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THE IMPORTANCE OF NON-NATAL POCKET ESTUARIES IN SKAGIT BAY TO WILD CHINOOK SALMON: AN EMERGING PRIORITY FOR RESTORATION

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May 2003

INTRODUCTION

The Skagit River basin, encompassing over 3,100 square miles (8,030 square kilometers), is one of the largest and last remaining strongholds of fish and wildlife habitat in the Puget Sound region. The geomorphic output from this watershed is an 80,728 acre (32,670 hectare) delta, connecting the river to Skagit Bay, part of the protected inland waters of the larger Puget Sound fjord estuary system. Together with Skagit Bay, the Skagit River watershed and delta estuary form the juvenile rearing habitats for endangered Skagit Chinook. For the last 10 years the Skagit System Cooperative (SSC) has been studying habitat use of juvenile chinook salmon in order to identify opportunities for habitat restoration. Past results have directed us to Skagit Bay nearshore habitats, where we have identified pocket estuaries (small sub-estuaries connected to Skagit Bay) as a priority for research and restoration.

PREVIOUS RESEARCH

SSC research has focused on patterns of juvenile wild chinook abundance, size, growth, survival, and population structure (i.e., juvenile life history types) within estuarine habitat available to Skagit-origin chinook. Due to conversion for agriculture and residential uses, pristine estuarine delta habitat has shrunk by approximately 80% (Collins *et al*., 2001). Enormous delta habitat loss has lead to research into whether present day estuarine habitat conditions may be adversely influencing wild Skagit Chinook populations, which have been shown to extensively use the delta for rearing (Beamer *et al*., 2000; Congleton *et al*., 1981).

Our results indicate that the relationship between freshwater wild juvenile chinook population size and wild juvenile chinook abundance in estuarine river delta habitat is density dependent (asymptotic) (Figure 1). This result supports the idea that present day Skagit delta habitat conditions are limiting the capacity of delta-rearing chinook. Conversely, the proportion of the total wild juvenile chinook population in Skagit Bay that bypasses rearing in delta habitats and migrates directly into Skagit Bay (we term this life history type: fry migrant) increases with wild

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smolt outmigration levels above 2,500,000 (Figure 2). This finding indicates that at least some of the density dependence occurring in the delta results in the displacement of juvenile chinook out of the rearing habitats in the delta where they end up in Skagit Bay. Additionally, an independent study (Greene *et al.*, 2003) using environmental data and adult returns of wild Skagit Chinook has shown that factors present during the nearshore life stage (i.e., when juvenile chinook are present in Skagit Bay and the Puget Sound fjord estuary) significantly influence adult spawning recruitment, further supporting the need to understand the nearshore ecosystem and its role in the recovery of Puget Sound Chinook. These findings have raised questions about where fry migrants go within Skagit Bay. Are there preferred habitats for fry migrant chinook? What functions do they serve? Could pocket estuaries be a significant habitat for wild Skagit Chinook displaced from the delta estuary?

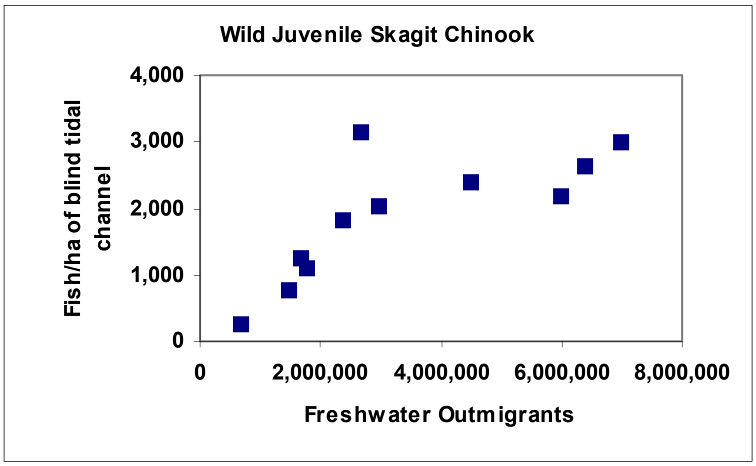


Figure 1. The relationship between freshwater wild chinook smolt population size and density of juvenile wild Skagit Chinook in Skagit River delta habitat, 1992-2002. The number of chinook per unit area within the delta levels-off as the total number of outmigrants increases, indicating density dependent use of the delta. Freshwater chinook smolt population estimates are from D. Seiler, WDFW, Olympia, WA. Juvenile chinook density estimates in delta habitat are seasonal averages derived from 8 index sites using fyke trapping methods.

