Estuarine Habitat-forming Processes

This section of the report characterizes the dominant habitat-forming processes in the Nooksack estuary and their geologic context. The Nooksack River delta and its assemblage of habitat types have largely been shaped by sediment, water, and wood transport. The changes in the nature of sediment and wood delivery to the river mouth through the historic period reflect watershed development and subsequent channel and habitat responses. Changes in these habitat-forming processes control the abundance, distribution, and persistence of different habitat types in the estuary.

The distribution and characteristics of deltas are controlled by a complex set of inter-related fluvial and marine processes and environmental conditions. These factors include climate, water and sediment discharge, river-mouth processes, nearshore wave power, tides, nearshore currents and winds (Coleman 1981). Of these factors, sediment input, wave-energy flux, and tidal flux are the most important processes that control the geometry, trend, and internal features of the progradational framework sand bodies of deltas (Galloway 1975, Galloway and Hobday 1983). Deltas are probably the most complex of depositional systems with more than a dozen distinct environments of deposition, or habitats. Through time, deltas change in form as they undergo constructional and destructional phases, depending on the degree of imbalance in the major controlling factors. During the active phases of delta out-building, most sedimentation processes on deltas are constructional in the sense that delta formation is dominated by sediment deposition. On the other hand, tidal currents and waves represent destructional processes to the extent that they cause erosion and redistribution of some sediment. Destructional processes become particularly important when deltas, or portions of deltas, enter an inactive phase where they are not being actively supplied with sediment. Channel or distributary abandonment, foundering owing to subsidence, or marine transgression may interrupt active construction of a delta. Such an interruption leads to a phase when erosion by waves and tidal currents becomes dominant as sediment influx to a portion of the delta from the river ceases.

The Nooksack delta has undergone the most dramatic growth of any coastal sedimentary feature in the Puget Sound region in historical times (Bortleson et al .1980). Its growth is a good example of an imbalance between marine processes, waves, and near-shore currents that remove sediment and wood from the delta and the supply of river sediment and wood to the delta. The processes of wood, sediment, and water delivery to the river mouth combine to create and maintain the habitat of the estuary. These processes, and how they have changed through time, have made the Nooksack River mouth a unique geologic feature in the Puget Sound.

Sediment

This section describes changes in sediment delivery to the delta through time and the implications for habitat development. The Nooksack River has a naturally high sediment load; evidenced by the rapid growth of the delta that predates widespread watershed development. This rapid growth of the delta translates into rapidly developing and changing estuarine habitat, as new sediment is deposited on the delta and habitat zones expand and advance into Bellingham Bay. Sediment deposition dominates habitat-forming processes in the delta and translates directly into more abundant and diverse instream habitat for the estuary. It is likely that the amount of sediment delivered to the estuary has increased with floodplain diking and widespread anthropogenic disturbance, leading to more rapid development of the prograding delta than would be expected under undisturbed conditions.

From the rapid growth of the Nooksack delta through the historic period, it is easy to see that there is an imbalance in the amount of sediment being supplied to the delta, compared with the ability of the marine system to transport the sediment offshore. The Nooksack River stands out among Puget Sound rivers for the amount of sediment transported out of its basin relative to the amount of run-off it produces (Figure 5). The Nooksack River discharges an estimated 580,000 tons of sediment per year (from a 1-2 year period of monitoring), with a mean discharge of 3180 cubic feet per second (Downing 1983). This is roughly 9% of the flow to the Puget Sound and 16.3% of the sediment. The only other comparable river is the Puyallup, where delta development has been severely altered by industrial development (Figure 6). The large amount of sediment deposited on the Nooksack Delta, along with the relatively small wave power and tides is what makes it this dynamically growing sedimentary feature.

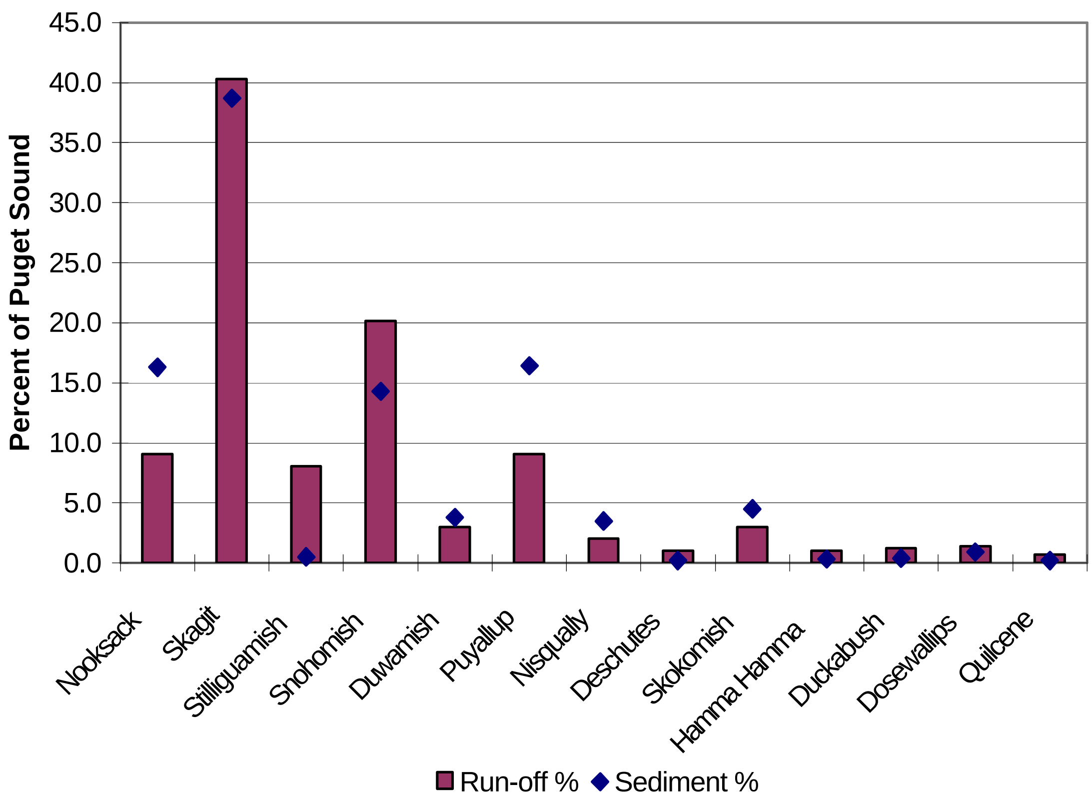


Figure 5. Percent of Puget Sound sediment and run-off contribution by major rivers

Figure 6. Nooksack River (left) and Puyallup River (right) estuaries.

Although from Figure 5, it is evident that the Nooksack basin naturally produces large amounts of sediment relative to the discharge from its watershed; land-use activities, such as forestry and agriculture, have likely increased the sediment load delivered to the river. Combined with the increase in sediment delivered to the river is the increase in sediment transported to the estuary caused by isolation of the floodplain along the mainstem Nooksack River (Figure 7). Dikes have reduced the active floodplain from 8670 hectares (33.5 mi^2) to 640 hectares (2.5 mi^2) between Everson and Marietta. This represents a loss of 31 mi^2 of sediment storage area that historically was dominated by vast freshwater wetlands (Collins and Sheikh 2002). Currently, the levees are only occasionally overtopped and sediment is deposited on the floodplain. During the October 2003 flood, the levees immediately upstream of Marine Drive were overtopped by ~10cm and substantial amounts of sand and silt were deposited on the floodplain (Figure 8).

Some of the loss of this sediment and floodwater storage area has been mitigated by the rapidly prograding Bellingham Bay delta. Wetlands have advanced seaward nearly a mile on the intertidal platform, producing 1.2 square miles of new bottomland, between 1887 and 1972 (Bortleson et al 1980). The impacts of a rapidly developing delta were identified early in the history of Bellingham Bay when, alarmed by the effect of rapid delta progradation on the economic development of the towns on Bellingham Bay, early residents sought to redirect the river and its sediment load back toward Lummi Bay:

> *"In view of the damage being done to the navigable waters of Bellingham Bay by the deposits brought down by the Nooksack River, the people of Whatcom are anxious to make the necessary surveys and restore the waters of that river to their original channel"* (Wm. Prosser 1892, cited from Wahl 2001).

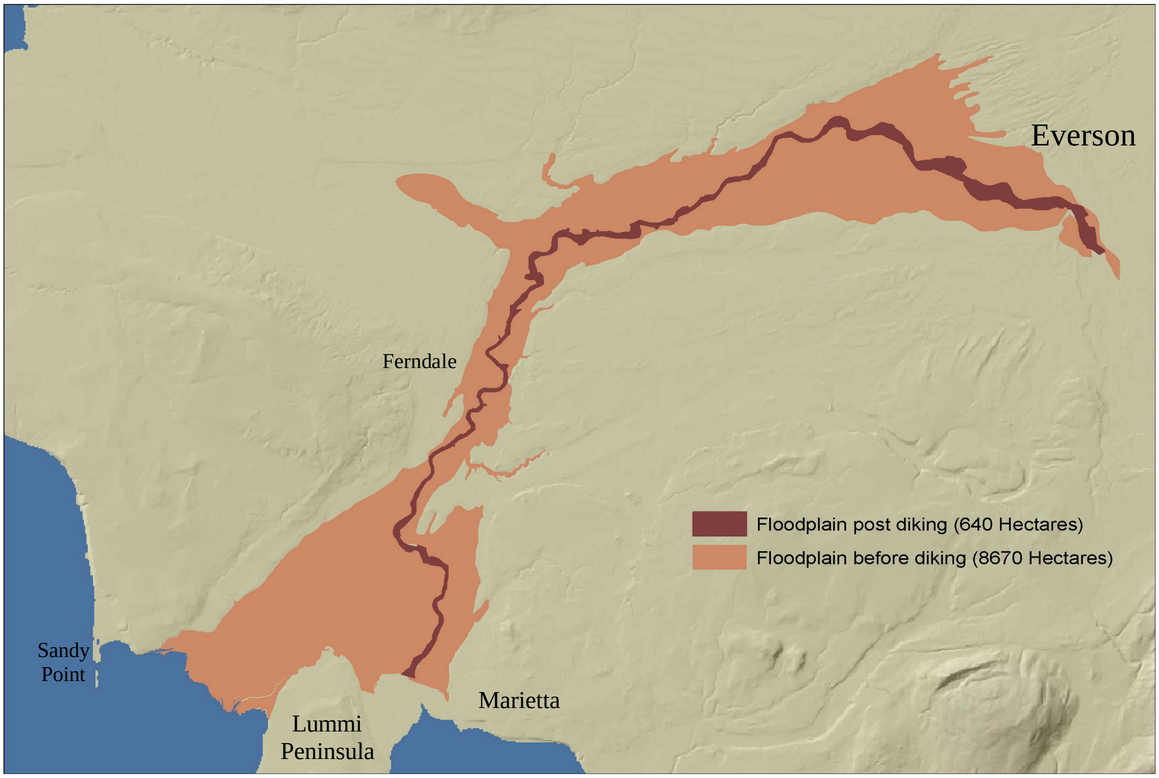


Figure 7. **Floodplain of the mainstem Nooksack before and after levee construction**

The interface between river and marine processes sorts the sediment brought to the delta by the river and longshore drift. Sand-sized material builds the delta platform, while the bulk of the finer material is transported offshore into the deeper water of Bellingham Bay. The intertidal platform of the Nooksack delta is covered with a layer of medium sand that contains about 12% silt and clay (Downing 1983). Transitional sediments, characteristic of neither bay mud nor platform sands, but falling between the two in size, are found in the zones where the two major sediment types meet (Sternberg 1961). Numerous shallow distributary channels 1.2 to 1.5 meters (4-5 feet) deep have cut across the delta platform sand in the active portions of the delta (Downing 1983). At low tide, the bedload from the river moves seaward in these channels, but during high tide, wave and tidal currents disperse the channel sands evenly over the delta platform. In portions of the delta not fed by distributaries, tidal action carves deep channels across the delta platform.

The two-step process by which river sand is distributed over the intertidal delta is probably not continuous. It requires storms to produce wind waves large enough to move these sands away from the channels. Small waves during calm weather move these sands only in the breaker zone. Part of the river-derived sand on the inner delta is transported onshore by waves and nourishes the beaches along the seaward shores of the inter-distributary islands and abandoned areas of the delta. Currents and waves are sufficient to redistribute the river-borne sediments, and ultimately control the depositional characteristics in the bay (Sternberg 1961, cited in Colyer 1998). Very little river silt and clay are deposited permanently on the intertidal delta because waves and tidal currents are sufficiently vigorous to keep the material in suspension and carry it to the deeper water seaward of the delta front. Sediment along most of Bellingham Bay consists of bay mud, a clayey silt on the Wentworth Scale (Wentworth 1922). Deposits of this finer material 1.5 to 6.1 meters (5-20 feet) thick have accumulated in the northern half of Bellingham Bay in post-glacial time (Downing 1983). Woody debris, primarily from the GP paper plant that is located on the eastern shore of Bellingham Bay, is found scattered within the bay mud, ranging from the Whatcom Waterway to the central bay (Shea et al. 1981).

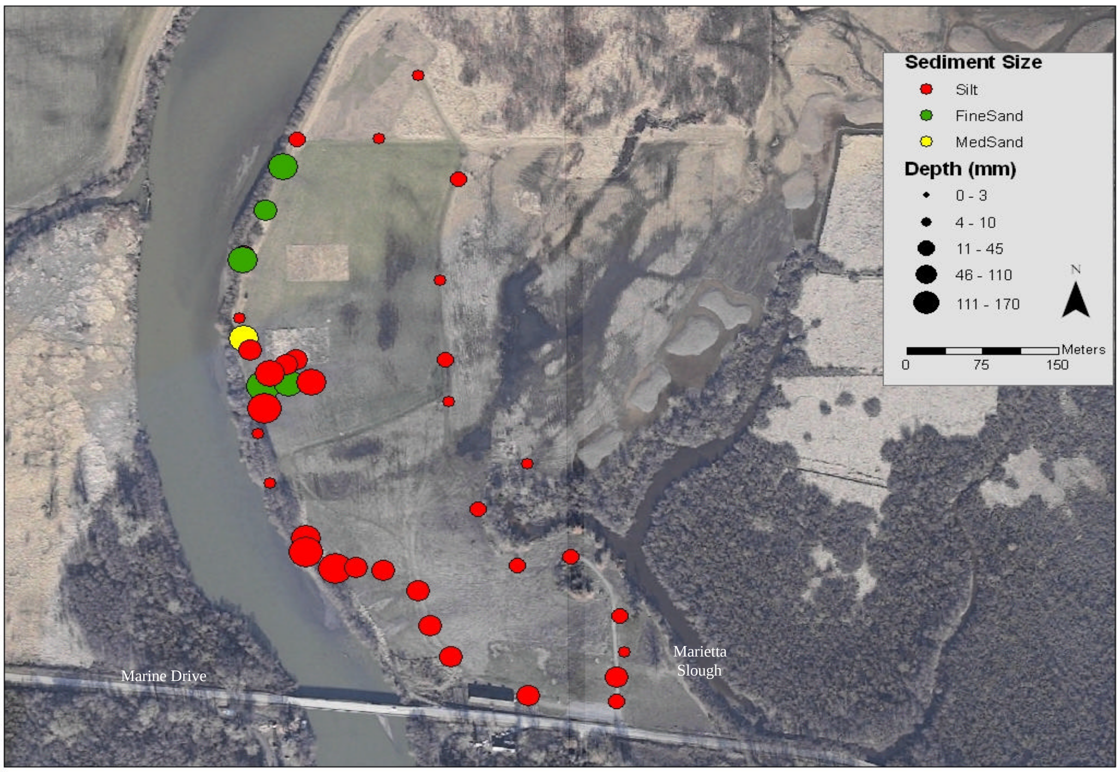


Figure 8. Floodplain sediment deposition at Marietta Slough following October, 2003 flood

The Nooksack delta can also be subdivided into active and abandoned zones. The active delta plain is the accreting portion occupied by functioning distributary channels. An abandoned portion of the delta plain results from the river changing its lower course and causing a shift in the locus of river-mouth sedimentation. Marine processes then rework the coastline of the abandoned depositional surface. The natural levees built by the distributary channels appear to be a major factor in the isolation of portions of the delta that allow tidal processes to dominate habitat formation (Figure 9). It is the abandonment of portions of the Nooksack delta by distributary channels that allows for the development of tidal channel complexes and blind channel habitat, as destructional process dominate. Because the delta is divided into active and abandoned zones, much of the delta platform is built by sediment moving from active areas to abandoned areas across the delta.

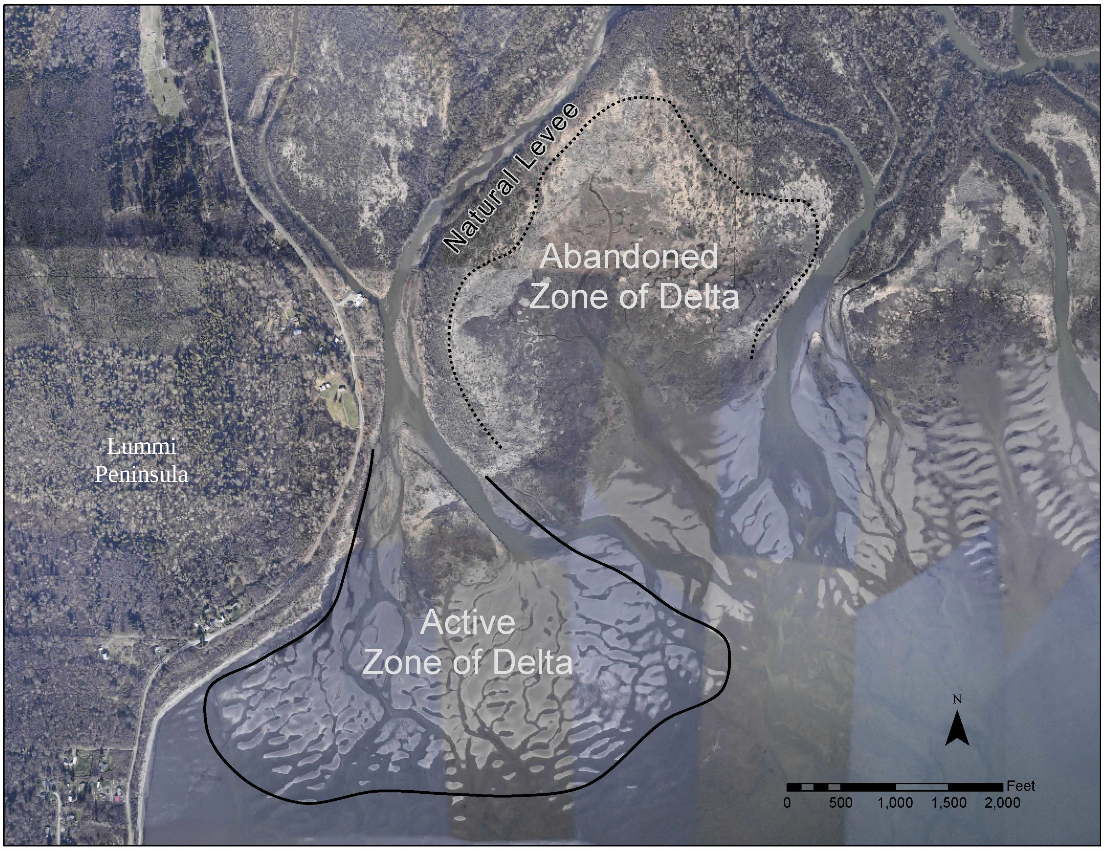


Figure 9. Example of abandoned portion of the Nooksack delta, isolated by natural levees (2004).

It is possible to model the physical sediment delivery processes affecting the character of river distributary channels in a laboratory flume. In one such modeling exercise (Chang 1967, cited in Schumm 1977) it was found that changes in a river channel are in direct response to changes in discharge, sediment load, flow resistance, tectonic events, or base level. Changes to these controlling factors of the channel affected the pattern of deposition and thus affect the delta or fan shape. Aggradation of the delta stream was induced by a rise in base level (or sea level), a decrease in water discharge, or an increase in sediment inflow; degradation was caused by the opposite of these factors. Based on laboratory observations, an aggrading delta stream tends to widen and become braided into branch channels; during degradation, however, the branches tend to merge into a single stream. Distributary channels have a much larger overall width than a comparable single channel, with the overall width varying in direct relation to the number of distributary channels, so the habitat diversity of the estuary likely changes as parts of the delta aggrade and subside (Chang 1988).

Several historic channel straightening episodes on the Nooksack River have artificially steepened the slope, although the naturally high sediment load of the river has maintained consistent growth in the length and number of distributary channels across the delta and has not led to the merging of distributary channels. Through these distributary channels, shallow water depth on the delta seaward of the river mouth leads to rapid deceleration and lateral expansion of the outflow (Boggs 1987). This in turn, leads to sediment deposition and the formation of subaqueous levees, triangular-shaped “middle-ground” bars, and distributary channel splitting. The continued splitting and growth of distributary channels across the delta plain, along with the abandonment of portions of the delta, leads to diverse channel habitat through a variety of terrestrial habitat zones. In general, as the number of channel bifurcations and distributaries increases, the width of the active subaerial delta and the width and continuity of the delta front increase, but the efficiency of the distributaries to transport sediment decreases. The decrease in the ability of the distributaries to efficiently transport sediment leads to shoaling and narrowing of the channel. As sediment continues to deposit along the margins of the channel and levees and bars grow and become vegetated, they stabilize the boundaries of the channel, as it grows across the delta plain. The growth and change in dominance of distributaries through time strongly impacts habitat conditions on the delta.

The rapid growth of the delta has lead to the differential expansion of various habitat zones. The transition of sand flat through salt marsh and shrub-scrub to floodplain forest is directly related to the sediment deposition and transport in distributary channels and across the delta front. The aggrading portions of the active delta build to an elevation where tidal influence is minimized and persistent woody vegetation can colonize. This vegetation then slows water velocity and encourages more sediment deposition, which is particularly important on the natural levees of the advancing channels. Because of the high amount of sediment entering the delta, this transition from higher elevation, forested floodplain to the lower, exposed sand flats is relatively steep, narrowing the width of the zones of salt marsh and shrub-scrub habitats that lie between. Historical maps from 1887 show the habitat gradient between forested natural levees and sand flat being much less steep on the Lummi Bay delta than on the Bellingham Bay delta, evidenced by the extensive salt marsh and shrub-scrub habitat (USC&GS 1887). This may be indicative of the cessation of flow to the Lummi delta and the emerging dominance of tidal forces on shaping the estuarine habitat.

As previously mentioned, 18th Century maps of the mouth of the Nooksack River show the majority of the flow discharging to Lummi Bay and the Bellingham Bay delta largely abandoned by river flow (Figure 10). Map sketches made for the US-Canada Boundary Commission in 1856-1858 show that the Lummi River was the dominant channel of the Nooksack River at the time of first Euro-American settlement (Wahl 2001). Deardorff (1992) discusses testimony in U.S. District court indicating the entire river had emptied into Lummi Bay in 1852. Assistant Engineer Robert Habersham later confirmed this, writing in the Army’s Annual Report of the Chief of Engineers that the Nooksack had been “only a small creek” prior to about 1860 (USACE 1880). In spite of Habersham’s description of the Nooksack River as a “small creek,” the 1856-1858 Boundary Survey mapping suggests that the Nooksack, while smaller than the Lummi, was not insignificant. The shifting of the major channel between distributaries through time is characteristic of a process that appears to have been mediated by logjams in Puget Lowland streams (Collins and Sheik 2002). It is certain that at different times in the post-glacial period the location and dominance of various distributary channels has changed through time. The earliest maps are snapshots of an on-going process of delta building.

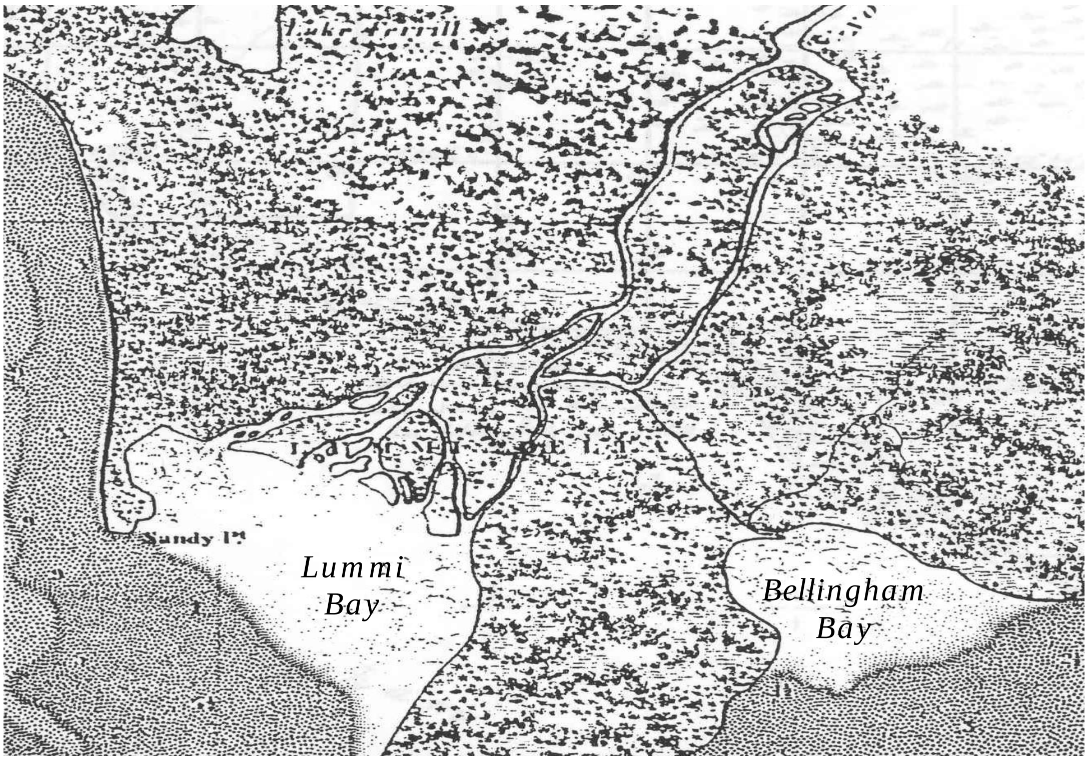


Figure 10. Nooksack River channel discharging to Lummi Bay in 1858 (Northwest Boundary Survey from Wahl 2001).

By the 1880s, maps showed the Nooksack River following a previously mapped distributary channel toward Bellingham Bay and discharging near the modern Marine Drive Bridge. The recently abandoned Lummi Bay basin showed evidence of a long occupation by the Nooksack River, with extensive delta and distributary channel development and sand flats that extended slightly beyond their current extent. Contrasting the well-developed distributary channels and salt marsh of the Lummi Bay delta with the lack of distributary and tidal channels or salt marsh on the Bellingham Bay delta, it is evident that the delta building had only been occurring in Bellingham Bay for a relatively short time. The changes in the lower river also had impacts to navigation channels through the estuary, such as Smuggler's Slough, which was noted by local landowners as undergoing rapid sedimentation as early as 1863 (Wahl 2001).

By the late 1800's, the Lummi River distributary channel was almost completely blocked from freshwater flow, which reduced the ability of the channel to transport sediment and further contributed to the narrowing of the channel. Assistant Engineer David Ogden of the U.S. Army Corps of Engineers noted in 1894 that:

> *"A close jam of logs and drift now closes the head of this channel so that little or no water flows into it…at ordinary high tide salt water flows throughout the entire length of the channel, giving it a depth of from 2 to 6 feet"* (cited in Wahl 2001).

The description of the depth of the channel would indicate that the main Lummi River channel had narrowed and filled considerably relative to the main Nooksack River channel in the approximately 30 years since the avulsion occurred. The location where the Lummi River split away from the current Nooksack channel likely looked much different before the avulsion, with many narrower channels anastomosing across the floodplain, making a direct comparison to the width of the Nooksack River inappropriate. While the Lummi River may have been split into several channels, the sum of these channels would be similar in size to the modern Nooksack River.

The rapid change in the Bellingham Bay delta from the 1860s on-ward, further indicates that the river had not deposited much sediment here prior to the most recent avulsion into Bellingham Bay. The recent history of the river mouth in Bellingham Bay reveals the rapid progradation of the delta and filling the bay with riverine sediment since the river began to deposit in the Bellingham Bay basin in the middle of the 19th Century (Figure 11). Comparing bathymetric charts from 1855 to 1992 has shown an estimated 164,100,000 cubic yards of deposition in Bellingham Bay through the 137-year period. Most of the deposition on the delta has occurred where the major west and east distributary channels enter the bay. The extent of the sand flats at the river mouth was noted in 19th century coastal surveys, well before extensive disturbance of the watershed:

> *"Very extensive shoals or flats extend out from its mouth. A small boat cannot get into the river at low tide. The shoal portion of the channel extends from the swampy islands (south) of the mouth until well out toward deep water. Once inside the river it is deep enough as far up as (Ferndale)"* (Gilbert 1887).

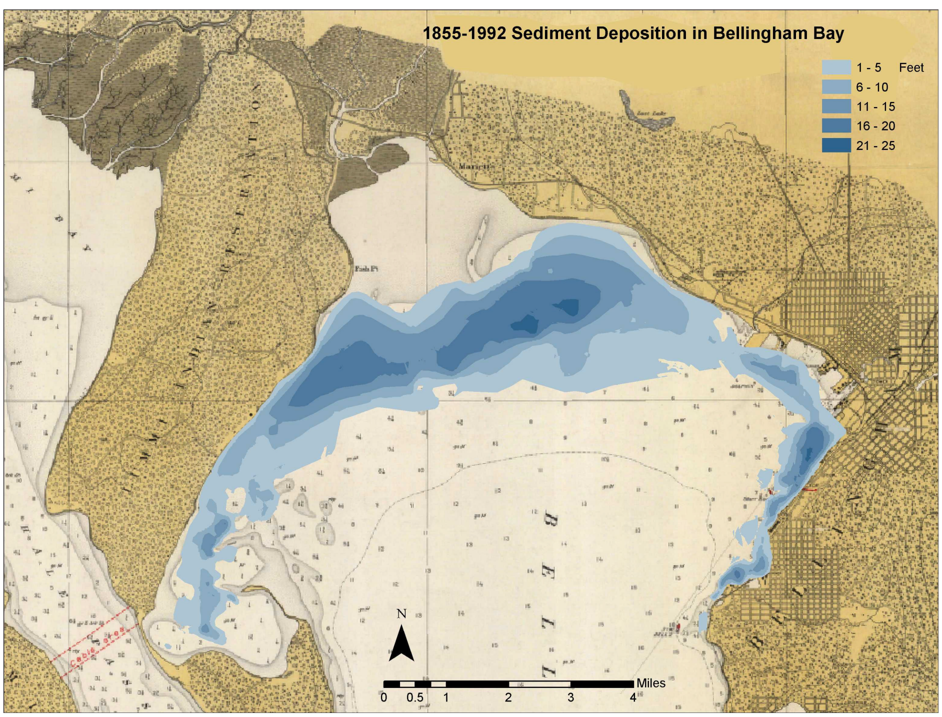


Figure 11. Deposition on the subaqueous portion of the Nooksack delta in Bellingham Bay (1855-1992).

Active management of the channel for economic development was well on its way by the turn of the century. The original Bellingham Bay distributary channels, which flowed west to east across the delta (named Steamboat Slough and MacDonald Slough on early maps), were truncated and the river was directed into a set of logbooms along the eastern edge of the Lummi Peninsula, forming the lower portion of Kwina Slough (Wahl 2001). Pilings were driven across the mouth of the slough to direct wood into the boomworks, which eventually contributed to sediment deposition and the sealing-off the former distributary channels (Figure 12). The river began to deposit sediment on the western side of the bay, where before it was building its delta from east to west across the bay. Shortly after the turn of the century, the river again changed course and the delta began to build in a new direction within Bellingham Bay. This major avulsion was caused by settlers seeking to straighten the river to improve transportation and fishing on the lower river and brought the river through "Larrabee Slough" and closer to the town of Marietta (Figure 11). This avulsion can readily been seen in the historic channel positions of the river (Figure 13). The new channel cut through wetlands and caused the truncation of the former delta and caused a new delta to rapidly build into Bellingham Bay as the river sought to adjust its slope. This avulsion led to the conversion of the former mainstem into slough habitat and greatly shortened the length of mainstem habitat in the delta. This new delta is still present in the 1933 aerial photo, about 25 years after the man-made avulsion, in Figure 14.

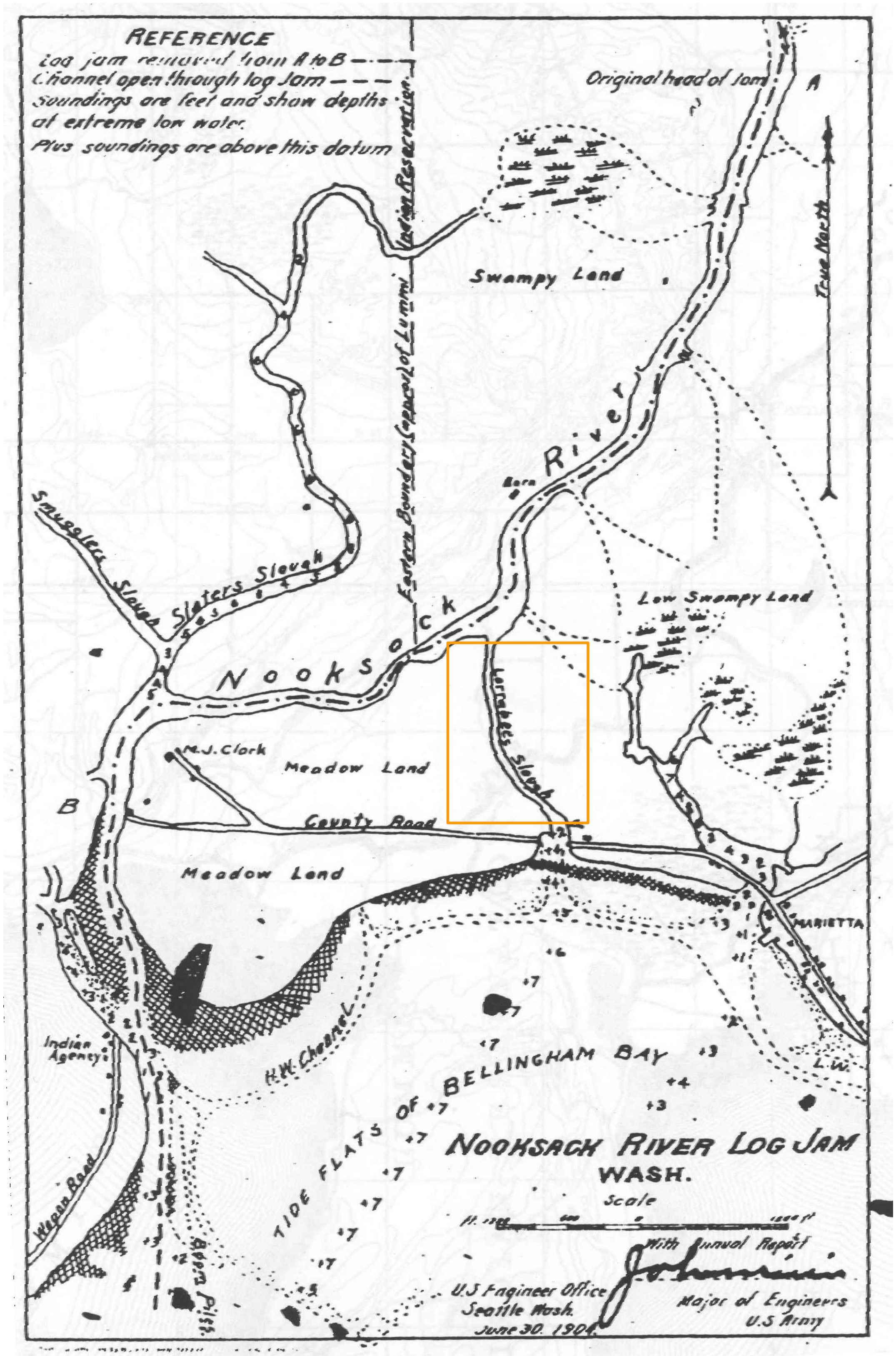


Figure 12. Nooksack River mouth in 1904, showing Larrabee Slough, the future Nooksack mainstem channel (USACE 1904, from Wahl 2001).

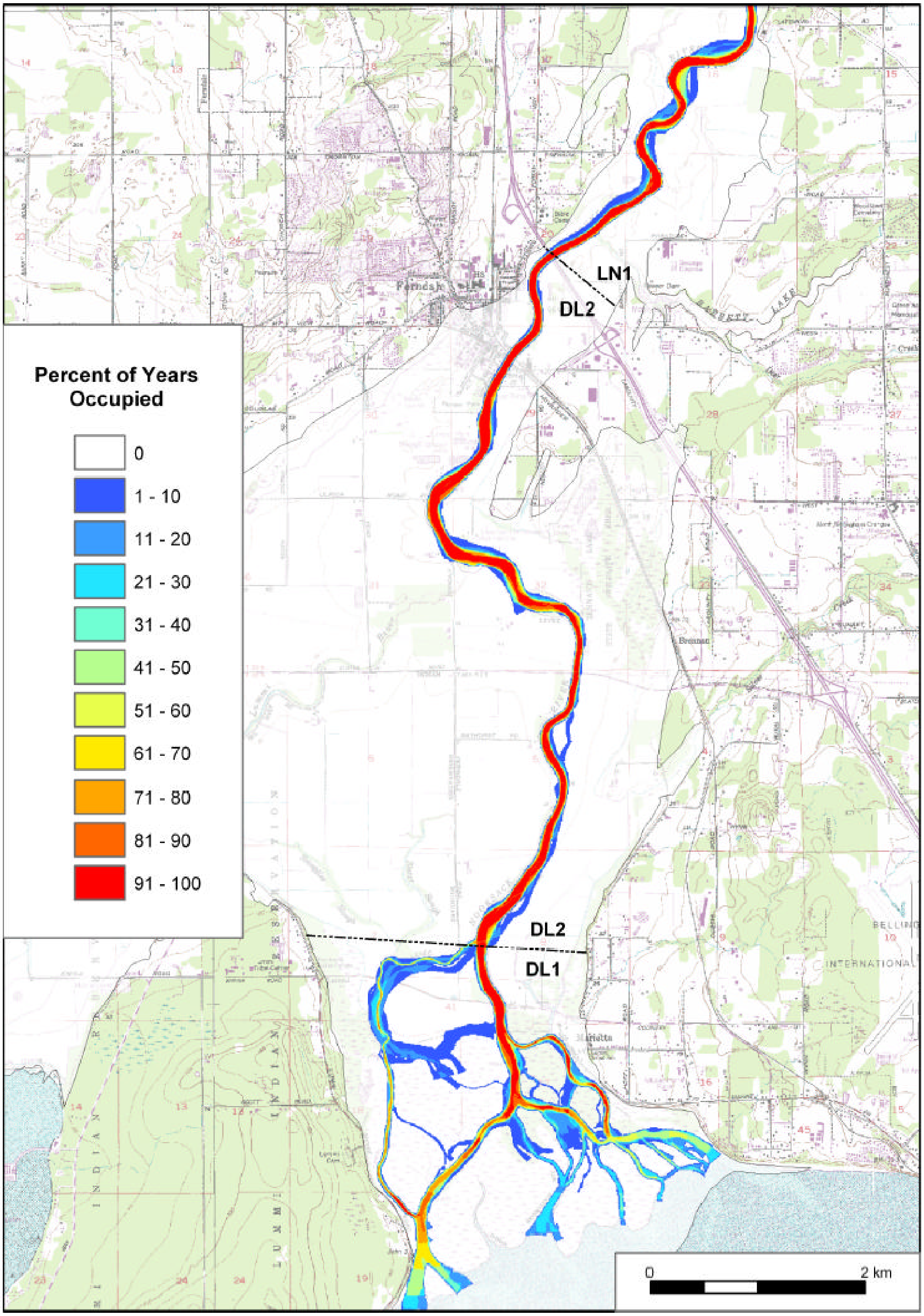


Figure 13. Percent channel occupation of a given location between 1880 and 2004 (Collins 2004).

By the first aerial photos taken in 1933, the effects of the forced avulsion through Larrabee Slough on distributary formation are still evident. This avulsion occurred along with sealing of the former main channel with pilings, which led to a complete re-shuffling of the distributary channel locations. Until the avulsion, Marietta Channel was the major high-flow channel of the Nooksack River across the sand flats, but it was reduced to a distributary by 1933. By this time, the Marietta channel was showing signs of the reduced flow such as shoaling and narrowing, well on it's way to becoming a slough. The artificial shortening of the mainstem channel through Larabee's Slough likely lead to upstream incision and channel adjustment as the channel reestablished its slope. The river can take many years to adjust to a major base level change, and may have only recently approached equilibrium conditions. In the case of the Nooksack River, it is unknown what the impacts of channel shortening have been, but it is possible that the shortening contributed to the disconnection of the Lummi River distributary, which is now perched several meters above the Nooksack River and has filled substantially from when it was an active distributary. The filling of the channel is a natural response to the loss of flow to the distributary. Once year-round maintenance flow in a distributary is halted, deposition from the main channel rapidly fills the channel during floods as velocity drops when the flood reaches the floodplain (Schumm 1977).

At the mouth of the river in 1933, several bars had built to a sufficient height to allow vegetation colonization. Whether these bars were depositional "middle ground" bars deposited after the avulsion, or were formed when the river was flowing through Kwina Slough and later dissected when the river avulsed, it is unclear. The vegetated bars did form the split where the major eastern and western channels will eventually form around the bar. With the river depositing sediment in the middle of the bay in 1933, the active portion of the delta changed location and two topographic basins formed along the margins of the active delta lobe (Figure 14). These basins will control the development of the two major distributary channels as the river seeks the steepest path across the delta. It is apparent in the 1933 aerial photo that the channels have not occupied their current location for long. No natural levees lined any of the channels and the main flow was braided across the sand flat. These conditions likely represent relatively poor juvenile rearing and transition habitat conditions in the estuary, as the unstable channel freely shifted across the delta. Virtually all instream habitat was located in the sand flat, with extremely limited salt marsh, shrub-scrub and forested habitat types. Because so much of the channel was in the sand flat, cover and food production were likely limited.

