SKAGIT BAY NEARSHORE HABITAT MAPPING

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June 2006

INTRODUCTION

Juvenile Chinook salmon travel through and utilize nearshore habitats as part of their life cycle. An understanding of how Skagit Chinook salmon utilize nearshore habitats, and how landscape processes and land uses determine and impact nearshore habitats, is necessary for the successful recovery of Skagit Chinook salmon. A study (Greene et al. 2005) using environmental data and adult returns of wild Skagit Chinook salmon has shown that factors present during the nearshore life stage (i.e., when juvenile Chinook are present in Skagit Bay and the Puget Sound fjord estuary) significantly influence adult recruitment, further supporting the need to understand the nearshore ecosystem and its role in the recovery of Puget Sound Chinook. Skagit River System Cooperative (SRSC) has begun an inventory and evaluation of nearshore habitats within Skagit Bay, Washington (Figure 1) as part of Skagit Basin-wide efforts to protect threatened Skagit Chinook salmon. This paper outlines nearshore habitat mapping methods to characterize substrate, vegetation, shoreline materials, and shoreline modifications. These data will be utilized to develop a landscape process based nearshore habitat model for estimating habitat potential and predicting the results of habitat and geomorphic process-based restoration efforts. These data will also be linked to fish distribution data to determine biotic response to habitat conditions.

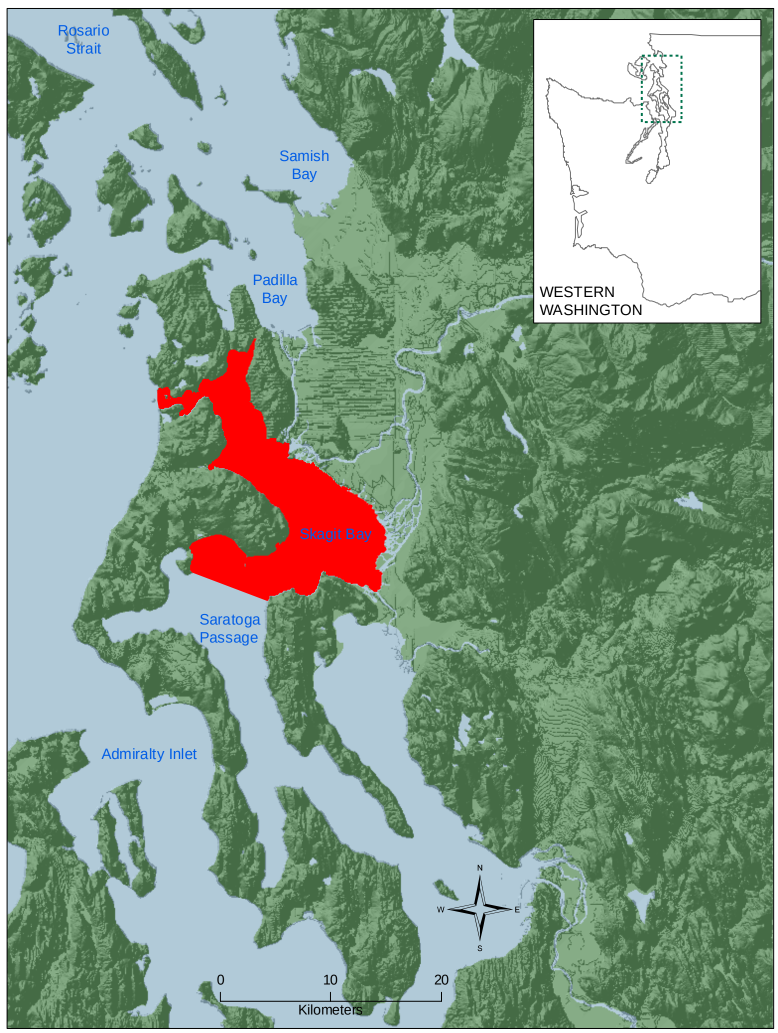

Figure 1. Location of Skagit Bay Nearshore Mapping Area.

PREVIOUS MAPPING

SRSC nearshore habitat mapping built upon the nearshore mapping work of the Washington State Department of Natural Resources (DNR) and researcher Ralph Keuler. The DNR completed an inventory of substrates and vegetation types in 1996 based on field mapping and remote sensing using Compact Airborne Spectral Imager (CASI) data (Berry and Ritter, 1997). The mapping by DNR was based on the nearshore habitat classification scheme developed by Dethier (1990). The DNR habitat inventory covered most of Skagit County, including the northern half of our Skagit Bay study area. Keuler (1979) completed a shoreline type map for the Skagit County portion of the study area for his master's thesis in geology. Keuler's shoreline classification focused on coastal geomorphology and sediment transport. These data and classification methods were used by SRSC as a model for mapping previously unmapped shorelines in Skagit Bay and refining the resolution of previously mapped areas.

