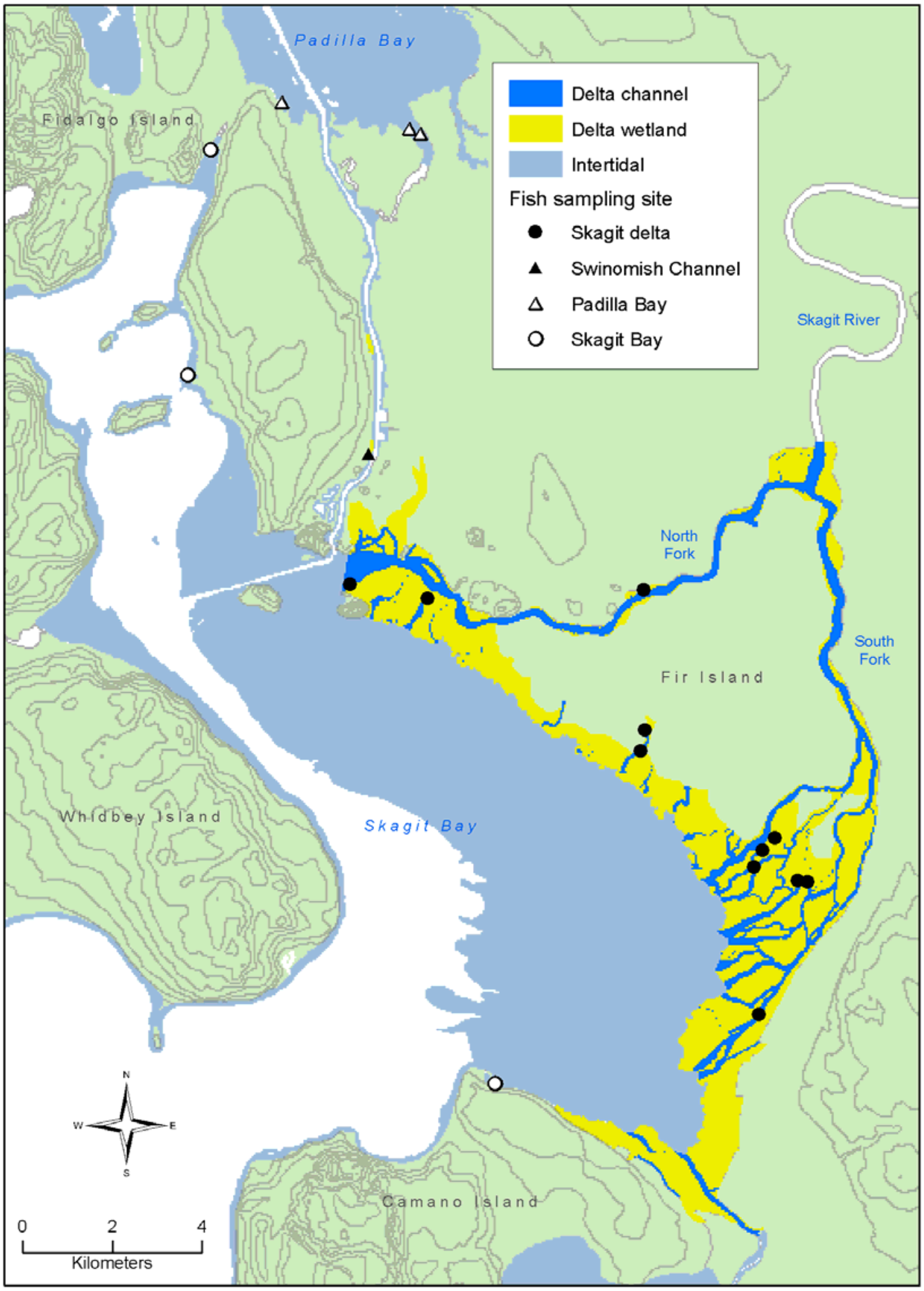
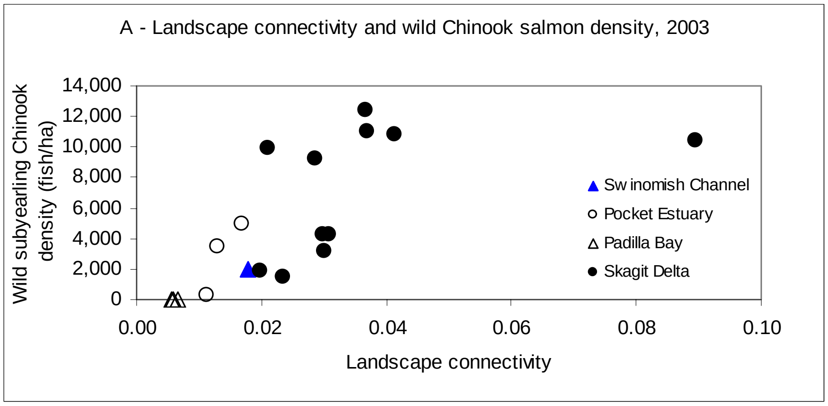


Figure 4.4. *Location of Skagit delta, Swinomish Channel, Padilla Bay, and Skagit Bay pocket estuary fish sampling sites in 2003.* Landscape scale connectivity values ranged from 0.0057 in Padilla Bay to 0.089 along the North Fork Skagit River.



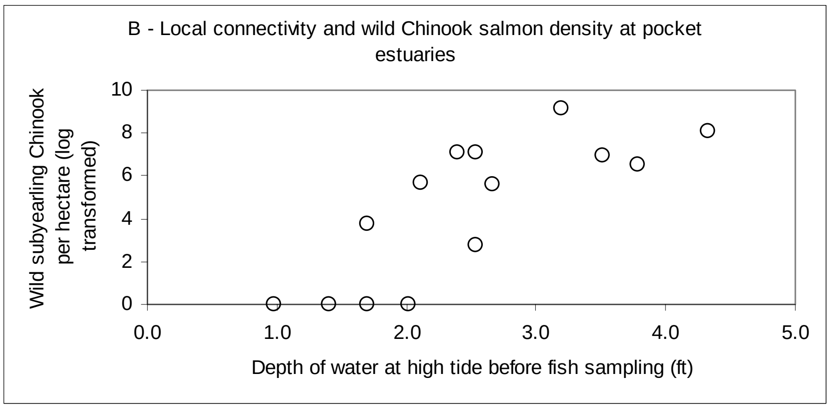


Figure 4.5. *Influence of landscape connectivity (A) and local connectivity (B) on juvenile Chinook salmon abundance at sites within the Skagit estuary.*

4.5. CURRENT CAPACITY OF THE TIDAL DELTA

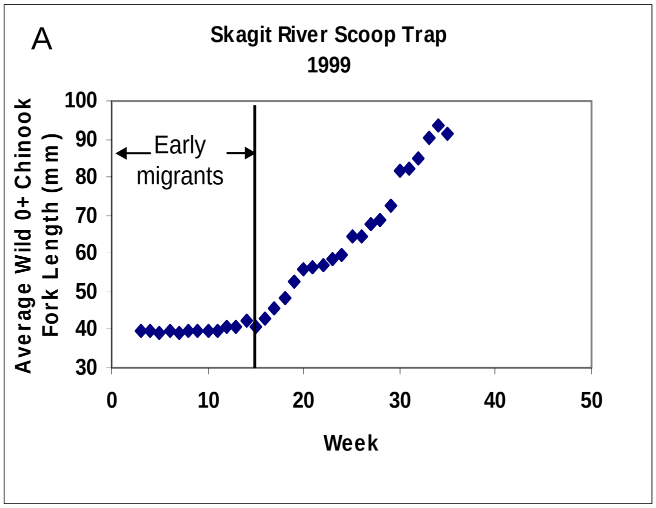
To quantify the need for and benefits of any restoration efforts, we need to know the fish rearing capacity of existing habitats. In this section we describe how we estimated the rearing capacity of the current Skagit River tidal delta. The fish population estimates and habitat capacities presented below and in following sections are average or point estimates that imply more precision than is warranted. For example, juvenile Chinook salmon population estimates should be considered accurate to the nearest 100,000. However, we presented our results in this manner to complete the modeling efforts needed to estimate the benefits of individual restoration actions. In a later version of this document we anticipate presenting confidence limits on estimates.

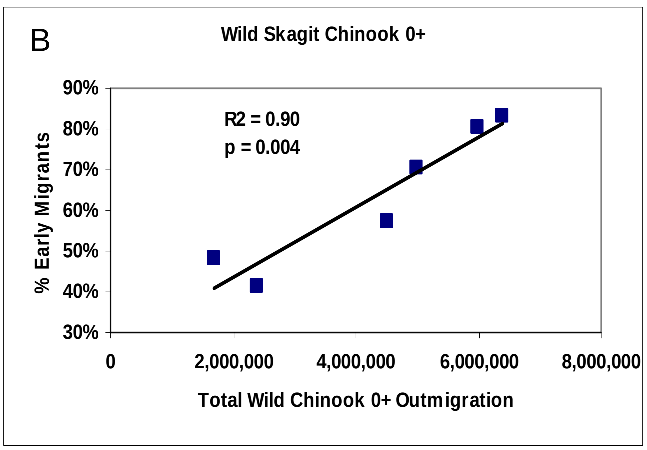
Limited capacity in the tidal delta results in a shift in life history type distribution within the juvenile Chinook salmon population (section 4.1). Our tidal delta density dependence model estimates the current tidal delta rearing capacity is reached at an outmigration population size of 5,100,000 freshwater migrants through the lower river. The model parameters used to estimate capacity include smolt population size and three principle components that relate to connectivity of current tidal delta habitat. While the details of this model are described in Appendix D.VII, the capacity of tidal delta habitat is observed simply in Figure 4.1. However, not all subyearling Chinook salmon passing through the lower river over the extended migration season have the opportunity to rear in tidal delta habitat or are the life history type that would rear in tidal delta habitat. While we observe juvenile Chinook salmon capacity in the tidal delta at an outmigration population size of 5,100,000 freshwater migrants, we need to subtract the parr migrants (fish that don't rear in tidal delta habitat) and the fry migrants (naturally occurring and those that are displaced from a tidal delta that is populated to capacity) to estimate the current tidal delta rearing capacity.

By examining the freshwater outmigration data we can break the migrating population into early and late migrants based on the population's weekly length trend (Figure 4.6A). Early migrants are smaller, while late migrants are larger. The later migrants are larger in size because of their longer rearing period in the freshwater environment. The proportion of population that exhibits early migration strongly fluctuates as a result of overall population size (Figure 4.6B). Conversely, the number of late migrants does not appear to fluctuate as a function of overall population size (Figure 4.6C). These figures indicate a limitation in freshwater habitat capacity; as freshwater habitat fills up, the excess fish respond by moving downstream. The number of late migrants is a good surrogate for the number of parr migrants. The number of parr migrants has averaged 1,320,419 over the period of record (1997-2002). Therefore, the number of subyearling Chinook salmon that could potentially rear in tidal delta habitat is 3,779,581 (5,100,000 – 1,320,419).

Next we need to account for the fry migrant population before we can estimate the capacity of the current tidal delta, because not all 3,779,581 juvenile Chinook salmon moving through the lower Skagit River will take up residence in tidal delta habitat. A significant proportion of this population, especially as tidal delta capacity is approached, will become fry migrants. Our field studies show the fry migrant population at an outmigration size of 5.1 million is approximately 30% of the Skagit Bay juvenile Chinook salmon population over the season (Figure 4.1). Assuming migration and survival rates within Skagit Bay are the same for all juvenile Chinook salmon life history types when they reach Skagit Bay, we can estimate the number of fry "exported" to Skagit Bay as fry migrants is 1,530,000 (5,100,000 x 30%). By accounting for the other life history types, we estimate the current tidal delta rearing capacity is a population of 2,249,581 sub-yearling Chinook salmon (5,100,000 minus 1,320,419 parr migrants minus 1,530,000 fry migrants).

Survival rates in Skagit Bay are probably lower for fry migrants compared to other life history types so the estimate of 1,530,000 fry migrants is probably conservative (low). If migration rates for fry migrants are faster than other life history types, then the population estimate would also be conservative. If migration rates are slower, then the estimate would be high. Existing juvenile otolith data does not find any fry migrants present in Skagit Bay habitat after 20 days while tidal delta rearing life history types are found in bay habitat for over 40 days (Beamer and Larsen 2004). Fry migrants either exit the bay or die quickly. We suspect the fry migrant estimate is low and therefore the tidal delta rearing capacity might be estimated high.





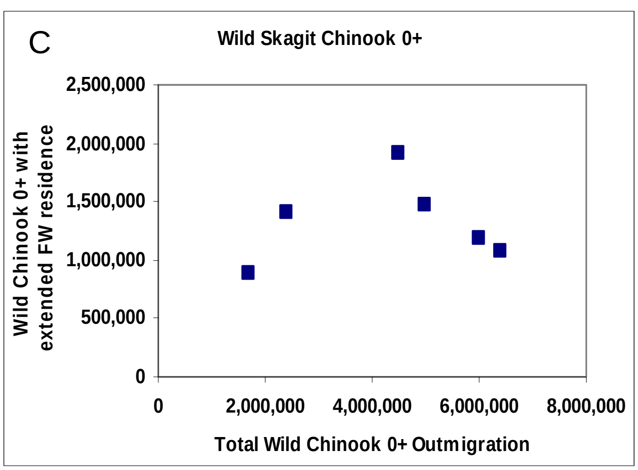


Figure 4.6. *Freshwater outmigration data.*

(A) Average length trend of subyearling Chinook salmon moving through the lower Skagit River in example year 1999. Fish captured before week 15 (mid-April) were similar sized reflecting a population that migrated relatively quickly following emergence. After week 15, the average length of juvenile Chinook salmon steadily increased reflecting a population that delayed in riverine habitat long enough to exhibit growth.

(B) The relationship between total freshwater wild Chinook salmon population size and the proportion of the population that are early migrants (those fish that don't exhibit significant growth in freshwater).

(C) The relationship between total freshwater wild Chinook salmon population size and the number of late migrants (those fish that do exhibit significant growth in freshwater).

Our research has demonstrated that members of each of our four juvenile Chinook life history strategies are produced each brood year. Absolute numbers, relative numbers (to the other life history stages), and survival of each of these life history stages undoubtedly varies within and between years. A number of factors can influence abundance and survival of life history strategies including variability in climate, habitat conditions, population of origin, biological interactions, and environmental conditions (e.g., flow). Our analyses show that two factors influencing the survival and abundance of the fry and parr life history strategies are limitations in the capacity of freshwater and tidal delta habitats to rear fish. In freshwater, we propose that as freshwater rearing habitat "fills up", the excess fish respond by moving downstream into the delta. We measure this response as increased fry abundance in the tidal delta as a function of outmigrant population size. Clearly, freshwater conditions will affect the proportion of each history strategy being produced by the population. Although we are fundamentally measuring this response at the population level, the density dependent processes that result in fry moving downstream to the estuary likely occur at multiple scales of space and time. For example, different portions of the watershed will vary in their capacity to support fish based upon the habitat conditions that are present there. Similarly, within one part of a basin, the outcomes of the interactions of individual fish as defined by food supply, physical habitat conditions, and environmental conditions, will determine what fish and how many of them ultimately move downstream.

In tidal delta habitats, we found the same type of density dependent response that appears to occur in freshwater. As tidal delta habitat fills up, the excess fish respond by moving downstream into Skagit Bay. Again, while we are fundamentally measuring this response at the population level, the density dependent processes that result in fry moving downstream into the bay likely occur at multiple scales. For example, different portions of the tidal delta will vary in their capacity to support fish based upon the habitat conditions that are present there. Similarly, within one tidal channel complex, the outcomes of the interactions of individual fish will determine what fish and how many move downstream. These processes are occurring continuously. We noted affects on size of tidal delta fry at varying densities but are unclear about the implications of these density dependent interactions to survival of the juvenile Chinook salmon. If fish size and survival are correlated as many studies have found (e.g., Healey 1991), then survival could be negatively affected

4.6. ESTIMATES OF MARINE SURVIVAL BY LIFE HISTORY TYPE

The year-to-year Chinook salmon production benefits of estuary habitat restoration will be influenced by survival of juvenile salmon in the marine environment. Large-scale climatic processes influence survival of salmon in marine habitat. Therefore, evaluating the consequences of marine survival on adult recruitment is critical to determine the long-term benefits of restoration. Marine survival estimates for wild Skagit Chinook salmon were generated as part of Greene et al. (2005). This study quantitatively synthesized information on spawning population sizes, age structure, and harvest to calculate return rates between 1974 and 1997 (spawners per spawner and recruits per spawner). Return rates were then correlated with environmental conditions occurring at different life stages. One primary result of the study is that the magnitude of incubation floods is an important predictor of return rate, corroborating the empirical relationship between flood magnitude and freshwater survival established by WDFW's outmigrant trapping (Seiler et al. 2003, R^2=0.84).

We used this empirical relationship to back-calculate freshwater survival based on flood magnitude for the entire 23-year period and factored this estimate out of the total survival estimate based on the return rate calculations. The resulting values, therefore, provide an estimate of marine-influenced survival (estuary residency through return) for wild Chinook salmon life history types. These estimates incorporate coded wired tag results only to estimate harvest.

During the 1974-1997 analysis period, we observed two different climate regimes influencing marine survival (Figure 4.7) corresponding to Pacific Decadal Oscillation (PDO) shifts in the region (Hare et al. 1999). We summarize these observations into three marine survival scenarios to incorporate large-scale climate patterns into our predictions for how restoration will benefit adult recruitment: 1) average marine survival under a high survival climate regime (1974-84 mean, Figure 4.7B), 2) average marine survival under a low survival climate regime (1985-97 mean, Figure 4.7B), and 3) low marine survival under a low survival climate regime (one standard deviation subtracted from the 1985-1997 mean using log-transformed data). These scenarios capture the normal range of marine survival as well as a "worst case scenario", based on the observed ranges of marine survival in the past. Values are shown in Table 4.1. We recognize that the worst-case scenario marine survival shown in Table 4.1 is lower than the lowest observed survival (Figure 4.7). However, the likelihood of detecting the worst-case marine survival in the 23 years of observation is low.

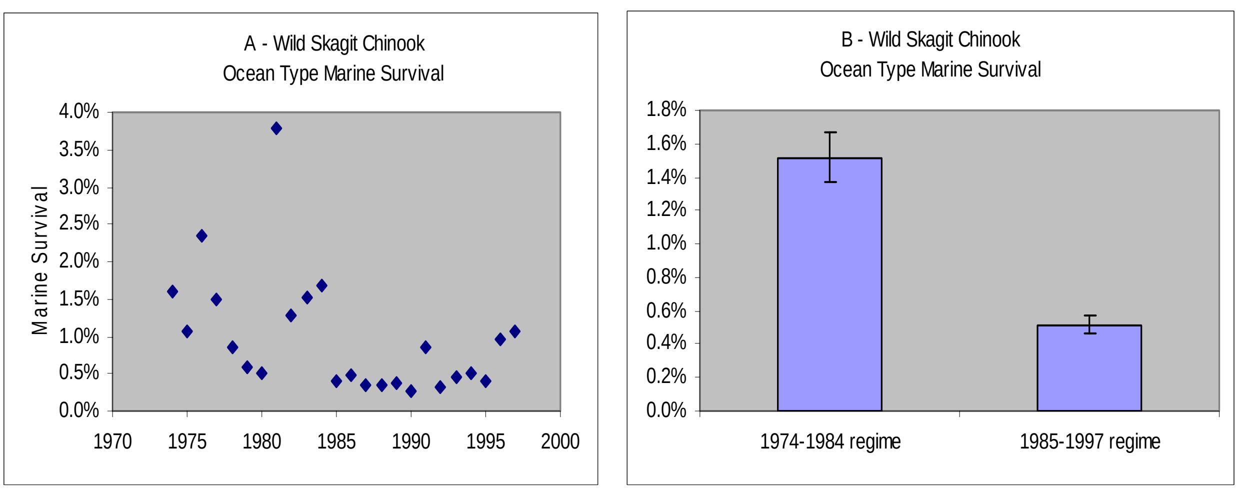


Figure 4.7. *Wild Skagit Chinook marine survival (A) trend and (B) average by climate regime. Error bars are 1 standard deviation.*

Marine survival of parr migrants and tidal delta rearing Chinook salmon are assumed to be the same because they leave the river system at the same time and at the same size (Hayman et al. 1996; SRSC/USGS unpublished otolith data). Both life history types achieve a similar size by occupying different habitat niches within the river or tidal delta for an extended period of time. Afterwards, they migrate from the river or tidal delta environment over the same time period and enter the marine environment together.

Table 4.1. *Summary of marine survival scenarios*. All adults recruited, accounts for fisheries.

Life History Type	Low survival (low regime)	Average survival (low regime)	Average survival (high regime)
Yearling Smolts	0.251%	1.191%	3.494%
Parr migrants	0.109%	0.518%	1.519%
Tidal delta rearing	0.109%	0.518%	1.519%
Pocket estuary rearing fry migrants	0.109%	0.518%	1.519%
Residual fry migrants (fry migrants that don't find pocket estuary habitat)	0.013%	0.060%	0.175%

Because fry migrants enter the nearshore environment much earlier than either parr migrants or tidal delta rearing Chinook salmon, we expect them to survive at a much lower rate. This thinking is supported by Skagit otolith data, where we have not observed a fry migrant with more than 20 days of bay residence, and the fact that we have not observed a fry migrant as a returning adult. Other studies support the position that fry migrant survival would be much lower than parr migrants or tidal delta rearing Chinook salmon (Parker 1971; Reimers 1973; Bilton 1984; Clarke and Shelbourne 1985; Levings et al. 1989; Greene et al. 2005).

One exception to this paradigm is the case where fry migrants find pocket estuaries. We assume fry migrants that take up immediate residency in pocket estuaries after leaving the river system survive at the same rate as tidal delta rearing and parr migrants. We base this on the size and timing of Chinook salmon within pocket estuary habitat and the evidence that pocket estuaries provide a significant refuge from predation (Beamer et al. 2003). Fry migrants that do not immediately find refuge in pocket estuary habitat we estimate survive at a rate of 11.5% of parr migrants and tidal delta rearing Chinook salmon. The reduction in marine survival is based on their small fish size and is calculated using allometric methods in McGurk (1996) and scaled to marine survival estimates for Skagit River Chinook salmon. We used the same method for yearlings only since they are larger than parr migrants and tidal delta rearing Chinook salmon their marine survival is higher.

We can estimate the adult Chinook salmon contribution for each life history type by multiplying their smolt population estimates by the marine survival estimates in Table 4.1. Results are shown in Table 4.2. Marine survival has a huge impact on the number of adult Chinook salmon surviving from each juvenile life history type. Our model of a 5,100,000 freshwater Chinook smolt migration could yield as few as 4,159 adults under very poor marine conditions or has high as 57,895 adults under more favorable conditions. Population recovery planning needs to take into account possible shifts in marine survival and ensure population recovery is achieved under a variety of conditions, including the worse case scenario.

Table 4.2. *Summary of capacity estimates for wild Skagit Chinook salmon at current (2005) estuarine habitat levels.*

Current Capacity	Juveniles per season	Adults per year (low survival on low regime)	Adults per year (average survival on low regime)	Adults per year (average survival on high regime)
Parr migrants	1,320,419	1,441	6,836	20,060
Tidal delta rearing	2,249,581	2,455	11,646	34,177
Pocket estuary rearing fry migrants	73,393[/a]	80	380	1,115
Residual fry migrants (fry migrants that don't find pocket estuary habitat)	1,456,607	183	866	2,543
Total	**5,100,000**	**4,159**	**19,728**	**57,895**

[a] Pocket estuary capacity for subyearling Chinook salmon is based on habitat area and connectivity.

5. IMPLICATIONS FOR RESTORATION

We have described how juvenile Chinook salmon utilize estuarine habitats in the Skagit tidal delta and nearshore environments, quantified anthropogenic habitat losses, and quantified how those habitat losses have impacted Chinook salmon populations. From this work we can conclude that estuary restoration in the Skagit tidal delta and nearshore would benefit Skagit Chinook salmon. In summary, our research leads to the following conclusions useful for Chinook population recovery planning:

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

2) Skagit tidal 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 tidal delta and pocket estuary sites.

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

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

5) Some fry migrant Chinook salmon rear and take refuge in pocket estuaries. Restoration of pocket estuary habitat can be a strategy to partially mitigate tidal delta density dependence and improve survival of naturally occurring fry migrants.
6) Differences in habitat connectivity influence juvenile Chinook salmon abundance in both tidal delta and pocket estuary habitats, indicating that habitat fragmentation, in addition to habitat loss, has been detrimental to Skagit Chinook populations. Connectivity is a function of both the pathways and distances that fish must travel to find habitat. 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 and 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 demonstrate that wild Skagit Chinook salmon populations will benefit from estuarine habitat restoration (both tidal delta estuary and pocket estuary habitat) and improved migration pathways within and between estuary habitats.

6. TOOLS FOR RESTORATION PLANNING

Having identified the need for restoration, we next must develop strategies and priorities for restoration to maximize the benefits to Chinook salmon recovery. Following are tools we have developed to predict benefits of candidate restoration sites. The first tool is a conceptual fish migration pathway model. This tool helps to identify which nearshore habitat areas might be more strategically located than others based on how fish might travel through the nearshore environment. The second tool is a capacity model to convert habitat areas of potential restoration sites to annual Chinook smolt production. These tools allow us to link potential estuary restoration with Skagit Chinook Salmon recovery goals.

6.1. A MODEL OF FISH MIGRATION PATHWAYS IN THE SKAGIT ESTUARY

Fish migration pathways link habitats. A model of fish migration pathways can inform us about where and when fish will be looking for habitat. We conducted a pilot drift buoy study to predict the migration pathways for fry migrant Chinook salmon leaving delta habitat and entering Skagit Bay (Appendix D.VI). The study documented the track of surface drifting buoys using GPS. Three to six buoys were set at the mouths of six different distributary channels at high tide and tracked over one ebb tide period. Water temperature and salinity were also collected just under the surface and at one-meter depth throughout the process of tracking each buoy. The study shows how surface waters move from the delta into Skagit Bay and provide a good starting point for linking delta habitat to Skagit Bay nearshore, something juvenile salmon must do as they migrate seaward. Our drift buoys averaged 1.3 km/hr over a 6 hour period suggesting fish could move over 7 km during one ebb tide. Migration rates range from 4-14 km/day for marked chum salmon in Hood Canal of the same approximate size as Chinook fry (Bax and Whitmus 1981).

The drift buoy study results are summarized with our juvenile Chinook salmon abundance data collected at index tidal delta and nearshore sites to hypothesize the current migration pathways of fry migrant Chinook salmon (Figure 6.1). Arrows indicate links between parts of the Skagit delta to specific nearshore areas in Skagit Bay. This has implications regarding which pocket estuaries are likely to be occupied by recently displaced fry migrant Chinook salmon. This gives us a strategic tool for planning restoration in both tidal delta and nearshore habitats by allowing us to include differences in migratory pathways as a factor in restoration site selection. We can also use this tool to consider the effects of restoring migration pathways on existing habitat.

In equating drift buoy data to juvenile Chinook salmon migration pathways, we assume that:

1) Young Chinook salmon fry are passive particles in open water at spatial scales larger than 1 km and therefore move in the general direction of the water.
2) Young Chinook salmon fry are surface water oriented in open water habitat. Therefore we could use surface water movement derived from drift buoy data as a surrogate for fry movement. This assumption is supported by townet work done by Stober et al. (1973).
3) Young Chinook salmon fry are shoreline oriented and prefer shallow habitats along shorelines to open water. Shoreline preference by young Chinook is illustrated directly by Skagit Bay juvenile Chinook salmon populations (Figure 2.1).
4) Young Chinook salmon fry prefer low salinity to high salinity water if available. This assumption is supported by Yates (2001), Beamer et al. (2003) and our work in tidal delta habitats (Appendix D.VII).

