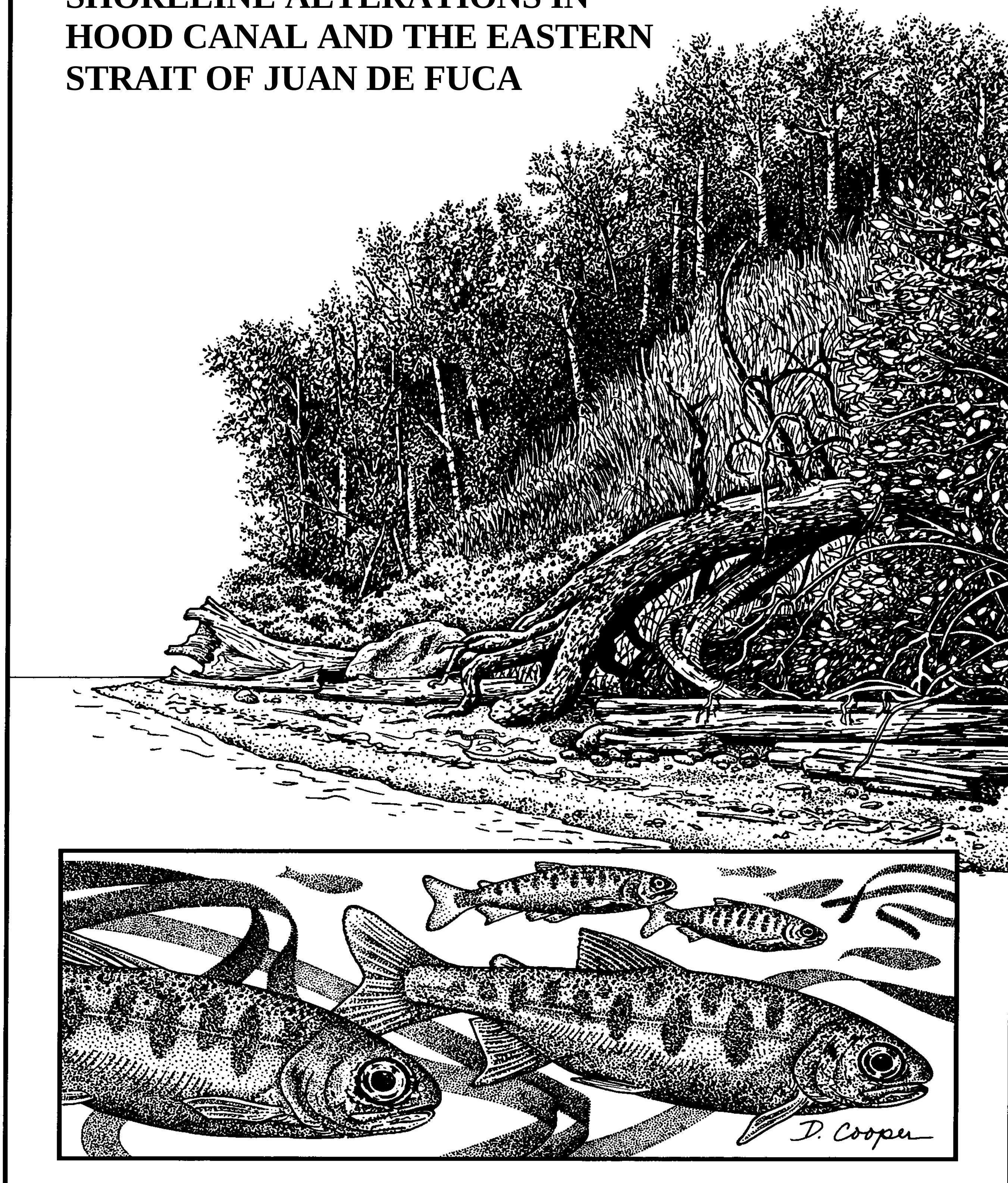
SHORELINE ALTERATIONS IN HOOD CANAL AND THE EASTERN STRAIT OF JUAN DE FUCA



Point No Point Treaty Council **Technical Report 03-1**

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Shoreline Alterations in Hood Canal and the Eastern Strait of Juan de Fuca

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SUMMARY

This report describes the results of an inventory of marine shoreline development throughout Hood Canal and the eastern Strait of Juan de Fuca. It also interprets the results on a large scale and for selected smaller areas.

Shoreline features were field mapped by boat employing a Global Positioning System to mark positions. Information collected included shoreline features as points (e.g. docks, jetties, launch ramps, etc.) and as lines (bulkheads and backshore landforms) along the shoreline. Data summaries were generated by attaching point and line features to shoreline Geographic Information System layers and grouping these results by drift cells within sub-regions that were, in turn, grouped within larger regions.

A total of 595 km of shoreline was mapped, extending from the Union River near Belfair in Lower Hood Canal to Dungeness Spit near Sequim in eastern Strait of Juan de Fuca. Bulkheads were found to cover approximately 18 % of the total mapped shoreline. Also, a total of 486 docks, 408 stairs, 118 rail launches, 128 launch ramps and 30 jetties/groins were identified. The rate and pattern of shoreline modifications were highly variable across the study area, whether evaluated at the scale of sub-regions or individual drift cells. However, Lower Hood Canal ("the Hook") exhibited the highest rates of bulkhead armoring (e.g. north shore at 66 % and south shore at 70%) and was among the highest in number and density of non-bulkhead shoreline alteration features.

Backshore landforms (such as high bluff, low bluff, barrier beach, saltmarsh) were identified where possible to provide context for the analysis of the shoreline modification patterns along contrasting shore types. However, at some locations, development was so extensive as to preclude the identification of backshore landforms; this situation was most pronounced in Lower Hood Canal and portions of southwest Hood Canal and the Port Townsend area.

Accuracy of shoreline feature mapping was evaluated by performing an onshore survey and comparing it with the boat survey at two locations within the study area. The onshore survey was considered to be accurate and therefore the benchmark for assessing the accuracy of the boat-based survey. We estimated a 19% error of omission (i.e., feature identified by onshore but not boat survey) for bulkheads and a 41% omission error for point features (e.g. docks, jetties, etc.), indicating that the estimates of shoreline development in this report are conservative.

Eight case studies, distributed throughout the study area are presented to illustrate how anthropogenic modifications can impact natural shoreline functions within zones of a drift cell (i.e. erosion zone, transport zone and deposition/accretion zone). The case studies specifically address the following locations: Lower Hood Canal, South Port Ludlow Bay, Southpoint, Point Julia, John Wayne Marina, Rat Island, Salsbury Point and Twin Spits.

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"There is no final ecological truth. All knowledge is a current approximation, and each addition to that knowledge is but a small, incremental step toward understanding. Not only are ecosystems more complex than we think, they are more complex than we can think."

Jack Ward Thomas, 1992

INTRODUCTION

The shallow nearshore of Hood Canal and the eastern Strait of Juan de Fuca provides significant habitat for a variety of fish and shellfish, notably juvenile salmon, sandlance, herring, clams, oysters, and many prey species that sustain both marine and terrestrial food webs. This habitat is naturally dynamic, changing in response to shoreline processes that link adjacent watersheds and backshore uplands with marine shores. Interrelated pieces of this ecosystem create a staggering complexity that defies simple characterizations and understanding as the above quotation from Jack Ward Thomas suggests.

In spite of the importance of the nearshore habitat to regional fish and wildlife populations, there is little information on habitat status and condition for Hood Canal and the eastern Strait of Juan de Fuca. Numerous habitat assessments have been completed for watersheds in this region. Thom et al (1994) summarize biological impacts due to armoring and MacDonald et al (1994) discuss impacts of shoreline armoring on geological processes and physical features. But there are no large-scale inventories of modifications to habitats in Hood Canal and the eastern Strait.

The impacts of bulkheads and other forms of armoring can reduce or eliminate productive, shallow water habitats through filling or alteration of sediment sources, sediment transport, and accretion of these sediments along the nearshore. Also, as the shoreline becomes armored with these structures, increased wave energy can erode and coarsen beach substrates, preventing the establishment of eelgrass that is adapted to finer sediments. These changes, along with shading from piers or docks and removal of riparian vegetation can alter habitat structure, reducing or interrupting eelgrass beds while degrading habitat conditions for juvenile salmon.

The magnitude, distribution and cumulative effects of shoreline modification have not been quantified at either a landscape scale or at appropriate finer scale resolution (i.e., the scales of habitat to which juvenile salmon respond), and thus we lack an understanding of how significant these changes have been for salmon.

This project is part of a larger program sponsored by the Point No Point Treaty Council to map and inventory nearshore habitat resources of Hood Canal and the eastern Strait of Juan de Fuca. Under this project, shoreline modifications and the natural backshore environment were mapped by boat using a global positioning system (GPS). A parallel project of this same program is using hyperspectral remote sensing to map eelgrass patch structure and contiguity (Garono et al. 2000). Ultimately, the data sets of these two projects will be combined to assess the relationship between shoreline modifications and eelgrass habitat.

This report describes results from the shoreline modification mapping effort and provides data summaries useful to resource managers and individuals interested in the condition of nearshore habitat in Hood Canal and the eastern Strait. The report includes a Background section in which we outline important natural processes that shape the nearshore marine environment and dependent biological resources. The Methods section follows in which we describe our approach to mapping and quantifying shoreline modifications and the natural backshore environment in the study area. Also in the Methods section, we discuss error quantification and alternative survey techniques that were evaluated. The Results and Discussion section summarizes the study results, noting patterns of shoreline developments. The Case Studies section discusses shoreline examples within the study area to illustrate complexities of the nearshore ecosystem and how specific locations have responded to human impacts.

BACKGROUND

Nearshore ecological processes are intimately tied to the transport of water, sediment, and wood into and along the shoreline. Geologists recognize “drift cells” as discrete zones of shoreline sediment recruitment, transport, and deposition. The cells function much like a watershed, moving sediment that falls from bluffs and depositing it on beaches. Much like a river transporting and depositing sediment along its channel, this movement of beach sediment and associated organic debris shapes shoreline features while creating and maintaining the long-term integrity of nearshore habitats. Sandy beaches, spits, and points are all examples of the formations created by the transport and deposition process.

In general, a beach with finer sand and gravel is a site of deposition also known as an accretion beach. Source sediments for these beaches are often found far “updrift” where eroding bluffs contribute the initial materials for the eventual accretion. Spits and similar hooks or points represent areas of accretion, but they often form at the terminus or starting point of a drift cell. Cuspate spits are those familiar, pointed shoreforms created where two drift cells converge, colliding where the forces of wind and water often attract high concentrations of marine life, including adult salmon and those who fish for them.

How A Drift Cell Functions

In an idealized drift cell, there are three zones where specific processes predominate. In the EROSION ZONE sediment is recruited to intertidal areas; sediment is moved along the beach in the TRANSPORT ZONE; and sediment settles onto the beach to create accretion features in the DEPOSITION ZONE (Tanner 1974).

Johannessen (1999) and Hirschi (1999) provide a textbook example of each zone along a drift cell mapped along the south and east shore of Port Ludlow Bay as shown in Figure (1). In the Erosion Zone (at A in Figure 1), sediments fall from bluffs at Tala Point and enter the nearshore. High, unvegetated “feeder bluffs” near the tip of the point are highly erosive, while lower, partially vegetated “contributing bluffs” at the southeast entrance to the bay (at B in Figure 1) supply woody debris and smaller volumes of sediment to the beach.

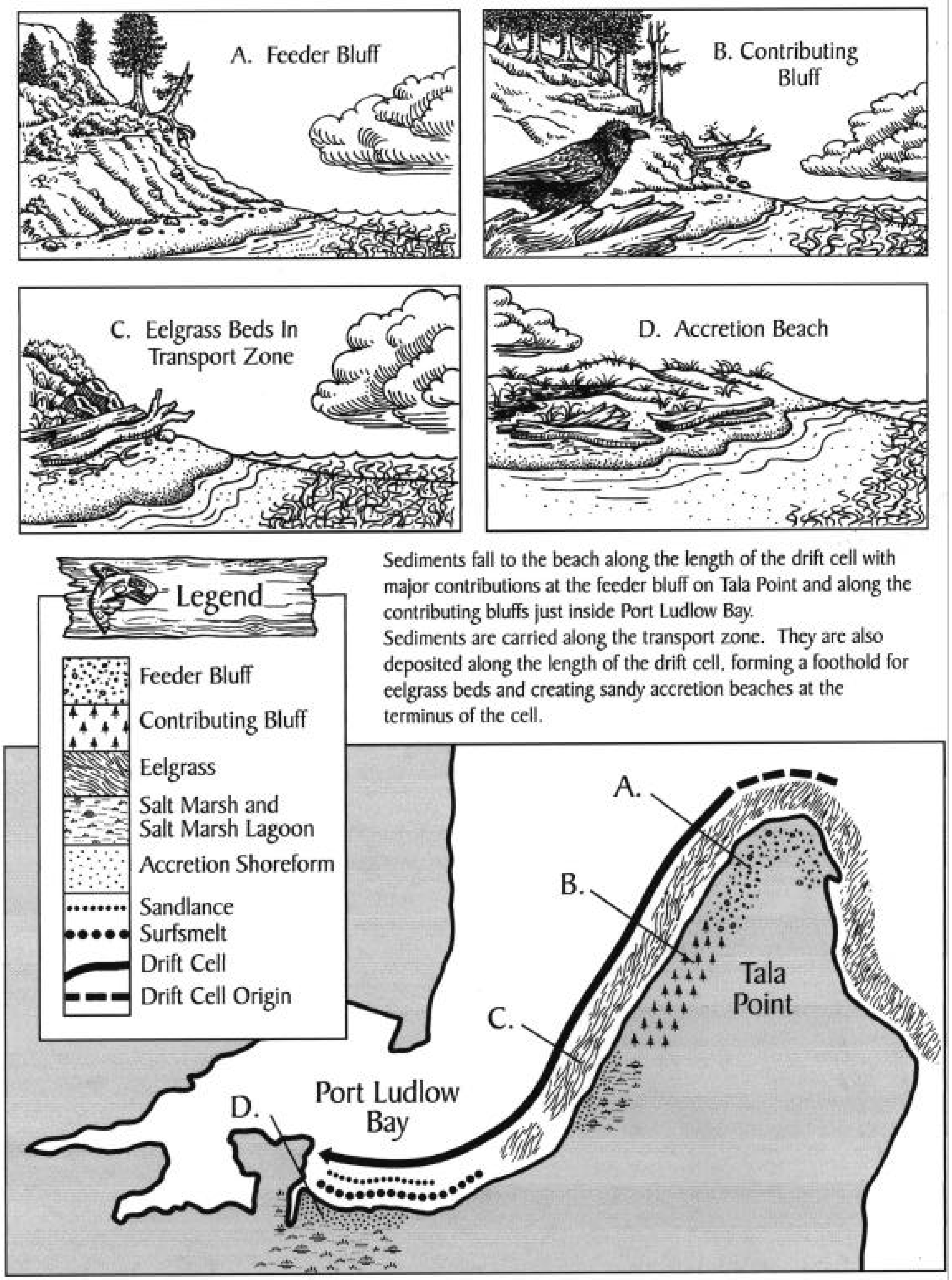

Figure 1. South shore of Port Ludlow Bay: Illustration of how a drift cell functions.

Both standing trees and woody debris are recognized as critical elements in shoreline ecology. Woody debris on beaches and standing trees and other vegetation on the backshore offer shade and cover for juvenile fish and their prey. They also help stabilize the supply and movement of sediment to and along the shoreline. Much of the woody debris in the nearshore originates from bluffs that serve as important supply points for sediment and wood along shore segments.

In the Transport Zone (general vicinity of C in Figure 1), sediments are carried along the beach by wind driven waves. Eelgrass lines this sediment pathway, partially holding the substrate in place with its roots. Eelgrass beds typically form in rather narrow bands concentrated in tidal elevations between approximately +1m and -2m, relative to mean lower low water, where it persists in mud to sand-gravel substrates. The presence of eelgrass is inhibited when the substrate coarsens (Phillips 1984) through the elimination of sediment recruitment updrift or where shading from structures such as docks occurs (Simenstad et al. 1998).

In the Deposition Zones, sediments settle to form a sand accretion beach (at C in Figure 1) and a long sand spit (at D) that is favored by sandlance for spawning (Hirschi 1999). While homes line the spit, it is notable for its lack of bulkheading. A tidal channel at the tip of the spit marks the terminus of the drift cell. This channel links the bay with a tidal lagoon formed behind the spit, a lagoon notable for its use as rearing and refuge habitat by juvenile salmonids.

Effects Of Shoreline Armoring

Human modification due to shoreline clearing can increase erosion rates, adding more sediment to the transport zone, which can ultimately increase the accretion of spits and other beaches. At times, artificial nourishment of the beach is employed to increase sediment supplies to impacted accretion beaches.

Jetties, groins, launch ramps, and bulkheads can hinder or stop sediment flow, causing spits to erode rather than accrete. Historic loss of accretion habitat can be seen most clearly at Southpoint in eastern Jefferson County, a site described in more detail below as a case study that exhibits this form of habitat loss.

Stream ecologists caution that "we all live downstream" when talking about the wisdom of considering impacts to the entire watershed due to alteration at a single site. Likewise, it is important to view the nearshore environment in a drift cell context. Shoreline property owners all "live downdrift" of others and impacts to surprisingly small segments of shoreline, bluff, or other nearshore habitat can also have significant impacts along the path of the drift cell.

Obvious interest along the drift cell includes the need to protect beaches from unplanned erosion. Homes and other waterfront property may be threatened in some areas due to human modifications many miles updrift. Likewise, homes and other property are often threatened when built on highly erosive feeder bluffs, which, by definition slump and contribute essential sediments to the beaches below.

Far more often, fish and wildlife habitat has been lost or altered as historic logging and land clearing have stripped essentially all the original old growth and much of the younger growth of trees along contributing bluffs and other backshore habitat.

Additionally, the placement of fill atop low-lying nearshore areas such as spits and saltmarsh has resulted in habitat loss that is extensive, but difficult to measure.

Bortelson et al (1980) reported that of 91 sq km of original saltmarsh, 55 sq km remained intact in their study of 11 major Puget Sound river mouths. Simenstad (1998) described losses of substantial amounts of habitats within subestuary deltas of Hood Canal. These subestuaries form at the mouth of rivers and streams and consist of marsh, lagoon, tidal slough, spit, and other land and shoreforms that comprise the transition zone between fresh and salt water. Each of the subestuaries along the length of Hood Canal and the eastern Strait serves as a stepping-stone along the migratory pathway of juvenile salmonids. Other nearshore habitats, especially eelgrass beds, offer a kind of linked highway system that connects the streams and subestuaries, providing food and a refuge habitat as well.

As many authors have pointed out, disruption of sediment transport and deposition along drift cells can result in loss or alteration of critical eelgrass habitat and dependent species (MacDonald et al 1994; Canning and Shipman 1995). One of the species highly dependent on fine sediments deposited along accretion beaches is the sandlance. Also known as candlefish, they spawn in the upper intertidal (from about +5 feet in tidal elevation to approximately the mean high water line) in sediments that range in size from sand particles to a mixture of sand and gravel up to 3cm in diameter (Pentilla 1995).

Bulkheads can block fine sediments from entering the transport zone along spawning beaches or increase wave energy, coarsening the sediments fronting them. For example, sandy beaches can change to areas with substrates of cobble and gravels above the 3cm size needed for successful sandlance spawning. Additionally, many bulkheads extend seaward, well beyond the mean high water mark, effectively eliminating former and/or potential sandlance spawning habitat. These physical impacts of bulkheads on the nearshore affect many other species as well (Thom et al. 1994). Recent research suggests that fine sediments further offshore may be critical for sandlance over wintering habitat and need to be monitored as well (Hoines and Bergstad 2000).

Sandlance are an important forage fish of salmon, seabirds, and marine mammals (Hart 1973) and the loss of spawning or other critical habitats will have indirect impacts on other species. Human modification to the nearshore also eliminates or alters salmon habitat more directly. As juvenile salmon migrate from the streams of their birth to more distant marine waters, all species appear to use a range of subestuarine rearing and feeding habitats within stream mouths as well as tidal lagoons with no appreciable freshwater input (Doty and Hirschi 2001).

Juvenile Chinook, chum, pink, and coho are known to move up and into saltmarsh lined lagoons formed in the backwaters of accretion beaches (Lichatowich 1993; Doty and Hirschi 2001). Juvenile chum and pink are especially dependent on shallow nearshore waters, using eelgrass beds as a kind of highway as they migrate to the Pacific (Simenstad 1998). Eelgrass also forms the base of many marine food webs (Albright et al 1980) and may be the most important source of organic matter in the nearshore (Simenstad and Wissmar 1985).

The cumulative impacts from loss of eelgrass, accretion beaches, lagoons, overhanging trees, and other natural features of the complex nearshore ecosystem contribute to the declines in salmon habitat in Hood Canal and the eastern Strait. Our study is an attempt to understand the extent of human modifications in this area and to begin a discussion of the impacts and potentials for restoration and protection of the nearshore components.

METHODS

Shoreline features were mapped by boat employing a Global Positioning System (GPS) to mark positions. These positions were then manually snapped to the shoreline in a Geographic Information System (GIS) to locate the positions of the features along the shoreline. At the project initiation, we evaluated several shoreline mapping approaches and alternatives. Oblique aerial photographs, available from the Washington Department of Ecology web site (http://apps.ecy.wa.gov/shorephotos/), proved useful for pre-survey screenings and post-survey validation checks, but could not be used for precisely mapping features due to lack of geo-referencing and the frequency of obscuring vegetation along the shoreline. Shore-based GPS mapping proved infeasible due to limitations of landowner permission, physical access, and extensive survey distances. Another alternative, employing a combination of high-precision GPS and laser rangefinder capabilities to map shoreline features from fixed offshore positions, was also evaluated and rejected due to equipment cost and manpower constraints. However, this approach would have markedly improved precision and reduced overall data processing time and, though we could not pursue this approach, we recommend future surveys of this nature thoroughly evaluate and consider this technique. In the end, we selected a less precise, boat-based, handheld GPS survey approach that generally provided the surveyor a clear view of all shoreline structures and backshore landform types, and could be implemented by one person under most conditions.

Field surveys were performed employing a handheld GPS unit (Trimble GeoExplorer II), mounted to the center console of a small outboard boat. The senior author navigated along the shoreline at or near high tide and approximately 30 to 100 m offshore, logging features as points (e.g. docks, jetties, launch ramps, stairs, changes to natural backshore landforms) or as lines (e.g. bulkheads) along a survey route and attributing these features according to the following data dictionary:

- Bulkhead (line), noting angle (vertical, sloped), material (concrete, rock, wood, other), and lowest position relative to ordinary high water (at, above, below)
- Dock (point)
- Rail Launch (point)
- Launch Ramp (point)
- Jetty or Groin (point)
- Stairs (point), only mapped where they occurred as isolated features, not when they occurred in association with a dock, bulkhead or other more intrusive large structure.
- Marina (line)
- Fill (line)
- Other (point or line, miscellaneous features not described above)
- High Bluff (>30 feet in height, point), noting vegetation category: vegetated (covering >70% of bluff face, by area), partially vegetated (30-70%), and unvegetated (<30%)

- Low Bluff (<30 feet in height, point), noting same vegetation categories as above
- No Bluff (point), noting dominant backshore landform: upland, saltmarsh, accretion type beach (e.g., spits, barrier beaches, and berms following the definitions of Johannessen (1999))

The latter three shoreline landform types were recorded as points where there was a change in the backshore geomorphology along the survey route; during subsequent data processing these points were then used to break the shoreline into segments representing discrete backshore landform types. We mapped backshore landform types to characterize the geomorphic context for shoreline modifications across the study area; armoring of high and low bluffs can eliminate sites of critical sediment and wood recruitment to the nearshore environment, and the significance of this modification is often obscured by simply reporting overall shoreline armoring rates. In the results section, we provide overall shoreline armoring rates as well as rates for high and low bluff-backed shore segments. We acknowledge this treatment of all bluff-backed shore segments as erosion shoreforms is a crude simplification; not all bluffs in Puget Sound are sites of natural erosion even in an unmodified state. Nonetheless, this treatment provides a rough gauge of shoreline armoring rates along eroding shore segments, which provides additional context on impacts from human modification to the nearshore estuarine environment.

Our approach was designed to characterize points and events along a linear shoreline, but was poorly suited for mapping fill or estuarine marsh habitat types which are better defined as areas or polygons in a GIS. In practice, it was very difficult to unequivocally identify areas of fill from the perspective of a boat offshore, and thus we caution that our measures of the linear extent of fill .underestimate the true extent of this alteration type by a considerable margin. Similarly, extensive shoreline development in certain areas (such as Lower Hood Canal) obscured the natural backshore landform type rendering our estimates of different landform types in heavily developed segments of questionable validity (see Shoreline Armoring in Results and Discussion section for more discussion of this problem).

At the conclusion of each sampling day, GPS files were downloaded and e-mailed to the Point No Point Treaty Council's GIS technician for geo-correction and processing. The first step in processing the data was to perform differential correction using Trimble's Pathfinder software and correction files from the Thurston County Roads and Transportation Department. The data were then exported into ESRI ArcView Shapefiles using Pathfinder's export utility. All data was projected into the Universal Transverse Mercator (UTM) coordinate system, zone 10 North, datum WGS 84, units meters using the same Pathfinder export utility. This coordinate system was chosen to match datasets used in the hyperspectral data acquisition efforts run in concert with this study (see Introduction).