DATA COLLECTION METHODS

Defining Habitat Zones

SRSC has adopted a regionally accepted definition of nearshore: the shoreline, intertidal, and shallow subtidal habitats of inland marine waters (Puget Sound, Georgia Strait and the Strait of Juan de Fuca, also known as the Salish Sea) extending to the edge of the photic zone and/or the extent of nearshore currents. We further divide the nearshore and adjacent geography into habitat zones based on tidal elevation (Table 1).

Because many juvenile Chinook salmon are shoreline-oriented during their outmigration period, especially during late winter and spring months (Beamer et al. 2005), and because intertidal habitats are easily changed by natural processes and human actions, the SRSC habitat inventory focused on the intertidal zone to start its nearshore habitat inventory. The intertidal zone is defined as the area between mean higher high water (MHHW) and extreme low water (ELW). Because our nearshore habitat mapping objective was to examine habitats potentially utilized by juvenile Chinook salmon after they leave their natal river delta, the Skagit delta was an exception to our general method of mapping the intertidal zone. Along the front edge of the Skagit River delta, we mapped only from the lowest extent of tidal marsh vegetation (approximately 6 feet tidal elevation, or mean tide level (MTL)) to ELW within the intertidal zone of the delta. Juvenile Chinook salmon utilize delta habitats "upstream" of the line drawn by this mapping project. However, our habitat mapping methods are different for the emergent marsh, estuarine scrub-shrub, and forested riverine tidal zones of the Skagit delta than those described in this document for nearshore habitat in Skagit Bay. Methods and results for the "upstream" part of the Skagit delta are reported in Beamer et al. (2005).

The National Oceanographic and Atmospheric Administration (NOAA) determined tidal datums and established tidal benchmarks at two sites in Skagit Bay for the purposes of this project and other high-resolution shoreline habitat mapping (Table 2). Vegetation within the intertidal zone is largely determined by tidal elevations. Substrates also are correlated to tidal elevations because wave energy impacts intertidal substrates differently depending on the ratio of water depth to wave amplitude. Energy differences equate to substrate grain size and grain sorting differences. We plan to utilize the relationships observed between tidal elevation and vegetation and substrate types to develop some empirically based rules regarding habitat composition and tidal elevation. We are in the preliminary stages of creating and analyzing detailed beach cross-section data.

Table 1. Habitat zones within and adjacent to the nearshore.

Watershed	Land above the upper limit of saltwater influence, above the coastal floodplain.
Backshore	Coastal deposits above MHHW that are still actively influenced by coastal processes and shoreline area above normal wave activity (MHHW), but within reach of storm waves (EHW). Can be spits, tombolos, cusps, barrier islands, backbeach berms, dunes, cliffs or bluffs, or engineered structures like bulkheads.
Intertidal	The area between MHHW and ELW, further divided into: beachface, low tide platform, channel, impoundment, emergent marsh, scrub shrub wetland, and forested wetland.
Subtidal	The area below ELW.

Table 2. Tidal datums in Skagit Bay. Tidal datums change over space and time, with sea level. The NAVD88 datum is fixed.

	Meters		Feet	
	Turners Bay	*Lone Tree Point*	*Turners Bay*	*Lone Tree Point*
Mean Higher High Water (MHHW)	3.165	3.377	10.38	11.08
Mean High Water (MHW)	2.887	3.099	9.47	10.17
Mean Tide Level (MTL)	1.841	1.957	6.04	6.42
Mean Sea Level (MSL)	1.816	1.945	5.96	6.38
Mean Low Water (MLW)	0.796	0.814	2.61	2.67
No. American Vertical Datum (NAVD88)	0.505	0.65	1.66	2.13
Mean Lower Low Water (MLLW)	0.000	0.000	0.00	0.00

Substrate Mapping

The substrate and vegetation inventory involved mapping 100% of the shoreline from Deception Pass to Crescent Harbor-Rocky Point along Saratoga Passage. We mapped substrates in the field on printed aerial photos, using a mapping-grade global positioning system (GPS) unit to verify the locations of substrate changes. We described substrates by visually estimating the percent of surface area covered by a specific sediment clast size within a relatively homogeneous area.