The drift buoy results explain how young Chinook fry can move into and across Skagit Bay over one ebb tide period and maintain their body in relatively low salinity surface water. For each drift buoy, salinity measurements were taken at the surface and at one meter below the surface throughout the ebb tide drift period (Figure 6.2). Each graph shows the average salinity at the surface is lower (fresher) than the average salinity at one-meter depth for each drift path. Salinity generally increases as distance from the river mouth increases but surface salinities remain below 10 ppt in most cases. The drift buoy results also explain how Chinook fry can reach shoreline areas around Skagit Bay within hours after leaving the tidal delta at high tide.

This study also revealed some potential effects of changing an estuary's mixing pattern or salinity regime. Our study shows that drift buoys generally moved in surface waters lower in salinity by approximately 5 ppt when compared to water one meter deep (Figure 6.2). However, salinity data from the buoys deployed on the north side of the North Fork did not follow this pattern. Buoys deployed from this area were influenced by the North Fork jetty. The jetty helps maintain a navigation channel between Swinomish Channel and Skagit Bay. The jetty shadows the area north of it from Skagit River flow, thus increasing the salinities north of the jetty. If low salinity water (from surface flowing river water) is an important variable for migrating juvenile Chinook salmon, then changes to the river hydrograph and changes to the pathways of river water within the tidal delta or nearshore environment (e.g., blocked-off sloughs, addition of jetties, or dredging channels) could influence how fish move within the delta estuary and nearshore landscape. This will influence the opportunity fish have to access existing or newly restored habitat.

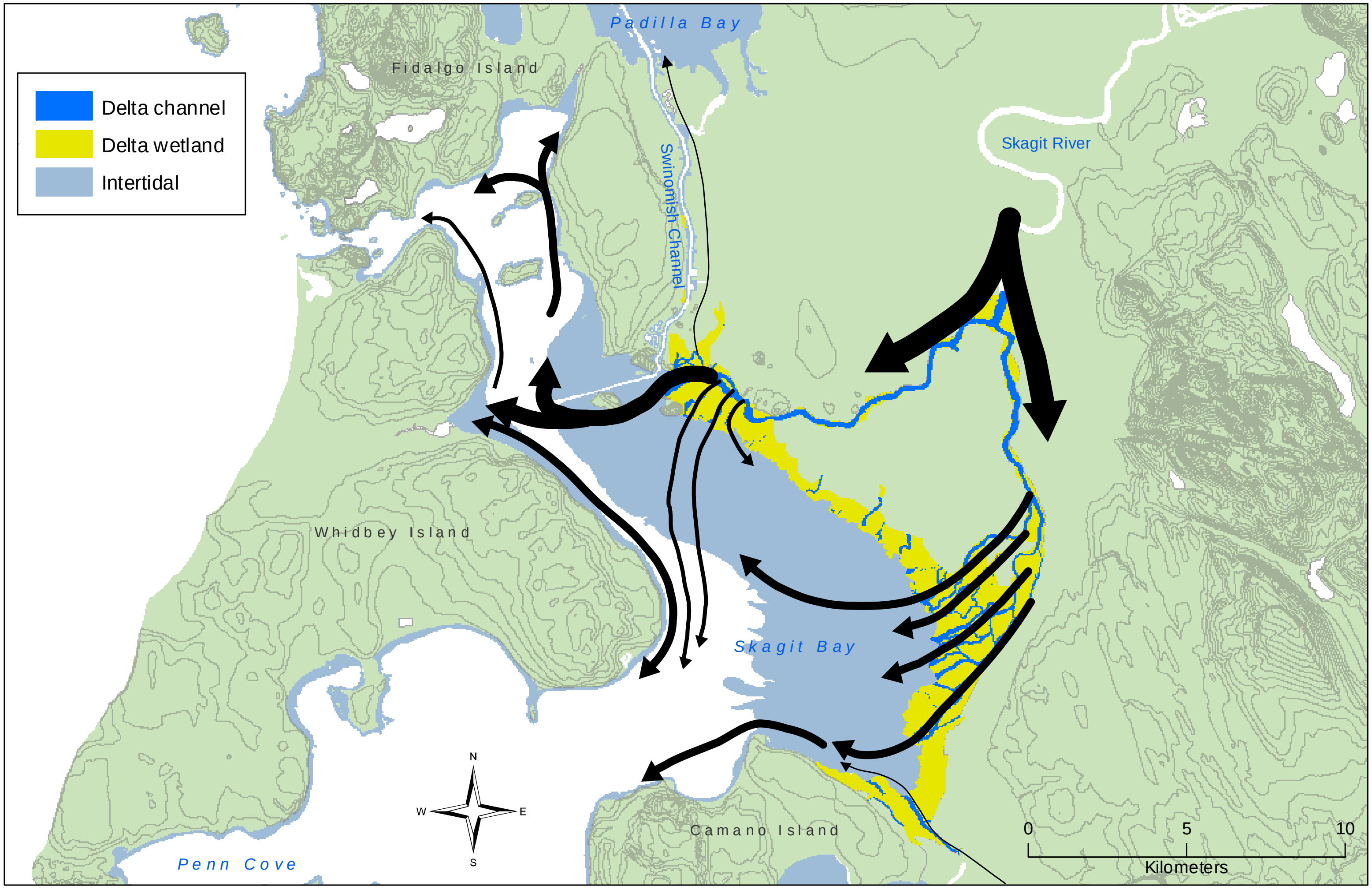


Figure 6.1. *Model of migratory pathways for juvenile Chinook salmon.* Under 2005 delta conditions, based on a synthesis of drift buoy results, connectivity, and spatial patterns in juvenile Chinook abundance. Arrow width represents fish use of pathways (wider arrows indicate more fish).

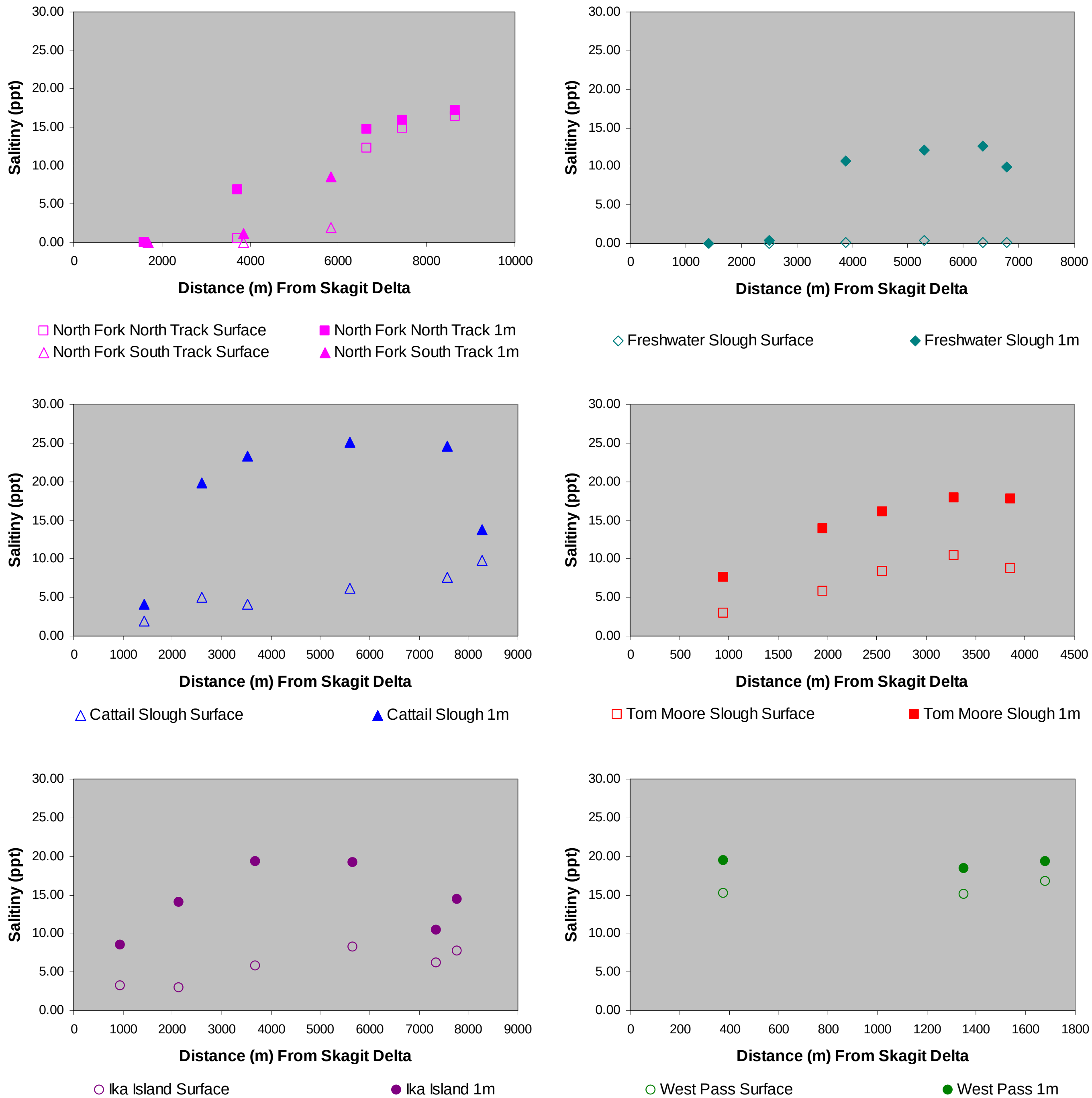


Figure 6.2. *Salinity at the surface and at one-meter depth along drift buoy paths.* Salinity is averaged for each hour of drift and plotted against distance traveled during that hour to show increasing salinity with increasing distance from the delta. In cases where salinity drops at the end of the drift cycle, buoys were nearing a pocket estuary freshwater source. At the North Fork site, drift buoys split into two distinctly separate paths, so they are graphed as such. The West Pass site is a tidal slough distributary of the Stillaguamish River, and thus is saltier overall than the other distributary sites monitored.

6.2. A MODEL FOR QUANTIFYING SMOLT PRODUCTION FROM HABITAT CAPACITY

Because each life history type depends on different habitats, we can observe the effect of current habitat limitation on population size and infer the effect of restoration on each life history type. For example, under current habitat conditions (and a sub-yearling outmigration population of 5.1 million) we have ~1.4 million residual fry migrants that produce proportionally few adult Chinook salmon (Table 6.1). Restoration actions that increase egg to fry survival will increase the number of residual fry migrants if no freshwater, tidal delta, or pocket estuary restoration is done. This will increase overall population size slightly but reduce overall productivity since the residual fry migrants' survival is the lowest rate of all life history types (Table 4.1). Actions that increase freshwater, tidal delta, or pocket estuary capacity will increase both overall population size and productivity. Below we estimate the benefits of completing tidal delta and pocket estuary restoration and compare them to existing conditions.

Table 6.1. *Summary of capacity estimates for wild Skagit Chinook at current (2005) estuarine habitat levels. (This is a repeat of Table 4.2.)*

Current Capacity	Juveniles per season	Adults per year (low survival on low regime)	Adults per year (average survival on low regime)	Adults per year (average survival on high regime)
Parr migrants	1,320,419	1,441	6,836	20,060
Tidal delta rearing	2,249,581	2,455	11,646	34,177
Pocket estuary rearing fry migrants	73,393[/a]	80	380	1,115
Residual fry migrants (fry migrants that don't find pocket estuary habitat)	1,456,607	183	866	2,543
Total	**5,100,000**	**4,159**	**19,728**	**57,895**

[a] Pocket estuary capacity for subyearling Chinook salmon is based on habitat area and connectivity.

We developed a statistical model using juvenile Chinook density data from six index sites, trapped bi-weekly from mid-February through mid-August within the Skagit tidal delta over the period 1992-2002, where the freshwater Chinook smolt outmigration ranged from 800,000 to 7,100,000. The density model predicts the daily density of Chinook smolts per m^3 at capacity for channel or open water impoundment habitat. The model explains 67% of the variation in observed density data. Abiotic factors related to connectivity account for 36% of the variation while density dependence (smolt outmigration size) accounts for 31%. The model is described in Appendix D.VII. Because we observed an asymptotic relationship between outmigration size and tidal delta habitat density, we can develop a model to calculate annual smolt capacity at any site where we know connectivity. We convert the daily capacity by multiplying it by the observed fish use period for the Skagit tidal delta and pocket estuary habitat (150 days) (Beamer and Greene 2005). We then adjust the seasonal capacity by an average resident period (35 days) for individual juvenile Chinook salmon in tidal delta habitat based on Skagit otolith data (Beamer et al. 2000a). This gives us the annual capacity of the restoration site in fish/m^3. The annual capacity is multiplied by the estimated habitat volumes for each potential restoration site to generate an estimate of juvenile Chinook per year. Methods for estimating habitat area and volume for tidal delta and pocket estuary sites are explained in Appendix D.III and Appendix D.IV, respectively. Juveniles per season are multiplied by the three different marine survival rates discussed in section 4.6 to yield the number of adult Chinook salmon under each marine survival scenario. Estimates for potential restored tidal delta and pocket estuary capacity are summarized in Table 6.2. Net changes (current and restored) are shown in Table 6.3.

Table 6.2. *Summary of capacity estimates for wild Skagit Chinook salmon at potential restored estuarine habitat levels.*

Restored Capacity	Juveniles per season	Adults per year (low survival-low regime)	Adults per year (average survival-low regime)	Adults per year (average survival-high regime)
Parr migrants (not changed)	1,320,419	1,441	6,836	20,060
Tidal delta rearing	3,602,371	3,932	18,649	54,729
Pocket estuary rearing fry migrants	221,264	241	1,145	3,362
Residual fry migrants (fry migrants that don't find pocket estuary habitat)	1,456,607	183	866	2,543
Total	**6,600,661**	**6,065**	**28,771**	**84,432**

Table 6.3. *Difference between current and restored estuarine habitat.*

Difference between Current and Restored	Juveniles per season	Adults per year (low survival-low regime)	Adults per year (average survival-low regime)	Adults per year (average survival-high regime)
Tidal delta restoration	1,352,790	1,476	7,003	20,552
Pocket estuary restoration	147,871	161	766	2,247

The current (year 2005) tidal delta Chinook smolt capacity estimate of 2,249,581 (shown in Table 6.1) does not directly use habitat areas multiplied by a juvenile Chinook capacity estimates per unit area of a habitat type; the 2,249,581 estimate is based on fish density data described in section 4.5. We can alternatively estimate current tidal delta capacity using the habitat area expansion method (the same method used to estimate the benefits of restoration) because we have a complete inventory of tidal delta habitat and an estimate of average connectivity. Current tidal delta capacity is 2,413,887 subyearling Chinook smolts annually under this method. Both methods estimate tidal delta capacity at similar levels.

7. DEVELOPING AN ESTUARINE HABITAT RESTORATION STRATEGY

The research presented herein, in combination with the planning tools developed, can be applied to Skagit Chinook salmon recovery planning. Our research has implication for tidal delta restoration and nearshore pocket estuary restoration.

7.1. TIDAL DELTA RESTORATION

Biological evidence strongly suggests that tidal delta habitat restoration and better connection to tidal delta habitat is required in order to improve wild Skagit Chinook salmon populations. In addition to restoring as much historic tidal delta habitat as possible, restoring connectivity within the tidal delta is important to optimize pathways for fish to access and occupy available habitat. Potential tidal delta restoration sites are shown in Figure 7.1.

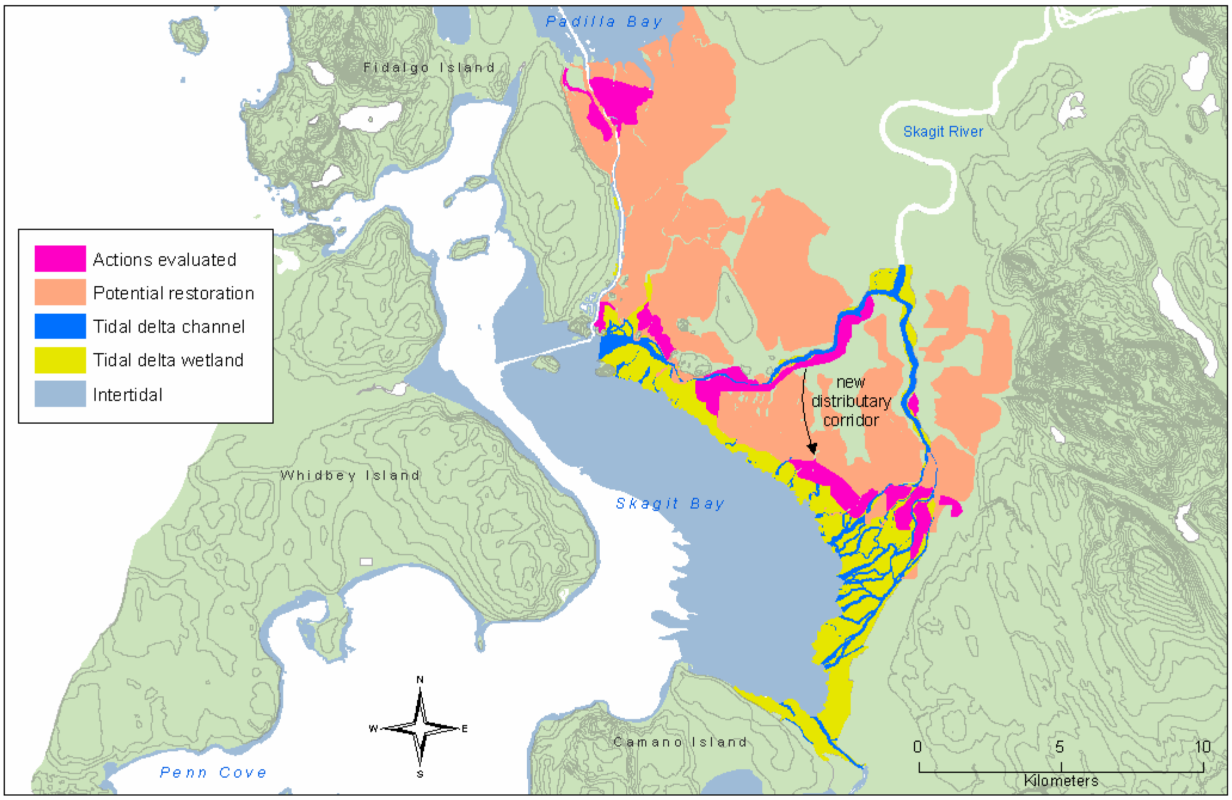


Figure 7.1. *Potential tidal delta restoration.* Location of existing delta habitats that are easily accessible to delta rearing Chinook salmon (yellow and blue polygons) and the location of delta restoration actions evaluated in this document (pink polygons). Polygons shown as "potential restoration" are areas where is it geomorphically possible to restore to tidal delta habitat (based on the historic limit of tidal delta habitat from Collins 2000).

Based on the arrangement of existing tidal delta habitat and the need for more of it, it is unlikely that we can achieve Skagit Chinook recovery without at least two tidal delta restoration projects that strongly improve the pathways for juvenile Chinook salmon to find and occupy tidal delta habitat. We propose two connectivity projects, one for central Fir Island (shown in Figure 7.1 as a new distributary corridor) and another for Swinomish Channel, as essential for maximizing the benefits of tidal delta restoration. The Swinomish Channel project will take advantage of the large restoration potential along Swinomish Channel and within southern Padilla Bay as well as improve pathways to existing underutilized nearshore habitat within Padilla Bay. The Fir Island project will reconnect the existing isolated tidal delta front to Skagit River distributaries.

7.2. NEARSHORE RESTORATION

Our nearshore restoration strategy focuses first on general precepts that can be applied throughout nearshore habitats in the Puget Basin that could be utilized by Skagit Chinook salmon as well as many Puget Sound and British Columbia stocks. Then, in more detail, we focus on restoration objectives in habitats specifically identified by our research in Skagit Bay: pocket estuaries utilized and preferred by Skagit-origin Chinook salmon.

Juvenile Chinook salmon utilize inland coastal waters such as the greater Puget Sound extensively, and survival during this residence period has been correlated with the overall success of their respective populations (Greene et al. 2005, Beamish et al. 2004). Chinook salmon using this area are exposed to different levels of survival risk due to differences in their migration timing, location, and duration of habitat use. Moreover, the greater Puget Sound environment is not homogeneous in habitat type or quality due to both natural and human causes. Thus Chinook salmon rearing potential varies across the landscape. A more specific understanding of the origins of juvenile Chinook salmon using this landscape will fill a glaring data gap needed for Puget Sound Chinook salmon population recovery by linking specific populations to specific areas within the greater Puget Sound and specific habitat types. The nearshore (intertidal and shallow subtidal) portions of the "salmonscape" can be influenced by human caused disturbances and thus can be improved by our management actions. A process-based restoration strategy is fundamental to long-term recovery because nearshore processes interacting with the landscape at a local scale determine and maintain the characteristics of habitats available to salmon and other species upon which salmon depend for their survival in the nearshore environment.

A process-based strategy requires that coastal and watershed processes influencing nearshore habitats remain or are restored to functional levels. These nearshore processes are both geomorphic and chemical. They include:

- Longshore sediment erosion, transport, and deposition within littoral cells
- Tidal erosion
- Tidal range, volume, and bathymetry
- Fluvial deposition
- Freshwater inflow and estuarine mixing
- Water and sediment quality

7.2.1 Landscape Process Restoration

Restoration at the landscape process scale ensures the sustainability of existing habitats and facilitates the recreation of lost historic habitat. Specific objectives of our strategy include:

1. Protect existing and restore lost pocket estuary marsh, channels and impoundments.
2. Protect existing and restore lost tidal connectivity and volume within pocket estuaries.
3. Preserve unarmored and restore armored sediment source beaches in littoral cells that create and maintain spits, forming pocket estuaries.

4. Restore lost pocket estuary sites over a large spatial scale to protect and restore regional scale connectivity between pocket estuaries and between deltas and pocket estuaries.
5. Protect existing and restore lost or degraded freshwater inputs (quantity and quality) to pocket estuaries.
6. Restore pocket estuaries of various geomorphic types to maintain habitat diversity and functionality throughout variable long-term climatic and oceanographic conditions.
7. Protect existing and restore armored coastal landforms, like spits and cusps, which form pocket estuaries such that these landforms can change and function naturally to protect and maintain pocket estuary habitat.
8. Remove impediments to fluvial and coastal sediment transport processes.
9. Protect and restore known forage fish habitats, including intertidal and subtidal spawning habitats for smelt, sandlance and herring as well as larval rearing areas (known to include pocket estuaries at least for smelt) and eelgrass meadows.
10. Identify and implement protocols that protect juvenile salmon in boat harbors and other industrialized or modified shorelines. Boat harbors are a common habitat in the current nearshore landscape. They are relatively protected from the natural coastal energy regime and therefore do attract juvenile salmon and other estuarine fishes. However, they are not natural habitats so we can expect the fish community to be different, possibly with the introduction of more predators or a changed food chain. Also, fish within these areas are exposed to risks such as direct pollution spills not present in natural habitats.
11. Plan for predicted sea level rise in all nearshore restoration projects.

In addition to landscape process restoration, part of ensuring safer transition of Chinook salmon from natal rivers to the open ocean is protecting “choke points” within the Puget Sound ecosystem from catastrophic human disturbances such as oil and toxic spills. Choke points are those places where large proportions of salmon populations must travel through. For Puget Sound Chinook salmon this would include Admiralty Inlet. For Skagit Chinook salmon, it would include Deception Pass, Swinomish Channel, and Saratoga Passage. One catastrophic disturbance in a choke point could destroy a very high percentage of an individual salmon population.

7.2.2 Pocket Estuary Restoration

The biological evidence from our research near the Skagit River indicates that restoration of pocket estuaries within the Skagit’s nearshore environment will help improve the abundance and resilience of Skagit Chinook salmon populations. Our nearshore restoration strategy is three-fold: 1) increase opportunity for juvenile Chinook salmon to utilize pocket estuary habitat close to their natal rivers so that outmigrants can make a safer transition from the river to the marine environment; 2) increase opportunity for juvenile Chinook salmon to utilize pocket estuaries throughout the Whidbey Basin for safe rearing and traveling through the nearshore; and 3) ensure healthy and functioning nearshore beaches connecting pocket estuaries for the benefit of forage fish and Chinook life history strategies that do not directly utilize pocket estuaries.

To maximize recovery benefits for Skagit Chinook salmon of any pocket estuary restoration, we first prioritize restoring and protecting pocket estuaries with a high degree of connectivity to the Skagit Delta. We have based our prioritization on existing fish migration pathways estimated from the drift buoy study (Appendix D.VI). We hypothesize that habitats "downstream" of tidal currents originating at river mouths are more important to fry migrant Chinook salmon populations than habitats "upstream" or distant from the same tidal currents. We base this hypothesis on our data suggesting pocket estuary habitats provide a rearing and refuge opportunity to fry migrants (Beamer et al. 2003) and on the idea that providing pocket estuary opportunity soon after fry leave delta or river habitats will reduce risk of mortality by reducing the time individual fish spend in the exposed nearshore or offshore environment at a small size.

Potential pocket estuary restoration sites are shown in Figure 7.2. Each site shown in the figure has existing habitat, restoration potential, or both. Based on our understanding of fish migration pathways from the delta to nearshore areas within Skagit Bay, juvenile salmon could reach any of these pocket estuary sites quickly, often within 5 or 6 hours after leaving the delta. Because it is reasonable to expect juvenile Chinook salmon can find these sites within a day of when they leave the river, we believe they are a restoration priority for fry migrants that experience tidal delta density dependence, or are flushed out of the river during a high flow event.

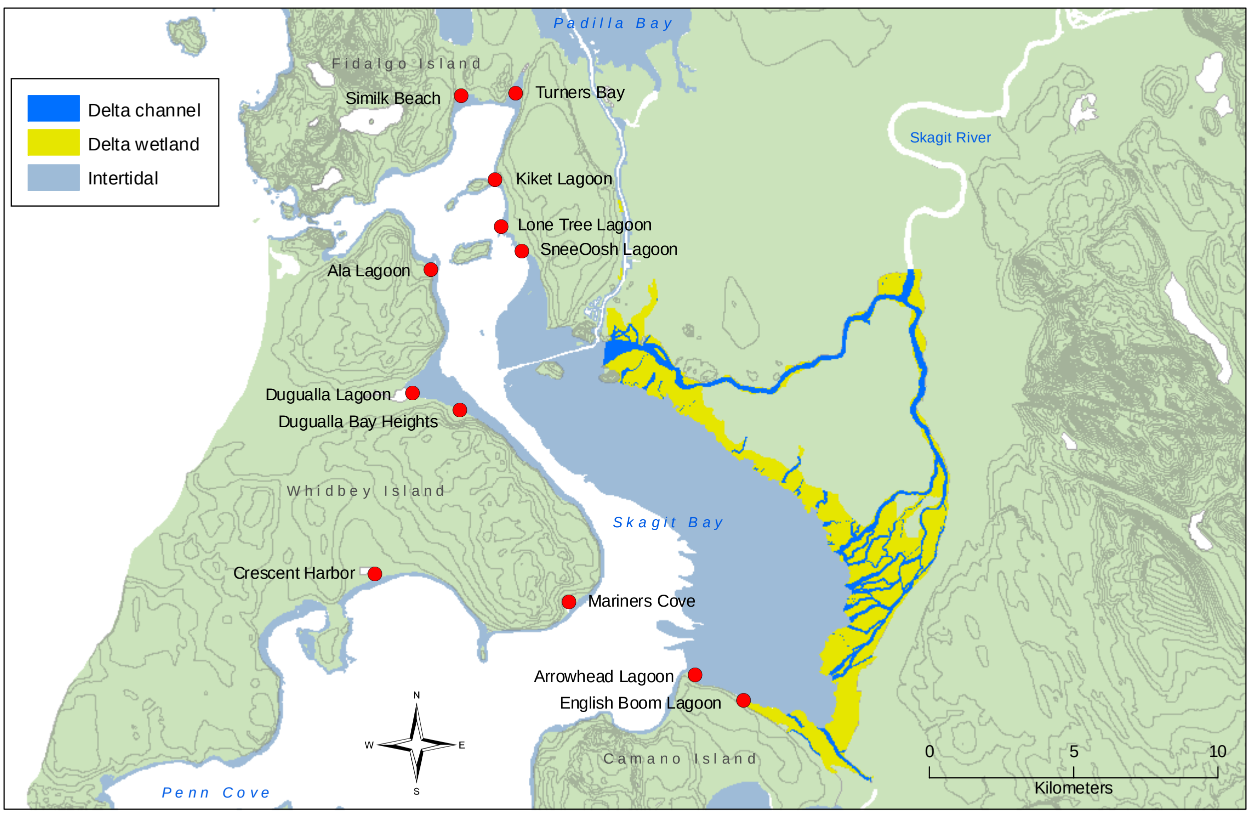


Figure 7.2. *Potential pocket estuary restoration sites.* Pocket estuary sites within one day's migration from the Skagit River delta by fry migrant Chinook salmon.