Since the data collection had been performed offshore of the actual features it was determined that the features needed to be connected to the actual shoreline. This was accomplished by snapping all features to the Washington Department of Natural Resources' shoreline coverage, which is a subset of the hydrographic layer. The snapped datasets were then visually checked to ensure a reasonable alteration of the original GPS data. Several sources of error reduce the overall precision of mapped features including distance of the survey boat from shore, the snapping procedure used to "fit" features to the digital shoreline layer, as well as sources of error inherent to DOE's drift cell and DNR's shoreline GIS coverages to which we attached our data.

To evaluate the accuracy of our approach relative to shore-based GPS mapping, we compared our boat-based, "snapped" data to features mapped on foot employing a high-resolution Trimble PathFinder Pro-XL GPS over two shoreline segments, a 6.3 km segment near Lofall, WA and a 3.3 km segment near Shine, WA. By this comparison, we estimated percent omissions (e.g. "missed" features) and horizontal accuracy errors (e.g. in the length and position of features in meters).

Data summaries were generated by attaching point and line features to the shoreline GIS layers and grouping these results by drift cells within sub-regions that were, in turn, grouped within larger regions. Regions are convenient geographical groupings within the entire project area; for example, Strait, Port Townsend, Northwest Hood Canal, etc. A sub-region is a "cluster" of drift cells that are contiguous and generally feed a common depositional landform such as a spit, embayment or point. Regions and sub-regions are depicted in Figure 2.

RESULTS AND DISCUSSION

From August 1999 through December 2000, 595 km of shoreline were mapped along Hood Canal and the eastern Strait of Juan de Fuca, extending from the mouth of the Union River near Belfair to Dungeness Spit near Sequim. The rate and pattern of shoreline modifications were highly variable across the study area, whether evaluated at the scale of sub-regions or individual drift cells. Table 1 provides information on drift cell sub-regions including: total length, length and percentage of armored shoreline, and the number and density (number/km) of docks, launch ramps, jetties, rail launches, and stairs. (The same information for individual drift cells is provided in Appendix 1.) Sub-regions exhibited shoreline-armoring rates that ranged from 0-70% (percent of shoreline length armored), and overall the densities of docks/jetties/ramps/rail launches/stairs were also highly variable, ranging from 0.2 to 8.2 per km (Table 1). At this broad scale, shoreline armoring rates did not correlate well with density of other human-origin features such as docks, jetties, ramps, rail launches, or stairs (Figure 3); that is, highly armored sub-regions did not necessarily exhibit a high density of other human-origin features. At a finer scale, there was also significant variation in development rates and patterns on a per drift cell basis across the study area (Appendix 1) which is discussed in more detail below. Figures 4 through 7 depict the distribution of bulkheads and other human built features across the study area.

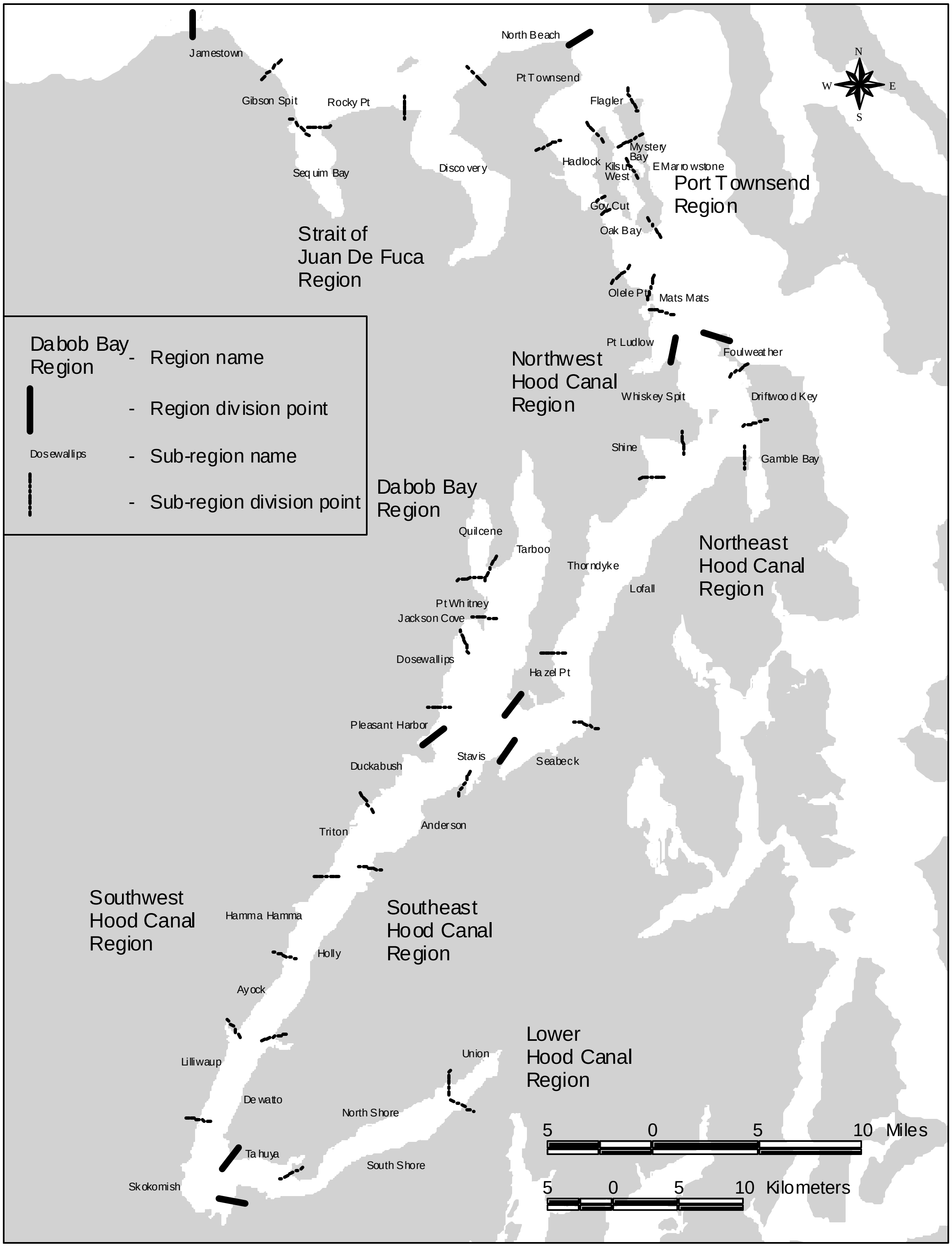

Figure 2. Regions and sub-regions of study area.

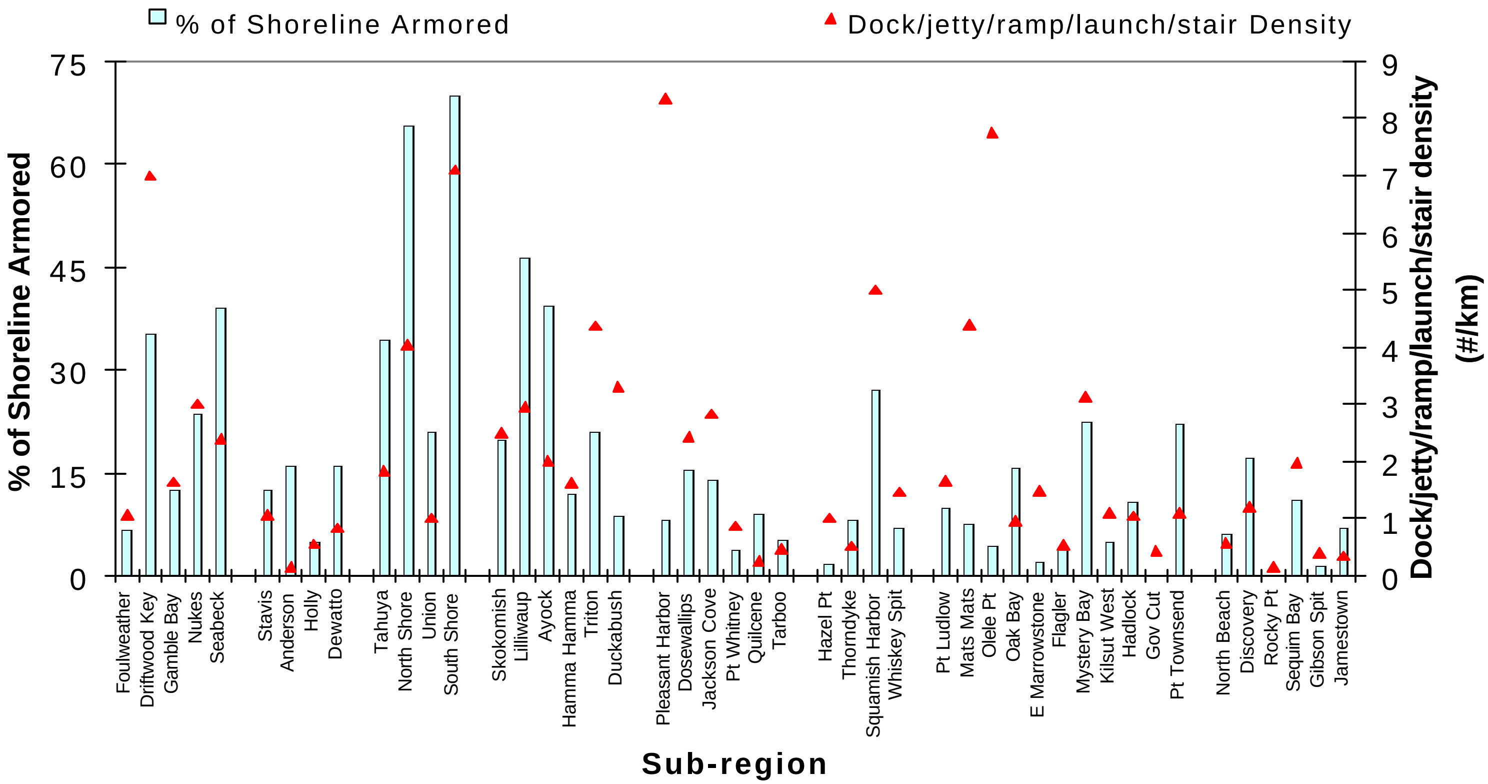

Figure 3. Shoreline modifications by sub-region

Table 1. Summary results for majority of shoreline structures by region and sub-region within Hood Canal and eastern Strait of Juan de Fuca. Also shown are the lengths of high and low bluff-backed shoreline and associated amounts of bulkheading (see text under Shoreline Armoring).

Regions &	Total	Bulkheads		Docks		Jetties		Launch Ramps		Rail Launches		Stairs[1]		High and Low Bluff		
Sub-regions	Lgth. (m)	Lgth.(m)	%	No.	Density[2]	No.	Density[2]	No.	Density[2]	No.	Density[2]	No.	Density[2]	Total	Bulkheaded	
														Lgth	Lgth	%
Northeast Hood Canal Region																
Foulweather	4,207	284	6.8	1	0.2	0	0.0	0	0.0	1	0.2	3	0.6	2,079	105	5.0
Driftwood Key	7,504	2,646	35.3	44	5.9	0	0.0	1	0.1	0	0.0	8	1.0	3,860	405	10.5
Gamble Bay	16,380	2,045	12.5	9	0.5	1	0.1	3	0.2	0	0.0	14	0.9	9,433	1,075	11.4
Lofall	27,951	6,661	23.8	17	0.6	0	0.0	7	0.2	10	0.3	52	1.8	21,291	4,472	21.0
Seabeck	13,340	5,231	39.2	4	0.3	0	0.0	3	0.2	18	1.3	8	0.6	8,655	3,715	42.9
Totals	**69,381**	**16,868**	**24.2**	**75**	**1.1**	**1**	**0.0**	**14**	**0.2**	**28**	**0.4**	**83**	**1.2**	**45,319**	**9,771**	**21.6**
Southeast Hood Canal Region																
Stavis	8,376	1,056	12.6	0	0.0	0	0.0	1	0.1	0	0.0	8	1.0	5,239	608	11.6
Anderson	12,085	1,927	16.0	1	0.1	0	0.0	0	0.0	0	0.0	1	0.1	9,684	1,382	14.3
Holly	16,842	843	5.0	2	0.1	0	0.0	2	0.1	0	0.0	6	0.3	13,658	187	1.4
Dewatto	15,473	2,482	16.0	5	0.3	0	0.0	2	0.1	2	0.1	5	0.3	7,298	391	5.4
Totals	**52,776**	**6,309**	**12.0**	**8**	**0.2**	**0**	**0.0**	**5**	**0.1**	**2**	**0.0**	**19**	**0.4**	**35,879**	**2,568**	**7.2**
Lower Hood Canal Region																
Tahuya	9,557	3,278	34.3	7	0.7	0	0.0	8	0.8	4	0.4	0	0.0	82	81	99.4
North Shore	16,454	10,786	65.6	21	1.2	8	0.5	21	1.2	18	1.1	0	0.0	0	0	0.0
Union	13,788	2,911	21.1	11	0.8	1	0.0	3	0.2	0	0.0	0	0.0	0	0	0.0
South Shore	22,885	16,033	70.1	146	6.4	1	0.0	12	0.5	3	0.1	1	0.0	0	0	0.0
Totals	**62,684**	**33,008**	**52.7**	**183**	**2.9**	**9**	**0.1**	**43**	**0.7**	**25**	**0.4**	**1**	**0.0**	**82**	**81**	**99.4**
Southwest Hood Canal Region																
Skokomish	15,710	3,130	19.9	12	0.7	2	0.1	3	0.2	23	1.5	0	0.0	435	8	1.8
Lilliwaup	10,619	4,917	46.3	17	1.6	3	0.3	1	0.1	11	1.0	0	0.0	1,445	8	0.6
Ayock	7,448	2,934	39.4	1	0.1	1	0.1	4	0.5	6	0.8	3	0.4	4,775	1,774	37.2
Hamma Hamma	9,254	1,114	12.0	2	0.2	1	0.1	4	0.4	0	0.0	8	0.9	4,115	510	12.4
Triton	9,373	1,962	20.9	7	0.7	1	0.1	5	0.5	13	1.4	15	1.6	7,219	930	12.9
Duckabush	11,529	1,007	8.7	6	0.5	1	0.1	4	0.3	2	0.2	25	2.2	7,091	539	7.6
Totals	**63.934**	**15.064**	**23.6**	**44**	**0.7**	**9**	**0.1**	**21**	**0.3**	**55**	**0.9**	**51**	**0.8**	**25.079**	**3.770**	**15.0**
Dabob Region																
Pleasant Harbor	5,512	455	8.3	17	3.1	0	0.0	0	0.0	0	0.0	29	5.3	4,642	455	9.8
Dosewallips	9,477	1,467	15.5	1	0.1	0	0.0	2	0.2	0	0.0	20	2.1	3,369	215	6.4
Jackson Cove	5,642	794	14.1	4	0.7	0	0.0	2	0.4	3	0.5	7	1.2	3,906	194	5.0
Pt Whitney	4,579	170	3.7	2	0.4	0	0.0	1	0.2	0	0.0	1	0.2	3,083	48	1.6
Quilcene	15,282	1,373	9.0	0	0.0	0	0.0	0	0.0	0	0.0	4	0.3	7,685	372	4.8
Tarboo	36,285	1,913	5.3	3	0.1	2	0.1	1	0.0	0	0.0	11	0.3	23,070	454	2.0
Totals	**76,777**	**6,172**	**8.0**	**27**	**0.4**	**2**	**0.0**	**6**	**0.1**	**3**	**0.0**	**72**	**0.9**	**45,754**	**1,739**	**3.8**
Northwest Hood Canal Region																
Hazel Pt	10,838	188	1.7	4	0.4	0	0.0	2	0.2	0	0.0	5	0.5	9,479	31	0.3
Thorndyke	20,993	1,703	8.1	2	0.1	0	0.0	0	0.0	0	0.0	9	0.4	13,522	323	2.4
Shine	8,996	2,429	27.0	26	2.9	1	0.1	4	0.4	0	0.0	14	1.6	4,620	1,160	25.1
Whiskey Spit	17,000	1,196	7.0	0	0.0	0	0.0	2	0.1	0	0.0	23	1.4	11,875	1,037	8.7
Totals	**57,826**	**5,517**	**9.5**	**32**	**0.6**	**1**	**0.0**	**8**	**0.1**	**0**	**0.0**	**51.0**	**0.9**	**39,496**	**2,551**	**6.5**
Port Townsend Region																
Pt Ludlow	13,130	1,315	10.0	15	1.1	1	0.1	0	0.0	1	0.1	5	0.4	9,680	1,186	12.2
Mats Mats	7,731	590	7.6	22	2.8	1	0.1	1	0.1	0	0.0	10	1.3	4,954	213	4.3
Olele Pt	2,772	125	4.5	2	0.5	0	0.0	5	1.6	0	0.0	16	5.6	2,089	85	4.1
Oak Bay	11,069	1,730	15.6	1	0.0	0	0.0	3	0.2	0	0.0	8	0.7	6,964	347	5.0
E Marrowstone	12,130	254	2.1	1	0.1	0	0.0	0	0.0	0	0.0	17	1.4	10,751	72	0.7
Flagler	5,436	224	4.1	1	0.2	0	0.0	2	0.4	0	0.0	0	0.0	3,404	55	1.6
Mystery Bay	4,771	1,076	22.5	7	1.4	0	0.0	1	0.2	0	0.0	8	1.6	2,648	716	27.1
Kilsut West	15,735	790	5.0	3	0.2	1	0.1	1	0.1	1	0.1	12	0.7	10,933	671	6.1
Hadlock	19,484	2,121	10.9	11	0.5	2	0.1	6	0.3	1	0.1	1	0.1	6,611	118	1.8
Gov Cut	4,416	0	0.0	0	0.0	1	0.2	0	0.0	0	0.0	1	0.2	1,471	0	0.0
Pt Townsend	13,965	3,112	22.3	13	0.9	1	0.0	2	0.1	0	0.0	1	0.1	3,209	172	5.4
Totals	**110,639**	**11,336**	**10.2**	**74**	**0.7**	**7**	**0.1**	**20**	**0.2**	**3**	**0.0**	**77**	**0.7**	**62,712**	**3,635**	**5.8**
Strait Region																
North Beach	9,508	582	6.1	1	0.1	1	0.1	2	0.2	0	0.0	3	0.3	8,141	267	3.3
Discovery	43,200	7,419	17.2	13	0.3	0	0.0	7	0.2	2	0.0	31	0.7	26,163	1,766	6.7
Rocky Pt	8,685	0	0.0	0	0.0	0	0.0	1	0.1	0	0.0	1	0.1	6,314	0	0.0
Sequim Bay	25,367	2,774	10.9	29	1.1	0	0.0	2	0.1	0	0.0	19	0.7	11,834	1,728	14.6
Gibson Spit	5,036	80	1.6	0	0.0	1	0.1	2	0.3	0	0.0	0	0.0	2,026	0	0.0
Jamestown	8,540	596	7.0	1	0.1	1	0.1	1	0.1	1	0.1	0	0.0	207	0	0.0
Totals	**100,336**	**11,450**	**11.4**	**44**	**0.4**	**2**	**0.0**	**13**	**0.1**	**3**	**0.0**	**54**	**0.5**	**54,685**	**3,760**	**6.9**
Grand Totals	**594,354**	**105,722**	**17.8**	**486**	**0.8**	**30**	**0.1**	**129**	**0.2**	**118**	**0.2**	**408**	**0.7**	**309,007**	**27,876**	**9.0**

[1] Includes only stairs observed independent of other structures

[2] Density is measured as no. per km

Following is a detailed description of the results considering in order: shoreline armoring, other shoreline alterations, and backshore landforms.

Shoreline Armoring

A total of 105.7 km of bulkheads covering approximately 17.8% of the total surveyed shoreline length were mapped in the study area (Table 1). Percent armoring along individual sub-regions ranged from 0% at Rocky Point (within the Strait region) to over 70% at South Shore in Lower Hood Canal. Armoring rates of high and low bluff-backed shore segments (sites of presumed active material recruitment to the nearshore environment) ranged from 0% at seven sub-regions clustered largely along the Strait and in Lower Hood Canal, to 37% and 43% at Ayock and Seabeck, respectively (see right side of Table 1). At one sub-region, Tahuya, 99% of the high and low bluff-backed shoreline was armored.

Our efforts to estimate shoreline armoring along high and low bluff-backed shore segments were confounded in certain areas of Hood Canal where extensive development obscured the natural shoreline geomorphology. As a result, our reported armoring rates for high and low bluff-backed shoreline are likely conservative and underestimate the true rate of armoring along eroding shore segments for heavily-developed areas (e.g. Lower Hood Canal); in these areas the built environment and intertidal fill frequently obscured views of natural backshore landform types to such an extent that determining their pre-modified state was impossible using our approach. One indicator of this effect was the percentage of shoreline that could not be classified (identified generically as "upland"). This statistic was estimated at less than 30% for all sub-regions outside of Lower Hood Canal with the exceptions of Lilliwaup (86%), Port Townsend (55%), Hadlock (37%) and Government Cut (31%) (Appendix 2). However, for the entire Lower Hood Canal region, 72% of the shoreline was identified as no bluff upland, indicating that considerable shoreline lengths could not be classified in a specific backshore landform class as a result of human alteration.

Though bulkheads were widely distributed throughout the study area (Figure 4) several regional patterns and individual areas are worthy of mention. Lower Hood Canal region exhibited the highest rates of armoring in all Hood Canal and the eastern Strait; rates of armoring were particularly heavy in the North Shore (66%), South Shore (70%), and Tahuya (34%) sub-regions (Table 1). But extensive armoring was also observed in the Southwest region at the sub-regions of Lilliwaup (46%) and Ayock Point (39%). Also of note in Lower Hood Canal was the frequency and extent of bulkhead and home construction on fill seaward of the ordinary high water line, effectively isolating the backshore environment from the adjacent nearshore environment (see Figure 8 presented below in the Lower Hood Canal case study). Other areas of high shoreline armoring rates included sub-regions at Seabeck (39%), Driftwood Key (35%), Shine (27%), Lofall (24%), Mystery Bay (22%), and Port Townsend (22%). In Southwest Hood Canal, long continuous sections of loosely placed, sloped rockery were observed at the foot of low bluffs just below Highway 101. A similar condition was observed at the head of Discovery Bay where an abandoned railroad grade, constructed at the base of high forested bluffs, blocks material recruitment to the nearshore environment.

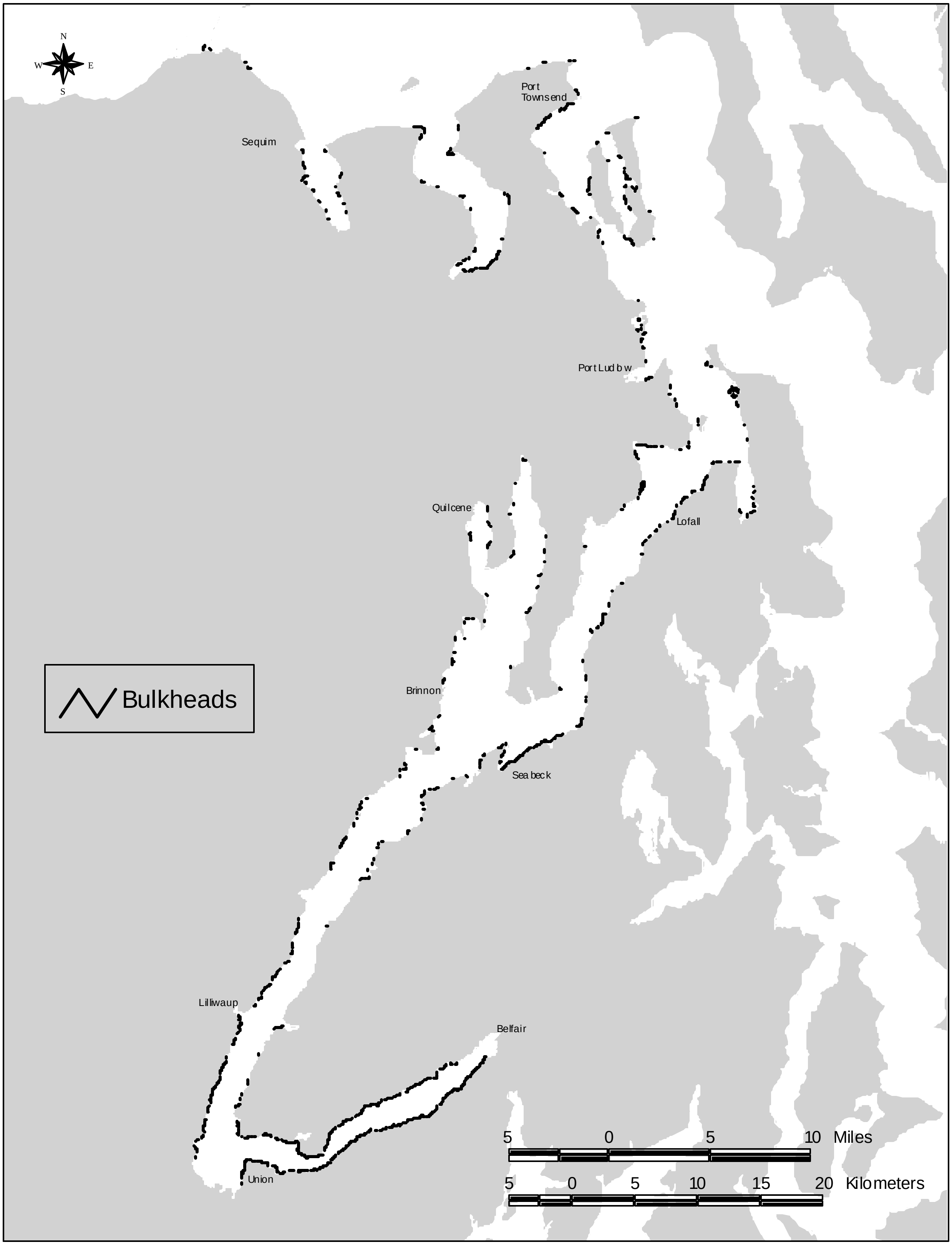

Figure 4. Distribution of bulkheads throughout study area.