Initially, visual estimation skills were calibrated by using a section quadrat to systematically estimate percent cover for substrate grain size. The general location of substrate polygons is accurate to within 3 meters. Most contacts between substrate types were gradational and are likely to shift seasonally with changes in wave energy magnitude and direction. SRSC substrate data are available digitally by request. Digital data include GIS polygons of mapped features attributed with substrate class (type), method of data collection, and GIS metadata. Figure 2 is a map of substrate data.

Substrate types are defined following the type classification of Dethier as implemented by Berry and Ritter (1997), with some modifications (Table 3). We labeled Dethier's *organic* substrate *saltmarsh* or *spit-berm*, as applicable, if the substrate could not be determined by surface examination because of the density of vegetation. In most cases we could separate vegetation to identify the substrate. We also added a substrate type for *fines with gravel*, which was a substrate combination not defined by Berry and Ritter. We found the *fines with gravel* substrate to be distinct from *mixed fines* and *mixed coarse* categories because of a higher percentage of coarse sediments compared to *mixed fines* and a higher percentage of fine sediments compared to *mixed coarse* substrates.

Table 3. Substrate classes.

Bedrock	>75% of the surface is covered by bedrock of any composition, commonly forming cliffs and headlands.
Boulder	>75% of the surface is covered by boulders >256mm in diameter.
Cobble	>75% of the surface is covered by clasts 64mm-256mm in diameter.
Gravel	>75% of the surface is covered by clasts 4mm-64mm in diameter.
Mixed Coarse	>75% of surface area is sand, gravel, cobble and boulder and cobbles and boulders make up >6% of the surface area.
Fines With Gravel	Fines (sand, silt, and mud) make up <75% of the surface area. Cobbles and boulders make up more than 6% of the surface area **and** gravel makes up >15% of the surface area.
Sand	>75% of the surface area consists of sand 0.06-4mm in diameter.
Mixed Fines	Fine sand, silt, and clay comprise >75% of the surface area, with no one size class being dominant. Gravel <15% and cobbles and boulders make up <6% of the surface cover. May contain shells. Walkable.
Mud	Silt and clay comprise >75% of the surface area. Often anaerobic, with high organics content. Tends to pool water on the surface and be difficult to walk on.
Driftwood	Accumulation of driftwood in the intertidal or back beach zones where >75% of the surface is large wood.
Artificial	Anthropogenic structures replacing natural substrate within the intertidal zone, including boat ramps, jetties, fill, and pilings.

