Shoreline Development on Puget Sound

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Introduction

Conceptual models are emerging for the links between shoreline armoring and disruption of natural sediment transport processes as well as the support functions for nearshore biota in Puget Sound. To identify what anthropogenic drivers changed the nearshore since European settlement of the Puget Sound region, and where those changes occurred, the Puget Sound Nearshore Ecosystem Restoration Project's (PSNERP) Nearshore Science Team (NST) conducted an analysis of change in nearshore ecosystems (Simenstad and others, 2010). The key elements of this analysis were that it be: (1) documented comprehensively over the entire Puget Sound basin; (2) directly related to physical and ecological change in ecosystem-scale processes; (3) spatially explicit; and (4) integrated within the NST's development of a geomorphic classification system of Puget Sound's shoreline features (Shipman, 2008).

For purposes of dividing Puget Sound's 2,500-plus miles of diverse shorelines into quantifiable units, drift cells mapped by Schwartz and others (1989) were "snapped" to the coastal drainage basins that directly drain to those mapped segments, using a 30-m resolution digital elevation model created by Finlayson (2006). The result was a comprehensive Puget Sound-wide geodatabase (Simenstad and others, 2010) of more than 828 "process units" corresponding largely to littoral drift cells and large deltas. Shipman (2008) lists the following Puget Sound rivers as having "large" deltas: Nooksack, Skagit, Stillagumaish, Snohomish, Duwamish, Puyallup, Nisqually, Skokomish, Elwha, and Dungeness. In addition, for purposes of the Change Analysis, PSNERP included the Deschutes, Samish, Hamma Hamma, Quilcene, Dosewallips, and Duckabush Rivers in the "large" river delta category. Geomorphic segments, or shoreforms, and shoreline drainage units are embedded within these process units, allowing for several spatial scales of analysis. Puget Sound also was divided into seven distinct subbasins that primarily reflect differences in oceanography and geomorphology (see Simenstad and others, 2010) for a description of subbasins). A Strategic Needs Assessment process interpreted change analysis summary data as a critical component of a Puget Sound scale nearshore restoration feasibility study being prepared by the U.S. Army Corps of Engineers (COE) as part of the General Investigation of the Puget Sound Nearshore under a cost-share agreement with Washington Department of Fish and Wildlife. A feasibly study is being prepared by the COE to determine whether there is a compelling national need for a particular suite of restoration projects and whether the COE can provide a solution.

Shoreline armoring represents one of the shoreline alterations or stressors analyzed in the PSNERP geodatabase. Armoring has varying degrees of impact generally related to the type of shoreform that is being altered, location on the beach, and the degree to which the structure interacts with wave energy. Coastal processes adversely impacted by the presence of shore armoring include reduced sediment supply, increased sediment transport rates and volumes, and reduced depositional processes largely resulting from reduced wave dissipation or increase wave reflectivity, which in turn reduces the deposition of fine sediment, driftwood or Large Woody Debris (LWD) and other organic material, such as beach wrack. Some shoreline armoring also can change the patterns of freshwater seepage onto the beach (Washington Department of Ecology, 1994). The most extreme example of this process disruption would be recorded in the geodatabase as a shoreform transition. A shoreform transition represents a change between historical and current shoreform types, including the transition to an artificial shoreline (fig. 1). Armoring tends to co-occur with other shoreline development components that also have adverse impacts on shoreline processes and functions, such as the removal of shoreline vegetation, increased impervious surfaces, septic system inputs and disturbance of riparian wildlife. When associated with artificial shoreforms, the disruption of processes from armoring may be less important than the alteration that destroyed the shoreform in the first place. In many cases, this alteration involves the filling or dredging of the shoreline to create deepwater access. Figures 2 and 3 below show different ways to express the co-occurrence of shoreline armoring and nearshore fill.

[1] People for Puget Sound.