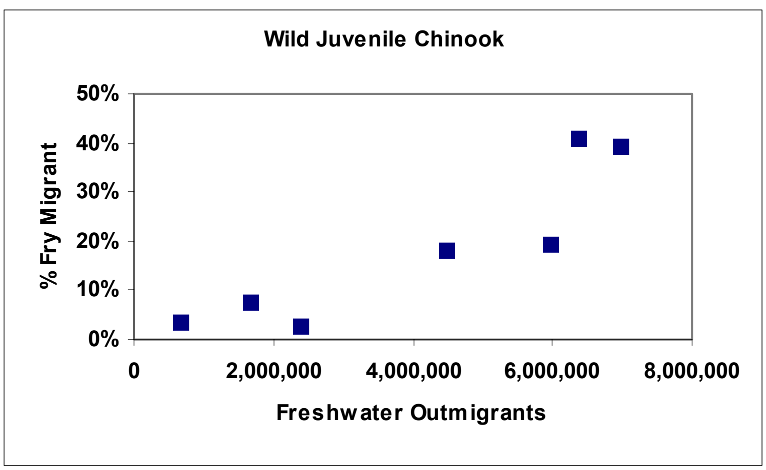


Figure 2. The relationship between freshwater wild chinook smolt population size and the proportion of wild juvenile chinook population with a fry migrant life history type, derived from Skagit Bay index beach seine sites, 1996-2002. The number of fry migrant chinook (those migrating directly to Skagit Bay without residing in the delta) increases as the outmigrating population increases, indicating that some fish are displaced from the delta and tend to become fry migrants. Freshwater chinook smolt population estimates are from D. Seiler, WDFW, Olympia, WA.

POCKET ESTUARY HABITAT

Pocket estuaries are small sub-estuaries within the larger Skagit Bay estuary, that form behind spit or barrier beach landforms at submerged, tectonically- or glacially-derived valleys or at small creek deltas (Figure 3). They are typically tidal lagoons with fringing unvegetated flats, saltmarsh and tidal channels. Compared to adjacent intertidal habitat in Skagit Bay, pocket estuaries: (1) reflect habitat types consistent with lower wave or long-shore current energy, and (2) have local freshwater inputs (surface or groundwater sources) where salinity is depressed during some part of the year (usually winter and spring). Historic pocket estuaries in Skagit Bay range in size from approximately 4 to 400 acres (1.6 to 162 hectares).