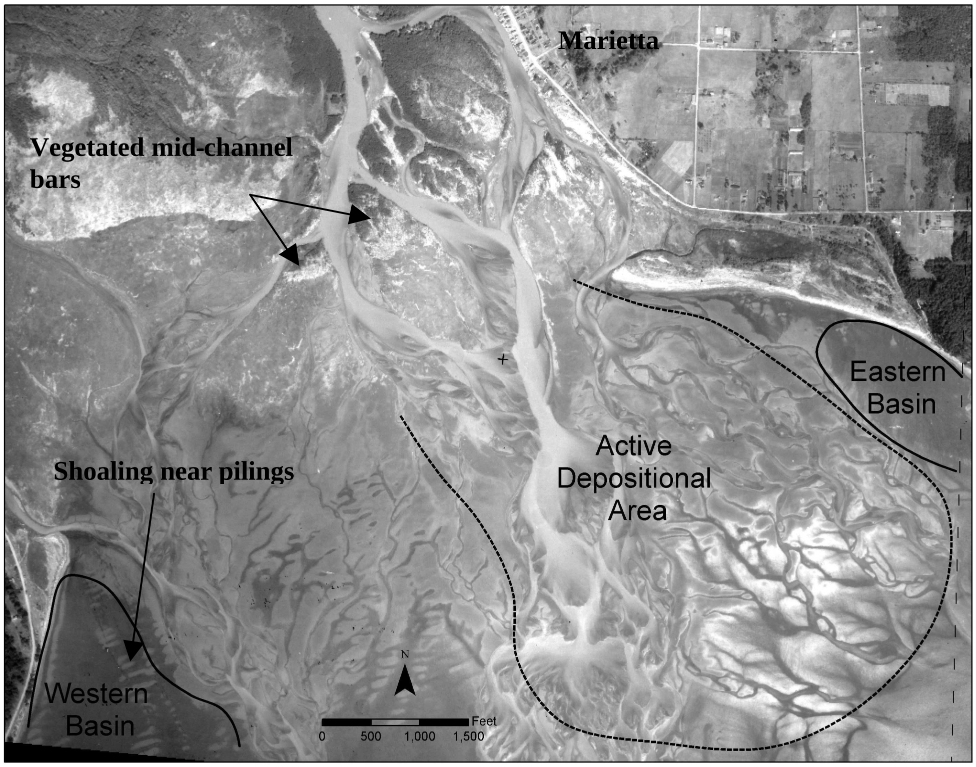


Figure 14. Channel development in 1933.

Also visible in these first aerial photos are lines of pilings constructed around the western basin in the late 1800s that were originally driven to trap wood transported down the river for milling. In both the 1933 and 1938 aerial photos, shoaling and sediment deposition around the pilings can be seen as northwest trending lines of sediment ripples (Figures 14 and 16). While sediment appears to be accumulating adjacent to the pilings, there does not appear to a direct effect on channel development at this time. It is possible that the sediment accumulation associated with the pilings accelerated the filling of the western basin by not allowing the sediment to be carried as efficiently offshore.

In 1933, the Lummi River looks similar to the current conditions, with a narrow, sinuous single-thread channel diverging from the mainstem Nooksack River. The point where the channel splits-off is well vegetated and a levee has been constructed across the head of the Lummi River. Although the dominant channel appears well preserved, evidence of an extensive network of channels leaving the mainstem of the Nooksack River and flowing toward Lummi Bay is present (Figure 14). These channels likely reflect the 1859 descriptions of “the whole country cut up by these sloughs, which are rapid and deep” noted by early surveyors (Smith et al. 1860, cited in Wahl 2001). This network of channels and crevasses in the natural levee of the Nooksack River likely means that the flow directed toward Lummi Bay was not confined to a single large channel as it is on the Bellingham Bay distributary, but rather through a series of smaller channels that spread across the floodplain. These channels, which were completely lost by 1933, would have represented excellent tidal freshwater juvenile rearing habitat, with abundant wood and a network of narrow, well-shaded channels.

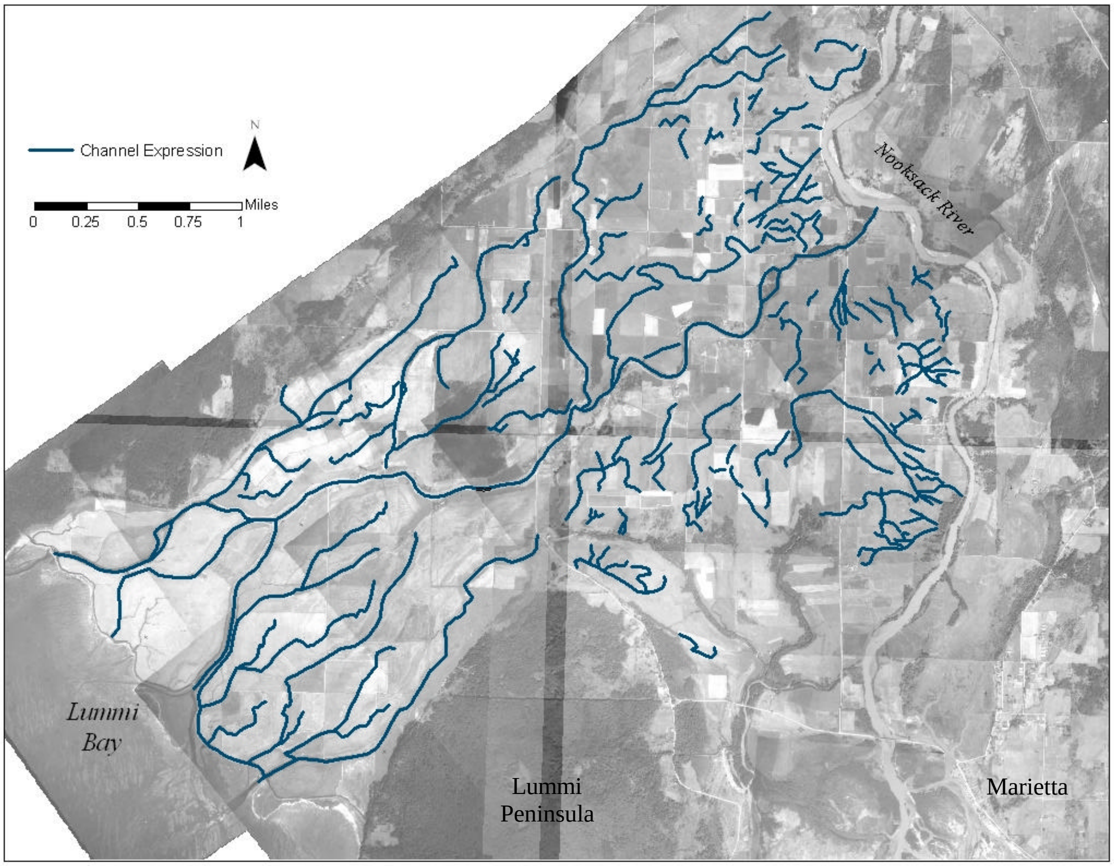


Figure 15. Expression of channels across Lummi River floodplain in 1933.

Between the 1933 and 1938 aerial photos, the Bellingham Bay distributaries changed considerably. The East and West distributary channels and the abandonment of a portion of the active delta (features that continue to persist) were all established before 1933 (Figure 15). Vegetation had begun to colonize on the bars inside the Marietta distributary channel, continuing to narrow the channel, and a sediment and wood deposit had begun to form at the head of the channel. From these photos to the present day, the channel has maintained two distinct main distributary channels and continued to fill the two topographic basins on the edges of the delta. In the case of the western distributary channel, the natural levees have isolated a portion of the delta front and a blind channel complex has developed in the abandoned area. This blind channel complex marks the first large tidal channel complex to develop on the Bellingham Bay side of the delta, and provides a unique habitat type, previously abundant only on the Lummi delta. From the 1938 photo year to the 1947 photo year, the western distributary experienced far more rapid growth than the eastern distributary (Table 1). The lengthening of the western distributary channel slows throughout the aerial photo record, eventually reaching only 18 feet per year between 1991-2004. The eastern channel length has stayed relatively constant through the aerial photo period, ranging between 77 and 96 feet per year.

Table 1. Distributary channel growth, represented by length of forested levee (feet per year).

Photo Period	West Channel	East Channels
1938-1947	181	77
1947-1955	123	96
1955-1991	62	84
1991-2004	18	85

While the disconnection of the Lummi River distributary was possibly not a natural avulsion, the slow closing of the western distributary channel may be an avulsion process on the delta. Natural avulsion generally is in response to two factors: (1) channel aggradation due to progressive extension of the delta into the sea (the increased length of the stream requires aggradation to maintain the gradient upstream), and (2) the presence of a shorter, steeper route to the sea that the river can adopt. In the case of the western channel, both of these conditions exist. Often avulsion can be a slow process, with overlapping use of several major distributaries before a main channel predominates. Through the historic period, there is no evidence of active channel avulsion, aside from the possibility of the avulsion from Lummi Bay to Bellingham Bay. There is topographic evidence across the floodplain below Ferndale of historic channel positions, and avulsion appears to have been a major means of adjusting slope. This can be discerned in Figure 14 on a preceding page.

Also visible in the 1938 aerial photo was the initiation of several of the mid-delta distributary channels (C-1 through C-4). In the case of C-1 and C-2, the distributaries occupied the 1933 main channel (Figure 16). Each of these channels had the connection where it breaks off from main channels stabilized with persistent vegetation. The vegetated levees appeared to be important for stabilizing the location of the channels and all of these channels continue to be major distributaries today. The rapid increase in distributary length between 1933 and 1938 marks a substantial increase in habitat abundance and diversity that was previously lacking. By the 1947 aerial photo, much of the mid-delta area had been vegetated and the various distributaries that flowed between the east and west channels had experienced rapid growth through the shrub-scrub and salt marsh habitat zones (Figure 16). Vegetated levees had extended 1700 feet down channel C-1 and over 1000 feet along channel C-4. While the channels had gained considerable length, they still appear to have narrowed, as the east and west channels conveyed most of the flow of the river. The abandoned areas of the delta continued to develop tidal channel complexes protected by the natural levees of the major distributaries. The salt marsh and scrub-shrub zones on the Bellingham Bay delta are still compressed in narrow bands relative to those evident on the Lummi Bay delta under pre-development conditions. These habitat zones are expanding rapidly as the delta advances into Bellingham Bay.

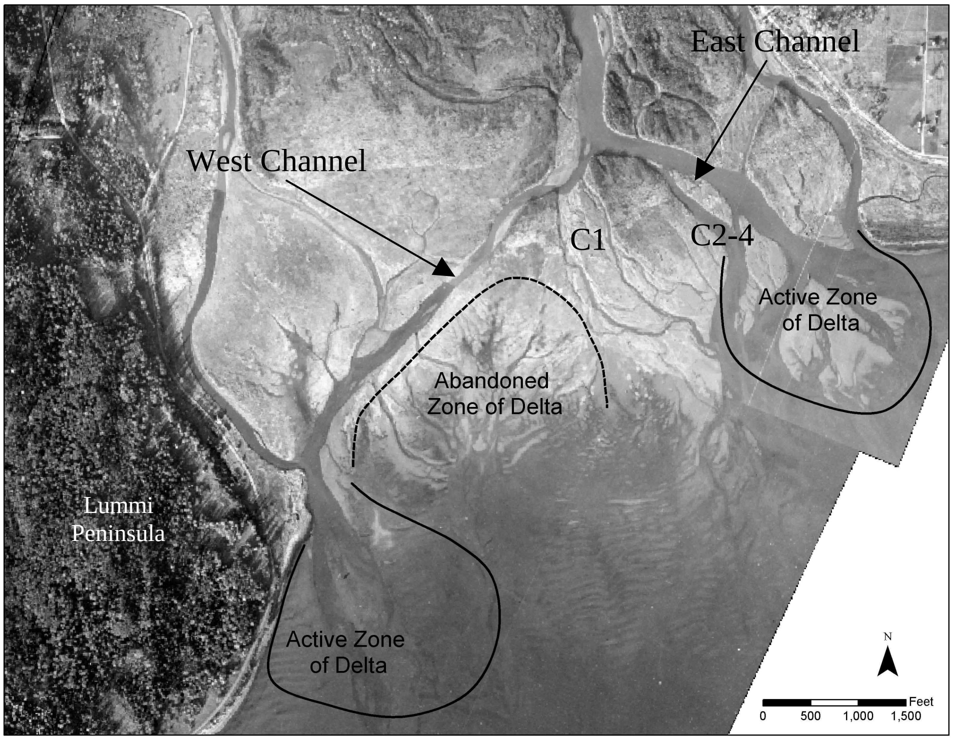


Figure 16. Nooksack delta channel development in 1938.

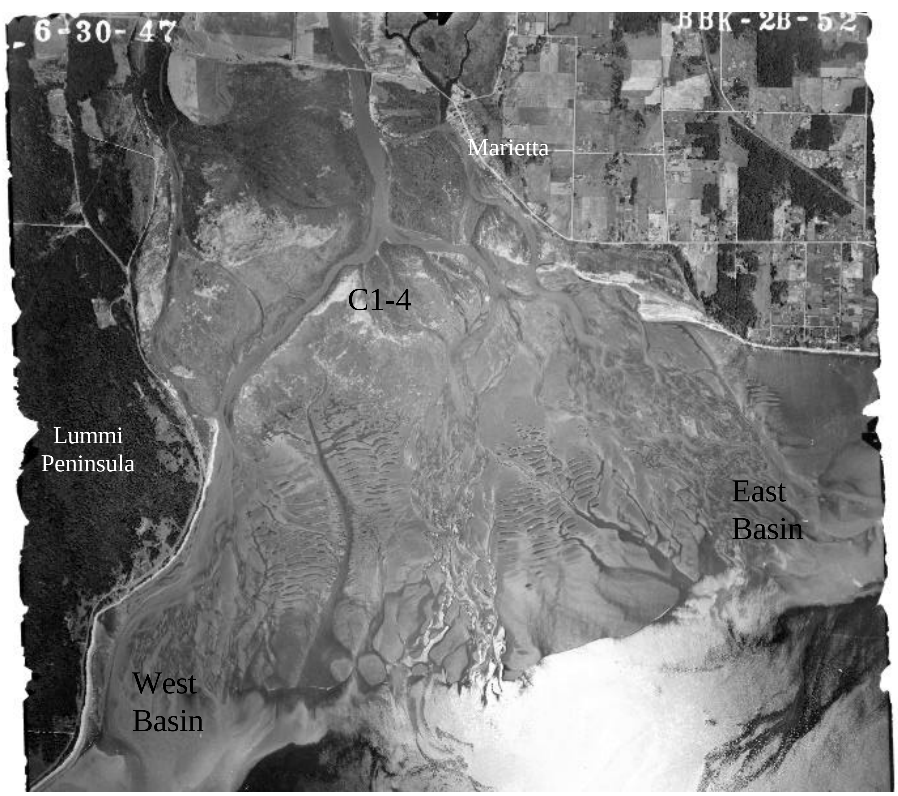


Figure 17. Nooksack delta distributaries in 1947.

It is apparent from the 1947 aerial photo (Figure 17) that the delta front has widened as it has prograded into Bellingham Bay, filling the area between the Lummi Peninsula and the Ft. Bellingham headland. Based on laboratory research and studies of other deltas, it is expected that as the width of the delta increases then the number of distributary channels would increase to deliver sediment across the delta (Chang 1988). This has been the case for the Bellingham Bay Nooksack delta (Table 2). As the delta front has widened with progradation through time, the number of distributaries feeding the delta has increased considerably. The rate of distributary channel development will slow as the constant supply of sediment and freshwater is deposited over an increasingly larger delta front. Based on these expected changes, the salt marsh and shrub-scrub habitat zones should widen as more of the delta front becomes less active and tidal processes begin to dominate a larger portion of the delta.

Table 2. Width of Bellingham Bay delta front and number of associated stable channels.

Width of Delta Front (kilometers)	Number of Channels
2.34	5
3.28	10
4.60	15
6.32	Stable distributaries not yet present*
7.46	Stable distributaries not yet present*

* Only ephemeral channels present on sand flat

Through the 1950s and 1960s, the growth of the eastern distributary channel led to a marked increase in the number of perennial distributaries across the delta front. This is likely due to the reduction in confinement of the delta between the Lummi Peninsula and high cliffs of the Ft. Bellingham headland. An increase in the number of distributary channels likely decreased the efficiency with which those channels could transport sediment across the delta plain. These changes are reflected in the slowing of the growth of the length of the western distributary. Virtually all of the distributary channels narrowed through this period and it was not until the early 1990s that this trend changed (Figure 18). While channel width and length cannot reflect changes in depth, there is little evidence of shoaling in either the western or eastern distributary channels until 2001.

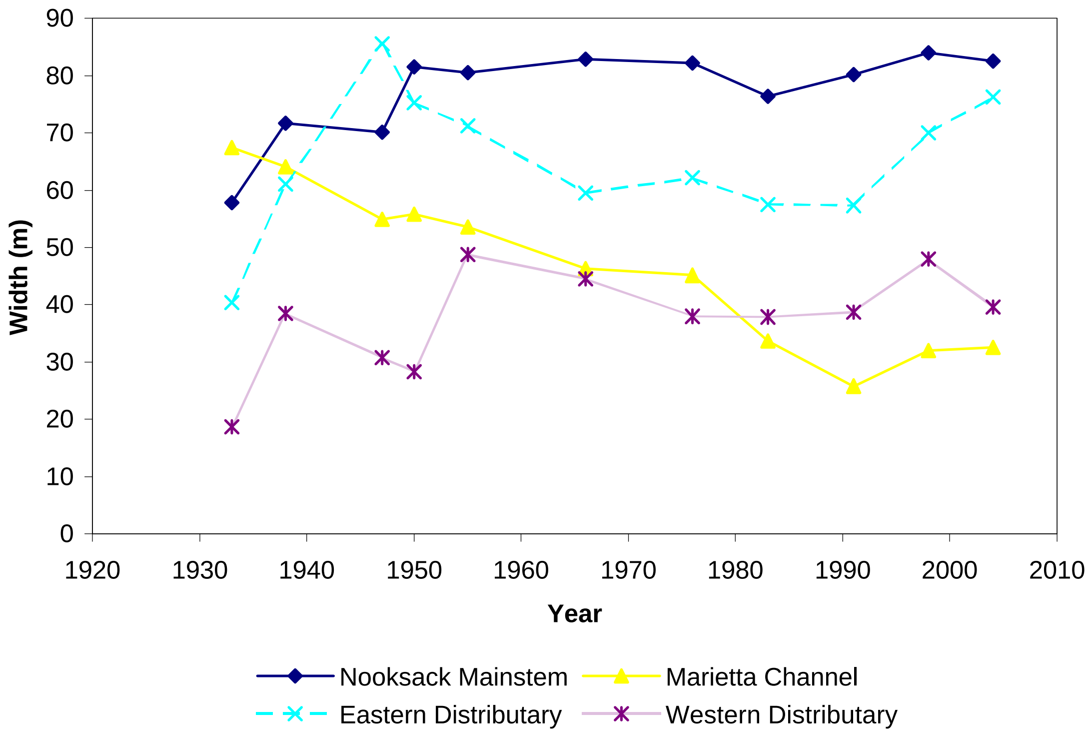


Figure 18. Distributary channel width.

While the channel width of the western distributary has shown a modest increase since the early 1990s, aerial photos have shown that the channel shoaling and developing a sinuous channel within its vegetated banks since 2001. It has begun to resemble the Marietta channel of the mid-1930s, when it was responding to the reduced flow caused by the man-made avulsion through Larrabee's Slough and began its decline in transport efficiency. While the western distributary channel has shoaled rapidly, the eastern distributary channel has continued to widen and lengthen considerably (Table 1 and Figure 18). Since the relative channel size is related to the input of wood, sediment and water, it appears that the west channel has been losing its ability to effectively transport sediment for many years, while the eastern distributary has continued to grow. Because the channel width was measured from geo-referenced aerial photos, measurement error likely exists between years. Even with a margin of error in mind, it is evident that the Nooksack mainstem immediately below Marine Drive widened modestly between 1933 and 1950, and since then has maintained a fairly constant width. The Marietta channel has steadily narrowed from the 1933 aerial photo year to 2004, reflecting its continued increase in length and corresponding decrease in efficiency. The eastern distributary has seen two periods of widening. From 1933 to 1947 the channel nearly doubled in width and from 1991 to 2004, the channel increased its width by nearly half. Between these times, the eastern distributary channel slowly narrowed. Since 2000, the lower eastern channel has experienced shoaling and an in width and length, possibly due to longshore currents transporting sediment into the mouth of the channel.

The Lummi River has also continued to narrow and fill since levees were constructed across its head in the 1920s. Several times between 1931 and 1951 the dike separating the Lummi and Nooksack rivers was breached during floods and repaired. After 1951, the dike was reconstructed and a 4-foot culvert was added to pass freshwater to Lummi Bay during high flow. Surveying of the connection in 2003 showed that sediment deposition had filled the channel to near the same elevation as the surrounding floodplain and channel incision by the mainstem has perched the Lummi River approximately 5 meters higher than the bed of the Nooksack River. With the current culvert configuration, flow is passed from the Nooksack River into Lummi Bay at a discharge above 9,600 cfs at the USGS gage at Ferndale. Since the gage was installed in 1966, the flow of the Nooksack River has exceeded the level necessary to activate the Lummi River channel 15 days per year on average. While it is most common for flow to access the Lummi River between November and March, flow has entered the culvert at least once in every month of the year. The most likely period for flow to enter the Lummi River represents a portion of the juvenile out-migration window for virtually all anadromous species in the Nooksack River.

From historical analysis, it is expected that the trends in channel development and closure in the delta will continue and the Bellingham Bay delta will continue to grow due to the naturally high sediment load produced by the Nooksack basin. As the delta continues to grow into the future it is likely that the rate of progradation will slow with a constant supply of sediment as it advances into deeper water because it requires more sediment to produce new surface area on the delta platform. While the delta progrades into Bellingham Bay, more distributary channels will continue to form, increasing the habitat available to salmon. The increased number of channels may also lead to a decrease in the ability of the channels to transport sediment, given the fixed amount of flow to maintain the channels and ultimately a narrowing and shallowing of some of the major distributary channels. Also, the amount of delta front that is not actively maintained by distributary channels will increase, likely leading to greater blind tidal channel development. With a greater proportion of the delta subject to marine forces, it is expected that the salt marsh and shrub-scrub zones will widen as the gradient of the delta lessens.

Restoration of sediment transport and depositional processes should focus on restoring the natural rate of sediment delivery to the delta by increasing floodplain storage upstream of Marine Drive. While fine sediment levels may not directly impair rearing and transitioning salmon, altering sediment delivery to the delta will help restore the rates of habitat change as the delta continues to prograde into Bellingham Bay. At some sites within the estuary, artificial barriers, such as pilings, slow water discharge through existing channels and likely increase local sediment deposition. Treating these artificial constrictions could improve sediment conveyance and storage within the side and distributary channels. In reaches where there is no riparian vegetation adjacent to the channel, tree planting could roughen the floodplain and encourage sediment deposition on the floodplain, where the river overtops its banks. All of these measures will work to restore the sediment transport processes in the estuary and contribute to restoration of habitat formation to more undisturbed conditions.

Large Woody Debris

Wood plays an important role in shaping in-stream habitat in the Nooksack River estuary. At a larger scale, accumulations of wood can slow water velocity, leading to sediment deposition, distributary channel closure or avulsion. At a finer scale, wood can provide high-flow cover and predation refuge for rearing juvenile fish. Wood can also provide important ecological functions for benthic and epibenthic organisms. The variety of functions wood provides occurring at a range of spatial scales makes it an important component of habitat formation in the estuary (Maser and Sedell 1994).

How wood accumulates in the estuary changes seasonally with changes in discharge and tidal range (Maser and Sedell 1994). At the "null point," where upstream movement of saline water is halted by the downstream flow of freshwater, waterlogged driftwood of all sizes is often stored (Maser and Sedell 1994). The position of the "null point" varies with the volume of water discharged by the river and is thus closer to the river's mouth during the rainy season, when downstream flow of fresh water dominates physical conditions in the estuary. Floating driftwood tends to be retained in the upper estuary during low flow months, when the influence of incoming fresh water is reduced and cannot flush the wood into the lower estuary. During low flow months, driftwood is moved downstream only during tidal cycles sufficiently high to reach it and float it downstream, where it becomes grounded on the delta. This dynamic maintains that wood storage in the upper extent is longer than it is in the lower extent, where it can be more effectively evacuated from the estuary. Wood tends to be retained longer in the upper regions of estuaries that are long relative to their width because of the longer flushing time of estuarine water (Maser and Sedell 1994). In the Nooksack estuary, the bulk of wood deposition occurs below Marine Drive in the first unconfined section of the channel below Everson (RM 24).

Woody debris enters the estuary through three general pathways: upstream, longshore drift, or from local estuarine sources. The relative importance of these three sources has likely changed through time, as human development has altered the landscape. More so than any other habitat-forming process, the recruitment, transport, and storage of wood in the estuary was completely changed between early mapping and descriptions in the mid-1800s and the earliest aerial photos in the early 1930s. In the course of 50 years, wood delivery to the estuary was drastically increased over the earliest descriptions by driving logs down the river and then quickly reduced to levels less than current levels.

Before land clearing for agriculture, the mainstem Nooksack River was literally choked with wood, making navigation impossible without extensive portages. The river flowed through dense forests in the higher elevation portion of the basin, which would have contributed large quantities of wood to the river channel. The General Land Office bearing tree data indicate that the species that would have provided very large wood to rivers, and potentially function as key pieces in logjams transitioned based on the elevation and floodplain conditions of the river (Collins and Sheikh 2002). The trees on the delta that could grow large enough to provide stable wood locally to the channel would have been limited to Sitka spruce (*Picea sitchensis*). In the lower mainstem, black cottonwood (*Populus trichocarpa*) would have augmented spruce, and in the upper mainstem, western red cedar (*Thuja plicata)* would have been the most common key piece, along with spruce, Douglas fir (*Pseudotsuga menziesii*) and cottonwood. In the forks, cedar and fir would have been the most commonly available large wood, and secondarily cottonwood and bigleaf maple (*Acer macrophyllum*). Estuarine scrub-shrub habitats lacked large trees and were dominated by small willow (*Salix, spp.*), Pacific crabapple (*Malus fusca*), and alder, filled in by an understory of nootka rose (*Rosa nutkana*), salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), and ninebark (*Physocarpus capitatus*) (Collins and Sheikh 2002).

Before active management, channel-spanning logjams dominated the river in several locations through the length of low gradient channels in the Nooksack basin. This includes the entire mainstem channel, as well as the lower portions of the main forks. In several locations, the logjams were several miles long and provided islands of stability in the dynamic river system. These logjams would also have formed barriers to downstream transport of wood through the system and increased the residence time of the wood in the river by trapping the transient wood in the logjam. Wood transported into the estuarine environment from upstream would likely have been as episodic pulses when upstream logjams came apart, or from long-shore drift and local estuarine sources. In the estuarine portion of the river, the forested areas tended to be confined to the narrow strips of the natural levees of the river, because these areas provided the elevation and stability for large wood to mature (Collins and Sheikh 2002). Behind the natural levees, the floodplain was dominated by tidally influenced marshes (Figure 19).

Under these conditions, it appears that the river did not actively migrate through the delta, but moved by avulsion, or jumping from one position to another position. In several of the older maps and aerial photos, crevassing can be seen through the natural levees of the river. While there is no direct evidence of natural channel avulsion in the historic period, the abundant crevassing of the natural levees could be a mechanism for the river to change position and increase slope. Evidence of channel migration, such as oxbow lakes, is lacking across the estuarine floodplain, but rather there appears to be a limited number of channel positions present on the floodplain. These historic channel positions show up as high elevation areas on the floodplain due to sediment deposition on natural levees adjacent to the channel. This sediment deposition led to the elevation of the channel above the floodplain. In Figure 19, the floodplain forest follows the higher elevation of the historic channel positions. The river would have continued to build its channel above the floodplain until a shorter and steeper path to the sea presented itself. Logjams may have exerted some control on the location that the channel avulsed, by damming flow or directing it at a likely avulsion point.

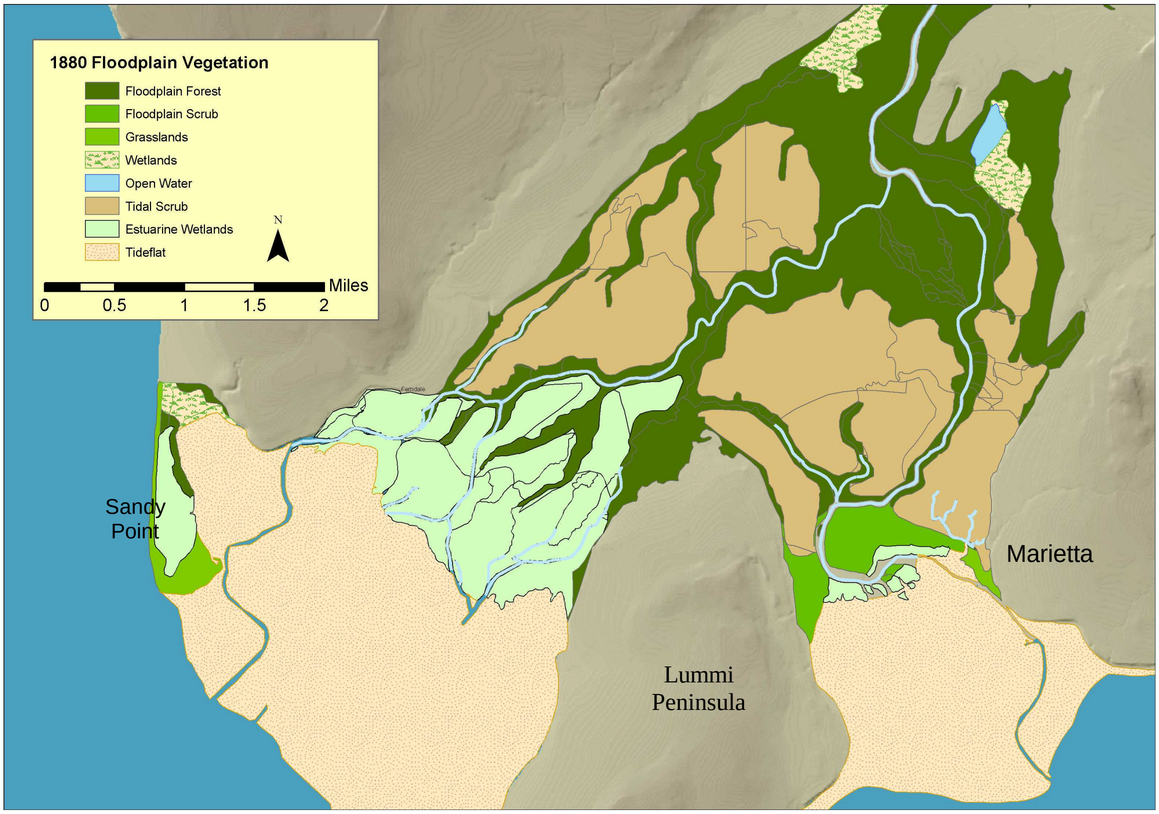


Figure 19. 1880 Lower Nooksack River floodplain habitat (Collins and Sheikh 2002).

The first maps of the Nooksack delta show the majority of the flow discharging to Lummi Bay through a complex network of channels. Commenting about the delta immediately downstream of the Lummi-Nooksack divergence, the GLO field survey party in 1859 wrote the "whole country [is] cut up by rapid, deep sloughs," which caused it to be "impassable" (Wahl 2001). The Lummi River distributary began near the downstream end of a persistent logjam in the mid-19th century (commonly referred to as the "Portage Jam") in the Nooksack River. Historic descriptions of the main channel flowing into Lummi Bay described it as "stopped with drifts and unfit for canoes", while the Bellingham Bay outlet was "navigable by canoe by making a portage" around the large logjam at the head of the Lummi River (Smith et al. 1860, cited in Wahl 2001). Located where river velocity declines due to gradient change and tidal rise, this logjam extended up river for a 1/3 of mile in what is called Hovander Bend (Custer 1858, cited in Wahl 2001). Several of these major channel-spanning logjams, such as the Portage Jam, became infamous to early settlers trying to navigate the river and were the focus of extensive removal operations beginning in the early 1860s. Although removal was nominally completed in 1876, the location continued to be a noted site of debris accumulation. The Portage Jam itself was apparently quite stable, it supported trees and brush and had an ancient 600-foot 'cut trail' with regular cross-timber skids built around it for portaging canoes (Custer 1857, cited in Wahl 2001).

The causes of subsequent change to the Portage Jam and the Lummi River distributary are unclear (Wahl 2001, Deardorff 1992). The official report of Assistant Engineer Robert Habersham, writing for the Army Engineers, suggests the Lummi River was closed by natural drift accumulation and channel avulsion:

> *"The [channel to Lummi Bay] was closed 20 years ago by a raft of driftwood 4 miles above its outlet, which turned the entire volume of water into the other, then only a small creek gradually enlarging it until it now constitutes the principal and only navigable channel"* (USACE 1881, cited in Wahl 2001).

However, historical research by Wahl (2001) suggests that the Army Engineers may have plugged the Lummi River in 1886 with wood from the former Portage Jam, which was finally removed in the early 1870s, using a snag boat that was clearing the Lummi River of logjams. While there has been no other evidence of channel avulsion in the historic period, certainly not of the main channel relocating into a small former distributary, the reduction in stable wood that could have mediated such a change may explain the lack of recent avulsions. Snag boats were active on the Nooksack and Lummi Rivers from the mid-1880s through the early 20th century, removing logjams and placing log berms to control the channel of the river. Whether the logjam that blocked the Lummi River was intentionally placed, or naturally formed, the main course of the river changed into its current configuration by the late 1880s and all wood transport from the Nooksack River to the Lummi estuary was halted (USC&GS 1887). The only sources of wood remaining to the channels of the Lummi River came from erosion of forest seaside bluffs and longshore movement of wood, or from local erosion of forested levees. The loss of flow in the channel would have greatly reduced the ability of the channel to erode its banks and recruit local wood the channel, making this pathway fairly limited.

As the combined efforts of transporting logs down the river and cleaning the channel of wood debris continued, much of the upstream wood was loosed to accumulate in the estuary of Bellingham Bay. In 1880, the Reveille reports there were still 7 logjams in the Nooksack River in and/or below the South Fork Nooksack River and that removal of these logjams will allow timber to be transported to Bellingham Bay. It is suggested that these logjams were caused by increased wood transport down river by timber harvesters (Wahl 2001). The dynamics of Bellingham Bay made it difficult for the wood to be evacuated from the mouth of the river. Even before the booms were constructed to contain the wood transported down the river, massive logjams of sawlogs formed in the estuary. Captain Jefferson of the snagboat Skagit commented that unlike other river mouths, the Bellingham Bay distributary did not purge itself of drift, which was instead held in place there by prevailing winds. Logjams had begun to form prior to boom construction; the Army Engineers first cleared a logjam in November 1888.

According to Deardorff (1992), to gather logs driven down river, the Bellingham Bay Boom Company constructed a piling boom across the channel in 1890 at the mouth of the Nooksack River. Following the construction of booms, litigation followed regarding the boom's blockage of the river to navigation. In the 1890s and 1900s, logjams formed frequently in the lower channel of the Nooksack River, accumulations at least in part caused by the log booms. Massive logjams began forming behind the boomworks as early as 1890 according to snagboat captain E. H. Jefferson:

> *"…It was found that the entrance to the river was blocked by saw logs that had come down upon a recent freshet, and was being held by rival boom companies who were at war with each other, and that nothing could be done by the snag boat towards clearing the obstruction without inflicting damage to the booms, and thus causing a serious loss of logs to their owners"* (USACE 1891, cited from Collins and Sheikh 2002).

Writing a few years later, Captain T. W. Symons indicated that these jams had made navigation nearly impossible:

> *"The great trouble with the navigation of the river is at its mouth. Here, where the river debouches into the tide flats, booms have been built for catching saw logs, and these constructions, together with the logs and drift of all kinds caught thereby, have very effectually closed the river to ordinary navigation. It is now almost an impossibility for boats to get into the river"* (USACE 1895, cited from Collins and Sheikh 2002).

These unnatural logjams were much larger than those that formed in predevelopment times. The resulting anthropogenic logjams, such as the "Boomworks Logjam," completely blocked the channel with sediment, shingle bolts and saw logs for more than 9300 feet and rendered the river impassible to boats. These anthropogenic logjams also led to major channel changes as the river responded to the increased wood load. For example, in 1893 a number of logging operations on the Nooksack and Bertrand Creek simultaneously released stockpiled logs during a flood in mid-March (Chris Siegel, cited in Wahl 2001). In response to the increased load of wood and sediment in the main channel downstream of the Lummi Bay distributary, the channel crevassed more frequently to the southeast into the swamps above Marietta and northwestward to Lummi Bay. Ogden (1894) observed that the logjam blocking the Lummi Bay distributary would soon be overcome by increased bank cutting (cited in Wahl 2001).

Between 1903-08, the US Army Corps of Engineers contracted for the removal of the "Boomworks Logjam," the last of the massive logjams in the lower river. The motivation for removing the logjam was apparently that it was causing flooding and crevassing upstream around the logjam. Later, with a "little encouragement" from dynamite, the current channel was opened adjacent to the town of Marietta and the former main channel became Kwina Slough (Howard Buswell, cited in Wahl 2001). With the diversion of the main channel around the remnants of the logjam, the dynamics for wood deposition below the diversion point was altered. More flow, sediment and wood were directed toward the east side of the Nooksack delta causing rapid growth toward the town of Bellingham. This man-made avulsion of the river also changed the local recruitment of wood to the channel. The river's avulsion through its vegetated banks into unforested wetlands and adjacent tide flat reduced potential recruitment of wood. While local recruitment was reduced, the increase in wood moved down the river for milling more than compensated for the reduction of local sources.

In the first aerial photos in 1933, the wood distribution in the Nooksack Delta looks nothing like the earliest descriptions or the descriptions of the log drives near the turn of the century. The floodplain of the river is entirely cleared for agriculture, often to the banks of the river, and sections have been straightened. The logjam at the head of the Lummi River has recently been replaced with an earthen dike, and any large logjams in the channel have been removed. Pilings have been driven across the head of Kwina Slough (the mainstem 20 years earlier) to reduce flow down the channel, resulting in the rapid narrowing of the channel. The channel straightening and blocking of historic channels has created a system where wood is not recruited or stored between Marine Drive and Everson, 24 miles upstream. Wood that is present in the estuary comes either from local sources below Marine Drive or from the basin above Everson. It is likely that this situation differs from the undisturbed conditions where much of the wood generated in the upper basin was stored in the main channel in large persistent logjams, or the conditions of the turn of the century, where large rafts of timber were transported down the river and stored in the estuary.

The local wood recruitment area for the estuary was limited by extensive clearing for agriculture. The forested floodplain by1933 was confined to a half-mile length of the river between Marine Drive and the transition to the shrub scrub zone (Figure 20). The former main channel position, now Kwina Slough, is clearly indicated by the distribution of the forest that occupies the high natural levees along the old channel. The 1933 main channel position in this figure is relatively recent, having been diverted approximately 25 years previously, and appears to truncate the delta that was being constructed below Marine Drive prior to diversion. Because the channel was diverted away from the forested levees of the historic channel, the local wood recruitment area for the delta has been greatly reduced.

Wood deposition in the 1933 channels also appears to have changed considerably from the accounts written 25 years previously of channels plugged with drift. All of the channels appear to be cleared of drift and the pilings that once trapped wood at mouth of the river are isolated from the main channel of the river. Wood is still present, but it distributed as a raft at the high tide line and as scattered pieces across the sand flat. Many of the active channels in the 1933 aerial photos appear cut through the raft of drift wood and older high tide deposits appear to be present bordering the forest zone.

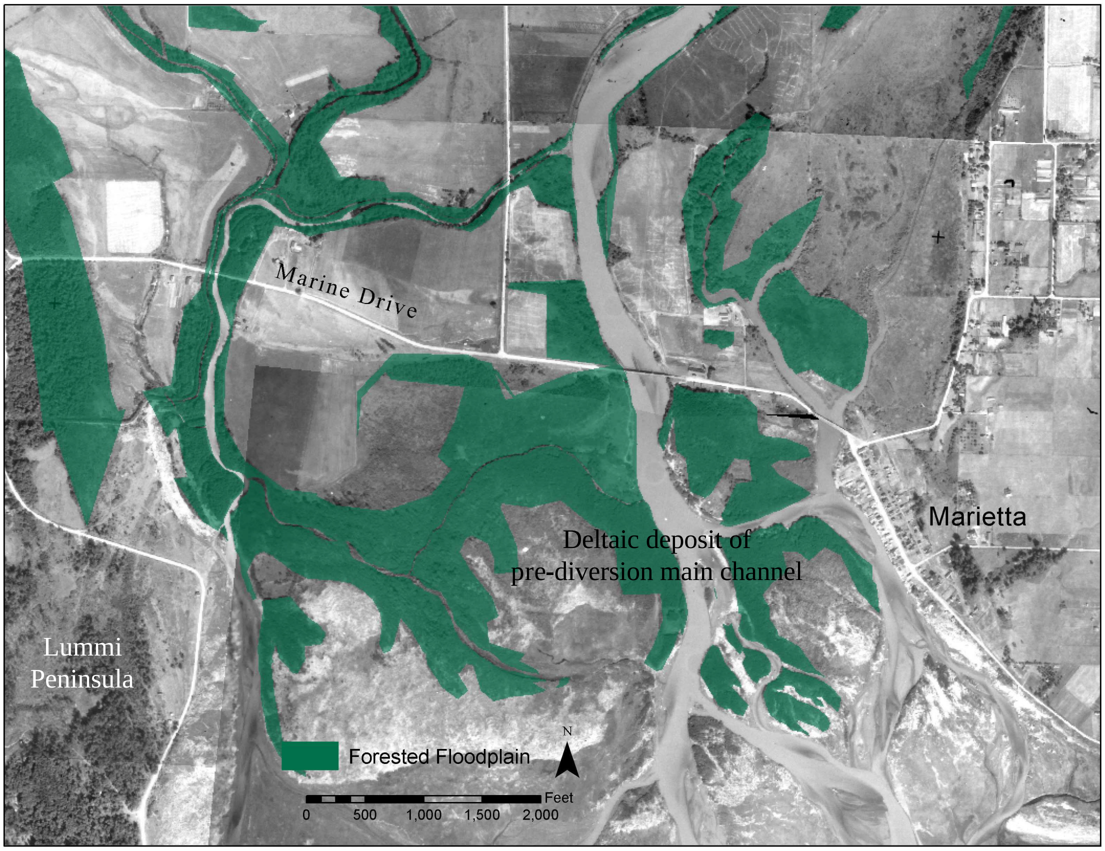


Figure 20. 1933 forested floodplain downstream of Marine Drive.

As the delta continued to prograde, the forested floodplain below Marine Drive continued to expand (Figure 21). The increased forested area led to an increase in local large woody debris recruitment potential for the delta, although upstream sources were rapidly succumbing to land clearing and loss of channel migration area to bank protection. Much of the loss of channel migration came in the mainstem near Everson and the Acme Valley of the South Fork, which were previously high wood recruitment areas. During the 1950s and 1960s, extensive channel cleaning was conducted by the Army Corps of Engineers associated with the construction of revetments along much of the channel in these areas. These changes in wood delivery to the delta changed both the amount and nature of the wood delivered to the delta. While areas that once supported large conifers were being cleared or isolated from the channel, the forested growth of the delta was largely early successional species such as red alder (*Alnus rubra*) and black cottonwood, much the same as today. Currently, only in the oldest portions of the forested delta are there young conifers present. Most of the material present in estuarine logjams is recruited from young deciduous trees of local sources, or well-weathered older conifers transported downstream.

