Executive Summary

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Introduction

In Puget Sound, forage fish are a significant part of the prey base for marine mammals, sea birds, and fish populations, including salmonid species. There are six main species of forage fish in Puget Sound: herring (*Clupea harengus pallasi*), northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*), surf smelt (*Hypomesus pretiosus*), longfin smelt (*Spirinchus thaleichthys*), and Pacific sand lance (*Ammodytes hexapterus*) (Bargmann 1998). Within the context of the Pacific salmon recovery, all forage fish species play an important role. However, of these six forage fish species, only surf smelt and Pacific sand lance spawn on the beach area (upper intertidal zone, approximately between MTL and MHHW). Consequently, only spawning habitat for these two species has been analyzed and discussed in this report.

This study is an assessment of beach and sediment characteristics, sediment sources, and sediment transport factors influencing surf smelt and Pacific sand lance habitat along marine shorelines of Thurston County. The principal focus of the study was to evaluate how shoreline armoring, particularly vertical bulkheads, influences forage fish habitat by altering beach morphology, substrate characteristics, and the supply and transport of sediment. This document describes the study objectives, theoretical and empirical background information, study approach and methods, results, and conclusions. The document also lays out a basic framework for prioritizing habitat preservation and restoration along the Thurston County marine shoreline.

Background

In order to properly characterize the beach sediment characteristics, sediment transport, and sediment budgets influencing surf smelt and Pacific sand lance spawning habitat along the marine shoreline of Thurston County, it is important to describe what is known about these species' biology and habitat and to describe the general coastal geomorphology and physical processes that influence sediment transport and beach characteristics. The ecological functions associated with the spawning habitat for these species depend on complex interactions that occur within nearshore habitat areas. Therefore, physical and biological processes that shape and control nearshore habitats and species assemblages were also characterized.

The background information included a general description of 1) a typical nearshore ecosystem; 2) the biology and life history of surf smelt and Pacific sand lance; 3) their spawning habitat within the nearshore zone; and 4) the theoretical and empirical background information on the general geomorphology and physical processes influencing sediment transport and overall beach morphology.

Methods

An essential part of this study was the development of a sampling protocol for an assessment of sediment and beach characteristics along the marine shoreline of Thurston County (Herrera 2003). The sampling protocol was developed in coordination with the Thurston Regional Planning Council, and was reviewed by the Thurston County Nearshore Technical Committee.

This study consisted of two general approaches: 1) a GIS analysis of existing aerial photographs and digital elevation data to identify sediment sources and sinks, impacts of bulkheads on upper beach areas, and long-term erosion and aggradation trends on the Thurston County shoreline; and 2) field surveys of representative beach profiles to document and categorize the various geomorphic beach characteristics present, to identify the effect of bulkheads on sediment characteristics and erosion, and to aid in identification of sediment sources and sinks.

A preliminary field investigation was performed on June 16, 2003, to test potential sampling protocols and to select representative beach sample sites. The major field phase of the study was performed between August 25 and August 28, 2003. In addition, field verification of beach profile data and of the results of the GIS analysis was performed at selected beach sites in September 2003. Thurston County's marine shoreline was analyzed using 29 paired beach sampling sites consisting of unarmored and armored sites (a total of 58 beach sampling locations), with five or more pairs sampled in each of the five inlets to provide statistical power.

In addition to the 29 paired beach sampling sites, three beach sites were surveyed at stream delta or drift cell confluences to determine accretion characteristics at these discrete sites in order to assess the relative importance of fluvial inputs from small streams. Six mass wasting sites were surveyed in the field to verify the GIS and digital elevation model map analysis performed for this study.

All sampling locations were georeferenced using a Trimble® GeoExplorer3 handheld global positioning system (GPS) unit (resolution +/- 6 – 16 feet). At these sites, the accuracy of existing site information (e.g., drift cells, habitat, bluff geology) was verified, and the GIS-based predictions of mass wasting potential were evaluated. Potential preservation and restoration sites were then evaluated in the field.

GPS and depth sounder methods were used to compare present-day bathymetry to historical information.