7.3. BENEFITS OF INDIVIDUAL TIDAL DELTA PROJECTS

The potential tidal delta restoration projects, if constructed, would increase the delta area exposed to river and tidal hydrology by 1,114.6 hectares (2,754.2 acres). We predict this newly restored tidal delta footprint will result in 58.2 hectares (143.8 acres) of restored tidal channel habitat, increasing the rearing capacity for tidal delta rearing Chinook salmon by 1,352,791 smolts annually (Table 7.1). The North Fork Setback and Cross Fir Island Connector clusters provide relatively higher benefits than all other project clusters because of their size and connectivity. The North Fork Setback cluster has the highest connectivity and largest potential footprint area. The clusters are located within the North Fork delta, the region with the least amount of habitat available (and therefore highest density dependence) for tidal delta rearing Chinook salmon. The Cross Fir Island Connector cluster has the largest potential channel area restored (due to formation of distributary channel as well as marsh habitats with blind channels) and the second highest connectivity. This project cluster increases tidal delta rearing capacity greatly and helps alleviate the density dependence along the North Fork by restoring a fish migration pathway directly to habitat within the central delta of Fir Island (Figure 7.1). The benefit of improving connectivity to existing central Fir Island delta is 67,828 smolts annually.

Significant restoration potential also exists along the northern end of Swinomish Channel. Two projects are shown in Figure 7.1. The smolt benefit for these projects is highly dependent on the Swinomish Channel Causeway project that improves connectivity between the North Fork and Swinomish Channel. Without the causeway project, the combined benefit for these two projects is 72,622 smolts annually. With the causeway project, the combined benefit for these two projects almost doubles to 133,616 smolts annually. The Swinomish Channel Causeway project also improves the value of existing habitat along Swinomish Channel and in southern Padilla Bay. The gain to existing habitat is 40,898 smolts annually. Another potentially important part the causeway project is that it improves migratory pathways to under-utilized eelgrass habitat within Padilla Bay (Yates 2001). We have not modeled a benefit for this aspect of the Swinomish Channel Causeway project.

Table 7.1. *Summary of potential habitat area, connectivity, and annual smolt benefit after restoration.*

Project Area	Potential estuarine area (ha)	Potential channel or openwater area (ha)	Connectivity index	Smolt capacity
Cross Fir Island Connector	191.175	14.628	0.026	264,486
Deepwater Slough Phase 2	108.515	4.516	0.045	95,516
Dodge Valley	34.201	1.039	0.060	30,036
Fisher Slough	27.503	0.810	0.042	16,431
Milltown Island	68.789	3.145	0.038	57,179
North Fork Setback	266.215	12.196	0.092	625,032
South Fork Setback	16.305	0.374	0.081	14,588
Sullivan Slough Setback	79.616	2.012	0.038	36,517
Swinomish Channel East[1]	196.926	14.918	0.016	113,145
Swinomish Channel West[1]	60.397	2.594	0.017	20,471
Wiley Slough	65.000	2.000	0.040	38,492
Swinomish Channel Causeway (change in existing habitat due to connectivity)	NA	NA	NA	40,898
Total	**1,114.642**	**58.232**		**1,352,791**

[1] These projects assume that the Swinomish Channel Causeway project will be constructed to increase connectivity from the North Fork to Swinomish Channel.

7.4. BENEFITS OF INDIVIDUAL POCKET ESTUARY PROJECTS

The potential pocket estuary restoration projects, if constructed, would result in a total of 311.5 hectares (769.6 acres) of intertidal/subtidal pocket estuary habitat available to fry migrant Chinook salmon within a day's migration from the Skagit River delta (Table 7.2). We predict this pocket estuary footprint will result in 31.1 hectares (76.8 acres) of habitat (e.g., tidal channels or impoundments, subtidal channels or open water). Pocket estuary capacity for fry migrant Chinook salmon would increase from 73,393 to 221,264 smolts annually. Dugualla Bay is the single most important site to restore since it has the second highest connectivity and the largest potential size of all pocket estuaries listed. This site is near the mouth of the North Fork Skagit River, the distributary pathway where density dependent migration of fry migrant Chinook salmon is highest within the Skagit tidal delta (Figure 6.1).

Table 7.2. *Summary of potential habitat area, connectivity, and annual Chinook smolt benefit by pocket estuary sites after restoration.*

Project Area	Potential Estuarine Area (ha)	Potential Channel or Open Water Area (ha)	Connectivity Index	Smolt Capacity
Ala Lagoon	10.012	1.789	0.017	14,122
Arrowhead Lagoon	4.773	0.691	0.011	3,671
Crescent Harbor	83.366	5.168	0.007	15,983
Dugualla Lagoon	156.939	9.730	0.020	93,758
Dugualla Bay Heights	2.550	2.398	0.023	26,025
English Boom Lagoon	9.551	0.563	0.013	3,418
Kiket Lagoon	1.416	0.900	0.014	6,219
Lone Tree Lagoon	2.590	1.318	0.017	11,038
Mariners Cove	8.007	5.394	0.011	27,448
Similk Beach	9.551	0.592	0.013	3,782
SneeOosh Lagoon	1.093	0.068	0.018	593
Turners Bay	21.610	2.469	0.013	15,203
Total	**311.457**	**31.080**		**221,264**

8. IMPACT OF SEA LEVEL RISE ON ESTUARY RESTORATION

Predicted climate change will increase rates of sea level rise over the next century and this has the potential to change existing estuarine habitats and may confound our predicted benefits of estuary habitat restoration. Therefore, the Skagit Chinook Recovery Plan must consider the impacts of sea level rise on existing nearshore and tidal delta habitats and any site-specific restoration proposals.

There have been several estimates for the amount of sea level rise that can be expected in the next century, ranging from 34cm (Titus and Narayanan 1995) to nearly 50cm (Warrick et al.

1996, Church et al. 2001). A recent study (ACIA 2004) indicates that continental glaciers in the arctic, particularly Greenland, are melting faster than expected and consequently a one-meter rise in sea level over the next century is now thought to be likely. A further consideration is that the eastern Pacific is projected to deviate from the global average by an additional rise of 20cm (Hengeveld 2000). The distribution and composition of intertidal vegetation is strongly dependent on inundation frequency and duration. Consequently, sea level rise will have significant impacts on tidal marsh vegetation, whether in large river deltas or small pocket estuaries. Climate change will also have additional impacts. In the Pacific Northwest, summer river flows are likely to decline by 30% and droughts are likely to become more common and severe as a result of climate change (Leung and Qian 2003). Decreased river flows are likely to increase marine influence on estuarine salinity. Some smaller streams may dry up seasonally or altogether, reducing the ability of fry migrant juvenile Chinook salmon to find pocket estuary habitat.

8.1. POCKET ESTUARIES

The predicted sea level rise will change the extent of existing pocket estuaries and distribution of vegetation and salinity conditions within pocket estuaries. We can make some rudimentary predictions as to how nearshore systems will respond to sea level rise. The following hypotheses are based on what we know about nearshore habitat formation and maintenance from a process-based geomorphic model of the Whidbey Basin (McBride and Beamer, in prep.). However, predicting site-specific responses will require additional modeling.

Shoreline topography, which constrains the tidal prism and determines the shape and gradient of adjacent nearshore geomorphic units, will be a primary determinant of how future nearshore habitats will look after significant sea level rise. Assuming that nearshore processes will persist, in the case of estuaries formed by embayments at valleys and floodplains, shoreline topography is the primary determinant of how the aerial extent of these geomorphic units will change in response to sea level rise. Pocket estuaries within steep-sided valleys (pocket beach estuaries, small stream deltas or drowned channel estuaries) will tend to decrease in area, and, in some cases, may disappear altogether. Tidal floodplain estuaries and estuaries in broad valleys will be more likely to maintain their aerial extent at a higher elevation. However, current land uses (e.g., diking or other fills) adjacent to existing estuarine habitats which encroach or constrain those habitats will prevent new estuarine habitats from forming at higher elevations because that land has been cutoff. Thus, pocket estuaries with intensive adjacent land use will not likely form new pocket estuary habitat as a response to sea level rise.

Sea level rise will change the current equilibrium of sediment erosion and deposition in nearshore environments. Longshore lagoon estuaries (built by coastal deposits alone) will be impacted to the degree that adjacent sediment sources and erosion rates can maintain the enclosing spit at a higher sea level. Drift cells with a high percentage of armored shorelines will be more impacted than un-armored cells. Limited sediment sources in the erosional units of these cells will starve down drift geomorphic units, resulting in erosion of spits and historically neutral or depositional beaches. The net result could include complete loss of the lagoon habitat at pocket estuaries with these sediment conditions.

8.2. SKAGIT RIVER TIDAL DELTA

Predicted sea level rise over the next century has the potential to decrease intertidal marsh habitat within the Skagit Tidal delta. A 45cm rise, which has a greater than 50% chance of occurring (Titus and Narayanan 1995, Hengeveld 2000), would cause a loss of 12% (235ha or 580ac) of the tidal marshes in the vicinity of Fir Island (Figure 8.1). We applied a conservative modeling scenario of an 80cm rise in sea level to understand the impact of the more recent study (ACIA 2004) predicting a one-meter rise in sea level over the next century. This scenario indicates a possible loss of 22% (437ha or 1080ac) of the tidal marshes in the vicinity of Fir Island. Assuming an average connectivity of 0.0229 and channel densities of the South Fork, tidal delta habitats lost to sea level rise correlate to a loss of over 211,000 and 530,000 smolt capacity, annual, for a 45cm or 80cm sea level rise, respectively. The Skagit Chinook Recovery Plan should consider additional restoration (freshwater, tidal delta, or pocket estuary) to compensate for this predicted loss.

We do not believe that potential restoration sites shown in Figure 7.1 are at significant risk of loss due to sea level rise. We base this on the model results illustrated in Figure 8.1, which shows the predicted loss of tidal delta habitat seaward of the restoration sites for both the 45 and the 80 cm sea level rise scenarios. The potential restoration sites may undergo changes in wetland plant communities due to sea level rise, but we have not yet predicted the effect this would have on channel area within each potential restoration site.

These estimates of marsh loss are preliminary and are based solely on sea level rise estimates, LIDAR data for the Fir Island area, and field-verified elevation preferences for tidal marsh vegetation in the Skagit marshes. They do not include potential effects of sea level rise on sediment accumulation in the marshes, marsh erosion from storm-generated waves in a deeper Skagit Bay, nor salinity increase due to decreased summer river flows resulting from lower snow pack. All of these factors will affect vegetation growth and persistence in tidal marshes. SRSC has begun collaboration with Western Washington University and the USGS to further develop and refine this model.

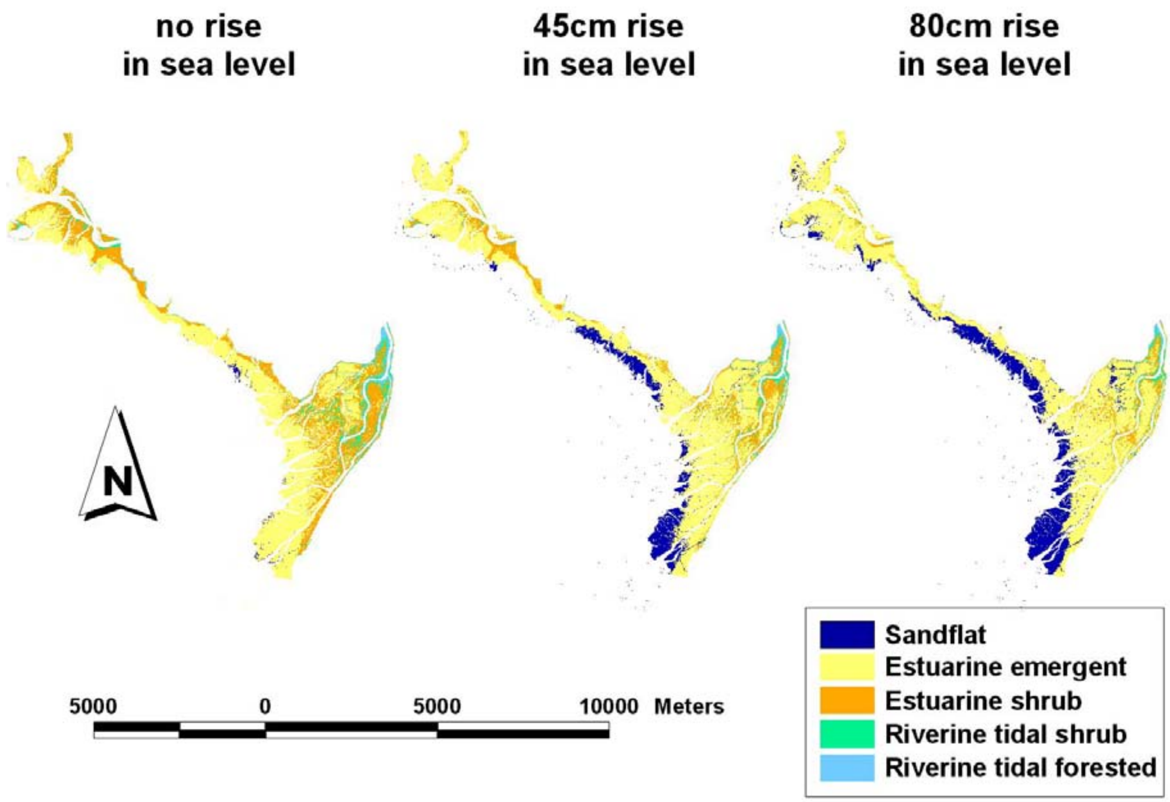


Figure 8.1. *Projected estuarine habitat under two sea level rise scenarios*. The marshes shown here include the North Fork mouth (NW), the South Fork mouth (SE) and bayfront marshes in between. Farmed land is to the NE of each figure, Skagit Bay to the SW.

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APPENDIX D.I. ESTUARINE FISH SAMPLING METHODS

Eric Beamer and Rich Henderson
March 2003

We sample estuarine habitat using three different methods depending on the habitat types: small net beach seine, large net beach seine, and fyke trap. Small net beach seine methods are used for sampling shallow intertidal shoreline areas of Skagit and Padilla Bays, pocket estuaries with lagoon impoundments, or distributary channel habitat in the Skagit tidal delta and Swinomish Channel. The areas seined are typically less than 4 feet deep (1.2 m), and have relatively homogeneous habitat features (water depth, velocity, substrate, and vegetation). Small net beach seine methodology uses an 80-foot (24.4 m) by 6-foot (1.8 m) by 1/8-inch (0.3 cm) mesh knotless nylon net (Figure D.I.1). The net is set in "round haul" fashion by fixing one end of the net on the beach while the other end is deployed by wading "upstream" against the water current, hauling the net in a floating tote, and then returning to the shoreline in a half circle. Both ends of the net are then retrieved yielding a catch. We typically conduct three sets per site. Average set area is 96 square meters.

Large net beach seine methods are used for sampling the intertidal-subtidal fringe of Skagit and Padilla Bays. These areas are typically 6-15 feet deeper than the areas seined by small net beach seine, requiring a longer and deeper net. Large net beach seine methodology uses a 120-foot (36.6 m) by 12-foot (3.7 m) by 1/8-inch (0.3 cm) mesh knotless nylon net (Figure D.I.2). The net is deployed by fixing one end of the net on the beach while the other end is set by boat across the current, a distance of approximately 60% of the net's length. After the set has been held open against the tidal current for a period of four 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 typically conduct three sets per site. Set area varies because of varying tow times, set widths, and tidal current velocities moving past the site. Average set area for 6 index sites in Skagit Bay is 486 square meters.

Fyke trap methods are used for sampling blind tidal channel habitat in the Skagit tidal delta, Swinomish Channel corridor, southern Padilla Bay, or pocket estuary sites dominated by tidal channels. Fyke trap methodology uses nets constructed of 1/8-inch (0.3 cm) mesh knotless nylon with a 2-foot (0.6 m) by 9-foot (2.7 m) diameter cone sewn into the net to collect fish draining out of the blind channel site (Figure D.I.3). Overall net dimensions (length and depth) are variable depending on the site's cross-sectional channel dimensions. All nets are sized to completely block fish access at high tide. The net is set across the blind channel site at high tide and "fished" through the ebb tide yielding a catch. The juvenile Chinook catch is adjusted by a trap recovery efficiency (RE) estimate derived from mark-recapture experiments using a known number of marked fish released upstream of the trap at high tide. The RE is usually related to hydraulic characteristics unique to the site (e.g., change in water surface elevation during trapping or water surface elevation at the end of trapping). Multiple RE tests (several times per season) at each site are used to 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.

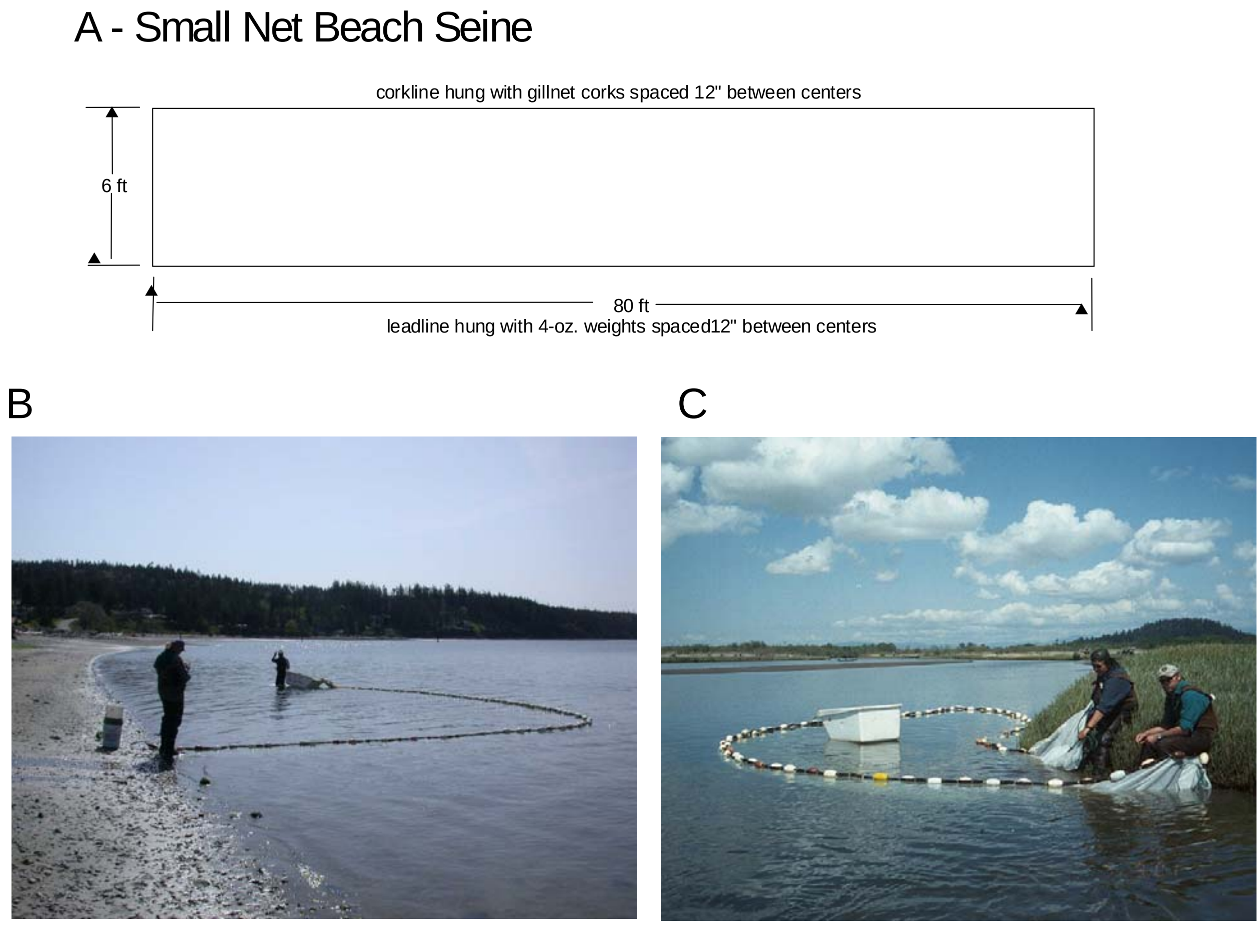


Figure D.I.1. *Small net beach seine methodology.* (A) design of net (not drawn to scale), (B) setting net out of tote on shallow intertidal beach, (C) beginning to haul net in distributary channel.

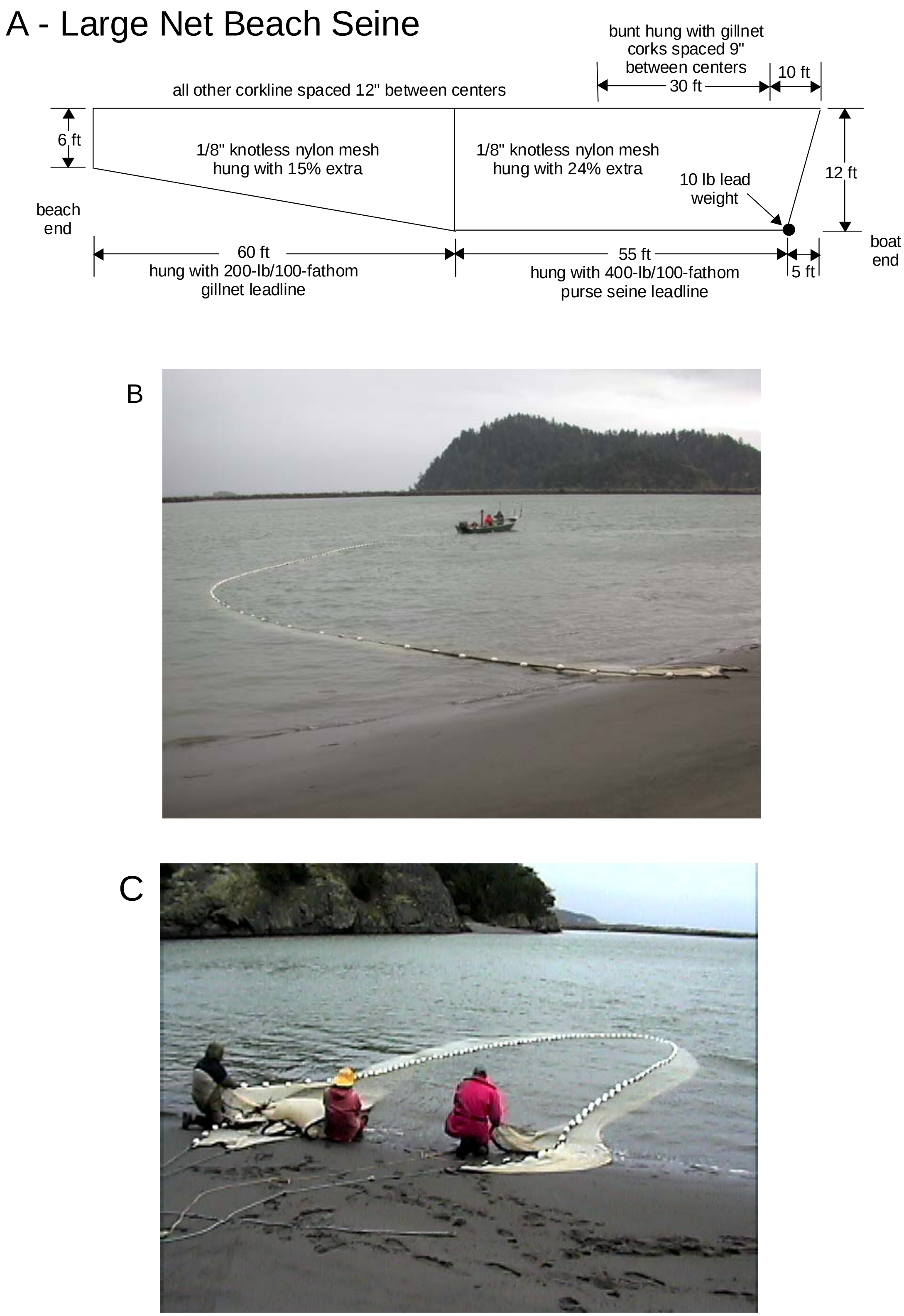


Figure D.I.2. *Large net beach seine methodology.* (A) design of net (not drawn to scale), (B) towing on net, (C) hauling net.

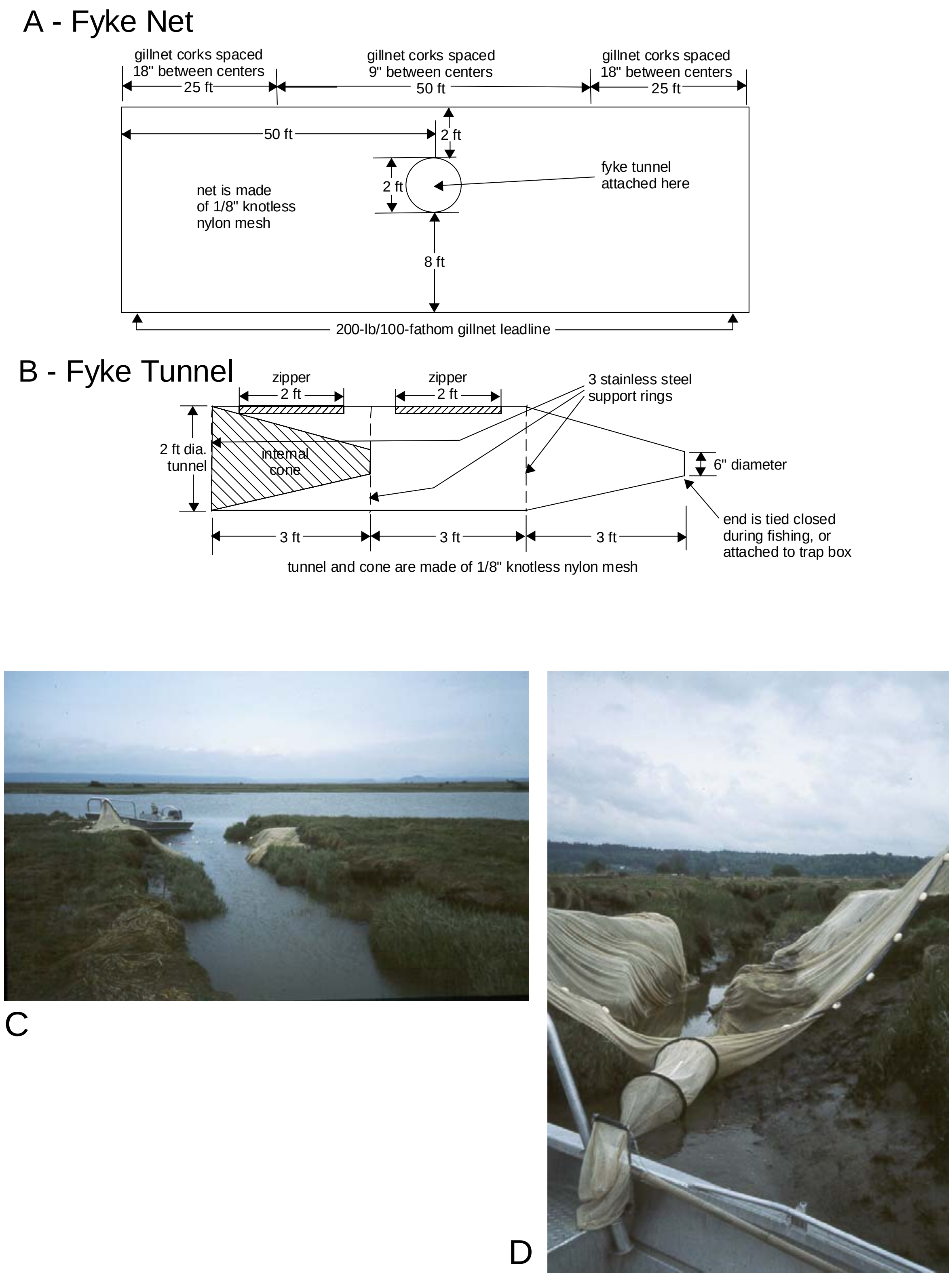


Figure D.I.3. *Fyke trap methodology.* (A) design of net (not drawn to scale), (B) design of tunnel (not drawn to scale), (C) fishing during ebb tide, (D) net at low tide (end of fishing).