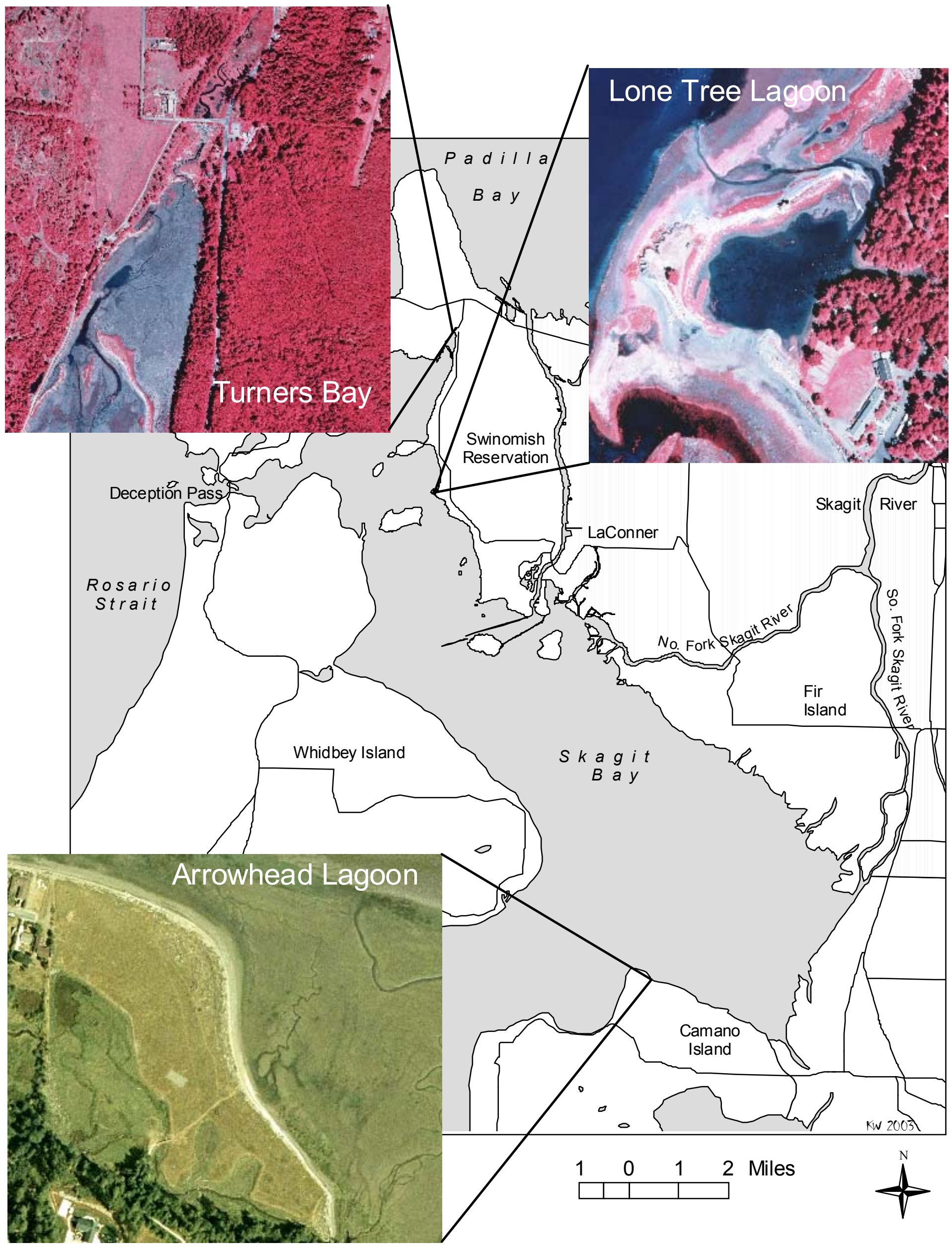
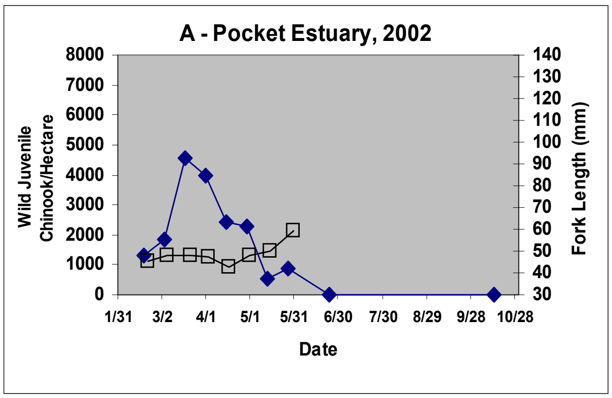


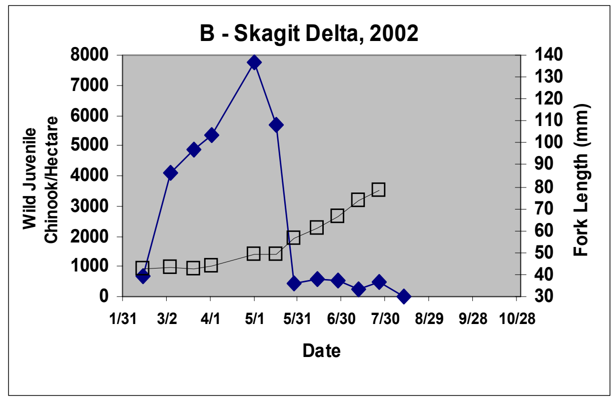
Figure 3. Examples of pocket estuaries in Skagit Bay that are currently accessible to non-natal salmon use.