Results

The following GIS layers were produced and delivered to the Thurston Regional Planning Council in ESRI shapefile format:

- Bathymetry.shp – Depths from four transects conducted in Thurston County corrected to MLLW and to NAVD88. Includes approximate 1930s depths from georeferenced U.S. Coast and Geodetic Survey maps.

- Bulkhead_areas.shp – Interpolated area of upper beach lost to bulkhead construction. Modern shoreline mapping data provided by Thurston County (GIS shapefile) were copied and modified to estimate natural or preconstruction shoreline, where bulkheads have been built on beaches. Shorelines in areas without bulkheads were used to estimate the bulkhead footprint area. This information was used to estimate the total area of habitat lost.

- Landslide_erode.shp – Areas with landslides and erosion were identified using aerial and oblique photos and lidar-derived shaded relief maps and were digitized over aerial photos and lidar shaded relief maps.

- Manmade_structures.shp – Structures that block sediment transport along drift cells were digitized using vertical and oblique aerial photographs (TGDC 2000; Ecology 2000, respectively).

- Shore_additions.shp – Areas where the wetted shoreline was artificially increased between 1944 and 2001.

- Shore_reductions.shp – Areas where the wetted shoreline was artificially reduced between 1944 and 2001. This shapefile also includes filled inlets.

- Transect.shp – Locations of 29 paired transects established on the Thurston County shoreline. Appendix D contains illustrations of the transects and Appendix E and the shapefile contain a summary of the data collected at each transect.

- Thurston_Shoreline_Geology.shp – Polygon shapefile of surficial geology along the Thurston County shoreline digitized from the Coastal Zone Atlas of Washington published by the Washington State Department of Ecology in 1980.

- Prioritization.shp – Reaches along the Thurston County shoreline that meet specific preservation or restoration criteria derived in this study. Reaches were designated high priority when the majority of the criteria were met.

- Preservation sites.shp – Specific sites with unique habitat-related characteristics that should be preserved or restored.

Table ES-1 provides a summary of the differences observed between unarmored and armored (typically bulkhead or rock revetment) for 29 transect pairs that were surveyed in this study.

Table ES-1. Summary of beach differences between unarmored and armored (bulkhead or rock revetment) for 29 transect pairs.

	Percentage of Transects with Driftwood Present Near Site	Presence of Shade Area on Upper Beach	Average Width of Beach between MTL and MHHW (feet)	Average Width of Beach Usable for Spawning Habitat (sand and gravel) (feet)	Average Height of Top of Beach Above MLLW (feet)	Average Percentage of Beach Surface Coarsening along Transect Between -2 and MHHW	Percentage of Transects With Exposed Beach Platform [a]
Armored beaches	3%	45%	37.5	33.2	14.0	26%	10%
Unarmored beaches	79%	90%	43.4	39.3	15.5	25%	17%
Statistically significant	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**

[a] Beaches where underlying bedrock is exposed.

Statistical analyses were performed to compare habitat and geomorphic attributes for paired unarmored and armored beaches. Specifically, a Wilcoxon rank sum test (Zar 1984) was used to evaluate whether there were significant ($\alpha = 0.05$) differences in the following attributes across paired linear transects for all major Thurston County inlets combined ($n = 29$) and individual inlets having sufficient data ($n > 4$):

- Width of beach between MTL and MHHW
- Width of habitat, or beach that is predominantly sand or gravel, between MTL and MHHW
- Beach slope between MTL and MHHW
- Percentage of the beach that exhibits beach surface coarsening between MTL and MHHW
- Top of beach height relative to MLLW.

Results from the statistical tests showed that both beach width and the width of habitat were significantly shorter between MTL and MHHW in front of bulkheads or other armoring structures when the data from all inlets were analyzed (see Table 4-2). Additionally, top of beach height was shown to be significantly lower in front of bulkheads or other armoring when data from all of the inlets were analyzed. Between MTL and MHHW, the percentage of beach surface coarsening (due to the presence of overlying sediments with a relatively large median grain size [D50, i.e., the size for which 50 percent of the material is finer]) and the slope of the beach were not shown to be significantly different between unarmored and armored beaches. For individual inlets, the top of beach height was shown to be significantly lower for armored beaches within Henderson Inlet.