APPENDIX D.II. JUVENILE CHINOOK SALMON USE OF TIDAL DELTA HABITAT

Eric Beamer and Rich Henderson
May 2004

We conducted small net beach seine sets (described in Appendix D.I) throughout distributary and blind channel habitats of the Skagit delta during the spring of 1997 to better understand what habitats were used by juvenile Chinook salmon. Surface water velocity and depth of the area seined were also measured at the time of seining. All data were collected at low tide because the wetted area of the delta is smallest and fish are more congregated compared to any other tidal stage.

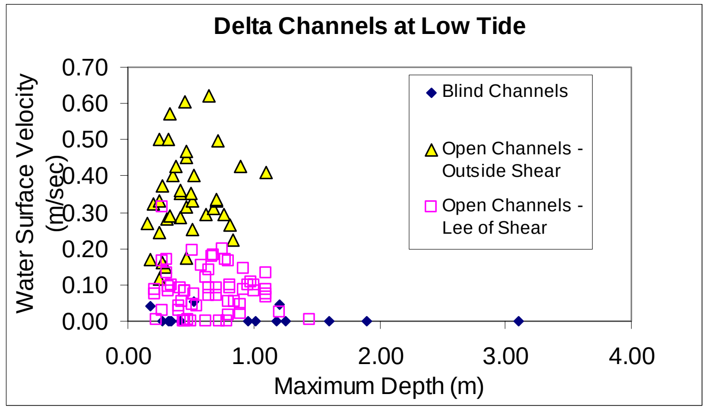
Larger open-ended (distributary) channels and blind channels have unique patterns of surface water velocity at low tide. We divided open-ended channels into areas based on visible differences in surface water movement. This applied only to channels larger than our beach seine could cover in one set (> 15 meters bankfull width). By observing water currents between shoreward eddies and the main downstream current, we found a visible break (shear line) in surface water currents that is explained by velocity measurements (Figure D.II.1 top). The water lee (shoreward) of the visible shear line was usually slower than 0.20 meters per second while the water outside the shear line was usually greater than 0.20 meters per second. We assigned sub-habitat types for each beach seine set based on these variables and examined juvenile Chinook density data to determine whether these habitat types influenced juvenile Chinook salmon distribution within delta channels.

We found more juvenile Chinook salmon in deeper and slower channel habitat (Figure D.II.1 bottom). Blind channels with water at low tide had especially high densities of juvenile Chinook. The slow water edges of distributary channels also had high densities of juvenile Chinook salmon at low tide. We observed threshold relationships for juvenile Chinook salmon density with water depth (Figure D.II.2) and water velocity (Figure D.II.3). Combining data over the entire sampling season (February through August), we rarely found juvenile Chinook in habitat shallower than 0.20 meters depth or water faster than 0.20 meters per second. Both threshold relationships do not remain at the same place with respect to depth or water velocity. They move to deeper and faster water as the season progresses (see month by month plots in Figures D.II.2 and D.II.3). This phenomenon is likely due to an increase in the size of fish (Figure D.II.4). Larger fish might prefer deeper water and could tolerate faster moving water due to an increase in swimming ability.

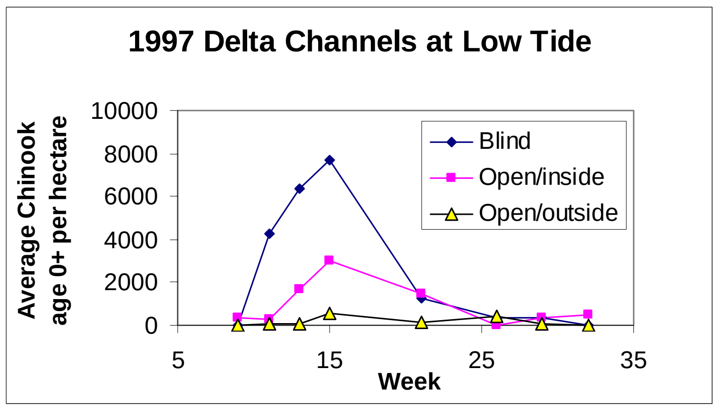
Based on this analysis, we conclude that primary juvenile Chinook salmon rearing areas include blind channel and open ended (distributary) channels where the wet area ≥ 0.20 meters depth and ≤ 0.20 meters per second water surface velocity. These areas are found throughout blind channels and the slower moving edge habitats of distributary channels. They are not commonly found in mid-channel areas since the very low velocities do not commonly occur mid-channel, except in smaller sand bar dominated distributary channels. We assume that juvenile Chinook use habitats deeper than those represented by our sampling if water velocities are within the range preferred by juvenile Chinook salmon. We had limited data collected in habitat deeper than one meter and there was no evidence of fewer fish with increased depth.

Figure D.II.1. *Delta channel habitat conditions and juvenile Chinook salmon.*

<u>Top Figure</u> – Relationship between depth and velocity by delta channel habitat type. Differences in surface water velocity explain the visible shear line observed in open channels. Blind channels at low tide have the lowest velocity.



<u>Bottom Figure</u> – Juvenile Chinook density by delta channel habitat type. Juvenile Chinook salmon are most abundant in blind channels followed by open channel areas that are low velocity. Weeks 5, 15, 25, and 35 correspond to early February, early April, mid-June, and late August, respectively.



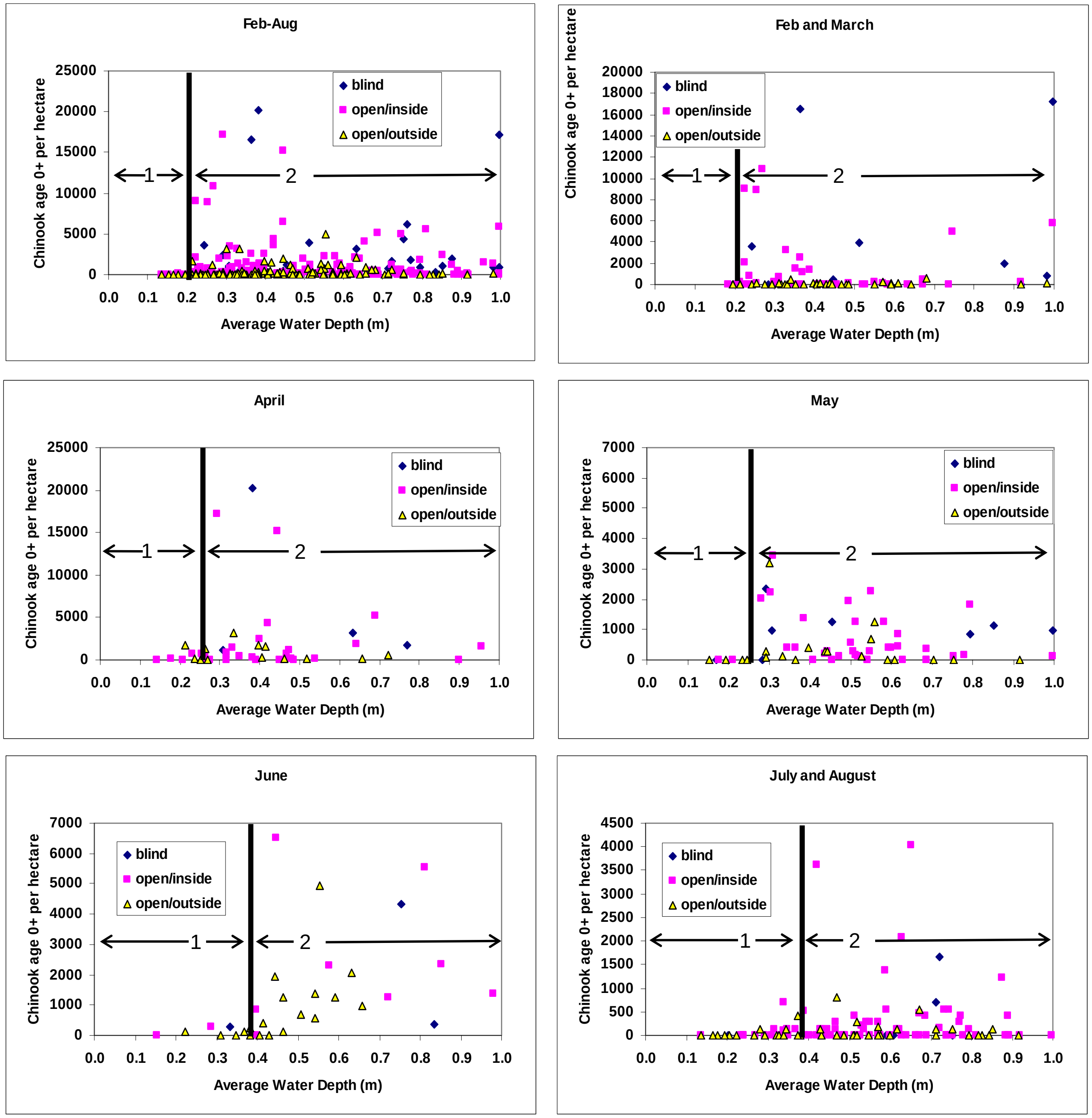


Figure D.II.2. *The relationship between juvenile Chinook salmon density and water depth in tidal delta channel habitat.* A threshold relationship is evident for average water depth of the area seined and juvenile Chinook salmon abundance. No juvenile Chinook salmon were captured in habitat shallower than 0.20 meters deep over the 6-month sampling period. However, the threshold relationship changes over the season, possibly due to habitat requirements of progressively larger juvenile Chinook later in the season. Region 1 noted on the graphs indicates depths where fish are rare and fish densities are low. Region 2 noted on the graphs indicates depths at which fish are common and densities high.

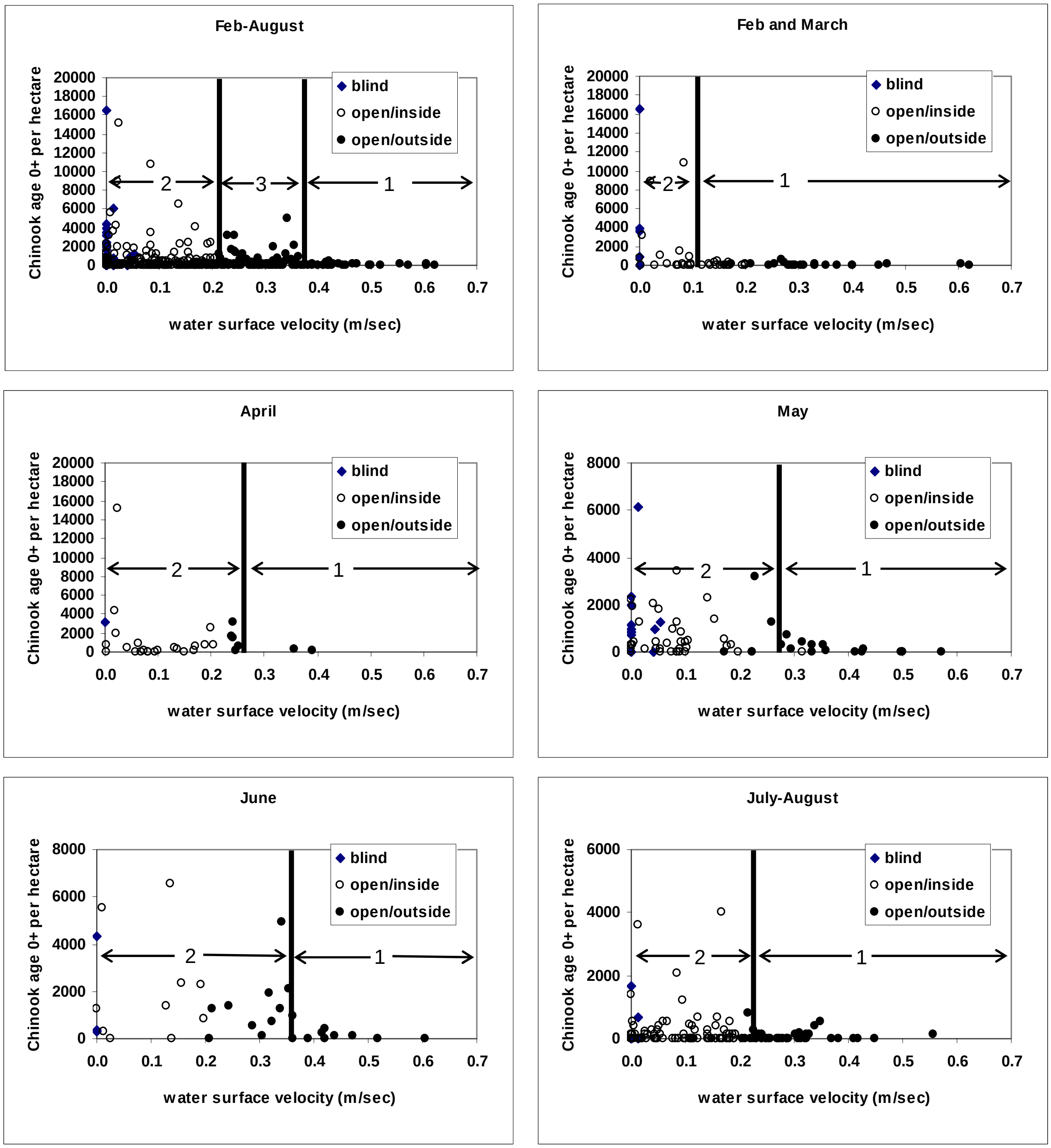


Figure D.II.3. *The relationship between juvenile Chinook salmon density and surface water velocity in tidal delta channel habitat.* A threshold relationship is evident for surface water velocity and juvenile Chinook salmon abundance. Few juvenile Chinook salmon were captured in water velocities greater than 0.20 meters per second and essentially none were captured in velocities greater than 0.38 meters per second over the six-month sampling period. When juvenile Chinook were captured in higher velocity habitat, it was later in the year when the fish were larger. Therefore, the threshold relationship changes over the season, possibly relating to an increased swimming ability of progressively larger juvenile Chinook later in the season. Region 1 noted on the graphs indicates velocities where fish are rare and fish densities are low. Region 2 noted on the graphs indicates velocities at which fish are common and densities high. Region 3 in the first graph indicates velocities at which fish are common, but densities are low.

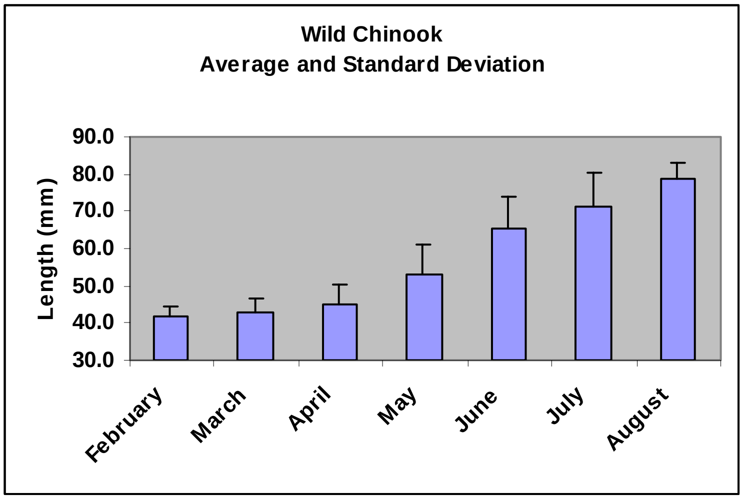


Figure D.II.4. *Seasonal length trend of wild Chinook salmon in tidal delta habitats.* Monthly average length of juvenile wild Chinook salmon increases from the 40 mm range in February to 80 mm in August. Data are from 2003 using all delta sites combined.

APPENDIX D.III. METHODS FOR ESTIMATING DELTA HABITAT

Greg Hood, Eric Beamer, and Rich Henderson
January 2005

Predictions of tidal channel surface area for delta restoration project areas are based on empirical regression relationships between tidal marsh area and tidal channel surface area, derived from 2004 infrared orthophotos with 15 cm pixel resolution. Two different sets of relationships were obtained, one for marshes of the North Fork Skagit River and one for marshes of the South Fork (Figure D.III.1). The greatest differences between the North and South Fork marshes occur for areas that are smaller than 10 hectares. Marsh areas that were extensively bordered by dikes were similar to other marsh areas far from dikes for a variety of parameters including total tidal channel surface area, channel count, total channel magnitude, and total channel length. The exception was the marsh along the Fir Island bayfront dikes between the North Fork marshes and South Fork marshes. This area is sediment starved and experiencing marsh erosion (Grossman and Hood, unpublished data), which is resulting in significantly lower tidal channel density in these marshes. For this sediment-starved area, preliminary results find a regression estimator for tidal channel area as:

Tidal Channel Area in hectares = 0.0015(Wetland Area in hectares)$^{1.44}$

To estimate potential tidal channel area for marsh in the northern end of the Swinomish Channel, we examined remnant tidal marshes fringing the southern margin of Padilla Bay and plotted them against the North and South Fork regressions. There were three Padilla Bay marshes extant, ranging in size from 0.8 to 7.8 ha (2 to 19 ac). All three were much more closely aligned with the South Fork than with the North Fork regression lines when total channel surface area, total channel length, and island magnitude (number of 1st order channels present) were regressed against marsh island area. Thus, the South Fork regression equations were used to predict potential restorable tidal channel surface area for the north Swinomish Channel marshes.

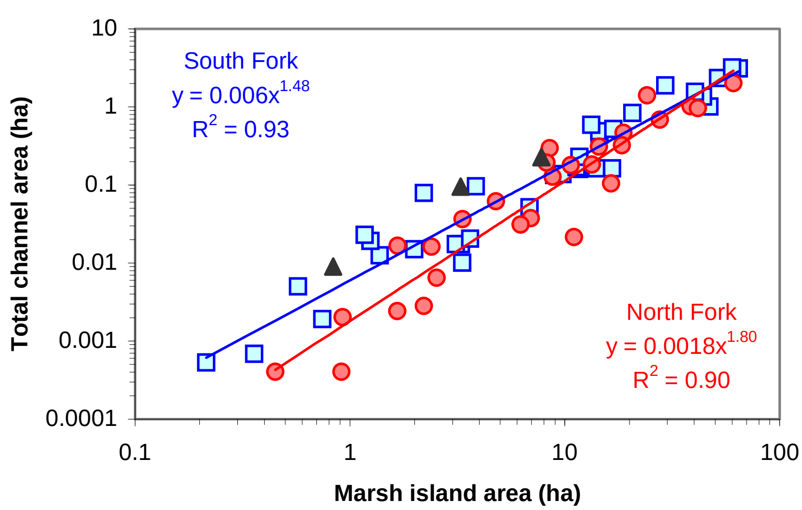


Figure D.III.1. *Relationship between tidal marsh island area and the total surface area of the tidal channels that drain each marsh island.* North Fork data are the red circles, South Fork data are the blue squares, remnant Padilla Bay tidal marshes are black triangles.

Appendix D.II shows that only a portion of distributary channels are consistently utilized by juvenile Chinook salmon. These areas were defined as the wetted area at low tide ≥ 0.20 meters depth and ≤ 0.20 meters per second water surface velocity. We measured water depth and surface velocity at 17 distributary channel cross sections ranging from 15 to 317 meters in width at low tide during May 2000 to determine the percentage of each cross section that fell within the depth and velocity ranges commonly utilized by juvenile Chinook salmon. We summarized the results into three channel width classes (Figure D.III.2) and applied the results to distributary channel areas for both historic and current delta habitat inventories to understand changes in delta habitat used by juvenile Chinook salmon.

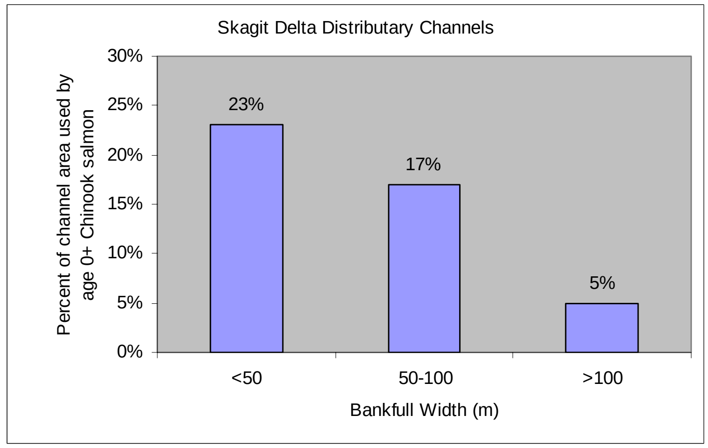
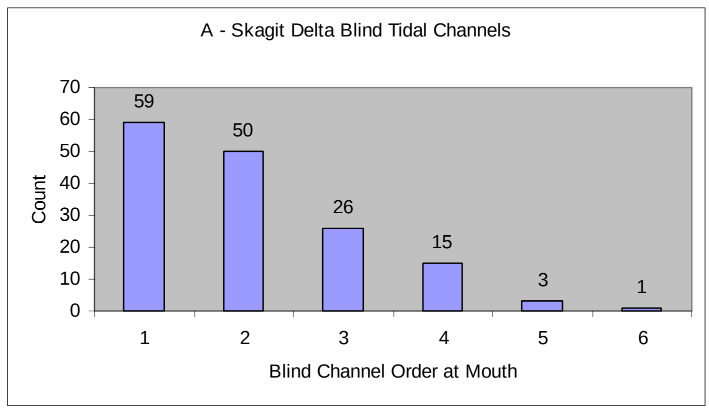


Figure D.III.2. *Percentage of distributary channel of varying widths that coincides with the depth and velocity ranges known to be used by subyearling Chinook salmon for rearing.* The area used by juvenile Chinook salmon decreases as a function of distributary channel width.

To convert channel area to volume we used a subset of 154 different Skagit delta blind channel complexes to represent the population of blind channels located throughout the Skagit delta. We ordered each blind channel complex using high-resolution color or infrared orthophotos to develop a frequency distribution of blind channels by their order (Figure D.III.3A). We then used the average channel depth statistics measured by Collins (1998) from a subset of Skagit blind channels by their order (Figure D.III.3B) to estimate the weighted average depth of all blind channels. The average depth of blind channels for all orders combined is estimated at 0.64 meters deep.

We multiplied channel area by average channel depth to estimate channel volume for predicting juvenile Chinook salmon benefits for potential habitat restoration projects using the model described in Appendix D.VII.



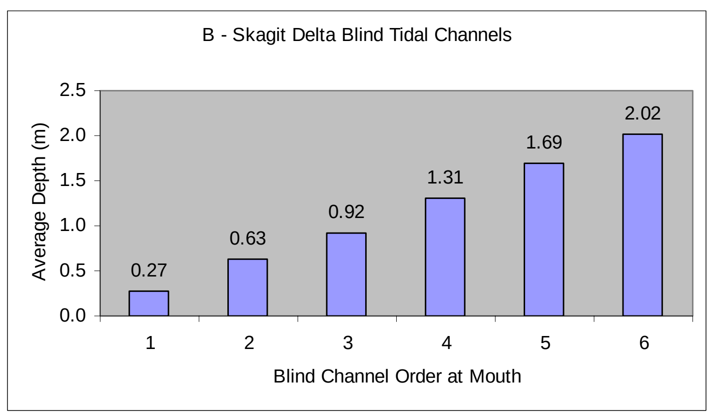


Figure D.III.3. (A) *Frequency distribution of Skagit delta blind channels by order at their mouth.* (B) *Average depth of Skagit delta blind channels by order at their mouth.*

APPENDIX D.IV. METHODS FOR EVALUATING HISTORIC CHANGE IN SKAGIT BAY POCKET ESTUARIES

Aundrea McBride, Karen Wolf, and Eric Beamer
January 2005

Non-natal pocket estuaries are important to juvenile Chinook salmon (Beamer et al. 2003). Within Puget Sound we have found that certain upland topography (which is a surrogate for tectonic setting and geologic history) and substrate material (which is a surrogate for cohesion and geologic history), when acted upon by a given landscape process or combination of processes, will produce and maintain a predictable suite of nearshore habitat conditions, unless modified by humans. Using this geomorphic model, we identified sites within Skagit Bay that currently are or historically have been pocket estuaries (Figure D.IV.1). To evaluate these pocket estuaries for existing and potential fish use, we mapped each site, distinguishing different tidal elevation zones. These zones correspond to fish use opportunity within the estuary at a given tidal height. From these data we were able to determine the maximum habitat area available to fish (at high tide) and the minimum habitat available (at low tide) for each pocket estuary.

Table D.IV.1. *SRSC geomorphic nearshore habitat classification.*

Nearshore Cell	Dominant Process/es	Shoreline Material	Shoreline Topography	Geomorphic Unit
Estuaries embayments & enclosures where *topography* & *processes* determine habitat	tectonic	bedrock	u-shaped valley	Tectonic Estuary
	glaciation	bedrock & glacial	u-shaped valley	Fjord Estuary
	fluvial and wave deposition	bedrock & fluvial	u-shaped valley	Pocket Beach Estuary
	tidal	coastal sediments	tidal flood plain	Tidal Channel Estuary
	tidal erosion and wave deposition	coastal sediments	tidal flood plain and coastal landform	Tidal Channel Lagoon
	fluvial deposition	fluvial sediments	v-shaped valley or tidal flood plain	Delta
	fluvial and wave deposition	fluvial & coastal	v-shaped valley or tidal flood plain and coastal landform	Delta Lagoon
	tidal erosion and fluvial deposition	any & fluvial sediments	v-shaped valley or tidal flood plain	Drowned Channel
	wave deposition and tidal erosion	coastal sediments	v-shaped valley or tidal flood plain and coastal landform	Drowned Channel Lagoon
	wave deposition	any & coastal sediments	bank or bluff with coastal landform	Longshore Lagoon
Littoral Drift Cells open beaches where *processes* & *material* determine habitat	wave deposition	cohesive sediments	bank or bluff	Depositional Open Beach
	wave erosion	cohesive sediments	bank or bluff	Sediment Source Beach
	wave transport	cohesive sediments	bank or bluff	Neutral Open Beach
	wave deposition	back beach coastal sediments	coastal landform	Accretion Shoreform Beach
Bedrock shorelines where *material* & *topography* determine habitat	wave erosion	bedrock	bank	Rock Platform
	wave deposition or transport	bedrock	bank	Veneered Rock Platform
	neutral	bedrock	bluff	Plunging Rock Cliff
	wave erosion and redeposition	bedrock & cohesive sediments	bluff	Pocket Beach
	no wave deposition	bedrock	no upland	Rock Reef

Because of human modifications to nearshore environments, current conditions do not reflect the maximum potential of nearshore habitats to support Chinook salmon. Evaluating historic change and potential restoration was achieved by cutting the 'current condition' polygons to reflect historic conditions. We re-mapped each pocket estuary using the oldest available data from historic orthophotos and USGS T-Sheets. When mapping from T-sheets, we digitized each sounding, converted sounding depths to tidal elevations using the nearest local tidal datum, and defined habitat zones based on those tidal elevations according to NOAA's published values for Mean Lower Low Water and Mean Higher High Water. Historic aerial photos were scanned at high resolution and georeferenced to 1998 DNR black and white orthophotos. We supported our photo interpretation of lower quality historic imagery with current geologic and topographic maps. In cases where mapping was limited to distinguishing only intertidal and subtidal from upland due to poor image quality, we used a regression developed from all sites within Whidbey Basin for which we had channel area data to determine a relationship between pocket estuary area and fish habitat area (subset of channel, impoundment, and subtidal area) (Figure D.IV.2). The final product is a single polygon layer coded for current and historic conditions by zone and subzone (Table D.IV.2). Total areas for historic and current conditions are summarized in Table D.IV.3. Figures D.IV.3 through D.IV.14 show comparisons of historic conditions in the twelve pocket estuaries that have existing habitat or restoration potential and are within one day of travel from the Skagit Delta for juvenile Chinook salmon.