Areas especially notable for lack of armoring included sub-regions in the vicinity of Rocky Point (0%), Gibson Spit (1.6%), Hazel Point (east shore of Toandos Peninsula, 1.7%), East Marrowstone Island (2.1%), Point Whitney (3.7%), Fort Flagler (4.1%), Olele Point (4.5%), Holly (5%), and the west shore of Kilsut Harbor (east Indian Island, 5%) (Table 1 and Figure 3). These sub-regions were among the most pristine and ecologically dynamic across the study area, with intact, forested bluffs and abundant large woody debris, owing largely to their undeveloped state.

Patterns of shoreline armoring at the scale of individual drift cells generally paralleled those noted above for the sub-regions in which they occurred (Appendix 1), with a few exceptions. In several instances, the clustering of drift cells into sub-regions for purposes of data summarization obscured important finer-scale patterns, "averaging out" areas of particularly heavy development as well as small, relatively pristine drift cells. For example, rates of shoreline armoring along select *drift cells* of the North Shore sub-region in Lower Hood Canal (with an overall armoring rate of 65%) ranged from 57 to 100% within individual component drift cells. Similarly, along the Triton shore sub-region, overall armoring rates of nearly 21% were observed, though one component drift cell (MA-1-2) measuring only 590 m in length exhibited armoring rates of just 4.6%. Thus our data summaries hide potentially important variation and users of the data are encouraged to refer to Appendix 1, for specific drift cell-level information.

<u>Other Shoreline Alterations</u>

A total of 486 docks, 408 stairs, 118 rail launches, 129 launch ramps, and 30 jetties/groins were mapped in Hood Canal and the eastern Strait of Juan de Fuca (Table 1). The distribution of docks, launch ramps, jetties, rail launches and stairs is depicted in Figures 5 - 7, and summaries of the number and density (no. per km of shoreline) of these features by sub-region are included in Table 1. For additional drift cell-level detail the reader is referred to Appendix 1. At the scale of sub-regions, those of Lower Hood Canal possessed among the highest number and density of non-bulkhead shoreline alteration features observed in all of Hood Canal and the eastern Strait. Of the 486 docks mapped, 146 (30%) occurred along the South Shore of Lower Hood Canal. This high concentration of docks coincided with areas of continuous armoring at and seaward of ordinary high tide, where homes have been built on fill and there is no shared community dock space. High concentrations were also observed at Driftwood Key, Sequim Bay, Shine, and Mats Mats sub-regions (Table 1).

Stairs and stair towers were the dominant shoreline alterations along steep banked shoreline segments, though it is important to remember that only stairs that were <u>not</u> associated with larger, more intrusive shoreline modifications (such as docks or bulkheads) were mapped. Sub-regions with high densities of stairs included Olele Point, Pleasant Harbor, Dosewallips, Duckabush, Lofall, Whiskey Spit, Discovery Bay, and East Marrowstone (Table 1). Vegetation removal from the top and face of natural bluffs was common in areas with stair construction. The effects of this vegetation removal and stair construction on natural bluff function are unknown and such an analysis was beyond the scope of this study. However, we suggest that stair number and density along high and low bluffs may serve as a useful indicator or barometer of shoreline alteration; assessment of this situation is needed, given the potential importance of sediment and wood recruitment from areas where stairs are commonly constructed.

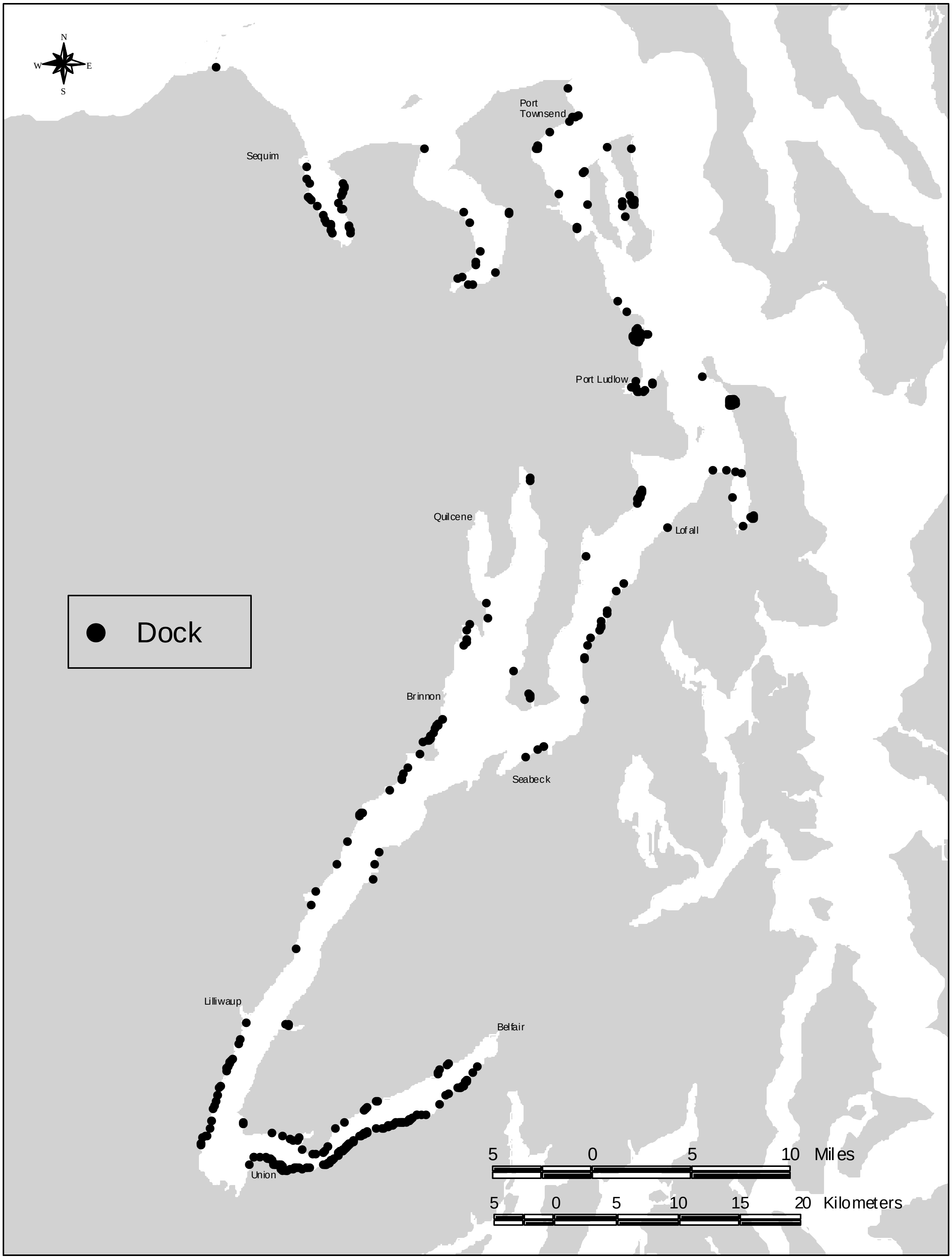

Figure 5. Distribution of docks throughout study area.

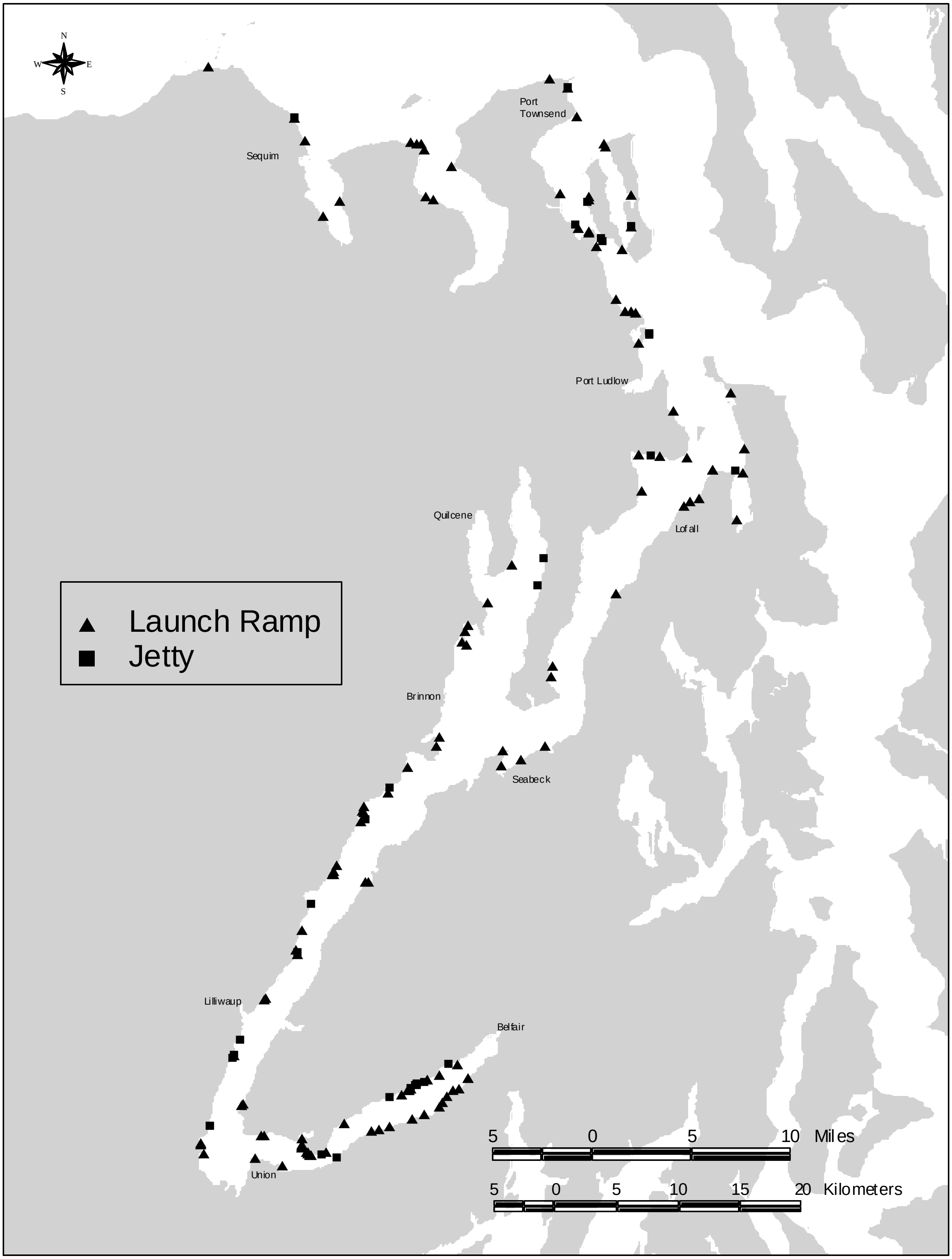

Figure 6. Distribution of launch ramps and jetties throughout study area.

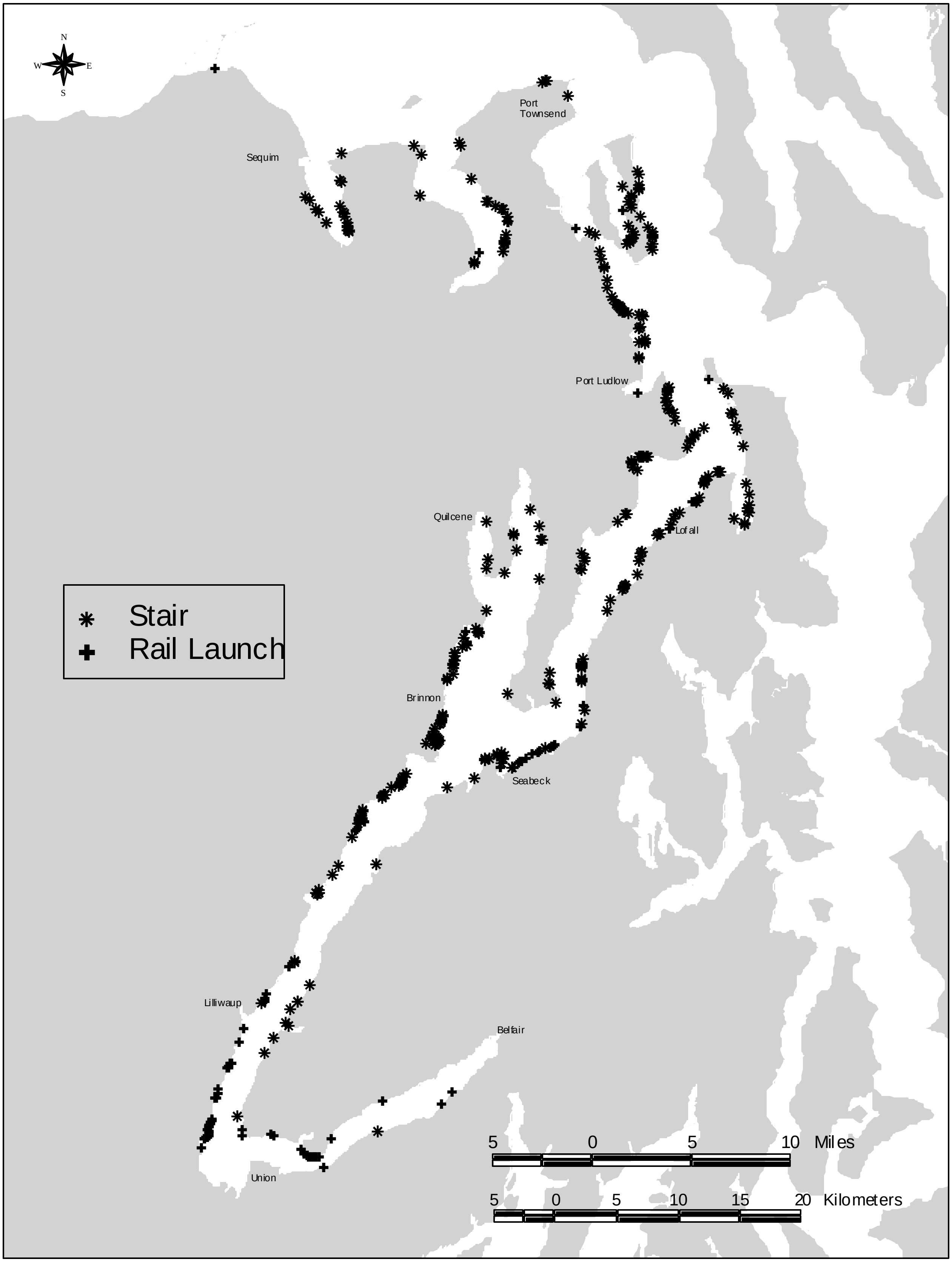

Figure 7. Distribution of stairs and rail launches throughout study area. Only stairs independent of other structures are shown.

Stairs often fall and many were observed that had been destroyed during recent slides along steep bluffs. This was far easier to observe along steep faces of unvegetated bluffs such as those along the east side of Marrowstone Island. Dangling remains of these modifications were also seen in other places and an initial attempt was made to record their presence. Since we did not accurately survey the entire study area, no mapped result is presented. It is interesting to note that these stairways continue to be built in the same highly erosive locations.

In contrast to stairs, rail launches, launch ramps, and jetties were typically mapped in association with a larger structure, such as a bulkhead. Most rail launches lay partially above the beach substrate and posed a lesser impact to alongshore drift, as compared to poured boat ramps or jetties. Of 118 rail launches, approximately 70% occurred in the Seabeck, North Shore, Skokomish, and Triton sub-regions (Table 1). Launch ramps were typically constructed of concrete or other hard materials lying on or in the intertidal beach, intercepting nearshore drift much like a jetty or groin. Like docks, launch ramps were frequently mapped in association with bulkheads, and were particularly dense in the Lower Hood Canal region; of the 129 mapped launch ramps, 43 (33%) occurred in Lower Hood Canal (Table 1). Similarly, jetties or groins, though few in number (n=30) were concentrated in the Lower and Southwest Hood Canal regions.

All communities up and down Hood Canal and the eastern Strait have access to public and commercially owned launch ramps at Salsbury Point, Triton Cove, Quilcene Bay, Shine, Gardiner, and other locations. Yet, individuals have placed 129 additional, private use concrete ramps and 118 rail launches into the nearshore throughout the study area. Community docks and marinas also exist in many areas, including Quilcene, Seabeck, and Pleasant Harbor. Yet shorelines are dotted with private docks, many of which extend out from bulkheads that cover or modify the nearshore spawning habitat of herring, smelt, and sandlance.

<u>Backshore Landforms</u>

Our chief aim was to map human shoreline modifications, but we also mapped natural shoreline geomorphology to provide context for the analysis of modification patterns along contrasting shore types. A particularly onerous challenge was determining original landform types along heavily developed shorelines (as discussed above). Nonetheless, though preliminary, our backshore landform mapping is useful for finding and comparing shore segments with similar natural geomorphic settings.

Appendix 2 presents total lengths and percentages of backshore landform types by sub-region. Appendix 3 describes in more detail the breakdown of backshore landforms by drift cell; this appendix contains information on total drift cell length, length of high and low bluffs; combined length of all "no bluff" shore types; and within the "no bluff" category, lengths of accretion type landforms, combined barrier beaches/spits/berms, saltmarshes, and other areas generically classified as "upland". Though outside conventional shoreline geomorphic categories, we were compelled to include the latter category due to the difficulty of accurately mapping natural backshore types along highly modified, low-lying shore segments. This shore type was generally applied where the extent of roadways, residential development, fill, or other human structures was so dense that the natural shoreline landform was obscured. Though untidy, the preponderance of "upland" shore segments (particularly in Lower Hood Canal) underscores a significant finding of this study: along certain shore segments of Hood Canal the extent and degree of shoreline modification is so pronounced that determining the original natural shoreline geomorphology through contemporary field investigation is extremely difficult, if not impossible. Some understanding of what has been lost in these areas can likely be inferred from other areas of Hood Canal. For example, though 309 km of high/low bluffs were mapped throughout study area (comprising 52% of the surveyed shoreline length), no high/low bluffs were mapped in the Union, North Shore, and South Shore sub-regions of Lower Hood Canal where the no bluff-upland shoreline landform type predominated (Appendix 2).

Accuracy Assessment

Our estimates of accuracy, based on comparisons between the boat-based survey and the onshore survey, included numbers of features inadvertently omitted during the survey and errors in horizontal placement; that is, in location and attributed length of features. We considered the onshore measurements to be accurate and therefore the benchmarks for estimating amounts of error for the boat survey. Results of the accuracy assessment are summarized in the following description. Detailed results are provided in Appendix 4.

The estimated overall error of omission for bulkhead features was 19.4%. Corresponding bulkheads between surveys had an average difference in center point position along the shore of 17.1 meters (standard deviation = 12.06 meters, standard error = 1.64 meters). A comparison of the boat-based survey bulkhead lengths to onshore survey bulkhead lengths showed an average difference of 22.8% (n = 54). The average percent error when the boat survey length was greater than the onshore survey length was 11.6% (n = 17), while the average percent error when the boat survey length was less than the onshore survey length was 28.0% (n = 37). Error analysis for description of bulkhead attributes indicates that 27.2% of the features have complete correspondence in material (concrete, rock, wood or other), angle (vertical or sloped) and position (above, at, or below ordinary high water) while an additional 58.6% agree in material and angle. The greatest error occurred with respect to identifying position of the bulkhead relative to ordinary high water.

For point features (including docks, jetties, launch ramps, and rail launches, but excluding stairs), the error of omission was 41.0%. There was also a 4.2% error of commission (i.e., features identified by boat survey but not by onshore survey). For point features, the average error in position along the shore was 15.97 meters (standard deviation = 13.43 meters, standard error = 2.80 meters).

CASE STUDIES

Our original intent was to walk the reader along the entire shoreline of Hood Canal and the eastern Strait of Juan de Fuca, providing a drift cell by drift cell account of habitat and modifications to the nearshore. Due to the large number of drift cells, length of shoreline, and exhaustive amount of modifications, we opted for the following set of case studies.

These examples were chosen to offer a broad range of geographical and ecological conditions while illustrating the many kinds of modifications and their impacts along the shore. The case studies were chosen for their illustration of how modifications impact each zone within a drift cell. It is important to remember that each shoreline area is unique and must be evaluated with its own special features in mind if and when any modification is proposed. But, general principles apply to all drift cells and modifications in each zone can be viewed as shown in Table 2:

Table 2. Typical shoreline modification impacts by drift cell zone

Zone Type	Zone Function	Impacts on zone
Erosion Zone	Initial supply of sediment to drift cell. Woody debris supply.	Sediment supply blocked, woody debris recruitment altered or eliminated, shade eliminated
Transport Zone	Eelgrass beds form. Sediment supply contributed with some accretion. Nearshore feeding and migration by juvenile salmonids. Large wood contributed.	Sediment supply reduced, woody debris altered, shade reduced, erosion of spits and beaches, loss of spawning and rearing habitats
Deposition/Accretion Zone	Accretion features established. Saltmarsh, tidal lagoons, estuarine habitats formed. Significant juvenile salmonid habitat.	Sediment deposition reduced, erosion of spits/beaches, loss of spawning and rearing habitats

<u>Lower Hood Canal</u>

No portion of Hood Canal or the eastern Strait has been more radically altered than the Lower Hood Canal region. Essentially no natural eroding bluffs remain in this region, which comprises the "hook" of south Hood Canal. Road and residential construction lying behind continuous armoring has isolated the shoreline from natural bluffs, denying the beach its natural sources of sediment and large woody debris recruitment.

As a result of this nearly complete modification to the shoreline in this area, it is impossible to accurately map natural shoreforms or successfully characterize contemporary shoreline patterns. We can predict where natural beaches may have occurred in the past based on drift cell zonation, but such extensive modifications obliterate their historic location and potential features. This is especially true for sandy shorelines which would have formed along transport zones and at the tail end of drift cells within the deposition or accretion zones as described earlier in our "textbook" example in Port Ludlow Bay (see "How a Drift Cell Functions" in above Background section).

Graphic evidence of the extent of bulkheading in the lower Hood Canal region is shown in Figure 8. Figure 9 paints an equally graphic picture of the saturation of other modifications in this area, including docks that alter overwater nearshore habitat. Table 3 provides the relative measure of impact to each drift cell zone in Lower Hood Canal.

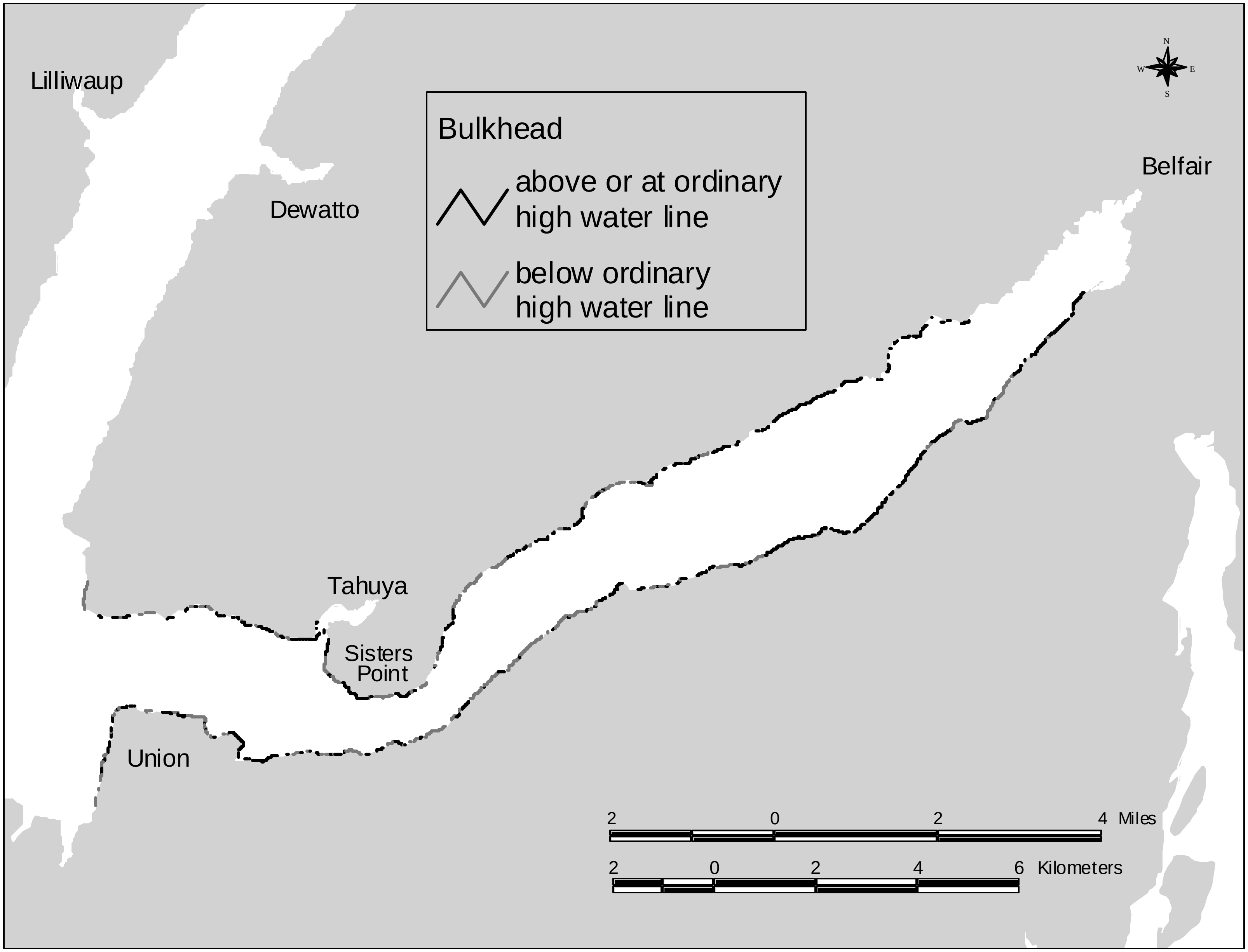

Figure 8. Lower Hood Canal case study. Distribution of bulkheads.