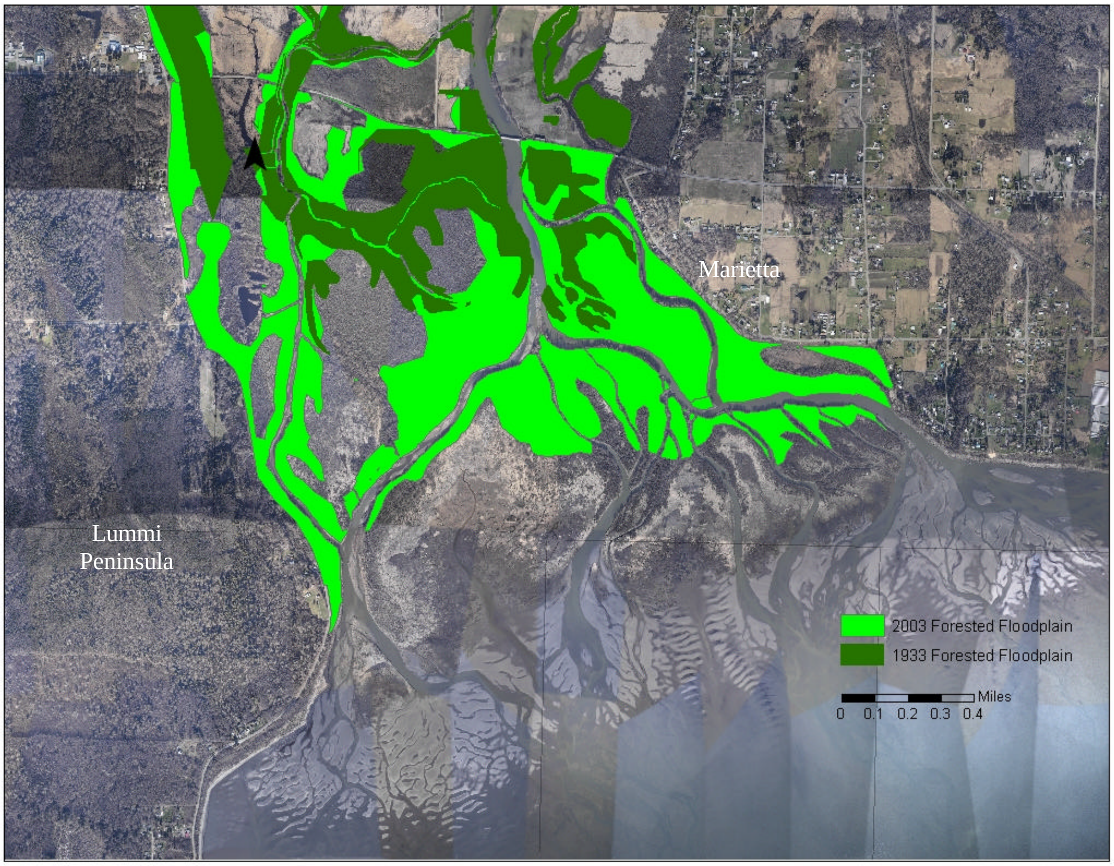


Figure 21. Forested floodplain advance between 1933 and 2003.

It is not until the 1955 that first depositional logjam is easily identified in the active channel at the head of the Marietta Channel distributary. From the first aerial photos up until that time, all of the major depositional areas occur at the high tide line. This logjam appears as a wood and sediment deposit growing upstream across the mouth of Marietta Channel (Figure 21). This type of deposition, occurring at the junction of a major distributary channel, will become more common between 1955 and 2001 with major logjams forming at nearly every major channel bifurcation. These types of logjams can help control channel distributary development and maintenance as they evolve. For example, the logjam deposited at the head of Marietta Channel has contributed to the narrowing of the mouth of the channel, reducing the flow that is passed into the channel and speeding channel narrowing and shallowing (shoaling). The logjam at the bifurcation of the east and west channel, which formed as that channel lost its ability to transport sediment and wood, has likely contributed to the narrowing and shallowing of the western distributary channel.

The logjams that occur at the channel splits provide high quality cover and juvenile rearing habitat for anadromous species as they prepare to emigrate from the river (Dunphy, pers. comm). The logjams are dense deposits of wood that reduce water velocity and accumulate sediment. As a result, they bury themselves in sediment and become stable deposited in the lower velocity environment. As the logjams age, they become more buried in sediment, until only the most active portion of the logjam is exposed. The exposed portion of newly recruited wood will provide the high quality habitat that is often associated with woody debris accumulations, while the older portion of the jam will often be completely buried in sediment. Much of the riverbanks through the delta are comprised of a mix of sediment and wood, as trees are recruited to the river, slow the water velocity, and are buried by the sediment. These woody banks, while not depositional logjams, are in-situ features formed by bank erosion that provide high quality edge habitat for rearing juvenile salmon.

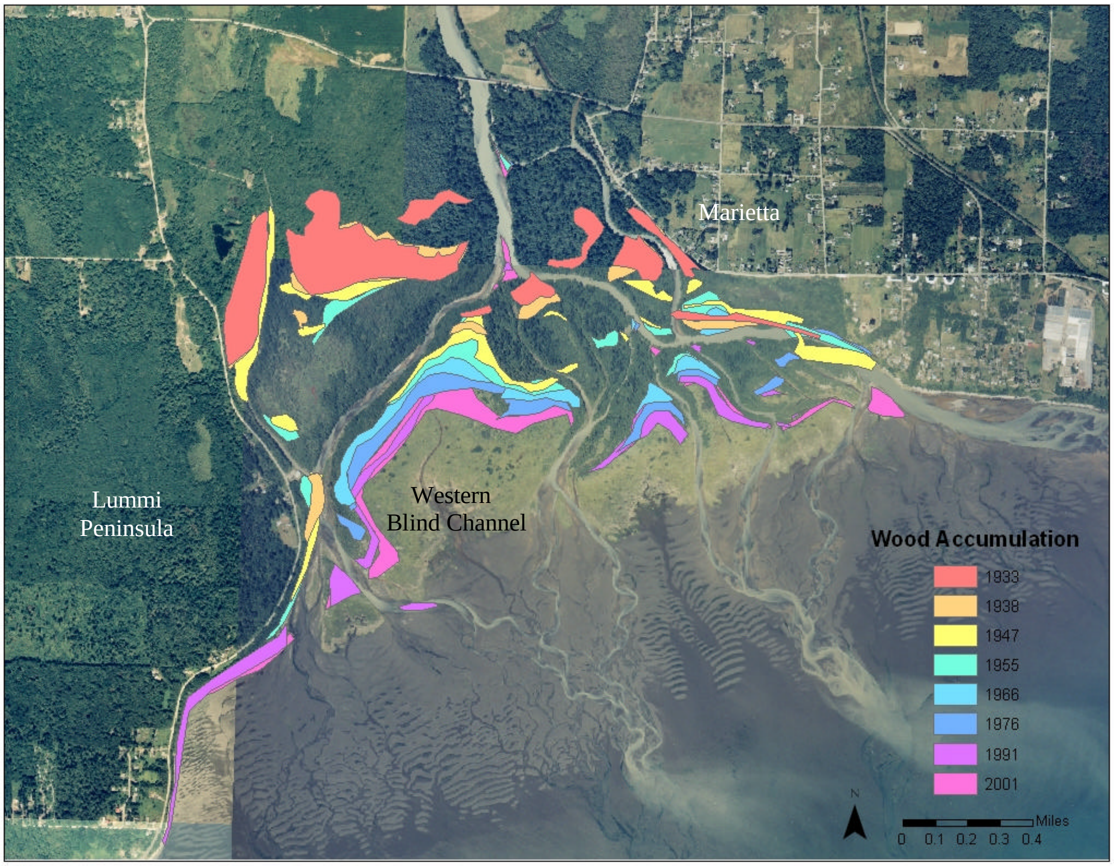


Figure 22. Areas of wood accumulation on the Nooksack Delta 1933-2001.

The accumulations of wood occurring at the high tide line have also changed through time as the delta has continued to prograde into Bellingham Bay. In the areas where tidal processes control habitat formation, the wood line has advanced into the bay as the delta has prograded. This process is evident in the western blind channel area between 1933 and 2001, and in the other more recent blind channel areas between 1966 and 2001 (Figure 22). In areas along the borders of the delta, where fluvial processes have dominated, the wood line has formed and been truncated by the river periodically through time. This process is evident on the eastern edge of the delta, below the Fort Bellingham headland, where the steady progradation of the wood line is not present, but rather the wood line has established at various locations depending on the interaction between riverine and tidal processes.

The driftwood also plays an important ecological role in the structure of the biological communities (Maser and Sedell 1994). This wood, though often dry during low tide periods, is important for encouraging sediment deposition and aggrading the area near the channel to allow persistent vegetation to colonize. The driftwood zone becomes a sort of platform for the advancing the shrub-scrub zone of the delta and speeds the conversion to a forested floodplain, acting as “nurse logs” for the advancing forest. As the drift leaves the Nooksack delta and enters the nearshore environment, it can be a locally important barrier to erosion, protecting erosive headlands and beaches from waves. A portion of the wood in nearshore areas is lost to woodcutting, likely affecting the ecological roles that driftwood can provide.

The ecological and geomorphic value of wood in the delta has changed considerably through time, from the pre-development conditions described in the mid-1800s, through the massive influx of wood from milling operations, to channel cleaning shortly after the turn of the century. Since the 1930s, it appears that wood function is increasing in the estuary, as local sources for recruitment expand and logjams are allowed to develop and persist in the channel. With the rapidly growing delta, it is expected that wood will play a greater role in habitat development and maintenance. Improving riparian conditions in the watershed, along with attempts to preserve adequate channel migration areas for the channel, will improve long-term recruitment of wood to the estuary and likely provide important habitat benefits that are currently lacking.

Restoration of wood function in the estuary will need to follow three general pathways: slowing the rate wood is delivered to the estuary from upstream, increasing local wood recruitment areas and increasing in-stream wood in channels where wood recruitment has been halted. Wood brought into the estuary from the mainstem channel could be slowed by restoring sites along the channel for wood to be stored and metered into the estuary. This would provide some excellent habitat local to the storage site and increase wood function in the mainstem. Wood from local sources has been lost to extensive land clearing, particularly on the Lummi Bay delta. Channels should be replanted with adequate buffers to provide multiple benefits to the channel, such as shading, wood recruitment and filtration.

Water Quality

Continuous mixing of fresh and salt water in the estuary creates a collection of habitats, each unique in the function they provide to fish and wildlife. Water temperature, salinity, conductivity, and dissolved oxygen are all variable in this ecosystem as daily tides ebb and flow out of the estuary, and river discharge increases and decreases seasonally. Three zones are derived from this constant mixing: a fluvial zone, characterized by the lack of seawater influence on water chemistry, but subject to water surface elevation rise and fall with sea level; a mixing zone, characterized by a salinity gradient produced by seawater chemistry, biology and physiology interacting with riverine freshwater; and a nearshore zone in the open sea, between the mixing zone and the seaward edge of the tidal plume.

The water quality section focuses on three parameters; salinity, temperature, and fecal coliform, that strongly affect fish habitat, fish distribution, and restoration potential. Salinity plays a significant role in defining estuarine habitat classifications (Cowardin et al. 1979), by controlling vegetation types and defining the transition area for smolting anadromous species. Salinity gradients, in flux with discharge and tidal inundation, dictate osmoregulatory processes that allow juvenile salmon to pass from freshwater habitats to nearshore and offshore. They also influence salmonid distribution in the estuary, with regard to fish tolerance of salt. Temperature is critical for optimum food web production and regulates fish respiration. This water quality attribute often becomes limiting to fish production in certain channel areas during the summer low flow period. Fecal coliform presence in the estuary is a characteristic of degraded fish habitat. Salmon are more susceptible to disease when fecal coliform counts are high, and elevated fecal counts are used as an indication of possible nutrient loading from pollution responsible for the presence of fecal coliform. The accurate characterization of water quality in the estuary is difficult, because values tend to vary with changes in the season, weather, time of day, and other factors (Cowardin et al. 1979). Historic water quality record for the Nooksack River is limited, although the Lummi Nation has monitored for water quality conditions on a regular basis since 1990.

Temperature

Temperature is the predominant physiochemical characteristic that influences juvenile salmonid development. It affects the amount of oxygen a given amount of water will hold, the rate of photosynthesis and decomposition, the ionization of ammonia, and the metabolic rate of most cold-blooded animals (Wedemeyer 2001). For optimum growth and production, fish residing in the estuary must be capable of movement to habitats with favorable water temperatures throughout the diel cycle. In the case of the Nooksack River estuary, temperature varies considerably by habitat type and degree of freshwater and tidal influence.

Juvenile salmonid rearing environments are variable throughout the early life history stages, and individual species have adapted a variety of strategies to facilitate survival. Individual species occupy aquatic environments with thermal regimes that vary daily, seasonally, annually as well as spatially, and each species has demonstrated well-defined temperature preferences and tolerances (Bjornn and Reiser 1991). Elevated water temperature can negatively impact salmonid development, including altered migration timing, exposure to diseases, increased juvenile mortality, changes in fish community structure that favor competitors of salmonids (USEPA 2003), and a rise in metabolic rate. The elevated metabolic rate increases cold-blooded organisms' energy requirements, a potential problem if food supply is limited (Oliver et al. 2001). The temperatures that chinook juveniles encounter in the estuary may influence their residence time, growth rates and life history strategy.

Optimal conditions for juvenile chinook, coho (*O. kisutch*), sockeye (*O. nerka*), and chum occur in water temperatures between 12 and 14°C, with suboptimal temperatures for rearing ranging between 18º C and 24º C (Brett 1952). Upper and lower lethal temperatures vary between species. Upper lethal limits range between 25.4°C for chum and 26.2°C for chinook; lower lethal limits range between 0.5ºC for chum and 3.1ºC for sockeye. According to Piper (1982) and the USEPA (2003), the upper incipient lethal temperature (where 50% of a sample dies) for chinook is 24° C, the upper limit displayed in temperature graphs below.

Nooksack Mainstem

The mainstem of the Nooksack River is the largest source of water to the estuary. It fills all distributary and side channels, and routes the greatest discharge to the nearshore. The Nooksack mainstem flows through all estuarine landscape types and is predominately diked agricultural land. But downstream of Marine Drive, the lower two river miles flow through a forested zone before reaching scrub shrub with younger vegetation and finally, a small band of salt marsh. The mainstem, along with incoming tides, is the most important source of cool water to the estuary during the warm summer months.

To gain an understanding of long-term trends in mainstem water temperature, LNR staff reviewed thirty years of daily water temperature data recorded by the Public Utility District No. 1 of Whatcom County (PUD) in the mainstem near Ferndale. While it was not the PUD's intent to study the effects of temperature on salmon, the data are useful for trend analysis. The records specify that the temperature in the mainstem at the head of the estuary so far does not exceed the juvenile chinook salmon upper incipient lethal temperature of 24°C. Their thirty-year record indicates that the highest temperature in the water column of the mainstem twice met the sub-lethal condition of 20°C. Ninety-eight percent of samples taken between December and August, the juvenile estuarine migration period, remained below 18°C. This migration period was determined by smolt trap and beach seine data collected between 1994 and 2004. On the basis of these data, we conclude that the mainstem river channel temperature falls within the ideal range for juvenile rearing year round, and does not threaten or stress salmonids migrating through the mainstem channel in the estuary.

A real-time temperature study using remote sensing to measure the surface temperature of the Nooksack River was conducted in August 2002 (Watershed Sciences 2002). Figure 23 displays a longitudinal profile of mainstem Nooksack River surface water temperatures (y axis) collected during the Watershed Science 2002 study graphed against River Mile (x axis). This study concluded that in the summer, the surface temperature cools downstream of the confluence of the North and South Forks, and remains cool over much of its length, warming slightly immediately upstream of the estuary. During this study period the entire length of the mainstem remained within the optimal temperature range for juvenile rearing.

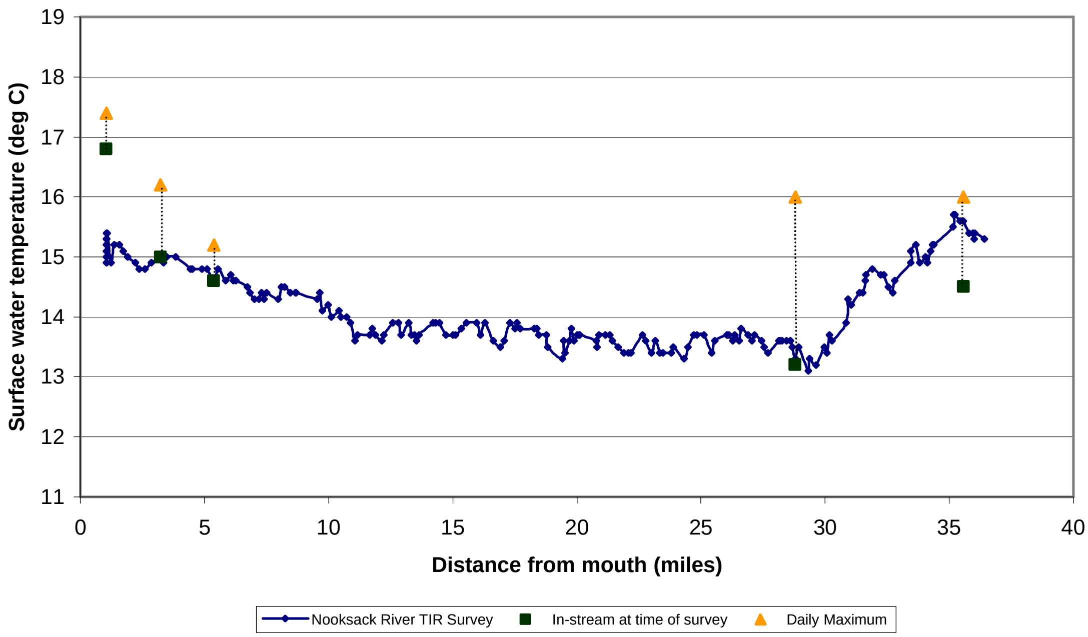


Figure 23. Longitudinal profile of thermal infrared-derived surface water temperatures of the Nooksack River during an August 21, 2002 flight.

How do these riverine temperature compare to those in the estuary? To monitor water temperature in specific fish habitats of the Nooksack River estuary and nearshore, LNR installed 10 temperature recorders throughout the estuary in January 2003 (Figure 24). Each data logger recorded hourly water temperature to ensure tidal trends, if applicable, were detectable. They were submerged to the benthic surface of each site, with the exception of a nearshore site that monitored sub-surface temperatures. The loggers were protected from any UV radiation influence on temperature by their placement either inside a perforated white PVC protective case that allows water to pass through it, or inside the hollow cavity of a cinder block anchor. Initial launching occurred in January 2003, and has remained continuous through December 2004, producing two full years of temperature data in the estuary.

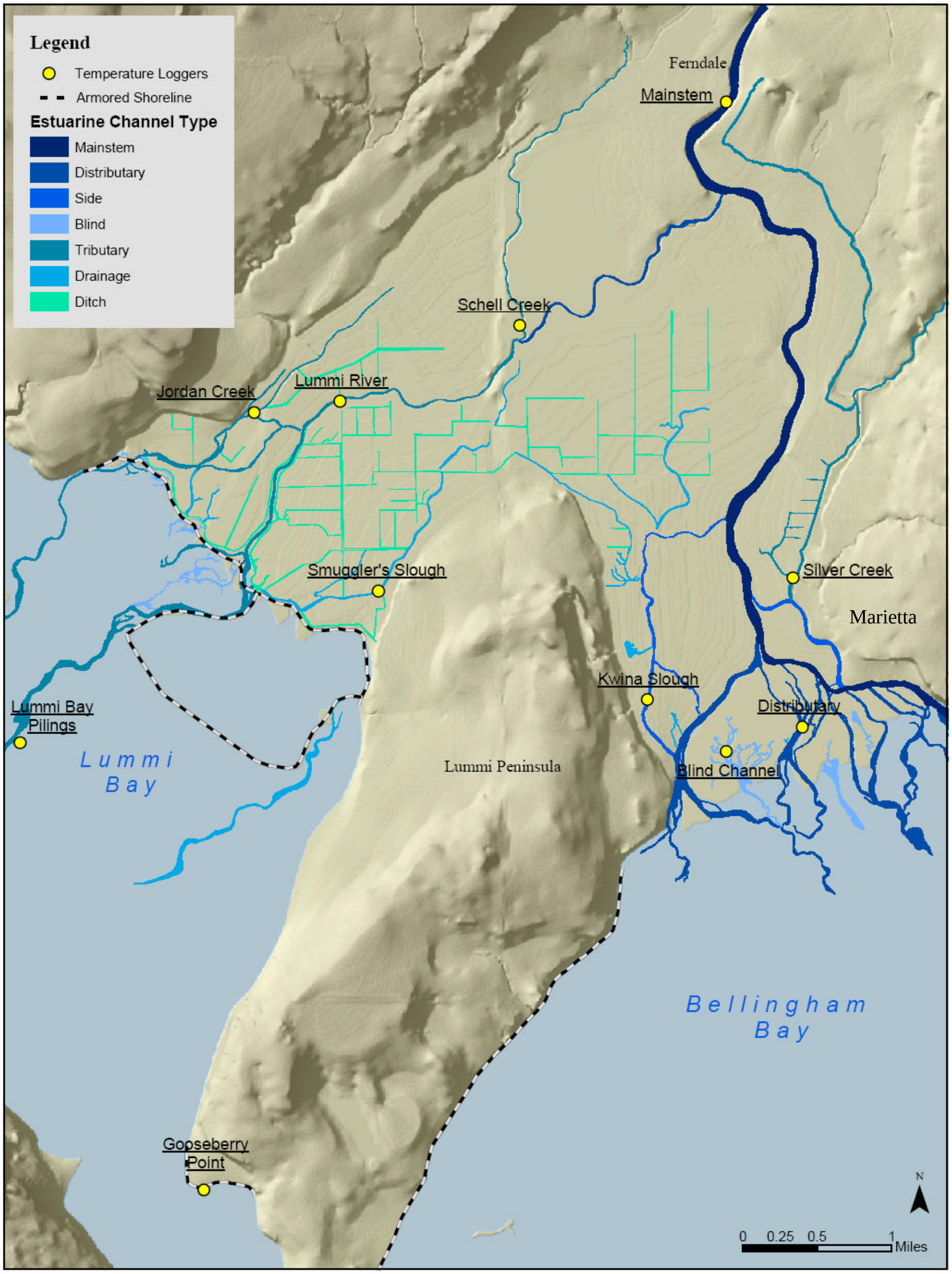


Figure 24. Lummi Natural Resources temperature probe locations.

Lummi River

The Lummi River channel is the main tidal channel connection between the upper estuary floodplain and the Lummi delta. The data from the temperature probe placed at the Lummi River site reflects a dynamic thermal regime that is influenced by Schell Creek, intermittent Nooksack River flow and unimpeded tidal flow from Lummi Bay. The habitat type is characterized as tributary because the channel primarily acts as the downstream extent of Schell Creek.

Daily maximums in the Lummi River lingered below 18°C through March and early April in both 2003 and 2004; however, temperatures markedly increased in May of both years, when temperatures reached nearly 23°C in 2003, and 26°C in 2004 (Figure 25). The lack of cold Nooksack spillage into the Lummi River channel, combined with the influence of Schell Creek discharge on Lummi River water temperatures, is the probable cause for this increase. Average water temperatures drop after the summer months, usually after the migratory period, and remain low until next summer.

Juveniles may access the Lummi River tidal channel after nearshore migration around Gooseberry Point into Lummi Bay. Releases from the Lummi Nation Hatchery in Lummi Bay occur during May, when temperatures rapidly approach lethal limits. Fish use of this habitat is believed to be limited by these high temperatures between mid-May and September.

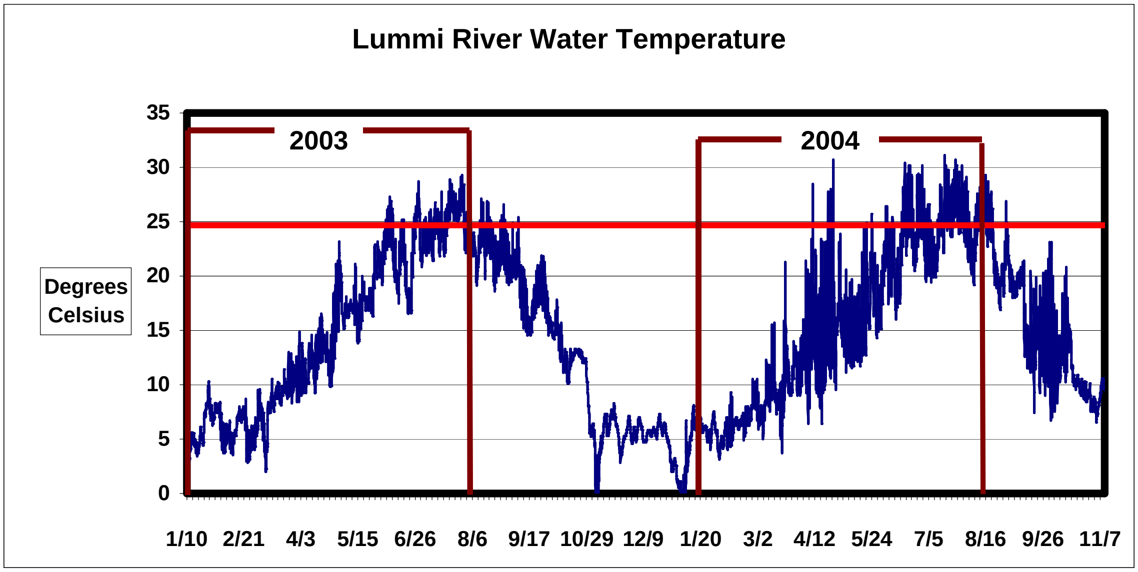


Figure 25. Lummi River water temperature under Hillaire Road Bridge, approximately 1.6 RM from the mouth. Red crossbar at 24°C represents the upper incipient lethal temperature for chinook salmon (Brett 1952). The 2003 and 2004 outmigration periods are delineated for reference.

Kwina Slough

Kwina Slough is a freshwater side channel of the Nooksack mainstem that is subjected to saline intrusion regularly at least as far upstream as the location of the data logger (Figure 26). Average water temperatures logged during the outmigration period were well below the sub-lethal limit of 18°C. The average Kwina Slough water temperatures in July and August of 2003 approach the 18°C limit, but do not meet or surpass it. The water temperatures in the middle channel scrub-shrub distributary and the Kwina Slough side channel are not significantly different between January and May 2003 ($p < 0.05$). Daily maximums (2004) at the Kwina Slough site remained under the sub-lethal limit through June, but through July temperatures increased significantly, and peaked at 28°C on July 31. Temperatures remained between 18°C and 24°C through mid-August, and fell below the sub-lethal limit on the 23rd. Kwina Slough temperatures remained cool thereafter. The average monthly and the daily maximum temperatures in 2004 did not significantly differ from those in 2003 ($p < 0.05$). While Kwina Slough is heavily influenced by the flow of the Nooksack River during high discharge events, a line of pilings at its head likely impacts its connectivity during the low flow period. We conclude that Kwina Slough water temperature is not a limiting factor to salmonid production early in the migratory period, but may critically impact survival after June, more than halfway through the migration.

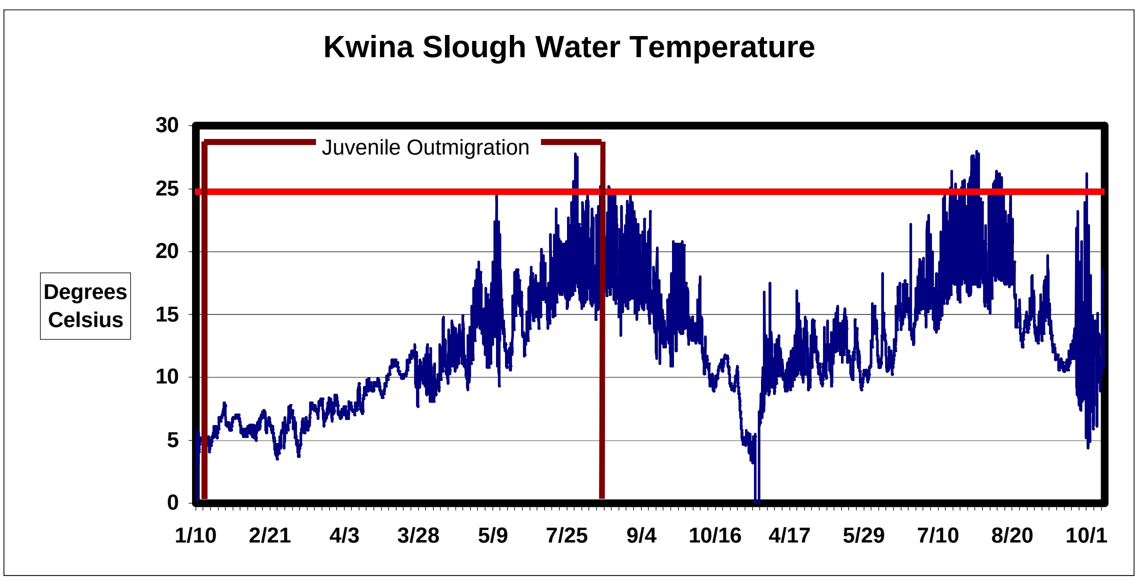


Figure 26. Year-round water temperature in the Kwina Slough side channel. The red line at 24° C marks the upper incipient lethal temperature for chinook salmon (Brett 1952).

Silver Creek/Marietta Slough

Of the three tributary streams in the Nooksack River estuary, Silver Creek provides the strongest cool water influence on migrating juvenile salmonids. Silver Creek is the longest tributary to the Nooksack River estuary. Its floodplain is subjected to agricultural land use before it enters the estuarine floodplain. Upon entrance to the estuary, its right bank remains dominated by agriculture, but its left bank riparian vegetation is intact. The trees and shrubs on this bank effectively shade the channel. Marietta Slough is a relict tidal channel that was disconnected from the mainstem when it was diked and drained for agriculture in the 1930's. The riparian zone of Silver Creek above its entrance to the estuary is developed primarily by agricultural and rural residential activities; however, the channel that drains through the floodplain is heavily shaded. Revegetation of the riparian zones of both channels is in progress, and anticipated to positively influence water temperatures in the future.

This data logger site is located at the mouth of Silver Creek, just below the Marietta Slough confluence. The site is not subject to saltwater intrusion. Temperatures during most of the outmigration period, December through June, are well below sub-lethal 18°C (Figure 27). The average high temperature in July, the hottest water temperature month of the migratory phase, was 18.4°C. Remaining monthly temperatures in Silver Creek were consistently lower than the other tributaries.

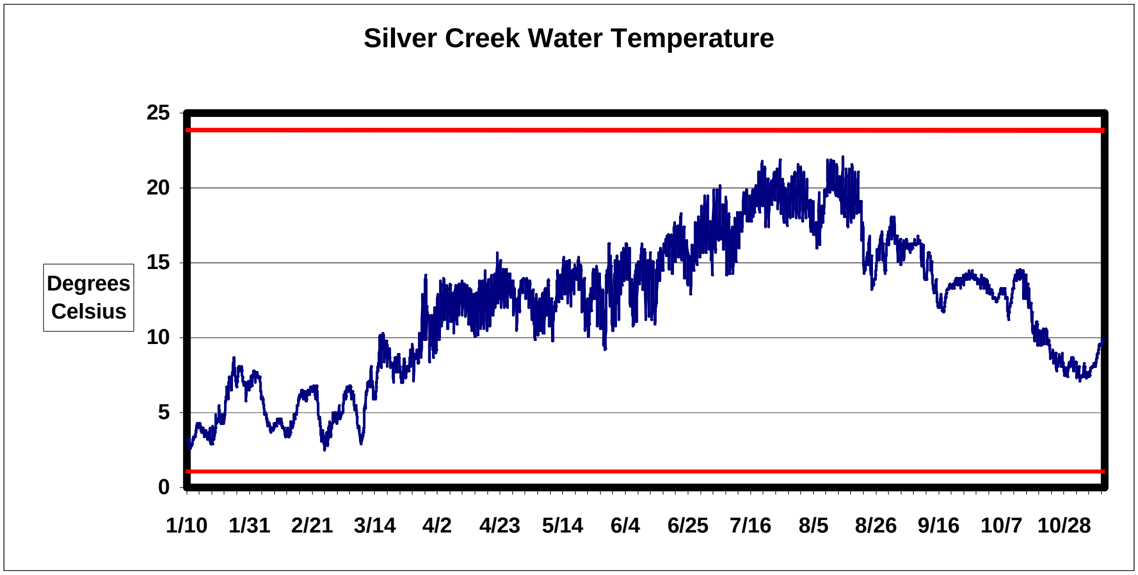


Figure 27. Benthic surface temperature of Silver Creek at the Marine Drive Bridge in 2003 and 2004 combined. Red lines at 24° C and 1° C mark the upper and lower incipient lethal temperatures, respectively, for chinook salmon (Brett 1952).

<u>Smuggler's Slough</u>

This channel was once a historic slough connecting Lummi Delta to the Nooksack Delta. It served as a major transportation route around the north end of the Lummi Peninsula between the Lummi Delta and the Nooksack River in the early 1800s. Sedimentation of the channel prohibited this use around 1870 (Wahl 2001). It is now an independent drainage channel that routes flow bi-directionally with the tides through flapper tidegates at both the Lummi Delta and at Kwina Slough. Its riparian zone is intermittently vegetated with several large trees and shrubs, but reed canary grass and blackberries dominate the banks of this slow-flowing channel. Temperatures at the data logger site were not influenced by incoming marine water.

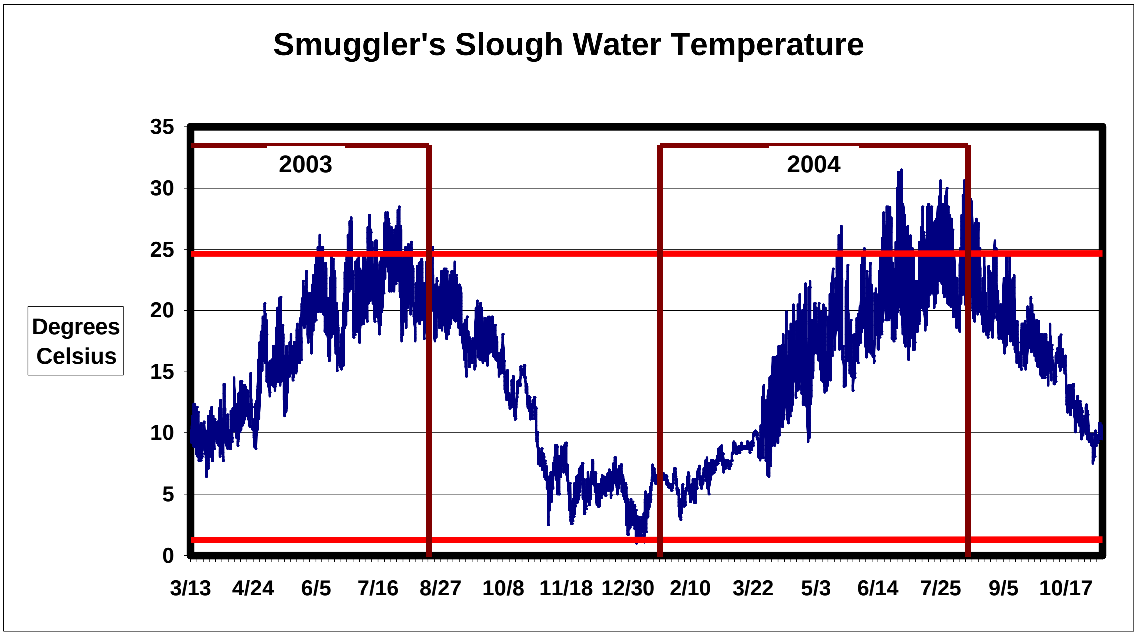


Figure 28. Benthic surface temperature near the mouth behind the Lummi Delta seawall, for the drainage channel Smuggler's Slough. Brackets designate the juvenile salmonid outmigration period for each year analyzed. Red lines at 24° C and 1° C mark the upper and lower incipient lethal temperatures, respectively, for chinook salmon (Brett 1952).

Similar to conditions observed in Schell Creek, Smuggler's Slough maintained ideal temperatures below the upper incipient sub-lethal 18°C during five of the nine months of the estuarine migratory period of juvenile salmon (Figure 28). Average temperatures in June, July, and August were above this limit, but remained below the lethal limit of 24°C.

<u>Nooksack Delta West Blind Channel</u>
This is a well-developed blind channel in the western side of the Nooksack Delta salt marsh landscape that has formed as a result of 70 years of sediment deposition into one of two active zones on the front. This channel is exclusively tidal, but maintains scour and channel-forming energy by routing salt marsh drainage through its complex network of feeder channels.

This blind channel in the Nooksack Delta maintains daily maximum temperatures below 18°C between December and mid-May (Figure 29). The diurnal tidal prism that flows across the Nooksack Delta affects water temperature in the blind channel. Incoming tides in the summer act to cool high temperatures and maintain critical habitat for juvenile salmonids using the channel to feed, hide and rest. However, average water temperatures in the blind channel meet or exceed the sub-lethal limit during the months of June, July, and August, when cooler tides are out during the heat of the day. By this later period of outmigration, most juvenile salmonids have smolted and left the delta habitats for nearshore. This temperature data can be considered representative of two smaller blind channels on the Nooksack Delta that provide comparable cover and nutrients.

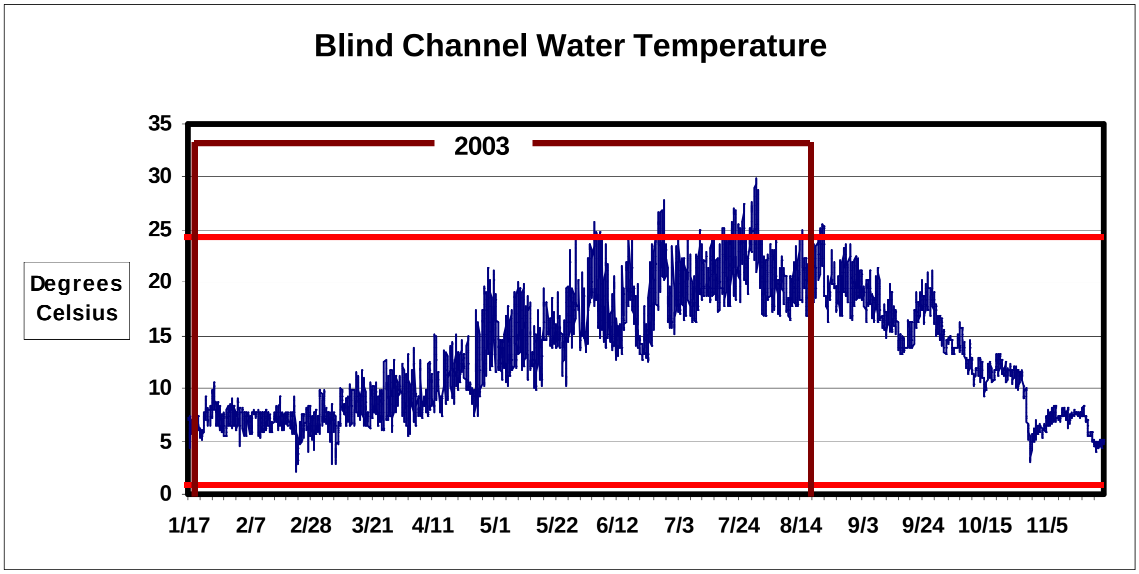


Figure 29. Benthic surface temperature in the West Blind Channel on the Nooksack Delta. The bracket designates the juvenile salmonid delta and nearshore period for 2003; data in 2004 were not downloaded before equipment disappeared.

<u>Gooseberry Point Nearshore</u>

This data logging site is located in the intertidal nearshore zone of Gooseberry Point, an exposed shoreline habitat on the southern end of the Lummi Peninsula. Water quality and general habitat conditions at this nearshore monitoring site are representative of those found at other nearshore sites in the area. The logger is attached to the underside of a floating dock submerged one foot below the surface shielded from direct UV radiation.

This nearshore site maintains the coolest water temperatures year round in the estuary study area (Figure 30). The highest recorded temperature at the Gooseberry site was 21°C on July 25, 2004; it hit this high and remained near 20°C for several hours before dropping back below a sub-lethal temperature.

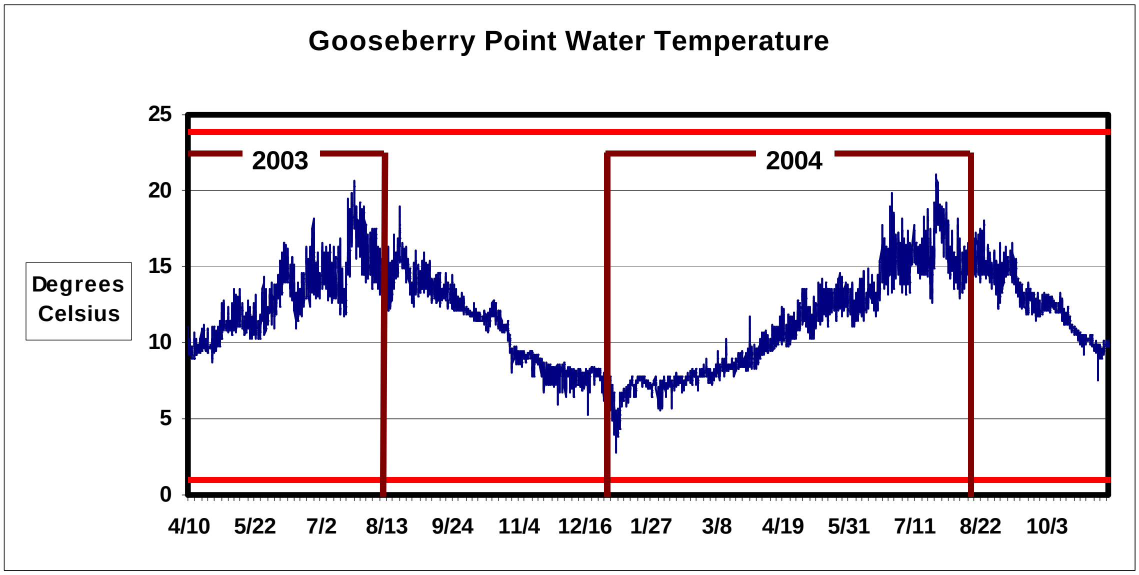


Figure 30. Water column temperature, one-foot below the surface of the nearshore at Gooseberry Point gas dock. The brackets designate juvenile salmonid delta and nearshore period for 2003 and 2004. Red lines at 24° C and 1° C mark the upper and lower incipient lethal temperatures, respectively, for chinook salmon (Brett 1952).

<u>Jordan Creek</u>

Jordan Creek is a tributary that drains March Point highlands and flows through excellent forest habitat before it enters the Lummi Bay estuarine floodplain. Its channel in the lowland floodplain flows through actively farmed pasturelands with little native riparian vegetation. There is a natural anadromous fish barrier at the edge of the floodplain boundary that prevents juvenile salmon from utilizing sections of this stream that maintain clean gravels, woody debris and a wide, thick riparian zone. The presence of this canopy upstream of the monitoring site cools water temperatures in the reach, keeping them lower than temperatures seen in other tributaries in the early months of the estuary migratory period.

Jordan Creek's water temperatures are maintained well below the upper incipient lethal limit of 24°C during much of the salmonid outmigration phase; however, maximum daily temperatures found in June, July, and August hover at or above the lethal limit of 24°C (Figure 31).