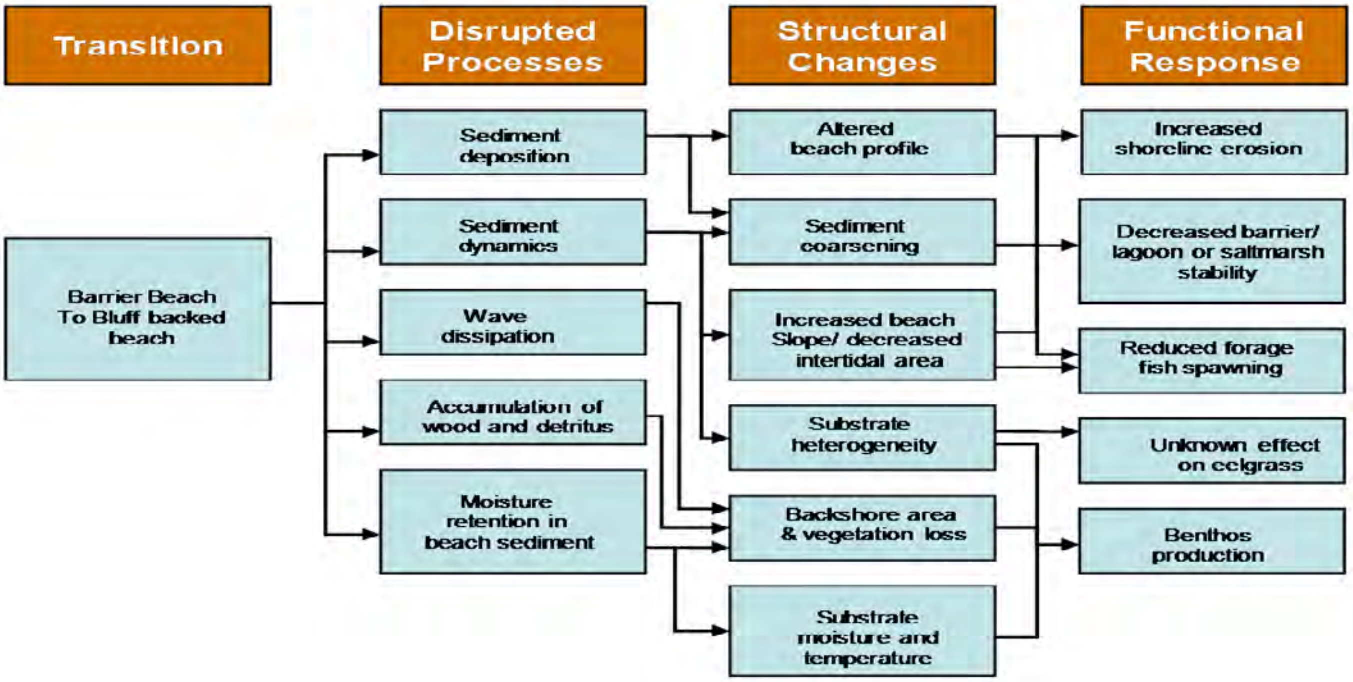

Figure 1. Conceptual model describing some of the implications of changing a barrier beach to a bluff backed beach.