Habitat and geomorphic attributes that were measured on a nominal scale (presence or absence) were also compared between paired unarmored and armored beaches using the McNemar's test (Zar 1984). The attributes tested included the presence/absence of beach surface coarsening, presence/absence of beach platform exposure, presence/absence of barnacles, and presence/absence of shade (Table ES-2). These tests showed that there was a significantly ($\alpha = 0.05$) higher number of unarmored beaches with shade relative to armored beaches.

Table ES-2. Statistical analysis of habitat and geomorphic attributes for paired unarmored and armored based on a NcNemar's test.

Attribute	χ^2 Value	p-Value [a]
Presence/Absence of Beach Surface Coarsening	3.13	0.0771
Presence/Absence of Beach Platform Exposure	0.57	0.4497
Presence/Absence of Shade	6.75	**0.0094**
Presence/Absence of Barnacles on Wood Debris	0.50	0.4795

[a] Values in bold indicate there was significant difference between unarmored and armored beaches for the indicated attribute ($\alpha = 0.05$).
Source: Zar 1984.

Initial analyses showed no statistically significant difference in beach surface substrate type between the unarmored and the armored shorelines. However, there does appear to be a slight, statistically nonsignificant shift from sand to gravel and (to a smaller degree) to cobble at armored areas.

Discussion

The elevation of shoreline armoring most directly determines both its direct physical impacts on the beach and the availability of suitable forage fish spawning habitat. Weggel (1988) classified seawalls into six types based on their location within the water column (Table ES-3).

Table ES-3. Seawall classification according to Weggel (1988).

Seawall Type	Seawall Type Description
Type 1	Base of seawall is located landward of the level of maximum wave setup and runup during times of maximum tide and storm surge.
Type 2	Base of seawall is located above water level that occurs at time of maximum combined tide and storm surge, but below level of maximum combined wave setup and runup.
Type 3	Base of seawall is above the maximum predicted tides excluding meteorological effects, but below storm surge plus tide level.
Type 4	Base of seawall is located within normal tide range, and thus the base is under water during part of the normal tidal cycle.
Type 5	Base of seawall is located seaward of the mean lower low water shoreline; it is subject to breaking and broken waves.
Type 6	Base of seawall is located in water so deep that incident waves do not normally break before reaching it.

Almost all of the observed bulkheads in this study were between MTL and MHHW, meaning that they were of Type 4, with the base of the bulkhead under water during part of the normal tidal cycle. This means that the existing bulkheads directly limit the availability of spawning habitat. For future bulkheads, a requirement for the elevation to be above the maximum predicted tides excluding meteorological effects (Type 2), or above the level of maximum combined setup and runup (Type 3), would eliminate this direct effect. Waves would still runup to meet the bulkhead, but the toe would not generally be under water.

In the long term, the availability of spawning habitat will be determined by the available sediment supply. Future changes to the sediment supply are likely to be varied, depending on land use and on direct actions at the shoreline (construction or removal of armoring). From a qualitative perspective it appears that a decrease in sediment supply will likely continue to occur, unless reasonable planning-level precautions are taken.

Restoration of the Deschutes River as an estuary has the potential to make a significant contribution to the sediment supply along the western shore of Budd Inlet, although very careful analysis and design for the restoration would be needed, and any changes would likely require decades to be fully established. Other fluvial sediment sources are likely to remain essentially constant, in that no major dam construction or removal efforts are anticipated and current stormwater management requirements do not allow developments to introduce significant changes to river and stream hydrology.

The following sections describe the present state of the marine shoreline of Thurston County in terms of the current condition of the beaches and the sediment supply.