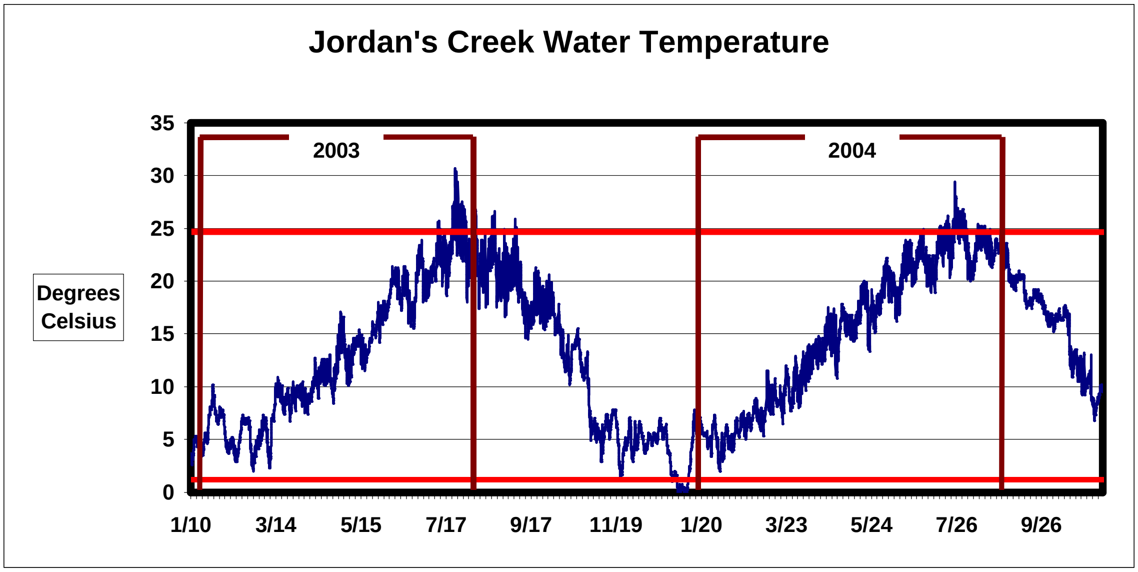


Figure 31. Benthic surface temperature of Jordan Creek at the North Red River Road. Brackets designate the juvenile salmonid outmigration period for each year analyzed. Red lines at 24° C and 1° C mark the upper and lower incipient lethal temperatures, respectively, for chinook salmon (Brett 1952).

Schell Creek

Schell Creek is a tributary that flows year round into the Lummi River at RM 3.1. Schell Creek is the primary contributor of discharge to the Lummi River.
The headwaters of Schell Creek originate in and around the city of Ferndale, above the Nooksack River floodplain. The channel drops down into the floodplain where it drains and impacted by heavy agriculture activity. Recent riparian restoration projects have restored native forest and scrub shrub vegetation along several large sections. Water quality measurements at this site have not revealed substantial salinity, but we are unsure at this point whether the marine water influences water temperature here.

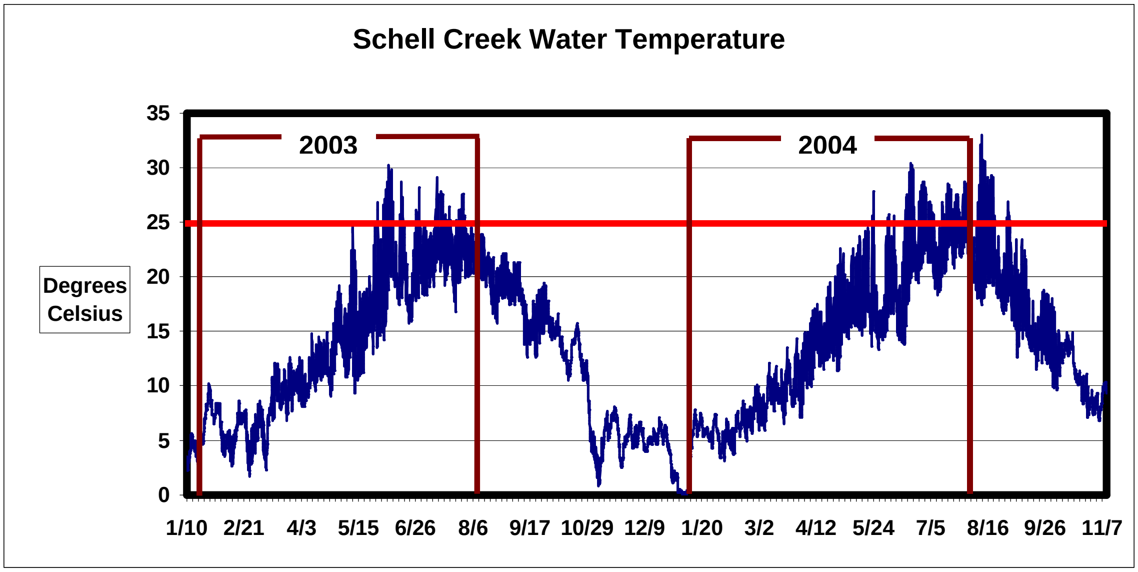


Figure 32. Schell Creek water temperature near the confluence with the Lummi River. Red crossbar at 25°C represents the upper incipient lethal temperature for chinook salmon (Brett 1952). The 2003 and 2004 outmigration periods are delineated for reference.

Nooksack River juvenile salmonid use of Schell Creek is limited by the lack of direct access between the Nooksack River and the Lummi River after May.
Schell creek temperatures spike above the chinook salmon lethal limit between May and August (Figure 32). Average daily maximum temperatures June through August in both years exhibited highs above 30°C. Before May, temperatures in Schell Creek are ideal for all juvenile salmonid rearing; after May, the stream is too hot to ensure survival. Natal coho and chum rear in Schell Creek, and are likely to leave the stream before the onset of high temperatures in May.

Lummi Delta pilings

This site is in the Lummi River channel of the Lummi Bay tide flat near the intertidal-subtidal interface. This temperature probe was placed in a protected nearshore environment. Water quality here is saline, although the Lummi River may dilute salt concentrations during high discharge periods. This channel maintains consistently cool water temperatures between tidal cycles year round, and serves migrating juvenile salmonids with an eelgrass bed in a functional corridor between delta and nearshore habitats. This logger has recorded water temperature of tide flat habitat for 700 days without interruption (Figure 33).

Between December and June we recorded daily maximum temperatures consistently below the 18°C sub-lethal temperature limit. Water temperatures thereafter changed with ambient air temperature. The daily maximums recorded during the summer months coincide with low tides during the heat of the day. Water temperatures at this site cooled with the incoming tides. Tidal channel habitat accessible from this site in the Lummi Delta does not offer refuge from high water temperatures in the summer, due to elevated temperatures in the Lummi River, the only viable tidal channel here. Therefore, it is assumed that fish will migrate out to cooler waters and back in with the tides.

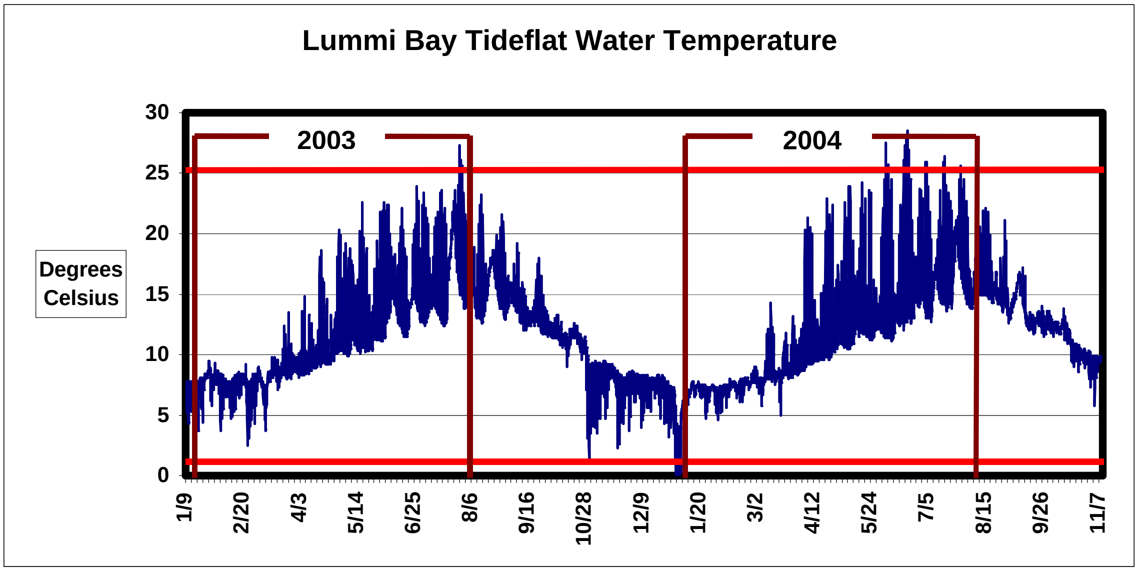


Figure 33. Benthic surface temperature on the Lummi Bay tide flat. The brackets designate juvenile salmonid delta and nearshore period for 2003 and 2004. Red lines at 24° C and 1° C mark the upper and lower incipient lethal temperatures, respectively, for chinook salmon (Brett 1952).

In summary, water temperatures in the Nooksack estuary during the juvenile salmonid migration period vary temporally and spatially following seasonal patterns. The best temperatures for salmon to effectively rest, feed and grow occur in winter and spring juvenile outmigration periods. Channels that were strongly influenced by the mainstem Nooksack River or saltwater maintained lower temperature water into the summer months. These moderating influences appear to beneficially impact migrating, rearing and transitioning juvenile salmon.

We assume that periods of high temperature in various potential habitats render them seasonably unsuitable for juvenile salmon. Fortunately, many of the salmon species that use the Nooksack River estuary for early smoltification, such as chinook, chum (*O. keta*), and pink (*O. gorbuscha*) fry migrants, do so between December and May.

During the warmest months of the migratory period, only the mainstem Nooksack River, its distributaries, and the nearshore environments maintain temperatures below sub-lethal limits. To ensure survival through summer months (June, July, and August), migrating salmon must reside in one of these three habitats. This selective migration may effectively limit juvenile residency time in otherwise productive habitats.

Several historic habitat alterations have likely impacted the water temperature of floodplain distributaries and the mainstem Nooksack River. Land conversion to agriculture led to the draining of floodplain wetland complexes and an increase in unshaded stream length through ditching. This was coupled with the clearing of vegetated natural levees that had grown along many of the larger channels. Bortleson et al. (1980) indicated that as much as 80% of the Nooksack estuarine floodplain had been cleared of native vegetation, drained, and converted from forest and scrub-shrub wetlands to agriculture. This loss of wetlands probably reduced summer outflow from floodplain complexes, which likely would have given the mainstem even a greater influence on estuarine water temperature. The subsequent loss of riparian cover throughout the watershed likely increased the summer water temperature in smaller tributaries and reduced their ability to provide high quality water to the estuary.

Water withdrawal from rivers for agricultural irrigation and urban/industrial use results in less river volume. A diminishment of cool water in the channel influences estuarine water temperature. This reduction in river flow volume can lead to higher maximum water temperatures in the summer. Water discharges from industrial and agricultural facilities also can add heated water to streams. These changes in the natural temperature regime of the river can have cumulative impacts on the water quality of the estuary.

Water temperature in the estuary varies daily with amount of freshwater discharge and marine influence. The sources of cooler water to the estuary change through the year. During the spring and early summer, floodplain tributaries contribute substantial cool water to estuarine channels. As tributaries experience low summer flow, their ability to provide cool water rearing habitat is reduced and other sources become increasingly important. During the warmer summer months, mainstem flow and tides provide cooler water to side channels, distributaries, and channels directly open to saltwater intrusion. These habitats act as potential summer refuge for rearing and transitioning juvenile salmon.

Smaller floodplain tributaries such as Jordan Creek, Schell Creek and Silver Creek provide flow to sloughs and distributary channels and their water quality heavily influences the water quality downstream. Intermittent sloughs seasonally distribute mainstem water across the floodplain. These channels, such as Smuggler's Slough and the Lummi River can provide important water quality benefits while they are active, although during low flow they provide little cool water benefit to salmon. When disconnected from the river, these channels maintain flow by routing groundwater or drainage ditches, but they lack the cooling influence of the mainstem flows that often prevents water from approaching lethal and sub-lethal temperatures.

Channels that do not receive direct river flow, such as blind and tributary channels, reflect different water quality characteristics than those that do. The effect of Marine water moving up into the estuary along the benthic surface moderates the water temperature in the channel, either cooling or warming the channel depending on the season. During the winter months, freshwater flowing downstream is usually colder than its marine counterpart; in the summer, the incoming tide often cools the freshwater component in channels that experience lower flows. Temperature probes deployed in areas affected by both fresh and salt water in the delta collected data that support this.

Economic development of the estuary has affected the ability of the tidal prism to cool channel habitats. For example, the seawall dike built across the Lummi delta front prevents tidal exchange from penetrating estuarine channels and cooling those habitats with warm summer temperatures, or preventing freeze-over during cold periods in the winter. The water quality in these disconnected channels largely unaffected by incoming tides.

Salinity

Salinity is another primary water quality characteristic that defines anadromous salmonid residency in the estuary. Salinity concentrations influence salmonid migration through the estuary. Variable concentrations of salts and other nutrients allow juveniles to adjust their osmoregulation (adapt from freshwater biological processes to salt water processes) and complete the smoltification process into marine fish. During smoltification, freshwater juvenile chinook are exposed to salinities that increase as they move further out of the river and into nearshore habitats. As they adapt to the nearshore environment, salmon often move in and out of the estuary, following tolerable salinity concentrations with the movement of the tide. It is believed that gradual adaptation to increased salinities promotes successful transition and survival to the adult life stage.

Immediately upon emergence, chinook fry typically migrate downstream, taking up residence in the river estuary, particularly if water quality is brackish, to feed and rear there to smolt size (Healey 1998). Although many chinook fry appear unable to survive immediate transfer to 30 ppt salinity, they are clearly able to survive transfer to 20 ppt or less, and osmoregulatory capability develops quickly in fry abruptly exposed to intermediate salinities (Weisbart 1968, Wagner et al. 1969, Clark and Shelbourn 1985, cited in Healey 1998). As chinook fry migrate to the estuary, they may remain in the low salinity or even freshwater areas for some time until they develop further. However, some chinook fry appear to move immediately to the outer edges and higher salinity portions of the estuary (Levings 1982).

Salmon smolts leaving delta habitats will commonly utilize the freshwater lens that sits on top of heavier saline water when river discharge is significant. This lens allows young fish to feed and use aquatic vegetation for cover in the marine environment before they are fully adapted to seawater regulation. Stratified fresh water floating on top of salt water is common in Bellingham Bay near the mouth of the river where significant fresh water is discharged from the Nooksack River.

The mouths of the Nooksack and Lummi Rivers are defined as salt wedge estuaries. Salt wedge estuaries occur when the mouth of a river flows directly into salt water. The circulation is controlled by river discharge that pushes back the seawater (Figure 34). The water within the salt wedge is denser than fresh water; therefore, it moves up into the estuary along the benthic surface of tidal channels. This creates a sharp boundary that separates an upper, less salty layer from an intruding wedge-shaped salty bottom layer (USEPA 2003). The salt wedge that moves in and up the Nooksack and Lummi Rivers from Bellingham and Lummi Bays, respectively, contributes to the definition of salinity concentrations here.

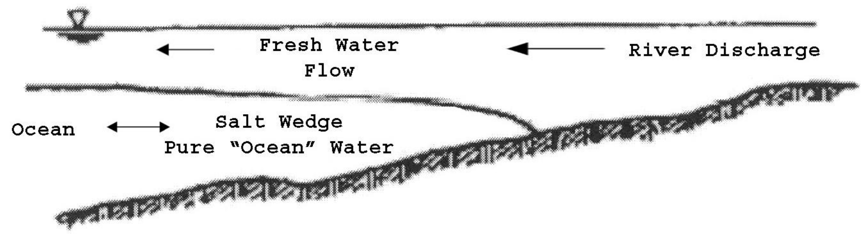


Figure 34. The salt wedge estuary. The high flow rate of the river holds back the lesser flow of salt water. Low river flows allow further penetration of the salt water (From USEPA 2001).

Saltwater intrusion into estuarine channels is critical for providing diverse transitional habitat for juvenile salmon. The further upstream the saltwater can penetrate, the greater the number of habitat types that the fish will be able to use for transitioning to saltwater. In the case of the Nooksack River estuary, the maximum extent of the freshwater-saltwater interface includes side channel, distributary, and main channel habitat types through the sand flat, salt marsh, scrub shrub and forested floodplain habitat types. Currently, the greatest saltwater penetration occurs on the Lummi River delta, where reduced freshwater flow creates over 3 miles of tidally influenced transitional area in the Lummi River channel. Other channels on this delta, such as Smuggler's Slough and the N. Red River distributary of the Lummi River, have the potential to provide freshwater-saltwater transitional habitat, but fish passage into them has been blocked by tidegates and levees.

The extent to which the salt wedge moves up into estuarine channels depends on two environmental factors: river discharge and tide height. River discharge, measured in the Nooksack estuary by USGS in cubic feet per second (cfs), acts as a force pushing against the tidal prism moving up into the estuary. Tide height, measured in feet, also affects the penetration capacity of the salt wedge into the estuary. During periods of low flow and high tide, the saline layer may move up into the estuary extensively (Figure 34). The current extent of the salt wedge's influence on estuarine water quality was physically measured and mapped in the Nooksack delta between January and March, 2004. During periods that combined events of high tide and low river discharge, LNR crews measured salinity both at the water's surface and within the salt wedge at the bottom of the channel. The following figure shows the upper extent of salt wedge influence as determined in that sampling.

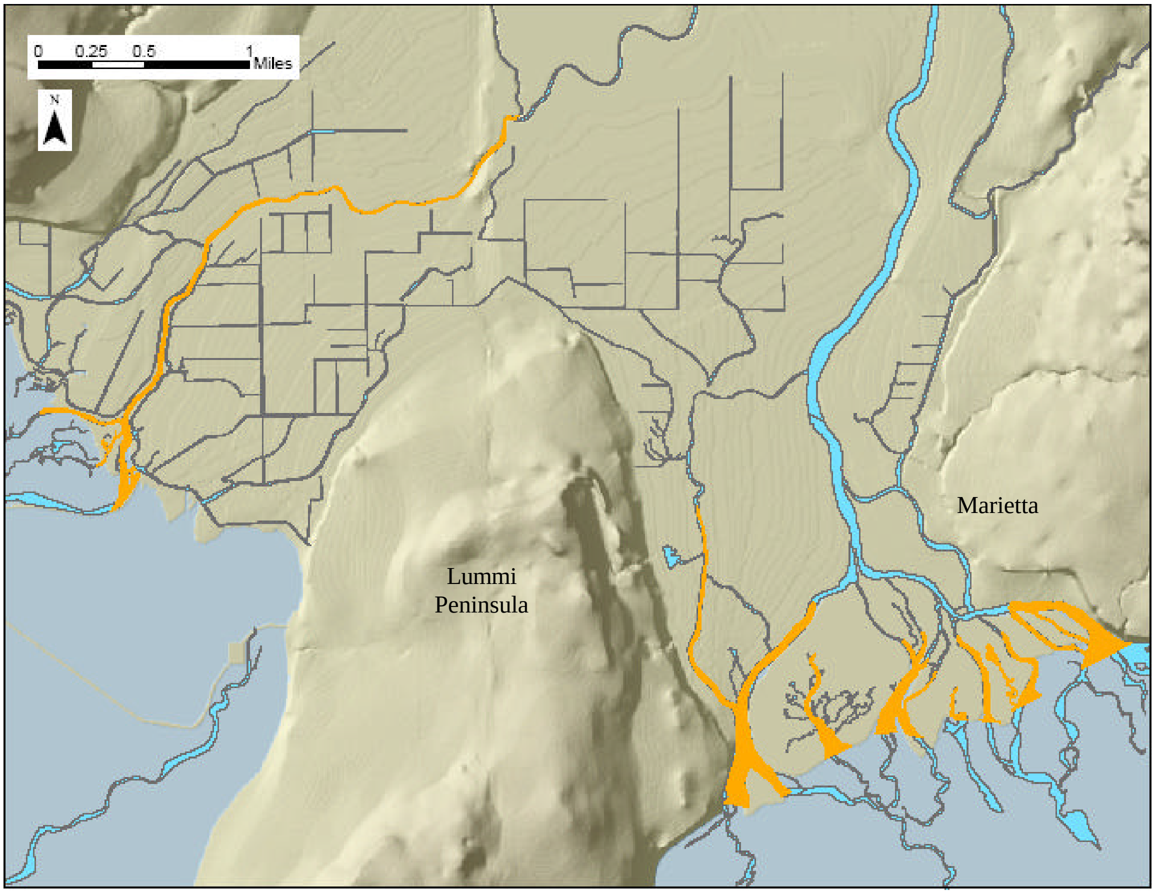


Figure 35. The Nooksack River estuary, its channels (in blue), with the observed extent of the salt wedge (in orange).

Anecdotal evidence, as well as aerial photo interpretation, indicates that the salt wedge's influence within the estuary once reached as far reaching upriver as the present-day location of Marine Drive bridge on the Nooksack's mainstem.

The growth of the Nooksack Delta front has reduced the salt wedge's intrusion capacity over the last 50 years. As the delta has extensively prograded toward Bellingham Bay and increased the size of the tide flat at the delta front, the extent of the salt wedge up river channels has decreased. However, several prominent rearing channels in the Nooksack Delta, as well as the Lummi River and Schell Creek are inundated with salt water during these events. In the mainstem channel, the salt wedge's influence rarely extends beyond the salt marsh vegetation zone near the mouth, approximately 2.5 RM downstream from the Marine Drive bridge; however, salt water intrusion is evident up the distributary channels off of the Nooksack mainstem, including the West Channel. It extends up the Kwina Slough side channel approximately 1.1 RM from its confluence with the West Channel (Figure 35). The salt wedge migrates up the Lummi River channel just past the mouth of Schell Creek at RM 3.4. The extent of this intrusion reiterates the influence that channel discharge has on salt wedge penetration. Discharge in the Lummi River channel is considerably less than it is in the Nooksack River and its distributaries; therefore, the salt wedge travels a greater distance up into the estuary via this channel than it does on the Nooksack Delta side.

Differences in salinity determine and are reflected in the species composition of plant and animal communities (Cowardin et al. 1979). A result, differing plant communities are maintained by salt marsh processes on the Lummi and Nooksack Deltas. Low discharge into Lummi Bay has resulted in the decreased dilution of the salt wedge that shapes salt marsh vegetation distribution on the Lummi Delta. Plant assemblages on this delta are very salt-tolerant, and attract invertebrates with similar water quality needs. Plants on the Lummi Delta salt marsh are low-growing and hardy, to withstand high salinities. The salt marsh plant communities in the Nooksack Delta, on the other hand, are brackish; they thrive in an area constantly diluted by high flows down the Nooksack River. This delta is dominated by grasses and sedges that grow tall in the summer and shade smaller tidal channels there. The plant community that has developed here attracts invertebrate families that differ from those in the Lummi Delta. Insects utilize various areas of the salt marsh, depending on how well they can withstand the drier conditions of the upper marsh or the wetter, saltier conditions that regularly occur in the lower marsh.

The freshwater discharge from the Nooksack River impacts the salinity of Bellingham Bay and its nearshore. The depth of the less saline surface waters in Bellingham Bay primarily depends on the volume of Nooksack River flows. Observations made after a period of discharge averaging 5,500 cubic feet per second (cfs) showed the salinity threshold of salinity at 26 ppt at depth of less than 6.5 feet (Collias et al.1966). Observations made after a larger discharge, averaging 6,800 cfs, showed the entire bay to Post Point covered with a 6.5 ft. layer of brackish water at 5 ppt (Collias et al. 1966). This event pushed the 26 ppt isohaline down to 36 ft. Samples taken in September 1961, when the discharge was a minimum 1,600 cfs revealed no distinguishable surface layer, with the 26 ppt isohaline within the 9.8 feet of the surface.

The upper and lower layers tend to be stratified strongest during high freshwater run-off between spring and early summer, and weakly stratified (if at all) during periods of small freshwater runoff. The distribution and depth of the surface layer is also dependent on wind speed, direction, and duration. A period of constantly high winds with strong gusts can blow patches of freshwater into regions where surface salinities are significantly different, causing spatial heterogeneity. South-blowing winds can cause deepening of less saline surface layers in the south end of the bay, while north-blowing winds can isolate the brackish water in the north end, causing higher surface salinities in the southern end. Freshwater residence in Region I (north of Post Point and Eliza Island) averages about 4 days, with a typical residence between 1-10 days (Collias et al. 1966).

The influence of salt water on delta landscapes may not be limited to direct contact with or inundation by brackish or salt water. Soil salinity may also be influenced through tidal prism percolation into groundwater. To assess potential presence of salt in the delta landscapes through groundwater mixing with, groundwater in the Lummi Delta was seasonally tested for temperature and salinity. Summer testing commenced when low tides on the delta were observed, June through August 2003. Winter testing commenced during high tides on the Lummi Delta, December 2003 through January 2004. The objectives of measuring groundwater near the Lummi Delta were threefold: 1) to test for marine influence on existing groundwater characteristics, 2) to establish baseline data to assist planning restoration projects in the initial stages, and to 3) accommodate monitoring efforts if restoration opportunities are realized. The data led us to conclude that there were saline influences on the landscape beyond that of the tidal salt wedge and that baseline soil salinity at potential restoration sites would need to be evaluated. See Appendix A for a more detailed review of the study methods and data.

Fecal Coliform

Fecal coliform bacteria indicate the likely presence of water-borne pathogenic bacteria or viruses, including E. coli. They are present in the intestinal tracts of all warm-blooded animals, including humans. Humans coming into contact with fecals can contract dangerous diseases. The main sources of fecal coliform are wastewater treatment facility discharges, failing septic systems, and animal waste.

Water quality is not directly impacted by fecals; however, their presence is often used as an indicator of wastes that are high in nitrogen. Increased levels of nitrogen promote algal blooms that require oxygen to survive. These blooms, often occurring during warmer weather, deplete oxygen when rising temperatures are naturally reducing dissolved oxygen levels in the water. Limited dissolved oxygen has detrimental impacts on fish respiration, plant function, and aquatic invertebrate survival. Plant and insect health is key to the survival of salmon, as they provide important shelter and food resources.

Fecal coliform tests performed on samples taken from the Nooksack River, estuary, Bellingham Bay, and nearshore areas have yielded high counts in the past, and many sampling sites remain problematic today. High counts of coliform are considered an indicator of a bacterial threat to human health from shellfish consumptions (DOE 2002). High fecal levels have been responsible for the closure of several shellfish beds in Portage Bay near the south end of the Lummi Peninsula to commercial harvest. These shellfish bed closures have a direct, substantial effect on the economic security and the health and welfare of the Lummi Nation and its members. Shellfish harvesting in Portage Bay has been a significant commercial, subsistence, and ceremonial activity for the Lummi Nation as part of its traditional culture. The reduction of fecal coliform levels in the Nooksack River is a common goal among conservation groups and natural resource managers.

Estuarine Habitat Characterization

Estuarine habitat is defined by channel and landscape types within a river's tidally-influenced floodplain. Salmon reside in aquatic habitat (channels) in the estuary, but are influenced by landscapes adjacent to channels. Estuarine floodplain landscapes, although not inhabited by salmon, are similarly important to the function of channel habitat. Stream and tidal channel attributes are shaped and maintained primarily by slope, hydrology, and sediment.

Landscapes are formed by geomorphology and defined by vegetation, which is defined by hydrology and water quality. Among the estuary landscapes are forested wetlands, scrub-shrub and salt marsh. Each landscape type uniquely affects channel function. Floodplain landscapes contribute nutrients, debris, and insects to channel habitats, and provide a variety of shading opportunities as well.

Vegetation species diversity within the estuary provides fish and other foraging organisms with a variety of insects available for their diets. Overhanging canopy vegetation, mostly red alder, willow species, and large shrubs supports terrestrial insect communities. The insects may enter estuarine channel habitat by wind drift or by falling out of trees and onto the water's surface. Herbaceous vegetation common in salt marshes provides structural habitat for both terrestrial and aquatic organisms that become available to foraging organisms such as salmonids.

Estuarine habitat assemblages are distributed along geomorphic, salinity, and exposure/energy gradients in the Nooksack lowlands. Vegetation (or the lack of as in the case of some delta tide flats) is often used as an indicator of topographic gradient in the estuary. The lowest topographic elevations in the estuary are subject to inundation by the highest concentrations of saline water as the tidal prism moves in from the sea, and are described as the areas too saline to support marsh vegetation. The result is the estuary's tide flat, a congregation of sediment packed into an expansive plain that may or may not support vegetation. Eelgrass is the most common plant found in tide flat habitat, thriving in protected, low energy environments. As the tidal salt wedge moves up the mouth of the river and into its lower channels, mixing with freshwater occurs. This lowers the salinity of the water column and the adjacent land with elevations higher than the tide flat. Salt marsh plants usually establish here, in accordance with their salinity tolerances. Distinct bands of vegetation move up the channels, paralleling the shoreline, a result of the change in topography and extent of saline influences.

Characterization of historic conditions can facilitate the creation of restoration models that favor the restoration of natural habitat forming and creation and maintenance processes. Although most Puget Sound estuaries have been cleared, drained, and developed for agriculture or urban use (Bortleson 1980), the Nooksack River delta retains most of its lower estuary habitat and vegetation in an undisturbed state. The lower river habitat in the active Nooksack Delta is developing as the delta progrades toward Bellingham Bay. The mouth of the mainstem was spared from dike and culvert building, and has been allowed to avulse through the delta since its arrival there in the mid 1800s. This natural progression of habitat construction has resulted in excellent conditions for juvenile salmon rearing at the front of the delta.

In contrast to the Nooksack River delta is the Lummi River delta. It has been disjoined from the sea by a permanent seawall with tidegates, and its floodplain disjoined from the channel by permanent levees. It was cleared of its native vegetation for agriculture in the 1800s. It has remained 'frozen' in its geographic location, neither growing nor retreating inland, featuring minimal but biologically significant high salt marsh habitat maintained by the Lummi River, Smuggler's Slough, and Lummi Bay.

The diking projects that commenced in the lower river in the 1920s developed profound effects on natural processes that form estuarine habitat here (Figure 36). The disconnection of the river and its distributaries from the floodplain has channelized the mainstem, disconnected many side channels, and routed the head of the Lummi River through a culvert that is impassable to most flows, sediment and woody debris. Upon construction of these dikes, habitats in the estuary were no longer capable of evolving as they had in the past under more natural processes.

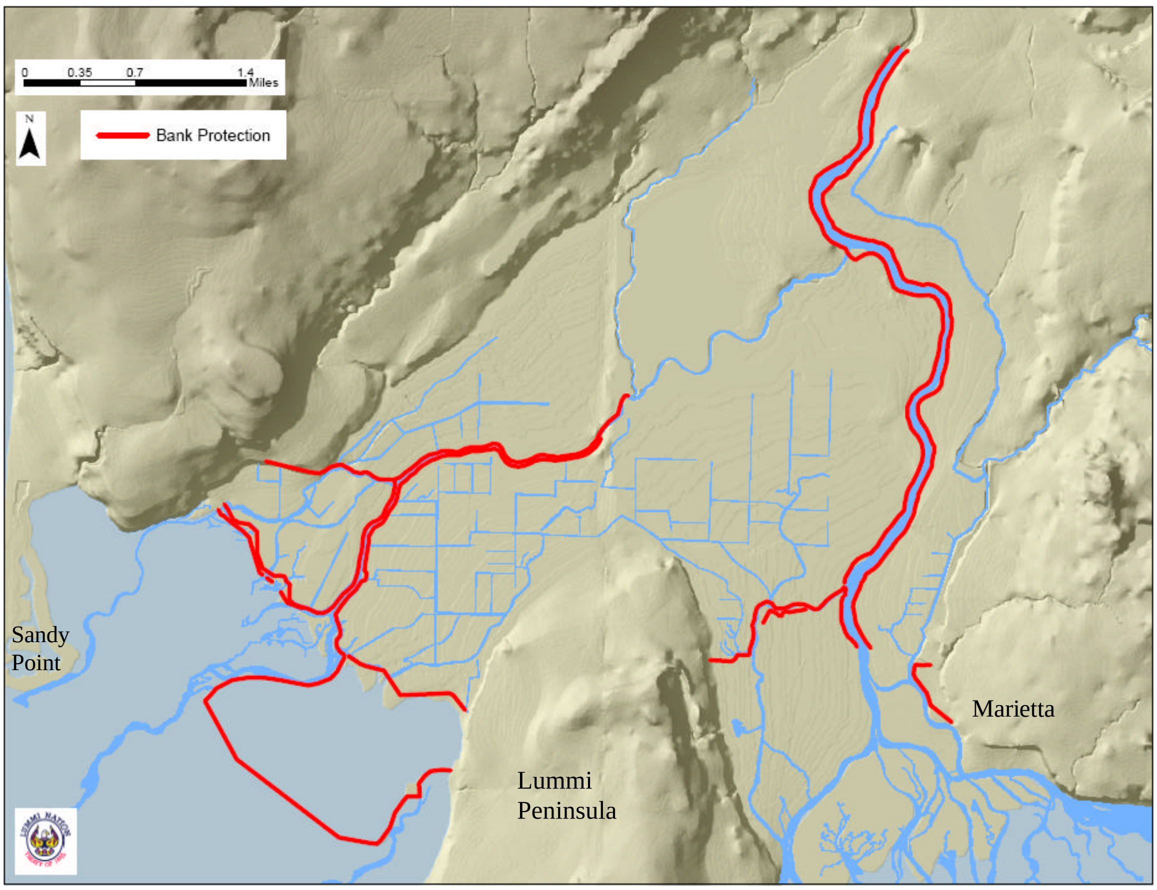


Figure 36. Bank and delta protection in the 2004 Nooksack estuary.

To compare historic to current habitat distribution, estuarine channel area was calculated from polygons digitized from historic maps and aerial photos in GIS. Our intent was to track the movement and alteration of river channels through the lower floodplain as habitat developed.

The comparison process was hampered by discrepancies in scope, resolution, and extent among our various maps and photo sources. The maps and photos used for this study reflect the best available information and our best efforts to reconcile these inherent discrepancies. The coverages produced from a set of orthorectified aerial photos flown in 2004 are the most accurate representation of conditions in the estuary, due to the opportunity of field-truthing habitats on site. Conditions not immediately recognizable on the 2004 photos were visited in the field, classified by GPS, and recorded by LNR field crews; similar conditions arising from older media could not be remedied, and were classified using best efforts. Estuarine channel habitat typing was done using the same methods described above for terrestrial habitat coverages. The areas calculated for each type of channel between 1887 and 2004 are estimates, limited by the lack of precision in the 1887 representation, and the presence of overhanging vegetation along river banks in the aerial photos. Not all land cover types characterized were detectable for each of the three years analyzed, and not all of the estuarine floodplain/nearshore was included in the extent of the maps and/or photos used.

In the Nooksack estuary (Figures 37 and 38), the tide flat band lies at the front of the delta, nearest the sea. It is devoid of significant vegetation. The salt marsh vegetation band establishes adjacent to the tide flat, followed by a band of scrub-shrub. Scrub-shrub vegetation usually consists of low-growing (under 10 m), freshwater/brackish shrubs and trees that can tolerate occasional salt spray. Forested wetlands, the well-established band of vegetation adjacent to the scrub-shrub vegetation, do not usually come into contact with saline water, and are protected from the salt wedge moving up the estuarine channels by a lens of freshwater at the surface. Natural levees on the banks of channels support different freshwater species because their elevations are higher than the floodplain. Less salt-tolerant species are found here, and from the figure below, it is evident that more mature forest vegetation has developed along the banks of distributary channels, on the tops of natural channel levees.

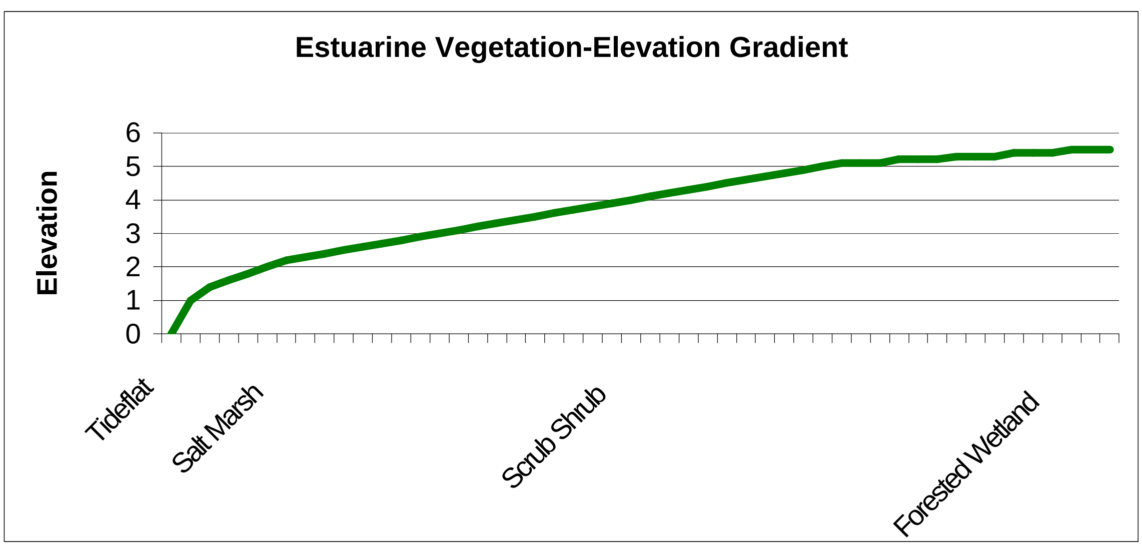


Figure 37. Relative stuarine vegetation distribution gradient by topographic elevation.

Figure 38. 2004 aerial photo depicting landscape habitat distribution on the Nooksack Delta, during a 5.2-foot tide.

Landscape Habitat Types

Agricultural Floodplain

The agricultural floodplain landscape describes areas of the estuary that once supported riverine, lacustrine, and palustrine wetlands, but is now used for crop and livestock rearing. It did not exist prior to 1860; however, today it is a significant land cover in the lower and estuarine Nooksack floodplains.

Although the estuarine floodplain of the Nooksack River did not serve large-scale farming interests of indigenous peoples prior to the 1850s, Euro-American settlers actively cleared 80% of the land for such uses (Bortleson 1980). This agricultural landscape still dominates the estuary today; it comprises 65% of the floodplain in the Nooksack River's entire estuarine drainage basin. The agriculturally influenced areas of the estuary floodplain once supported a mature forest, wetland marsh and scrub-shrub within this basin.

The upper estuary's wetlands once maintained a diverse community of native hardwoods and shrubs, as well as dozens of herbs, grasses, and ferns. This diverse matrix of native vegetation supported the natural development of salmon habitat, nourishing the food web, recruiting large wood and providing shade during summer months. Today, most of this land is used for agricultural purposes, primarily crop and livestock production.

Historic scrub-shrub and forested wetlands in the Nooksack estuarine floodplain were slowly cleared and converted to agriculture with the development of drainage ditches, beginning in the late 1800s. By the 1930s, dikes and levees were in full operation across the delta in Lummi Bay, and along the mainstem of the Nooksack River. The disruption of natural floodplain processes such as sediment and nutrient deposition from the river resulted in the transport and deposition of these materials downstream of the dikes, and eventual floodplain compaction. Large areas of the floodplain, no longer recharged by floods, dried out and became habitat for livestock, crops and invasive species.

Unplanted fields left for grazing or fallowing were eventually invaded by reed canary grass (*Phalaris arundinacea*). This grass was introduced to the Nooksack lowlands in the early 1900s by farmers seeking a reliable, cheap, and easy crop to feed their livestock. Harrison et al. (1996) found in Schoth (1929) that most of the reed canary grass fields in the Pacific region can be traced to a seedling produced in 1895 in Coos County, Oregon.

This invasive has become an aggressive, difficult to control species that alters hydrology and disrupts biological and chemical processes within aquatic habitats. Reed canary grass forms dense, highly productive single species stands that pose a major threat to many wetland ecosystems. The species grows so vigorously that it is able to inhibit and eliminate competing species (Apfelbaum and Sams 1987). It usually grows and dominates as a monoculture (Harrison et al. 1996). In addition, areas that have existed as Reed canary grass monocultures for extended periods may have seed banks that are devoid of native species (Apfelbaum and Sams 1987). This invasive species falls extremely short in replacing the role of native hardwoods and shrubs in the development of salmon habitat. It chokes small streams, impeding flow and fish passage, does not recruit insects or wood for the estuarine food web, or provide much needed shade in the summer.

The implications of this habitat conversion are significant, and basin-wide efforts to restore areas along stream channels have been underway for several years. Since 1990, several hundred acres along riparian corridors in the estuary have been purchased for restoration by tribal, state, and federal agencies. Native tree and shrub species that once dominated the undeveloped estuary have been planted in these areas, and are beginning to replace Reed canary grass and invasive blackberry shrubs. Replacing invasive species with native species restores seed banks and reduces maintenance in vital fish habitats.

Forested Floodplain

The forested floodplain in the estuary is often referred to as forested wetland. Prior to clearing and draining land-use practices, spruce, alder and crabapple and willow dominated this landscape. Today, its species composition is similar, but much younger, with limited distribution, and largely lacking the conifer component. We find mature stands of red alder willow and cottonwood with a dense shrub understory. Although the water chemistry is predominately fresh and not subject to direct contact with saline water, this zone of the estuary bears the influence of daily changes in river surface elevation. The riverine-tidal channels that flow through this landscape have markedly steep banks, and the discharge velocity slows as the incoming tide in the tidal prism pushes water upstream from the sea. The roots, stems, and leaves of forested wetlands regulate flood flows by slowing them, thus reducing streambank and shoreline erosion (Graff and Middleton 2003). They also stabilize the natural levees formed by distributary channels as they prograde across the delta.

Overhanging vegetation nurtures insect species that drop from above into channels, providing important terrestrial food sources to aquatic predators in the channels below. Large pieces of wood from forested habitat are recruited by windfall or flood events, in turn creating high flow refugia for fish and substrate for detritus and invertebrates. Several studies cite the presence of terrestrial, riparian-derived insect species in the stomach contents of juvenile chinook (Koehler et al. 2000, Brennan et al. 2004). Juvenile salmon reside in forested, freshwater tidal channels, feeding primarily on insects before migrating further downstream into higher salinity environments (Aitkin 1998) where food items come primarily from aquatic invertebrates and fish.

The historical and current extent of forested wetlands in the combined Nooksack-Lummi deltas is described in Figure 39, below. In the 1880s, when the Nooksack estuary was smaller than it is today, it supported over 3,200 acres of forested wetlands. Today, the Nooksack Delta supports 900 acres of forest in its floodplain, mostly along channels downstream of the riverbank dikes. The successional forest that has established on the Nooksack Delta below Marine Drive Bridge is a direct result of the lack of artificial impediment presented by dikes, levees and dredging; where natural habitat-forming processes such as sediment deposition and flooding have been allowed to occur. During high discharge events, the riverine-tidal forest habitats may be inundated by floodwaters. High tide events coinciding with high discharge push freshwater back upward into the channels, facilitating floods and deposition of sediments and nutrients. During these events, sediment previously deposited on the floodplain, along with leaf litter, insects and woody debris can be carried back into channel habitat and down through the estuary as the flood recedes.