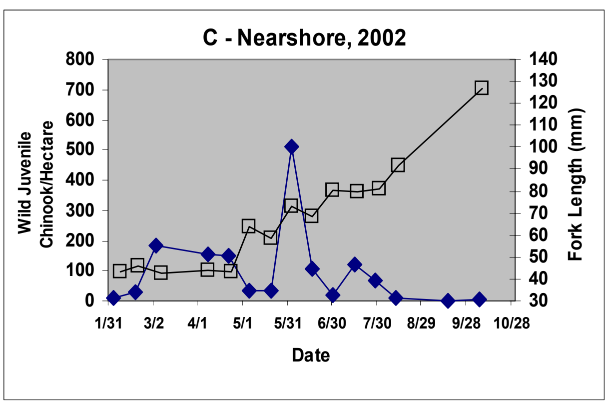
Pocket Estuaries as Rearing Habitat

Juvenile chinook salmon utilize pocket estuaries (Figure 4A). We term juvenile chinook use of pocket estuaries as “non-natal” because chinook do not originate from the watersheds draining into the pocket estuaries. All chinook utilizing pocket estuaries must find them via migration pathways through Skagit Bay. Skagit River origin chinook can migrate from the larger Skagit River and delta into nearshore areas of Skagit Bay, and then into a pocket estuary adjacent to Skagit Bay.

Abundance of wild chinook fry migrants in pocket estuary habitat (Figure 4A) more closely mimics wild juvenile chinook use in the delta (Figure 4B) than in nearshore (Figure 4C) or offshore (Figure 4D) areas adjacent to pocket estuaries. Juvenile chinook are over 100 times and 10 times more abundant in pocket estuary habitat than in offshore or nearshore habitat, respectively.







◆ Wild Juvenile Chinook/Hectare
☐ Average Fork Length

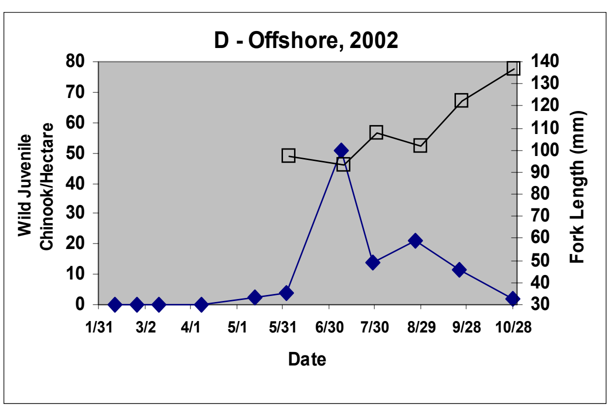


Figure 4. Abundance and length trends for wild juvenile chinook by habitat zone within the north end of Skagit Bay and Skagit Delta, 2002. Note differing Y-axis scales for abundance. Offshore and nearshore data were collected at sites immediately adjacent to pocket estuary habitat. Offshore data were collected using tow net surface trawling methods by C. Rice, NOAA Fisheries, Northwest Fisheries Science Center, Seattle WA. All other data were collected by Skagit System Cooperative using beach seine (pocket estuary and nearshore habitat) or fyke trap (delta blind channel habitat) methodologies. Abundance and timing of wild chinook fry migrants in pocket estuary habitat (Figure 4A) more closely mimics wild juvenile chinook use in the delta (Figure 4B) than in nearshore (Figure 4C) or offshore areas adjacent to pocket estuaries (Figure 4D). Juvenile chinook are over 100 times and 10 times more abundant in pocket estuary habitat than in offshore or nearshore habitat, respectively. The shift in habitat occupancy also corresponds to the size of fish. Larger fish are found in offshore habitats later in the season whereas smaller fish are found in shallow, more protected habitats earlier in the year.