Totten Inlet

Totten Inlet is not severely erosional; the beaches in front of bulkheads are not significantly narrower than other beaches. The sediment supply is approximately evenly divided between the fluvial supply (primarily Skookum, Kennedy, and Schneider Creeks) and landslides (including bluff erosion). There is no strong evidence that sediment is being lost offshore into the inlet. A relatively small portion of the Totten Inlet shoreline is armored (19 percent).

The sediment deficit appears to be relatively small, on the order of 4,000 cubic yards per year of sand-size and coarser sediments, and could be offset by a program of beach nourishment.

Squaxin Passage

The north-facing beaches of Squaxin Passage receive the highest wave energy in Thurston County. The majority of this reach, (i.e., 71 percent) is armored, and the area continues to erode as evidenced by the high proportion of exposed footings on bulkheads in this area.

Encroachment of bulkheads onto the beach is a significant issue. Because of the high wave energy and relatively large wave runup, the unarmored beach reaches an elevation 5 feet or more above MHHW. Therefore, bulkheads that have been constructed with their toes at MHHW immediately encroach some tens of feet onto the beach.

Another impact of the high wave energy in this area is the relatively high rate of alongshore transport. Thus, sediment added to beaches in this area rapidly moves north and away, past Steamboat Island and therefore limits beach nourishment opportunities implemented without structural elements such as groins or offshore reefs/berms to retain littoral sediment.

Eld Inlet

Eld Inlet is similar to Totten Inlet in that the sediment supply is approximately evenly divided between the fluvial supply (Perry and McLane Creeks) and landslides (including bluff erosion). There is more shoreline erosion in Eld Inlet compared to Totten Inlet, and the level of armoring is greater (36 percent in Eld Inlet compared to 19 percent in Totten Inlet).

It appears likely that there is some loss of sediment offshore into Eld Inlet. This is based upon the high level of shoreline erosion observed in Eld Inlet compared to the other identified sources and sinks. Shoreline erosion in Eld Inlet is likely to lead to more shoreline armoring, and therefore Eld Inlet should be targeted for improved bulkhead siting and more complex bulkhead structures that dissipate wave energy and trap sediment.

Budd Inlet

Budd Inlet is the only inlet in Thurston County that is fed by a large river, the Deschutes. More sediment is transported by the Deschutes River than by any other stream in Thurston County except for the Nisqually River; this sediment is now trapped in Capitol Lake.

Budd Inlet is the most heavily developed and most heavily armored of the four inlets. Forty five percent is armored, including 71 percent of the western side of the inlet. The amount of measured erosion is surprisingly small given the level of development. The transect studies showed average beach narrowing of 2 feet in front of armored shorelines. However, particularly on the western, more developed side of Budd Inlet, beaches are narrow and are cut off below MHHW and generally do not provide desirable spawning habitat for forage fish.

These observations are representative of a sediment-starved system backed by a relatively unerosive perimeter (west shoreline). Along the western part of Budd Inlet, it appears that there is little bluff or backshore erosion even in unarmored areas.

Dana Passage

Dana Passage is similar to Squaxin Passage, although it is less erosional.

Henderson Inlet

Uniquely, among the four inlets in Thurston County, Henderson Inlet traps some sediment from outside the inlet due to littoral drift. The drift direction directly northwest of the inlet along Dana Passage is to the south, into the inlet. Henderson Inlet also appears to be the most rapidly eroding of the four inlets and is similar to the much more exposed Dana Passage. For example, bulkhead footings were observed to be exposed at all of the bulkhead transects in Dana Passage. This suggests that significant amounts of sediment are being lost offshore. Unlike Budd Inlet and Totten Inlet, Henderson Inlet appears to be actively “filling-in”.

Nisqually Reach

There is no one predominant drift direction along the Thurston County portion of the Nisqually Reach, suggesting that much of the beach sediment in this area is locally sourced from bluffs. Field observations suggest that this reach is more erosional than indicated by the statistical analysis of beach profile performed in this study. Hardpan and other qualitative evidence of erosion was observed in several transects, and 40 percent of the reach is armored.

Conclusions

Development along the marine shoreline of Thurston County has led to extensive shoreline armoring, dominated by vertical concrete bulkheads. Less than half of the county shoreline associated with gravel and sand beaches remains unarmored.