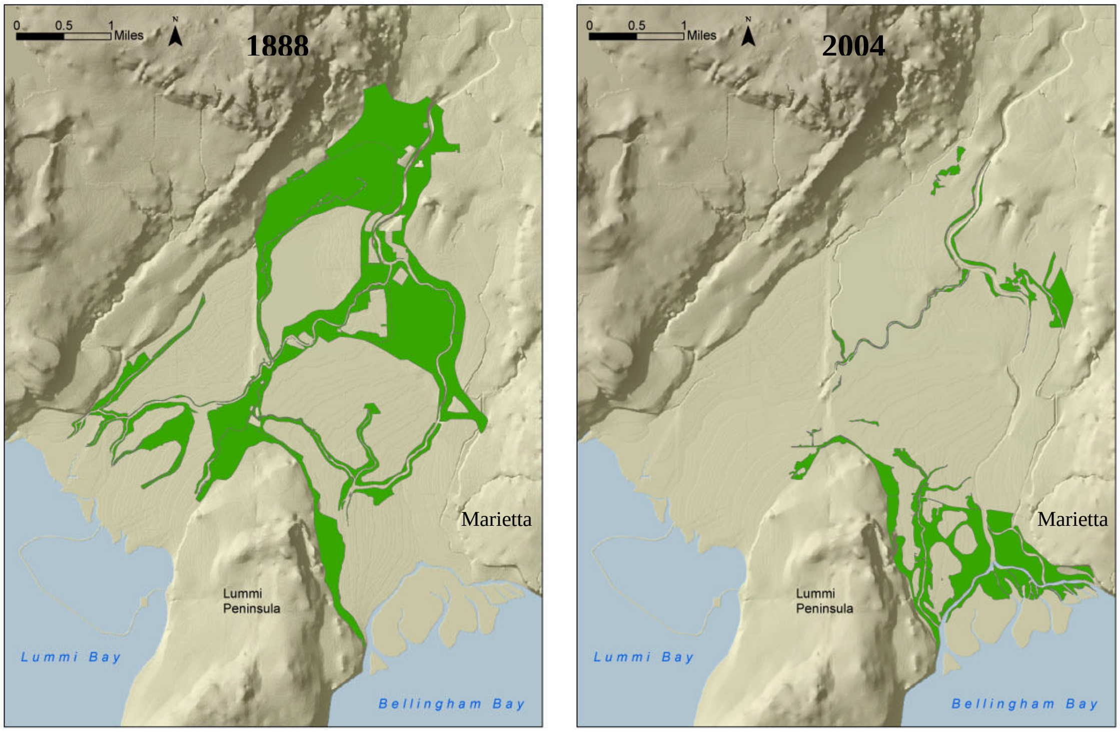


Figure 39. Maps showing the extent of wetland forests in the estuary in 1888 *(left),* and in 2004 *(right).*

The Lummi Delta maintains little more than 200 acres of forested wetlands. As the flow of the Lummi River became intermittent in the late 1800s and the threat of flood diminished behind artificial dikes, forested wetlands were cleared by settlers and converted into agriculture land. Today, the estuarine floodplain on the Lummi River side is still missing much of its historic forest, in fact, 97% of forested wetlands have been removed from the Lummi Delta since the late 1800s. In fact, only a few small patches of red alder, black cottonwood and mature willow on the banks of the Lummi River represent forested riparian zone here.

Scrub-Shrub

Scrub-shrub habitat represents wetland habitat dominated by shrubs and immature trees. It usually represents a successional stage between herbaceous cover and forested wetland habitat, but can be a stable, static community (Cowardin et al. 1979). Along delta areas in the Nooksack estuary, scrub-shrub occupies the transition zone between marine shorelines and freshwater channels, as well as the one between the aquatic shoreline and the drier upland forests. Scrub-shrub can also represent a transition in time, as red alder, willows, and sapling trees such as cottonwood are among the first plants to recolonize marginal wetlands after environmental disturbance (Michigan DNR 2004). The natural progression of herbaceous or salt marsh habitats to scrub-shrub in the Nooksack estuary is the result of the flux of the hydrology/salinity gradient between the front of the delta and mature forest habitats, periodic flooding that pulls trees from the streambank into the channel, activity by beavers that remove the more mature forest, and other landscape disturbances.

Nooksack delta scrub-shrub habitat hosts a variety of plants and animals within its open wetlands and many relict channels. The scrub-shrub landscape of the Nooksack estuary is characterized by intermittent standing water, clay-rich soils, and numerous snags. While the scrub-shrub landscape at times resembles a tangled thicket, the semi-open canopy allows considerable light to pass through. Shrub species adapted to this environment in the Nooksack estuary include clumps of red-osier dogwood (*Cornus stolonifera*), salmonberry (*Rubus parviflorus*), snowberry (*Symphoricarpos albus*), indian plum (*Oemleria cerasiformis*), twinberry (*Lonicera involucrata*), spirea (*Spiraea douglasii*), and several low-growing willow species such as Sitka willow (*Salix sitkensius*). Notable invasive species detected in the Nooksack estuary scrub-shrub habitats are Japanese knotweed (*Polygonum cuspidatum*), Himilayan blackberry (*Rubus discolor*), and reed canary grass (*P. arundinacea*).

Estuarine scrub-shrub riparian vegetation does not provide as much protective cover to fish as the forested habitats do; the young canopy does not shade channels to the extent that the more mature canopy in the older forests upland does. On the other hand, insect recruitment into the water column of estuarine channels is a significant attribute of scrub-shrub habitat; there are many flowering shrubs in this landscape that attract flying insects during the salmonid outmigration period. In the Nooksack estuary, there is an abundant supply of large woody debris on the scrub-shrub floodplain, within and on the banks of channels in scrub-shrub habitats, placed here by both downstream transport, and the deposition of logs floating in on incoming tides. This wood element is important to fish for its cover and insect recruitment characteristics.

Scrub-shrub habitats occupy a wide range of areas, providing different hydrologic functions. They function similarly to wetland habitats, and can trap sediment, control pollution, and recharge ground water. Riparian corridors, both shoreline and streambank, are lined with shrubs which hold soils in place, controlling erosion while removing nutrients from water bodies.

The growing Nooksack Delta boasts a large and clearly defined zone of scrub-shrub habitat near its front, where it transitions from salt marsh to forest. Scrub-shrub habitat is also found throughout the estuarine floodplain in patches that have revegetated with species that once existed at similar elevations. Although these areas are young, they will age and mature into an established forest as the delta grows.

Scrub-shrub habitat in the Nooksack estuary floods on a seasonal basis. It establishes at elevations slightly higher than the salt marsh, but does not usually flood with saline waters brought up by the diurnal tidal prism. Sediment deposition on the scrub-shrub floodplain is heavily influenced by flood and tide events, but is stable enough to allow the establishment of woody shrub species. The establishment of trees and shrubs, in turn, recruits more sediment deposition. Sediment characteristics in the channels of this habitat reflect lower elevations, discharge, and the tidal prism that pushes the river upstream. Discharge and flowing tides slacken here, and the vegetation, sediments, invertebrate communities and water quality display deltaic characteristics. The channels flowing through the shrub scrub habitat is where sediments settle out of the water column. Finer sediments and less mobile invertebrates establish here, large and small wood deposit on the banks of and within the channels.

Within the context of the combined Nooksack and Lummi deltas, scrub-shrub habitat has been reduced by 70% since the 1880s. In the Lummi Delta, all but a few pockets of scrub-shrub remain. Scrub-shrub habitat on the Lummi Bay side of the estuary (15% of historic coverage) is mainly concentrated at the edges of forested habitat, and is represented by immature tree species and brushy shrubs.   Figure 40 below illustrates the changes in shrub-scrub habitat extent between 1880 and 2004.

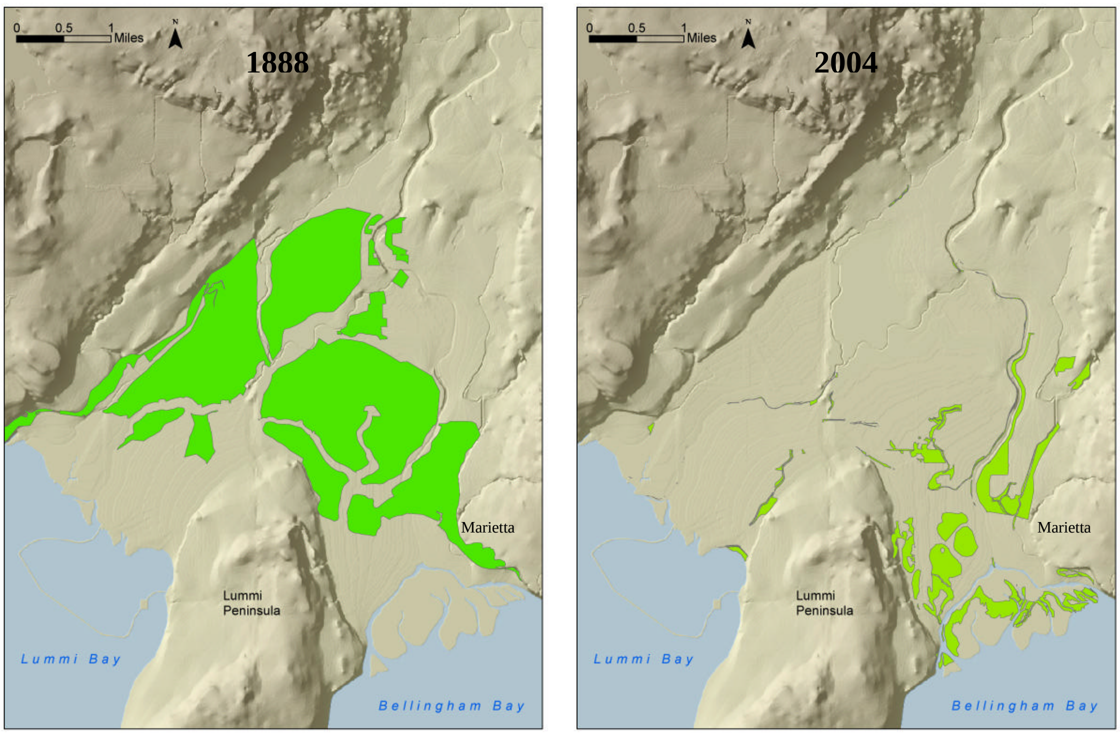


Figure 40. Maps showing the extent of scrub-shrub habitat in the estuary in 1888 *(left)*, and in 2004 *(right)*.

Freshwater Wetlands

Freshwater wetlands have a natural supply of water, either from tidal flows, runoff or groundwater sources. Marshes recharge groundwater supplies and moderate streamflow by providing water to streams. This is an especially important function during periods of drought (EPA 2003). Wetland marshes are notable in their contribution to the delta's water table and supply year-round aquatic habitat for mammals, birds, insects, and various amphibians. An important wetland habitat process that contributes to improved water quality in the estuary is the filtration of pollutants and nutrients that may harm aquatic organisms. Wetlands can clean water in two ways. Some pollutants can become trapped by wetland vegetation and stored within layers of sediment, others are transformed into less harmful forms by sunlight, wetland plants and microbes (NCCF 2000, Graff and Middleton 2003). Wetland habitats are often used for rearing by juvenile coho salmon, thereby providing an additional benefit to fish.

Wetland vegetation and microorganisms absorb excess nutrients that can otherwise pollute surface water such as nitrogen and phosphorus from fertilizer (EPA 2003). In fact, marshes are so good at cleaning polluted waters that people are now building replicas of this wetland type to treat wastewater from farms, parking lots, and small sewage plants. Because water in a wetland is shallow and exposed to sunlight, bacteria are killed before the water flushes out into other systems (NCCF 2000). According to wetland scientists, restored wetlands have lowered the fecal coliform counts to an undetectable level (Khatiwada and Polpresert 1999, ASHE 2004).

Freshwater wetland habitat found in the Nooksack and Lummi deltas is characterized by seasonal or perennial inundation. The primary vegetative species found here include reed canary grass (*P. arundinacea*), cattails (*Typha* spp.), skunk cabbage (*Lysichiton americanum*), and bulrush (*Scirpus* spp.), with nootka rose (*Rosa nutkana*) and willow (*Salix* spp.) on the fringes. Wetland marsh habitat on the Nooksack Delta characteristically includes ponds of standing water and native wetland vegetation. Beaver dams are commonly found in this lowland habitat, built along relict channels and drainage ditches to slow drainage of the ponds. Wetland marshes on the Lummi Delta are generally drier and maintain grasses. Reed canary grass is very common in freshwater wetlands on this side.

The extent of historic wetland marsh habitat in the Nooksack estuary is difficult to distinguish from maps and photos. U.S Coast and Geodetic Survey records from 1887 show 362 acres of marsh habitats while our 2004 aerial interpretation shows 799 acres of wetland marsh. Significant delta areas that were characterized as well-drained agricultural land the 1950 aerial photos have now reverted to marshland. It is certain that nearly all terrestrial habitat in the estuary, including forested and scrub-shrub habitats was frequently inundated with tides or fresh standing water. Most of the early estuary floodplain was described as wetland marsh "swamp" in historic literature and maps. Wetland marsh habitat identified and mapped in the estuary in 2004 is primarily land that was once a sink, maintained by ground and surface water, but drained, cleared, and used for agriculture. After its abandonment by farmers, it filled in with a matrix of vegetation dominated by invasive grasses and shrubs and rounded out by some native wetland species. There are several wetland habitats in the Nooksack estuary floodplain that have historically maintained natural functions, storing, filtering, and supplying water to the delta.

Emergent Salt Marsh

Emergent (salt) marshes develop as freshwater-influenced, intertidal shorelines are colonized by perennial, rooted, and herbaceous plants that vary greatly in their sensitivity to salt water concentrations (Cowardin et al.1979). Salt marsh at the front of the delta helps reduce wave energy entering the estuary by slowing and storing water. It recruits sediment and nutrients deposited as the river and tides combine and dissipate each other's energy. The salt marshes on both of the Nooksack estuary's deltas have built upon the settled sediment and nutrients brought together by the tide and streams. As water moves slowly through a marsh, sediment and pollutants settle to the substrate, or floor of the marsh.

Emergent marsh habitat is important to juvenile salmon. Estuarine fish feed heavily on a diverse diet of invertebrates and small fish in distributary channels and blind channels here. High tides pull terrestrial salt marsh insects into the water column, and small fish use tidal channels to navigate the estuary with the tidal prism. When the marsh is inundated during high tides, fish may roam the rich salt marsh plain in search of insects that inhabit vegetation. Low-flow velocities, woody debris deposition, and meandering form are characteristic of tidal channels. Fish may also benefit from various microhabitats associated with reduced current velocity and back-eddies characteristic to this environment (Macdonald et al. 1987).

Distribution of emergent marsh in the 1800s was extensive on the Lummi Delta, when the Nooksack River's outlet was Lummi Bay and tidal inundation was unrestricted (Figure 41). Salt marsh covered over 1,300 acres of the delta on this side, and dozens of miles of notable blind channel habitat was established within this landscape. Shortly after the Nooksack River diverted into Bellingham Bay in 1860, emergent marsh habitats on both deltas began to change. The small salt marsh developed at the head of Bellingham Bay by the small distributary emptying there became inundated with significant freshwater discharge from the Nooksack River. Distribution of this landscape at the young Nooksack delta in 1888 was minimal. At that time, salt marsh forming processes had not yet established a well-defined landscape.

The emergent marsh habitat on the Lummi Delta, in the absence of Nooksack River flows, became more saline. In 1883, H.B. Stewart (Wahl 2001) noted that crabapple and spruces, species normally tolerant of brackish conditions, were dying on opposite sides of the Lummi Bay delta. Stewart observed that this shift in vegetation could be attributed to increased saltwater intrusion into areas previously fed by the Nooksack River. The lack of flow from the Nooksack River has limited discharge and sediment delivery to the Lummi Delta. The current salt marsh is highly saline, and supports three primary species: saltgrass (*Distichlis spicata*), spearscale (*Atriplex patula*), and pickleweed (*Salicornia pacifica)*.

The seawall built across the Lummi delta front in the 1930's significantly reduced the size of the salt marsh plain there. The seawall blocks the tidal prism from pushing water up through nearly all of the delta's historic tidal channels. Because tidal influence in small, protected channels was eliminated, they began to fill in and compact.

In contrast to the Lummi Delta, the salt marsh on the Nooksack Delta front is comparatively brackish. There is very little saltgrass, and no evidence of pickleweed. This lower delta habitat supports species that are limited in their salt-tolerance, reflecting the highly mixed water that inundates this floodplain. Plants found on the Nooksack Delta emergent marsh include spike rush (*Eleocharis obtuse*), slough sedge (*Carex obnupta*), bulrush (*Scirpus americanus*), and cattail (*Typha latifolia*). Figure 41 below illustrates the changes in extent and distribution of emergent salt-marsh habitats between 1888 and 2004.

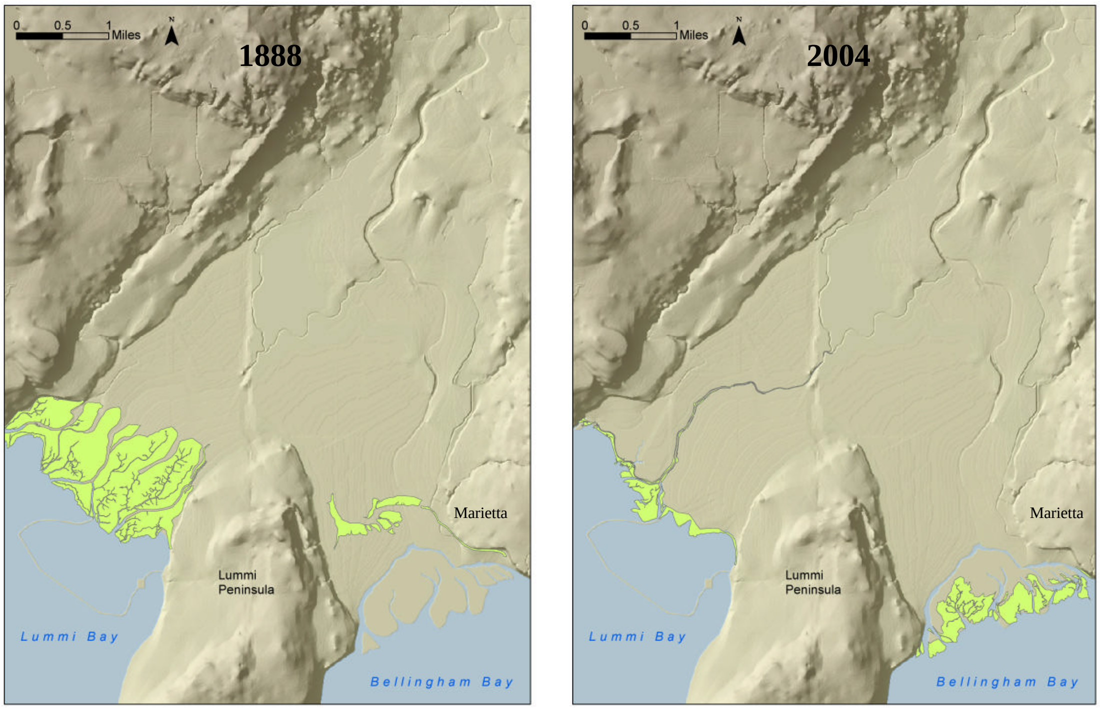


Figure 41. Maps showing the extent of salt marsh habitat in the estuary in 1888 *(left)*, and in 2004 *(right)*.

Factors influencing salt marsh vegetation distributions in the Nooksack Delta are its relatively high topographic gradients and a high volume of fresh water flows. The lowest elevation that supports salt marsh vegetation on the Nooksack Delta is 1.7 feet, the highest elevation in the salt marsh is 8.2 feet, where the vegetation is dominated by Reed canary grass. This invasive grass is a prime example of a moderately salt tolerant plant species (Hutchinson 1991) that begins to thrive as the elevation increases and the environment becomes less saline.

Emergent marsh on the current Lummi Delta is profoundly different from both the current Nooksack Delta and its historic conditions. Limited freshwater inundation of high gradient areas outside of the seawall dike has created a narrow band of highly saline marsh. An interesting attribute in the lower Lummi River has resulted from its role as the sole tidal channel on this delta. The tidal prism penetrates the Lummi River channel extensively, forming benches on the lower banks that support high-salt marsh vegetation, primarily pickleweed. The result is channel habitat that maintains high salt vegetation flanking the low, flat banks of the Lummi River; eelgrass establishment in the lower channel; and many intertidal invertebrates established on or in channel sediments.

In summary, changes in the estuarine landscape over the last 150 years are dramatic. Very little forested wetland and scrub-shrub habitat that covered the upper Lummi Delta remains today. Most of this landscape was cleared for agriculture, and has never been restored. Fields that were farmed in the past but now sit fallow have become wetland marshes, covered with some native wetland species, but predominately by Reed canary grass. Most are divided into sections by dikes and drainage ditches. In addition, the large salt marsh and tidal channels and landscapes that thrived in the Lummi Delta in 1888 disappeared after the mainstem Nooksack River was diverted to Bellingham Bay, channels were diked, large sections of the estuarine floodplain were drained, and the seawall constructed. Table 3 below summarizes changes in habitat type areas form 1888 to the present.

Table 3. Change in Nooksack terrestrial estuary habitat area 1888 - 2004.

Habitat Type		Habitat Type by Year (acres)			Net Change (acres)	
		1888 Acres	**1933 Acres**	**2004 Acres**	**1888-1933**	**1887-2004**
Lummi	Agriculture	0	4122	3258	4122	3258
	Forested	1986	264	68	-1723	-1918
	Scrub-Shrub	1945	19	323	-1926	-1621
	Salt Marsh	1220	124	156	-1096	-1064
	Tide flat	3666	2970	3840	-696	174
	Wetland Marsh	191	???	535	???	344
Nooksack	Agriculture	17	2210	2702	2193	2685
	Forested	1083	894	940	-189	-143
	Scrub-Shrub	2076	265	624	-1810	-1451
	Salt Marsh	113	274	300	161	187
	Tide flat	1469	943	2954	-526	1485
	Wetland Marsh	172	0	264	-172	92
Combined	Agriculture	17	6332	5960	6315	5943
	Forested	3069	1158	1008	-1912	-2061
	Scrub-Shrub	4020	284	948	-3736	-3072
	Salt Marsh	1333	397	456	-936	-877
	Tide flat	5136	3914	6794	-1222	1659
	Wetland Marsh	363	???	799	???	436

We compiled a history of change in delta habitat composition based on maps, reports and notes. These changes in character and use are represented in GIS format in Figures 42 and 43 below.

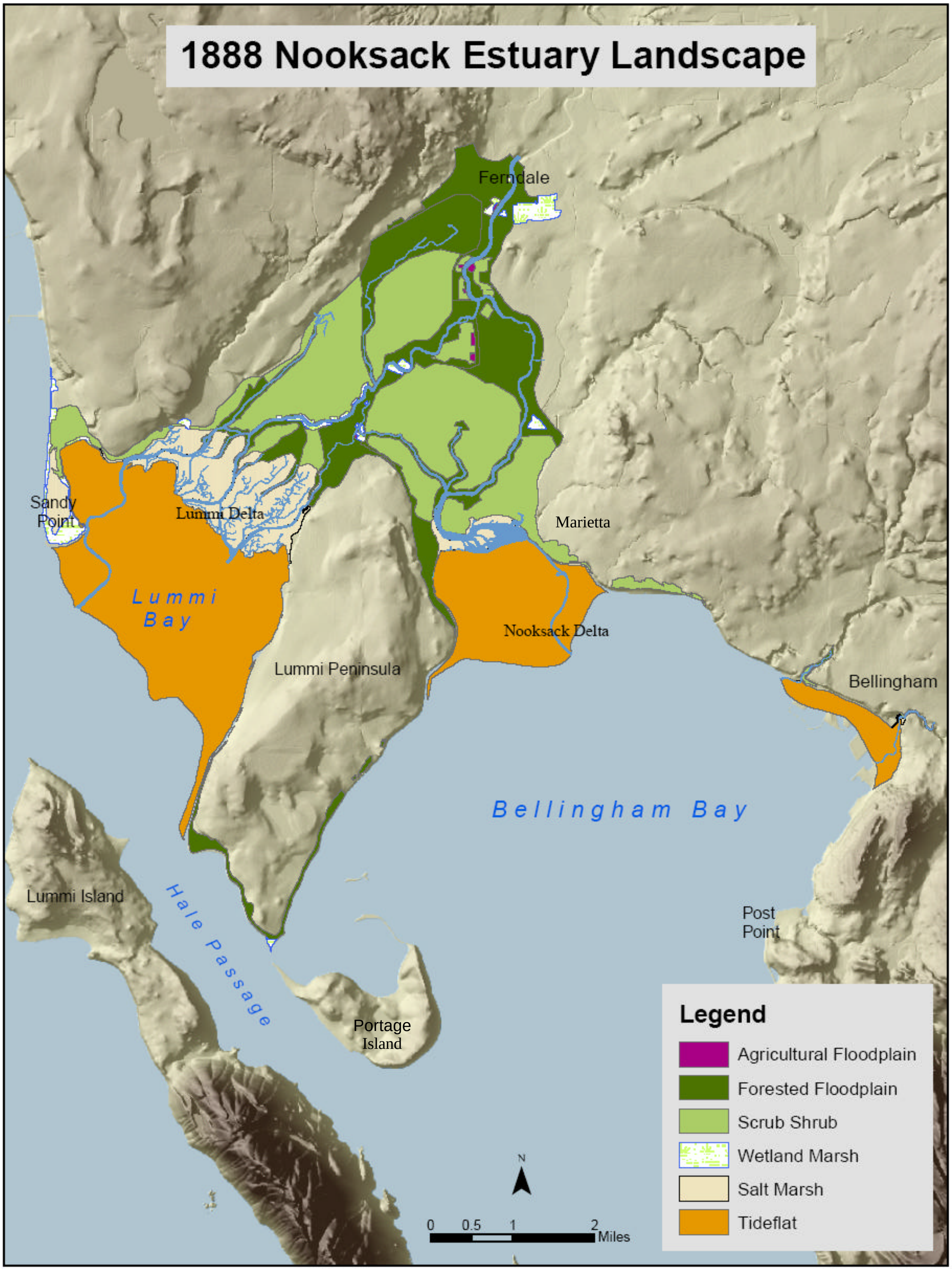


Figure 42. Estuarine landscape types in 1888.

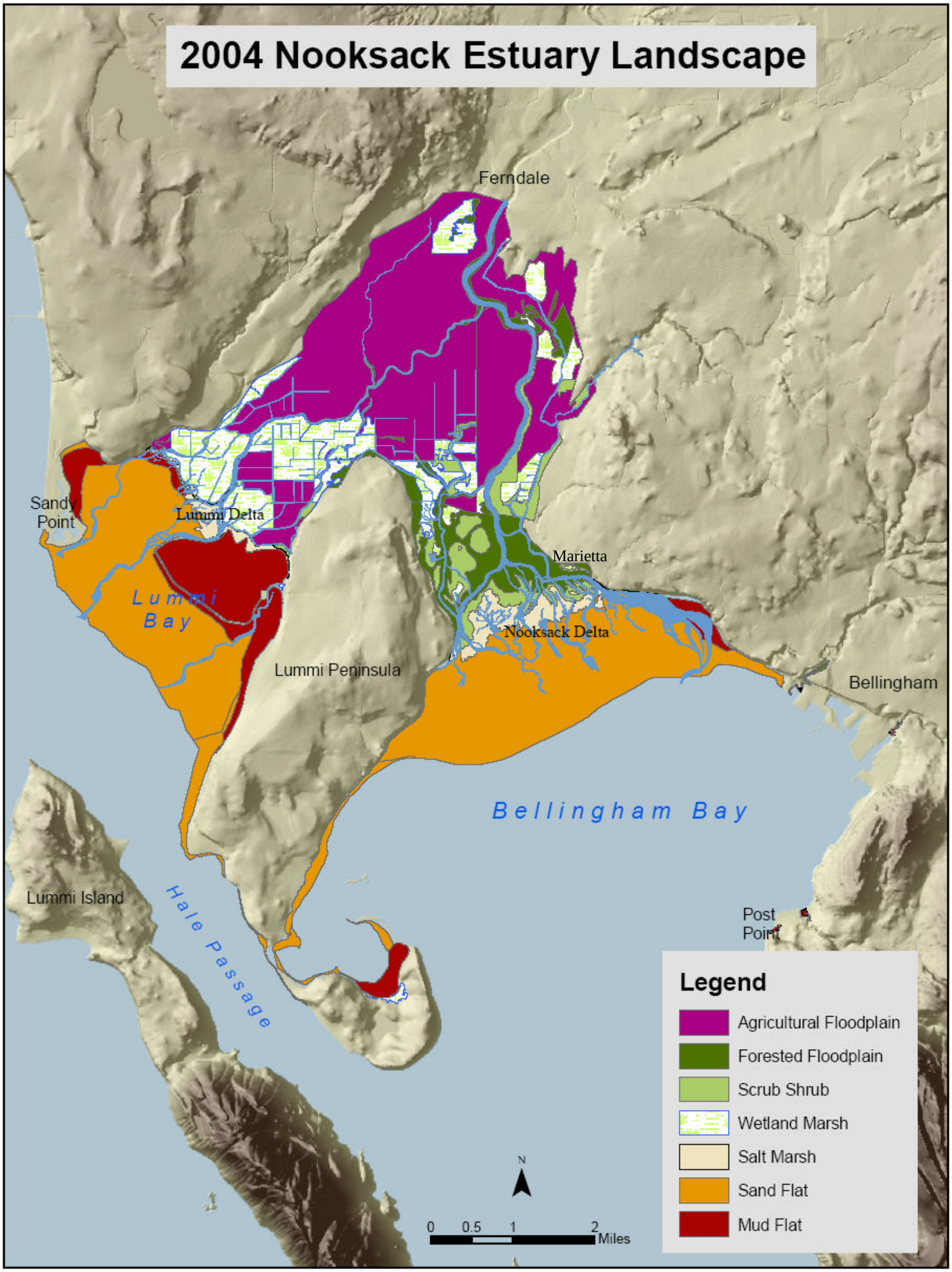
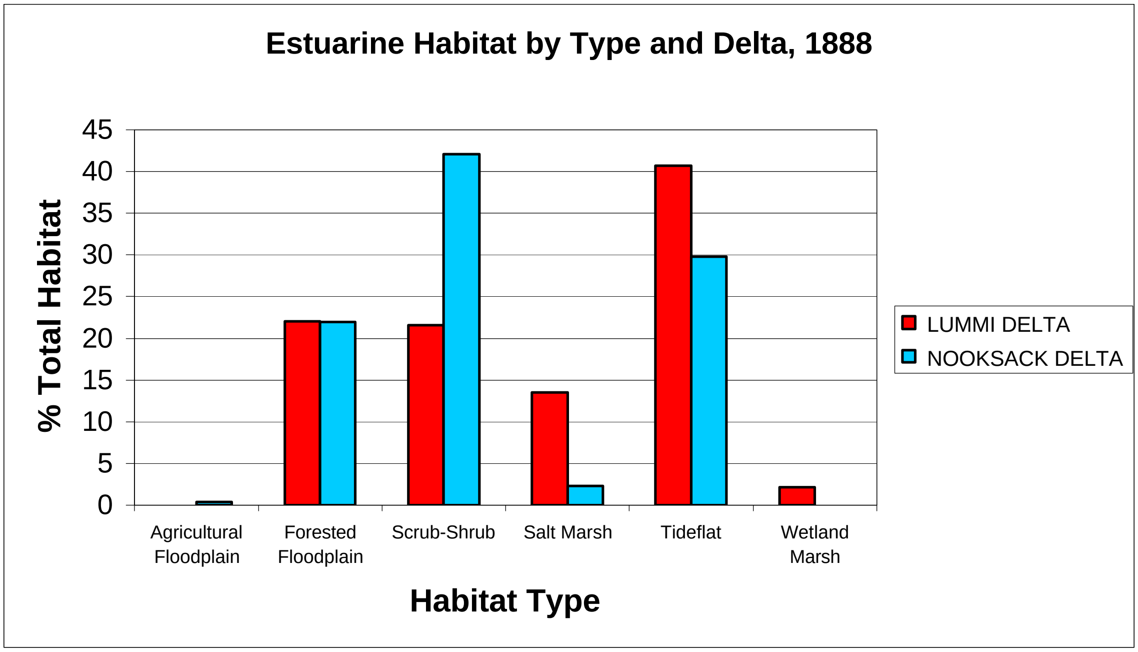


Figure 43. Estuarine landscape types mapped in 2004.

Figure 44 below describes the changes in habitat type distribution between 1888 and 2004, represented in bar graph format.



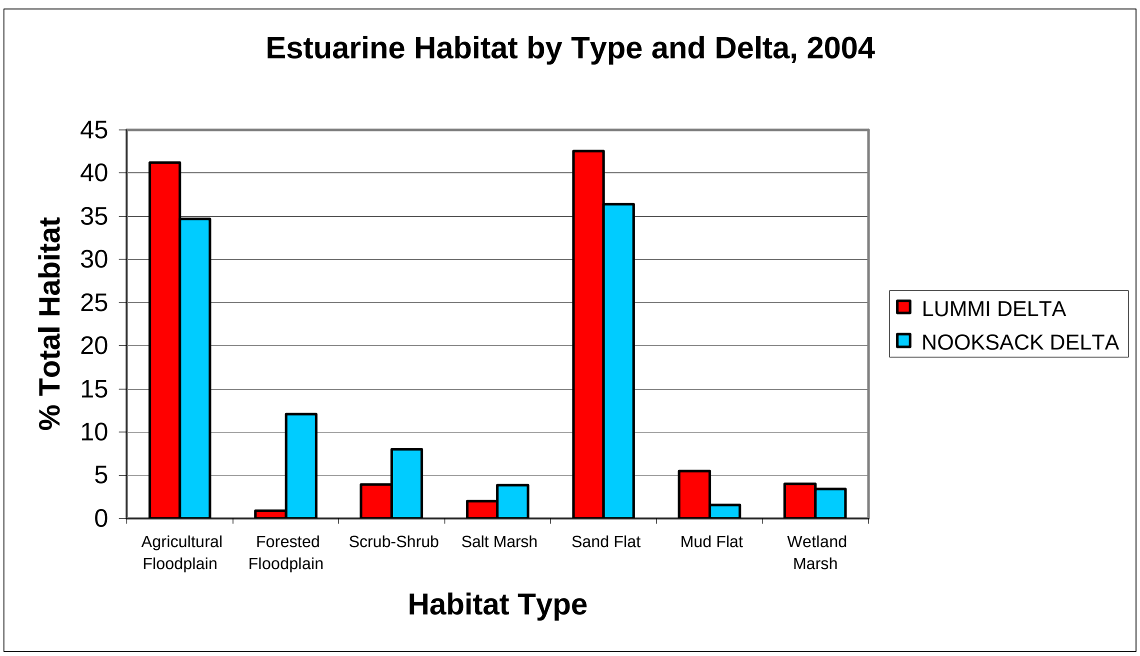


Figure 44. Comparison of estuarine landscape habitat distribution in 1888 (top), and in 2004 (above). (Note: tide flat habitat in the 1888 map was not described by sediment type; 2004 media and groundtruthing allowed for the specific delineation between sand and mud flat habitat.)

The replacement of salt marsh, forested wetland and scrub-shrub wetland with agriculture between 1888 and 2004 was a dramatic change. Habitat forming processes were disrupted, resulting in a less natural environment, a changed environment with reduced habitat area associated with juvenile salmon populations. Restoring forest, scrub-shrub, and salt marsh habitat forming processes may beneficially impact future fish productivity.

Channel Habitat Characterization

Several channel types exist in the Nooksack estuary. They are defined by hydrology, topography, and use of their adjacent landscape. At the upstream end of the estuary, flow is confined to a single mainstem channel. As it descends through its floodplain, the mainstem divides into several types of smaller, low flowing distributary and side channels. Each of these distinct channel types provides unique habitat relevant to the juvenile life stage of salmon.

It is widely believed that young salmonids, after migrating through the higher velocity mainstem of the river, seek refuge in shallow, slower moving microhabitat afforded by branched distributary, tidal, and side channels (Healey 1998, Gregory and Levings 1998, Miller and Simenstad 1997, Healey 1982). In these channels, sediment deposition and erosion processes support the establishment of diverse invertebrate communities (food) and wood structures (shelter).

Fisheries production from the estuarine environment can be substantial. Kerwin and Nelson (2002) cite that in the Skagit River system, up to 50% of chinook may rear as fry in freshwater-dominated portions of the estuary, in channel margins with low water velocities (Hayman et al. 1996). Levings (1982) found that while chinook fry resided in the Fraser River estuary, they utilized tidal channels, predominately the edges of emergent marshes at the highest points reached by the tides. In addition, they were the last fish to vacate tidal channels in the marsh when the channels dried up at low tide.

Several physical processes determine stream channel morphology. Rivers determine, shape, and maintain their own channels. Rivers are in dynamic equilibrium between erosion and deposition, regulated by common hydraulic processes (Allan 1996). The interaction of physical variables, such as flow velocity, grain size of sediment load, bed roughness, the degree of sinuosity, and the degree to which the channel may interact with its floodplain, shape the state of river channels (Allan 1996). River channels shift and move about their floodplains constantly. The shape of channels is always changing in response to discharge and material transport, and in the estuary, what the tide brings in.

Diking activities in the Nooksack in the 1920s and 1930s reduced channel interaction with floodplain habitat. Stream channels became isolated from many of the natural processes that shape and maintain channel habitat. Confined within dikes and levees, channels no longer migrate through the floodplain to exchange sediment. They tend to remain in place, incising under the influence of discharge energy carving the streambed and delivering sediment and other materials to the end of the channel. Channel migration between the City of Ferndale, at the head of the estuary, and Marine Drive Bridge has been arrested. Nooksack River banks along this section of the estuary have been made stationary by dikes (Figure 36). In the absence of dikes below Marine Drive Bridge, however, channel migration and floodplain interaction have been vigorous. Resulting from this natural habitat formation and maintenance are well-established distributary and side channels, blind channel habitat, and mature forest wetland, scrub-shrub, and salt marsh riparian zones.

An important attribute of channel habitat in the estuary is the specific type of landscape habitat each channel flows through. These landscapes are manifested in various vegetation assemblages described and categorized in the previous section. The GIS analysis in this report goes beyond characterizing habitat by channel types and breaks each channel into sections corresponding to the terrestrial (vegetation) habitat type it flows through. Forested streambanks in the Nooksack estuary provide shade, leaf litter, large wood, terrestrial insects, and other organic matter directly to the channel.

In the last several thousand years, the Nooksack River has alternatively used two main delta channels: the Lummi River, flowing into Lummi Bay, and the present channel that empties into Bellingham Bay. Prior to 1860 (Wahl 2001, Bortleson 1980), the river flowed through the Lummi River channel. Anthropogenic manipulations resulted in the diversion of the Nooksack River from Lummi Bay into Bellingham Bay.

Government Land Office maps, known as t-sheets, from 1888 describe conditions resulting from the formation of a new Nooksack delta less than 30 years old. The physical processes that shaped the estuary observed in 1888 had been active long enough to support salt marsh and wetlands formation, but these were not as well developed as the estuary habitat seen at the mouth of the Lummi River featuring many well-developed tidal channels.

The areas calculated in Table 4 represent temporal changes in surface area (in acres) by channel type in specific estuarine landscapes between 1888 and 2004. Due to the dynamic nature of conditions in the estuary and limitations associated with using different historic media (hand drawn channels vs. spatially referenced stereo-aerial photos), areas are approximate.

Table 4. Channel area (acres) by landscape type, and total stream miles characterized in the Nooksack River estuary for the years 1888, 1933, and 2004.

Year	Channel Habitat Type	Landscape Habitat Type (Acres)						Total (Acres)	Stream Miles
		Tide flat	Salt Marsh	Wetland Marsh	Scrub Shrub	Forested Wetland	Agriculture		
2004	Mainstem	195	6	0	0	46	139	387	7.1
	Ephemeral	0	0	0	0	16	0	16	2.0
	Side	0	0	0	0	33	0	33	3.3
	Tributary	27	82	22	1.4	5	8	147	15.7
	Distributary	82	23	0	34	29	0	168	8.0
	Drainage	27	0	16	10	6	1	63	8.8
	Blind	14	28	0	0	0	0	42	4
	Ditch	0	0.0	33	0	1	36	71	26
	Non-channel wetland	6446	457	1866	762	973	5048	15553	n/a
1933	Mainstem	83	13	n/a	158	0	6	261	5
	Ephemeral	0	0	n/a	2	8	0	10	2
	Tributary	9	31	n/a	8	14	42	107	14
	Distributary	116	52	n/a	0	16	4	190	9.2
	Drainage	9	5	n/a	19	0	57	9	18
	Blind	39	4	0	0	0	43	1	2.3
	Non-channel wetland	3914	550	1	223	1120	6385	12195	n/a
1888	Mainstem	15	79	0	0	113	0	208	6.6
	Ephemeral	0	0	0	0	0	0	0	0.0
	Tributary	0	18	0	0	47	0	65	9.4
	Distributary	44	83	0	0	69	0	196	11.6
	Drainage	0	0	0	0	0	0	0	0
	Blind	2	44	0	0	2	0	4	14
	Non-channel wetland	5135	1333	363	4020	3069	16	13938	n/a

Mainstem Channel

The mainstem channel carries the major load of water and sediment into the estuary. As it moves down to Bellingham Bay, the mainstem Nooksack River is fed by tributaries, and routes watershed drainage down into the estuary, where it branches off into a series of smaller distributary and side channels.

The mainstem of the Nooksack River enters the estuary near the city of Ferndale (RM 6.0). When flows exceed 9,600 cubic feet per second (cfs) a portion of its flow is routed into its first distributary, the Lummi River channel (RM 4.5). This distributary channel intermittently carries freshwater to the delta in Lummi Bay. From RM 4.5, the mainstem flows through the agricultural sectors of the floodplain to the forested floodplain that has developed below the Marine Drive Bridge.

Generally, there is a low ratio of riparian cover to channel area and a non-saline water quality along the mainstem channel. Upstream of the Marine Drive Bridge, the mainstem channel's banks are bordered by dikes, so tree cover and bank habitat interactions are limited. A wide bankfull in the mainstem limits the extent of surface shading by riparian vegetation (Figure 46). Downstream of the bridge, dikes are not present. As a result, wood and sediment accumulate along the banks, and scrub-shrub and mature forest hang over the water's surface.

There has been a slight increase in area characterized as mainstem channel habitat since 1887, primarily due to the accretion of the delta in Bellingham Bay. As the delta landscape builds on sediment deposited at the front, the mainstem channel continues to carve a path to the bay, thus increasing its length. Mainstem channel length from the front of the salt marsh at RM 0 to the City of Ferndale at present-day RM 6.0 has increased 1.2 miles between 1933 and 2004. Between 1887 and 1933, the mainstem lost more length (0.7 miles) in its straightening than it gained in its delta progradation. Figure 45 below shows the 1887 channel superimposed on a 2004 aerial photo.

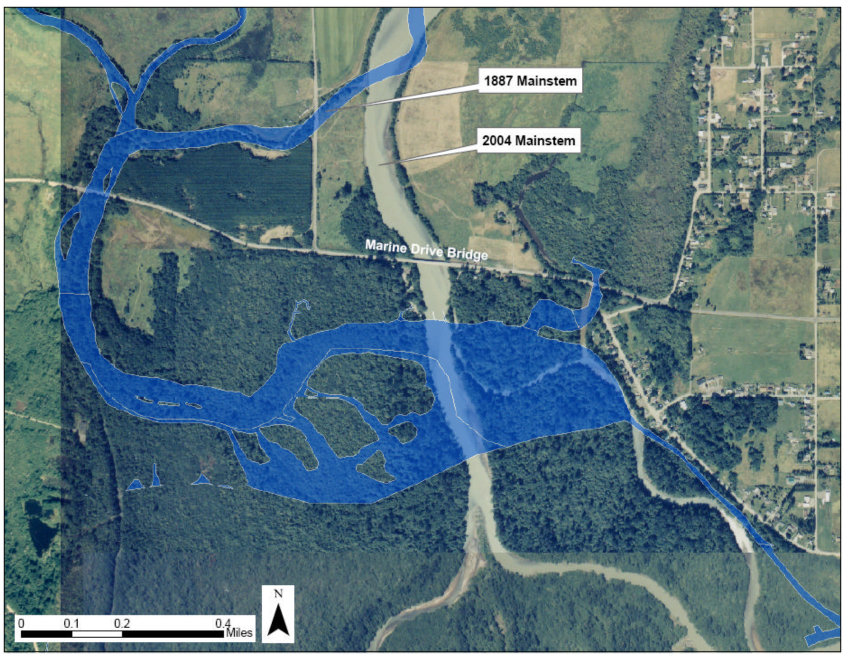


Figure 45. 1887 channel configuration (in blue) overlaid onto 2004 aerial photo. Marine Drive Bridge in the middle of the figure can be used to monitor the growth of the delta and its landscapes.