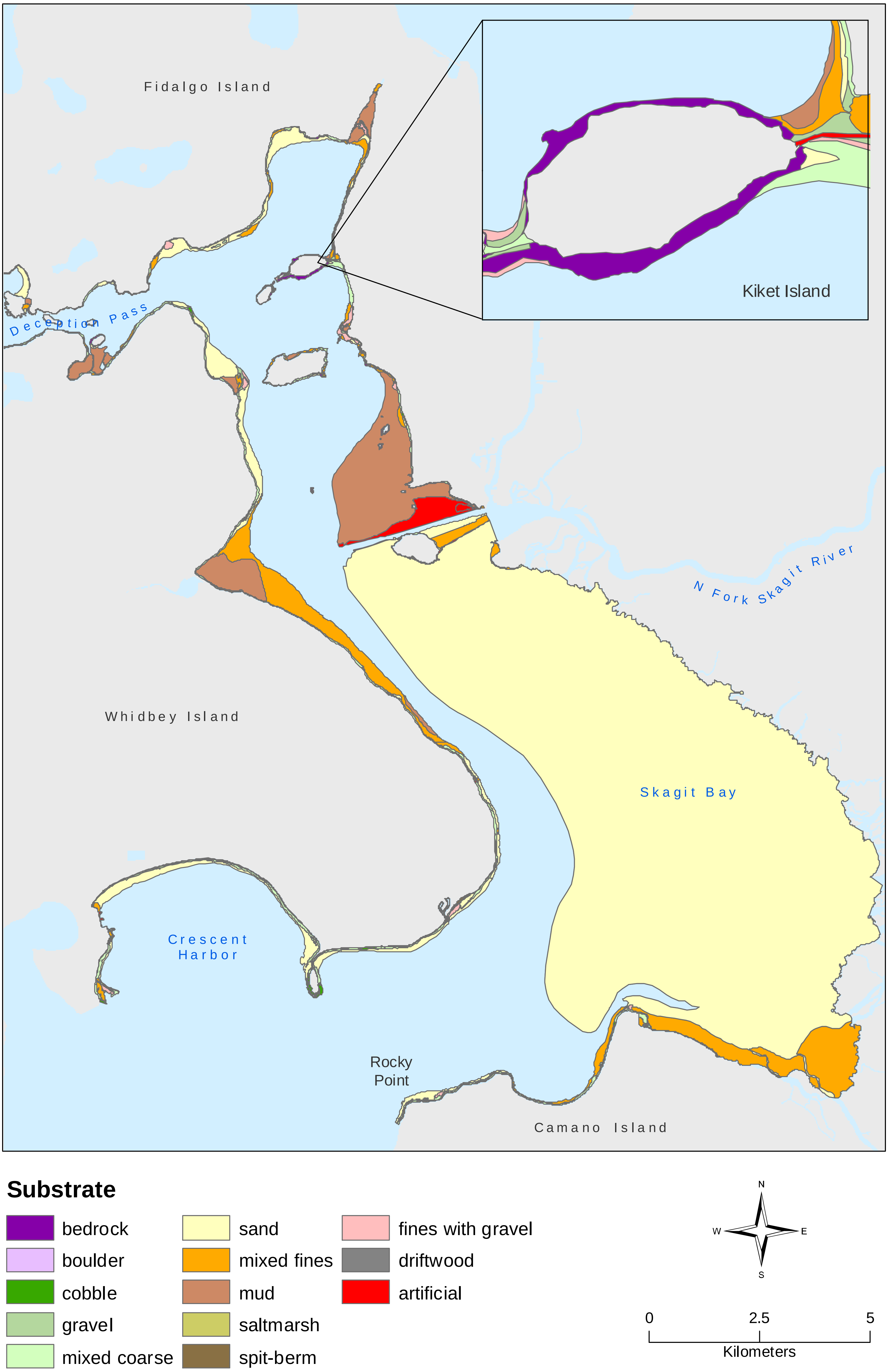

Figure 2: Substrates mapped in Skagit Bay.

Vegetation Mapping

Vegetation types were mapped by a combination of field mapping and aerial photo interpretation using high resolution color and color infrared orthophotos. Specific methods for mapping each polygon and the photo set upon which it was mapped are included in the digital map data. Vegetation was described by visually estimating percent cover within a vegetation bed or within a quarter-meter square frame placed at a representative point within the bed. GPS reference points validated geographic positions during field mapping. Vegetation data are available digitally by request. Digital data include GIS polygons of mapped features attributed with vegetation classes (see Table 4), method of data collection, and GIS metadata. Figure 3 is a map of vegetation data. Some vegetation polygons extend into the back beach and subtidal zones, as interpretation of aerial photos and photo resolution allowed. Vegetation maps were field-checked for accuracy; however, vegetation features change more frequently than substrates.

Table 4. Vegetation classes

Eelgrass	More than 75% of the vegetative cover is beds of *Zoster marina*, *Zoster japonica*, *Phyllospadix spp*. and *Ruppia maratima.*
Brown Algae	More than 75% of the vegetative cover is brown algae including *Fucus spp.* and *Sargassum muticum* (Division Phaeophyta).
Kelp	More than 75% of the vegetative cover is large brown algae (*Order Laminariales*), including floating kelp (*Nereocystis luetkeana*).
Green Algae	More than 75% of the vegetative cover is algae belonging to the taxonomic group Division Chlorophyta, including *ulva.*
Red Algae	More than 75% of the vegetative cover is algae belonging to Division Rhodophyta, including nori. (Note: Areas dominated by red algae that are large enough to map at air photo resolution rarely occur in the summer in the intertidal zone.)
Mixed Algae	Areas in which red, green or brown algae coexist, but no single type occupies more than 75% of the vegetated cover.
Saltmarsh	More than 75% of the vegetative cover is emergent wetland plants including *Salicornia, Distichlis* and *Carex* sedge.
Spit- Berm	More than 75% of the vegetative cover is plants such as dune grass, gumweed, and yarrow, which generally occur above the highest tides, but still receive salt influence.

Figure 3: Vegetation mapped in Skagit Bay.

Shoreline Types and Shoreline Modifications

Natural shoreline characteristics (Table 5) were digitized from Keuler (1979) and Dragovich et al. (2000), and then field-verified (Figure 4).

Modifications to the shoreline and within the intertidal zone (Table 6) were mapped by GPS and aerial photo interpretation (Figure 5). Bulkheads were mapped using GPS. All GPS data were post-processed using Skagit County base station correction files. Dikes and overwater structures such as docks and fish net pens were more easily mapped by digitizing over aerial photos. Shoreline modifications were classified by construction material (concrete, pilings, natural driftwood, tires, etc.). Overwater structures were not classified, but the digital data includes a text description of each feature (Figure 6).