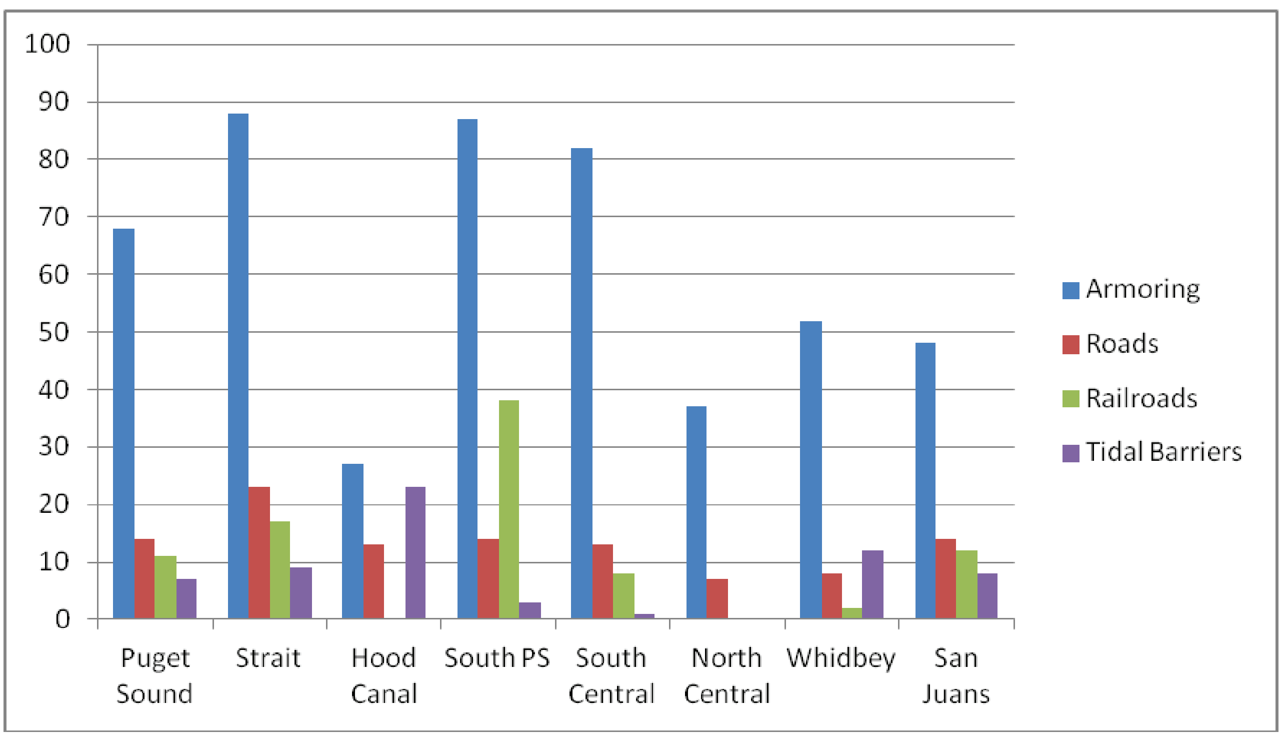

Figure 2. Presence of different stressors along mapped fill shoreline for Puget Sound and subbasins, expressed as a percentage (%) of fill length that stressors occupied (for example, Armoring was present along 68 percent of filled shoreline length in Puget Sound as a whole) (Strait, Strait of Juan de Fuca; PS, Puget Sound; Whidbey, Whidbey Basin).