Quantitative evidence gathered in this investigation clearly demonstrates that armoring (bulkheads) has reduced, both directly and indirectly, the upper tidal zone beach habitat used by forage fish to spawn along the Thurston County marine shoreline. The greatest effect occurs in the upper-most portion of the shoreline between MHW and MHHW. Armoring can invoke physical changes to beaches that would otherwise not occur. Armoring affects sediment recruitment by decreasing or obstructing sediment input from actively eroding bluffs and landslides.

Key Findings

Following are several key findings of this study regarding the geomorphic characteristics of the marine shoreline in Thurston County.

1. Shorelines with armoring, particularly bulkheads, differ significantly from unarmored shorelines with regards to the following characteristics:

    - Reduced beach area and thereby reduced forage fish spawning habitat in the upper tidal zone

    - Reduced local sediment recruitment potential

- Lowered elevation profile of beaches
- Reduced area of sand and small gravel in relation to beach width
- Lack of wood debris either from adjacent riparian areas or offshore
- Reduced shade/cover along upper beach

2. No significant differences were found between unarmored and armored shorelines with regards to the following characteristics:
   - Beach slope
   - Substrate grain size, although a statistically non-significant coarsening was observed along armored shorelines, which warrants further investigation

3. The following trends were observed regarding the geomorphology of Thurston County shorelines:
   - Coastal bluff height tends to increase from south to north, as does the frequency of landsliding
   - Shoreline armoring has had the likely effect of stopping landslides and may reduce upland inputs of sediments over years or decades, but not over the long term
   - There is a general coarsening of beach sediments from south to north in Totten, Eld, and Henderson Inlets, which generally reflects an increasing potential wave energy from south to north

4. Development of a general sediment budget for each inlet within the marine shoreline of Thurston County's marine shoreline indicates the following:
   - Landslides and larger rivers both provide a potentially significant source of sediment.
   - Small, typically unnamed creeks do not and have not historically provided a significant source of sediment.
   - If the sediment transported by the Deschutes River could be delivered to the littoral system of Budd Inlet through restoring Capitol Lake to an estuary, the nearshore environment of the western shore of Budd Inlet could be significantly improved. Careful study would be needed to determine whether this is possible, given the present morphology and south-directed shore drift in the area.

- Most of the sediment sourced in Thurston County is eventually delivered out of the inlets to the north and into the deep channels to the north of Thurston County. A significant fraction of the sediment, particularly in Eld and Henderson Inlets, is being lost offshore within the inlet.

5. The loss of upper beach habitat is more pronounced as the percentage of shoreline armoring increases.

6. Preservation of unarmored shorelines will minimize further impacts to upper beach habitat.

7. Restoration action should focus on evaluating potential solutions for reducing upper beach loss along armored shorelines by increasing the elevation at which bulkheads are built and roughening the structures to dissipate wave energy and trap sediment.

Data Gaps

This study identified several data gaps that include:

1. Repeated topographic surveys of beach profiles over time are needed to obtain more accurate estimates regarding the rate of beach erosion and accretion, including both seasonal and long-term effects. The profiles established in this study could provide a baseline for future surveys. However, it would be necessary to obtain explicit permission from landowners to set up a fixed survey marker in unarmored areas where the back beach may not be fixed.

2. Additional data collection is necessary to quantify the effect of bulkheads on wave reflection and whether these structures contribute actively to erosion of the upper beach. The repeated topographic surveys recommended in (1) above are a significant portion of this. More intensive direct studies of sediment transport at unarmored and armored shorelines, and in areas with and without wood debris should also be performed.

3. Statistically unbiased forage fish surveys are needed to better correlate fish utilization with the physical beach characteristics observed in this study. (Existing fish sampling was clearly biased based on beach substrate type.)

4. Role of wood on coastal beaches needs to be investigated, particularly within the context of forage fish spawning habitat maintenance. This should include the role of wood in trapping sediment and in dissipating wave energy for water levels at or above MHHW.