Table 5. Shoreline types.

Artificial	Dredge spoil deposits, causeway fill, or other fill, located within the intertidal zone and forming an artificial shoreline. These are new shorelines where none existed previously, rather than modified natural shorelines.
Bedrock	Back beach and watershed zones are comprised of bedrock (any slope, ranging from cliff to gentle ramp).
Channel	Stream and river distributary channels intersecting the back beach-intertidal boundary.
Coastal Deposits	Accretion shore forms with back beach and immediately adjacent watershed zones comprised of recent (last 500 years) wave-deposited sediments. These include spits, tombolos, beach dunes and barrier beaches.
Low Bank	Unconsolidated sediments forming a low-relief shoreline, usually along major river flood plains or tidal flood plains.
Marsh	Diffuse shoreline of estuarine marsh/wetlands in the intertidal zone, grading to tidal wetlands (tidal hydraulics, but no freshwater/saltwater mixing) and then freshwater marsh in the watershed zone.
Sediment Bluff	Unconsolidated, cohesive sediments forming bluffs or steep banks.

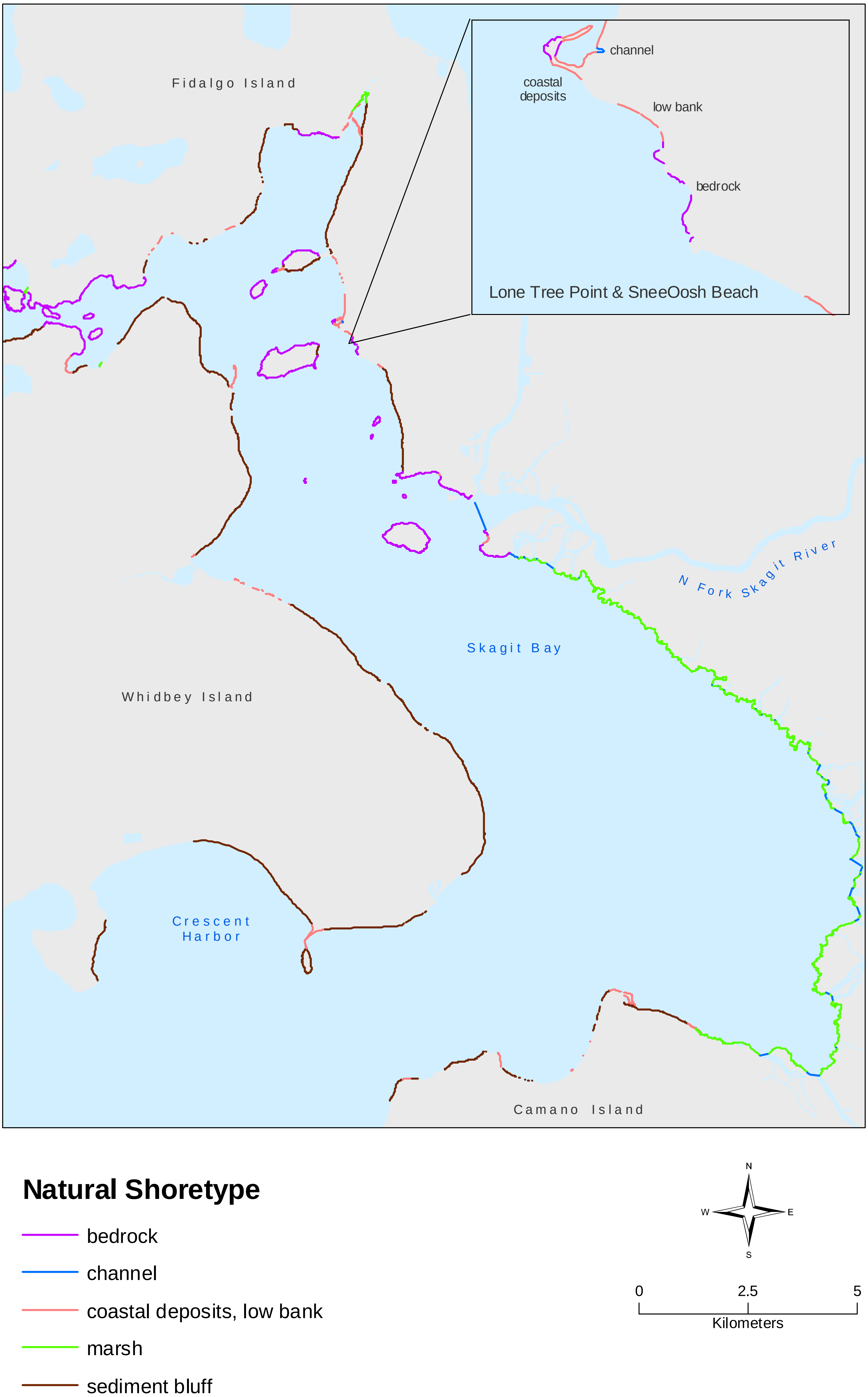

Figure 4: Natural shoreline types mapped in Skagit Bay.