Fluvial dynamics in the 1888 mainstem channel built natural levees along its banks, supporting a forest landscape on the higher elevations. Greater sinuosity in this section added surface area to catch wood and build complex bank habitat. The sediment sub-section describes this wood delivery area and significant logjams that accumulated there around the turn of the century. Incoming tides also contributed to wood accumulation in the lower channel by pushing debris in from the nearshore.

Between 1888 and 2004, the mainstem was straightened, and dikes were built to limit floodplain interaction with the channel. Resulting conditions in this section were less complex, with limited wood recruitment and an absence of overhanging bank vegetation, two important attributes of salmon habitat.

Figure 46. The mainstem channel below Marine Drive Bridge, in 2003. This is what the mainstem channel probably looked like in the early 1800s, before diking and agriculture took over its streambanks.

Diking the banks of the mainstem has affected biological and ecological processes in the estuary. Erosion control has resulted in the loss of channel sinuosity, thereby reducing total area of habitat. The decrease in channel-floodplain interaction and the subsequent reduction of sediment and nutrient deposition has altered soil quality by altering natural processes that maintained floodplain nourishment in the past. Occasionally, the river tops its dikes in the estuary. During these events, the river sends thick layers of sediment onto its floodplain. Immediately following one such event in 2003, LNR crews measured deposition of new sediment on the floodplain inundated during high water, and found depths ranging from zero to nearly seven inches.

The substrate layer on the bed of the mainstem today is predominately sand with particle size ranging between 1/16 – 2 mm on the Wentworth (1922) grain-size scale for sediments. Fluvial energy is high in this channel, creating an environment where materials roll along the bottom of the channel instead of settling out and accumulating. As a result, benthic macroinvertebrate populations are very low. Establishment of insect communities within the interstitial spaces of tightly packed sand maintained by high flows is difficult. Insects do, however, regularly inhabit wood that accumulates along the lower mainstem's naturally maintained banks. Initial results from macroinvertebrate sampling from large wood habitat yielded *Ephemeroptera* (mayfly) larvae, an important food source for freshwater juvenile salmon.

It is evident that in the absence of dikes and other hydrological modifications, the river naturally continues to build and utilize its floodplain. Sinuous channels are carved through natural landscapes, recruiting materials from the floodplain and using the processes of sedimentation and scour to maintain their shape. It is believed that channels formed under these conditions form habitats with greater complexity and greater salmon production.

Tributary Channels

Tributary channels route water from a source within a stream's watershed to the mainstem or other primary channel in the drainage network. They are usually fed by a perennial source of water such as groundwater upwelling, a lake or pond, not by the river itself. Rather than distributing river flow, they contribute to it. The tributaries in the estuary route significant discharge during wetter months, and run considerably lower in the summer; however, they maintain year-round flow. Smaller, low-flow channels afford softer substrate and a detrital layer, attracting abundant invertebrate populations that feed on detritus and are able to burrow in the top layers of the sediment.

Tributary channels in the Nooksack River estuary harbor a variety of habitats. Riparian landscape varies with location and proximity to agricultural land use. Much of the riparian zone of tributary channels in the Nooksack estuary has been altered by land clearing for drainage improvement. The floodplains of these channels bear mostly Reed canary grass if they are not actively farmed. However, sections of each tributary in the Nooksack estuarine floodplain have been or are in the process of riparian restoration. These restoration projects involve a systematic approach that replaces invasive species with native tree and shrub species historically present.

There are four tributary channels in the Nooksack River estuary, Silver and Tennant Creeks on the Nooksack Delta side, and Jordan and Schell Creeks on the Lummi Delta side (Figure 47). Each of these streams provides invertebrate resources to the food budget of juvenile salmon, as well as low-flow refuge for resting during outmigration.

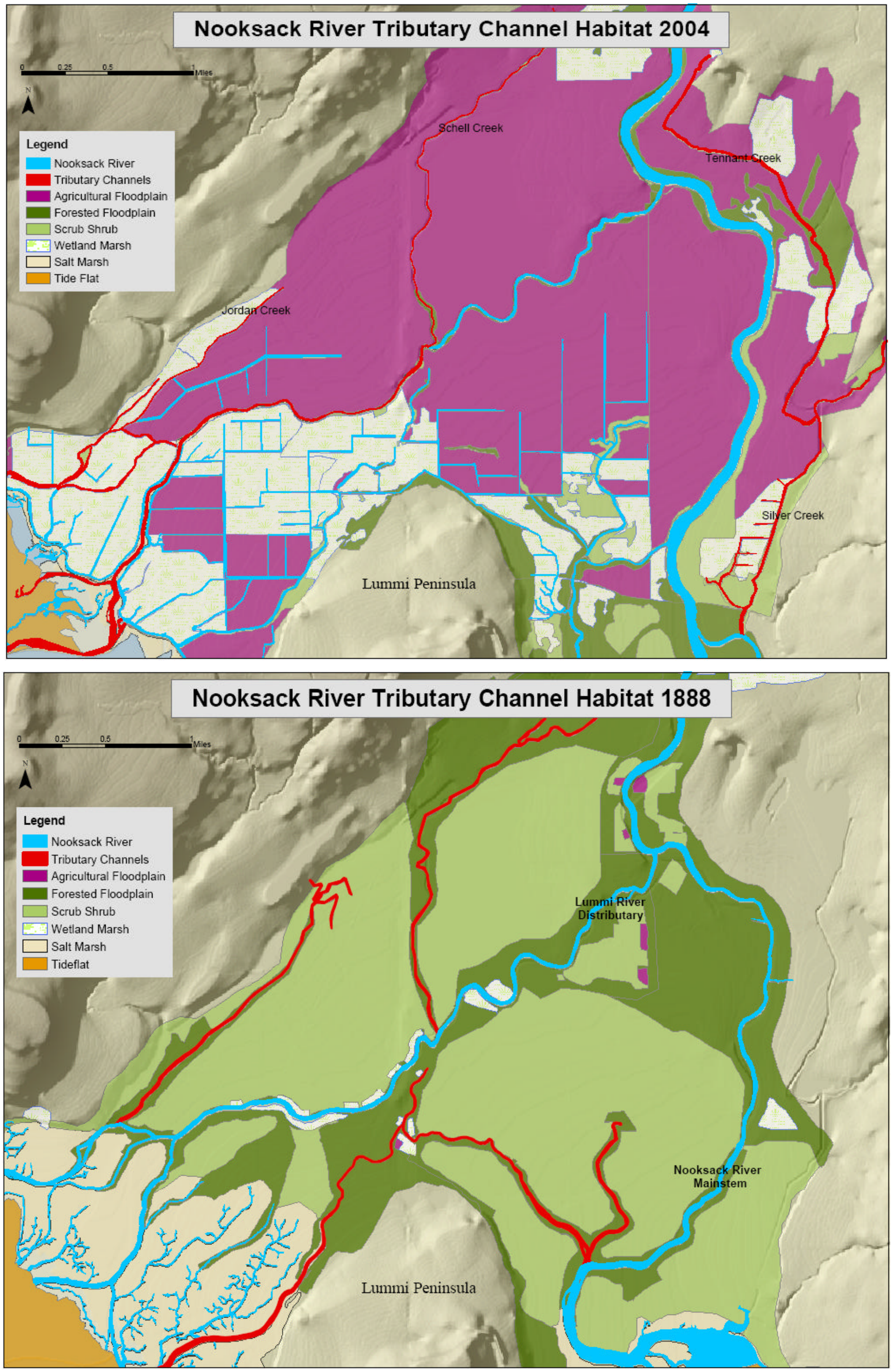


Figure 47. Tributary channels (in red) and their surrounding landscapes in 2004 (top) and in 1888 (above).

Silver Creek

Silver Creek joins Marietta Slough just north of Marine drive and joins Marietta Channel, flowing to the Nooksack Delta in Bellingham Bay. Draining agricultural-residential land west of Interstate 5, its basin is the largest of the estuary tributaries, draining approximately 6,000 acres. The lower 2.25 miles of stream channel flow along the eastern fringe of the estuarine floodplain. This section of Silver Creek functions mostly as a ditch through wetlands in the Nooksack River floodplain. Native scrub-shrub and forest vegetation was cleared for drainage improvements in the early 1900s, and straight channels were carved into the landscape for irrigation. However, there are riparian restoration and enhancement projects currently in progress and others being planned for the right bank buffer between Silver Creek and Marietta Slough.

Upon entrance to the estuarine floodplain, Silver Creek's left-bank riparian zone is steep and bears mostly mature red alder and scrub-shrub species. There are shading and cover opportunities for juvenile salmonids in this section of Silver Creek. Over 88 acres of riparian vegetation remains intact in this section.

During peak salmonid outmigration, Silver Creek contributes significant flow, along with nutrients derived from upland sources. During low flow periods, discharge is very low (less than 100 cfs). The section of channel that runs through the estuary is a settling zone, where sediments tend to fall out of the water column and onto the streambed. The benthic layer in this channel is predominately silt and clay. Silver Creek is an insignificant source of wood debris to the estuary since it has low transport capacity through floodplain wetlands, but it does contribute notable detritus, benthic invertebrates, and drift insects.

Tennant Creek

Tennant Creek drains 1,400 acres along the eastern side of the estuarine floodplain below the City of Ferndale. It flows into lower Silver Creek ½ mile above Marine Drive. Tennant Creek takes water from the mainstem during flood events, but does not maintain summertime flows or temperatures that cater to juvenile salmonid utilization. Its floodplain covered mostly by reed canary grass that filled in after native forest vegetation was converted to agriculture. There are opportunities for riparian restoration along Tennant Creek's downstream of Slater Road.

Jordan Creek

Jordan Creek is a small but significant stream that enters the Lummi Delta through a relict Lummi River channel. It is the only tributary of the current four that was well marked as stream channel in delta habitat in the 1880s. It drains nearly 4,000 acres of uplands outside of the estuarine floodplain, and about 500 acres along the western side of the estuarine floodplain. Most of the channel flows through mature forest as it descends to the floodplain through a steep gorge that has a natural fish passage barrier. Although it only contributes 1.4 stream miles of anadromous fish habitat to the estuary, it flows for over a mile through a steep, heavily forested canyon, effectively cooling surface water temperatures. Deltaic wood recruitment in Jordan Creek is low. Riparian cover and terrestrial insect recruitment, however, are high. During both LNR water temperature sampling seasons (2003 and 2004), the Jordan Creek tributary maintained water column temperatures well below the 24°C lethal limit for rearing salmon up until July, when flows decreased and temperatures rose significantly.

Schell Creek

Schell Creek, originates above the estuarine floodplain in the City of Ferndale, and drains agriculture and urban landscapes. Its drainage basin is nearly 2,000 acres in size. It flows through the Nooksack floodplain for approximately 2.7 stream miles, where it enters the Lummi River near Slater Road, and continues through the Lummi Delta to Lummi Bay. Invertebrate populations are abundant in Schell Creek. Wood recruitment in Schell Creek is low due to riparian harvest and maintenance for agriculture and residential interests. Three sections of Schell Creek totaling 1.3 miles with 180-foot buffers from the stream channel have been restored by planting native scrub-shrub and forest species in the riparian zone. The temperature of the water Schell Creek contributes to the Lummi River channel during juvenile salmonid migration often exceeds the 24°C lethal limit after May. As restored riparian vegetation matures and decreases UV penetration of the surface, water temperatures during hot, low-flow months are expected to fall.

Side and Distributary Channels

Side channels are remnant main channels that branch off, carry minor or intermittent flows and then rejoin the main channel downstream. Distributaries are similar to side channels except that they flow directly into the marine environment, sometimes after additional branching. They are often commonly generically referred to as sloughs. These channels provide many habitat features for salmonids. The mosaic of distributary channels draining the estuary may protect young fish from being swept downstream by high river flows or tidal currents (Levy et al. 1979, in Aitkin 1998). During high flow events in distributary channels, refugia exist within debris complexes, which provide fish microhabitats with reduced current velocity and back-eddies (Macdonald et al. 1987, in Aitkin 1998). Flow velocities in these smaller, meandering channels are lower than those in the mainstem. This lower flow allows smaller salmonids to rest, feed, and avoid predators during spring's high flow events, without being flushed out of the system into marine and nearshore habitats too early. The lower velocities found in the side and distributary channels not only afford juvenile salmonids the opportunity to rest, but encourage the collection of limbs, trees and shrubs pulled into the channels from streambanks during flood events. Most distributary channels in the lower Nooksack River are plugged with wood on the surface year-round (Figure 48).

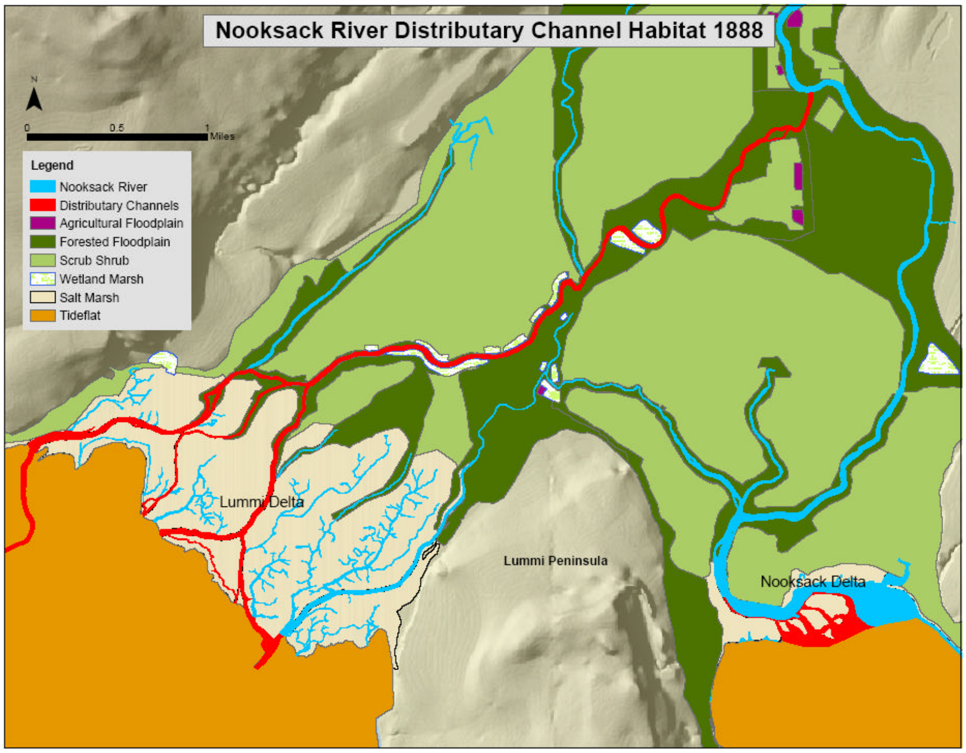
Figure 48. A typical Nooksack Delta distributary channel (channel C-3 on the site map, figure 22) with overhanging vegetation, instream wood, and riparian wood recruitment potential.

Wood assemblages, common in Nooksack River distributary channels, attract small-grain sediments and create ideal conditions for detritus accumulation. Detritus as a primary indicator of habitat function is becoming increasingly important (Meyer 1979, Simenstad et al. 1982, Aitkin 1998). It forms the lowest level of the estuarine food chain, and is recognized as an organic layer of fine sediment and fine particulate organic matter. It attracts several juvenile salmonid prey targets, including invertebrates and small fish. Juvenile salmonids passing through these channels as they continue smoltification prioritize feeding. Feeding and growth share a positive relationship (Healey 1998), and it is well documented that larger sized salmon entering ocean conditions stand a higher chance of survival (Brennan 2004, Miller and Sadro 2000, Aitkin 1989, Healey 1982, Dunford 1975). These channel types provide significant habitat for growth and survival of rearing juvenile salmonids.

By 2004, distributary and side channel habitat accounts for nearly seventy percent of the total channel habitat in the lower Nooksack delta. The side and distributary channels that drain the Nooksack floodplain into the delta in Bellingham Bay make up the majority of channels in the lower system. The numerous distributary channels in the lower river delta are the result of undisrupted natural habitat-forming processes continuing to shape habitat over time. The riparian zones of these channels are well covered with native forest species, predominately red alder, black cottonwood, crab apple, several willow species and numerous other shrubs.

Historically, the river maintained only a few distributary channels on the Lummi Delta (Figure 49). The majority of channel habitat in the 1888 Lummi Delta was blind channel, formed by tides rather than the river. Side channels were not prominent habitat in the estuary in either 1888 or 2004.

A more detailed description of individual side and distributary channels will be provided in the following sub-section.



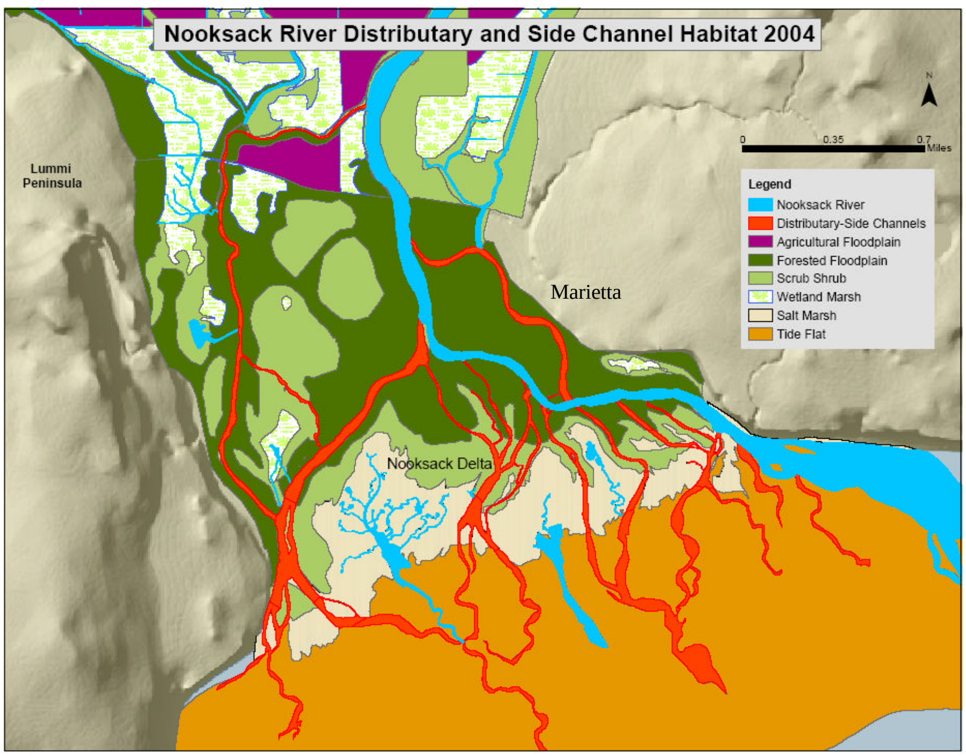


Figure 49. Distributary and side channels (in red) in the Nooksack Delta in 1888 (top), and in 2004 (above).

Kwina Slough

The longest distributary channel on the Nooksack delta is Kwina Slough. This channel flows through approximately 2.5 miles of forested wetland before entering the salt marsh on the western side of the delta. Lower off channel flows and Kwina Slough's thick riparian canopy characterize it as good rearing habitat for juvenile salmon. Between 1880 and 1908 (Wahl 2001), this channel served as the mainstem of the lower Nooksack River. Dynamiting efforts around 1910 cleared land and created a path to a tidal channel that was straighter than the previous route. The new channel routed much of the flow from the mainstem, eventually becoming the new and present mainstem channel. The remnant of the old channel (currently Kwina Slough), much smaller but still taking water from the mainstem, has lengthened with the progradation of the delta out into the bay, and returns water to the delta through its confluence with the West Channel distributary. Hydrology in this channel was disrupted by a series of bank-to-bank pilings driven into the bed at its intersection with the mainstem channel. The pilings in the channel have increased sediment deposition and narrowing of the side channel.

Marietta Channel

Marietta channel is the major side channel on the Nooksack delta. It splits from the mainstem on the left bank, just below the Marine Drive Bridge. This channel also once was the mainstem channel, cut off during the same avulsion period that formed Kwina Slough. Since the main flow was diverted from the channel, it has narrowed and become a side channel. Today, Marietta channel is about one mile in length. It is forested and is covered on its banks by mature forest and overhanging scrub-shrub vegetation in the late spring, summer, and early fall seasons (Figure 50). The mature vegetation that shades Marietta channel helps maintain cool water temperatures in the summer and provides cover from predators for juvenile salmon. It remains connected to its floodplain, thus, nutrients and sediment are regularly deposited by floods for the enrichment of riparian vegetation. As a result, scrub-shrub and forested wetland trees and shrubs abound, contributing leaf litter, wood and insect recruitment, and shade to the channel.

Figure 50. Overhanging vegetation on the bank of Marietta Channel, important side-channel habitat in the Nooksack estuary.

West Channel

The largest distributary channel that branches off of the mainstem is the West Channel. It is nearly 1.5 stream miles in length, with a bankfull width that varies between 200 and nearly 400 feet. Its substrate is mostly sand with some gravel that has accumulated on bars that have formed on the inside of bends. Since its initial development as a channel off of the mainstem, it has filled in with sediment, and is no longer navigable by large boats or even canoes during low tides. This channel supports wood assemblage along its banks, and pools scoured under them protect juvenile salmonids from high flows and predators. Overhanging vegetation on the West Channel's banks provides a good source of shade and food resources for juvenile salmon.

Distributary Channels C1-C8

The remaining distributary channels branching off of the mainstem carry significant biological value, as well. Referred to channels C-1 through C-8, these distributary channels are smaller than the main West Channel distributary. The progradation of the delta has increased the number and the length of these channels over the last fifty years. Their average length in 2004 was approximately 0.75 stream miles, and bankfull widths averaged 70 feet. Figures 48 and 50 depict representative shading, cover, and feeding opportunities available to juvenile salmonids in these channels. Wood cover is notable; it is recruited from distributary channel riparian zones, as well as upstream sources during high flows and marine sources during high tides. These channels flow through forested wetlands, scrub-shrub wetlands, and salt marsh landscapes, and provide the best habitat to rearing salmon in the estuary. The water temperatures found in these channels during migration periods mirror those found in the mainstem, the source of their flows.

Nooksack Delta distributary channels serve as valuable estuarine rearing habitat, maintaining cool water temperatures, overhanging vegetation, terrestrial insect communities, wood assemblages and wood recruitment. These habitats should continue to develop as the delta progrades into Bellingham Bay. Elongation of deltaic channels ought to persist as the delta front moves away from the mainland. This pattern is encouraging to habitat managers because the river and tides are naturally creating and maintaining valuable salmon habitat. Natural processes that create and maintain habitat in the lower Nooksack Delta have not been interrupted or manipulated for several decades, and the results may be key to the restoration of critical habitat.

Drainage Channels

Drainage channels drain the floodplain and route water through small beds out to the delta. They were excavated to improve drainage in farmed wetlands, or are historic channels with reduced flow regimes. If they occupy remnant channel locations, they were long ago separated from the river channel network by sedimentation, meander cutoff, or levee building. Historically, their riparian zones were forested wetlands and successional scrub-shrub vegetation. There are few drainage channels in the Nooksack estuary that would qualify as viable fish habitat, as most lack significant flow during dry periods and are prone to higher than lethal temperatures during the outmigration period. The drainage channels in the agricultural floodplain of the river are often choked with reed canary grass. Bank vegetation along these channels is commonly low shrub and grass, similar to that found in fallow agricultural fields. Although the low flow through these channels affords thick detrital buildup for the sustenance of an estuarine food web, the water temperatures in these habitats are often higher than those observed in flowing channels. The lack of complex riparian vegetation along Nooksack estuarine drainage channels, coupled with limited flushing by fresh or salt water, is most likely responsible for near-lethal temperatures in the summer. To follow are descriptions of various major drainage channels.

Figure 51. A drainage channel draining the Howell wetland complex into the Smuggler's Slough drainage channel.

Smuggler's Slough is an example of a remnant river channel now relegated to drainage duties. Today, it is the largest drainage channel in the lower river system (Figure 51). It was a main transport route through the estuary in the early to mid-1800s (Deardorff 1992, Wahl 2001). At that time it was a deep, wide channel that connected Lummi Bay to Bellingham Bay, routing water with incoming and retreating tides daily. Nooksack River flows contributed significant water to this channel, maintaining its navigation attributes, and providing a migratory path of tidal channel habitat for juvenile salmon. The Nooksack's diversion from Lummi Bay into Bellingham Bay had almost an immediate impact on the habitat of Lummi River side of the delta. In the absence of freshwater flushing on the delta, sedimentation became notable, and tidal channels began filling in:

> *"…Went to Sandy Point to see the Lummi catch salmon – went by way of (Smugglers Slough). It is fast filling up and at its present rate will not last much longer."* (John Tennant 1863, cited in Wahl 2001).

Installation of dikes with tidegates at both ends removed marine and river flushing influences from its hydrologic regime, exacerbating sedimentation. It no longer routes flow bi-directionally, but rather drains runoff into Lummi Bay. The macroinvertebrate community established here is diverse as well as abundant; however the water temperature exceeds 24°C in May and remains high through September. Due to barriers to cool river flows and fish passage at both ends of the channel, this habitat is not available for juvenile rearing. It has potential to be restored and used by juvenile salmon. Restoring riparian vegetation and the removal of passage barriers would improve habitat significantly.

Drainage channels include the agricultural ditches found throughout the agricultural areas of the floodplain. Ditches are prevalent in the Lummi Delta and upper Nooksack Delta, but are nearly non-existent in the Nooksack delta below Marine Drive. During wet seasons, lowland ditches are commonly filled with water, and are often influenced by tides, although tidegates prevent salt intrusion. There are several ditches in the Lummi delta that function as year-round channels, filling and draining with the tidal prism, but do not qualify as habitat because fish access into them is blocked by tidegates and the Lummi Delta seawall. Borrow pits carved during the construction of dikes along channels also qualify as ditches, and regularly fill with freshwater drainage trapped behind tidegates. Several of these "borrow pit" channels have revegetated since the initial construction of the dikes, and have potential to serve as rearing habitat once fish passage is restored.

Blind Channels

Blind channels provide unique estuarine habitat to outmigrating salmon. Carved by the combination of salt marsh drainage and ebbing and flowing tidal energies, blind channels often sustain deep undercut banks that can provide refuge from predators and UV radiation. Blind channels are generally wide relative to their length, very sinuous, with a high drainage capacity. As the tide retreats from the salt marsh floodplain into the bay during low tides, the blind channel becomes one of few opportunities for residence in the delta for those fish that do not follow the tidal prism out.

Blind channel sediments are often characterized as very soft and nutrient rich, excellent opportunity for detritus accumulation. These conditions support benthic invertebrates such as *Corophium*, amphipods that that serve as food for migrating juvenile salmon and other small fish (Schabetsberger et al. 2003). The flood and retreating tide cycles that shape the blind channels and salt marsh habitat can redistribute invertebrates across marsh plains and into channels, where they continue to be available to fish.

Both the Lummi Delta and the Nooksack Delta support blind channel networks; however the seawall barrier across the Lummi delta front limits tidal exchange, and therefore, blind channel development and maintenance. The seawall barrier has significantly reduced blind channel capacity since its construction in the 1930s. It prevents freshwater drainage from flowing to the delta through tidal channels. It also prevents the tide from entering the estuarine floodplain to build and maintain tidal channels.

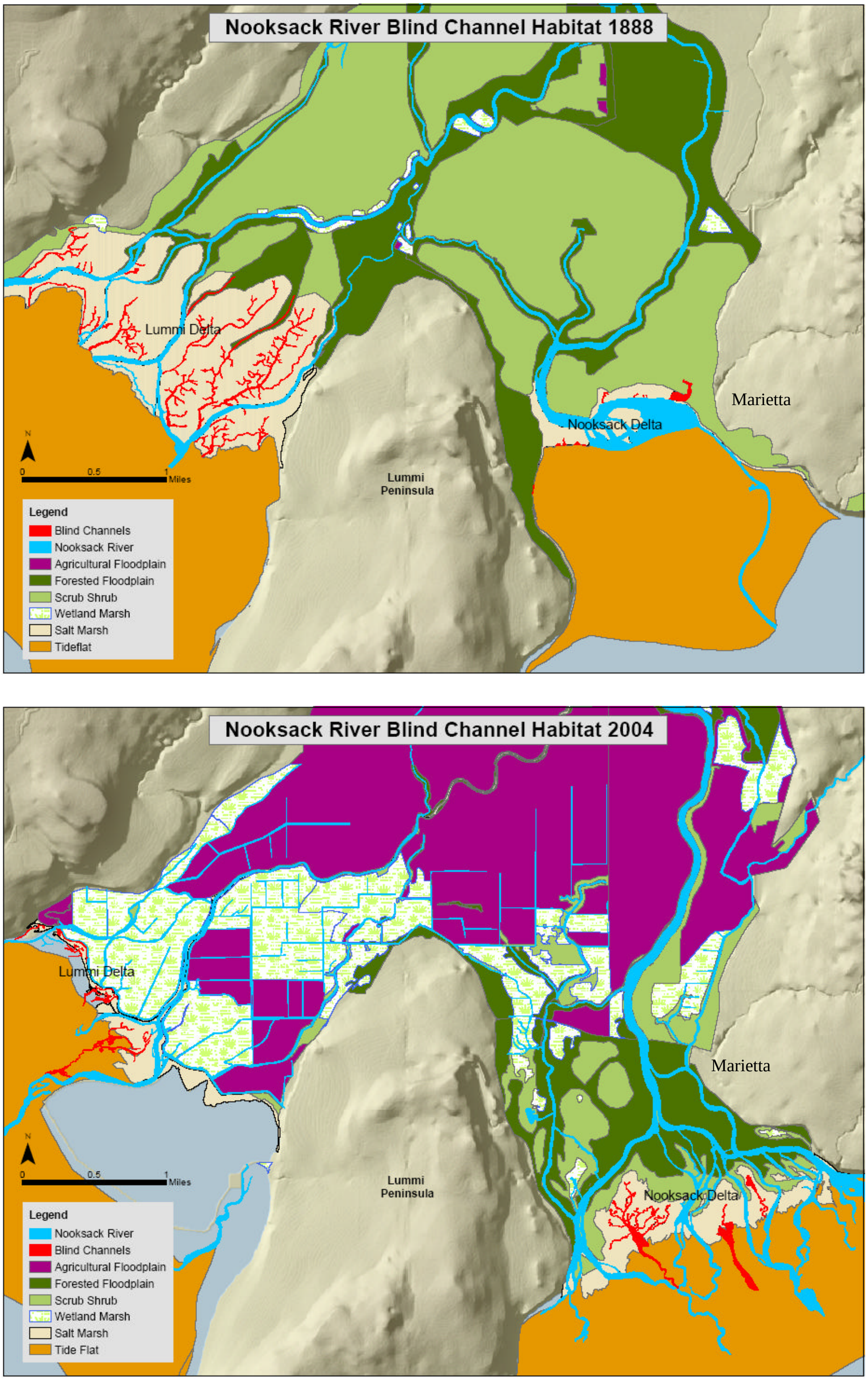


Figure 52. Blind channel distribution across the Nooksack estuary in 1888 (top), and in 2004 (above).

Historically, blind channel complexes existed at the Silver Creek Bridge on Marine Drive, and where Kwina Slough enters the West Channel. The blind channel at Marine Drive was ditched and converted for agriculture and drainage, and the one at Kwina Slough was assimilated into the forested floodplain as the landscape grew and aggraded south.

The Nooksack delta currently has three main blind channels (Figure 52). The western-most Nooksack blind channel provides nearly 2.5 miles of diverse channel habitat within the salt marsh landscape, and another mile of tide flat channel draining out from the salt marsh complex. This foremost blind channel in the Nooksack delta has been developing for the past seventy years. Carved by decades of tidal action, this channel has a 5.0-foot bank full depth near the middle of its longitudinal profile, and a 62.0-foot bank full width at its mouth in the salt marsh zone.

More than a dozen smaller floodplain-draining channels that connect it to adjacent salt marsh plain maintain this western blind channel. These drainage channels provide additional tidal/salt marsh habitat for juvenile salmonids. Several of the dozen or so drainage channels that consistently feed the primary channel are also deep, ranging between 2.0 and 4.5 feet. Deeply undercut banks along this blind channel and the feeder channels that drain into it provide cover from predators for juvenile salmon. In the summer season, tall marsh grasses and sedges supply UV protection; in the winter when the grasses die back, they hang over the banks into the channel. This grass cover may provide refuge for smaller organisms. It also attracts insects that feed on accumulated detritus. This blind channel serves as a moderate-to-high salinity migration corridor between vegetated salt marsh, through the tide flat out into the nearshore environment. The other two Nooksack Delta blind channels, centrally located on the delta front, each provide nearly one half mile of channel habitat within the salt marsh landscape. These two smaller channels become shallow on the tide flat, and may not be accessible at low tides like the larger (West) blind channel.

Three of the four Lummi delta blind channels are shallow, short in length, and low in complexity with no undercut bank. They form in salt marsh habitat that maintains low-growing emergent vegetation providing scant coverage for organisms seeking refuge from predators. Because the majority of the salt marsh landscape in the Lummi Delta has been confined to a narrow strip between the impediments of the seawall dike and the pilings installed to protect it, drainage into the blind channels here is limited. The main blind channel in the Lummi delta provides more complexity during low tide than the other three channels. It has carved about a half mile of channels into an island of salt marsh habitat between the east and west mouths of the Lummi River. It extends another mile out into the tide flat, where it shallows and dewaters at low tide. Juvenile salmonid rearing habitat restoration opportunities in the Lummi Delta are abundant, primarily the redevelopment of tidal channels that filled in and disappeared after extensive diking activities.

Juvenile salmonids generally prefer estuarine habitats that are vegetated, channelized with a moderate-slope bank, and which offer a wide range of water salinities. This habitat provides low velocity refugia at low tide, overhanging vegetation cover, large woody debris, and abundant food resources for juvenile salmon (Aitkin 1998). The estuary maintains these preferable attributes in several areas, primarily in the Nooksack Delta. Blind channels were once abundant in the Lummi Delta as late as the 1920s, but a severe reduction in freshwater input and tidal exchange has limited the maintenance of such critical habitats here. The blind channels in the Nooksack Delta are complex, still developing, and support moderate numbers of juvenile chinook in the early part of their outmigration season. We anticipate further development of tidal channel habitat in the estuary as the main delta progrades and expands.

Nearshore Habitat

The nearshore environment is the interface between terrestrial and marine environments and can be broken into four general habitat types: exposed shorelines, protected shorelines, pocket estuaries and river mouth estuaries or deltas (B. Graber, cited in Averill et al. 2004). For salmon, these nearshore habitats serve to span delta estuarine-rearing areas and effectively transition to open-water migration.

The nearshore environment is a unique. It has consistently higher species diversity, density, and production than deeper marine habitats (Shaffer 2003). Juvenile salmon and forage fish, which form the basis of the marine food web, utilize nearshore habitats for feeding and migration (Shaffer 2003) before moving offshore and out to sea. Smaller-grained sediments in the upper nearshore are used by sand lance (*Ammodytes hexapterus*) and surf smelt (*Hypomesus pretiosus*) as spawning habitat. These two species in egg and larval stages are notable prey items for juvenile salmon (WDFW 2004). Aquatic vegetation collects detritus, a staple food item for marine invertebrates that are preyed upon by juvenile salmon. Logs, aquatic vegetation, and large rocks in the nearshore provide shelter for smaller fish and add diversity to this habitat.

Marine vegetation in estuary and nearshore habitats plays several important ecological roles. It provides living space and structure for many species that grow on or among its blades, on its roots, or in the stabilized substrate it colonizes. Dense populations serve as a refuge from predators for small fish and invertebrates. Many commercial and recreationally important species, such as herring (*Clupea pallasi*), Dungeness crab (*Cancer magister*), and juvenile salmon (*Oncorhynchus* spp.) use vegetation, specifically eelgrass as a nursery. Macroalgae, tidal marsh plants, phytoplankton, and eelgrass help fuel the marine ecosystem through primary productivity. Biomass is produced in the spring and summer growing seasons, dies in the fall, and contributes substantial organic matter to the detrital food web. Epibiota associated with aquatic vegetation provides food for foraging fish, birds, and invertebrates. Isopods, for example, consume the leaves and blades of vegetation. Amphipods eat the isopods, and juvenile fish and invertebrates eat the amphipods (ADFG 2004).

As juvenile salmon leave their natal estuary and begin migrating along the coastline, they encounter other major estuaries and small "pocket estuaries." Nearshore habitat serves to bridge these widely dispersed estuarine deltas areas and create high quality corridors for the fish to use as they grow. Natural beaches, eelgrass beds, and functioning "drift cells," all provide productive, protected migratory corridors for salmon and other aquatic species. In a sense, drift cells are analogous to terrestrial watersheds in delineating the landscape into discrete areas that function as an interconnected unit, which can control nearshore habitat attributes such as slope, sediment size and vegetation characteristics within the adjacent nearshore area. A drift cell is defined as a sediment system consisting of three components: a site (erosional feature or river mouth) that serves as the sediment source and origin of a drift cell; a zone of transport, where wave energy moves drift material alongshore; and an area of deposition that is the terminus of a drift cell.

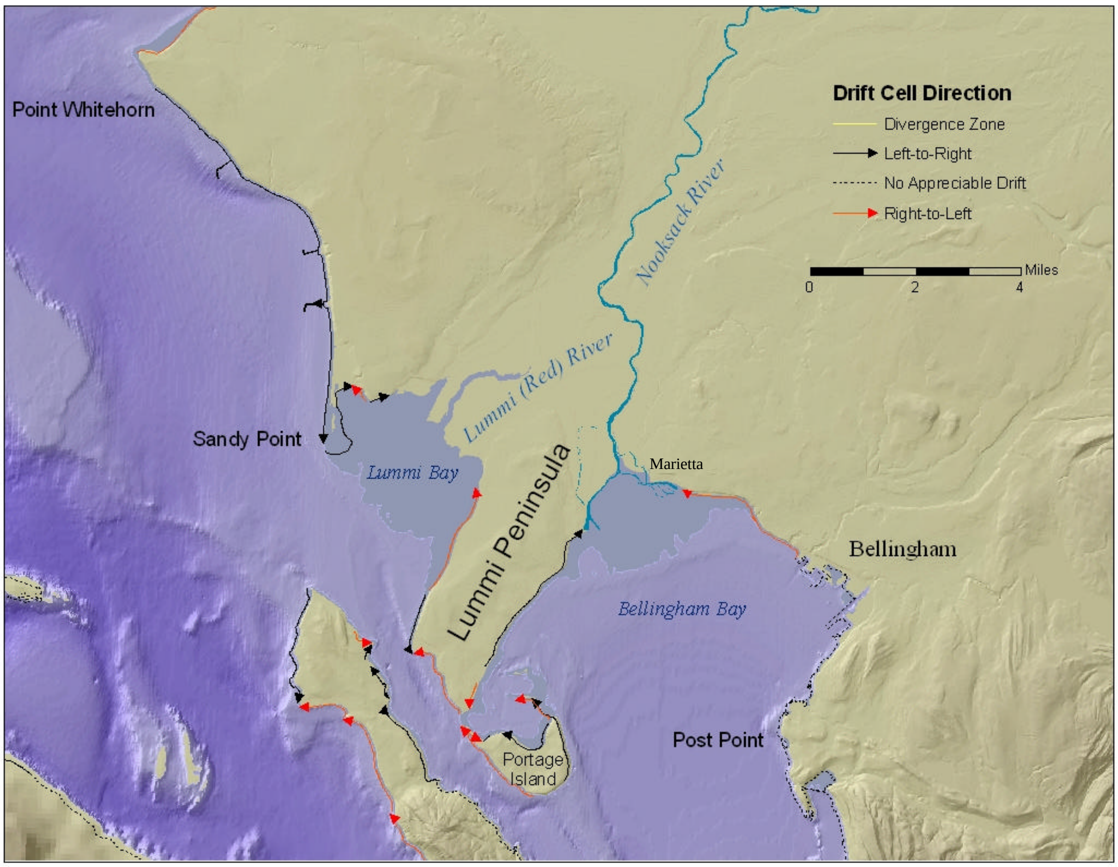


Figure 53. Nearshore area associated with Nooksack River showing drift cell direction (WDOE 1991).

The nearshore habitat associated with the Nooksack estuary covers over 55 miles of shoreline from Post Point to Point Whitehorn (Figure 53). Before upland and shoreline development began in the 1850s, the shoreline flanked cliffs composed of sandstone and glacial deposits, either glacial marine drift or glacial outwash. The natural erosion that pulls sediment and other materials from the cliffs to nourish the beaches below and feed the longshore drift cells is an important process in the sustenance of complex nearshore habitat. When cliff erosion and sediment transport processes are disrupted by the construction of over-water structures or artificial armoring with riprap (large boulders), nearshore habitat-forming processes, in turn, can be disrupted. Disruptions in habitat-forming processes can cause shifts in biotic communities, reductions in juvenile salmonid prey resources, changes in migratory behavior, and loss of rearing habitat (Levings 1980, Waldichuk 1993, Thom 1994, Simenstad and Fresh 1995 cited in Aitkin 1998).

Industrial shoreline development began in the 1880s, on the beachfronts of what is now the City of Bellingham (Wahl 2004). Activities included dredging sediment for transportation, dumping municipal wastes, dock and pier construction, bulkheading, and shore stabilization with rock and wood structures. Today, nearly 12 miles, or 20% of the total shoreline within the nearshore environment associated with the Nooksack estuary, has been armored with riprap or bulkheads (Figure 54). In addition, over six miles of shoreline have been developed for industrial use, which also entails some sort of artificial armoring protection from sediment erosion and deposition. Nearly one-third of shoreline habitat within the estuary has been modified by artificial means, which is consistent with the amount of shoreline modified statewide (DNR 1996). Across the state, nearly 55% of the shoreline modification is associated with single-family homes.