5. Measurements of bedload transport on the beach for various wave conditions are needed to better estimate sediment mobility of representative beach profiles and substrates.

6. The significance of alternative shoreline armoring techniques needs to be investigated through the use of prototype armoring structures (i.e., “prototype bulkheads”), in order to explore the maximum rehabilitation potential of the Thurston County marine shoreline.

7. The role of littoral drift in shoreline erosion requires additional investigation in which more sample sites are examined than were possible in this study.

Recommendations

A general protocol for prioritizing sites for preservation and restoration of forage fish habitat was developed specifically with regards to beach sediment and upper beach habitat. The first factor influencing upper beach environments consisting of coarse sediment (grain sizes equal and larger to sand) is the sediment supply to sustain these conditions. Sediment supply is provided by either local sources of coarse sediment such as bluffs, streams and rivers, or littoral drift that conveys supply reaches to the site in question. Since littoral drift and beach erosion are both directly affected by wave energy, site exposure and fetch should also be factored into an assessment of preservation or restoration. Sites lacking a major source of coarse sediment and wave energy offer limited opportunity for providing upper beach forage fish habitat. Such areas include much of the low-relief shorelines found at the southern ends of Totten, Eld, and Henderson Inlets. Priority sites will tend to be located in those shoreline areas toward the northern end of Thurston County that are characterized by high bluffs. These are sources of coarse sediment (e.g., glacial outwash and inter-glacial fluvial deposits) that are susceptible to mass wasting and high rates of littoral drift due to their exposure and fetch.

Much of the marine shoreline of Thurston County is erosional due to regional sediment starvation. This sediment starvation is believed to be partly natural and partly a result of human impacts including modifications to the Deschutes River and sediment impoundment behind bulkheads. The restoration and preservation opportunities identified in this report include the following:

- Reconnection of the natural sediment supply to the littoral zone, through reconnection of landslides and bluff failures to the beaches. A discussion regarding the potential removal of the Capitol Lake dam is included in this report.

- Pilot projects to improve sediment trapping and decrease the rate of erosion and littoral drift through placement of woody debris, alone or in conjunction with beach nourishment.

- Localized restoration and preservation actions to improve the quality of specific habitat areas through actions such as the reintroduction and preservation of riparian vegetation.

- Planning actions to diminish the regional impact of future development and shoreline protection in the area.

The results of this study suggest that riparian forests play an important role in providing shade and the recruitment of woody debris. Therefore, attention should be given to the proper management, preservation, and restoration of marine riparian forest areas along the marine shorelines of Thurston County because they support habitats that are heavily impacted by the construction of bulkheads and other human activities. Active programs to reforest impacted shorelines will enhance intertidal beach habitats for forage fish species. Improved shade and overhanging vegetation can be established even along armored shorelines through riparian reforestation and limiting tree clearing.

The potential for successful preservation and restoration varies by inlet and as a result of the differing sediment supply, wave energy, and development practices within each inlet. The following general guidance for the most suitable approach to preservation and restoration in each inlet is given.

- Totten Inlet is relatively non-erosive and relatively lightly developed: as a result, the level of shoreline armoring is also low. The focus in Totten Inlet should be on preservation actions, particularly through planning actions that limit new armoring. Beach nourishment could also be effective in restoring upper beach habitat, both locally and as a regional (inlet-wide) action.

- Squaxin Passage is very highly developed and receives the highest wave energy in Thurston County. The shoreline is very erosive and heavily armored. The shoreline is also susceptible to deep-seated landslides. These landslides have historically provided significant sediment to the littoral system. However, the sediment does not remain in Thurston County, it rapidly moves north and is lost offshore, past Steamboat Island.

  The focus in Squaxin Passage should be on slowing sediment transport, possibly through the introduction of woody debris, and on the reconnection of landslide-generated material to the littoral zone. Howver, given the high level of development, this area may not be cost-effective for restoration.

- Eld Inlet is more erosional than Totten Inlet, and the level of development and armoring is higher. Restoration and preservation actions should consider a combination of beach nourishment and slowing sediment transport.