Table 6. Shoreline modifications.

Anchored Driftwood	Sloped, permeable shoreline armoring made of permanently anchored driftwood, located at or below the pre-existing land-water interface.
Boat Ramp	Concrete boat ramps overlying natural shoreline materials.
Causeway	Road fill located within the intertidal zone and forming an artificial shoreline. These are new shorelines where none existed previously, rather than modified natural shorelines.
Concrete Bulkhead	Vertical, impermeable shoreline armoring, made of cement or creosoted timbers located at or below the pre-existing land-water interface.
Dike	Sloped, impermeable, linear feature made of fill and boulders, located at or below the pre-existing land-water interface.
Dredged	Historic intertidal zone areas that have been dredged to subtidal depths.
Dredge Spoils	Dredge spoil deposits located within the intertidal zone and forming an artificial shoreline. These are new shorelines where none existed previously, rather than modified natural shorelines.
None	No structural shoreline modification located at or below the land-water interface.
Piling Bulkhead	Vertical shoreline armoring made of treated wood pilings located at or below the pre-existing land-water interface.
Pilings with Riprap	Vertical shoreline armoring made of treated wood pilings with riprap in front of the pilings, located at or below the pre-existing land-water interface.
Riprap	Sloped, impermeable shoreline armoring made of boulders and/or other large, solid materials located at or below the pre-existing land-water interface.
Tidegate	Closable culvert controlling tidal flow into and out of a tidal wetland.
Tires	Sloped shoreline armoring made of tires, located at or below the pre-existing land-water interface.