Table D.IV.2. *Nearshore zones and subzones.*

Zones	Subzones
Subtidal—The area below extreme low water (ELW).	Impoundment Trough Platform Ramp Basin
Intertidal—The area between MHHW and ELW.	Beach Face Low Tide Platform Reef Rocky Driftwood Channel Impoundment Emergent Marsh Scrub-Shrub Wetland
Back Beach—Coastal deposits above MHHW that are actively influenced by coastal processes.	Spit (includes cusps and tombolos) Bar Island Berm Dunes
Tidal Delta—Transition and mixing zone between major river and nearshore environments.	Channel Impoundment Emergent Marsh Scrub-Shrub Wetland Forested Wetland
Tidal Wetland—Freshwater that is pushed by the tides, but not mixed with marine water.	Channel Impoundment Emergent Marsh Scrub-Shrub Wetland Forested Wetland
Watershed—Land above the upper limit of saltwater and tidal influence.	Upland Lake Wetland Nearshore Riparian

Note: Each zone can include modified areas, labeled as dredged, filled and isolated subzones.

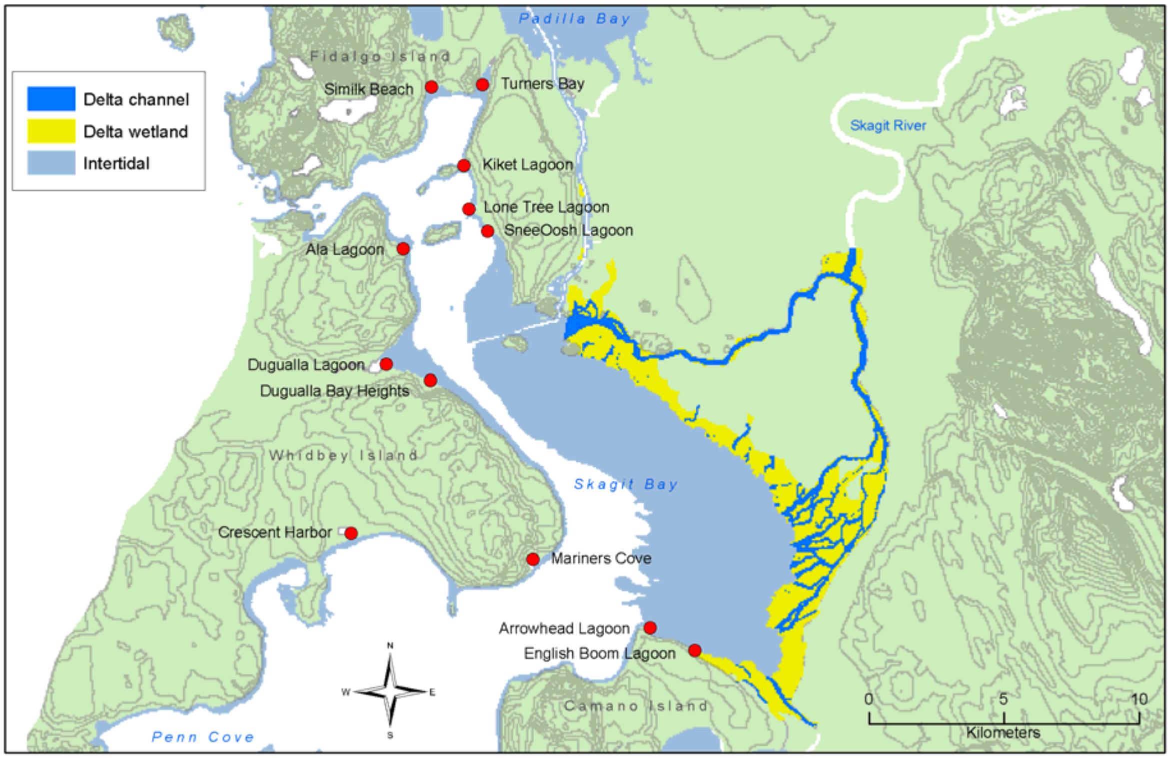
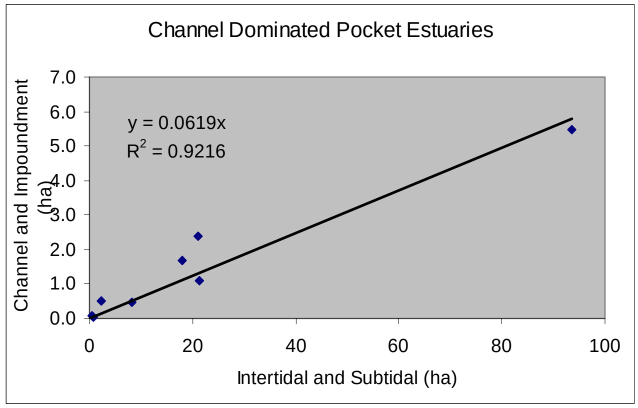


Figure D.IV.1. *Pocket estuaries reachable by juvenile Chinook salmon within one ebb tide from Skagit delta.* Some of these pocket estuaries are currently not accessible to fish (Dugualla Bay and Heights, Crescent Harbor, SneeOosh Lagoon, Similk Beach). All are impacted in some way.

Table D.IV.3. *Change analysis for pocket estuaries.* All measurements are in hectares. 'Habitat' is the total area of channels and impoundments within a pocket estuary. 'Restorable Habitat' is any part of the historic habitat that currently has no permanent structures on it. The 'Total Pocket Estuary Area' includes back beach, emergent marsh, and low tide platform areas in addition to channels and impoundments.

Pocket Estuary	Current Habitat	Historic Habitat	Restorable Habitat	Total Habitat After Restoration	Total Pocket Estuary Area After Restoration
Ala Lagoon	1.781	0.013	0.009	1.789	10.012
Arrowhead Lagoon	0.541	0.299	0.151	0.691	4.773
Dugualla Lagoon	0.000	10.138	9.730	9.730	156.939
Dugualla Bay Heights	0.000	0.612	2.398	2.398	2.550
English Boom Lagoon	0.486	1.512	0.078	0.563	9.551
Kiket Lagoon	0.890	0.210	0.010	0.900	1.416
Lone Tree Lagoon	1.305	0.395	0.013	1.318	2.590
Mariners Cove	5.221	0.858	0.173	5.394	8.007
Similk Beach	0.000	1.532	0.592	0.592	9.551
SneeOosh Lagoon	0.000	0.289	0.068	0.068	1.093
Turners Bay	1.700	2.266	0.769	2.469	21.610
Crescent Harbor	0.000	6.046	5.168	5.168	83.366

Figure D.IV.2. *Estimating habitat for pocket estuaries.* A regression tool was used to estimate the amount of fish habitat (channels and impoundments) based on the mapped intertidal/subtidal footprints of pocket estuaries. Channel and impoundment habitat in hectares = 0.0619 **x** intertidal and subtidal area in hectares. This tool allowed us to estimate habitat loss for pocket estuaries that could not be mapped in detail with data sources available, and to estimate potential habitat gain after restoration.



Digital mapping references

Year	Project/Publication Information	Format	Scale
1890	H-sheets, US Coast and Geodetic Survey	sketched field maps with soundings, georeferenced by Puget Sound River History Project, University of Washington	1:20,000
1941	US Army Corps of Engineers	mosaiced black and white aerial photos, scanned and georeferenced in-house	1:20,000
1956	CWD project, US Agricultural Stabilization and Conservation Service, Salt Lake City	black and white aerial photos, scanned and georeferenced in-house	1:20,000
1964	BBI project, US Agricultural Stabilization and Conservation Service, Salt Lake City	black and white aerial photos, scanned and georeferenced in-house	1:20,000
1965	WF project, Pacific Aerial Surveys, Seattle	black and white aerial photos, scanned and georeferenced in-house	1:60,000
1966	WHIDBEY ISL project, WA Department of Transportation, Olympia (?)	black and white aerial photos, scanned and georeferenced in-house	1:24,000
1971	NASA 189 project	color infrared aerial photos, scanned and georeferenced in-house	1:58,000
1972	S72021 project, US Army Corps of Engineers	black and white aerial photos, scanned and georeferenced in-house	1:24,000
1979	SEABLOCK project, WA Department of Transportation, Olympia (?)	black and white aerial photos, scanned and georeferenced in-house	1:24,000
1980-1981	HAP 80 (high altitude photography) project, US Agricultural Stabilization and Conservation Service, Salt Lake City	color infrared aerial photos, scanned and georeferenced in-house	1:58,000
2000	Resource management project, Triathlon Ltd, Swinomish Indian Tribal Community, LaConner	color infrared digital orthophotos	1-ft pixel
2000	Nearshore mapping project, Triathlon Ltd, Skagit River System Cooperative, LaConner	true color digital orthophotos	2-ft pixel
2001	Resource management project, WA Department of Natural Resources, Olympia	true color aerial photos, scanned and georeferenced in-house	1-ft pixel
2004	Resource management project, Triathlon Ltd, Swinomish Indian Tribal Community, LaConner	color infrared digital orthophotos	0.5-ft pixel

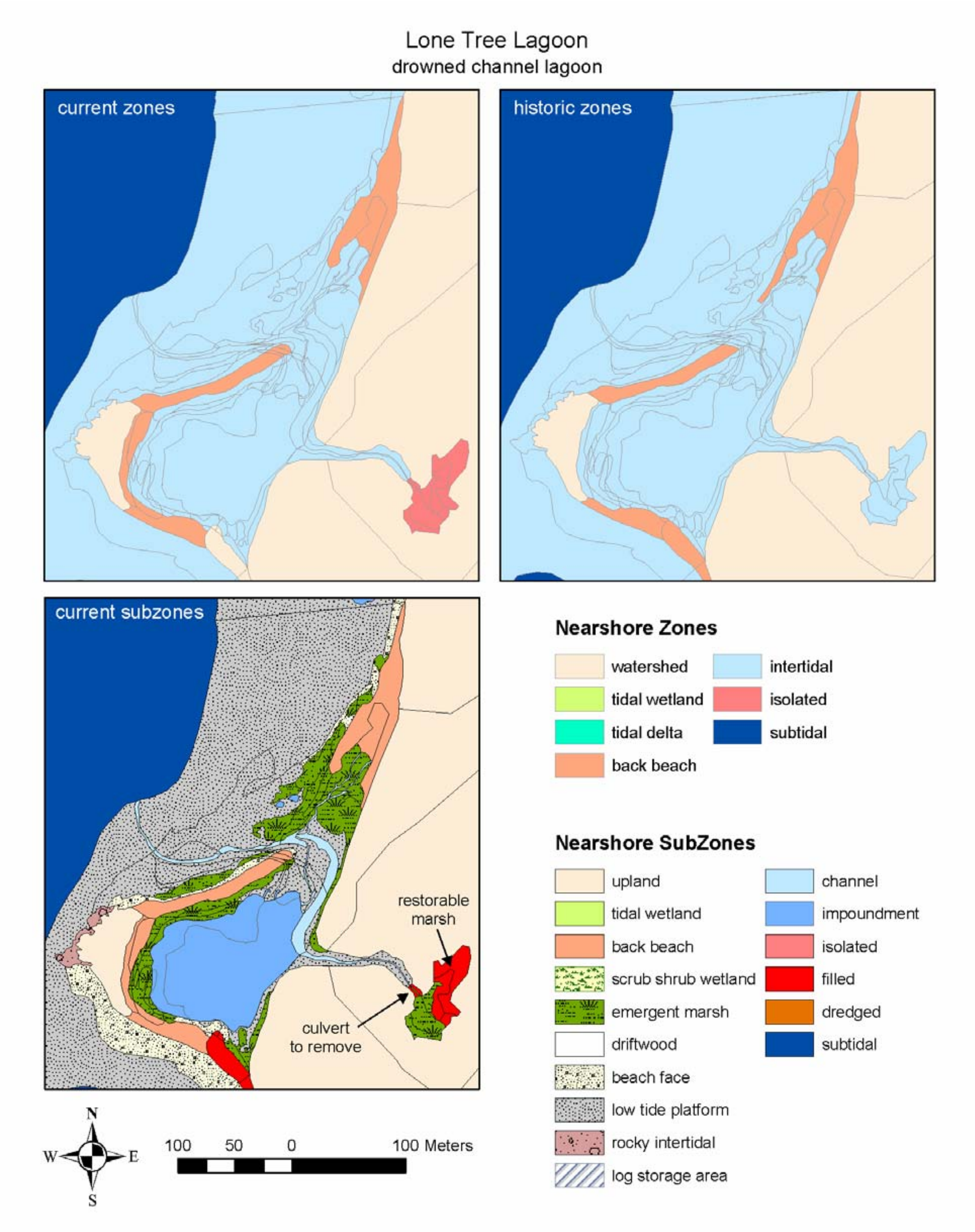


Figure D.IV.3. Lone Tree Lagoon is mostly intact. However, its watershed is severely impacted by paving and hydrologic modifications. This site is currently being studied for restoration. The culvert and tidal marsh to be restored are labeled in red.

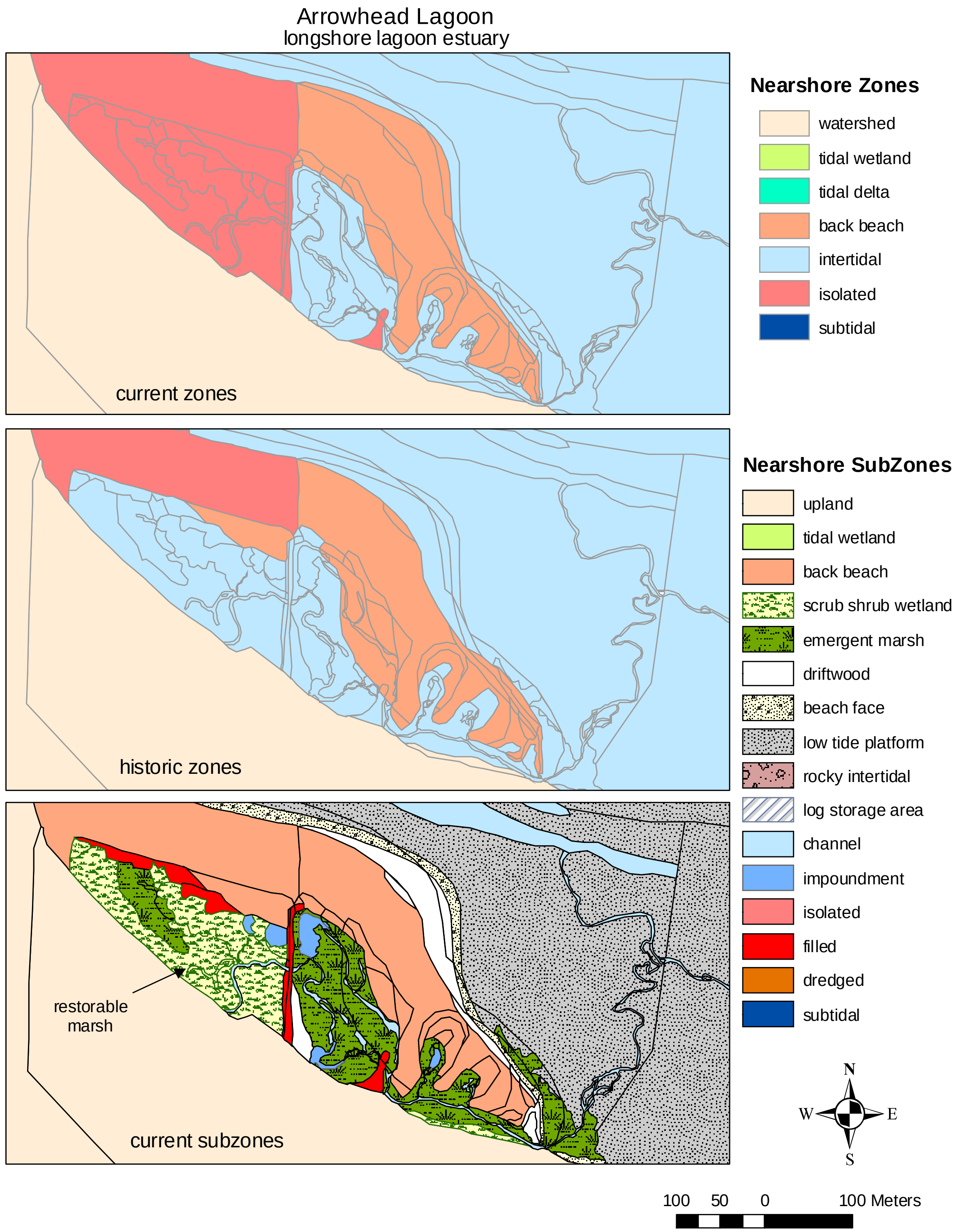


Figure D.IV.4. Arrowhead Lagoon has been diked and filled to isolate its western half. The outer beach of the spit is armored and the inner edge of the spit is partially armored and filled. This spit appears to have grown steadily to the east, with easterly curved fingers extending into the marsh as the spit has prograded. Maintaining sediment sources for this spit will be an important part of restoration and habitat protection.

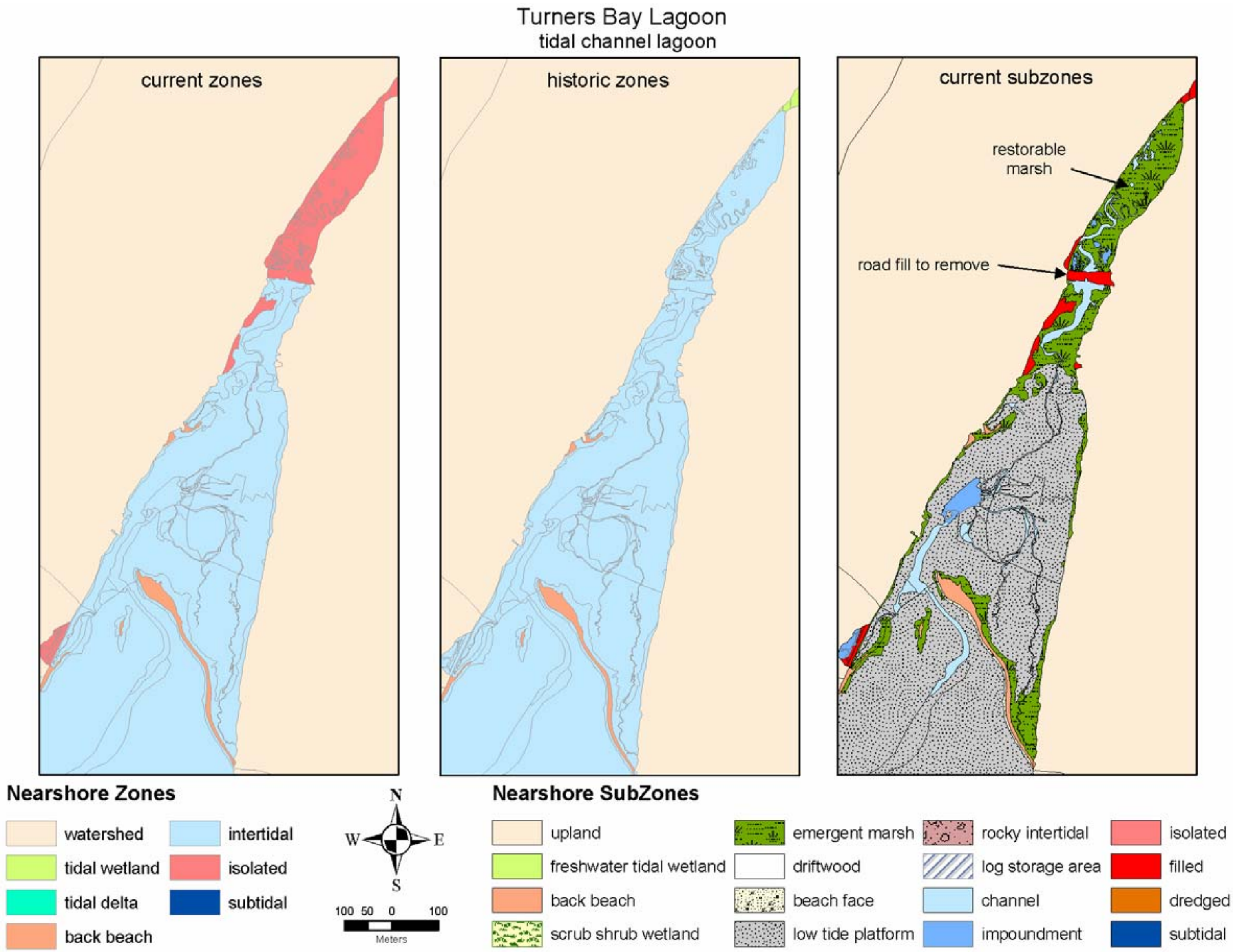


Figure D.IV.5. Turners Bay Lagoon is a tidal channel lagoon with a small creek and wetland at its head. It is probable that the pocket estuary connected to Padilla Bay at some point during its evolution. A tide gate and road fill has isolated the upper wetland of Turners Bay Lagoon.

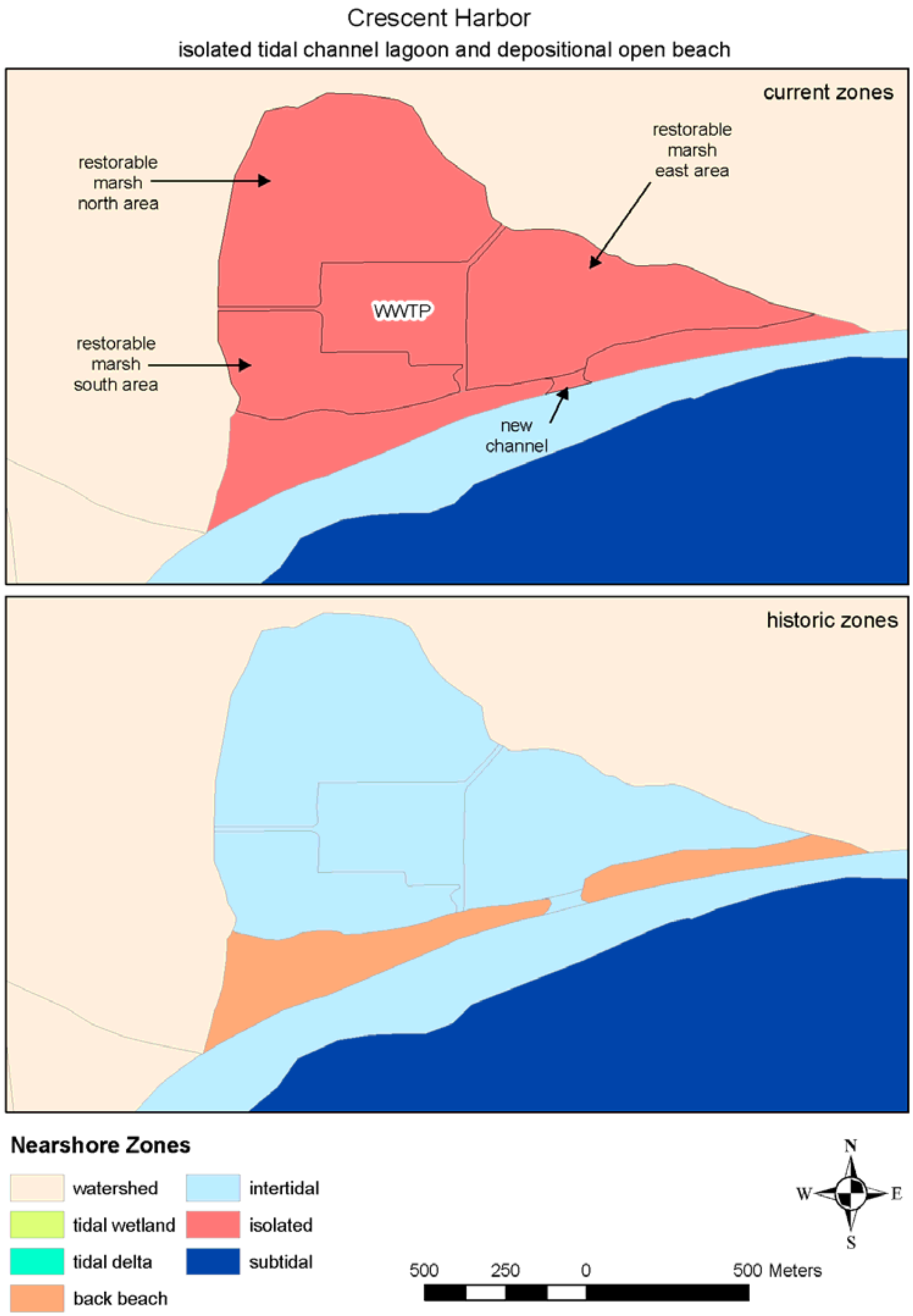


Figure D.IV.6. Crescent Harbor pocket estuary has been completely cut off from tidal exchange except through ground water. The former spit is armored along its eastern half and filled with a road along the crest of the berm. The isolated marsh system, associated with a creek, is ditched and piped to the beach via a tide-gated culvert. Most of this system is restorable, minus a wastewater treatment pond (WWTP) and intake pipes in the middle of the marsh. The restorable marsh is in three separate segments, divided by the WWTP and intake pipes.

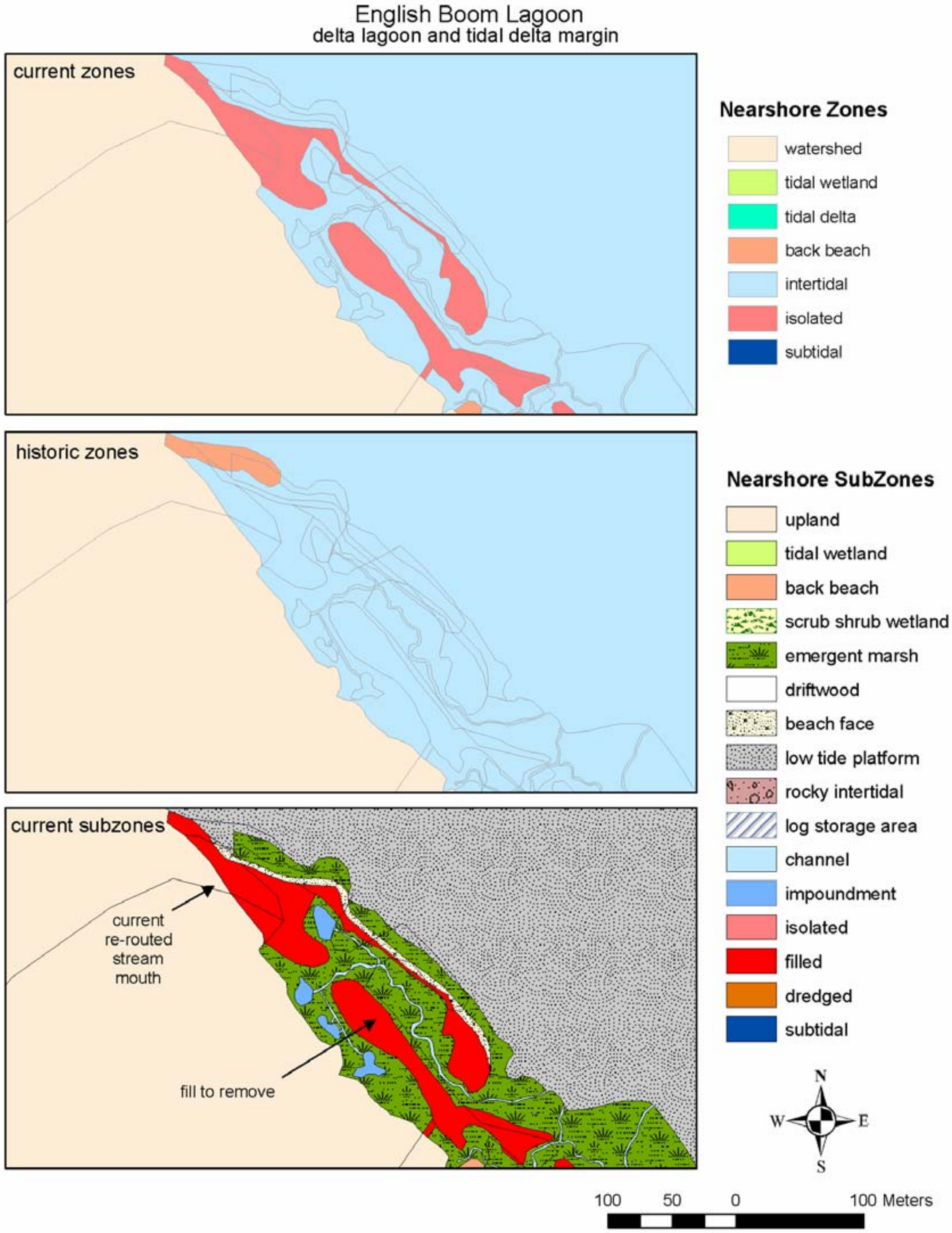


Figure D.IV.7. English Boom was originally a small spit formed along the margin of the tidal delta marsh of the Skagit/Stillaguamish deltas. The area has been filled and dredged for log storage historically. More recently those modifications have been left to coastal and delta processes and have evolved into a partially artificial channel/marsh complex. The re-routed stream could be returned to a course emptying into the pocket estuary (the probable historic condition) to improve habitat quality within the pocket estuary.