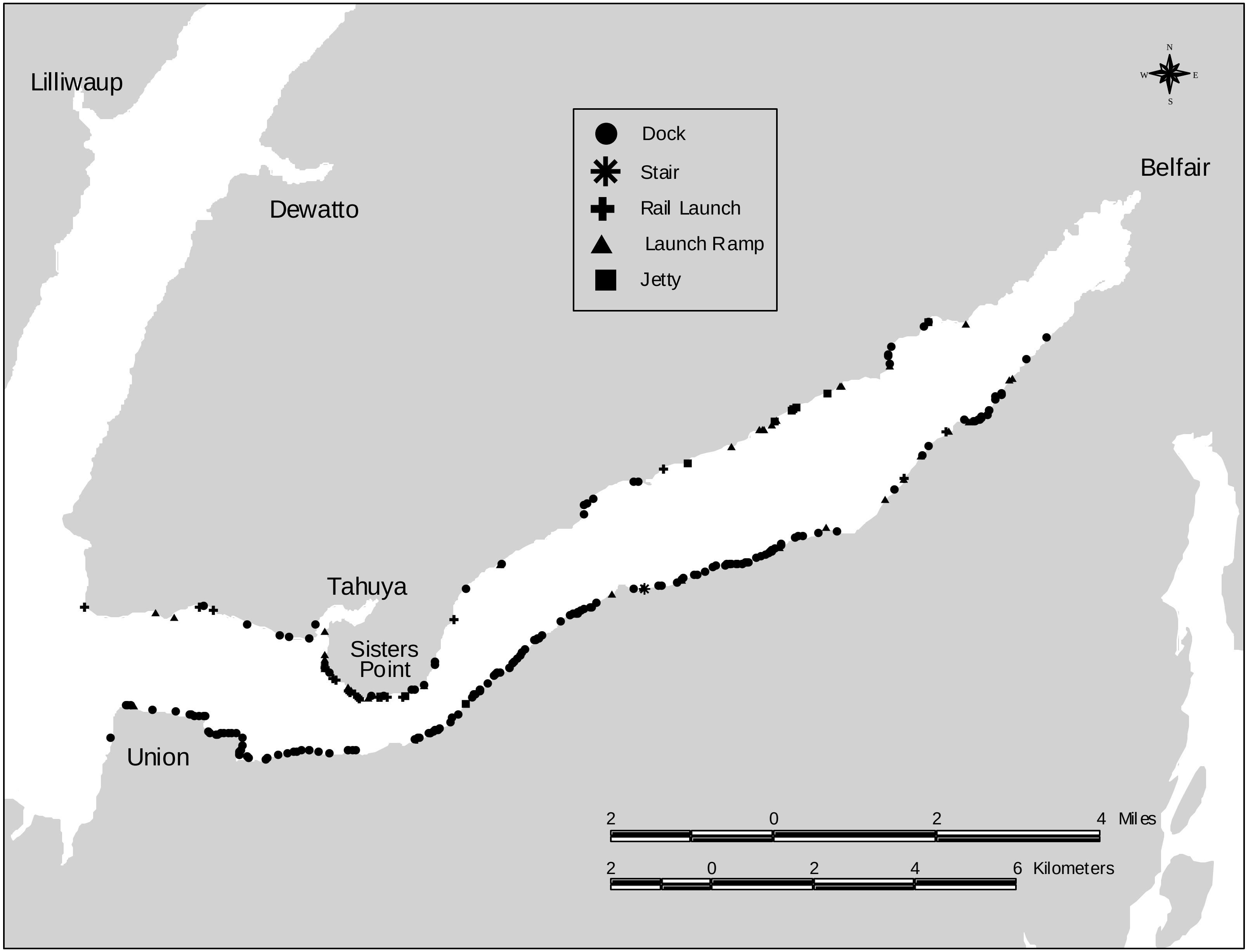

Figure 9. Lower Hood Canal case study. Distribution of docks, stairs, rail launches, launch ramps, and jetties.

Table 3. Relative degree of impacts to drift cell zones in Lower Hood Canal

	Severe	Moderate	Minimal
Erosion Zone	+		
Transport Zone	+		
Accretion Zone	+		

Figure 10 gives an indication of the extent of impacts on populations of nearshore habitat species. Historically, sandlance would have found extensive spawning in the transport and accretion zones of unimpaired Lower Hood Canal drift cells. The four remaining spawning sites shown on the map are tiny pockets of sand isolated between the near continuous mass of cement and rock walls lining the shoreline.

The single bluff remnant mapped in Figure 10 is a stark reminder of conditions that severely impact nearshore habitat and several species. Bluffs once formed the backshore of most beaches in Lower Hood Canal. Roads, homes, bulkheads, and other structural changes have been carved between them and today's nearshore, isolating the sources of sandy sediments that once provided sandlance the substrate needed for spawning. Bulkheads placed on top of the intertidal also covered former spawning sites. We refer to these combined impacts as cumulative effects – sand sources are blocked and sand deposition sites are eliminated.

We know sandlance have suffered severe declines due to alterations in the Lower Hood Canal region, simply by measuring the modification of their spawning habitat. Losses to their population are reflected in the minimal occurrence of spawning sites left intact. Unfortunately, we do not have as extensive information on salmon habitat changes. This is due in part to the need for more information on how juvenile salmon use the nearshore environment of Hood Canal and on the need for more accurate maps of eelgrass beds on which they depend. We can assume that impacts on the salmon's food supply have begun to express similar cumulative effects. That is, sandlance are salmon food and natural shores are salmon habitat. With impacts to both, salmon populations suffer the cumulative impacts resulting from loss of shoreline in areas such as Lower Hood Canal.

Bulkhead construction in the Sisters Point vicinity provides a more detailed example of shoreline conditions in the Lower Hood Canal region. As can be seen in Figure 11, bulkheads line much of drift cell MA 9-1. The drift cell originates west of Sisters Point where the cell extends for 2.2 km to the east, terminating at the convergence with another drift cell west of Sisters Point. Some 1.8 km (83%) of the length of this drift cell has been armored (Appendix 1), and much of the bulkhead construction has occurred below the ordinary high water line (Figure 11), obscuring original beach conditions and eliminating productive intertidal habitat.

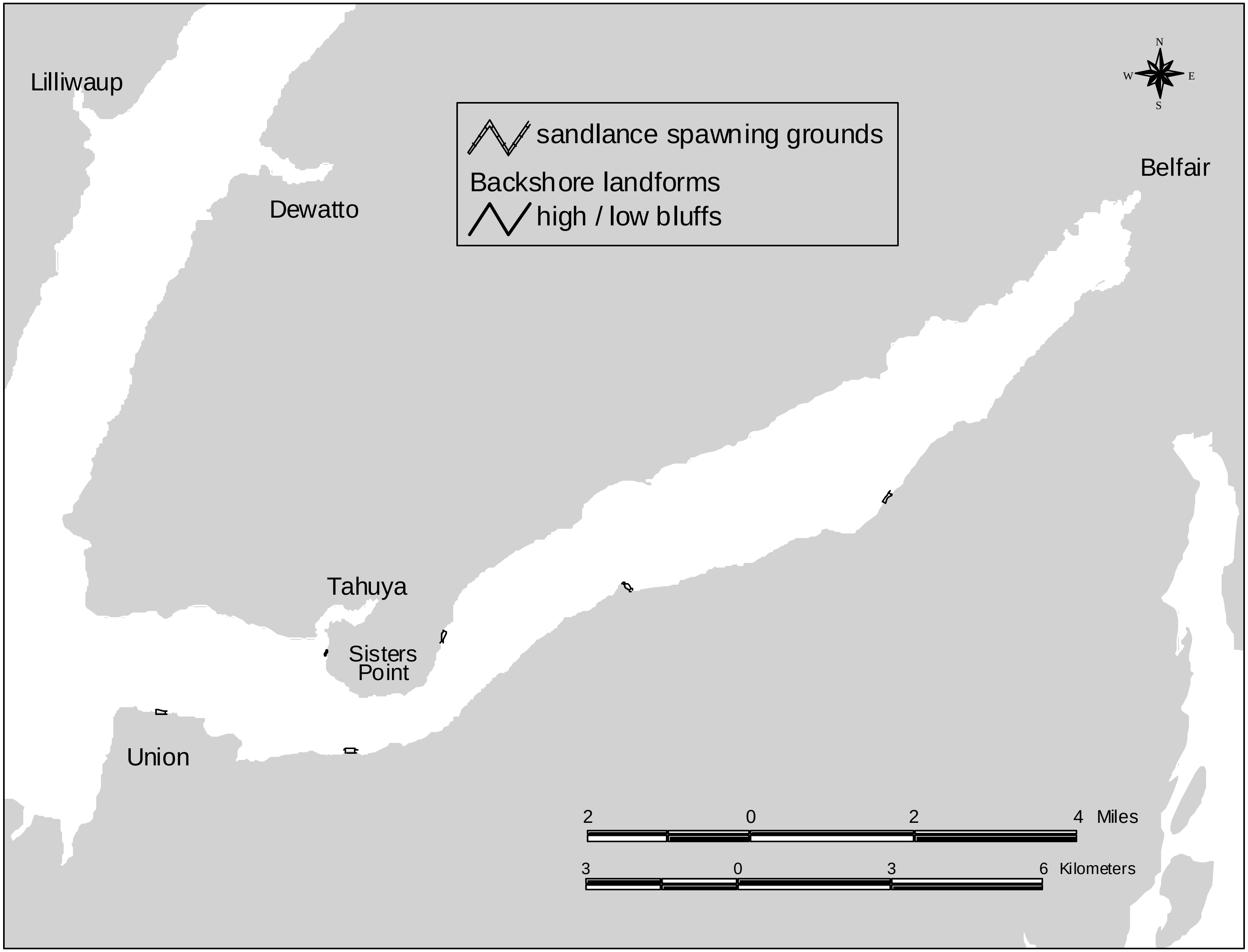

Figure 10. Lower Hood Canal case study. High/low bluffs and Sandlance spawning areas.

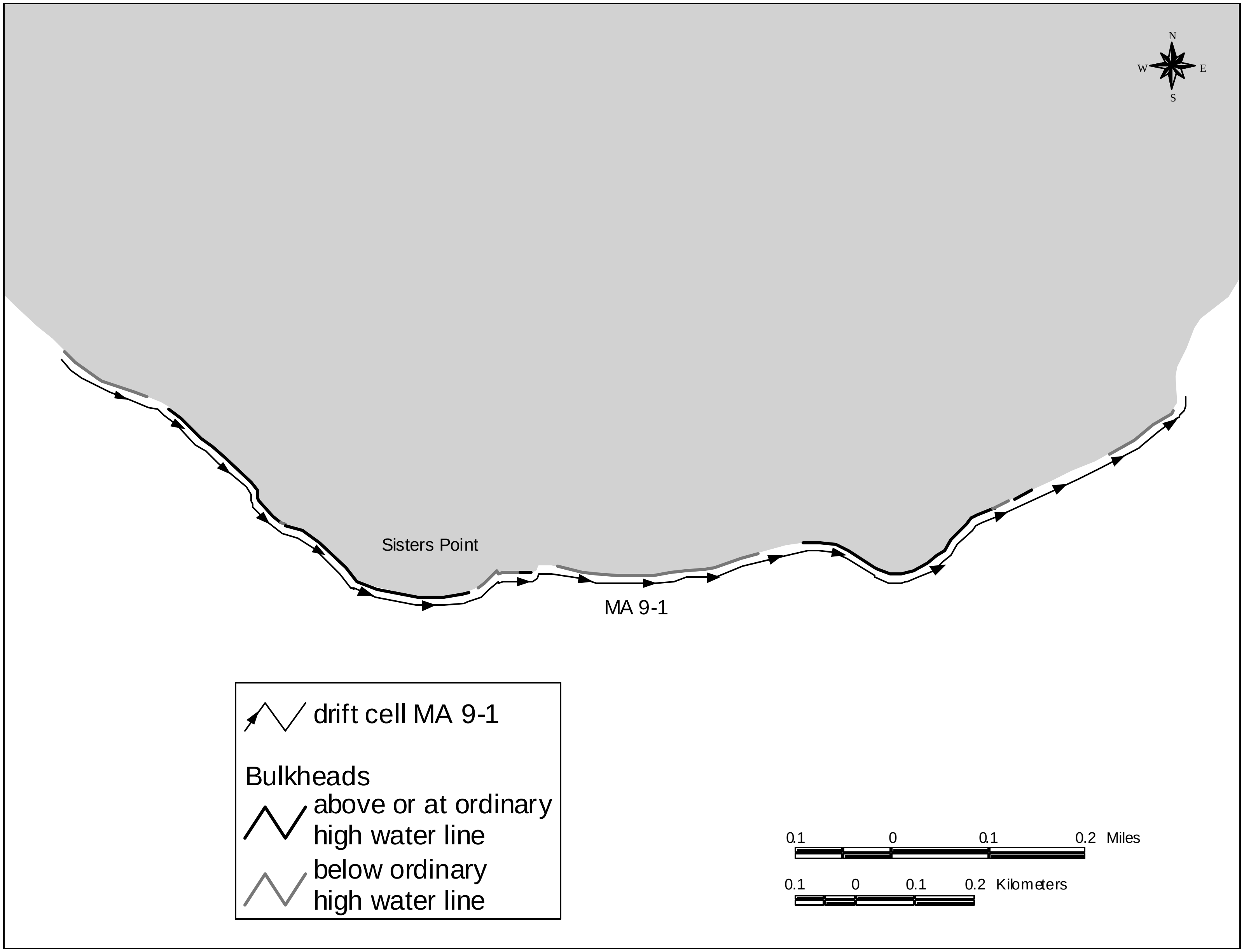

Figure 11. Lower Hood Canal case study. Bulkheading in drift cell MA 9-1.

In spite of these impacts from shoreline armoring, remnant overhanging natural vegetation is present in the Sister's Point area. This is in stark contrast to other south Hood Canal beaches where extensive, and in some cases, complete vegetation removal is the rule. Natural vegetation remains near Sister's Point primarily where armoring occurs along roadbeds with no adjacent housing. A more typical Lower Hood Canal pattern of modification can be seen along much of the armored shores where little or no vegetation is associated with homes or other buildings built on fill supported by bulkheads. These often extend out onto the intertidal to further impact shoreline habitat.

It is difficult to fully integrate and explain the consequences of such intensive alterations on nearshore marine habitat, especially where human development has obliterated important natural backshore landforms. But we do know armoring and development at and below the historical water line has resulted in the filling and permanent removal of productive intertidal habitat, while overwater shading from docks and piers has likely diminished the productive capacity of remaining areas.

One approach to understanding impacts due to these changes is to provide illustrations of a particular area over time. Figure 12 portrays historic changes along one Lower Hood Canal shoreline segment near Union. Usually, a geologist uses local landforms to identify shoreline features, but in their description of this drift cell, Swartz and Blankenship (1982) could only point to evidence of shoreline dynamics with reference to human modifications. For example, they state there is "evidence of northeasterly drift seen at the ends of dozens of bulkheads and groins where sediment accumulations occur on the southwest and beach erosion on the northeast."

As can be seen in the historical changes at Union (Figure 12), bluffs were gradually isolated from the shoreline. Sediment sources were isolated as well and the beach substrate coarsened. As homes were built shoreward of the road, fill covered upper intertidal habitat where sandlance once spawned, clams lived, and juvenile salmon migrated in the shade of overhanging trees.

Today, we live and recreate along these shores. But it is important to remember how the shoreline once existed in harmony with the bluffs, trees, and drift cell dynamic. The Union shores lack natural features, making it difficult to impossible for us to measure natural resource changes and potential habitat value.

South Port Ludlow Bay

The south side of Port Ludlow Bay has been largely residential for many centuries, occupied by S'Klallam Tribal members for many years and several waterfront homes today. Except for the ribs of a single decaying schooner, no industrial or commercial modifications appear to have impacted the shoreline. A single, relatively unaltered drift cell (JE-6) extends from Tala Point along this shoreline, terminating with a long sandy spit that encloses a tidal lagoon (Figure 13). This drift cell has been described in the introduction of this report but is briefly mentioned again here to allow comparison with Southpoint, a site with similar structure but with far greater impacts due to human modifications.

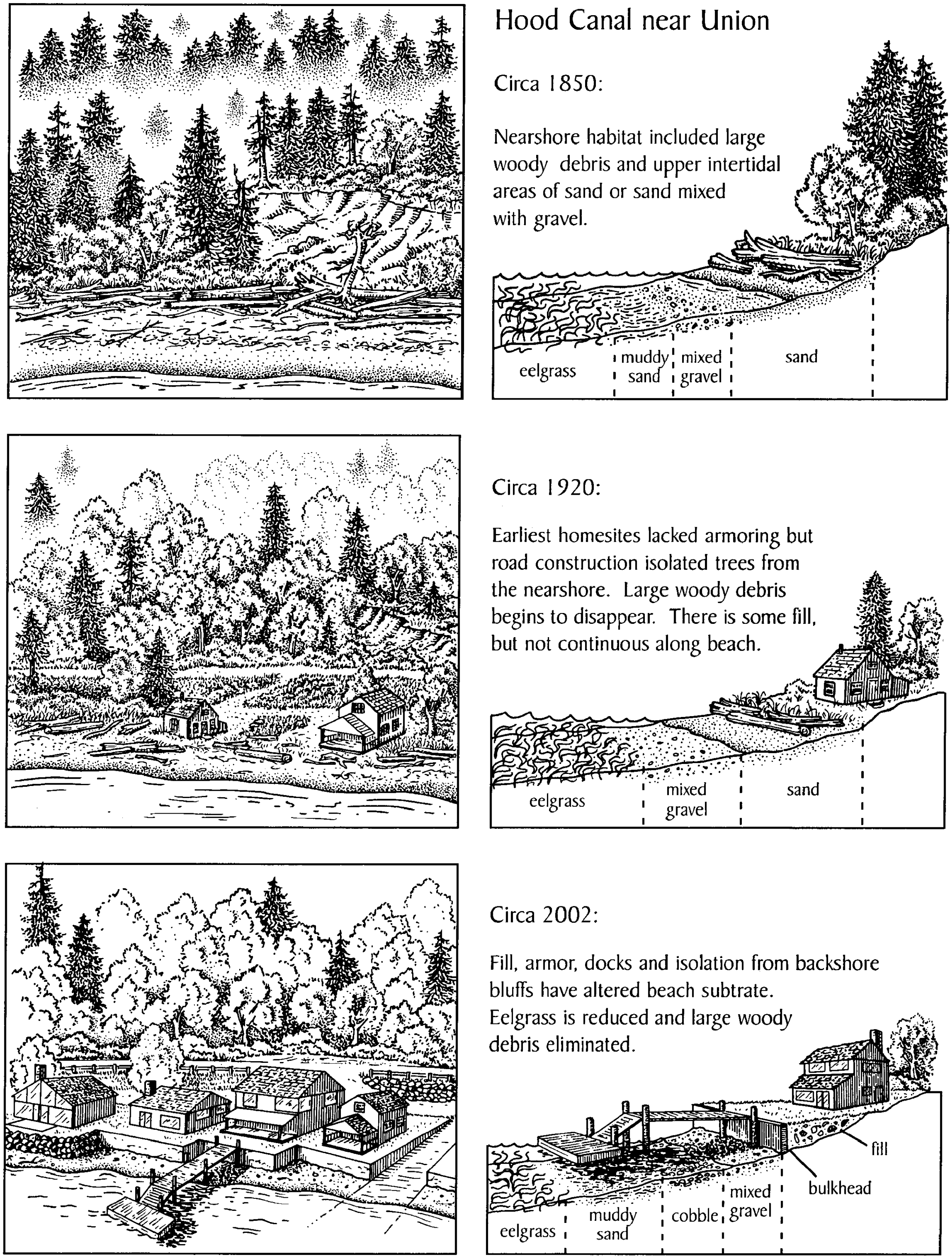

Figure 12. Lower Hood Canal Case Study. Historic changes projected along a shoreline segment near the town of Union.

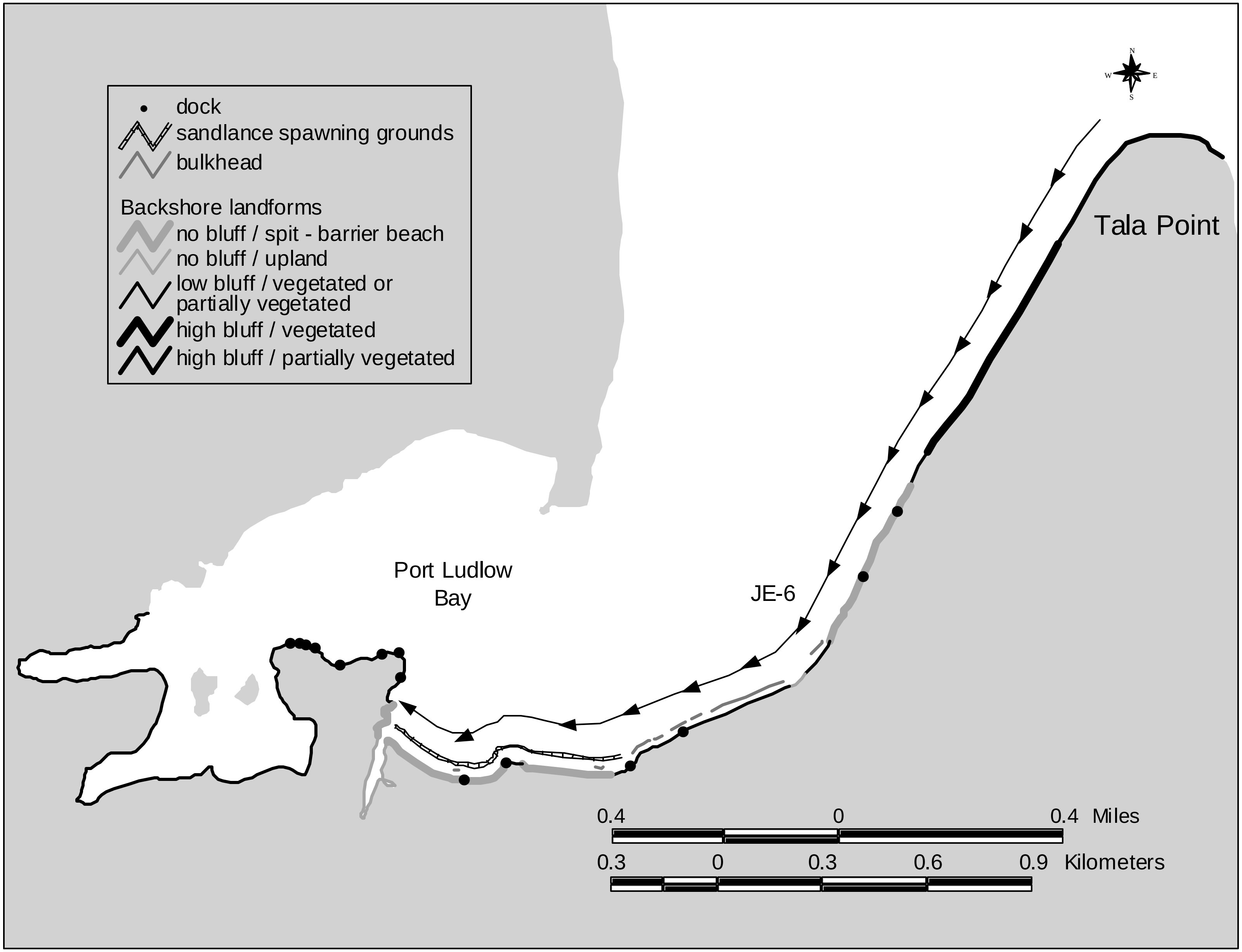

Figure 13. South Port Ludlow case study. Shoreline features within drift cell JE 6.