There is a seasonal shift in habitat occupancy by juvenile chinook from shallow, more protected habitats, like pocket estuary and delta blind channel, to offshore areas later in the year. During the period from February through May large numbers of fry migrant chinook utilize and appear to prefer pocket estuary habitat connected to Skagit Bay, compared to adjacent nearshore and offshore areas. Timing of wild chinook fry migrants in pocket estuary habitat (Figure 4A) more closely mimics wild juvenile chinook use in the delta (Figure 4B) than in nearshore (Figure 4C) or offshore (Figure 4D) areas adjacent to pocket estuaries.

The shift in habitat occupancy also corresponds to the size of fish. Larger fish are found in offshore habitats later in the season whereas smaller fish are found in shallow, more protected habitats earlier in the year. Juvenile chinook start out similar sized in February, but for the rearing period before May, juvenile chinook in the shallow pocket estuary habitat (0.5 m max. depth) averaged 4-6 mm longer than juvenile chinook sampled from the deeper (2.8 m max. depth) nearshore sites immediately adjacent to the pocket estuary (T-test, $p < 0.001$). This suggests that the fish within the pocket estuary may be a more isolated (and a rearing rather than migrating) population, or that pocket estuary habitat may be more productive than the more exposed nearshore environment. After May, fish in the nearshore environment were larger than the few remaining fish in the pocket estuary. The increase in average fork length coincided with fish leaving pocket estuary and delta habitats. These fish presumably migrated to Skagit Bay nearshore and offshore habitats.

Pocket Estuaries as Refuge from predatory fish

Pocket estuaries appear to be a refuge from larger predatory fish for fry migrant chinook, compared to the adjacent nearshore environment. This working hypothesis is based on: (1) preliminary data establishing a relationship between predator size and prey size, and (2) applying the relationship to size and abundance data of potential predator species and juvenile chinook found in both pocket estuary and adjacent nearshore habitat.

We assembled predator fish species into three groups: yearling salmonids (coho and chinook), larger salmonids (subadult cutthroat and steelhead, and subadult and adult native char), and scuplins (mostly Pacific Staghorn). This preliminary analysis did not include flatfish because of a too low sample size of flatfish diets. Each species included in the predator/prey dataset were observed to prey on fish, including juvenile chinook salmon. Our predator/prey relationship was derived from diet samples of 101 predators ranging in length from 42mm to 640mm collected in the Skagit estuary during the juvenile chinook outmigration season. Overall, 39.6% of the predator samples had fish in their diet. With our limited dataset, the frequency of fish in the diets of predators was related to predator size, not the groupings of species. Fish were not present in the diets of predators until they reached a length range of 75mm to 100mm. Fish were consistently present in the diets of predators greater than 60% of the time when the predators were larger than 125mm in length.

By applying these results to estimate the density of predators that are large enough to prey on juvenile chinook, we find that rearing in pocket estuaries exposes fry migrant chinook to a much lower risk of predation than nearshore habitat. Sculpins are very abundant in pocket estuary habitat (Figure 5A), but they are not large enough to prey on averaged-sized chinook salmon (Figure 5C). Conversely, though predator density is lower in nearshore habitat (Figure 5B), a high percentage of predators (100% in the case of larger salmonids) are large enough to prey on average-sized juvenile chinook (Figure 5D).