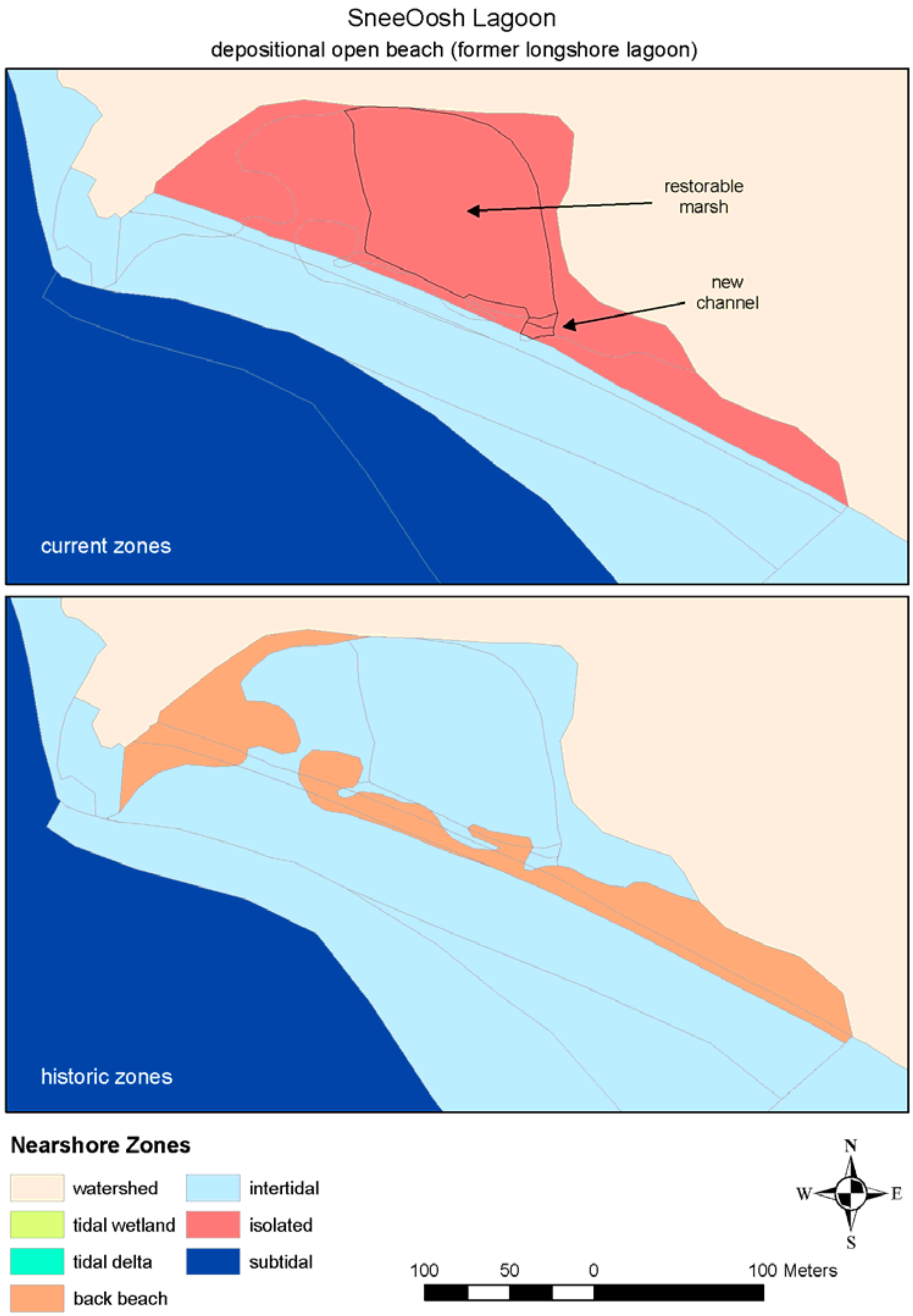


Figure D.IV.8. SneeOosh Lagoon has been isolated and partially filled. The isolated marsh is drained by a pumping station and pipe to the beach. The beach is armored. Restoration would involve reconnecting the isolated marsh via a new channel, as the original channel location is built upon.

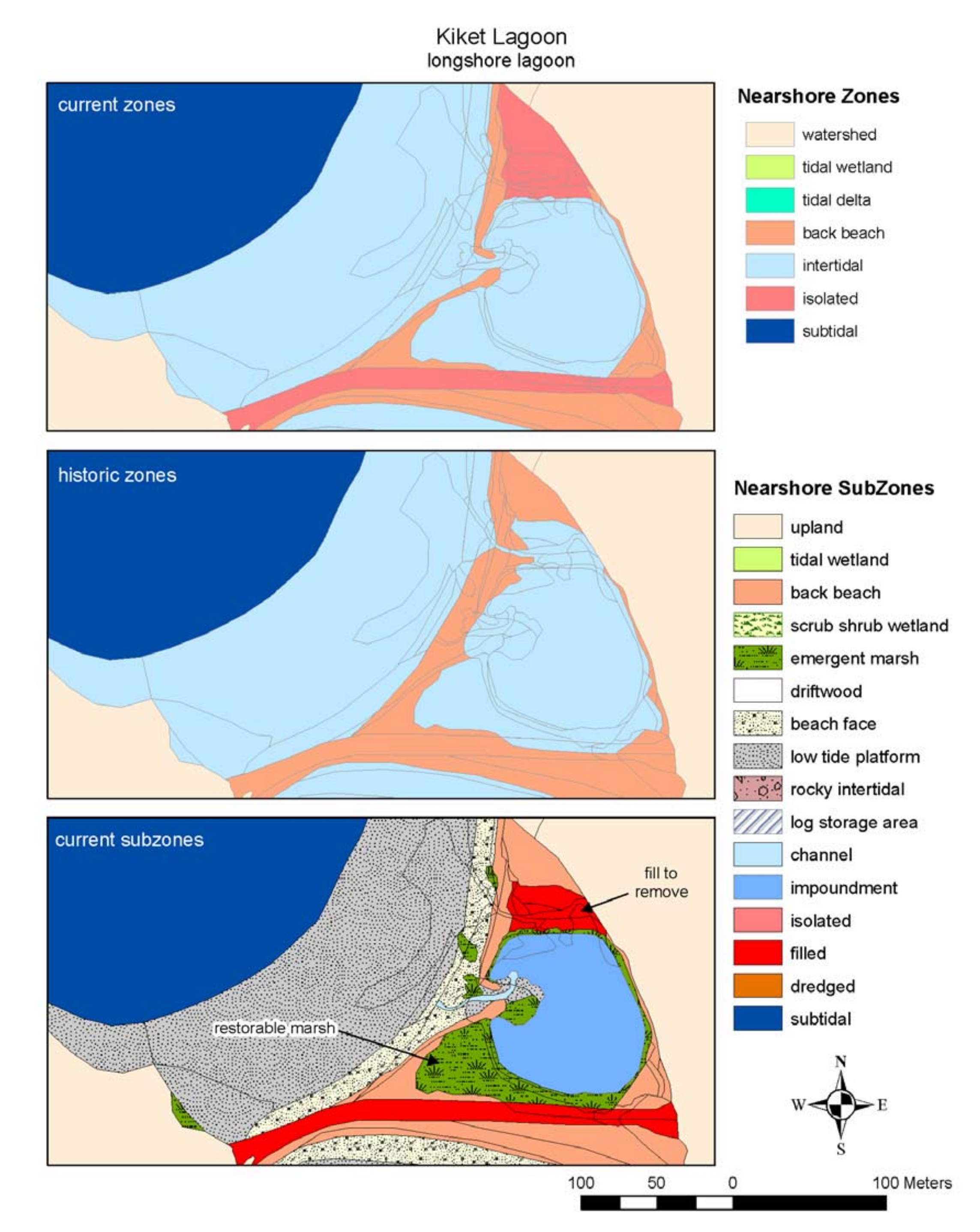


Figure D.IV.9. Kiket Lagoon is mostly intact, with only about ¼ of its historic footprint filled. However, the southern tombolo is completely armored, isolating the back beach from longshore drift and natural habitat development. Drift cell armoring at sediment source beaches in Kiket Bay may also be impacting this pocket estuary.

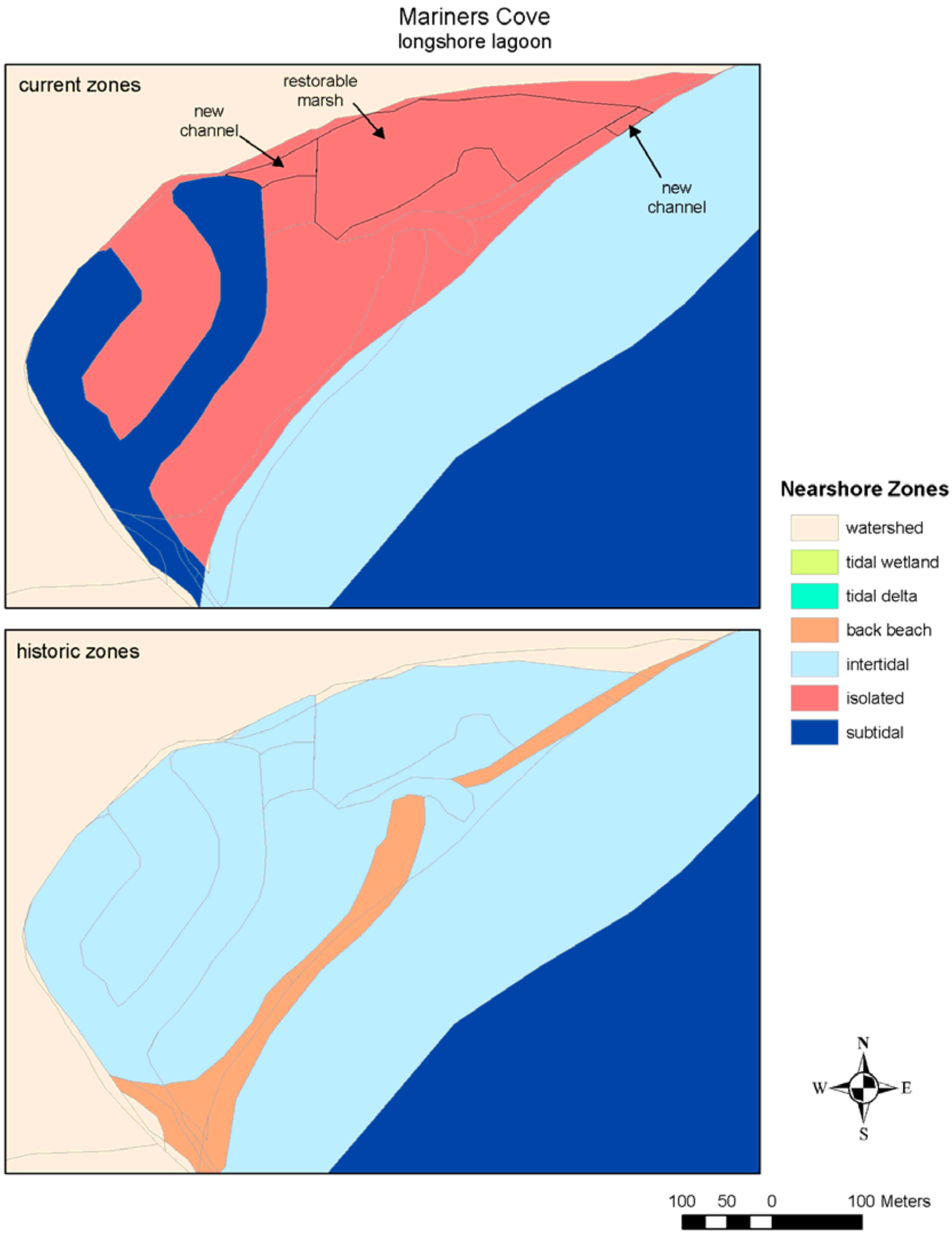


Figure D.IV.10. Mariners Cove has been completely altered from its original form of a longshore lagoon into a dredged boat basin. Restoration is possible for a section of existing, isolated marsh along the northeast edge of the former pocket estuary. Two new channels would need to be dredged to connect the marsh to tidal inundation and to the existing boat basin to maximize habitat potential under the existing restoration limitations.

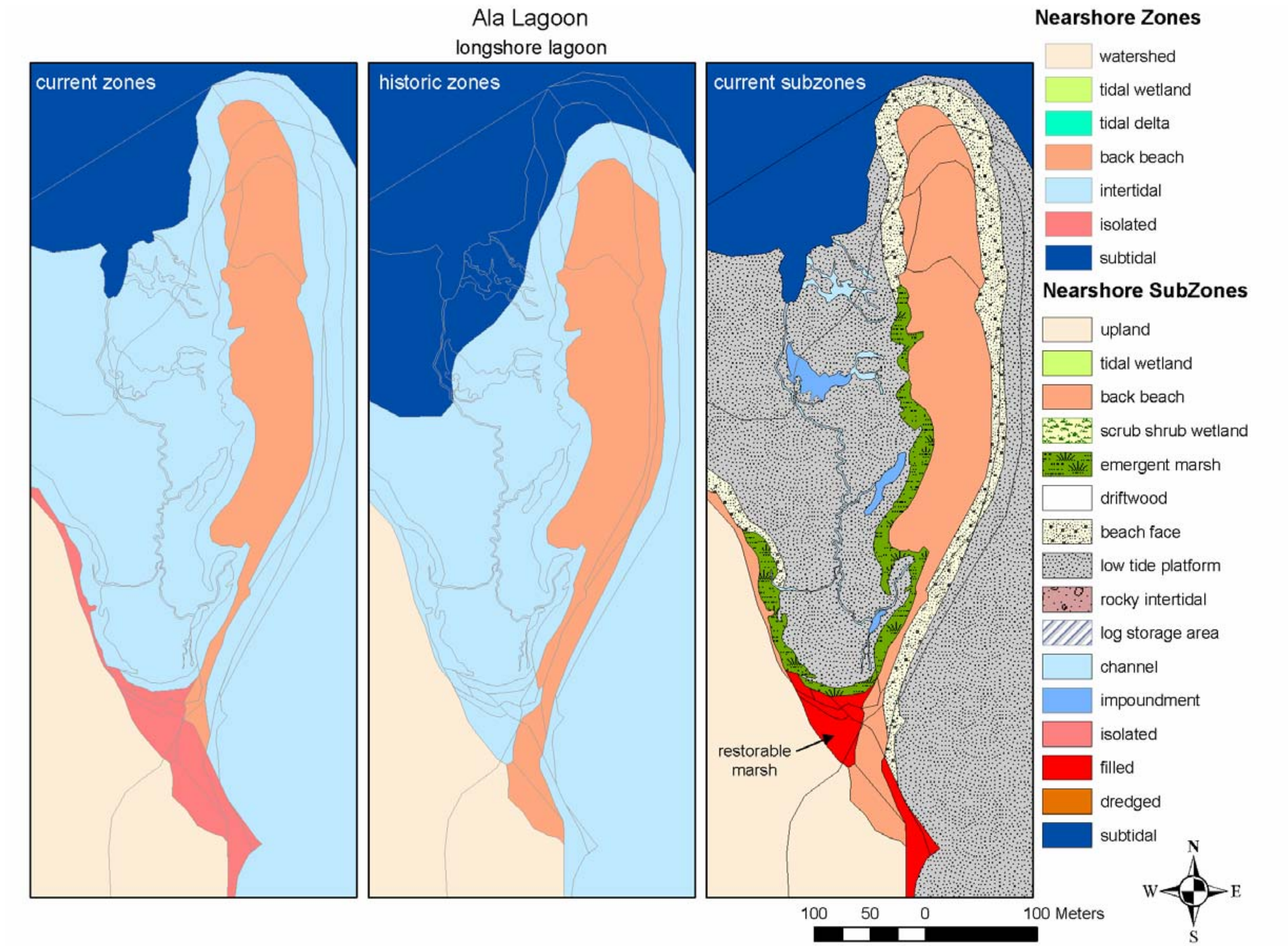


Figure D.IV.11. Ala Lagoon has been modified by an access road that partially filled and cut off a small section of tidal marsh. On the south edge of the spit, shoreline armoring and filling has cut off some sediment sources that contributed to the spit historically. Protecting sediment sources for the spit is the primary concern for this site.

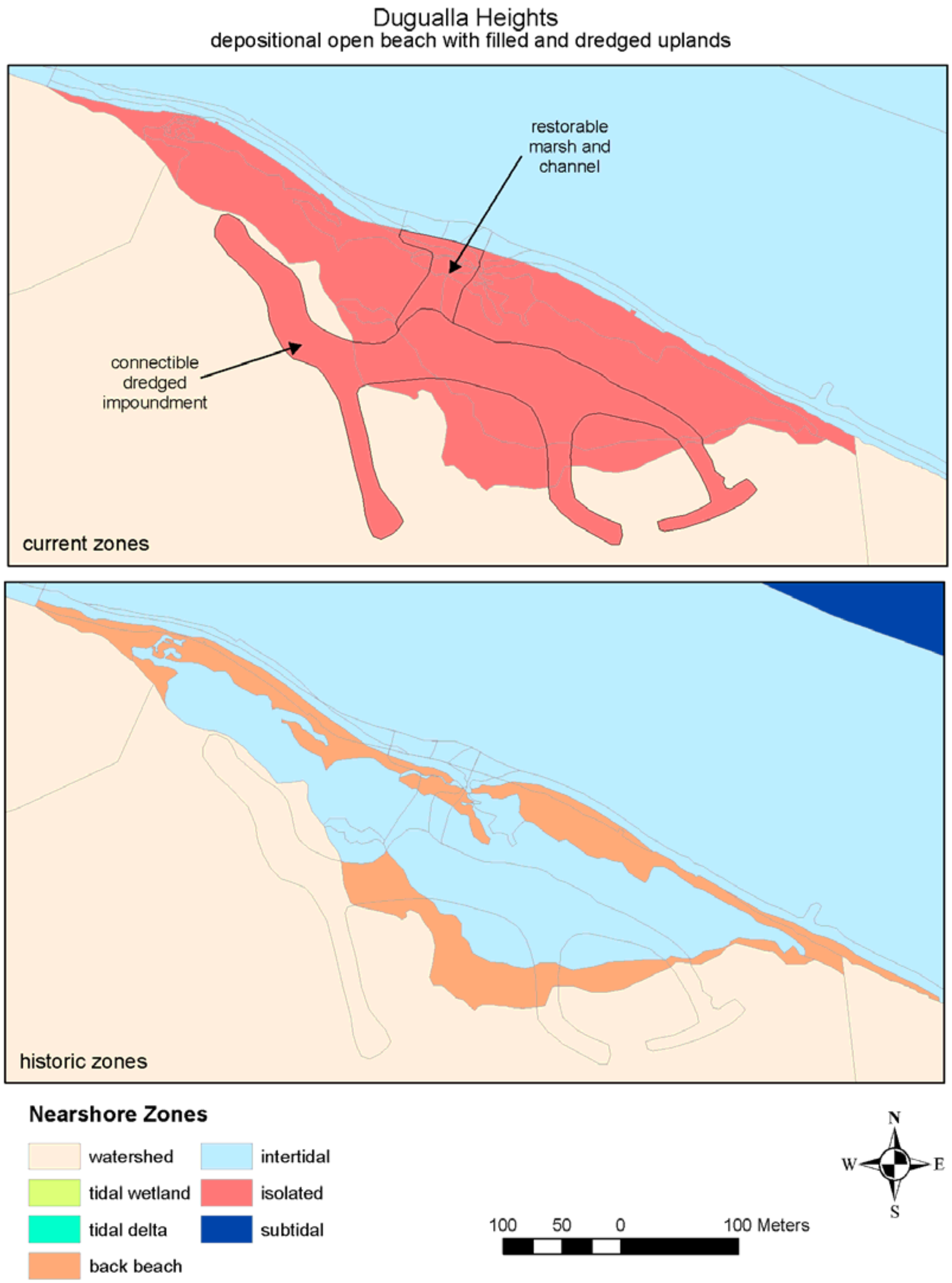


Figure D.IV.12. Dugualla Heights was formerly a longshore lagoon. The historic impoundments have been cut off from tidal exchange, enlarged, dredged, and armored to create a lake. The former spit beach is also armored. Restoration could reconnect the artificial lake to tidal influence via a constructed channel through a narrow piece of existing marsh. The area is heavily built and armored.

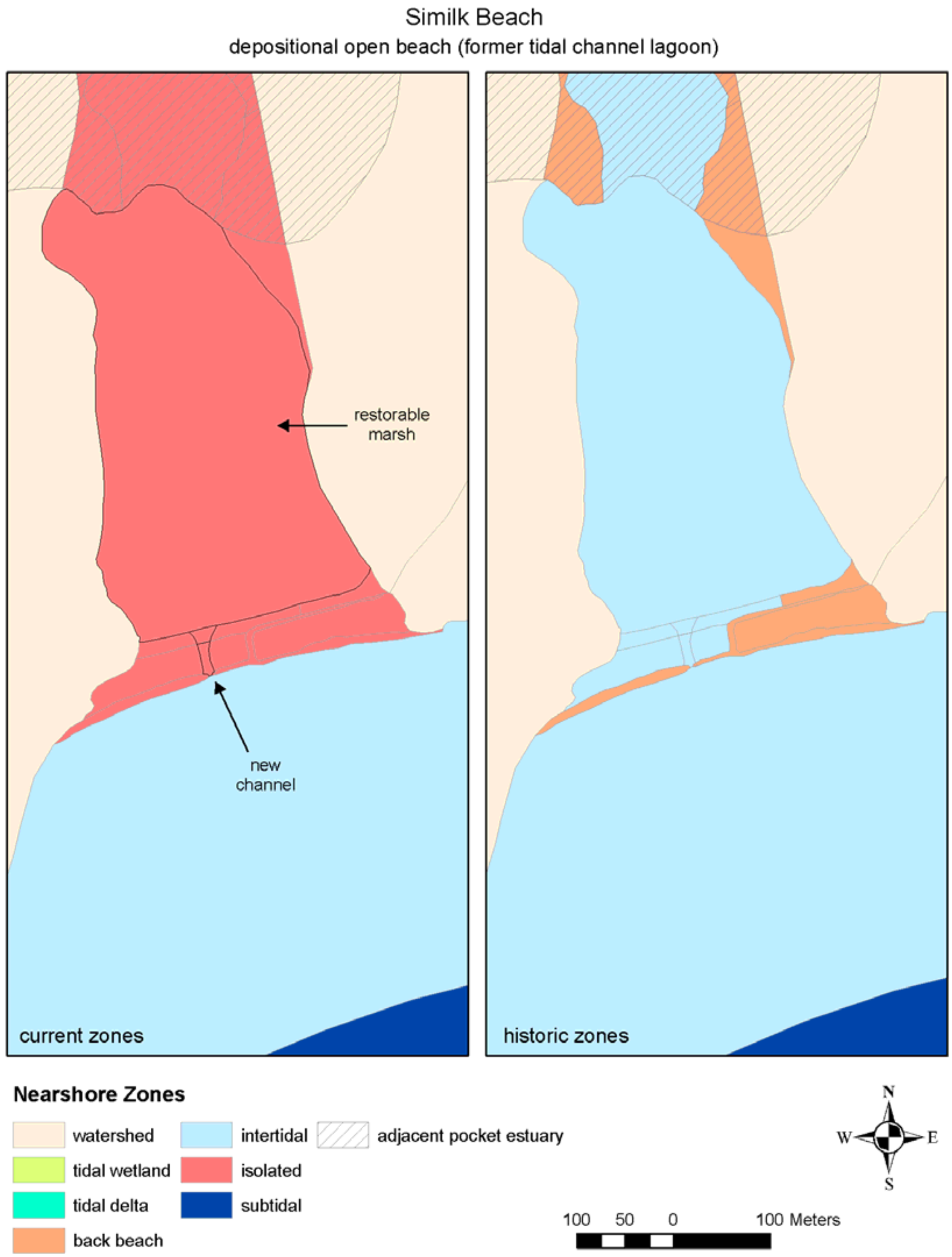


Figure D.IV.13. Similk Beach is a former tidal channel that is now a golf course. This site floods every winter because of its low relief. The beach face is diked, with a pumping station and pipe to drain the golf course. Data for mapping historic conditions were of poor quality. Further investigation and site characterization would be necessary to determine appropriate restoration actions.