As can be seen in Figure 13, the long, sandy spit enclosing the lagoon at the terminus of this drift cell is relatively undisturbed. A few bulkheads have been constructed updrift of the spit, but they do not greatly impair movement of fine sediments due to their location high in the intertidal and low number. Additionally, sediment sources from Tala Point feeder bluffs and contributing bluffs along the transport zone of the drift cell both remain relatively natural. Large wood and sediment fall freely to the beach. Impacts on the shore zones of the drift cell are moderate to minimal as shown in the following table.

Table 4. Relative degree of impacts to drift cell zone in South Port Ludlow Bay

	Severe	Moderate	Minimal
Erosion Zone			+
Transport Zone		+	
Accretion Zone			+

The resulting spit and subestuary complex formed at the JE-6 drift cell terminus provides significant rearing habitat for coho and cutthroat throughout the complex's length and for chum in the lower reaches of the tidal slough and shallow nearshore near the tip of the spit (Hirschi and Doty 2002). In comparison, this kind of complexity has been lost in much of the Southpoint area at the terminus of drift cell JE-13 as seen in the following case study.

Southpoint

Southpoint is the former site of a Washington State Ferry terminal and is in view of the Hood Canal Bridge on the west side of Hood Canal at the southern shoulder of Squamish Harbor. It is also the site of Bridgehaven, a housing development and small marina, and is the terminus of one of the longest drift cells on Hood Canal.

Drift cell JE-13 originates just north of Hazel Point and extends north for just over 20km in the Northwest Hood Canal sub-regions (Figure 14). Net shore drift is northward along the Toandos Peninsula and Thorndyke Bay until terminating artificially at the jetty on the north side of the Bridgehaven marina near Southpoint. Most southern reaches of this shoreline are unarmored and only 8.4% of the entire length has been modified with bulkheads. The erosion and transport zones are predominantly natural vegetation on high and low bluffs that account for 78% of the entire drift cell length.

Extensive U.S. Navy and Olympic Resource Management timberland properties have protected the nearshore from alteration near Thorndyke Bay and along much of the bluff habitat on the east side of the Toandos Peninsula. Natural accretion occurs along just over 6.7 km of the drift cell, including prominent shoreforms such as the spit at Brown Point.

Diverse nearshore habitats in this drift cell include a stream mouth lagoon and broad delta formation at the head of Thorndyke Bay. A long sandy spit partially encloses the large tidal lagoon with significant coho and chum rearing habitat. High, unstable

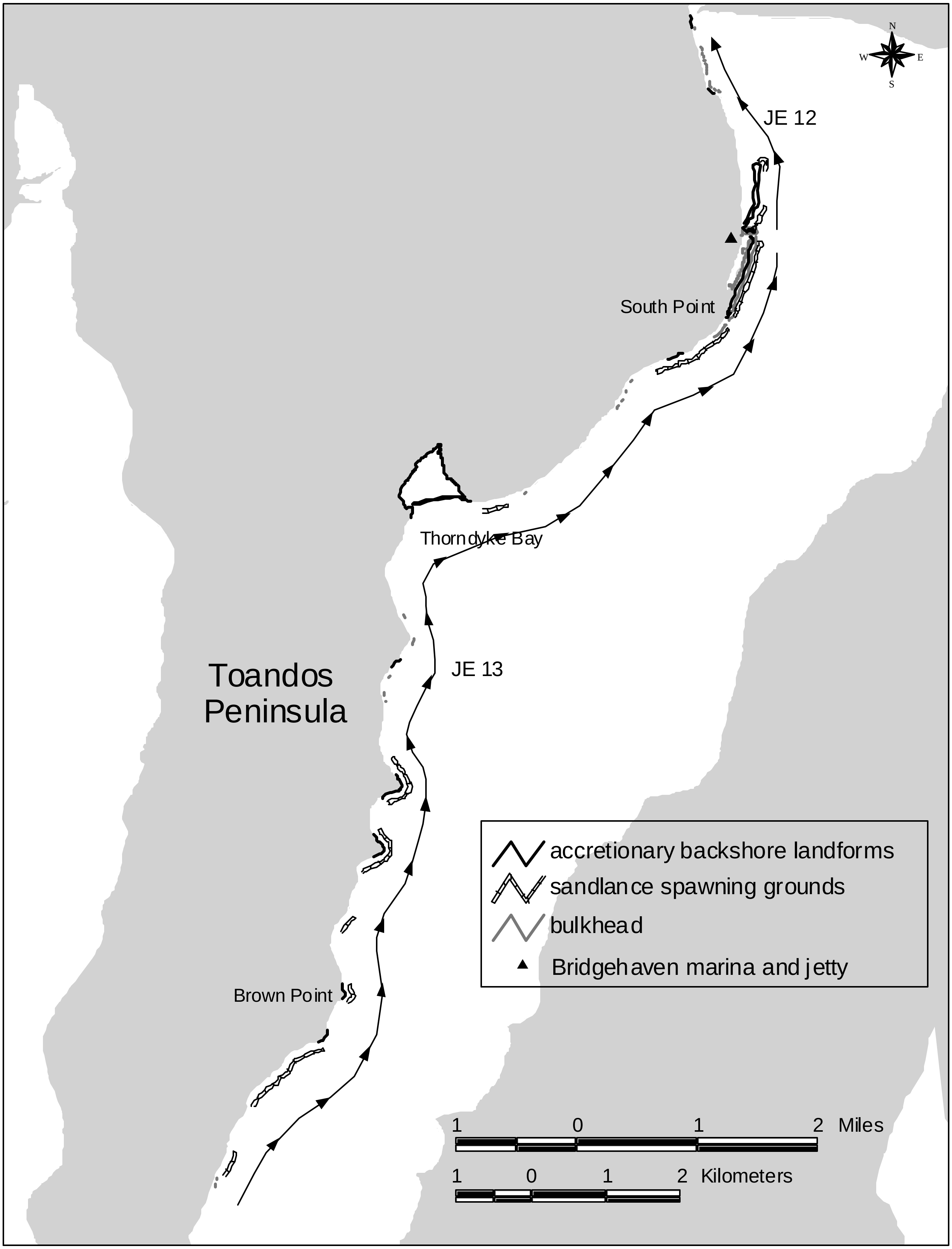

Figure 14. Southpoint case study. Accretionary backshore landforms, bulkheads and sandlance spawning grounds for drift cells JE12 (north of Bridgehaven jetty) and JE13 (south of Bridgehaven jetty).

bluffs to the east and north of the bay contribute large volumes of sediment as soil and vegetation slip off the top of clay banks not far from Southpoint. Some of this sediment is directed updrift to build and maintain the Thorndyke spit, but net drift remains northward, continuing along the transport path of the cell until natural conditions abruptly change at Southpoint. The presence of extensive north and south fetch at this point along Hood Canal may indicate the development of sub-cells within the larger drift cell (Thorndyke Bay vicinity) or the segmentation of this long drift cell (Hugh Shipman, personal communication).

A clear indication of the alteration of drift cell dynamics can be seen most clearly in the Southpoint/Bridgehaven complex. Historically, a natural spit and an associated subestuary habitat formed at the terminus of this drift cell, just as exists today in South Port Ludlow Bay at the terminus of JE-6. Though much longer and far more complicated along its shoreline route, the historic Southpoint spit and subestuary habitat was once much more extensive and complex with significantly more salmon habitat and very likely, a spawning stream as well (Figure 15).

Historic losses are not easy to quantify and fully understand due to their severity, but much of the change over time can be linked to modifications clearly evident today, primarily within the drift cell accretion zone as indicated in Table 5.

Table 5. Relative degree of impacts to drift cell zone at Southpoint

	Severe	Moderate	Minimal
Erosion Zone			+
Transport Zone			+
Accretion Zone	+		

These accretion zone impacts are likely a cumulative and confusing result of the following:

1) Dredge and fill of the tidal channel, saltmarsh, and lagoon from Soutpoint to the marina.
2) Jetty construction at the marina.
3) Bulkheading and wing wall construction from Southpoint, northward along the Bridgehaven spit.

The dredging and filling of the marsh and shallow intertidal habitat has resulted in severe loss of salmon habitat. Hirschi and Doty (2002) have reported a lack of juvenile salmon in samples within the tidal areas behind the built spit at Bridgehaven. They have also reported adult chum salmon nosing into the impassable culvert that separates the remnant marsh and tidal channel south of the dredged area. In sharp contrast, their samples taken in tidal channels behind the protective natural spit (Figure 15) include large numbers of both pink and chum salmon during spring outmigration.

A new drift cell (JE-12) originates at the jetty associated with the Bridgehaven marina (Figure 14). Historically, the drift cell JE-13, continued into Squamish Harbor,

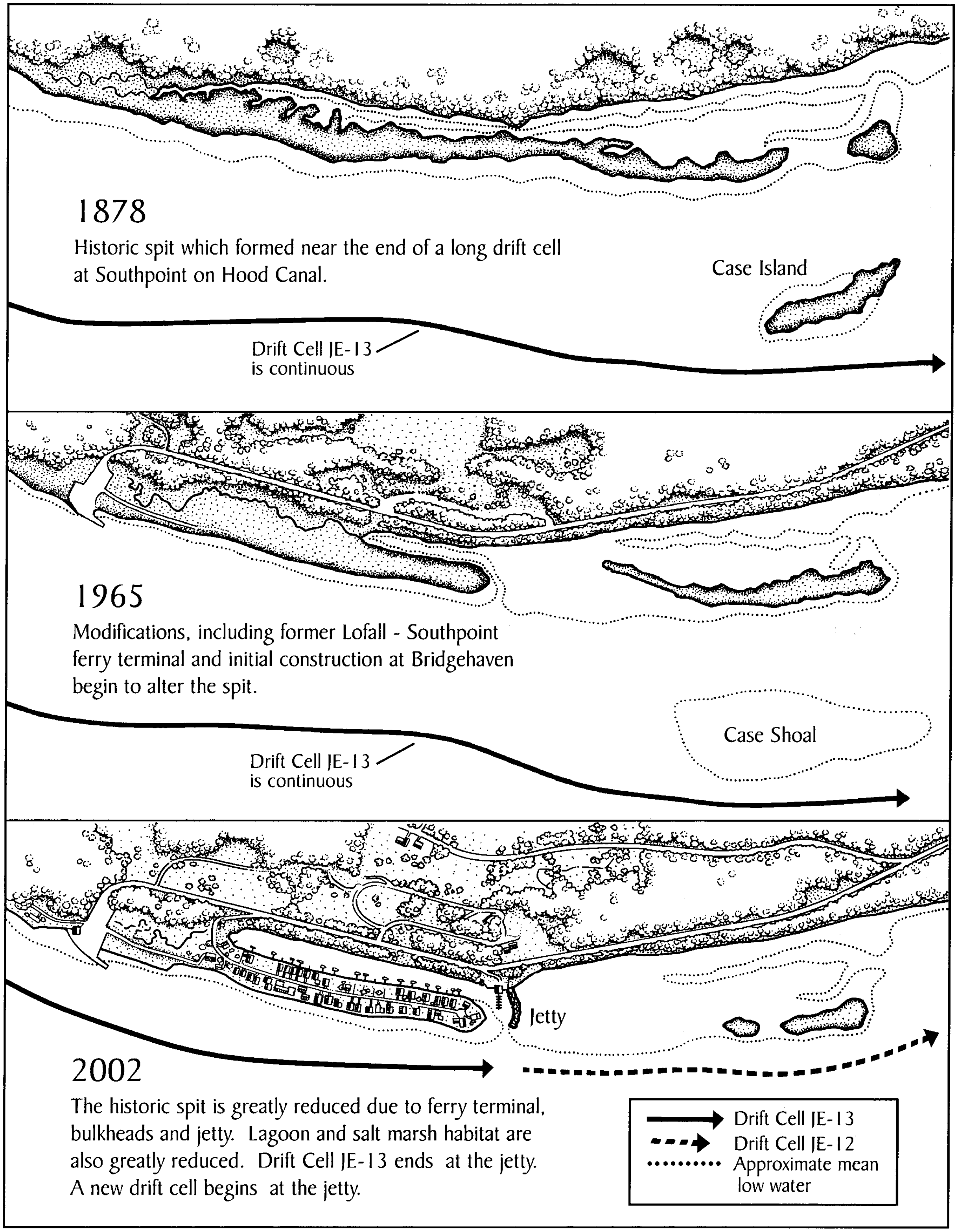

Figure 15. Southpoint case study. Illustration of changes to the Southpoint spit over time.

depositing sediment along the entire length of the contiguous, historic spit complex. Stated another way, this former accretion zone has been split by the new erosion zone at the starting point of drift cell JE-12.

Fine sediments once deposited along the natural drift cell terminus of JE-13 are now (artificially) washed away and transported to the north and into Squamish Harbor as the northern half of the spit disappears. Likewise, property owners along the built segment of the southern half of the spit have been seeing their beachfront erode and sediments coarsen in front of their bulkheads as immigration of new sediments is blocked by updrift structures.

This erosion/accretion balance is further complicated by the extensive bulkheading, filling, and wing wall structures between Southpoint and the Bridgehaven jetty. Sediment volume may have been reduced in the eroded gap between the two, now separated spits, due to accretion of material near Southpoint where sediments are diverted out into Hood Canal by armoring and the former ferry structures (Johannessen 1992). The proliferation of seawalls near Southpoint and Bridgehaven, the installation of the jetty, or cumulative impacts from all the above may also be at play.

One might hope that the relatively natural spit complex at Port Ludlow will be regarded as a model of how people have been able to enjoy a waterfront residential area while maintaining the integrity of the dynamics of each segment of the drift cell and its resultant habitat values. At the same time, a comparison of the two sites may give property owners and shoreline managers ideas of how to restore functions and values in the highly altered Southpoint/Bridgehaven complex. Juvenile salmon habitat needs suggest that restoration may need to proceed quickly since the erosion and destruction of the remaining intact spit and subestuary habitat now rests within an unnatural erosion zone.

Point Julia

In strong contrast to the Southpoint example, Point Julia also has extensive human use of a spit complex, but essentially no impact to nearshore habitat. Also known as Boston Point, Point Julia is at the northeastern entrance to Port Gamble Bay on the Port Gamble S'Klallam Reservation (Figure 16). It forms at the terminus of a north directed drift cell, KS-2-2. As seen in the map of the cell, and as reflected in Table 6, very little modification has occurred along this nearshore with the exception of armoring along the transport zone midway up the eastern shore of the bay.

Table 6. Relative degree of impacts to drift cell zone at Point Julia

	Severe	Moderate	Minimal
Erosion Zone			+
Transport Zone		+	
Accretion Zone			+

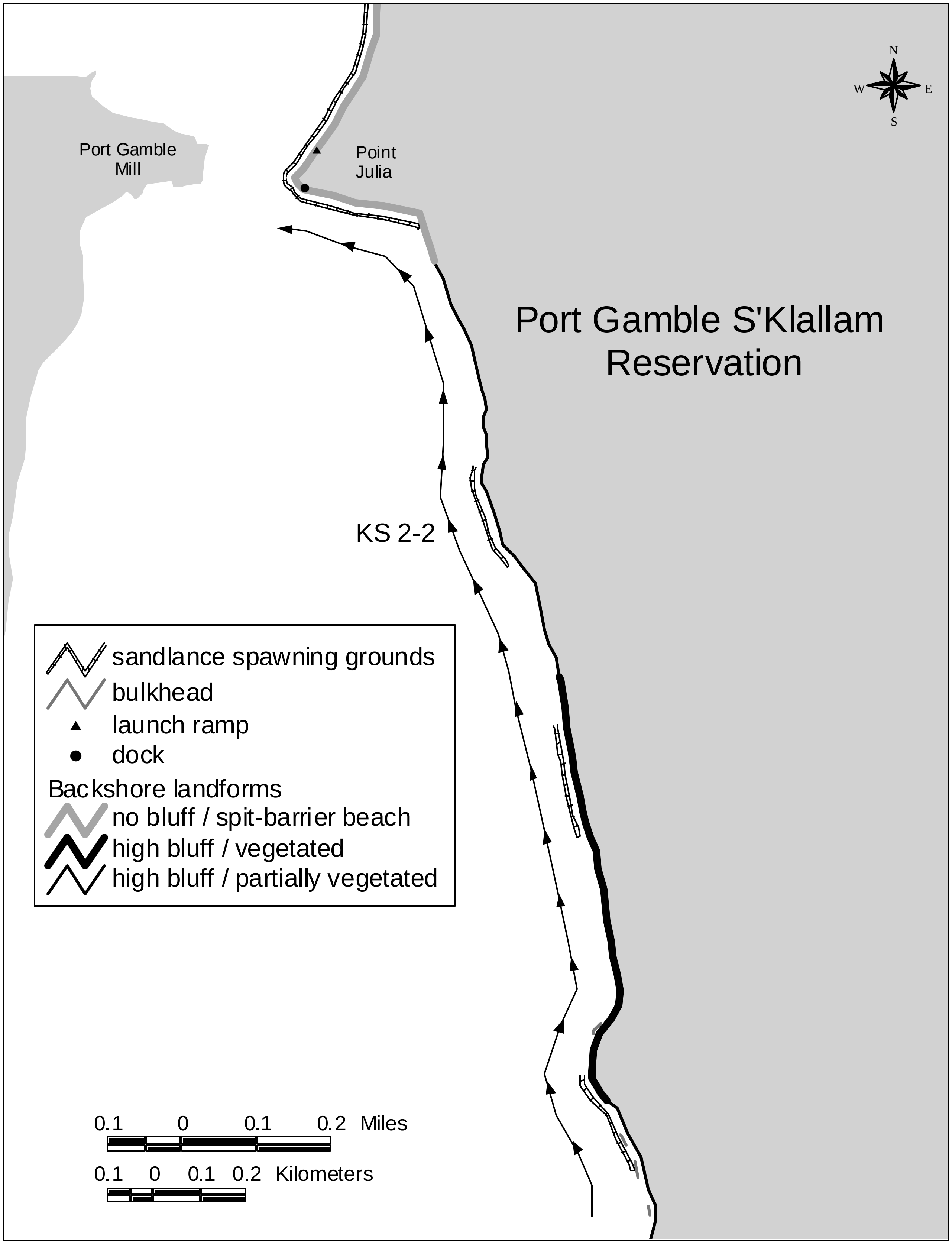

Figure 16. Point Julia case study. Backshore landforms, shoreline features and sandlance spawning grounds for drift cell KS 2-2.

Shorelines in the reservation section of the drift cell are little changed with significant wooded bluffs contributing sediment supply to the spit at Point Julia as well as overhanging shade for outmigrating salmon and large wood structure in the nearshore. As can be seen in Figure 16, a single dock and launch ramp are located on the Point. No bulkheads rim its shores. Yet, this site is one of the most heavily used, if not the most heavily used shorelines in Hood Canal and the eastern Strait. The cultural use of the site may be a good starting point for discussions of how we all view and all use the nearshore. Differing significantly from most other residential areas up and down the study area, Point Julia is the focal point for a community that has valued the nearshore environment for many centuries.

Port Gamble S'Klallam Tribal members likely used the spit earlier, but first moved to the site for long-term occupancy in 1853. At that time, the Port Gamble Mill Company arrived and chose a mill and town site on the opposite shore at a sandy spit known as Teekalet (Jerry Gorsline, unpublished). The mill owners offered jobs in the mill, wood for homes, or other promises to tribal members if they would move from their ancestral village site at Teekalet to the Point Julia side of the bay (Rose Purser, personal communication).

The mill at Port Gamble was built atop Teekalet spit, obscuring all vestiges of the former spit. At Point Julia, homes were built, but all tribal members now live above the accretion beach area, well away from the nearshore and Point Julia. One dock serves the entire community. A launch ramp has also been built. These two shoreline modifications serve the S'Klallams, many of whom make their living fishing, clamming, or harvesting other resources from Hood Canal and surrounding marine waters. Like others, tribal members also make use of public boat launches and docks in the study area.

Phil Dorn, a planner for the tribe, estimates that as many as two to three hundred people visit Point Julia each day for work on the beach or access to Hood Canal, or to otherwise enjoy the entire length of beach along the reservation shorelines. Despite what may well be the most frequently used and most heavily accessed spit complex on Hood Canal, Point Julia maintains natural functions and values. This is evident in the significant spawning along the beach by sandlance (Figure 16). Point Julia is also a known surf smelt spawning site (Pentilla 1999) and the Port Gamble herring stock which spawns in adjacent intertidal and shallow subtidal habitats is the second largest in Washington State (Pentilla 2000).

This example suggests that it is far easier and less expensive to promote ongoing protection of existing nearshore functions than to restore altered sites such as Southpoint/Bridgehaven. A single dock and launch ramp certainly alter the point to a degree and any future developments along this shoreline need to take drift cell dynamics into consideration. But existing conditions suggest that true community access can focus large numbers of people onto modifying structures that impact the nearshore minimally.

At other locations, when docks, launches, and other access structures were constructed in the past, drift cell dynamics appear to have been disregarded. This is evident for example at two sites, John Wayne Marina and Rat Island, at which an attempt was made to satisfy the need of nearshore access while adjacent habitats were altered. The following descriptions of these two examples point to both the impacts and to potentials for restoration, and also to the need to address habitat issues and drift cell dynamics prior to construction of similar facilities in the future.

John Wayne Marina

The marina, dock, fill, parking lots, and launch ramp at John Wayne Marina obscure the nearshore and subestuary habitats once present at Pitship Point in northeastern Sequim Bay. The site, like Point Julia, had a long history of occupancy by S'Klallam Tribal members up until the time of non-Indian settlement (Kennedy and Thomas 1977). Also like Point Julia, the intent of the marina is to allow public access to nearby waters. But the impacts of John Wayne Marina on nearshore habitats have been far greater. A more thorough comparison with community and cultural values may help explain some of the differences between the two sites.

As can be seen in Table 7, impacts are severe in the erosion zones for two drift cells that diverge at the marina complex (Figure 17). This drift cell divergence shaped Pitship Point as sediments were transported to the south and north, away from the present day marina location. Johnson Creek, a stream with a severely abbreviated subestuary due to fill and armoring at its mouth, is also located within this drift cell divergence area. It is difficult to determine natural shoreline functions in the area, but an extensive marsh to the south and the tip of the historic delta of Johnson Creek suggests significant subestuarine habitat values once existed.

Table 7. Relative degree of impacts to drift cell zones at Pitship Point

	SEVERE	MODERATE	MINIMAL
Erosion Zone	+		
Transport Zone		+	
Accretion Zone	+		

Regardless of history, the marina appears to be permanently established. Thus it would seem little can be done to remove the substantial amounts of fill and alteration at the immediate marina site. However, the marsh habitat partially isolated by road fill to the south of the marina is of interest for restoration and likely supports or can support juvenile salmon (Byron Rot, personal communication).

As can be seen in Figure 18, substantial numbers of docks and other shoreline modifications have occurred along the shores of Sequim Bay, despite the presence of the facilities at John Wayne Marina. This is also in contrast to Point Julia and Port Gamble Bay where community access to the water occurs primarily at single facilities, a cultural concept that may be needed to foster greater protection and restoration efforts in the future. However, even a single modification can sometimes have severe impacts if placed inappropriately, as can be seen in the following example near Rat Island.