The area to the north of Frye Cove is a significant source of sediment through landsliding. However, this sediment is relatively fine. This means that the coarse fraction is important in supplying sediment to the littoral system as a whole, so that the connection of the landslides to the littoral system should be preserved.

- The west shore of Budd Inlet is the most heavily developed and heavily armored shoreline within Thurston County, with the exception of Squaxin Passage. It appears that the bluffs in Budd Inlet are relatively unerosive and subsequently contribute little sediment to the beach. Unarmored and armored sites exhibit poor upper beach habitat conditions. The scope for local restoration is limited here.

  A regional restoration action with considerable potential for the west shore of Budd Inlet would be to open up Capitol Lake in such a way as to make the sediment supply from the Deschutes River available to the littoral zone of Budd Inlet. If this could be achieved, the nearshore environment of the western shore of Budd Inlet could be significantly improved. Careful study would be needed to determine the level of improvement, given the present morphology and south-directed shore drift in the area.

- The eastern shore of Budd Inlet is less heavily armored than the western shore. In this area, it is critical to preserve the connection between erosive bluffs and the littoral zone: reconnection of the bluffs to the shore through bulkhead removal would also be extremely valuable here. The northern part of this shore is characterized by tall bluffs subject to toe erosion. This means that even relatively benign shore protection, if it is successful in reducing toe erosion, is likely to reduce the sediment supply to this inlet. This is an area where conservation easements may be particularly valuable in preserving the sediment supply.

- Dana Passage is similar to, although less erosional than, Squaxin Passage. Localized restorations in pocket beaches and at estuaries could be effective, and measures to slow sediment transport could be tested. Improvements to the sediment supply would be difficult because of the high rate of littoral transport. Sediments sourced here would rapidly be lost offshore without restoration measures to retain them.

- Henderson Inlet is lightly developed and lightly armored at present. However, it is the most erosive of the four inlets. This means that pressure for further armoring is likely to grow. This area, along with the eastern shore of Budd Inlet, should be a particular focus of soft protection measures.

- Finally, the fact that there is no one predominant drift direction along the Thurston County portion of the Nisqually Reach suggests that much of the beach sediment in this area is locally sourced, despite the presence of the Nisqually River to the east. The tall bluffs towards the north part of this reach provide a source of sediment through bluff toe erosion. The reach is actively eroding and local restorations at pocket beaches and at estuaries could be effective. Limitations and criteria for new bulkhead construction are recommended to help sustain current conditions.

Pilot projects incorporating complex, stable driftwood revetments in areas where bulkheads are threatened should be constructed and evaluated. Beaches in front of bulkheads often erode, lack shade, have less area covered by sediment on which forage fish spawn, and experience increased periods of tidal inundation. Such pilot projects should attempt to reverse these trends by creating complex structures that emulate natural wood debris accumulations at the top of the beach and trap sediment. Driftwood at the top of the beach may also slow littoral drift and erosion by reducing wave energy and wave reflection energy and by creating pockets where larger sediment will accumulate.

Monitoring

Monitoring beach changes along the Thurston County marine shorelines is a critical need to understand what is happening to shoreline habitat and the effects of existing erosion control measures. This is particularly important in the preservation, restoration, and control of sites identified in this report. Beach profiles obtained in this study represent a baseline from which future studies should build upon to further investigate and monitor beach sediment changes along the Thurston County marine shorelines. Additional beach profile sites (permanent georeferenced transects) should be established at locations within the preservation and restoration areas.

It is strongly recommended that a beach width monitoring program be set up to measure erosion rates directly. This would include measurements of both the erosion rate due to regional sediment starvation and any increased (active) erosion caused directly by shoreline armoring.

Beach response, as measured by sediment types, beach profiles, and forage fish habitat utilization, should be monitored to measure the efficacy of any pilot project. While the structures constructed in a pilot project should resemble complex accumulations of wood debris, they would need to be stable assemblages of real logs or concrete logs. Applying several treatments in similar settings is also recommended.