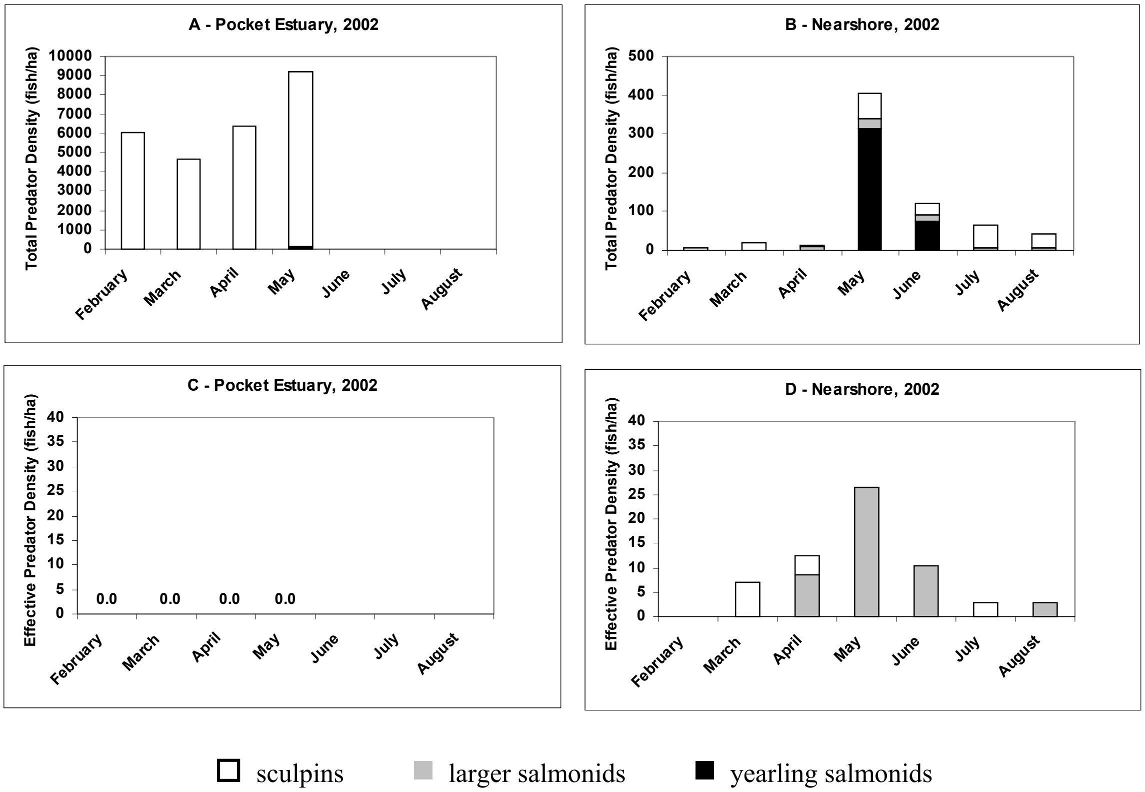


Figure 5. Density of all predators in pocket estuary compared to nearshore habitats (5A and 5B), and density of effective predators (i.e., predators large enough to eat sub-yearling chinook) in pocket estuary compared to nearshore habitats (5C and 5D). We derived a linear regression relationship ($r^2 = 0.69$, $p = 2.21 \times 10^{-11}$) between predator length and the maximum length of prey found in the 40 samples of predators with fish in their diet. The regression equation is: Maximum Prey Length in mm = 0.238 (Predator Length in mm) + 21.6. We applied the regression analysis to the length frequency of predators by month to calculate the proportion of the predator population that effectively posed a risk to averaged-size sub-yearling chinook. The proportion was used to calcuate the density of "effective" predators in pocket estuary (Figure 5C) and nearshore habitat (Figure 5D). We only graphed months when significant numbers of juvenile chinook are present in pocket estuaries or nearshore habitat.

Pocket Estuary Loss and Proposal for Restoration

Loss and degradation of pocket estuary habitat reduces the ability of fry migrant chinook to rear in a shallow, more protected estuarine environment. All twelve historic pocket estuaries in our Skagit Bay study area, totaling nearly 656 acres (265 hectares), have been either degraded or completely removed from non-natal salmon rearing through land use, thereby significantly limiting the opportunity for fry migrant chinook to utilize these habitats (Figure 6). Eighty-nine percent (89%) of the total historic pocket estuary area is currently inaccessible to non-natal salmon use and the habitat-forming forces of tidal hydrology. The main causes of inaccessibility include: tide gates, roads, or other fills within tidal wetlands. An additional one percent (1%) of the historic pocket estuary area has been dredged to create a small boat basin. While estuarine restoration in the Skagit has recently focused on habitat in the delta (e.g., U.S. Army Corps of Engineers, 1998), an additional chinook recovery priority should include restoration and protection of the pocket estuaries within the Skagit Bay nearshore environment.