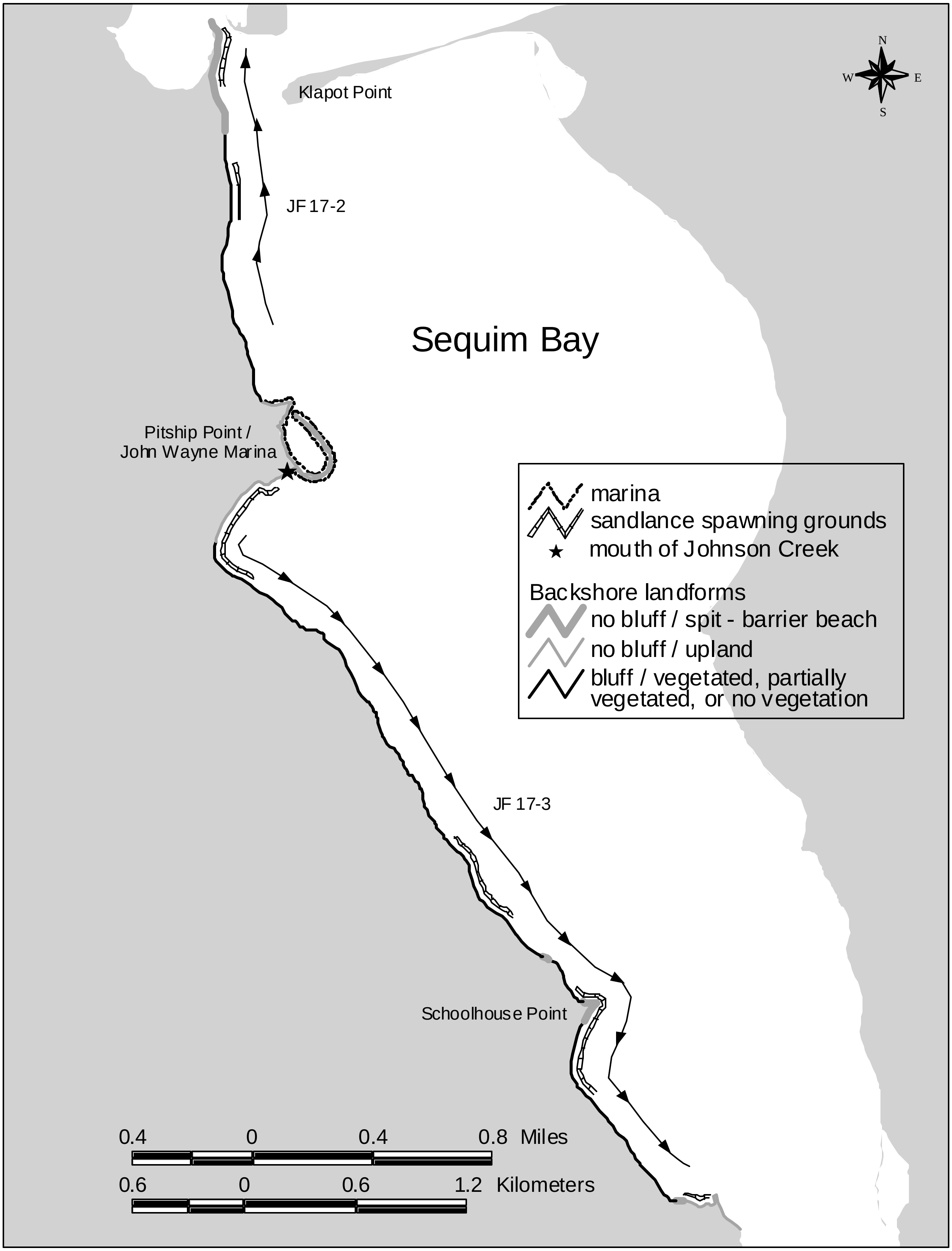

Figure 17. John Wayne Marina case study. Backshore landforms and marina within drift cells JF 17-2 and JF 17-3.

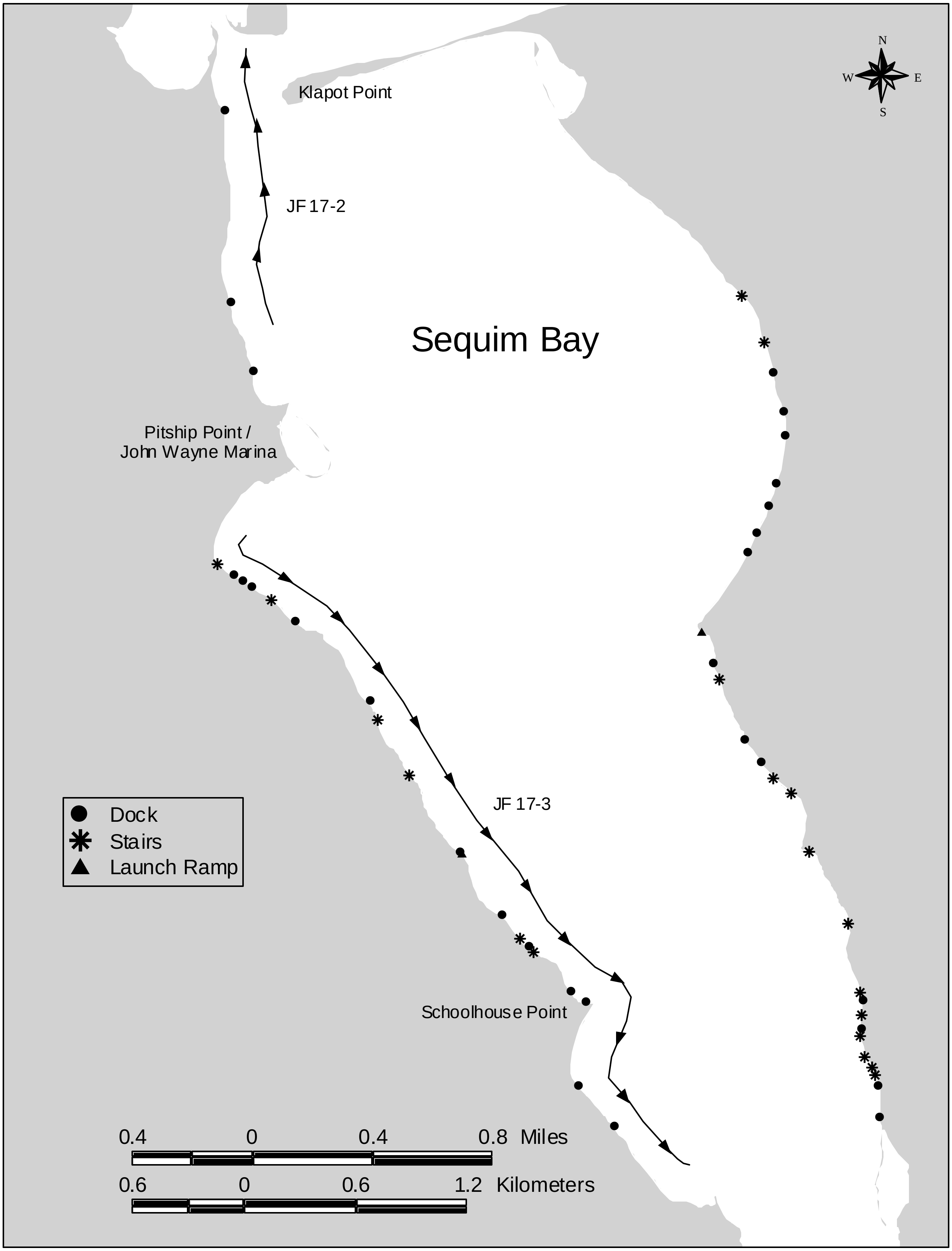

Figure 18. John Wayne Marina case study. Docks, stairs and launch ramps within Sequim Bay.

Rat Island

Rat Island has not always been an island as can be seen in the historical coast survey map shown in Figure 19. The island is a popular beach site often visited by boaters. It is an accretion shoreform once connected to Marrowstone Island as part of a long spit at the southwestern edge of Fort Flagler State Park. According to Ray Lowrie (personal communication), the spit was separated from the mainland approximately 60 years ago when military maneuvers included beaching and dragging boats across the spit. The narrow, sandy spit was breached by this activity and strong tidal currents flushing Kilisut Harbor have helped keep the opening from filling in since that time. The disconnection of Rat Island from its historic spit also appears due to effects of a launch ramp located updrift. Sediment supplies once delivered to the spit have been substantially blocked by this single human modification.

The public launch ramp on Marrowstone Island that extends into Port Townsend Bay at Fort Flagler State Park (Figure 20) is an example of how a small modification has altered the shoreline in an otherwise pristine setting. The ramp is located near the terminus of drift cell JEF-5. No bulkheads and no other modifications occur along this drift cell's entire length. High feeder bluffs with no residential or commercial structures line the erosion and transport zones of the cell until sediments are virtually stopped at the ramp site.

The ramp juts out into the intertidal from a low upland area along the accretion beach just before the start of the historic spit (Figure 20). Natural beach grassland habitat backs the sandy gravel beach, but an abrupt change in the beach and backshore begins downdrift of the ramp.

The land mass updrift of the ramp is approximately 12 meters seaward of the downdrift side of the ramp. This suggests long-term blocking of sediments that once continued along the beach to the spit, including the breached portion (Rat Island connection). Sediment does move past the ramp as noted by park personnel who maintain it with constant removal of sand, rocks, and large woody debris. Boat owners typically use another ramp located on the inner, more protected side of Kilisut Harbor. Ironically, large woody debris that would normally provide the structure around which the spit might restore itself is now dragged off the beach into place upland to define parking places for boat owners and other park visitors. Relative impact on the drift cell zones is shown in Table 8.

Table 8. Relative degree of impacts to drift cell zone at Rat Island.

	SEVERE	MODERATE	MINIMAL
Erosion Zone			+
Transport Zone	+		
Accretion Zone	+		

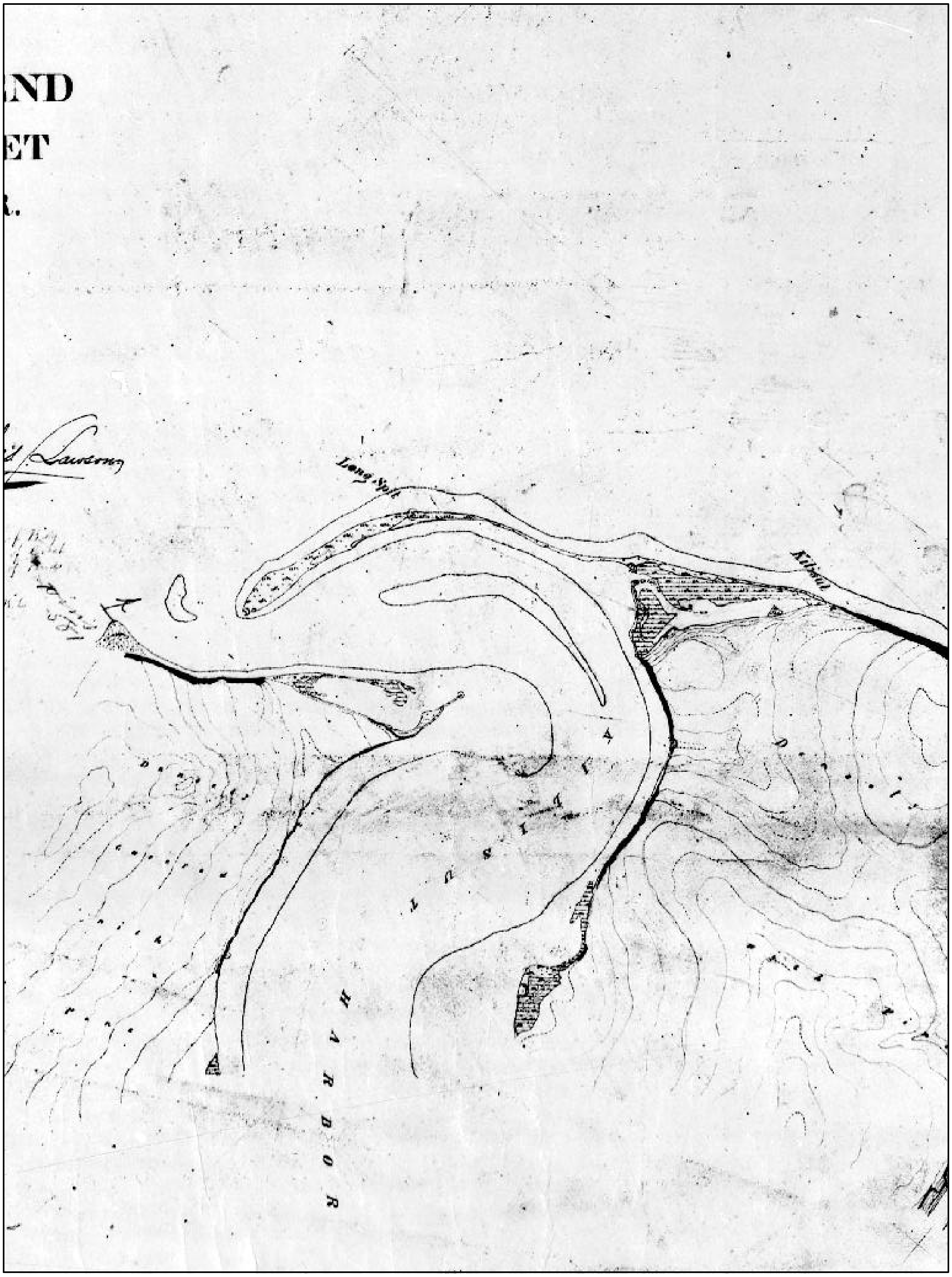

Figure 19. Rat Island case study. United States Coast and Geodetic Survey map T-582, 1856.

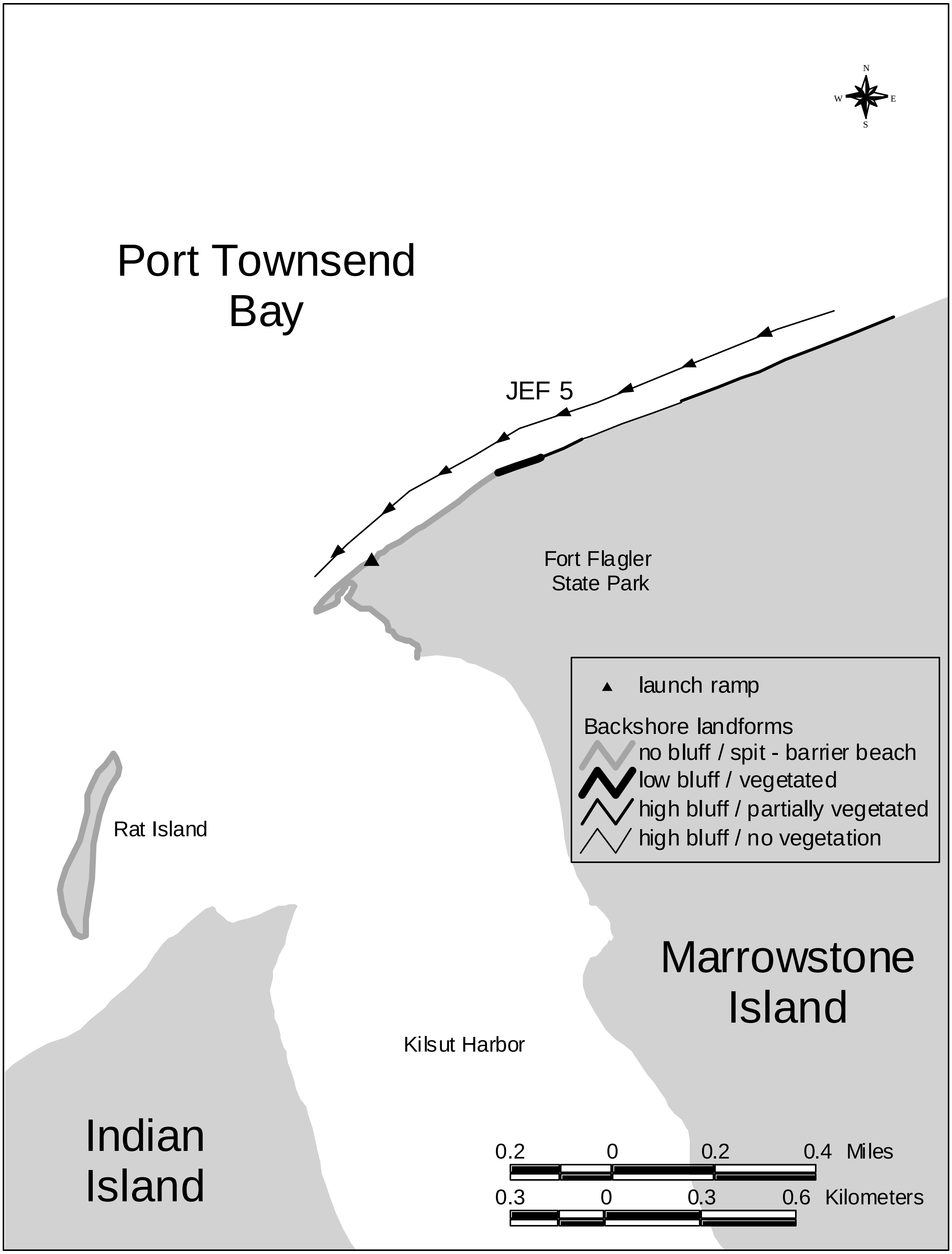

Figure 20. Rat Island case study. Launch ramp and backshore landforms within drift cell JEF 5.

Salsbury Point And Twin Spits

Salsbury Point and Twin Spits are included to help in understanding modifications that mask natural functions and values at highly significant subestuary and intertidal habitats. Present day visitors to Salsbury Point County Park would likely be surprised to learn that the launch ramp and parking lot area were once a tidal lagoon as can be seen in Figure 21. The spit and lagoon were formed as sediments were transported along a drift cell originating to the south. Much of the sediment's movement is interrupted by the Hood Canal Bridge, but fill placed at the site in the 1950s or 1960s is responsible for most of the alteration. Like John Wayne Marina, the changes have been severe and values to fish have been greatly diminished.

Though larger, the northernmost spit of the Twin Spits (Figure 22) is a good approximation of what Salsbury Point once looked like and it is also a valuable reference for how Salsbury Point and other altered spits once functioned. Like the historic Salsbury Point, Twin Spits is formed by sediments that have created a spit with a tidal lagoon. A narrow channel flushes the lagoon with each tide and separates the tip of the spit from the mainland at high tides.

No appreciable freshwater enters the Twin Spits lagoon. However, significant numbers of juvenile chum and pink salmon enter the lagoon as they migrate from other streams along Hood Canal's nearshore and on to the Pacific Ocean (Hirschi and Doty 2002). Schools of young salmon are not easy to see due to the small size of individual fish (30-60mm in length) and many casual observers walk past them in the tidal shallows. Local residents and owners of the spit say they have never seen fish in the channel or lagoon. Perhaps this is why no alarms were raised when Salsbury Point's tidal lagoon was filled, eliminating significant salmon rearing and refuge habitat. Regardless, it is hoped that future plans at other similar sites take great care in protecting these sites – seemingly small and insignificant, but valuable for juvenile salmon.

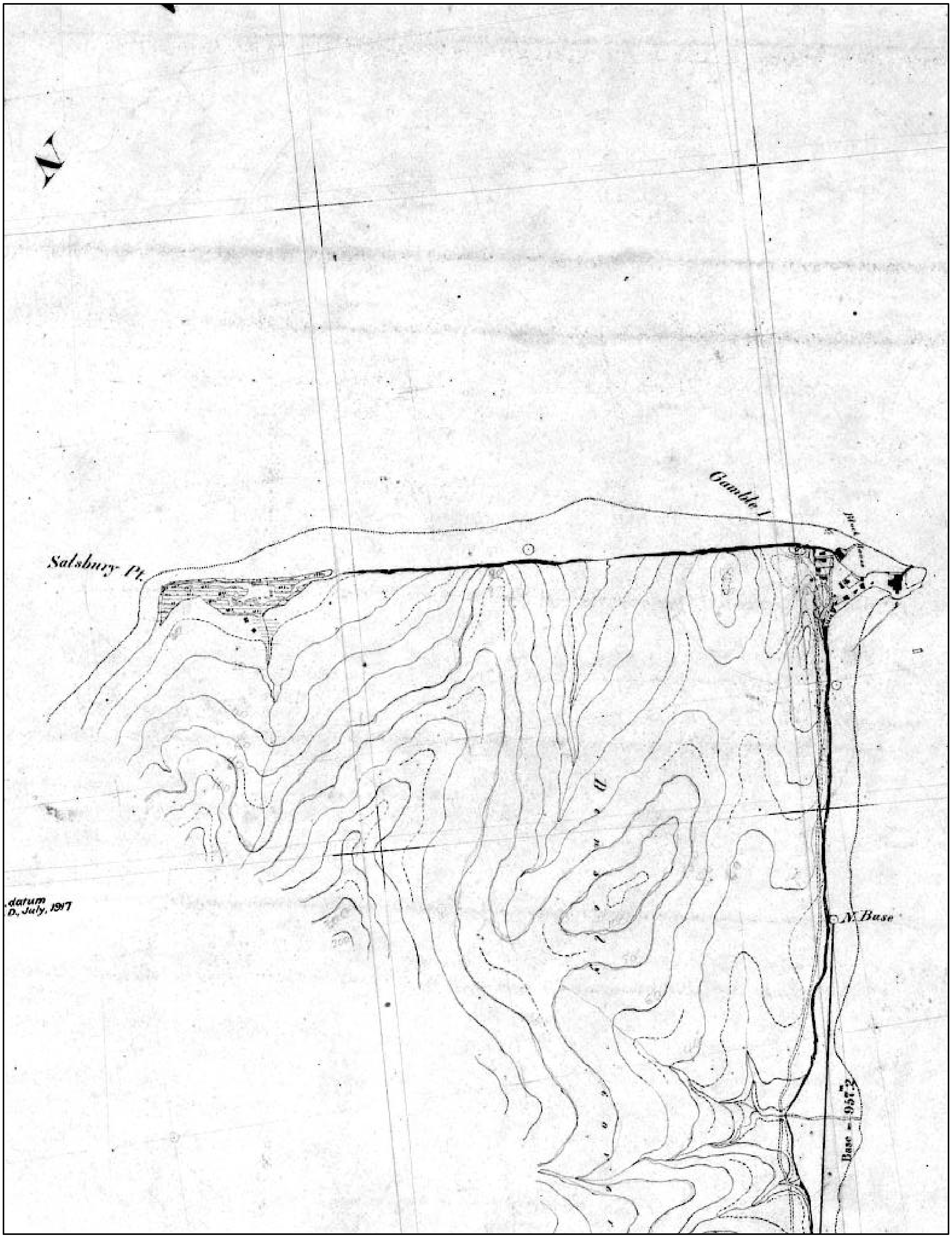

Figure 21. Salsbury Point case study. United States Coast and Geodetic Survey map T-585, 1856.

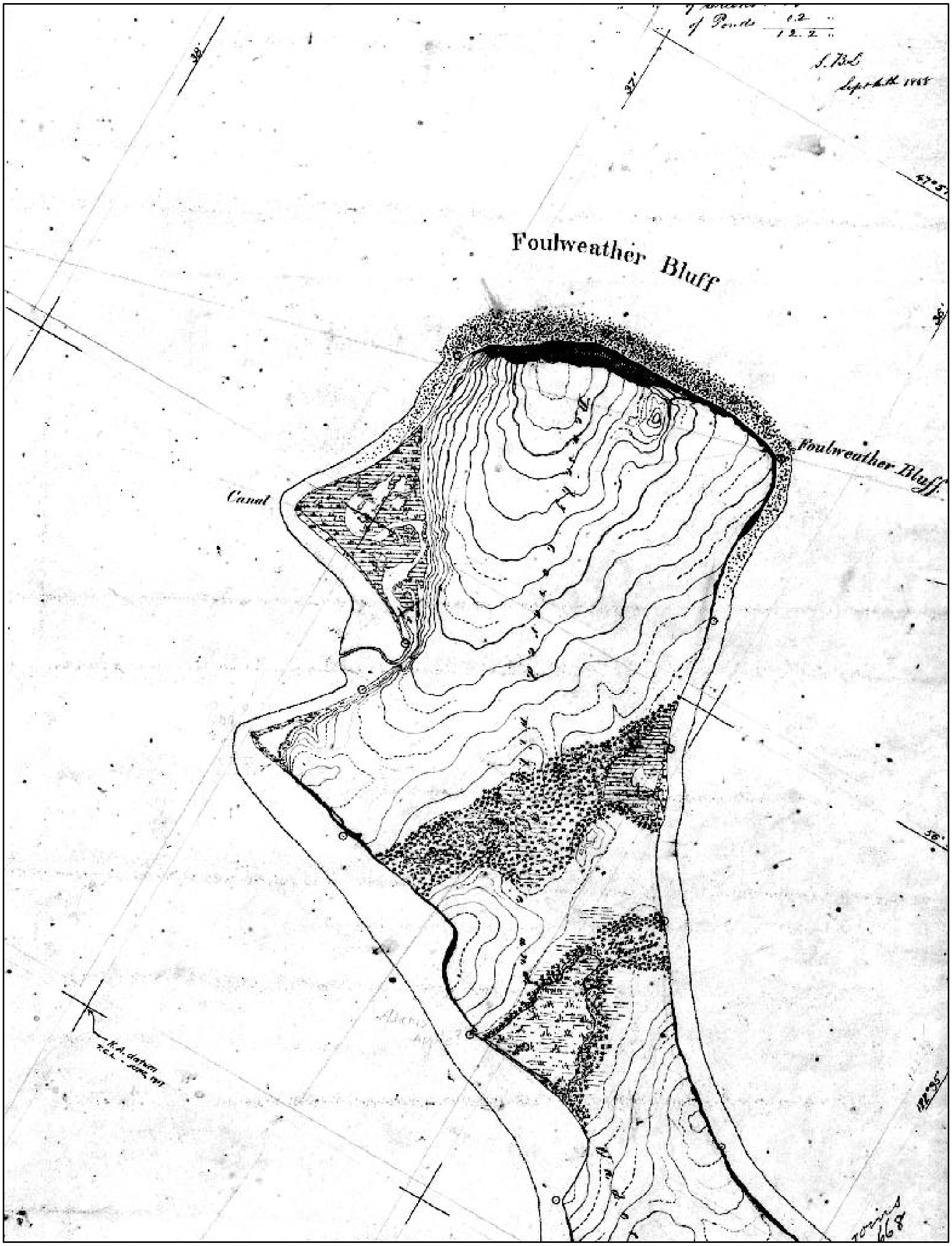

Figure 22. Twin Spits case study. United States Coast and Geodetic Survey map T-669, 1857.

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Appendix 1. Summary results for shoreline structures by drift cell.