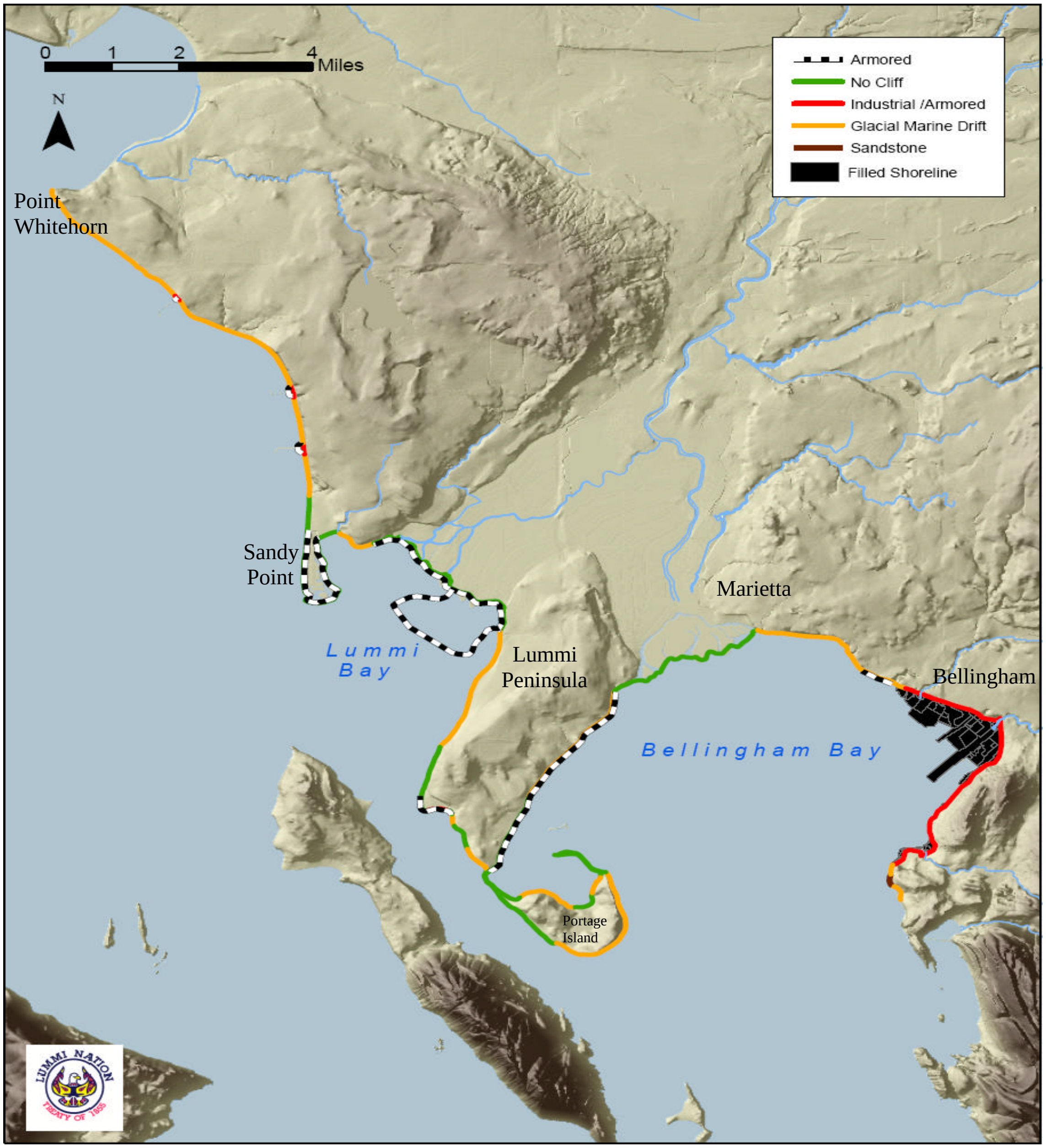


Figure 54. Shoreline characterization, 2004.

As the need for housing and transportation grew in the late 1900s, the erosion of cliff sediments down to the Nooksack estuary and nearshore beaches, long a natural beach nourishment process, began to impact road and home building near marine terraces and cliffs. Armoring at the toes of the cliffs was initiated to slow the erosion of materials from the cliffs to the beaches below, in turn stabilizing the cliff structure. Cliff and beach stabilization efforts have afforded the development of lands on and above nearshore habitat for industrial, public and private use. Figure 54 shoreline characterizations include armored shoreline areas where the interface between the upland and the shoreline is packed with large rock/concrete or artificially armored with logs and cement. Although drift cells continue to maintain sediment transport along the beaches, armoring has greatly reduced the material load supplied to beaches below. Sediment sources have been reduced, leading in some cases to increased down-drift erosion. In the case of Lummi Shore Drive (flanking western Bellingham Bay), the loss of sediment delivery by natural erosion has been mitigated by extensive artificial beach nourishment.

In contrast, thirty-eight miles (67%) of shoreline associated with the Nooksack estuary remains unarmored. This unarmored shoreline is classified as sustaining no cliff, sandstone cliff or glacial cliff (Figure 54). Thom and Hallum (1990) note that the Nooksack delta shoreline, salt marsh, and tide flat habitats, if allowed to develop naturally without further diking, dredging, or development, could retain benefits of valuable fish and wildlife habitat. Increases in intertidal habitat through the progradation of the delta could offset sea grass losses of up to 30% that occurred in Bellingham Bay because of commercial and industrial development in the nearshore. These newly forming beaches sustain a natural distribution of fine and coarse sediments that have historically supported nearshore food webs and structural habitat for juvenile salmonids migrating from their natal streams to ocean habitats.

Using nearshore characteristics such as drift cell boundaries, erosion potential, exposure to fetch, and aquatic vegetation distribution, nearshore habitat units were delineated for the area associated with the Nooksack estuary (Figure 55). For each of these units, the sediment, drift, vegetation and fish use characteristics are described and alterations to the habitat-forming processes are identified. Each unit is grouped into one of the four functional nearshore habitat types: exposed shoreline, protected shoreline, river delta, or pocket estuary.

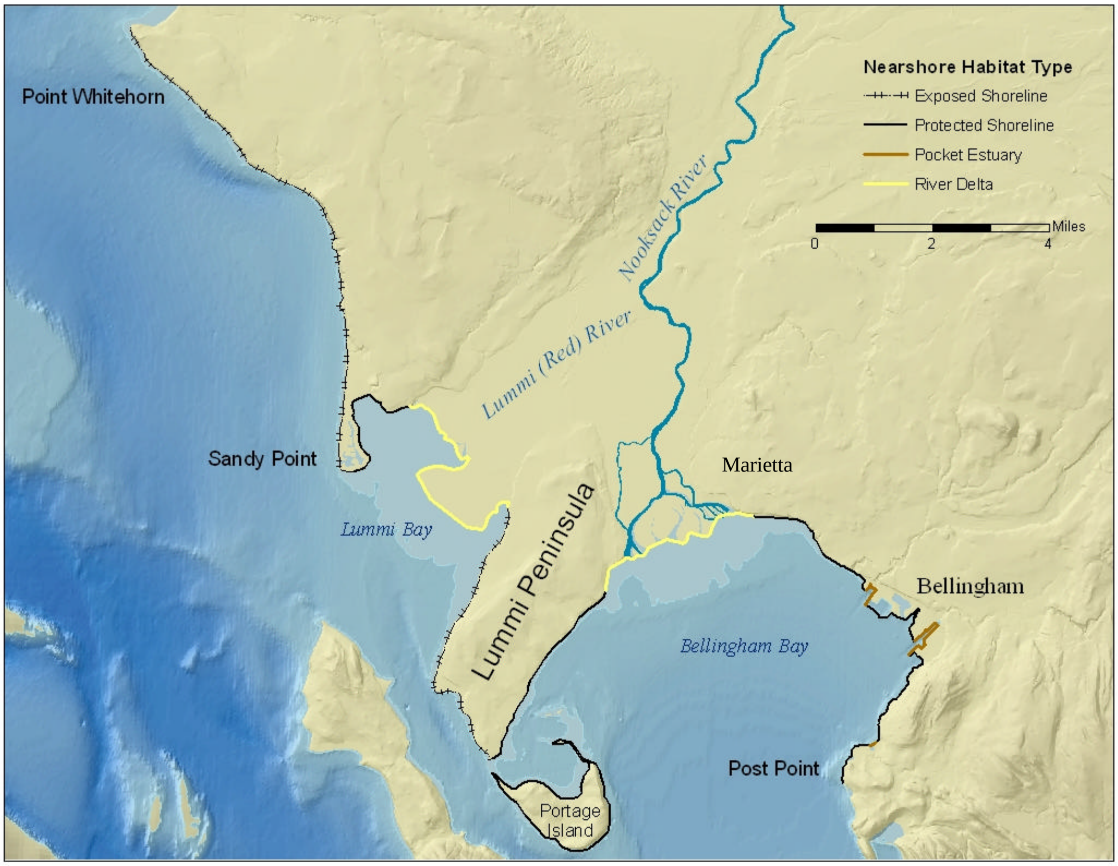


Figure 55. Nooksack nearshore habitat units.

Exposed Shorelines
Exposed shorelines are nearshore habitats that are subject to greater wave and current energy than protected shorelines, due to the greater distance over which wind and waves can travel. It is hypothesized that this may make the function of refuge from predation and extreme events difficult for smaller migrating and rearing juvenile salmon (Averill et al. 2004). It is further hypothesized that open shoreline habitat provides critical functions, including feeding and growth, refuge from predators, migratory corridors, and to a lesser degree physiochemical transition, for larger juvenile salmon once they migrate into the neretic zone. Important year-round, the open exposed shorelines become increasingly important later in the calendar year as juvenile salmon move out of protected areas and into open shoreline habitat. Individual exposed shoreline units will be detailed in the following paragraphs.

Point Whitehorn to Sandy Point
This habitat unit runs from Point Whitehorn, the northern most point in the study area, to the southern end of Sandy Point, and likely represents an important transportation corridor for migrating juvenile salmon between the shelters of Lummi Bay and Birch Bay. The 145-kilometer fetch (the uninterrupted distance traveled by a wind or wave) along the Strait of Georgia causes predominant waves to hit this drift from the northwest, leading to a southerly net shore drift. At Point Whitehorn, the shore is mainly an

erosional platform, with only a narrow, thin veneer of sediment. Just northeast of the apex of Point Whitehorn, in Birch Bay, the nearshore consists of barnacle-covered boulders, making it appear unlikely that large amounts of sediment enter the drift cell from the north (WDOE 1991). The southern end of this cell is a large spit, Sandy Point, building to the south.

Beach sediment generally grades from coarse cobbles at Point Whitehorn to mixed sand and gravel at Sandy Point, with some local reversals. Although the Arco Refinery pier, completed in 1971, appears to have no effect on drift because it crosses the foreshore on pilings; both the Intalco aluminum plant pier, built in 1966, and the Mobil oil refinery pier, completed in 1954, act as partial barriers to net shore drift. At these latter two sites, large riprap and bulkhead platforms built over the entire foreshore effectively stop the movement of the coarse sediment fraction, although sand has been observed moving around the barriers. This impediment to sediment transport has caused a noticeable accumulation of sediment on the north sides and erosion on the south sides of both the Intalco and Mobil piers (WDOE 1991). Along the length of the drift cell coast there is a general trend toward increasing vegetation on the bluffs and the decreasing bluff slope to the south, although increasing erosion of the bluff is evident just south of the Mobil pier, where there is no longer a beach present. Much of the length of this drift cell (Figure 56) is considered to have high erosion potential.

The biotic community of the exposed shoreline area of the nearshore is diverse, and important to migrating juvenile salmon. In addition to sorted sediment that serves as spawning habitat for forage fish (juvenile salmonid food resources) in the upper intertidal zone, submerged vegetation in the lower intertidal zone provides predator avoidance opportunities and resting refuge for smaller fish and other nearshore dwellers. Chinook salmon is the primary species of juvenile Pacific salmon that has been observed using the Point Whitehorn to Sandy Point shoreline for migration and rearing. Juvenile chum are also commonly caught here, as well as pink salmon, surf smelt, and sandlance (LNR 2004).

Eelgrass beds along this section of nearshore habitat once supported the largest fishery of pacific herring (*Clupea pallasi*) in Puget Sound (Bargman 2001); however, the beds are sparse today (Figure 56). Herring are considered a keystone species in northern Puget Sound, playing a central role in the marine food web. Herring populations in this area have declined 94% in the past 20 years. This decline has been attributed to habitat loss and degradation, as eelgrass habitat here is affected by nearshore development and commercial vessel traffic (Bargman 2001). Today, bull kelp (*Nereocystis luetkeana*) is the primary aquatic species that serves these functions between Point Whitehorn and Sandy Point in the Strait of Georgia.

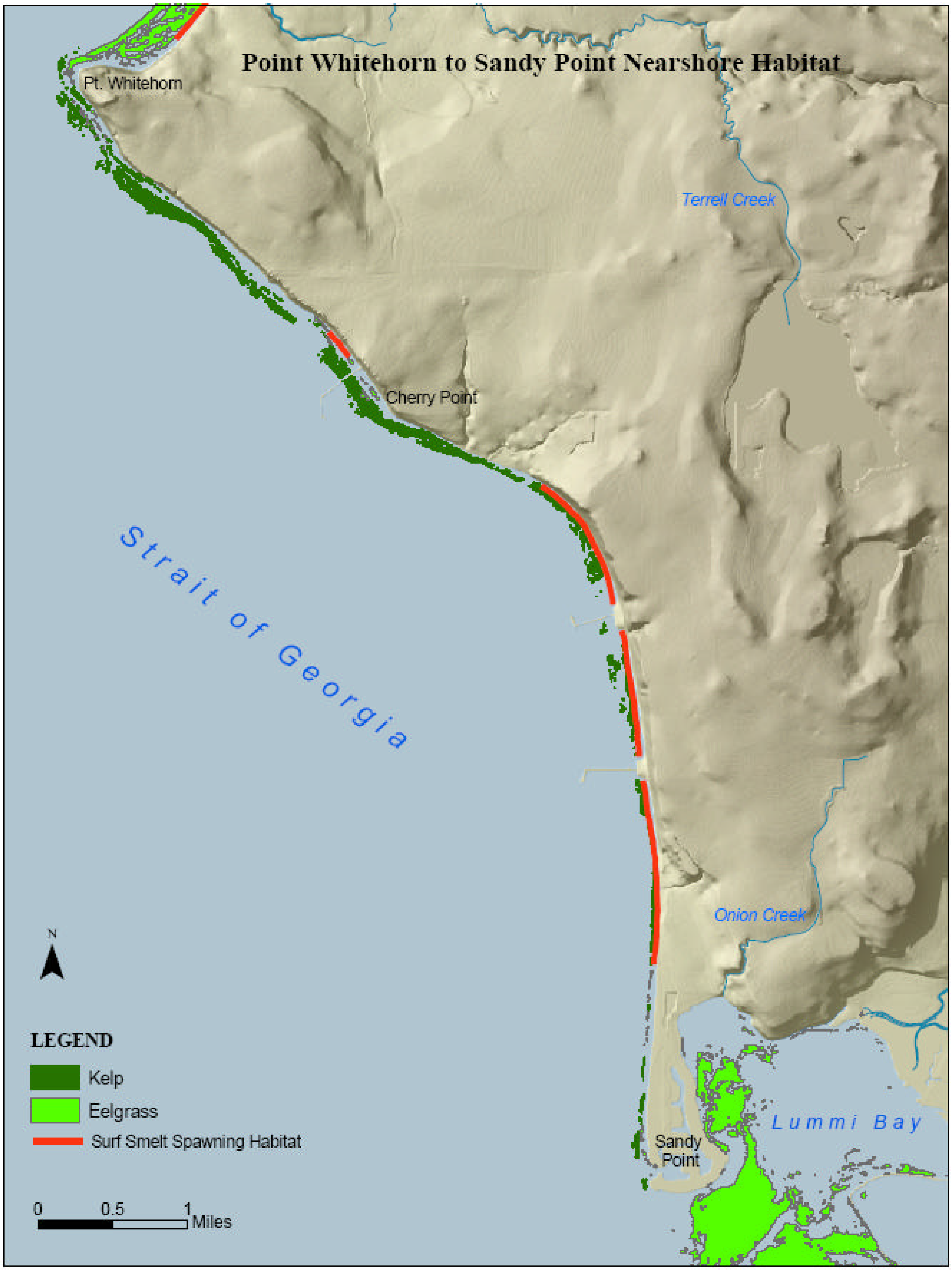


Figure 56. Habitat delineation for the exposed shoreline between Point Whitehorn and Sandy Point. (*Vegetation data, DNR-1996; surf smelt data, Northwest Straits Commission-2002).*

Bull kelp is one of the largest brown algae species in Puget Sound (Figure 57). Held in place on hard substrate by holdfasts, kelp stipes may reach lengths of 100 feet. Air bladders at the surface hold up to 50 fronds that float on the surface for photosynthesis and may grow to 10 feet in length, depending on local conditions. Large communities of kelp in the nearshore often comprise forests or beds, and are indicators of good marine habitat health. Kelp forests exist in shallow or deep marine habitats, and this versatility allows the plants to be used by both sub- and intertidal organisms. Kelp beds off of nearshore areas reduce beach erosion by reducing the force of waves against the shoreline.

Figure 57. Bull kelp (*Nereocystis luetkeana*) forest (left), and a single plant (right).

Juvenile salmon utilize the protective qualities of kelp beds when the tide moves away from the intertidal zone (Shaffer 2003). Long, narrow stalks allow many plants to inhabit a small area and produce thick beds of kelp. The wide fronds near the surface cover substantial area to provide small, migratory species protection from predators. Adult salmon also hide and feed in these kelp beds.

West Beach- Lummi Peninsula

The exposed shoreline of the west side of the Lummi Peninsula has two drift cells; one moving to the north toward the Lummi River and the other moving south toward Gooseberry Point. The northern drift cell stretches from the south wall of the Lummi Aquaculture dike to a point about 1.6 kilometers northeast of Gooseberry Point and carries sediment to the northeast toward the Lummi Delta (WDOE 1991). The bluffs along this portion of the coast gradually change from steep, unvegetated, and eroding slopes in the southwest to well-vegetated, more gradual slopes in the northeast. Mass wasting is common along the shoreline. The beach broadens northeastward and beach sediment grades from cobbles in the southwest to sand and gravel in the northeast. On the coast immediately west of the intersection of Robertson Road and Boynton Road, a beach is undergoing active accretion and a small spit is building northeastward. Further to the northeast, where a creek reaches the coast just south of the end of the Lummi Aquaculture dike, a small spit is building north across the creek mouth. Sandy Point to the north provides some protection from waves produced by the predominant northwest winds from the Strait of Georgia. Most likely, waves refracting around Sandy Point from the northwest and winds moving across the much shorter 16-kilometer fetch to the west are responsible for the drift direction in this cell. The central portion of the West Beach area has somewhat direct exposure from the northwest, a shallower nearshore due to the delta in Lummi Bay, and is considered a moderate erosion hazard. The northern portion of West Beach has seen little very slow erosion rates and is considered a low erosion hazard (Johannessen 2003).

The southern drift cell along West Beach carries sediment to the southwest toward Gooseberry Point, a cuspate spit, from a small headland approximately 1.6 kilometers northeast of Gooseberry Point (WDOE 1991). The beach widens to the southwest, and beach sediment grades from cobbles in the northeast to sand in the southwest. Coastal bluffs, some of which have bulkheads built along them by landowners, become more vegetated to the southwest for 1.2 kilometers. While Gooseberry Point itself is an accretion landform, erosion rates between 0.2 and 0.4 feet per year were measured between 1951 and 1995 (Johannessen 2003). The southern section of West Beach is exposed to a long fetch from the northwest and contains almost no bulkheading. Erosion rates of up to 0.7 feet per year were measured here and it is considered a high erosion potential area (Johannessen 2003).

Biologically, the two drift cells along the west coast of the Lummi Peninsula are very different (Figure 58). The nearshore of the southern drift cell contains only small patches of aquatic vegetation (predominantly eelgrass) on a largely exposed mixed course and sand substrate. Sandy substrate and high-energy nearshore currents are likely the limiting factors in vegetation distribution. The northern cell is influenced by the Lummi delta deposit and covered by the Lummi Bay eelgrass bed. Where eelgrass is not present the nearshore is characterized by exposed, mixed fine sediment. Kelp is not notable along this section of shoreline, nor are spawning grounds for forage fish.

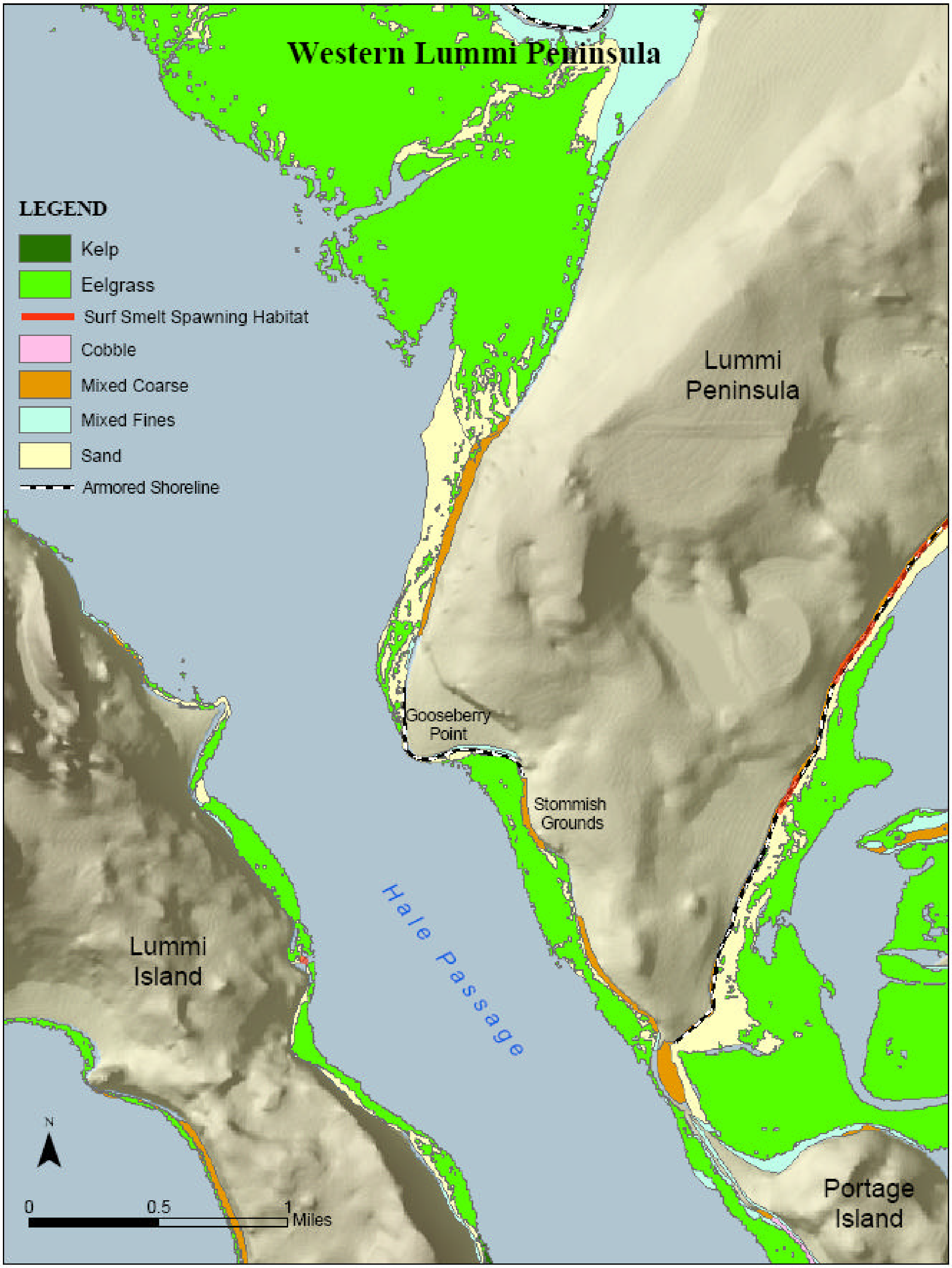


Figure 58. Exposed shoreline habitat on the western Lummi Peninsula, Gooseberry Point, western Portage Island, and eastern Lummi Island.

Gooseberry Point to the tombolo of Portage Island

This drift cell includes the coast from Gooseberry Point to the Portage Island tombolo, a spit that connects Portage Island with the Lummi Peninsula (Figure 58, previous page). Net shore drift is northerly from Portage Island across the tombolo and along the shore to Gooseberry Point. The beach broadens to the north and the coarsest fraction of sediment grades from boulders and cobbles just north of the Portage to sand on the west side of Gooseberry Point (WDOE 1991). This northerly drift appears controlled by predominant southeast winds blowing across the 10-kilometer fetch in Hale Passage. The erosion potential is predominantly low through this drift cell, although a section just north of the Portage was classified as high based on measurements of 2.3 feet per year of erosion at one location (Johannessen 2003).

Eelgrass habitat in this drift cell section is well established; the Stommish eelgrass bed extends the entire length of the cell from Gooseberry Point to Portage Island. This area does not provide forage fish spawning, but larval-stage individuals have been captured in the nearshore (MacKay 2004, in prep.). Although all of the Pacific salmon species have been observed using this habitat during the juvenile out-migration season, chum salmon are the most common, followed by chinook and coho (MacKay 2004, in prep.).

Protected Shorelines

Protected shorelines are less subject to wave and current energy than open, exposed shorelines. These shoreline habitats provide critical functions for juvenile salmon, including feeding and growth, refuge from predation, migratory corridors and physiological transition. It is hypothesized that protected shorelines are very important for early fry migrants and may be important to more mature juvenile salmon, for example, parr migrants and yearlings (Averill et al. 2004). These protected shorelines are considered to be important to all life history stages earlier in the year before water temperatures in these areas increase. Protected shorelines often host large spawning aggregations of forage fish, and are very important for generating prey base for fry migrant salmonids and providing refuge from predators and extreme events (Averill et al. 2004). In the following paragraphs, individual protected shoreline units will be detailed.

Onion Bay

This protected shoreline unit runs from the south side of Sandy Point to the start of the Lummi Bay seawall (Figure 59). The Onion Bay nearshore environment is comprised almost entirely of unvegetated mudflat, with a narrow strip of mixed fines along the shorelines. It contains three drift cells, two of which transport sediment toward the mouth of Onion Creek and the third transports sediment east toward the mouth of the Red River distributary. The net shore drift is east around the southern end of Sandy Point, then northward to Onion Creek. Several groins on the south end of Sandy Point all show marked erosion on the east and accumulation on the west. Since the dredging of the inlet to the Sandy Point Marina, the southern end of the spit has been undergoing rapid erosion (Johannessen 2003). The southernmost beach, being starved of sediment, is now composed of cobbles, as the finer sediment has been transported away and not replaced from up-drift sources.

Another drift cell runs from Onion Creek to the northwestern end of the Lummi delta seawall. The net shore drift is to the northwest to Onion Creek from the headland near the center of the cell. From this same headland, drift is to the northeast to the end of the piling dike that extends across the coastal flood plain of the Lummi River. The eroding headland bluffs grade to well-vegetated slopes both to the west and east. West of the headland, a lobe of gravel and cobbles can be seen built to the northwest. Sediment size decreases and beach width increases to the northwest. The mouth of Onion Creek is diverted to the west by mostly gravel sediment that seems to overlie finer sediment coming from the previous drift cell (WDOE 1991). To the east of the headland, sediment grades become finer to the northeast, and the beach broadens considerably to the northeast. Sediment transport in this area is dominated by the 10-kilometer fetch to the south and, to a lesser extent perhaps, by waves refracting around Sandy Point. Although the habitat characteristics of these mudflat areas are consistent with the general description of protected shoreline, the unique contributions of this area have yet to be determined.

Figure 59. The Onion Bay protected nearshore habitat unit.

<u>Portage Island</u>

The nearshore habitat of Portage Island has six drift cells associated with it (Figure 60). Two long cells run from the south to the north along the outside of either side of the island and four smaller drift cells transport sediment along the Portage Bay side of the island. The long drift cell on the southwestern side of the island runs from the southeastern apex of Portage Island to the point where Portage Island connects with the Lummi Peninsula. Drift is to the northwest in this cell. Sediment size grades from cobbles at the southeast to mostly coarse sand and gravel at the northwest and the beach gradually widens to the northwest (WDOE 1991). The fact that the spit has been eroding slightly (less than 0.1 feet per year) may indicate a decrease in sediments, or an increase in storms from the southeast (Johannessen 2003). Most of this cell is characterized as a low or moderate erosion risk, although the bluffs on the south side of the island have been eroding at greater than 1 foot per year and considered a high erosion risk. The drift cell along the eastern side of Portage Island transports sediment from the eroding bluffs in the south toward Brandt Spit and Brandt Island at the island's northeast corner. Changes in the shoreline show that the middle section of the drift cell is accreting while the northern end, along Brandt Spit, has been eroding rapidly (approaching 2 feet per year at one transect) (Johannessen 2003). It is felt that changes in the two large spit complexes (Brant Island and the Portage) that surround Portage Bay will substantially alter water circulation in the bay and consequently change the amount of flushing and fecal coliform contamination patterns (Johannessen and Chase 2002).

The Portage Bay side of Portage Island has a more complex sediment transport and deposition pattern. Sediment moves northwest along Brandt Spit and grades from cobbles at the southwest to fine gravel at the northwest (WDOE 1991). From the base of Brandt Spit, another drift cell stretches from just west and south of where Brant Point connects to Portage Island and continues along the northern crescent-shaped coast of Portage Island towards the west, about two-thirds of the distance to the Portage. The net shore drift is to the southwest and then northwest around the bay. Erosion is occurring at the eastern end of the cell, as evidenced by small, vertical, unvegetated scarps behind the beach, while the western part of the sector is composed of two accumulation beaches, separated only by a short section of low eroding bluff. The most easterly accumulation beach has diverted a stream sharply to the west, while the more westerly beach appears to widen towards the west. Sediment particle size grows finer from Brant Point west, with the exception of the small vertical bluff, which separates the two accumulation beaches, and adds sediment to the beach. The next drift cell continues to move sediment west from the last cell. For the most eastern part of this sector, there is little, if any, evidence of drift (WDOE 1991). Grass grows at the shore and cobbles covered with barnacles lie in mud. A small, wave-cut scarp, which is about half a meter high, is visible behind the beach. The western end of this sector exhibits a fining of sediment size to the west, indicating that at least a small amount of drift is occurring there. The last drift cell on the Portage Bay side of Portage Island transports sediment south from the Lummi Peninsula down the east side of the tombolo that connects with Portage Island. The beach widens to the south and sediment grades from gravel in the north to sand in the south (WDOE 1991).

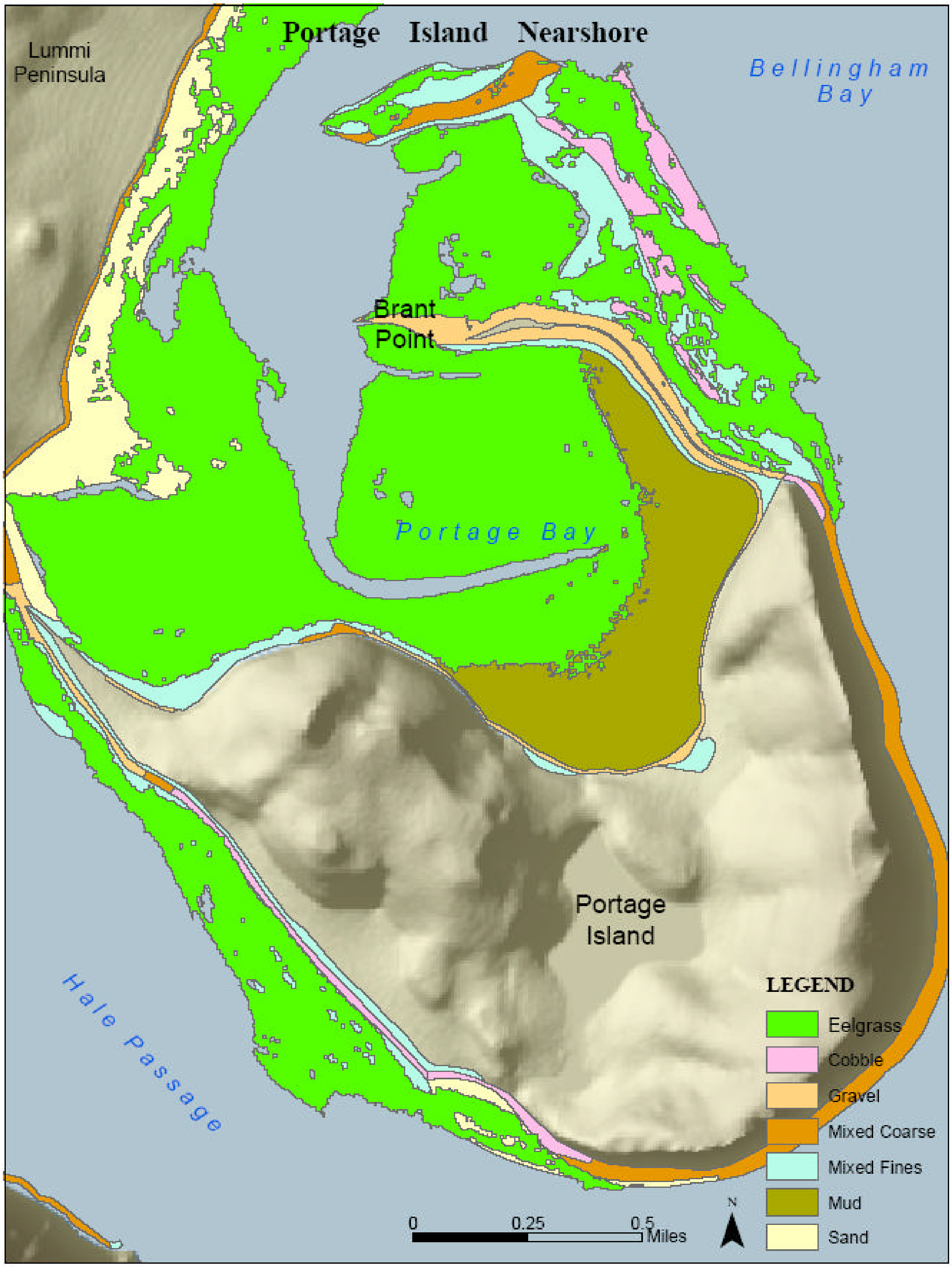


Figure 60. Portage Island nearshore habitat.

Juvenile salmon habitat in Portage Bay and around the east and west edges of Portage Island is a diverse matrix of algae and eelgrass. The Portage Bay eelgrass beds are very rich, and support many species of invertebrate food items for juvenile salmon, such as forage fish spawn, copepods, amphipods, annelids, and larval shellfish. The area is too protected and shallow to sustain kelp communities; however, fish, shellfish and invertebrates are found throughout the protective Portage Bay eelgrass bed. Within the Portage Bay eelgrass bed, abundant shellfish resources exist. Today, Portage Bay supports Manila clams (*Venerupis philippinarum*), butter clams (*Saxidomus giganteus*), horse clams (*Tresus capax*), and Pacific oysters (*Crassotrea gigas*). Considered a staple of historical Lummi Nation people, these species continue to be harvested by the Lummi Nation.

Figure 61. A sunflower star (*Picnapodia helianthoides*) embedded in eelgrass at low tide, covered with Pacific herring (*Clupea pallasi*)-spawned eggs.

<u>Portage Island Tombolo to the Nooksack Delta</u>

This nearshore habitat unit begins at the Portage on the eastern coast of the Lummi Peninsula and continues northeast to Fish Point, near the Nooksack Delta. Net shore drift in this unit is to the northeast toward the delta and divided into two distinct cells; Portage to near Brant Spit and Brant Spit to Fish Point. The entire length of the cell was armored (over two miles of continuous revetment) between 1994 and 1998 (Figures 62 and 63). To protect surf smelt and sand lance spawning, the Lummi Nation has added over 8,000 cubic yards of sediment between 1999 and 2003. Monitoring of the surf smelt and sand lance spawning grounds here showed slight changes in beach elevation (lowering in the south and rising in the north) consistent with the net northward transport of sediment (Johannessen and Chase 2004). Beach profiles monitored in 2003 and 2004 found changes in the beach face indicative of both minor onshore and northward alongshore sediment transport. Sediment transport was found to be in accordance with the local northerly net shore-drift, with the size of the coarsest beach sediment grading finer and the beach widening to the northeast for approximately 1.6 kilometers (WDOE 1991, Johannessen and MacLennan 2004). North of Cagey Road, the shallow Nooksack River delta is actively prograding and an accreting beach provides protection from erosion to the bluff. The greatest fetch for this drift cell runs for 21 kilometers to the southeast.

Shoreline monitoring following construction of the revetment showed up to 1 foot per year of accretion in some sections, and 2.7 feet of erosion in others. In spite of rapid movement of the sediment added as a part of the beach nourishment program, the whole drift cell is considered a low erosion risk due to the extensive armoring (Johannessen 2003).

While the nearshore habitat along the eastern side of the Lummi Peninsula is heavily influenced by sand deposition from the Nooksack River, extensive eelgrass beds do exist in the southern portion of the unit (Figure 63). Juvenile salmon use this habitat as a migratory corridor from the Nooksack Delta to valuable eelgrass beds in Portage Bay. The eelgrass bed in Portage Bay densely covers over 700 acres of mud and sand, and sustains many species of invertebrates that feed young salmon. Portage Bay nearshore habitat is a combination of sand and mud flat, flanked by a mix of intertidal cobble, gravel, and sand that sustains key feeding grounds for salmon smolts during their first few weeks of saltwater life.

Figure 62. Nearshore habitat along Lummi Shore Drive (the eastern edge of the Lummi Peninsula on Bellingham Bay). This beach is used as a juvenile salmon migratory corridor between the western distributaries of the Nooksack River and Portage Bay.

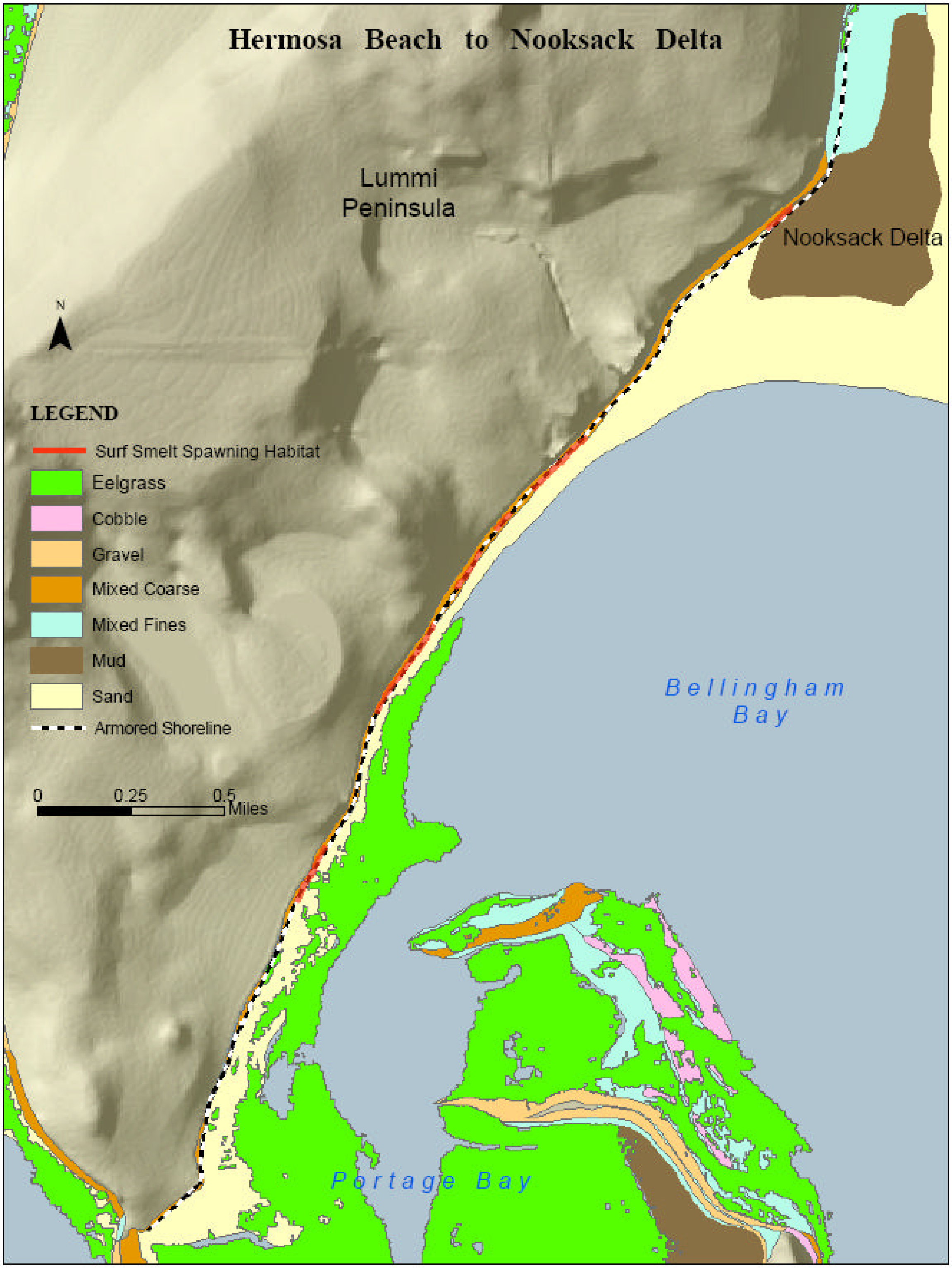


Figure 63. Eastern Lummi Peninsula nearshore habitat between Portage Bay and the Nooksack River delta.

South of Nooksack Delta

The heaviest development of the nearshore environment associated with the Nooksack River has occurred in Bellingham Bay related to the development of the port of Bellingham (Figure 64). A history of dredging, filling, armoring and over-water construction has led to the alteration of much of the nearshore environment in the assessment area. The result is a long section of industrialized shoreline that has no appreciable drift. From Marine Park in southern Bellingham to the southern boundary of Whatcom County, the coast is comprised of riprap placed along a railroad line, and rocky cliffs.

North of the City of Bellingham, net shore drift moves along the north shore of Bellingham Bay in a northwesterly direction from the armored log yard behind the Mount Baker Plywood Company toward the Nooksack Delta. Beach sediment size decreases and the beach width widens to the northwest for about one kilometer, to a long pier near Little Squalicum Creek (WDOE 1991). Logs have jammed up against the pier's foundation, thereby accelerating accumulation to the southeast of the pier and erosion on the northwest. The beach widens towards the northwest again for about one half a kilometer, until it reaches a section of shore where drift is minimal in the upper foreshore. The bluffs above this section of the shoreline have been armored to protect the railroad and nearby houses from erosion. Past the end of this riprap, behind the Columbia Cement Company plant, there is a large dumpsite where refractory bricks, concrete and large iron objects are bulldozed over a bluff onto the shore (WDOE 1991). This material is acting as artificial nourishment for a long stretch of beach. The bricks, concrete, and iron form identifiable sediment, which is found only to the northwest of the cement plant and grows distinctly finer in size to the northwest.

The visible beach sediment for the next one to two kilometers is comprised mainly of wood in the form of sawdust, wood chips, bark, twigs, branches, and logs, which widens to the west. Much of the beach through this section is armored with wood transported down the Nooksack River and deposited at the mouth of the mainstem channel. The bluffs behind the beach become less steep and more vegetated toward the west. The extreme western end of the beach seems to be a lobe of wood and sediment built to the west. The greatest fetch runs to the south about 22 kilometers. This drift cell was not characterized for its erosion potential, although the extensive armoring of the eastern sections would suggest that bluff erosion is a problem for local property owners.

Juvenile salmon use this shoreline as a migratory corridor between the mouth of the Nooksack River and nearshore habitats. The bulk of salmon leaving the river do so from the mainstem and eastern distributary channels that flows out of the delta and along this shoreline (MacKay 2004, in prep.). Historically, this nearshore habitat was rich with eelgrass and other submerged vegetation (Wahl 2001) that stabilized sediment and provided salmon with food and predator refuge resources. Today, it remains an important spawning beach for surf smelt. However, over half of the historic shoreline has been degraded. Vegetation is patchy at best, and industrial development over the last 100 years has hardened shorelines, resulting in the destruction of natural beach nourishing and maintenance processes. Toxic sediment accumulation from industrial and municipal dumping is another devastation to this shoreline. These habitat impediments may be limiting factors to the survival of juvenile Nooksack salmon. The apparent lack of food and shelter resources here, coupled with poor water quality, does not improve the survival of these fish.