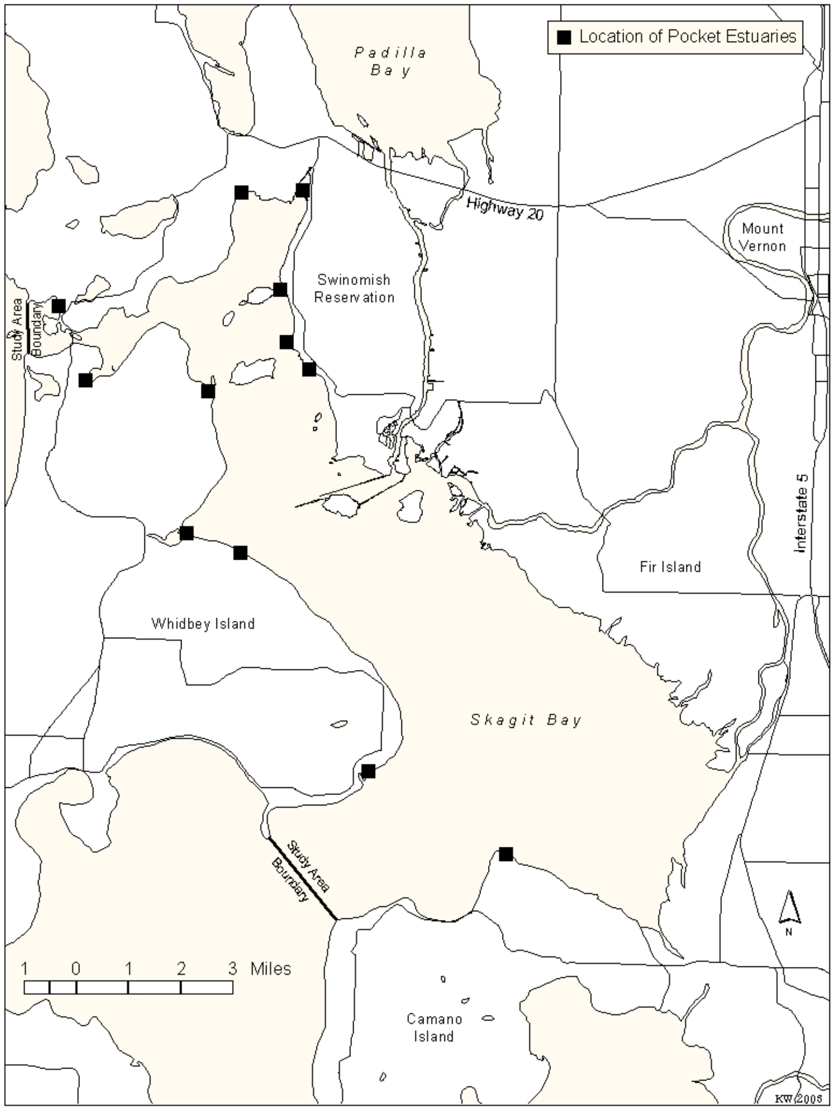


Figure 6. Location of present day or historic pocket estuaries in Skagit Bay.

CAN POCKET ESTUARY RESTORATION REPLACE DELTA RESTORATION?

We assert that both pocket estuary and delta estuary restoration are important to the recovery of Skagit Chinook. Because present day delta conditions appear to be contributing to a higher percentage of the total juvenile wild ocean type chinook population being fry migrants there may be the temptation by some habitat managers or interest groups to advocate pocket estuary restoration as a substitution for delta restoration. Pocket estuary restoration is not a substitute for delta restoration because of differences in restoration potential and habitat use by different life history types.

The limited extent of pocket estuary habitat cannot substitute for the vast extent of delta habitat. Pocket estuaries are limited in extend by geology, landform, and coastal processes (long shore sediment drift, wave energy/exposure). Under present day conditions, the contiguous habitat area of the Skagit delta that is exposed to tidal and river hydrology totals about 7,883 acres (3,190 hectares). This is mostly the delta area in the vicinity of Fir Island, but it also includes a fringe of estuarine emergent marsh habitat extending from La Conner to the north end of Camano Island. Historically, the contiguous habitat area of the Skagit delta included the same area, but also included the Swinomish Channel corridor and extended to the southern end of Padilla Bay (Collins *et al*., 2001). The historic area equaled 28,370 acres (11,481 hectares). In contrast, our preliminary inventory of historic pocket estuary area estimates 656 acres (256 hectares) were available to juvenile salmon. Under present day pocket estuary conditions, only about 73 acres (30 hectares), including the pocket estuary dredged into a boat basin, can be utilized by juvenile salmon. Therefore, the potential for pocket estuary restoration is limited to 583 acres (236 hectares). Delta restoration potential is over 20,000 acres (8,093 hectares). While societal issues will reduce both amounts significantly, the dramatic difference in the potential area that could be restored between delta and pocket estuaries makes substituting pocket estuaries for delta habitat a physical impossibility. Even if 100% of historic pocket estuary is restored, less than 3% of the total lost estuary habitat in the Skagit is regained.