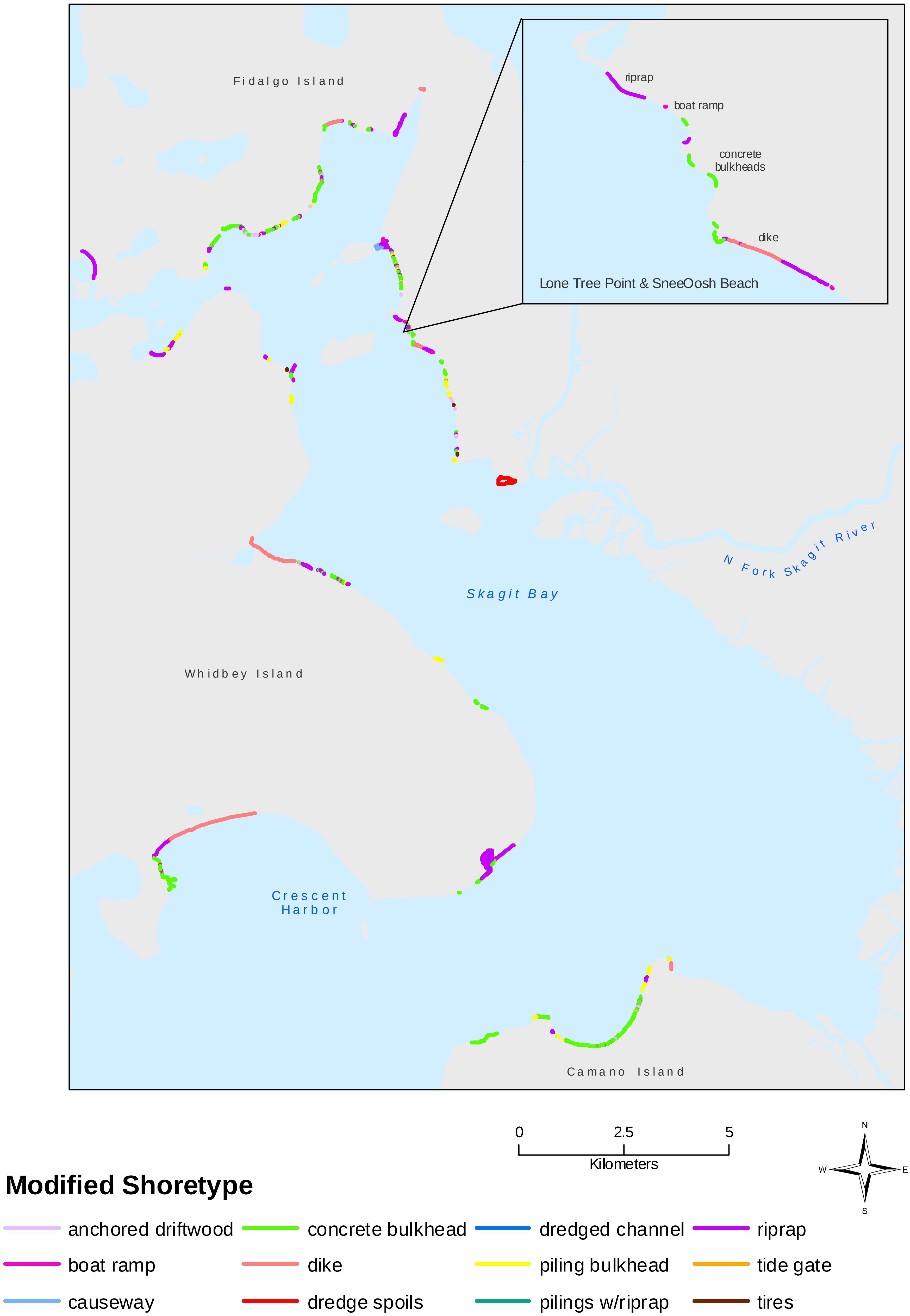

Figure 5: Modified shoreline types mapped in Skagit Bay.