Regions & Sub-regions	Drift Cells[1]	Total Lgth. (m)	Bulkheads Lgth.(m)	Bulkheads %	No. Docks	No. Jetties	No. Launch Ramps	No. Rail Launches	No. Stairs[2]
Northeast Hood Canal Region									
Foulweather	KS-1-3	669	0	0.0	0	0	0	0	0
	KS-1-3/KS-1-4	217	0	0.0	0	0	0	0	0
	KS-1-4	3,116	284	9.1	1	0	0	1	2
Foulw / DKey	KS-1-4/KS-1-5	409	0	0.0	0	0	0	0	1
Driftwood Key	KS-1-5	997	141	14.2	0	0	1	0	1
	KS-1-5/KS-1-6	2,798	1,992	71.2	44	0	0	0	0
	KS-1-6	3,239	512	15.8	0	0	0	0	6
DKey / GBay	KS-1-6/KS-1-7	530	0	0.0	0	0	0	0	0
Gamble Bay	KS-1-7	2,451	93	3.8	0	0	2	0	1
	KS-1-7/KS-2-2	100	0	0.0	1	0	0	0	0
	KS-2-2	2,584	110	4.3	0	0	0	0	2
	KS-2-2/KS-2-3	564	3	0.6	0	0	0	0	4
	KS-2-3	3,018	1,096	36.3	6	0	0	0	5
	KS-2-3/KS-2-4	1,625	25	1.5	0	0	0	0	0
	KS-2-4	1,699	318	18.7	0	0	1	0	2
	KS-2-4/KS-2-5	4,074	310	7.6	2	1	0	0	0
Lofall	KS-2-5	27,885	6,393	22.9	17	0	7	9	51
Lofall / Sbeck	KS-2-5/KS-5-2	748	536	71.6	17	0	0	1	1
Seabeck	KS-5-2	9,467	4,329	45.7	4	0	2	15	3
	KS-5-2/KS-6-2	576	8	1.4	0	0	0	0	0
	KS-6-2	2,826	623	22.0	0	0	1	2	4
Sbeck / Stavis	KS-6-2/KS-6-3	193	7	3.8	0	0	0	0	0
Southeast Hood Canal Region					0				
Stavis	KS-6-3	5,292	991	18.7	0	0	1	0	8
	KS-6-3/KS-6-4	2,620	0	0.0	0	0	0	0	0
	KS-6-4	202	45	22.3	0	0	0	0	0
Stavis / Anders	KS-6-4/KS-6-5	331	34	10.4	0	0	0	0	0
Anderson	KS-6-5	3,428	516	15.1	0	0	0	0	1
	KS-6-5/KS-7-2	103	0	0.0	0	0	0	0	0
	KS-7-2	3,836	708	18.5	0	0	0	0	0
	KS-8-1	3,060	355	11.6	0	0	0	0	0
	KS-7-2/KS-8-2	51	0	0.0	0	0	0	0	0
	KS-8-2	1,303	309	23.7	1	0	0	0	0
Anders / Holly	KS-8-2/KS-8-3	275	43	15.7	0	0	0	0	0
Holly	KS-8-3	422	72	17.2	1	0	0	0	1
	KS-8-3/KS-8-4	860	0	0.0	0	0	0	0	0
	KS-8-4	3,373	698	20.7	1	0	2	0	0
	KS-8-4/KS-9-2	998	0	0.0	0	0	0	0	0
	KS-9-2	1,753	0	0.0	0	0	0	0	0
	KS-9-2/KS-9-3	92	0	0.0	0	0	0	0	0
	KS-9-3	9,037	51	0.6	0	0	0	0	4
Holly / Dewatt	MA-4-5/MA-4-6	337	0	0.0	0	0	0	0	1
Dewatto	MA-4-5	459	49	10.7	0	0	0	0	1
	MA-4-4/MA-4-5	3,394	332	9.8	3	0	0	0	0
	MA-7-1	10,640	1,546	14.5	2	0	2	0	3
	MA-7-1	377	369	97.8	0	0	0	1	0
Dewatt / Tahuy	MA-7-1/MA-7-2	870	372	42.8	0	0	0	1	0
Lower Hood Canal Region									
Tahuya	MA-8-1	4,379	2,388	54.5	5	0	2	2	0
	MA-8-1/MA-8-2	3,900	39	1.0	1	0	0	0	0
	MA-8-2	612	435	71.0	0	0	2	0	0
Tahuy / NShore	MA-8-2/MA-8-3	461	461	100.0	1	0	7	2	0
North Shore	MA-9-1	2,159	1,786	82.7	5	1	7	15	0
	MA-9-2	311	0	0.0	0	0	0	0	0
	MA-9-2/MA-9-3	514	205	39.8	2	0	0	0	0
	MA-9-3	513	365	71.0	0	0	0	0	0
	MA-9-4	354	282	79.8	0	0	0	1	0
	MA-9-4/MA-9-5	703	596	84.8	1	0	0	0	0
	MA-10-1	2,491	1,424	57.1	1	0	1	0	0
	MA-10-2	329	329	100.0	3	0	0	0	0

Appendix 1 (Continued)

Regions & Sub-regions	Drift Cells[1]	Total Lgth. (m)	Bulkheads		No. Docks	No. Jetties	No. Launch Ramps	No. Rail Launches	No. Stairs[2]
			Lgth.(m)	%					
	MA-10-3	1,472	1,016	69.0	3	0	0	0	0
	MA-10-4	309	226	72.9	0	0	0	0	0
	MA-10-4/MA-10-5	483	204	42.2	0	0	0	1	0
	MA-11-1	4,907	3,423	69.8	0	6	8	0	0
	MA-11-2	1,268	746	58.8	4	0	1	0	0
NShore / Union	MA-11-2/MA-11-3	819	269	32.9	2	1	0	0	0
Union	MA-11-3/MA-11-6	9,629	172	1.8	0	0	1	0	0
	MA-11-6	3,520	2,375	67.5	7	0	2	0	0
	MA-11/5/MA-11-6	459	459	100.0	5	0	0	0	0
South Shore	MA-11-5	433	307	71.0	5	0	1	0	0
	MA-10-8	6,993	5,520	78.9	39	0	7	2	0
	MA-10-7/MA-10-8	411	204	49.6	2	0	0	0	0
	MA-10-7	673	181	26.9	1	0	1	0	1
	MA-8-6	8,439	5,933	70.3	63	1	1	1	0
	MA-8-5/MA-8-6	457	412	90.1	3	0	0	0	0
	MA-8-5	353	99	27.9	2	0	0	0	0
	MA-7-4	4,398	2,804	63.8	28	0	2	0	0
SShore / Skok	MA-7-3/MA-7-4	996	688	69.0	0	0	0	0	0
Southwest Hood Canal Region									
Skokomish	MA-7-3	456	105	23.1	0	0	0	0	0
	MA-6-2/MA-7-3	10,752	596	5.5	3	0	3	1	0
	MA-6-2	3,062	1,401	45.7	6	2	0	20	0
	MA-6-1/MA-6-2	1,885	1,367	72.5	5	0	0	4	0
Lilliwaup	MA-5-2	3,444	2,241	65.1	11	2	1	7	0
	MA-5-1/MA-5-2	862	70	8.2	0	0	0	0	0
	MA-4-3	3,065	1,914	62.4	3	1	0	2	0
	MA-4-2/MA-4-3	1,495	0	0.0	0	0	0	0	0
	MA-4-2	619	8	1.3	0	0	0	0	0
Ayock	MA-4-1/MA-4-2	384	0	0.0	0	0	0	0	0
	MA-3-3	6,395	2,658	41.6	0	1	3	6	3
	MA-3-2	482	186	38.6	1	0	1	0	0
Hamma Hamma	MA-3-1/MA-3-2	758	180	23.8	0	0	0	0	0
	MA-2-3	3,120	796	25.5	1	0	1	0	0
	MA-2-2/MA-2-3	3,020	8	0.3	1	1	0	0	2
	MA-2-2	444	13	2.9	0	0	0	0	5
	MA-2-1/MA-2-2	399	0	0.0	0	0	0	0	0
	MA-2-1	1,035	3	0.3	0	0	0	0	0
	MA-1-5/MA-2-1	509	8	1.5	0	0	2	0	1
	MA-1-5	235	84	35.8	0	0	1	0	0
Triton	MA-1-5/MA-1-5	229	225	98.5	0	0	0	0	0
	MA-1-4	518	179	34.5	1	0	1	0	1
	MA-1-3/MA-1-4	1,048	0	0.0	0	0	0	0	0
	MA-1-3	3,238	1,105	34.1	1	0	1	7	2
	MA-1-2/MA-1-3	482	38	7.9	0	1	0	1	0
	MA-1-2	590	27	4.6	0	0	0	3	4
	MA-1-1	632	117	18.6	5	0	1	0	4
	JE-30	1,999	383	19.1	0	0	2	0	2
Duckabush	JE-29/JE-30	751	0	0.0	0	0	0	2	2
	JE-29	1,097	41	3.7	1	1	1	0	2
	JE-28/JE-29	4,041	420	10.4	4	0	1	2	12
	JE-28	3,745	229	6.1	1	0	0	0	0
	JE-27	2,127	294	13.8	0	0	1	0	9
	JE-26/JE-27	519	23	4.4	0	0	1	0	2
Dabob Region									
Pleasant Harbor	JE-26	717	27	3.7	1	0	0	0	11
	JE-25/JE-26	2,017	0	0.0	7	0	0	0	2
	JE-25	2,019	429	21.2	9	0	0	0	13
PHarbor / Dose	JE-24/JE-25	1,519	0	0.0	0	0	0	0	6
Dosewallips	JE-24	8,050	1,376	17.1	0	0	0	0	16
	JE-23	668	91	13.6	1	0	2	0	1
Jackson Cove	JE-22/JE-23	638	0	0.0	2	0	0	2	2
	JE-22	905	181	20.0	1	0	1	1	1
	JE-21/JE-22	4,100	612	14.9	1	0	1	0	4
Pt Whitney	JE-21	3,072	131	4.3	2	0	1	0	1

Appendix 1 (Continued)

Regions & Sub-regions	Drift Cells[1]	Total Lgth. (m)	Bulkheads Lgth.(m)	Bulkheads %	No. Docks	No. Jetties	No. Launch Ramps	No. Rail Launches	No. Stairs[2]
	JE-20	1,151	38	3.3	0	0	0	0	0
PWhitney / Quil	JE-19/JE-20	711	0	0.0	0	0	0	0	0
Quilcene	JE-19	3,180	53	1.7	0	0	0	0	0
	JE18/JE19	7,093	740	10.4	0	0	0	0	1
	JE-18	4,170	579	13.9	0	0	0	0	3
Quil / Tarboo	JE-17/JE-18	965	0	0.0	0	0	0	0	0
Tarboo	JE-17	9,849	636	6.5	0	0	1	0	4
	JE-16/JE-17	5,881	109	1.8	2	0	0	0	0
	JE-16	19,326	1,168	6.0	1	2	0	0	7
Tarboo / HazelP	JE-15/JE-16	1,494	0	0.0	0	0	0	0	0
Northwest Hood Canal Region									
Hazel Pt	JE-15	6,506	0	0.0	4	0	0	0	1
	JE-14	2,966	188	6.3	0	0	2	0	4
HazelP / Thorn	JE-13/JE-14	1,238	0	0.0	0	0	0	0	0
Thorndyke	JE-13	20,374	1,703	8.4	2	0	0	0	9
Shine	JE-12/JE-13	1,896	1,163	61.3	26	0	1	0	0
	JE-12	3,022	307	10.1	0	0	0	0	8
	JE-11	3,706	959	25.9	0	1	3	0	6
	JE10-/JE11	743	0	0.0	0	0	0	0	0
Whiskey Spit	JE-10	3,467	279	8.1	0	0	1	0	4
	JE-9/JE-10	2,616	0	0.0	0	0	0	0	0
	JE-9	1,263	203	16.1	0	0	0	0	4
	JE-8/JE-9	277	0	0.0	0	0	0	0	0
	JE8	1,302	0	0.0	0	0	0	0	0
	JE-7/JE-8	41	0	0.0	0	0	0	0	0
	JE-7	7,468	714	9.6	0	0	1	0	15
WhisSpt / PLud	JE-6/JE-7	386	0	0.0	0	0	0	0	0
Port Townsend Region									
Pt Ludlow	JE-6	3,024	466	15.4	6	0	0	1	0
	JE-5/JE-6	5,468	0	0.0	9	0	0	0	0
	JE-5	4,445	849	19.1	0	1	0	0	5
Mats Mats	JE-4/JE-5	7,731	590	7.6	22	1	1	0	10
Olele Pt	JE-4	894	85	9.5	0	0	2	0	2
	JE-3/JE-4	237	0	0.0	0	0	1	0	1
	JE-3	227	40	17.6	1	0	0	0	0
	JE-2	1,003	0	0.0	0	0	1	0	11
OleleP / OakBay	JE-1/JE-2	823	0	0.0	1	0	1	0	3
Oak Bay	JEF-1	5,085	767	15.1	0	0	1	0	6
	JEF-2	4,697	932	19.8	0	0	1	0	0
Oakbay / EMarr	JEF-2/JEFF-3	1,753	63	3.6	0	0	0	0	0
E Marrowstone	JEF-3	10,037	40	0.4	1	0	0	0	17
	JEF-3/JEF-4	173	0	0.0	0	0	0	0	0
	JEF-4	620	181	29.3	0	0	0	0	0
EMarr / Flagler	JEF-4/JEF-5	848	0	0.0	0	0	0	0	0
Flagler	JEF-5	1,640	0	0.0	0	0	1	0	0
	JEF-5/JEF-6	288	0	0.0	0	0	0	0	0
	JEF-6	2,342	182	7.8	1	0	1	0	0
Flagler / MystB	JEF-6/JEF-7	1,484	84	5.6	0	0	0	0	0
Mystery Bay	JEF-7	1,750	568	32.5	1	0	1	0	1
	JEF-7/JEF-8	1,904	430	22.6	5	0	0	0	6
MystB / KilisutW	JEF-8	750	72	9.7	1	0	0	0	1
Kilisut West	JEF-9	4,003	645	16.1	2	1	1	1	11
	JEF-9/JEF-10	1,901	0	0.0	0	0	0	0	0
	JEF-10	3,864	0	0.0	0	0	0	0	0
	JEF-10/JEF-11	1,263	0	0.0	0	0	0	0	0
	JEF-11	3,008	5	0.2	0	0	0	0	0
	JEF-11/JEF-12	87	0	0.0	0	0	0	0	0
	JEF-12	546	104	19.0	0	0	0	0	0
KilisutW / Hlock	JEF-13	1,374	0	0.0	1	0	0	0	0
Hadlock	JEF13/JEF-14	2,236	0	0.0	1	0	0	0	0
Hadlock	JEF-14	1,175	66	5.6	0	0	0	0	0
Hadlock	JEF-15	3,250	1,104	34.0	1	1	2	0	0
Gov Cut	JEF-2/JEF-15	1,310	0	0.0	0	0	0	0	0
Gov Cut	JEF-1/JEF-16	3,106	0	0.0	0	1	0	0	1

Appendix 1 (Continued)

Regions & Sub-regions	Drift Cells[1]	Total Lgth. (m)	Bulkheads Lgth.(m)	Bulkheads %	No. Docks	No. Jetties	No. Launch Ramps	No. Rail Launches	No. Stairs[2]
Hadlock	JEF-16	1,048	177	16.9	0	0	2	0	1
Hadlock	JEF-16/JEF-17	1,566	0	0.0	0	0	0	0	0
Hadlock	JEF-17	982	305	31.0	7	1	1	1	0
Hadlock	JEF-18	1,794	469	26.2	0	0	0	0	0
Hadlock	JEF-19	2,460	0	0.0	0	0	0	0	0
Hadlock	JEF-19/JEF-20	243	0	0.0	0	0	0	0	0
Hadlock	JEF-20	1,752	0	0.0	0	0	0	0	0
Hadlock	JEF-20/JEF-21	670	0	0.0	0	0	1	0	0
Hadlock	JEF-21	888	0	0.0	1	0	0	0	0
Hlock / PtTowns	JEF-21/JEF-22	1,469	0	0.0	0	0	0	0	0
Pt Townsend	JEF-22	12,326	2,946	23.9	12	0	1	0	1
PtTowns / NBch	JEF-22/JEF-23	1,808	332	18.4	1	1	1	0	0
Strait Region									
North Beach	JEF-23	7,856	415	5.3	0	0	1	0	3
NBch / Disco	JEF-23/JEF-24	1,495	0	0.0	0	0	0	0	0
Discovery	JEF-24	5,525	537	9.7	0	0	1	0	2
	JEF-24/JEF-25	651	280	43.1	0	0	0	0	0
	JEF-25	6,457	662	10.3	2	0	0	0	10
	JEF-25/JEF-26	2,412	153	6.4	0	0	0	1	9
	JEF-26	2,620	854	32.6	1	0	0	0	3
	JEF-26/JEF-27	7,732	2,349	30.4	4	0	0	0	0
	JEF-27	3,086	632	20.5	3	0	0	1	4
	JEF-27/JEF-28	1,644	0	0.0	0	0	0	0	0
	JEF-28	1,452	51	3.5	1	0	0	0	0
	JEF-28/JEF-29	1,450	347	24.0	1	0	0	0	0
	JEF-29	4,468	369	8.3	0	0	2	0	1
	JEF-29/JF-18-5	1,142	0	0.0	0	0	0	0	0
	JF-18-5	2,329	351	15.1	1	0	1	0	1
	JF-18-4	1,256	884	70.4	0	0	2	0	1
Disco / RockyP	JF-18-3/JF-18-4	459	0	0.0	0	0	1	0	0
Rocky Pt	JF-18-3	675	0	0.0	0	0	0	0	0
	JF-18-2/JF-18-3	126	0	0.0	0	0	0	0	0
	JF-18-2	1,619	0	0.0	0	0	0	0	0
	JF-18-1/JF-18-2	978	0	0.0	0	0	0	0	0
	JF-18-1	4,941	0	0.0	0	0	0	0	1
RockyP / SeqB	JF-17-5/JF-18-1	234	0	0.0	0	0	0	0	0
Sequim Bay	JF-17-5	1,298	0	0.0	0	0	0	0	0
	JF-17-5/JF-17-6	966	0	0.0	0	0	0	0	0
	JF-17-6	1,429	93	6.5	0	0	0	0	0
	JF-17-6/JF-17-7	1,424	160	11.3	3	0	0	0	2
	JF-17-7	4,532	582	12.8	11	0	1	0	11
	JF-17-3/JF-17-7	3,232	0	0.0	0	0	0	0	0
	JF-17-3	4,877	581	11.9	12	0	1	0	6
	JF-17-2/JF-17-3	2,683	879	32.8	1	0	0	0	0
	JF-17-2	1,681	479	28.5	2	0	0	0	0
	JF-17-1/JF-17-2	3,126	0	0.0	0	0	0	0	0
Gibson Spit	JF-17-1	3,345	56	1.7	0	0	1	0	0
	JF-16-6/JF-17-1	3,382	48	1.4	0	1	1	0	0
Jamestown	JF-16-6	6,849	572	8.3	1	0	0	1	0

[1] Drift cells are identified by alphanumeric code: e.g.,KS-1-3. Some drift cells have combination codes that indicate a single drift cell: e.g., KS-1-3/KS-1-4. In many cases, a drift cell may overlap two subregions (or regions). Such cases are indicated by a combination of abbreviated subregion names; e.g., the name Foulw / DKey, indicates the drift cell KS-1-4/KS-1-5 overlaps into the subregions Foulweather and Driftwood Key.

[2] Includes only stairs observed independent of other structures.

Appendix 2. Backshore landform lengths and percentages by region and sub-region within Hood Canal and eastern Strait of Juan de Fuca.

Regions & Sub-regions	Total Lgth. (m)	High and Low Bluff		Barrier Beaches / Spits / Berms and Saltmarshes		Upland	
		Lgth. (m)	%	Lgth. (m)	%	Lgth. (m)	%
Northeast Hood Canal Region							
Foulweather	4,207	2,079	49.4	1,987	47.2	142	3.4
Driftwood Key	7,504	3,860	51.4	1,482	19.7	2,162	28.8
Gamble Bay	16,380	9,433	57.6	2,504	15.3	4,442	27.1
Lofall	27,951	21,291	76.2	4,005	14.3	2,655	9.5
Seabeck	13,340	8,655	64.9	2,584	19.4	2,101	15.8
Totals	**69,381**	**45,319**	**65.3**	**12,561**	**18.1**	**11,502**	**16.6**
Southeast Hood Canal Region							
Stavis	8,376	5,239	62.6	1,999	23.9	1,137	13.6
Anderson	12,085	9,684	80.1	1,585	13.1	815	6.7
Holly	16,842	13,658	81.1	1,510	9.0	1,674	9.9
Dewatto	15,473	7,298	47.2	3,825	24.7	4,351	28.1
Totals	**52,776**	**35,879**	**68.0**	**8,920**	**16.9**	**7,977**	**15.1**
Lower Hood Canal Region							
Tahuya	9,557	82	0.9	2,052	21.5	7,424	77.7
North Shore	16,454	0	0.0	3,859	23.5	12,595	76.5
Union	13,788	0	0.0	10,637	77.2	3,150	22.8
South Shore	22,885	0	0.0	918	4.0	21,967	96.0
Totals	**62,684**	**82**	**0.1**	**17,466**	**27.9**	**45,136**	**72.0**
Southwest Hood Canal Region							
Skokomish	15,710	435	2.8	10,815	68.8	4,461	28.4
Lilliwaup	10,619	1,445	13.6	31	0.3	9,144	86.1
Ayock	7,448	4,775	64.1	1,447	19.4	1,226	16.5
Hamma Hamma	9,254	4,115	44.5	4,130	44.6	1,009	10.9
Triton	9,373	7,219	77.0	849	9.1	1,305	13.9
Duckabush	11,529	7,091	61.5	3,652	31.7	786	6.8
Totals	**63,934**	**25,079**	**39.2**	**20,924**	**32.7**	**17,931**	**28.0**
Dabob Region							
Pleasant Harbor	5,512	4,642	84.2	789	14.3	81	1.5
Dosewallips	9,477	3,369	35.5	3,895	41.1	2,214	23.4
Jackson Cove	5,642	3,906	69.2	1,089	19.3	647	11.5
Pt Whitney	4,579	3,083	67.3	627	13.7	869	19.0
Quilcene	15,282	7,685	50.3	6,347	41.5	1,249	8.2
Tarboo	36,285	23,070	63.6	9,218	25.4	3,998	11.0
Totals	**76,777**	**45,754**	**59.6**	**21,965**	**28.6**	**9,058**	**11.8**
Northwest Hood Canal Region							
Hazel Pt	10,838	9,479	87.5	696	6.4	663	6.1
Thorndyke	20,993	13,522	64.4	6,737	32.1	734	3.5
Shine	8,996	4,620	51.4	2,467	27.4	1,909	21.2
Whiskey Spit	17,000	11,875	69.9	4,443	26.1	682	4.0
Totals	**57,826**	**39,496**	**68.3**	**14,342**	**24.8**	**3,988**	**6.9**
Port Townsend Region							
Pt Ludlow	13,130	9,680	73.7	1,775	13.5	1,675	12.8
Mats Mats	7,731	4,954	64.1	517	6.7	2,259	29.2
Olele Pt	2,772	2,089	75.3	684	24.7	0	0.0
Oak Bay	11,069	6,964	62.9	2,851	25.8	1,255	11.3
E Marrowstone	12,130	10,751	88.6	818	6.7	561	4.6
Flagler	5,436	3,404	62.6	1,920	35.3	112	2.1
Mystery Bay	4,771	2,648	55.5	921	19.3	1,202	25.2
Kilsut West	15,735	10,933	69.5	3,894	24.8	907	5.8
Hadlock	19,484	6,611	33.9	5,625	28.9	7,248	37.2
Gov Cut	4,416	1,471	33.3	1,570	35.5	1,375	31.1
Pt Townsend	13,965	3,209	23.0	3,127	22.4	7,629	54.6
Totals	**110,639**	**62,712**	**56.7**	**23,702**	**21.4**	**24,225**	**21.9**
Strait Region							
North Beach	9,508	8,141	85.6	987	10.4	380	4.0
Discovery	43,200	26,163	60.6	10,318	23.9	6,719	15.6
Rocky Pt	8,685	6,314	72.7	2,335	26.9	36	0.4
Sequim Bay	25,367	11,834	46.7	9,709	38.3	3,824	15.1
Gibson Spit	5,036	2,026	40.2	2,799	55.6	210	4.2
Jamestown	8,540	207	2.4	8,212	96.2	121	1.4
Totals	**100,336**	**54,685**	**54.5**	**34,360**	**34.2**	**11,291**	**11.3**
Grand Totals	**594,354**	**309,007**	**52.0**	**154,240**	**26.0**	**131,107**	**22.1**

Appendix 3. Summary results for backshore landform length estimates by drift cell.