Pocket estuary and delta habitat are utilized by different juvenile chinook life history types and are therefore not necessarily equal on a per area basis. This is especially true if differences in survival to the adult life stage exist between juvenile life history types, and recovery of the overall chinook population is a management goal. Pocket estuary restoration should be pursued for the benefit the fry migrant life history type. The Skagit results show a consistent presence of fry migrant chinook in Skagit Bay over seven years of sampling (Figure 2). While we do not currently know Skagit Chinook survival differences between three possible juvenile life history types that vary in early estuarine rearing: (1) fry migrants that use pocket estuaries, (2) fry migrants that do not use pocket estuaries, and (3) delta-rearing individuals, collaborative research supported by Skagit System Cooperative, USGS Western Fisheries Research Center, Seattle City Light, Washington Department of Fish and Wildlife, and NOAA Fisheries is studying this question using otolith technology. Several studies, however, show that juvenile chinook with shorter (or no) estuary residence periods survive to the adult life stage at much lower rates than juvenile chinook with extended estuary residence periods (Reimers 1973, Levings et al., 1989). The definitions of estuarine rearing in these studies more closely resembled the estuarine use by juvenile chinook that occurs in delta habitat and not the more exposed habitats in Skagit Bay or the larger Puget Sound estuary system.

Pocket estuary use by chinook displaced from rearing in delta habitat can be viewed as their “Plan B” option to early estuary rearing (“Plan A” was rearing in the delta). Survivors from both the delta-rearing and fry migrant life history types must ultimately migrate to Skagit Bay. The fry migrants, however, do so at an earlier time of year and at a much smaller size. Even if survival potential after early estuary rearing is the same for delta-rearing and pocket estuary rearing chinook, fry migrants are exposed to the perils of finding pocket estuary habitat in Skagit Bay (a minimum distance of 7-11 miles) at a time of year (February and March) when they are very small in size (<45 mm fork length) compared to the size of delta-rearing fish (>60 mm fork length) at the end of delta residence in May or June. The presumed higher mortality associated with this earlier migration of smaller fish through Skagit Bay would be an additional source of mortality not mitigated by increases in pocket estuary habitat alone.

CONCLUSION

Pocket estuaries are clearly utilized by wild juvenile fry migrant chinook during late winter through spring. Early in the year, pocket estuaries may be a safer environment for fry migrant chinook than the more exposed nearshore and offshore areas of Skagit Bay. Similar to our understanding of delta habitat for delta-rearing chinook, pocket estuaries could provide extended rearing and growth opportunity for fry migrant chinook during late winter and spring months, and refuge from larger predatory fish. Juvenile chinook later in the year are much larger in size and presumably are more capable of handling the perils of deeper and more offshore habitats.

Considering the dramatic loss of pocket estuary habitat within our study area, habitat restoration makes sense. Ample opportunities for habitat restoration projects of various size and complexity exist within the Skagit Bay. Pocket estuary restoration should be pursued for the benefit of the fry migrant life history type known to be consistently present in Skagit Bay. Pocket estuary restoration may secondarily be a strategy to alleviate the effects of delta overcrowding, but delta restoration should remain the primary restoration strategy for delta-rearing chinook. Continued research regarding fry migrant use of pocket estuary habitats will help to further prioritize and support restoration efforts.

ACKNOWLEDGMENTS

This research has been conducted, in part, through funding provided by: U. S. Department of Interior Pacific Salmon Treaty Implementation, U. S. Department of Commerce Pacific Coastal Salmon Recovery, and Seattle City Light.

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