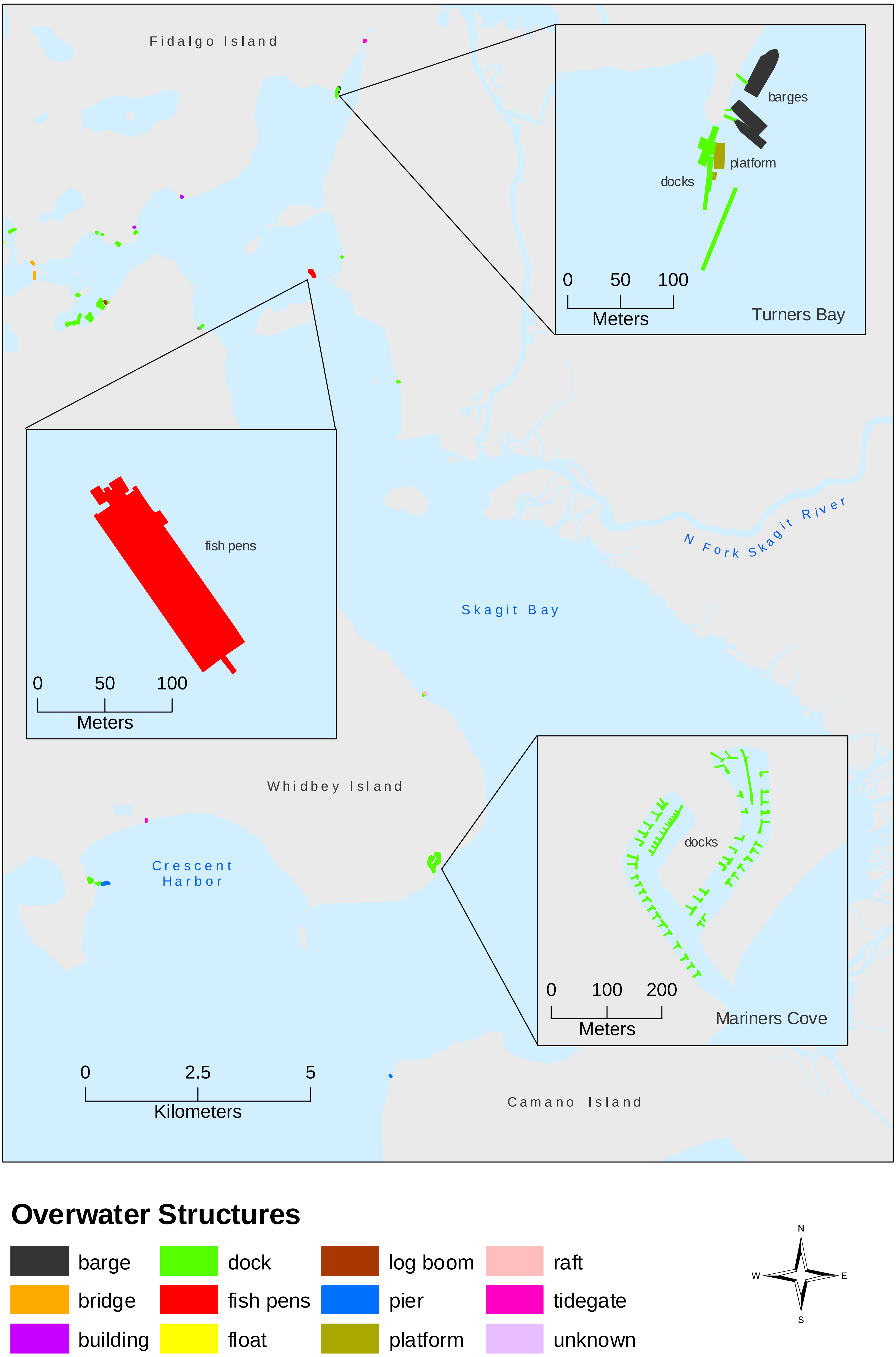

Figure 6: Overwater structures mapped in Skagit Bay.

RESULTS

Individual maps for vegetation, substrate, shore types, and overwater structures are presented above. These are also available as digital data in ArcGIS shapefile format. The following general analysis of nearshore habitat conditions applies to mapped areas of Skagit Bay excluding the Skagit River delta front. In general, approximately 35% of the intertidal zone is vegetated. The amount of eelgrass in Skagit Bay is 7,033 acres (Table 7). Most of this is in eelgrass meadows along the Skagit delta front. Only canopy-forming vegetation was mapped in the subtidal.

Sediment beaches comprise 73% of the non-delta shoreline (Table 7). A coarse (gravel to cobble) sediment beachface grading to a fine (sand to mud) sediment low tide platform typifies sediment beaches in Skagit Bay. Bedrock beaches, making up 27% of the non-delta shoreline, are most commonly plunging rock cliffs.

In total, 24% of the shoreline is modified (again, not including the upper intertidal delta front, which is almost completely modified by dikes). Table 8 summarizes the percentage of each shoretype that has been modified by shoreline armoring, boat ramps, or fill. Data are presented as a percentage of a given natural shoretype. Low bank and coastal deposits have been most impacted by shoreline armoring. Based on historic reconstructions of some nearshore areas, most of the low bank shorelines are actually modified coastal deposits.

Table 7. Area of intertidal vegetation and substrate.

Vegetation Type	Acres
brown algae	18.9
green algae	623.1
red algae	0.1
eelgrass	7033.2
kelp	73.3
mixed algae and/or eelgrass	62.1
saltmarsh vegetation	64.2
spit-berm vegetation	45.9

total intertidal acres **21839.3**

Substrate Type	Acres
artificial substrates	211.7
boulders	11.4
cobbles	26.8
driftwood	19.1
fines with gravel	76.1
gravel	200.3
mixed coarse	340.8
mixed fine	1498.4
mud	1503.8
bedrock	65.0
sand	17885.8

Table 8. Percent modified shoreline for each shoretype.

Bedrock	1.3%
Sediment bluff	12.4%
Low bank	75.7%
Coastal deposits	48.8%
Marsh	15.1%

CONCLUSIONS

Patterns in nearshore habitats, as defined by vegetation and substrate, are determined by landscape processes plus human land uses. Biota respond to habitat conditions as determined by landscape processes and land uses. We plan to construct a landscape-process-based model for remotely determining nearshore habitat types or geomorphic units. Vegetation and substrate as mapped in Skagit Bay provide a basis for identifying habitat patterns and correlating habitats with landscape processes and land uses. We will test the applicability of the geomorphic model and habitat correlations in other parts of Puget Sound, starting with all of Whidbey Basin and Hood Canal.

Another outcome of this study is a quantitative picture of eelgrass meadows in Skagit Bay. The amount of eelgrass in Skagit Bay (7,033 acres) is comparable to the area of eelgrass in Padilla Bay (just under 8,000 acres). Most of this is in eelgrass meadows along the Skagit delta front. As Padilla Bay eelgrass beds are the focus of extensive study and protections, Skagit Bay may also present an opportunity for protecting eelgrass habitat. SRSC has begun a cooperative study with the United States Geological Survey (USGS) to evaluate historic changes and plant health within the Skagit delta meadows.

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FUNDING ACKNOWLEDGEMENTS

Partial funding for nearshore habitat mapping was provided by Seattle City Light. Additional funding was provided by the Northwest Indian Fisheries Commission through two funding initiatives: Pacific Salmon Treaty Implementation and Pacific Coastal Salmon Recovery.