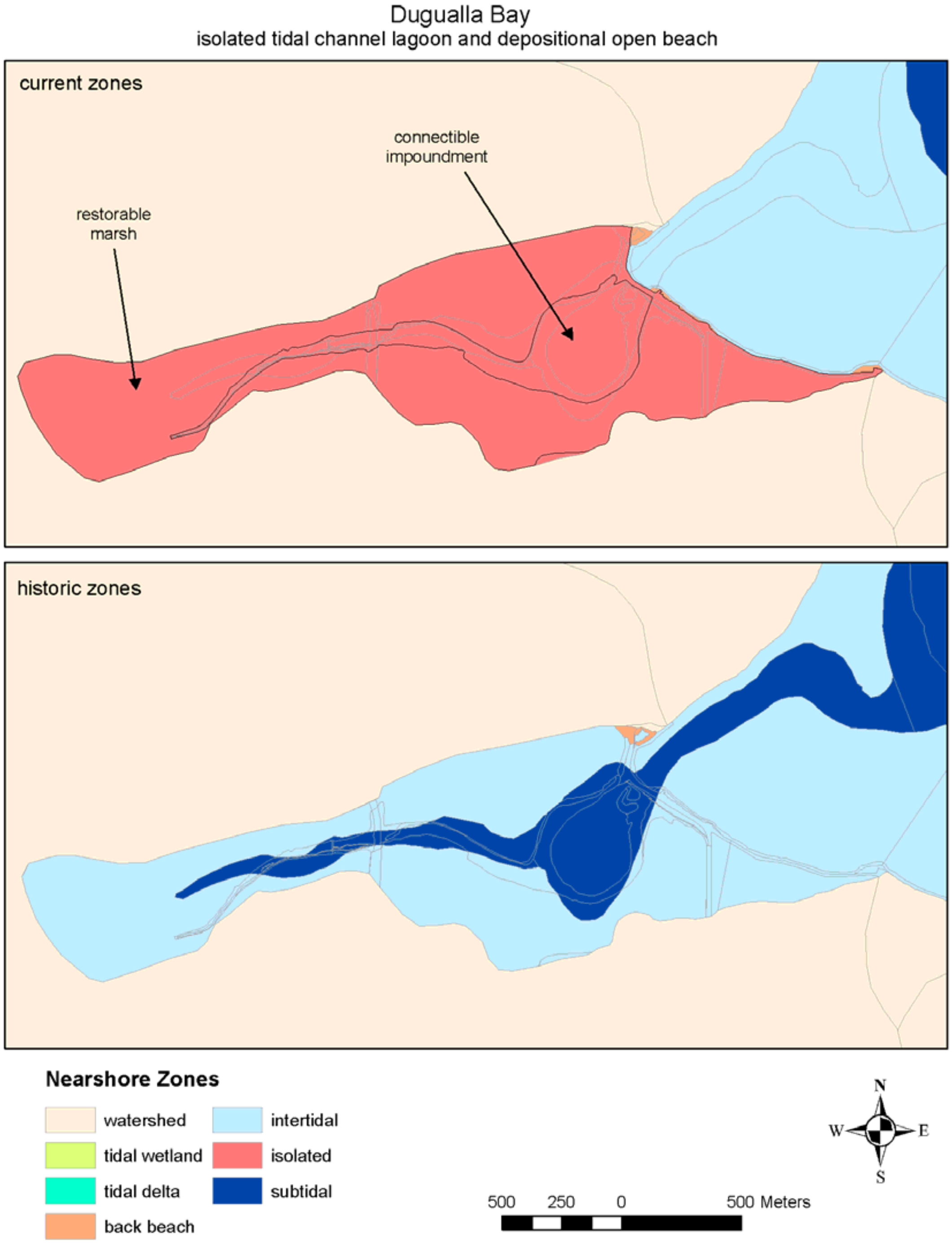


Figure D.IV.14. Dugualla Bay has been completely cut off from its historic tidal channel and associated marsh/channel complex. The original pocket estuary probably included a spit that does not show on these maps because historic data in the central part of the bay were too coarse in resolution to identify any coastal landforms. Development pre-dates 1941. This site is of particular importance due to its close proximity to the Skagit Delta.

Appendix D.IV Reference

Beamer, E. M., A. McBride, R. Henderson, and K. Wolf. 2003. The importance of non-natal pocket estuaries in Skagit Bay to wild Chinook salmon: an emerging priority for restoration. Skagit System Cooperative research report. Available at www.skagitcoop.org.

APPENDIX D.V. METHODS FOR DETERMINING BIFURCATION ORDER OF SKAGIT DELTA CHANNELS

Eric Beamer
January 2005

Distributary channel ordering of the Skagit delta was classified starting with the lower Skagit River upstream of North and South forks as a 1st order channel because 100% of the flow to the estuary must go through this area under normal flows. The main North and South Forks were classified as 2nd order because they are roughly two equal pathways for water flow based on their width. Following this pattern, a change in bifurcation order was assigned in ascending order (e.g., 3rd order, 4th order) where: 1) one distributary channel splits into two downstream channels of approximately the same width near the point of bifurcation; and 2) bifurcation order is known for the upstream channel. By applying this definition to the Skagit delta (year 2000), we find ten points of bifurcation in the entire delta where the resulting channels are ordered by our definition (Figure D.V.1). These ten observations show that the head-end of each downstream channel pair varied in width by an average of 13%, with the largest difference observed at 30%. This sets a context for determining what is "approximately" equal in width for true bifurcation by our definition.

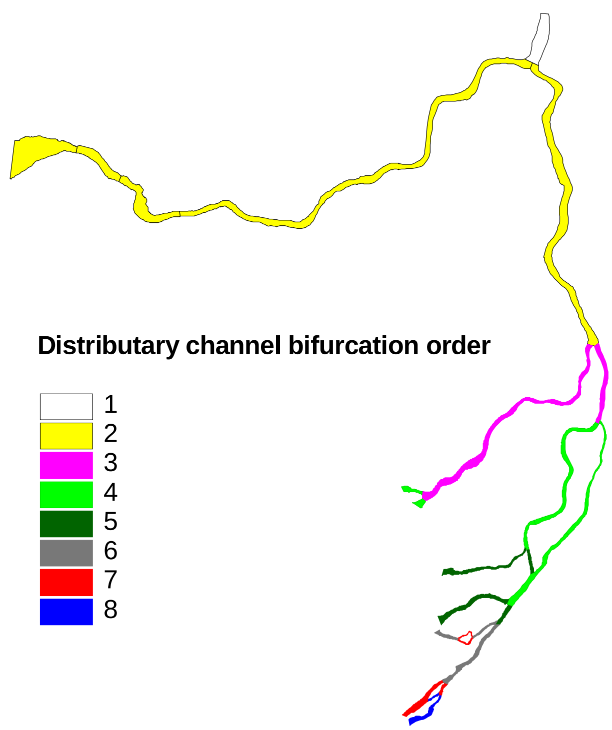


Figure D.V.1. *Distributary channel order, year 2000, Skagit delta.* One distributary channel (upstream channel link) splits into two downstream channels of approximately the same width; bifurcation order is known for the upstream channel.

The many remaining channel splits within the Skagit delta could not be ordered by this method because they either break into unequal downstream channels or somewhere upstream in the channel network, bifurcation order could not be traced cleanly to the Skagit mainstem (our 1st order channel just upstream of the forks). Therefore, we assigned bifurcation order to these remaining channels based on an empirically derived pattern in channel width reduction after bifurcation (Figure D.V.2) and applied it using Table D.V.1. We use distributary channel order results to estimate landscape scale connectivity (see section 3.4 of this document).

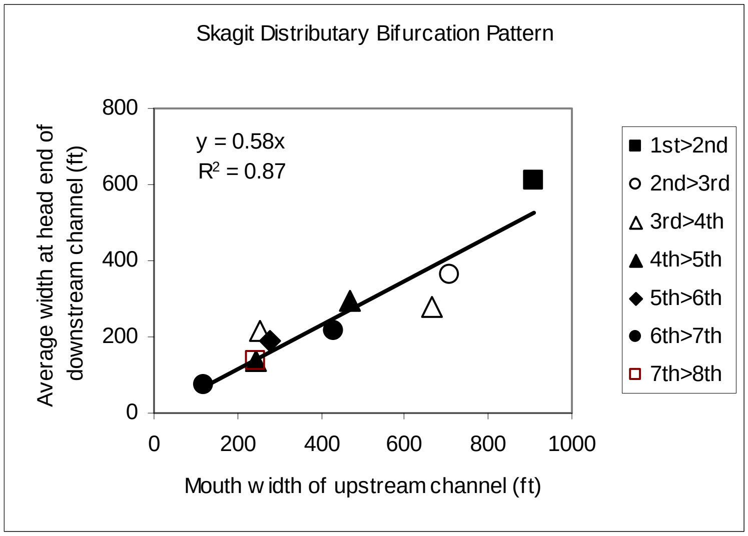


Figure D.V.2. *Channel width relationship between upstream and downstream channels at the point of distributary bifurcation.*

Table D.V.1. *Assignment of distributary channel order for channels that split into unequal widths.*

Bifurcation order of downstream channel equals:	Downstream channel head-end width (% of upstream channel mouth width)	Low end of range	High end of range
Upstream channel order plus 1	60%	75%	45%
Upstream channel order plus 2	36%	45%	27%
Upstream channel order plus 3	22%	27%	16%
Upstream channel order plus 4	13%	16%	10%
Upstream channel order plus 5	8%	10%	6%
Upstream channel order plus 6	5%	6%	3%
Upstream channel order plus 7	3%	3%	2%
Upstream channel order plus 8	2%	2%	1%
Upstream channel order plus 9	1%	1%	1%

APPENDIX D.VI. SKAGIT ESTUARY DRIFT BUOY STUDY

Eric Beamer and Rich Henderson
February 2005

We conducted a pilot-level experiment using drift buoys to approximate small-scale ebb tidal currents originating at the Skagit River. Buoys were constructed to minimize wind resistance and optimize response to tidal currents in the top meter of the water column (Figure D.VI.1). We launched buoys at several river distributaries at high tide (Figures D.VI.2 through D.VI.5). We selected high tide based on the assumption that juvenile salmon leave delta habitats on the ebbing tide. We tracked the buoy sets with a boat and used GPS to document each buoy's position for about a six-hour period. We also measured salinity and water temperature at the surface and one-meter depth each time a buoy's position was documented. Salinity measurements are summarized in Figure D.VI.6.

Collectively, drift observations approximate a pathway for fish to get from the river mouth to shoreline areas, demonstrating how shoreline oriented fish might cross a larger and more marine water body than they otherwise would prefer (Figure D.VI.7). Though drift is not actual fish migration, it appears to be a good enough approximation upon which to develop hypotheses regarding fish migration pathways within the Whidbey Basin.

Conclusions about juvenile fish migration based on drift observations:

1) If young salmon fry were completely passive to water current speed and direction, it would only take them 6 hours to travel from the river mouth to shoreline areas (i.e., the intertidal/subtidal fringe area) on either side of Skagit Bay (Figures D.VI.2-D.VI.5).
2) Young salmon fry migrating out of the Skagit River are dispersed into Skagit Bay to nearshore estuarine habitats north and south of the delta depending on where they originate (Figures D.VI.2-D.VI.5).
3) Young salmon fry could move in low salinity surface water (< 10 ppt) across Skagit Bay to the Whidbey Island shoreline within hours after high tide (Figure D.VI.6).

This study also revealed some potential effects of changing an estuary's mixing pattern or salinity regime. Our study shows that drift buoys generally moved in surface waters lower in salinity by approximately 5 ppt when compared to water one meter deep (Figure D.VI.6). However, salinity data from the buoys deployed on the north side of the North Fork did not follow this pattern. Buoys deployed from this area were influenced by the North Fork jetty. The jetty helps maintain a navigation channel between Swinomish Channel and Skagit Bay. The jetty shadows the area north of it from Skagit River flow, thus increasing the salinities north of the jetty. If low salinity water (from surface flowing river water) is an important variable for migrating juvenile Chinook salmon, then changes to the river hydrograph and changes to the pathways of river water within the delta or nearshore environment (e.g., blocked-off sloughs, addition of jetties, or dredging channels) could influence how fish move within the delta estuary and nearshore landscape. This will influence the opportunity fish have to access existing or newly restored habitat.

Figure D.VI.1. *The drift buoy.* The base is 13 inches by 13 inches, and made of plywood. The pole is a bamboo garden stake. The base has a four-ounce fishing weight attached for displacement.

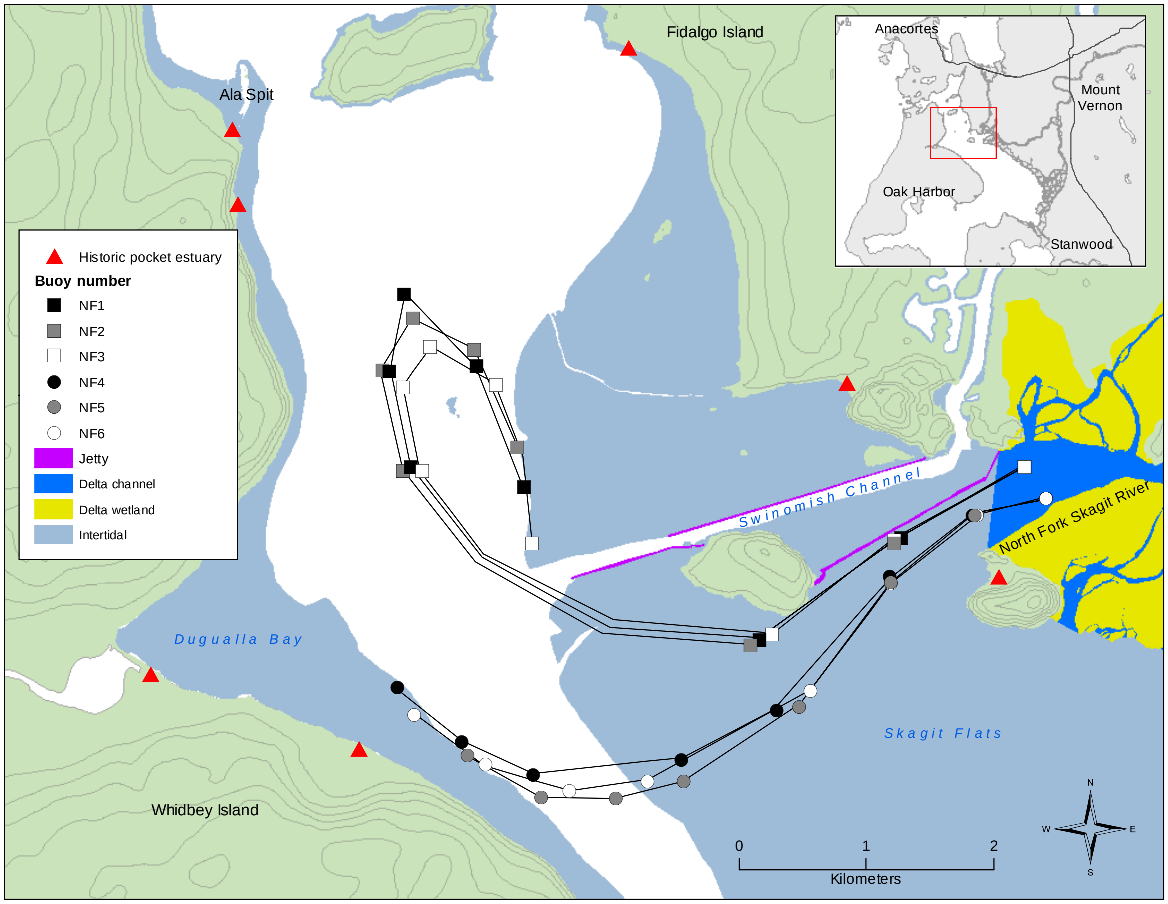


Figure D.VI.2. *Trajectory of drift buoys launched in the mouth of the North Fork Skagit River.* Six drift buoys were released at high tide in the North Fork on 9/17/04. Tidal drop for this ebb tide based on Ala Spit tide tables was 6.5 feet. The daily average river discharge was 30,000 cfs., measured at the Mt. Vernon gage. The buoys were deployed in two groups, one group on the north side of the river and the other group on the south.

The drift buoys released near the south bank of the river drifted southwest, for a distance of approximately 5,840 meters in just under 3 hours. The buoys were lost soon after entered Dugualla Bay. Surface salinities were at or near 0.0 ppt across the flats, increased to 5.8 ppt in the trough along Whidbey Island, and then dropped to about 2 ppt at the edge of Dugualla Bay. Surface temperatures ranged from 11.6^{o}C to 12.3^{o}C. Salinity at one-meter depth ranged from 0.0 ppt to 4.5 ppt across the flats, increased to approximately 12 ppt while crossing the trough, and dropped again to 3.6 ppt at the edge of Dugualla Bay. The temperature at the one-meter depth was between 11.6 and 12.5^{o}C.

The three buoys deployed along the north side the river traveled north for a distance of approximately 8,600 meters in just under 6 hours. Surface salinities were at or near 0.0 ppt across the flats, and increased to 12.1 ppt to 15.3 ppt while buoys drifted in the Whidbey Island trough. Temperatures ranged from 11.6 ^{o}C to 12.8 ^{o}C. Salinity at 1 m depth ranged from 0.0 ppt to 7.5 ppt across the flats, and 14.1 ppt to 16.2 ppt in the Whidbey Island trough. Temperatures ranged from to 12.0^{o}C to 12.7^{o}C. The North Fork jetty that helps maintain a navigation channel between Swinomish Channel and Skagit Bay appears to shadow the area north of it from Skagit River flow thus increasing the salinities experienced by the buoys drifting north of the jetty.

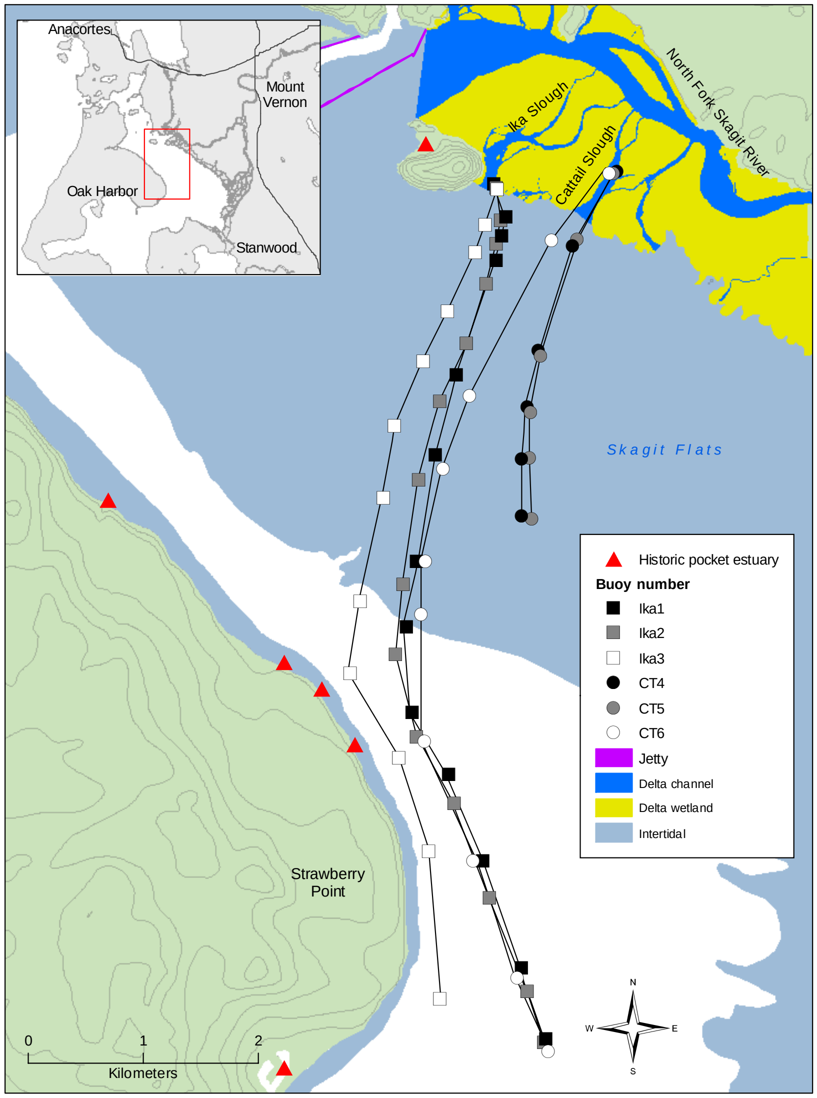


Figure D.VI.3. *Trajectory of drift buoys launched in North Fork Skagit River distributaries.* Three drift buoys were launched at high tide each in Cattail Slough and Ika Slough on 11/2/04. The daily average discharge for the Skagit River at Mount Vernon was 31,800 cfs. High tide for Ala Spit was predicted to be 10.2 feet and low tide 7.3 feet. The buoys in Cattail Slough were deployed one on each side and one in the middle of the channel. Surface salinity ranged from 0.0 ppt at release to 7.9 ppt before loss of two of the buoys. Surface temperature was constant at 8.8 ^{o}C. Salinity at one-meter depth ranged from 0.0 ppt at release to 26.1 ppt, and temperature from 8.7^{o}C to 10.6 ^{o}C. The one continuing Cattail buoy traveled into the Whidbey trough where salinity at the surface reached 10.4 ppt. Salinity measured at 1 m depth ranged from 17.2 ppt to 25.8 ppt. Salinity at 1 m dropped to 10.7 ppt when the buoy reached the southern end of the bay near Strawberry Point. Surface temperature was constant at 8.8 ^{o}C. Temperature at 1 m ranged from 8.7 ^{o}C to 10.6 ^{o}C. Total distance traveled by this buoy was 8,285 meters in just over 5 hours. For the three Ika Slough buoys surface salinity ranged from 1.6 ppt to 7.5 ppt across the flats and increased to 8.1 ppt to 15.2 ppt in the Whidbey Island trough. As the buoys traveled south along the trough, surface salinity dropped to 4.2 ppt – 9.0 ppt. Surface temperatures were steady at 9 ^{o}C throughout the trial period. Salinities recorded at 1-meter depth were 4.9 ppt to 6.9 ppt across the flats, increasing to 20.5 ppt in the Whidbey Island trough. Total distance traveled for the 3 Ika buoys was approximately 7,500 meters over 5 hours.

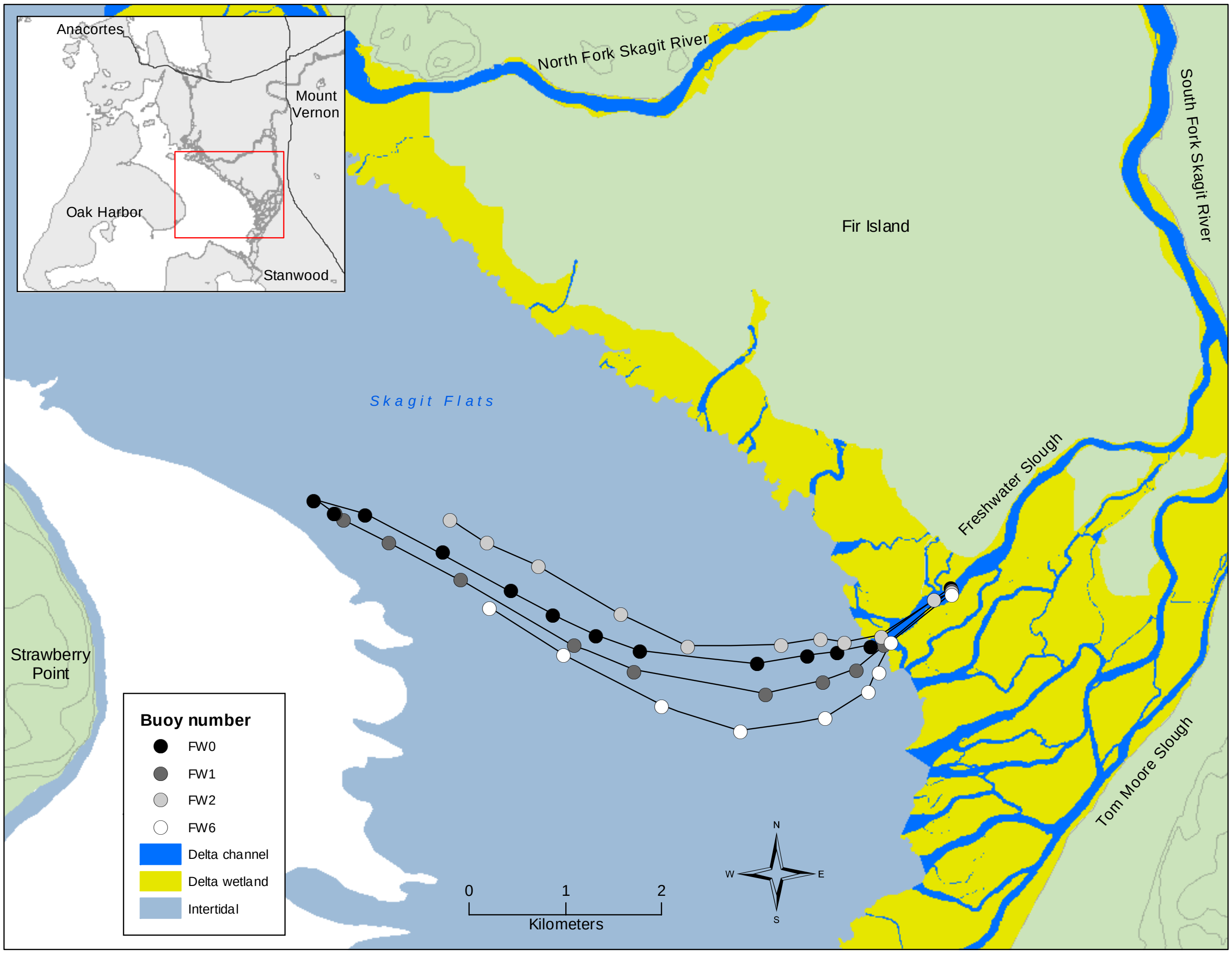


Figure D.VI.4. *Trajectory of drift buoys launched at high tide in South Fork Skagit River at Freshwater Slough distributary.* Four buoys were deployed at Freshwater Slough on 11/3/04. The daily average discharge for the Skagit River at Mount Vernon was 35,000 cfs. High tide for Ala Spit was predicted at 10.2 feet and low tide at 7.3 feet. Surface salinity ranged from 0.0 ppt to 1.9 ppt and temperatures from 7.4 ^{o}C to 9.1 ^{o}C. The higher temperatures were reached as the buoys traveled further away from the mouth of the river, towards the west side of the flats. Salinity measured at 1 m depth ranged from 0.0 ppt to 1.9 ppt, and temperature constant at 7.5 ^{o}C for the first 2,900 m from the launch point. After this distance the salinity at one meter increased and varied from 10.6 ppt to 13.1 ppt. The distance traveled in just over 5 hours by the 4 buoys varied from 5,703, to 7,420 meters.

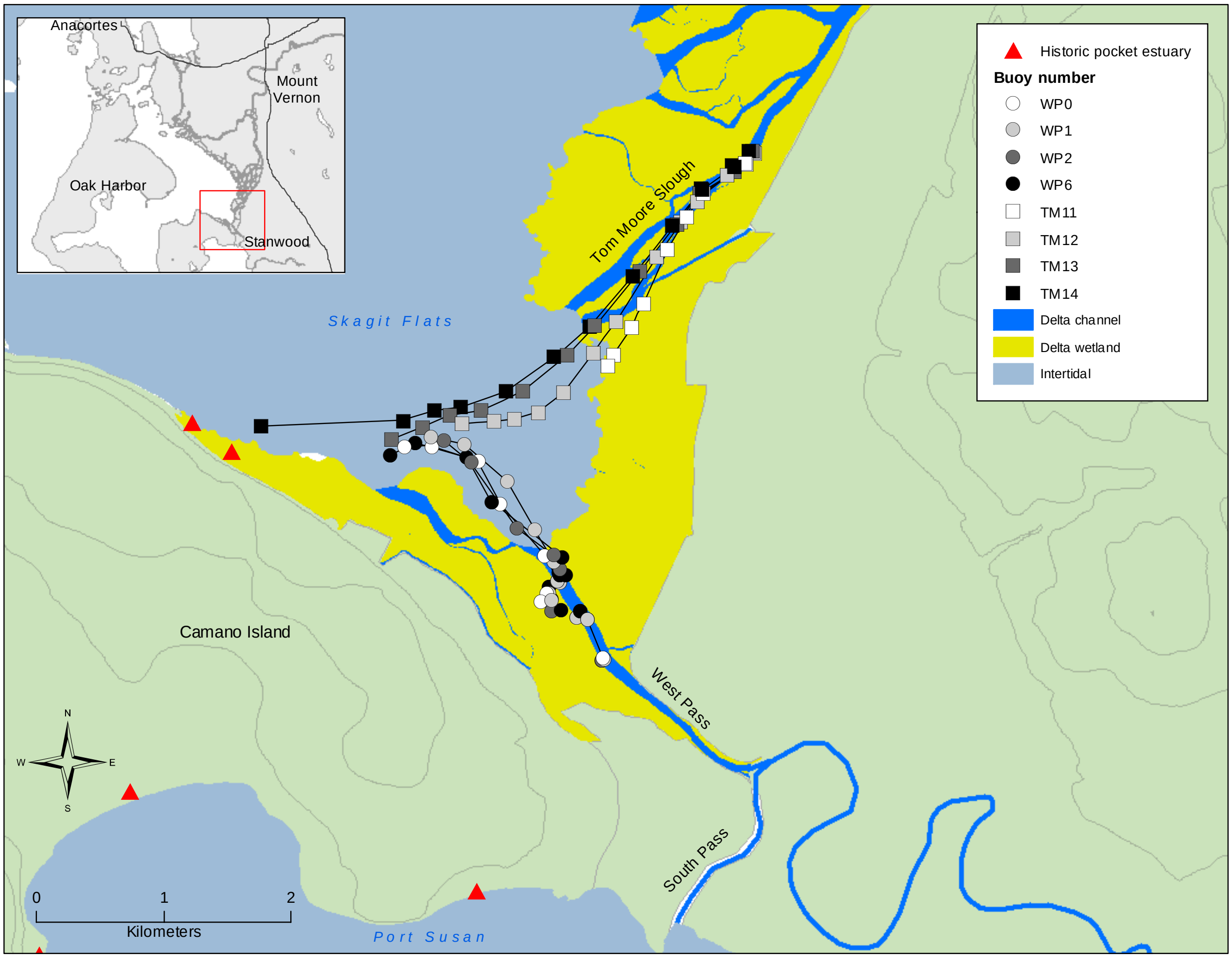


Figure D.VI.5. *Trajectory of drift buoys launched at Tom Moore Slough and West Pass.* Four drift buoys were deployed on 11/17/04 in Tom Moore Slough and also in West Pass of the Stillaguamish River. The average daily discharge for the Skagit River was 17,600 cfs at the Mount Vernon gage. High tide at Crescent Harbor was predicted to be 12.75 feet and low tide 7.01 feet. One of the Tom Moore buoys stranded in marsh grass as the tide dropped. It had traveled 2,055 meters when it was retrieved. The remaining three Tom Moore buoys continued west. Surface salinity ranged from 2.5 ppt to 11.0 ppt and temperature from 7.0 °C to 8.7 °C. Salinity measured at one-meter depth ranged from 6.7 to 18.1 ppt. Total distance traveled was approximately 3,900 meters in four hours. The four West Pass buoys were launched while the tide was still flooding in this area. They were stranded several times before finally drifting west as the ebb tide began in full force at the beginning of hour 3 of the experiment. High tide at Stanwood was predicted to be 7.68 feet at 09:55 a.m. and low tide 2.26 feet at 16:28 p.m. The buoys were originally launched at 09:43. Full ebb tide was observed at 11:30 a.m. Surface salinities were between 14.2 ppt and 18.8 ppt. Surface temperature ranged from 7.7 °C to 8.6 °C. Salinity measured at 1 m depth ranged 18.2 ppt to 19.8 ppt, with temperatures from 8.9 °C to 9.6 °C. Total travel distance was approximately 1,600 meters over the 2.5 hours of actual drift. When the West Pass buoys were retrieved, they were within 100 meters of the drift buoys launched from Tom Moore Slough.