Regions & Sub-regions	Drift Cells[1]	Total Lgth. (m)	High Bluff Lgth. (m)	Low Bluff Lgth. (m)	No Bluff Lgths. (m)				
					Total (m)	Accretion Type Landforms[2]	Barrier Beaches/ Spits/Berms	Saltmarsh	Upland[3]
Northeast Hood Canal Region									
Foulweather	KS-1-3	669	339	0	330	330	330	0	0
	KS-1-3/KS-1-4	217	0	0	217	217	217	0	0
	KS-1-4	3,116	1,256	279	1,581	1,440	1,440	0	142
Foulw / DKey	KS-1-4/KS-1-5	409	409	0	0	0	0	0	0
Driftwood Key	KS-1-5	997	153	460	384	384	384	0	0
	KS-1-5/KS-1-6	2,798	0	0	2,798	636	636	0	2,162
	KS-1-6	3,239	2,017	761	461	461	461	0	0
DKey / GBay	KS-1-6/KS-1-7	530	530	0	0	0	0	0	0
Gamble Bay	KS-1-7	2,451	1,713	0	738	738	738	0	0
	KS-1-7/KS-2-2	100	0	0	100	100	100	0	0
	KS-2-2	2,584	2,222	0	362	362	362	0	0
	KS-2-2/KS-2-3	564	448	117	0	0	0	0	0
	KS-2-3	3,018	0	1403	1,614	133	133	0	1,481
	KS-2-3/KS-2-4	1,625	0	0	1,625	512	512	0	1,113
	KS-2-4	1,699	852	0	848	546	546	0	301
	KS-2-4/KS-2-5	4,074	2,414	0	1,660	113	113	0	1,547
Lofall	KS-2-5	27,885	14,954	5963	6,660	4,005	3,953	52	2,655
Lofall / Sbeck	KS-2-5/KS-5-2	748	141	607	0	0	0	0	0
Seabeck	KS-5-2	9,467	992	5791	2,684	738	592	146	1,946
	KS-5-2/KS-6-2	576	0	0	576	576	0	576	0
	KS-6-2	2,826	10	1392	1,425	1,270	364	905	155
Sbeck / Stavis	KS-6-2/KS-6-3	193	193	0	0	0	0	0	0
Southeast Hood Canal Region									
Stavis	KS-6-3	5,292	1,403	2030	1,860	723	723	0	1,137
	KS-6-3/KS-6-4	2,620	0	1403	1,217	1,217	856	361	0
	KS-6-4	202	0	142	59	59	59	0	0
Stavis / Anders	KS-6-4/KS-6-5	331	245	85	0	0	0	0	0
Anderson	KS-6-5	3,428	2,704	0	724	572	572	0	152
	KS-6-5/KS-7-2	103	0	0	103	103	103	0	0
	KS-7-2	3,836	2,674	447	716	546	546	0	170
	KS-8-1	3,060	2,304	397	359	242	242	0	118
	KS-7-2/KS-8-2	51	0	0	51	51	51	0	0
	KS-8-2	1,303	628	228	447	71	71	0	376
Anders / Holly	KS-8-2/KS-8-3	275	158	118	0	0	0	0	0
Holly	KS-8-3	422	0	408	14	14	0	14	0
	KS-8-3/KS-8-4	860	0	112	748	748	0	748	0
	KS-8-4	3,373	1,607	431	1,336	77	0	77	1,259
	KS-8-4/KS-9-2	998	998	0	0	0	0	0	0
	KS-9-2	1,753	1,258	0	496	195	195	0	300
	KS-9-2/KS-9-3	92	0	0	92	92	92	0	0
	KS-9-3	9,037	8,156	384	498	384	384	0	114
Holly / Dewatt	MA-4-5/MA-4-6	337	337	0	0	0	0	0	0
Dewatto	MA-4-5	459	72	277	110	49	0	49	61
	MA-4-4/MA-4-5	3,394	0	384	3,010	1,573	0	1,573	1,436
	MA-7-1	10,640	5,206	1190	4,244	2,203	1,288	915	2,041
	MA-7-1	377	0	0	377	0	0	0	377
Dewatt / Tahuy	MA-7-1/MA-7-2	870	0	0	870	0	0	0	870
Lower Hood Canal Region									
Tahuya	MA-8-1	4,379	0	0	4,379	1,456	847	610	2,923
	MA-8-1/MA-8-2	3,900	0	0	3,900	499	148	351	3,402
	MA-8-2	612	0	82	531	97	97	0	434
Tahuy / NShore	MA-8-2/MA-8-3	461	0	0	461	0	0	0	461
North Shore	MA-9-1	2,159	0	0	2,159	0	0	0	2,159
	MA-9-2	311	0	0	311	133	133	0	178
	MA-9-2/MA-9-3	514	0	0	514	0	0	0	514
	MA-9-3	513	0	0	513	236	236	0	277
	MA-9-4	354	0	0	354	20	20	0	334
	MA-9-4/MA-9-5	703	0	0	703	0	0	0	703
	MA-10-1	2,491	0	0	2,491	287	0	287	2,204

Appendix 3. (Continued)

Regions & Sub-regions	Drift Cells[1]	Total Lgth. (m)	High Bluff Lgth. (m)	Low Bluff Lgth. (m)	No Bluff Lgths. (m) Total (m)	Accretion Type Landforms[2]	Barrier Beaches/ Spits/Berms	Saltmarsh	Upland[3]
	MA-10-2	329	0	0	329	11	0	11	318
	MA-10-3	1,472	0	0	1,472	271	226	45	1,202
	MA-10-4	309	0	0	309	228	228	0	81
	MA-10-4/MA-10-5	483	0	0	483	0	0	0	483
	MA-11-1	4,907	0	0	4,907	1,275	0	1,275	3,633
	MA-11-2	1,268	0	0	1,268	989	0	989	278
NShore / Union	MA-11-2/MA-11-3	819	0	0	819	819	0	819	0
Union	MA-11-3/MA-11-6	9,629	0	0	9,629	8,964	0	8,964	665
	MA-11-6	3,520	0	0	3,520	1,264	0	1,264	2,256
	MA-11/5/MA-11-6	459	0	0	459	0	0	0	459
South Shore	MA-11-5	433	0	0	433	77	77	0	356
	MA-10-8	6,993	0	0	6,993	152	139	13	6,841
	MA-10-7/MA-10-8	411	0	0	411	0	0	0	411
	MA-10-7	673	0	0	673	182	182	0	491
	MA-8-6	8,439	0	0	8,439	29	29	0	8,410
	MA-8-5/MA-8-6	457	0	0	457	0	0	0	457
	MA-8-5	353	0	0	353	0	0	0	353
	MA-7-4	4,398	0	0	4,398	0	0	0	4,398
SShore / Skok	MA-7-3/MA-7-4	996	0	0	996	956	0	956	41
Southwest Hood Canal Region									
Skokomish	MA-7-3	456	0	0	456	456	0	456	0
	MA-6-2/MA-7-3	10,752	0	0	10,752	9,150	249	8,902	1,601
	MA-6-2	3,062	0	435	2,628	720	720	0	1,908
	MA-6-1/MA-6-2	1,885	0	0	1,885	23	0	23	1,862
Lilliwaup	MA-5-2	3,444	0	87	3,357	0	0	0	3,357
	MA-5-1/MA-5-2	862	0	491	370	0	0	0	370
	MA-4-3	3,065	0	189	2,876	19	0	19	2,857
	MA-4-2/MA-4-3	1,495	0	0	1,495	0	0	0	1,495
	MA-4-2	619	0	486	133	0	0	0	133
Ayock	MA-4-1/MA-4-2	384	0	384	0	0	0	0	0
	MA-3-3	6,395	907	3282	2,207	981	645	336	1,226
	MA-3-2	482	0	16	466	466	466	0	0
Hamma Hamma	MA-3-1/MA-3-2	758	0	758	0	0	0	0	0
	MA-2-3	3,120	0	2023	1,097	556	313	243	541
	MA-2-2/MA-2-3	3,020	61	0	2,959	2,959	0	2,959	0
	MA-2-2	444	63	382	0	0	0	0	0
	MA-2-1/MA-2-2	399	0	389	11	11	0	11	0
	MA-2-1	1,035	0	431	604	604	0	604	0
	MA-1-5/MA-2-1	509	0	325	184	0	0	0	184
	MA-1-5	235	0	65	170	0	0	0	170
Triton	MA-1-5/MA-1-5	229	0	0	229	0	0	0	229
	MA-1-4	518	0	182	337	0	0	0	337
	MA-1-3/MA-1-4	1,048	0	1048	0	0	0	0	0
	MA-1-3	3,238	0	1991	1,247	661	661	0	586
	MA-1-2/MA-1-3	482	0	482	0	0	0	0	0
	MA-1-2	590	0	590	0	0	0	0	0
	MA-1-1	632	0	509	123	0	0	0	123
	JE-30	1,999	0	1667	333	188	110	79	144
Duckabush	JE-29/JE-30	751	0	751	0	0	0	0	0
	JE-29	1,097	0	932	165	165	0	165	0
	JE-28/JE-29	4,041	0	3181	860	860	0	860	0
	JE-28	3,745	1,556	0	2,189	1,874	145	1,729	316
	JE-27	2,127	380	673	1,074	754	754	0	320
	JE-26/JE-27	519	0	368	151	0	0	0	151
Dabob Region									
Pleasant Harbor	JE-26	717	0	636	81	0	0	0	81
	JE-25/JE-26	2,017	0	1988	28	28	28	0	0
	JE-25	2,019	541	1337	141	141	141	0	0
PHarbor / Dose	JE-24/JE-25	1,519	0	280	1,239	1,239	0	1,239	0
Dosewallips	JE-24	8,050	0	2726	5,324	3,113	187	2,926	2,211
	JE-23	668	0	503	165	163	163	0	2
Jackson Cove	JE-22/JE-23	638	0	285	353	0	0	0	353

Appendix 3. (Continued)

Regions & Sub-regions	Drift Cells[1]	Total Lgth. (m)	High Bluff Lgth. (m)	Low Bluff Lgth. (m)	No Bluff Lgths. (m) Total (m)	Accretion Type Landforms[2]	Barrier Beaches/ Spits/Berms	Saltmarsh	Upland[3]
	JE-22	905	0	376	528	238	0	238	290
	JE-21/JE-22	4,100	0	3245	855	851	660	191	3
Pt Whitney	JE-21	3,072	814	1034	1,223	387	387	0	836
	JE-20	1,151	374	405	272	240	240	0	33
PWhitney / Quil	JE-19/JE-20	711	711	0	0	0	0	0	0
Quilcene	JE-19	3,180	2,752	127	301	186	186	0	116
	JE18/JE19	7,093	742	0	6,351	5,464	45	5,419	887
	JE-18	4,170	3,075	152	944	698	698	0	247
Quil / Tarboo	JE-17/JE-18	965	965	0	0	0	0	0	0
Tarboo	JE-17	9,849	0	525	3,286	2,982	2,982	0	304
	JE-16/JE-17	5,881	0	881	5,000	2,383	2,383	0	2,617
	JE-16	19,326	11,385	3113	4,828	3,768	3,768	0	1,060
Tarboo / HazelP	JE-15/JE-16	1,494	1,227	63	204	172	172	0	32
Northwest Hood Canal Region									
Hazel Pt	JE-15	6,506	3,391	2678	437	383	383	0	54
	JE-14	2,966	27	238	810	227	227	0	583
HazelP / Thorn	JE-13/JE-14	1,238	1,217	0	21	0	0	0	21
Thorndyke	JE-13	20,374	10,198	2716	7,460	6,737	4,728	2,009	723
Shine	JE-12/JE-13	1,896	0	0	1,896	314	314	0	1,583
	JE-12	3,022	0	1811	1,211	1,142	1,059	84	69
	JE-11	3,706	34	2403	1,269	1,011	339	672	258
	JE10-/JE11	743	453	291	0	0	0	0	0
Whiskey Spit	JE-10	3,467	1,419	694	1,354	852	852	0	502
	JE-9/JE-10	2,616	0	1231	1,385	1,385	1,385	0	0
	JE-9	1,263	241	716	307	307	307	0	0
	JE-8/JE-9	277	277	0	0	0	0	0	0
	JE8	1,302	824	190	288	288	288	0	0
	JE-7/JE-8	41	0	0	41	41	41	0	0
	JE-7	7,468	5,159	559	1,750	1,570	1,570	0	180
WhisSpt / PLud	JE-6/JE-7	386	386	0	0	0	0	0	0
Port Townsend Region									
Pt Ludlow	JE-6	3,024	975	858	1,191	1,132	1,132	0	59
	JE-5/JE-6	5,468	0	4540	928	136	136	0	792
	JE-5	4,445	1,613	1501	1,331	507	507	0	824
Mats Mats	JE-4/JE-5	7,731	0	4954	2,777	517	0	517	2,259
Olele Pt	JE-4	894	0	456	438	438	438	0	0
	JE-3/JE-4	237	0	216	20	20	20	0	0
	JE-3	227	0	147	80	80	80	0	0
	JE-2	1,003	0	858	145	145	145	0	0
OleleP / OakBay	JE-1/JE-2	823	378	445	0	0	0	0	0
Oak Bay	JEF-1	5,085	3,052	447	1,586	1,355	1,355	0	231
	JEF-2	4,697	778	1399	2,520	1,496	1,496	0	1,024
Oakbay / EMarr	JEF-2/JEFF-3	1,753	1,081	672	0	0	0	0	0
E Marrowstone	JEF-3	10,037	8,599	509	928	368	368	0	561
	JEF-3/JEF-4	173	0	0	173	173	173	0	0
	JEF-4	620	342	0	278	278	278	0	0
EMarr / Flagler	JEF-4/JEF-5	848	848	0	0	0	0	0	0
Flagler	JEF-5	1,640	767	147	726	726	726	0	0
	JEF-5/JEF-6	288	0	0	288	288	288	0	0
	JEF-6	2,342	1,331	133	878	766	766	0	112
Flagler / MystB	JEF-6/JEF-7	1,484	790	414	280	280	280	0	0
Mystery Bay	JEF-7	1,750	221	703	825	545	401	144	280
	JEF-7/JEF-8	1,904	0	770	1,134	236	0	236	898
MystB / KilisutW	JEF-8	750	0	702	48	0	0	0	48
Kilisut West	JEF-9	4,003	1,428	2164	412	28	0	28	383
	JEF-9/JEF-10	1,901	0	0	1,901	1,901	0	1,901	0
	JEF-10	3,864	420	2691	753	460	417	43	293
	JEF-10/JEF-11	1,263	961	303	0	0	0	0	0
	JEF-11	3,008	469	1305	1,233	1,026	1,026	0	207
	JEF-11/JEF-12	87	0	0	87	87	87	0	0
	JEF-12	546	0	300	246	246	246	0	0
KilisutW / Hlock	JEF-13	1,374	1,072	12	290	290	290	0	0

Appendix 3. (Continued)

Regions & Sub-regions	Drift Cells[1]	Total Lgth. (m)	High Bluff Lgth. (m)	Low Bluff Lgth. (m)	No Bluff Lgths. (m)				
					Total (m)	Accretion Type Landforms[2]	Barrier Beaches/ Spits/Berms	Saltmarsh	Upland[3]
Hadlock	JEF13/JEF-14	2,236	97	0	2,139	1,871	1,871	0	268
Hadlock	JEF-14	1,175	863	0	312	186	186	0	126
Hadlock	JEF-15	3,250	364	926	1,960	281	281	0	1,679
Gov Cut	JEF-2/JEF-15	1,310	0	805	506	433	433	0	72
Gov Cut	JEF-1/JEF-16	3,106	0	666	2,440	1,137	1,137	0	1,303
Hadlock	JEF-16	1,048	0	667	381	175	175	0	206
Hadlock	JEF-16/JEF-17	1,566	0	0	1,566	322	322	0	1,244
Hadlock	JEF-17	982	0	56	926	371	371	0	555
Hadlock	JEF-18	1,794	597	196	1,000	0	0	0	1,000
Hadlock	JEF-19	2,460	207	0	2,252	82	0	82	2,170
Hadlock	JEF-19/JEF-20	243	243	0	0	0	0	0	0
Hadlock	JEF-20	1,752	61	614	1,077	1,077	1,077	0	0
Hadlock	JEF-20/JEF-21	670	0	0	670	670	670	0	0
Hadlock	JEF-21	888	444	0	444	444	444	0	0
Hlock / PtTowns	JEF-21/JEF-22	1,469	1,469	0	0	0	0	0	0
Pt Townsend	JEF-22	12,326	2,260	215	9,852	2,223	2,223	0	7,629
PtTowns / NBch	JEF-22/JEF-23	1,808	0	0	1,808	1,808	1,808	0	0
Strait Region									
North Beach	JEF-23	7,856	7,070	324	463	83	83	0	380
NBch / Disco	JEF-23/JEF-24	1,495	1,495	0	0	0	0	0	0
Discovery	JEF-24	5,525	3,599	380	1,546	1,037	1,037	0	510
	JEF-24/JEF-25	651	0	0	651	651	651	0	0
	JEF-25	6,457	4,117	1488	852	852	852	0	0
	JEF-25/JEF-26	2,412	2,277	134	0	0	0	0	0
	JEF-26	2,620	245	594	1,781	651	651	0	1,130
	JEF-26/JEF-27	7,732	199	1285	6,248	2,233	167	2,067	4,015
	JEF-27	3,086	1,826	662	599	372	372	0	226
	JEF-27/JEF-28	1,644	1,644	0	0	0	0	0	0
	JEF-28	1,452	692	342	417	417	417	0	0
	JEF-28/JEF-29	1,450	62	28	1,359	817	817	0	542
	JEF-29	4,468	1,993	767	1,707	1,559	674	885	148
	JEF-29/JF-18-5	1,142	1,058	0	84	84	84	0	0
	JF-18-5	2,329	1,531	0	798	798	798	0	0
	JF-18-4	1,256	276	0	979	847	847	0	132
Disco / RockyP	JF-18-3/JF-18-4	459	425	0	34	0		0	34
Rocky Pt	JF-18-3	675	295	0	380	380		0	0
	JF-18-2/JF-18-3	126	0	0	126	126	126	0	0
	JF-18-2	1,619	1,429	0	190	171	171	0	19
	JF-18-1/JF-18-2	978	978	0	0	0	0	0	0
	JF-18-1	4,941	3,305	96	1,541	1,541	1,541	0	0
RockyP / SeqB	JF-17-5/JF-18-1	234	0	0	234	234	234	0	0
Sequim Bay	JF-17-5	1,298	0	123	1,175	1,175	1,175	0	0
	JF-17-5/JF-17-6	966	0	517	449	449	449	0	0
	JF-17-6	1,429	852	40	538	485	485	0	53
	JF-17-6/JF-17-7	1,424	1,175	82	168	0	0	0	168
	JF-17-7	4,532	1,054	2031	1,447	1,379	1,379	0	67
	JF-17-3/JF-17-7	3,232	0	0	3,232	2,094	550	1,543	1,138
	JF-17-3	4,877	1,359	3109	409	274	274	0	135
	JF-17-2/JF-17-3	2,683	0	420	2,263	0	0	0	2,263
	JF-17-2	1,681	773	300	608	608	608	0	0
	JF-17-1/JF-17-2	3,126	0	0	3,126	3,126	433	2,694	0
Gibson Spit	JF-17-1	3,345	1,875	0	1,470	1,380	1,380	0	90
	JF-16-6/JF-17-1	3,382	253	49	3,080	2,839	2,839	0	241
Jamestown	JF-16-6	6,849	56	0	6,793	6,793	4,325	2,468	0

[1] Drift cells are identified by alphanumeric code: e.g.,KS-1-3. Some drift cells have combination codes that indicate a single drift cell; e.g., KS-1-3/KS-1-4. In many cases, a drift cell may overlap two subregions (and regions). Such cases are indicated by a combination of abbreviated subregion names; e.g., the name Foulw / DKey, indicates the drift cell KS-1-4/KS-1-5 overlaps into the subregions Foulweather and Driftwood Key.

[2] Accretion type landforms include barrier beaches, spits and berms (compiled together as one grouping) and saltmarshes. Total lengths for accretion type landforms, for combined beaches, spits and berms, and for saltmarshes are shown.

[3] The upland category generally applies where the extent of roadways, residential development, fill, or other human structures is so dense that the natural landform is obscured. See also discussion in Backshore Landforms section under Results and Discussion in main body of report.

Appendix 4. Error analysis

To evaluate the accuracy of our approach relative to onshore based GPS mapping, we compared our boat-based, “snapped” data to features mapped on foot employing a high-resolution Trimble PathFinder Pro-XL GPS over two shoreline segments, a 6.3 km segment near Lofall, WA and a 3.3 km segment near Shine, WA. By this comparison, we estimated percent omissions (e.g. “missed” features) and horizontal accuracy errors (e.g. in the length and position of features in meters).

Bulkhead omission/commission analysis:

For the bulkhead error analyses the onshore survey was considered to be accurate and the degree of error for the boat survey was established using this benchmark.

The first analysis measured errors of omission and commission. The onshore survey recorded 67 bulkheads of which 13 were not observed in the boat-based survey. This yielded an omission error rate of 19.40% (Table 1). There were no errors of commission. The average length for missed bulkheads was 17.56 meters (standard deviation = 9.32 meters, standard error = 2.59 meters). The average length for corresponding bulkheads was 72.52 meters (standard deviation = 53.15 meters, standard error = 7.23 meters).

Table 1: Omission/Commission errors

		Boat Survey		
		bulkheads observed	bulkheads not observed	percent omission error
Onshore	bulkheads observed	54	13	19.40
Survey	bulkheads not observed	0		
	percent commission error	0		

Bulkhead length analysis:

The second bulkhead error analysis focused on a comparison of the bulkhead lengths for the 54 features observed in both the onshore and boat surveys. The length of the onshore survey bulkhead (Ls) was subtracted from the length of its corresponding boat survey bulkhead (Lb). The absolute value of this number was then divided by the onshore survey bulkhead length and multiplied by 100.

$$(|Lb-Ls| / Ls)*100$$

This calculation yields the percentage of error in the measure of the boat survey bulkhead when the onshore survey bulkhead length is considered accurate. These percentages were then averaged for all 54 features and yielded a 22.84% length error rate. The sample was then split into two subsamples, one in which the boat survey lengths were greater than the corresponding onshore survey lengths and one in which the boat survey lengths were less than the corresponding onshore survey lengths. For the subsample of longer boat survey lengths there were 17 features with a length error rate of 11.65%. For shorter boat survey lengths there were 37 features with a length error rate of 27.98%. These statistics show a bias towards more frequently underreporting bulkhead lengths and doing it with a higher margin of error (Table 2).

Table 2: Length errors

	Percentage	Number of bulkheads
Overall average percent error	22.8	54
Average percent error when boat survey length was greater than onshore survey length	11.6	17
Average percent error when boat survey length was less than onshore survey length	28.0	37

<u>Bulkhead position analysis:</u>

Positional differences along the shoreline for corresponding bulkheads in both surveys were analyzed using the center points for these features. The average distance between the location of a boat survey center point and a corresponding onshore survey center point was 17.08 meters (standard deviation = 12.06 meters, standard error = 1.64 meters).

<u>Bulkhead attribute analysis:</u>

The final bulkhead error analysis involves the accuracy of bulkhead attributes (i.e., construction material, angle[vertical or sloped], and position [above, at or below ordinary high water]). The following analysis compares 70 features between the onshore and boat surveys. This number of features is higher than for the above omission/commission, length and center point analyses because of instances where it was felt that the boat survey had identified a bulkhead correctly in relation to its existence and size, but had not correctly identified all the attribute changes that had occurred along its length as identified by the onshore survey. This analysis takes into account these missed changes in the bulkhead attributes.

Table 3 describes the number of features and percent of total features where the attribute classification of the boat survey matched that of the onshore survey. The results of the table show that while for only 19 of the features (27%) did all three attributes match, the angle and material attributes together matched for 60 of the 70 features (19 + 41=60) or 86% of the time. The position attribute matched for only 23 of the 70 features (19+2+1+1=23) or 33% of the time. The material and angle attributes matched for 62 (19+41+1+1=62) and 66 (19+41+2+4=66) of the 70 features respectively, or 87% and

94% of the time. Thus it can be seen that the largest attribute error occurred in describing the bulkhead position as above, at or below ordinary high water.

Table 3: Attribute errors

type of attribute match	number of features	percent of total
match of all attributes	19	27.2
match of angle and material attributes only	41	58.6
match of angle and position attributes only	2	2.9
match of material and position attributes only	1	1.4
match of angle attribute only	4	5.7
match of material attribute only	1	1.4
match of position attribute only	1	1.4
match of no attributes	1	1.4
Totals	70	100.0

Omission/commission analysis for other shoreline features:

This analysis addresses errors of omission and commission for features other than bulkheads, including docks, jetties, launch ramps and rail launches. Stairs were not included in these analyses because the onshore survey did not use the same criterion to identify stairs as the boat survey.[1] Again, for the point error analysis the onshore survey was considered to be accurate and the degree of error for the boat survey was established using this benchmark.

The onshore survey recorded 39 features of which 16 were not observed in the boat-based survey. This yielded an omission error rate of 41%. One feature out of 24 observed in the boat-based survey was not recorded in the onshore survey yielding a commission error rate of about 4% (Table 4).

Table 4: Omission/Commission errors

		Boat Survey		
		points observed	points not observed	percent omission error
Onshore Survey	points observed	23	16	41.0
	points not observed	1		
	percent commission error	4.2		

[1] The boat survey only identified stairs that were separate from other more intrusive features such as bulkheads. The onshore survey identified all stair features.

Position analysis for other shoreline features:

Positional differences along the shoreline for corresponding non-bulkhead features were also analyzed. The average distance between the location of a boat survey point and a corresponding onshore survey point was 15.97 meters (standard deviation = 13.43 meters, standard error = 2.80 meters).