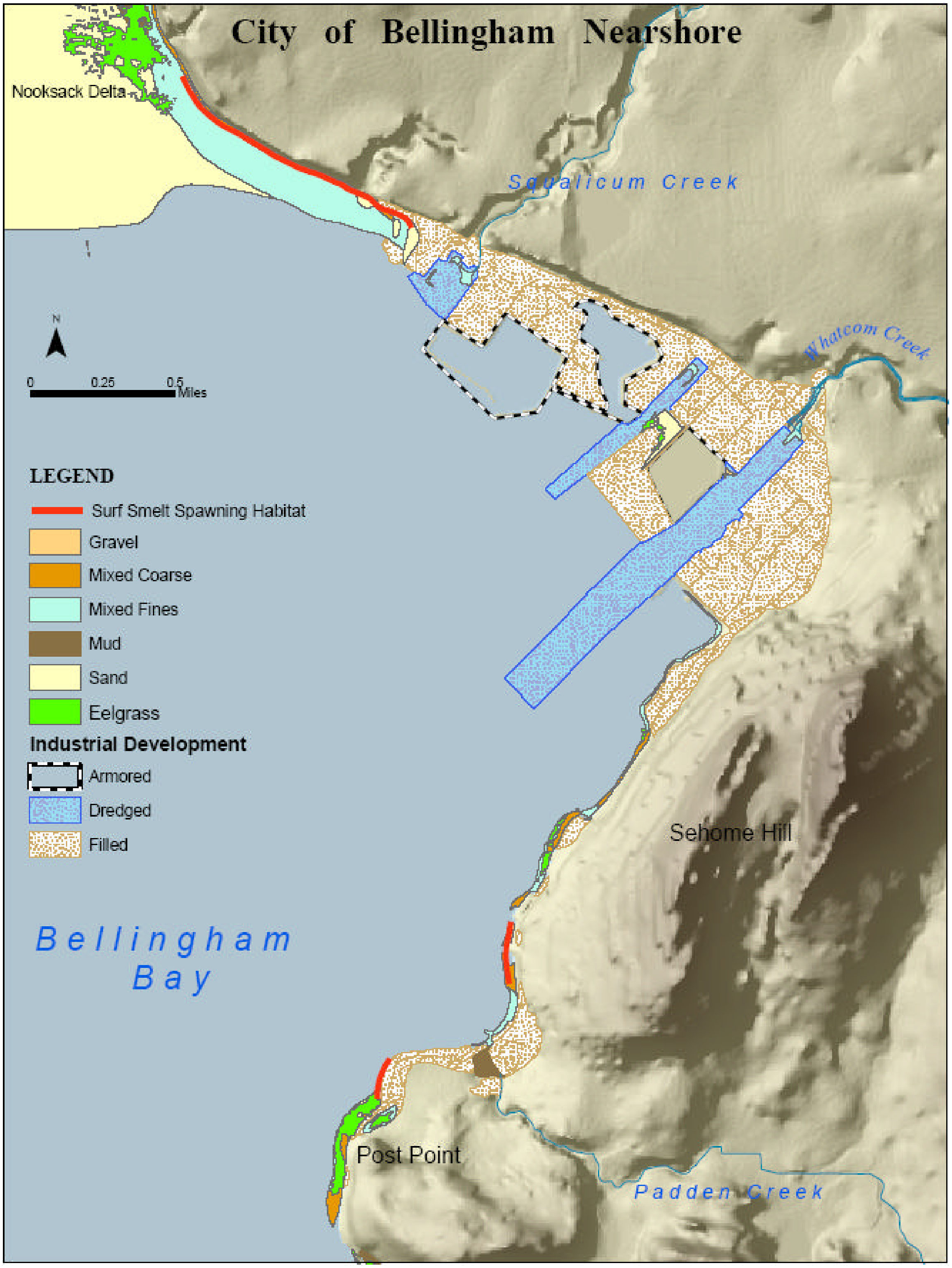


Figure 64. Nearshore habitat in eastern Bellingham Bay.

River Mouth Estuaries and Deltas

River mouth estuaries and deltas are thought to play critical roles in the early life stages of salmon, including rearing (feeding and growth) and refuge from predation and extreme events. Deltas also provide the opportunity for physiological transition and migratory corridors for juvenile salmon progressing into the smolt life history stage (Averill et al 2004). Delta and estuarine habitats have been extensively described in this report; this section focuses on the nearshore habitat of deltas.

<u>Lummi Bay Delta</u>

The Lummi Bay delta has developed a very soft sediment layer atop its tide flat (Figure 65). Once the dominant outlet of the Nooksack River, it accumulated a notable sand flat that filled Lummi Bay. Years of diking and the significant reduction of freshwater influence to the bay have reduced flushing energy here, affording a mud flat community that sustains a healthy eelgrass population. Because large macrophytes cannot attach to loose and shifting substrate, primary productivity can be limited in soft bottom areas. However, eelgrass and some algae species, such as sea lettuce (*Ulva* sp.), can grow on the surface, and microscopic phytoplankton live on and between large silt and clay grains.

Tide flats develop on low gradients where the substrate material is exposed to sorting by wind, current, and wave action. However, the alteration of runoff from the Nooksack River into both Lummi and Bellingham Bays has brought about the most significant change to the processes that shape the deltas. The resulting decrease in discharge into Lummi Bay has contributed to a soft, mud and sand tide flat. The Lummi River delta has been isolated from Lummi Bay by an armored seawall and line of pilings. This section has no appreciable net shore drift and is considered a low erosion hazard due to the armored seawall (WDOE 1991, Johannessen 2003). Extensive mudflats are visible beyond the seawall and a small delta has developed at the mouth of the Lummi River. Since the 1880s, the sand flat in Lummi Bay has advanced toward the seawall as the salt marsh vegetation has receded. This may be related to delta subsidence caused by the loss of the Nooksack River as a sediment source to the delta.

Nearshore habitat in Lummi Bay is some of the best in the Nooksack estuary, in large part due to the expansive eelgrass bed here. The eelgrass meadow established in Lummi Bay is one of the largest in Northern Puget Sound (DNR 1996). Eelgrass plays an important role in the estuarine residence of salmon. Juvenile salmon utilize eelgrass habitat for resting during migration, predator avoidance, and feeding. Herring, an important food item in its larval stage to juvenile salmon, spawn on eelgrass, laying as many as three million eggs on a single blade in the spring (Figure 61) (Hood and Zimmerman 1986, cited in ADFG 2004). Research conducted on cutthroat preying on juvenile salmonids found that predation was significantly reduced in the presence of aquatic vegetation (Gregory and Levings 1996, in Aitkin 1998).

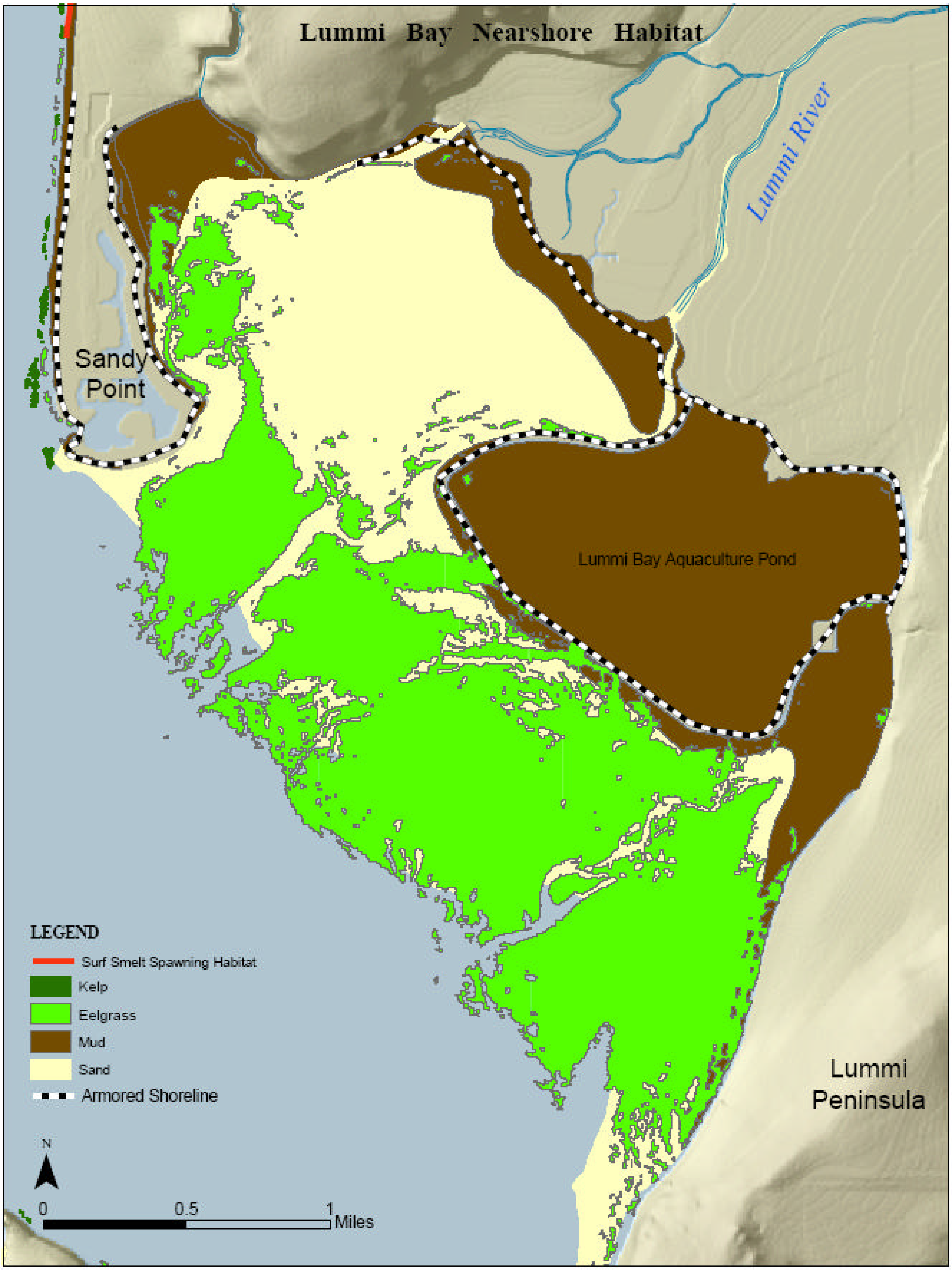


Figure 65. Nearshore habitat in Lummi Bay.

Eelgrass is a keystone species in the nearshore and estuary environment, playing many important roles that build habitat and perpetuate the food web. Like a coral reef or kelp forest, the physical structure of the eelgrass beds provides increased living substrate and cover for invertebrates and fish (Figure 66). The beds also generate food and nutrients for the soft bottom community through primary productivity and plant decay (ADFG 2004). The perennial root and rhizome systems stabilize the fine substrate sediments, buffering the erosive forces of tidal flushing and seasonal storms (McConnaughey and McConnaughey 1985, cited in ADFG 2004). Eelgrass also increases the productivity of soft substrate habitats, by ensuring food and shelter for all the species that forage and hide in the eelgrass (ADFG 2004). Eelgrass indirectly provides food for people by supporting fisheries for Dungeness crab (*Cancer magister*), salmon, and Pacific herring (*Clupea pallasi*) populations (ADFG 2004).

An associated community of worms, isopods, amphipods, shrimp, hermit crabs, gastropods, clams, and other invertebrates graze eelgrass blades for epiphytic diatoms, algae, bacteria, and other food sources (Ricketts and Calvin 1968, cited in ADFG 2004). Shellfish species that are harvested from Lummi Bay habitat include primarily Manila clams (*Venerupis philippinarum*), and secondarily, native littlenecks (*Protothaca staminea*), and heart cockles (*Clinocardium nuttallii*).

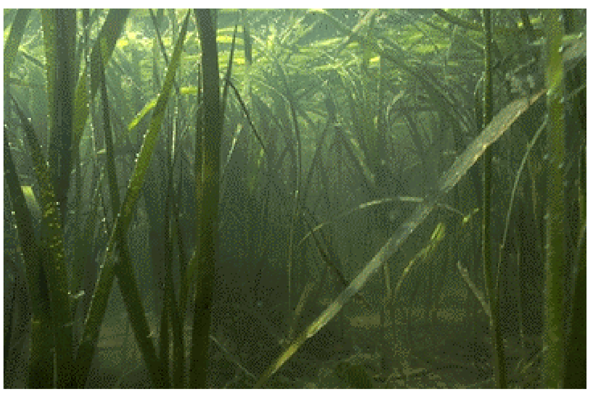


Figure 66. Eelgrass habitat at high tide.

Bellingham Bay Delta

The Bellingham Bay delta of the Nooksack River has been the dominant delta since the mid-1860s, when the river changed its course from Lummi Bay. The nearshore habitat on this delta is dominated by a large sand flat (Figure 67). Tide flats are composed of sediment, usually sand, mud, or a combination of the two. Enclosed bays and protected deltas usually maintain a softer flat, largely comprised of mud and silt. Sandy tide flats are constructed at the fronts of deltas built by high flows and tides, where smaller, lighter sediment is flushed away by currents and waves and heavier sediment is left behind. In the case of the Nooksack River, the abandoned Lummi Bay delta has accumulated finer sediment compared to the Bellingham Bay because of its protected exposure and the loss of coarser sediment deposition by the river.

Exposure and hydrology affect the biological function of tide flats. Flats in exposed, higher energy deltas do not often support abundant plant and animal communities. The interstitial spaces between sandy grains are not large enough to support invertebrate populations. While eelgrass is shown on the eastern fringe of the delta in Figure 67, it is an unlikely location for eelgrass and is possible that it is a detached clump that drifted onto the sand flat while aerial delineations were being made (DNR 1996). In addition, detritus does not build up on sediments that are rolled and sorted constantly. Detritus is essential to biological communities as the lowest link of the food chain. Smaller substrates that accumulate on lower-energy flats are able to support a detritus-based community that maintains invertebrates and macrophytes. Sheltered bay environments, or deltas with low energy exchange between river discharge and tides, are able to sustain a detrital layer on the surface of sediments, and muddy flats result.

Today, the Nooksack Delta bears a predominately sandy tide flat. High discharge from the Nooksack River and diurnal flooding from Bellingham Bay, coupled with predominate winds from the south keep small particles and detritus off of the tide flat and pushed to its edges. As a result, the Nooksack Delta does not maintain aquatic vegetation, and its macroinvertebrate community is very sparse. On this tide flat, large wood lines the nearshore interface along the west and east flanks. Decomposition of this wood adds vital nutrients to the food web. Along the western and eastern edges of the flat, silt, mud and detritus accumulates, and invertebrates were more abundant.

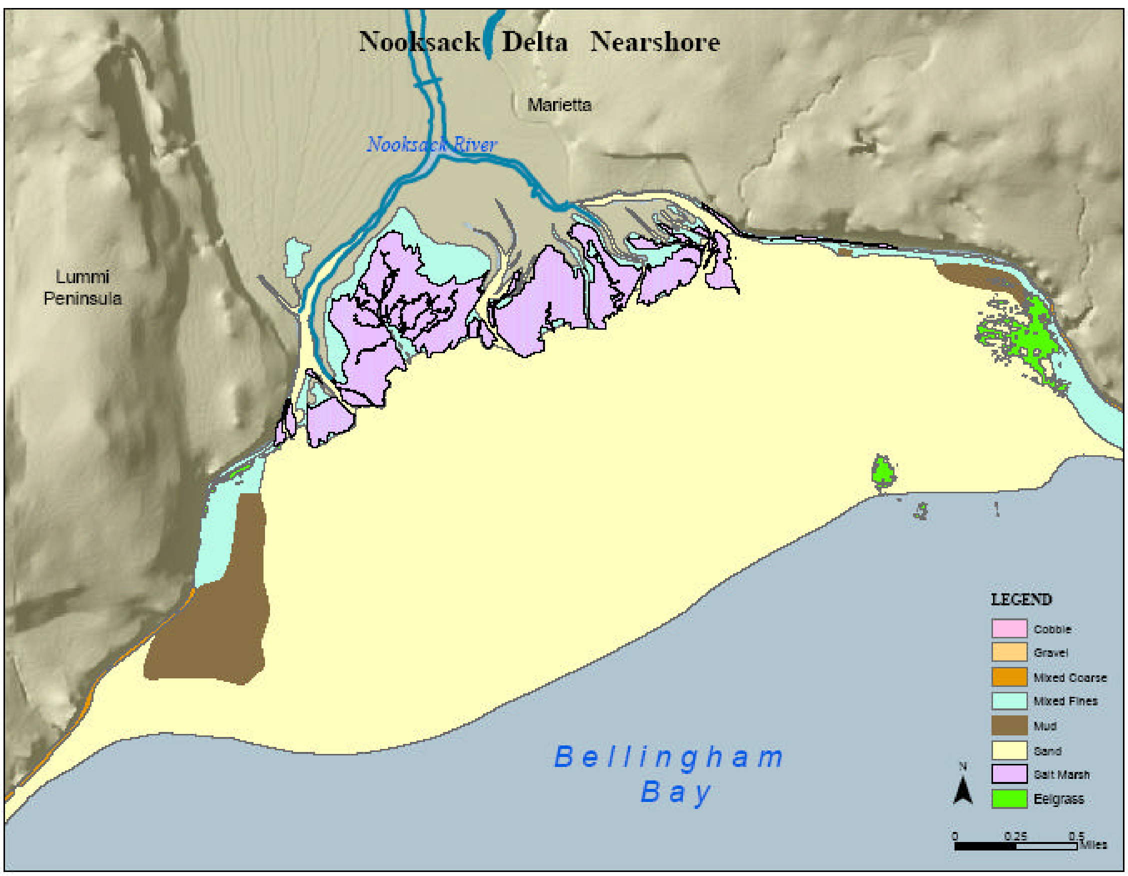


Figure 67. Nooksack Delta nearshore habitat.

Pocket Estuaries

Pocket estuaries are small lagoon systems within larger estuaries and nearshore environments that maintain fresh, brackish, and marine water quality. Tidal channels, along with tide flats and small deltas comprise pocket estuary habitat; in some cases, scrub-shrub and forest vegetation border upland areas. Habitats within pocket estuaries are defined by processes similar to those prominent in larger estuaries, but on a finer scale. Freshwater discharge and the tidal prism unite to create a diverse, low-energy system that supports diverse communities that differ from those found in freshwater and nearshore environments.

Pocket estuaries provide critical functions, including rearing (feeding and growth), refuge from predators and extreme conditions, and opportunities for physiological transition to salt water environments (Averill et al. 2004). Pocket estuaries are utilized by juvenile salmon as resting places along migratory pathways between their natal estuary and the offshore environment. Flood tides extending into upper intertidal areas can provide fish with access to terrestrial insects and detritus that may live in the driftwood line. Ebb tides force juveniles out into the lower intertidal areas, or up into tidal channels within pocket estuaries, if present. Benthic invertebrate foraging is common during this time. Juvenile salmon may seek pocket estuaries to complete osmoregulation if they were not able to do so in their natal estuary, depending on exposure, tidal inundation, and discharge variables.

The Nooksack nearshore contains three pocket estuaries that are utilized by juvenile salmon during the outmigration period of January to August (Figure 68). All three estuaries are located within nearshore areas that have been extensively developed by industrial and urban interests in and around the city of Bellingham. Although their natural function as an estuary has been compromised by development, all three have retained estuarine habitat processes where delta habitat is intact. Juvenile salmon in the nearshore have been caught here (MacKay 2004, in prep.), indicating that these small sub-estuaries may be important habitat to migrating salmon.

Beamer et al. (2003) found that in the Skagit River nearshore, juvenile chinook salmon abundance in pocket estuary habitat was 100 times greater than it was in other nearshore habitats. He also describes chinook use of pocket estuaries in the Skagit River system as 'non-natal,' referring to the presence of this species in pocket estuary habitat when the species does not originate from feeder watersheds. The presence of chinook in Bellingham Bay pocket estuary habitat and the absence of chinook in streams that maintain them, leads us to believe that these sub-habitats serve the rearing needs of migrating juvenile salmon, possibly Nooksack River salmon.

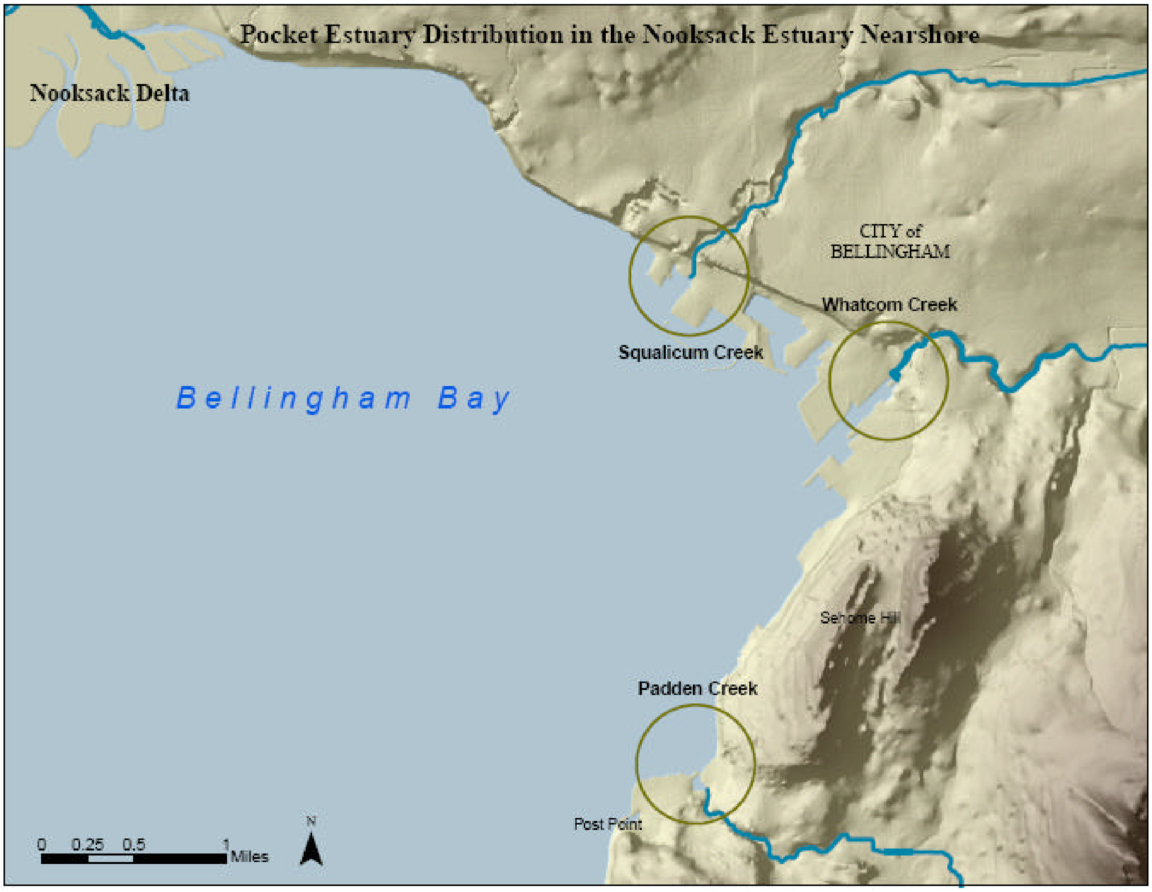


Figure 68. Pocket estuary distribution in the Nooksack River estuary nearshore.

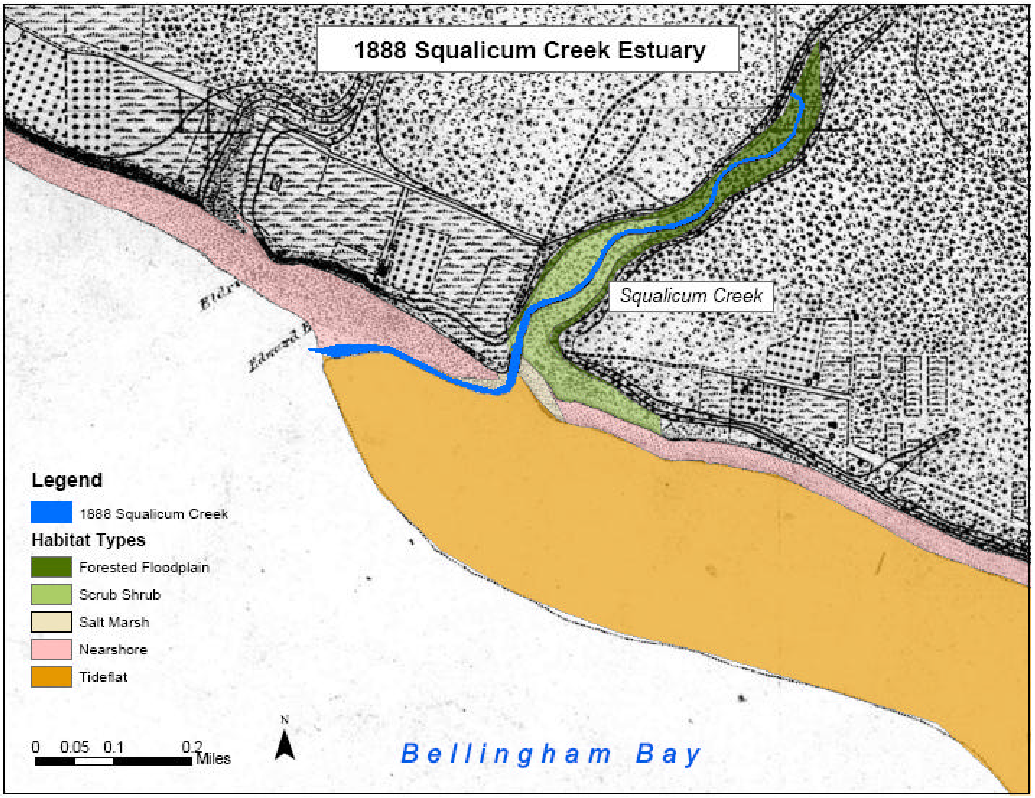
Shoreline development between the late 19th century and today has significantly altered natural habitat processes that maintained these sub-estuaries for fish use. Tide flats and nearshore beaches were dredged and/or filled for the construction of docks and piers, and large sections of the upper intertidal shoreline were fortified to protect uplands from erosion by wind and waves. Important salt marsh habitats were replaced with road easements, a boat harbor, and general construction of buildings along stream banks. Construction of the railroad along the shoreline required heavy fortification also, and substantial sections of shoreline remain packed with large boulders to slow erosional forces of the tides. The elimination of exchange between upland sediment and the tides and drift cells that transport materials along the shoreline for deposition elsewhere has created nearshore habitats that have substituted sand and gravels with large rocks and boulders. Historic pocket estuary habitat change is described in the table below.

Table 5. Historic and current habitat in Bellingham Bay's sub-estuaries, in acres.

	Habitat Type	1888	2004	% Remaining
Squalicum Creek	Salt Marsh	1.6	0.1	3.1
	Tide Flat	24.0	2.1	8.8
	Scrub Shrub	10.6	2.6	24.5
Whatcom Creek	Salt Marsh	3.6	0.7	19.4
	Tide Flat	335.0	1.0	0.3
	Scrub Shrub	1.3	1.8	138.5
Padden Creek	Salt Marsh	13.1	1.0	7.6
	Tide Flat	18.6	3.0	16.1
	Scrub Shrub	0.0	1.4	n/a

Squalicum Creek Estuary

Squalicum Creek estuary is the smallest of the three pocket estuaries in the Bellingham Bay nearshore, but its location is closest to the mouth of the Nooksack River. It is the first estuary refuge encountered by juvenile salmon migrating along the nearshore after leaving the Nooksack Delta. This estuary has undergone many structural changes since development of the area began in the late 1800s, and is severely confined between barriers of bulkheads, docks, and rip rap (Figure 69). Meandering of the stream has been straightened, and the majority of salt marsh and tide flat habitat have been developed for industrial and urban use. What was a pristine pocket estuary 150 years ago is now a small, confined pocket of fractional estuary remnants at the mouth of an urban stream. Fish must navigate around an armored dock facility and into a shipping area to utilize salt marsh and mudflat habitats.



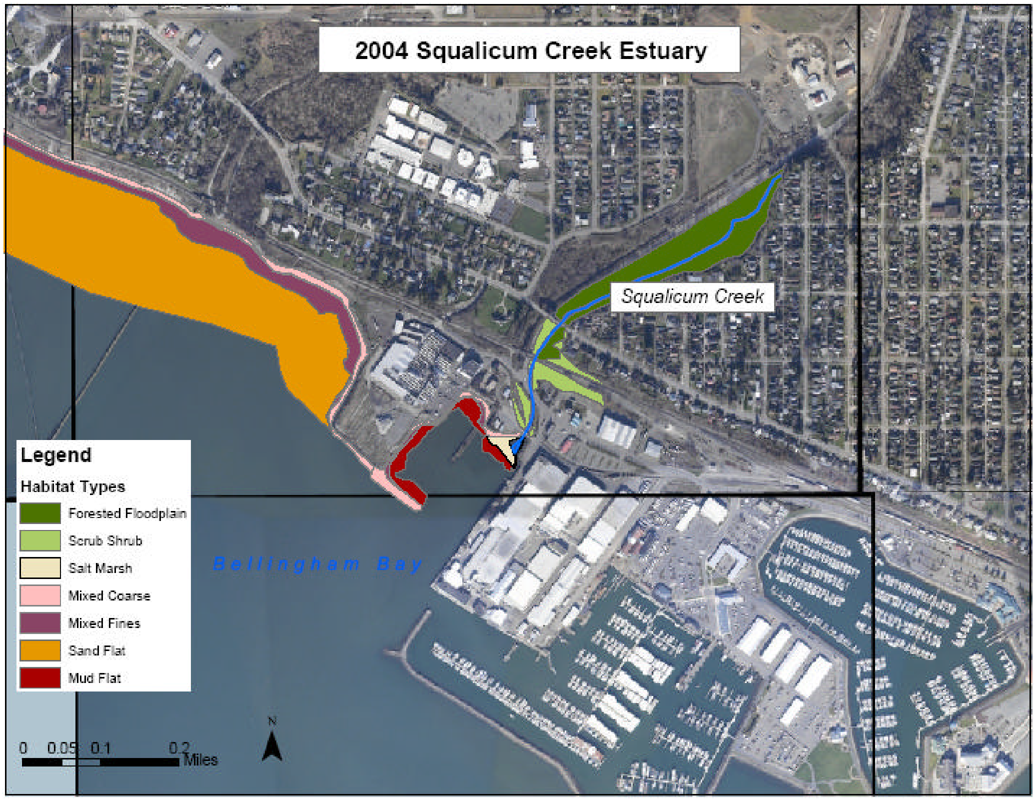


Figure 69. Squalicum Creek estuary in 1888 (top), and in 2004 (above).

Historical use of the Squalicum Creek estuary by natal and migrating salmonids is unknown. We assume that Squalicum Creek's location near the mouth of the Nooksack River made it a nearshore refuge for outmigrating Nooksack salmon. The stream's small size and historic tide flat and salt marsh habitat along the shoreline created a low-energy feeding refuge for nearshore species. Squalicum Creek salmon stocks today include coho and chum salmon, and steelhead and cutthroat trout (WSR 2003). Additionally, LNR stock assessment efforts in the area have observed chinook juveniles using habitat at Squalicum Creek nearshore sites.

Whatcom Creek Estuary

Whatcom Creek estuary is adjacent to the Squalicum Creek estuary, and is a nearshore refuge for juvenile salmon. Like Squalicum Creek, this estuary has been dramatically impacted by urban and industrial development and its habitat has been severely compromised (Figure 70). The historic Whatcom Creek estuary was small in comparison to the Squalicum or Nooksack estuaries, but it maintained an expansive tide flat that buffered tidal energy from the shoreline and supported benthic invertebrates, making this section important for juvenile salmon seeking food and shelter resources.

Whatcom Creek estuary is utilized primarily by chum salmon, and secondarily by chinook (MacKay). It is important to note that at the mouth of Whatcom Creek is a fish hatchery that produces several million chum salmon every year. Chum salmon fry are important food resources for juvenile chinook salmon (Hart 1980, Healey 1998). The release of chum salmon fry into the Whatcom Creek estuary accounts for high populations of this species, and may be a factor in the increased juvenile chinook populations seen here in 2003 and 2004 (MacKay 2004, in prep.).

Salt marsh and tide flat habitat has been reduced by development in Whatcom Creek. However, recent Whatcom Creek estuary restoration projects by the City of Bellingham and local non-profit groups include restoring the shoreline profile on a small scale to increase mudflat and salt marsh area usable by fish, and planting and seeding native salt marsh species along the northern corridor of the estuary.

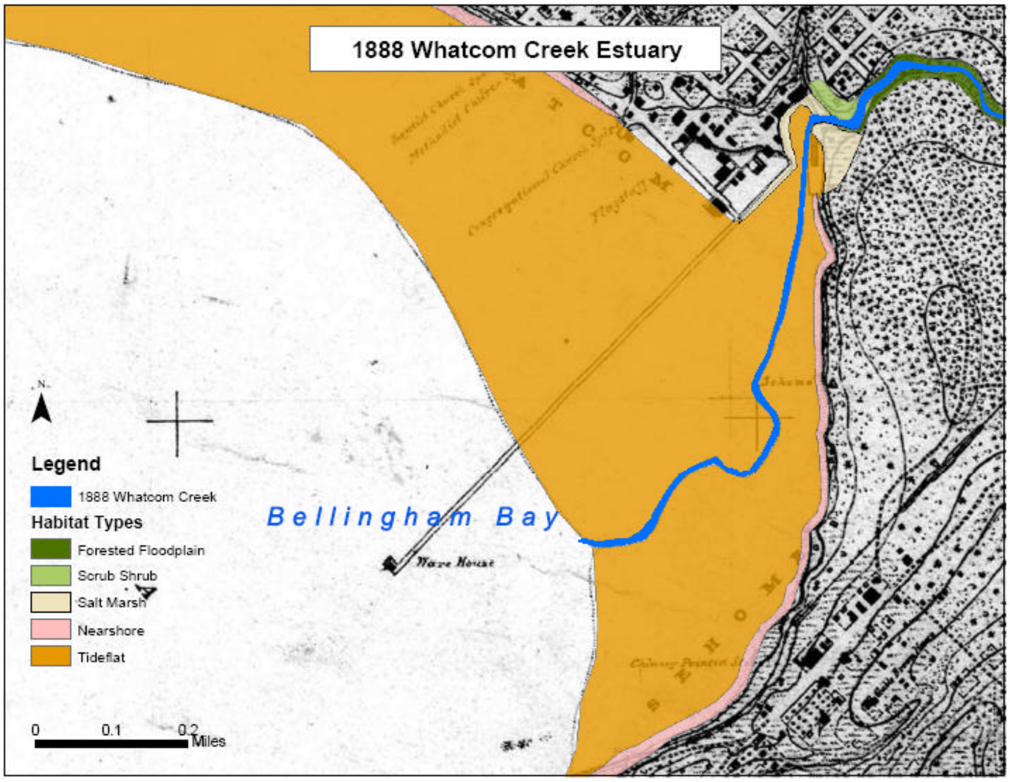
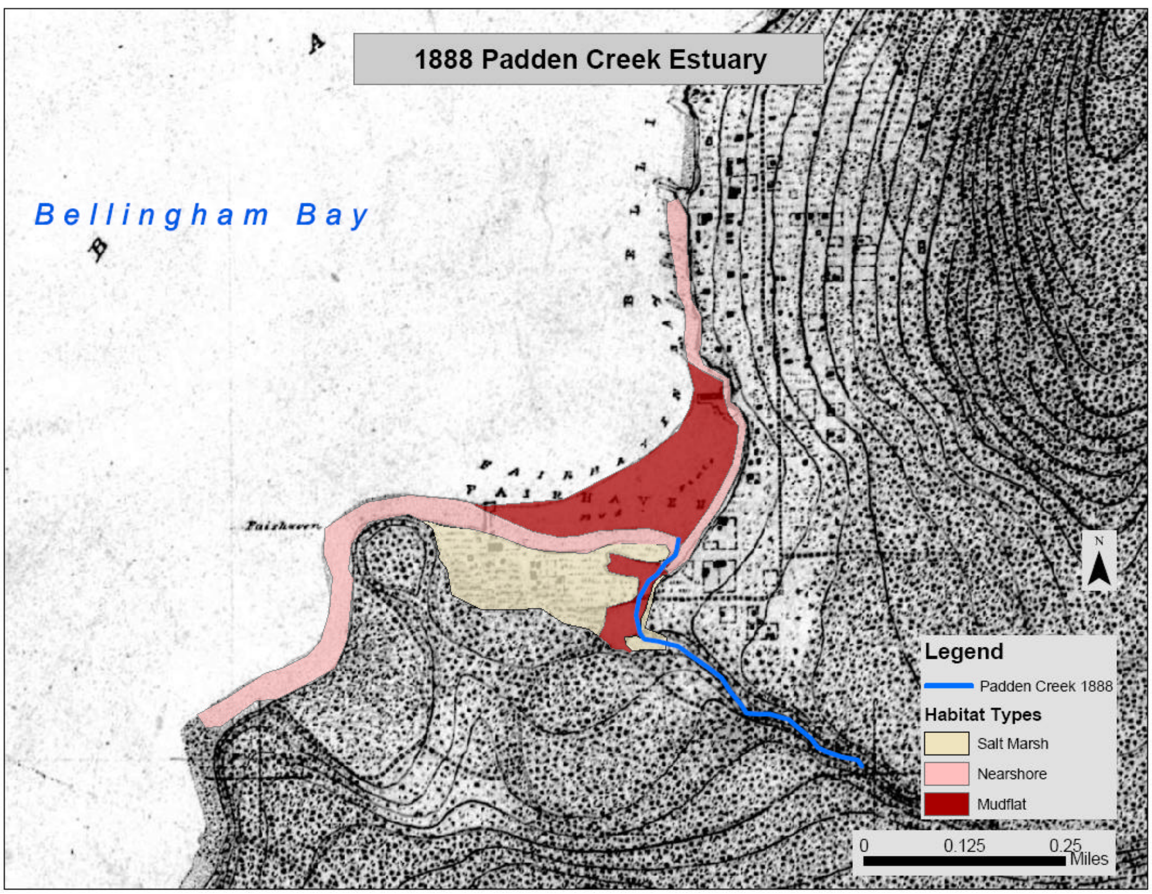


Figure 70. Whatcom Creek pocket estuary in 1888 (top), and in 2004 (above).

Padden Creek Estuary

Padden Creek estuary is located on the southeast shoreline of Bellingham Bay in the Fairhaven district of Bellingham. Historically, it was a small lagoon with notable salt marsh habitat along its southern flank (Figure 71). Although we know that today chinook, chum, and coho salmon, as well as cutthroat and steelhead trout use Padden Creek, historic fish use is unknown. In 2003 and 2004, juvenile coho and chinook use of the small delta and nearshore here was sparse, but chum use was notable (MacKay 2004, in prep.).

Padden Creek estuary has a large mudflat that supports many benthic invertebrates, a primary food source for juvenile salmon (Schabetsberger et al. 2003, Koehler et al. 2000). Vegetation is sparse, both aquatic and terrestrial, mainly due to the extensive removal of native vegetation and subsequent development all around the lagoon. Eelgrass at the mouth of Padden Creek was once lush; today, it is nearly non-existent (Wahl 2004). A small lagoon southwest of the Padden Creek estuary maintains a large mudflat and ample eelgrass at its entrance. Fish use here is key; chinook populations were high in 2004, and chum salmon juveniles are always abundant (MacKay 2004, in prep.). This environment is transitory for juvenile salmon, as the freshwater input to this lagoon is intermittent and does not support native runs of fish.



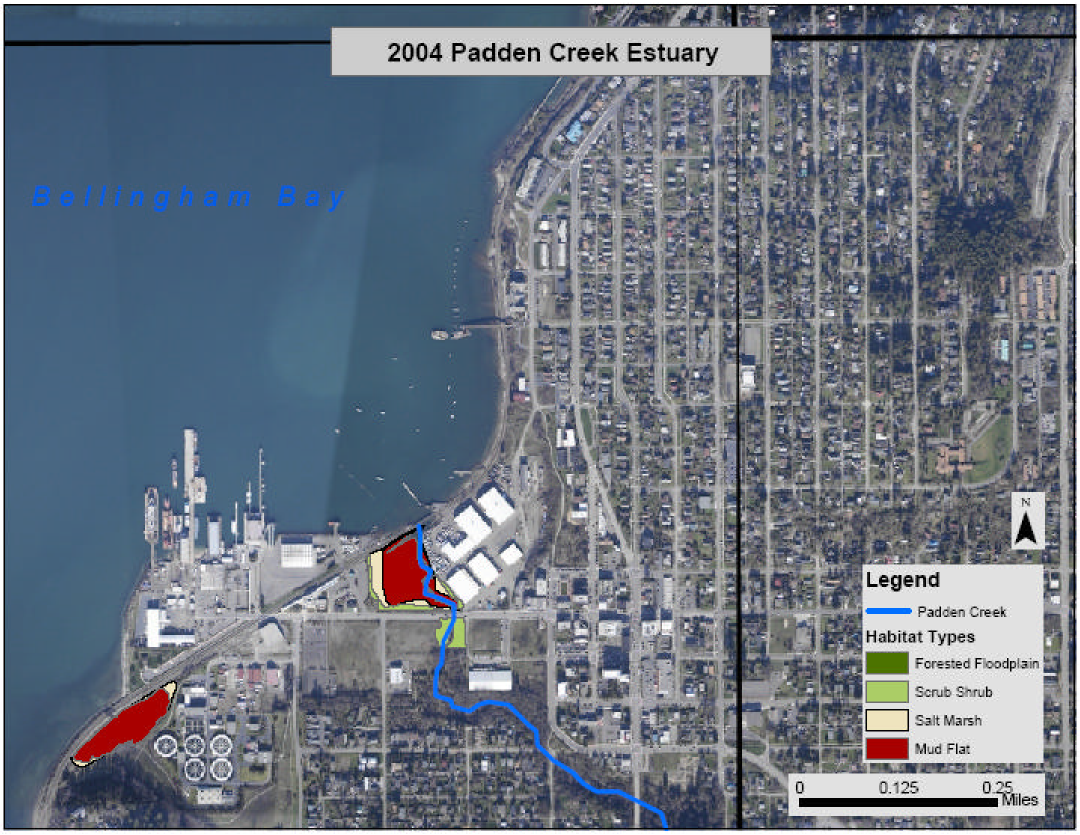


Figure 71. Padden Creek pocket estuary in 1888 (previous page), and in 2004 (above).

Nearshore area associated with the Nooksack River estuary provides a variety of habitat types for rearing and migrating juvenile salmon. The diversity of habitat types is important to meet the needs of the different life history strategies of Pacific salmon. Habitat restoration in the nearshore should focus on improving and protecting habitat across all habitat types. Development of the shoreline here has negatively impacted all pocket estuary habitat, making it the most limited of the nearshore habitat types. Restoration projects focused on improving the estuaries of Squalicum, Whatcom, and Padden creeks will greatly benefit salmon life histories that rely on these habitats for rearing. Exposed and protected shorelines that are currently undeveloped should be protected to ensure that the habitat formation in these areas is preserved. Restoration projects have the potential restore the productive capacity of degraded nearshore habitats.