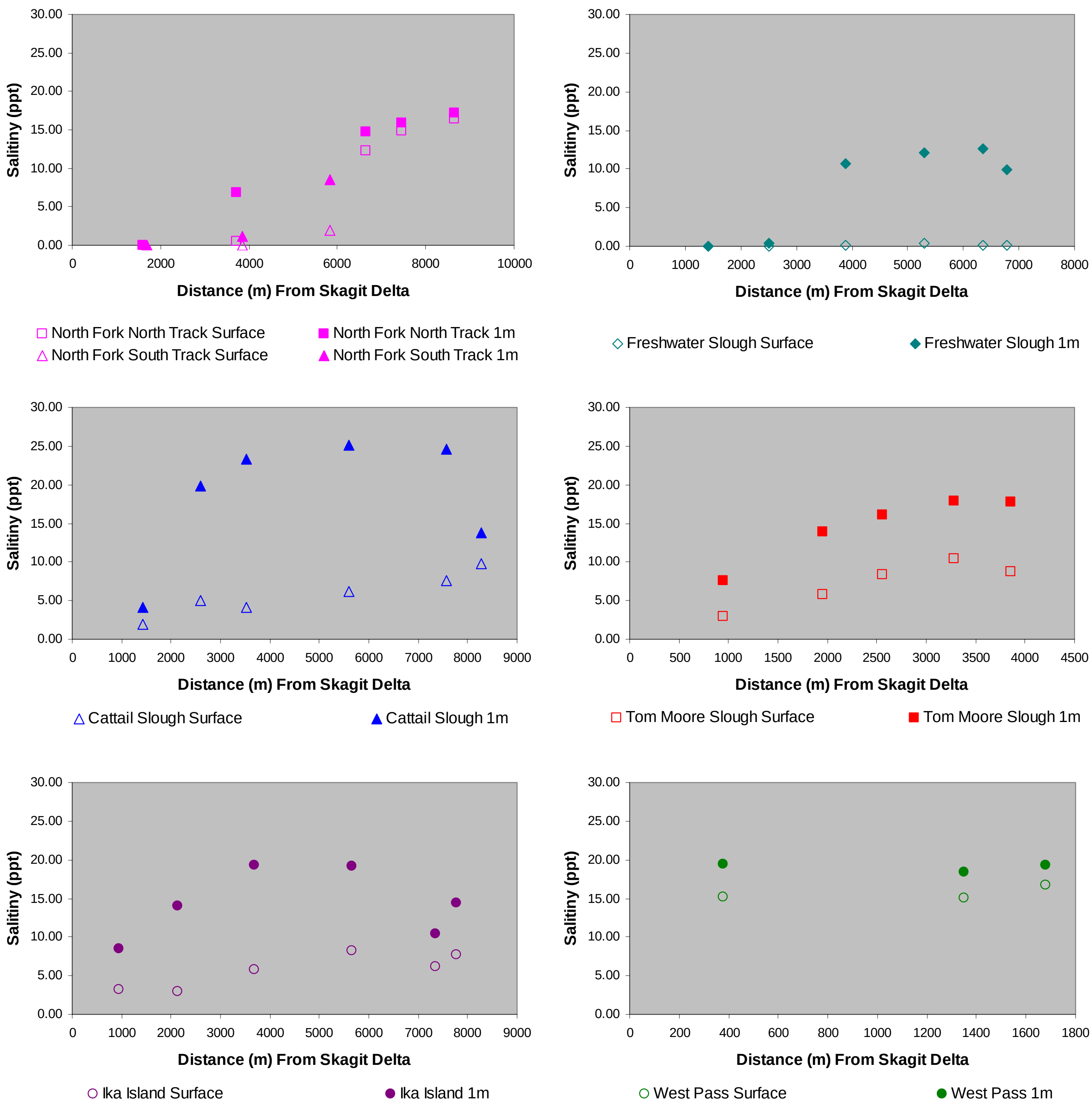


Figure D.VI.6. *Salinity at the surface and at one-meter depth along drift buoy paths.* Salinity is averaged for each hour of drift and plotted against distance traveled during that hour. Graphs generally show increasing salinity with increasing distance from the delta and higher salinity at one-meter depth compared to the water surface. At the North Fork site, drift buoys split into two distinctly separate paths, so they are graphed as such. The West Pass site is a tidal slough distributary of the Stillaguamish River with much less freshwater flow, and thus is saltier overall than the other distributary sites monitored.

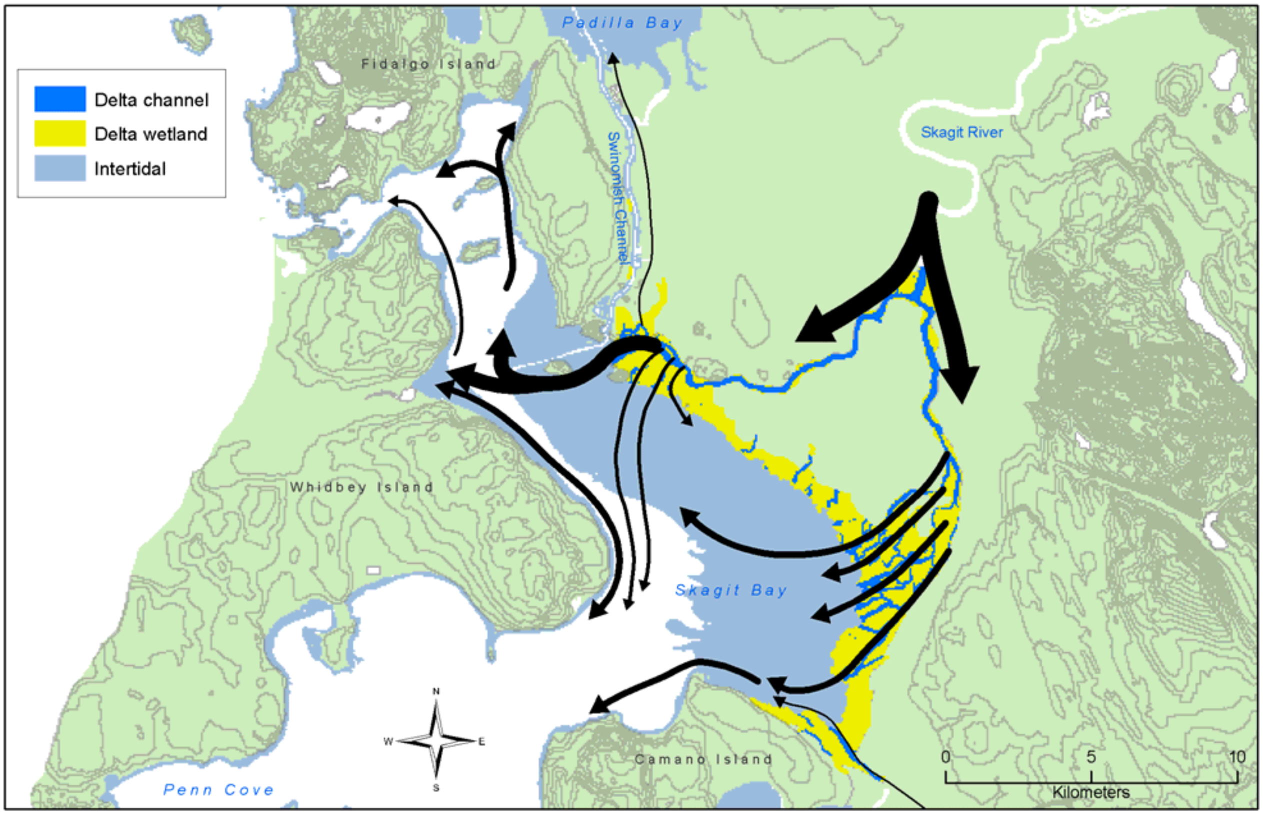
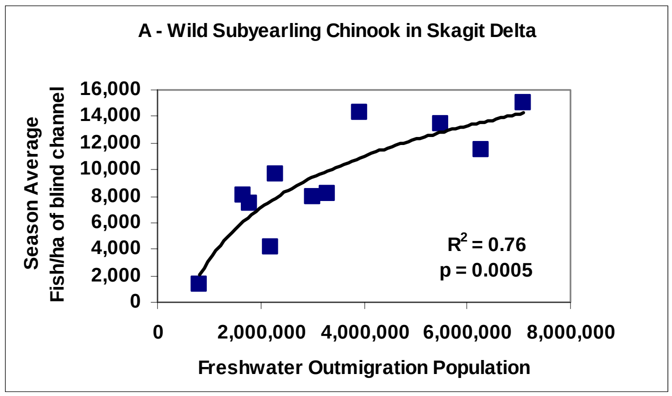


Figure D.VI.7. *Cartoon of migratory pathways for fry migrant Chinook salmon.* Under current (year 2005) delta conditions based on a synthesis of drift buoy results, connectivity, and spatial patterns in juvenile Chinook abundance. Arrow width represents fish use of pathways, where wide arrows indicate pathways used by more fish than narrow arrows.

APPENDIX D.VII. ESTIMATING CARRYING CAPACITY OF JUVENILE CHINOOK SALMON IN SKAGIT ESTUARINE HABITATS

Correigh Greene and Eric Beamer
February 2005

Monitoring wild juvenile Chinook salmon abundance blind channel habitat within the Skagit delta over population sizes ranging from 800,000 to 7,100,000 shows the relationship between freshwater wild juvenile Chinook population size and wild juvenile Chinook abundance in estuarine river delta habitat is density dependent (asymptotic) (Figure D.VII.1A). We also find a mirror image when examining the average length of juvenile Chinook rearing in delta habitat (Figure D.VII.1B). As the total freshwater smolt population increases, average length of delta rearing fish declines.



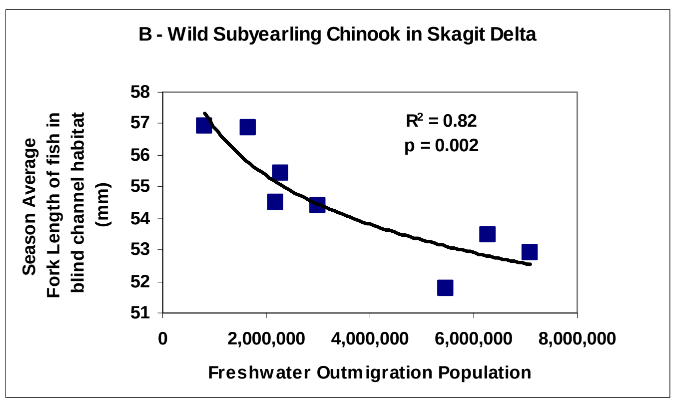


Figure D.VII.1. *Density dependence in the Skagit delta.*

(A) Relationship between juvenile Chinook abundance in delta habitat and total outmigration population size. The number of wild juvenile Chinook per unit area within delta blind channel habitat levels off as the total number of outmigrating Chinook salmon increases, indicating that delta habitats are filling up.

(B) Relationship between juvenile Chinook size and total outmigration population size. The size of wild juvenile Chinook salmon rearing in delta blind channel habitat declines as total juvenile Chinook population increases.

Juvenile Chinook density estimates in the delta are 1992-2002 seasonal averages derived from 6 index sites using fyke-trapping methods. Freshwater Chinook smolt population estimates are from WDFW, Olympia, WA.

We evaluated the role of Chinook salmon density dependence in delta habitats using statistical models to estimate the capacity of delta blind channel for juvenile Chinook salmon. We used data from six index sites collected over the period 1992 through 2002 (Figure D.VII.2). The analyses were done in a two-step process to first control for environmental variation among sampling sites and then to predict the density of juvenile Chinook salmon (fish/m^3) subject to density dependence as a function of the number of outmigrants. As such, the analysis takes advantage of the multiple data points sampled per year to estimate the effect of increasing outmigration on density.

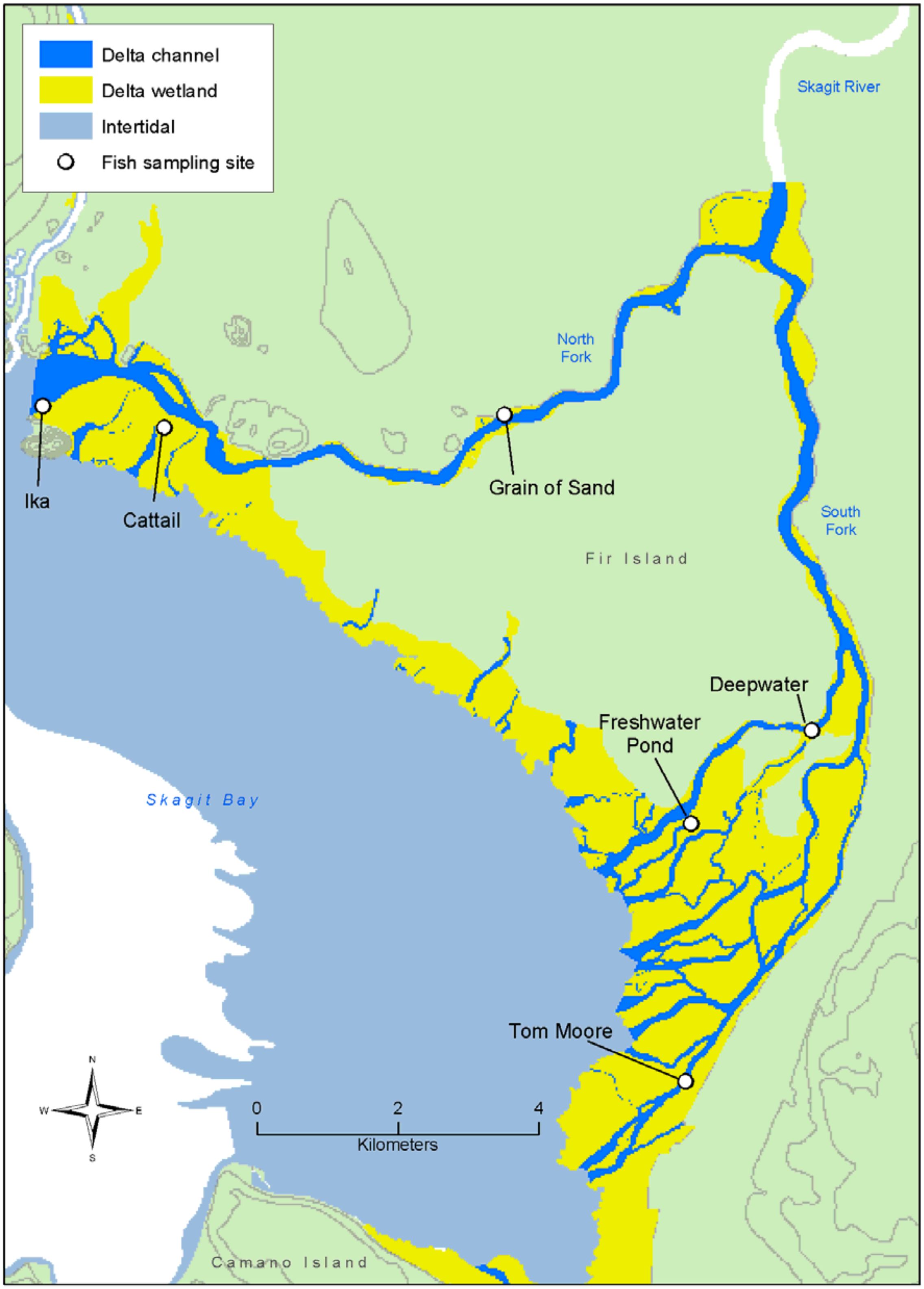


Figure D.VII.2. *Skagit tidal delta index sites.* Location of delta estuary blind channel sites used to monitor wild juvenile Chinook salmon abundance 1992 through 2002.

STEP 1: CONTROLLING FOR ENVIRONMENTAL VARIATION

The six sites in the tidal delta vary over time based primarily on temperature, salinity, tidal height, and river discharge. Because all these variables covary, we performed a principle components analysis over the annual rearing season (February-June) using site means for these variables. This analysis resulted in a habitat factor that described local conditions at different sites.

Table D.VII.1 demonstrates that the habitat factor generated by the analysis was strongly positive correlated with salinity, but negatively correlated with river discharge. We used a linear model to examine the effects of the habitat factor on annual fish density during the rearing period at the different sites. The model indicated a significant effect of the Habitat Factor upon fish density. The equation for this relationship is:

Table D.VII.1. *Factor loadings of the principal components analysis.*

Variable	Factor loading
Discharge	-.619
Water temperature	.786
Salinity	.874
Tidal drop	.826

ln(density) = -1.81275 - 0.72541 * Habitat Factor

We used this relationship in two ways. First, we examined how the Habitat Factor varied as a function of connectivity. This would enable us to predict the effect of connectivity on fish density. Second we used the residuals of the analysis in a density-dependent model (discussed in Step 2).

Table D.VII.2. *ANOVA table of the Habitat Factor regression.* Type III Tests of Fixed Effects(a). $R^2 = 0.36$.

Source	df	Denominator df	F	Sig.
Intercept	1	40.237	367.936	.000
Habitat Factor	1	30.878	92.050	.000

The Habitat Factor correlates well with connectivity. Average Habitat Factor at each site is graphed as a function of connectivity in Figure D.VII.3, which reveals a strong logarithmic relationship ($R^2 = 0.80$). Over time then, the average effect of abiotic factors should be proportional to the log of connectivity. In other words, one could replace Habitat Factor with the connectivity relationship to estimate density for sites varying in connectivity. This replacement was used to estimate the expected density of fish at potential sites that vary in their level of connectivity.

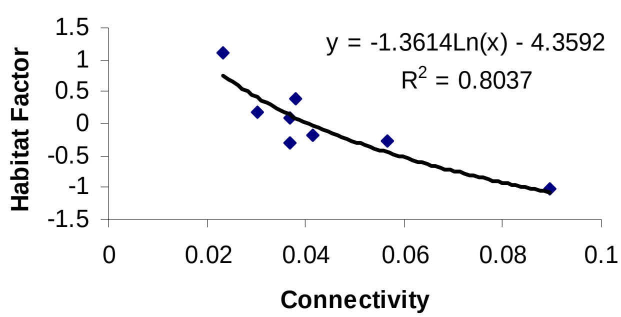


Figure D.VII.3. *The relationship of mean Habitat Factor with Connectivity.*

STEP 2: EVALUATING DENSITY DEPENDENCE

We used a Ricker relationship to examine the role of density dependence in the Skagit delta. This was based on the assumptions that the Ricker model is better for delayed effects of density on recruitment (e.g., if there was density dependence starting in freshwater), and when fish compete for resources but not territories (as is the case for fish in tidal delta habitat, which tend to school rather than set up territories). Although fish compete with one another for food, they may also benefit from association with conspecifics by reduced predation if they swim in schools. This is an example of an Allee effect. The Allee effect can be modeled using a rectangular hyperbola (Dennis 1989). Hence the combined model we used is:

$$R = ADe^{-BD}\frac{D}{(D+E)}$$

where R is the residual density, A and B are parameters for the Ricker relationship, D is the number of outmigrants measured at the mainstem trap operated by WDFW near Mount Vernon (Seiler et al. 2003), and E is the rectangular hyperbola parameter. This equation can be rewritten in log-transformed form as

$$\log(R) = A + \log(D^2) - BD - \log(D+E)$$

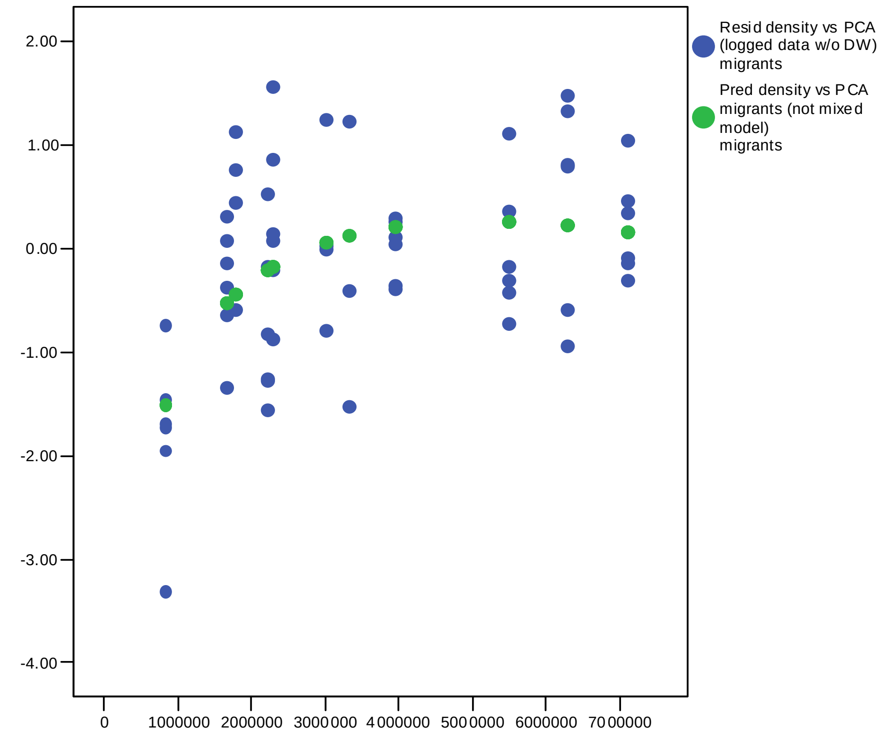
As the original data used for the Habitat Factor analysis was already log-transformed, we used this equation on the raw residuals from Step 1. This model was evaluated using nonlinear regression (Table D.VII.3).

Table D.VII.3. *Ricker model with parameters.* R^2 = 1 - Residual SS / Corrected SS = .31373

Parameter	Estimate	Std. Error	Asymptotic 95 % Confidence Interval	
			Lower	Upper
A	-13.34298542	2.073626799	-17.49695906	-9.189011776
B	2.68911E-07	1.99437E-07	-1.30608E-07	6.68431E-07
E	3084207.8945	8354054.0561	-13650973.36	19819389.147

All parameters are significant, and the resulting density dependent relationship explains about as much variation as the Habitat Factor (R^2 = 0.31). The resulting equation predicts a peak density (capacity) at 5,100,000 juvenile Chinook salmon migrants (Figure D.VII.4). Density at capacity is predicted to be 1.314 fish/m^3. Further analysis using other equations enabled us to discover that all density dependent parameters (including the Allee effect) are informative predictors of variation in density.

Figure D.VII.4. Observed (blue) and predicted (green) residual values of log transformed juvenile Chinook salmon density as a function of total wild Chinook salmon smolt outmigration population (outmigrants).



USING THE MODEL TO ESTIMATE CARRYING CAPACITY

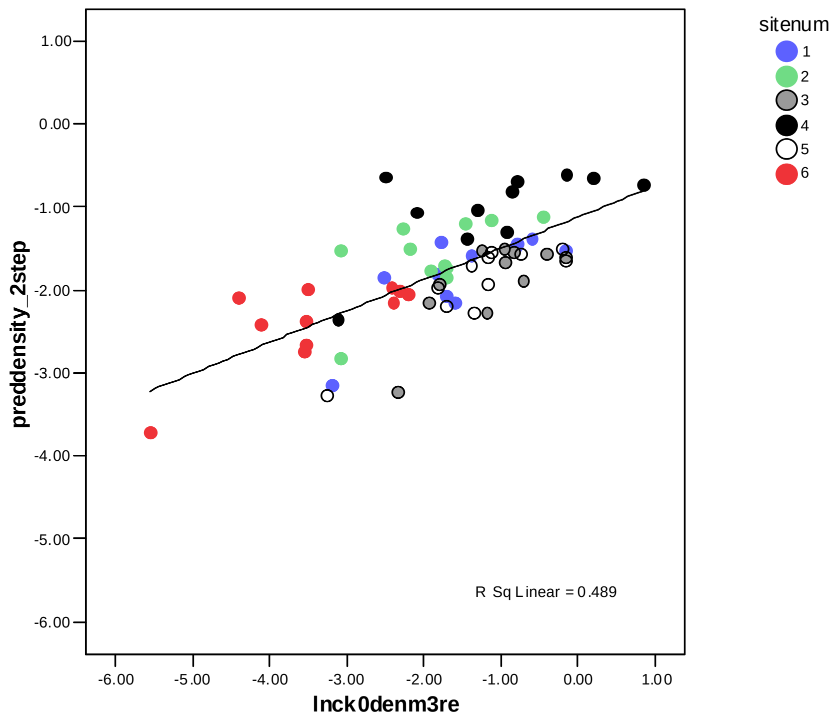
Steps 1 and 2 can be combined additively to make predictions about the simultaneous effects of capacity and connectivity. The equation for the predicted density at the delta capacity of 5,100,000 juvenile Chinook salmon migrants is:

Predicted ln(fishdensity/m3) = -1.6481287 -.7507409*(-1.345*Ln(Connectivity) - 4.298) +1.314

Comparing observed and predicted densities (Figure D.VII.5) allows us to examine how well the entire two-step model does. These results indicate that the model is conservative. In other words, the prediction tends to be worse than the observed, so we might expect our actual response of the juvenile Chinook salmon population to restoration may be even better than what we predict here. Hence, from a conservation perspective, this model applies the precautionary principle.

We can use this model to predict the capacity of juvenile Chinook salmon for any place within the estuary where we know its connectivity. Connectivity can be estimated for any estuarine location using the methods described in section 3.4 and Appendix D.V of this document. This model was used to predict juvenile Chinook salmon smolt capacity for potential estuarine restoration sites discussed in section 4 of this document.

Figure D.VII.5. *Observed and predicted values at six different index sites in the tidal delta.* The Y-axis is the predicted density (log-transformed Chinook per m^3), and the X-axis is the log-transformed observed density (Chinook per m^3).



APPENDIX D.VII REFERENCES

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