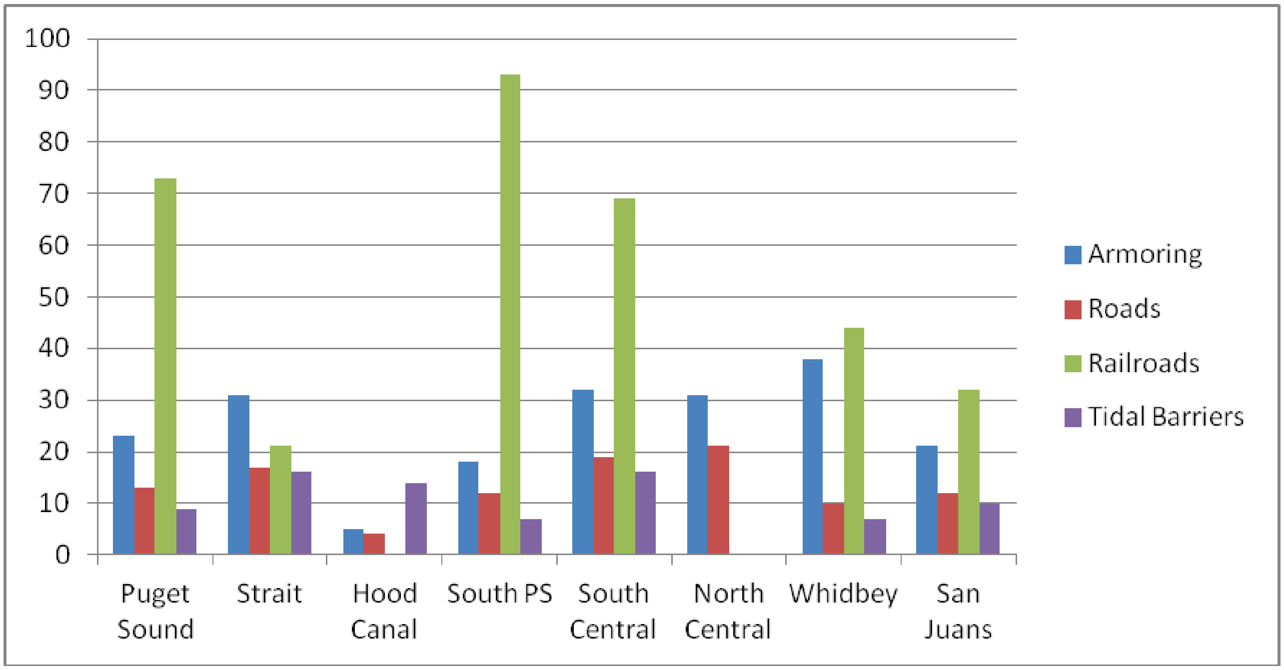

Figure 3. Presence of mapped nearshore fill along shorelines with other stressors, expressed as a percentage (%) of stressor length that fill occupied (for example, fill occurred along 23 percent of armored shoreline length in Puget Sound as a whole). (Strait, Strait of Juan de Fuca; PS, Puget Sound; Whidbey, Whidbey Basin.)

Results of the PSNERP Change Analysis show that shoreline armoring occurred along 27 percent of Puget Sound. The percent of armored shoreline varied considerably (9.8–62.8 percent) across the subbasins that comprise the study area. The South-Central Puget Sound subbasin had the most armoring, accounting for close to 63.0 percent of the subbasin's shoreline. Other subbasins with considerable shoreline armoring include: South Puget Sound (34.5 percent), Whidbey Basin (22.5 percent), and Hood Canal (21.2 percent). The subbasins with the least amount of shore armoring include North Central Puget Sound (9.8 percent), San Juan Islands–Strait of Georgia (14.0 percent), and the Strait of Juan de Fuca (16.1 percent). The average length of armoring across all process units in the Sound was 29.5 percent. Twenty-five percent of all process units in the Puget Sound basin had armoring more than 50.0 percent of the shoreline length. The average percent armoring within process units was as low as 7.8 percent in the North Central Basin and only 11.8 percent in the San Juan Islands-Strait of Juan de Fuca subbasin. Subbasins with the highest average percent armoring among process units include the South Central Puget Sound (56.6 percent) and South Puget Sound (45.5 percent) subbasins. Different shoreforms had varying degrees of armoring (table 1).

Table 1. The amount of armoring (percentage) by shoreform type as defined by Shipman (2008).

[km, kilometer]

Current shoreform type	Armored length (km)	Total length (km)	Percent armored
Artificial	244.1	325.2	75
Barrier Beach	119.9	440.2	27
Barrier Estuary	11.2	163.6	7
Barrier Lagoon	9.2	60.8	15
Bluff Backed Beach	511.3	1,529.2	33
Closed Lagoon Marsh	0	4.0	0
Delta	51.5	310.3	17
Plunging Rocky	0.9	185.5	0
Rocky Platform	21.5	503.9	4

Case Study: Beach Transitions

Because of site-scale findings and anecdotal information, a major premise of the Corps of Engineers General Investigation was that the change analysis data would point specifically to transitions empirically linked to certain stressors, such as loss of barrier beaches linked to armoring. One particular change analysis output of interest to this phenomenon is the transition of beaches from one type to another. As predicted by the geomorphic classification system (Shipman, 2008), we expect real transitions from one geomorphic type to another to be rather rare. Throughout Puget Sound, 42 barrier beaches were lost, but 29 new bluff-backed beaches appeared on the landscape. This would suggest an overall loss of depositional beaches, which we expect from our conceptual model linking armoring to disruption of sediment transport processes. However, both beach types lost shoreline length, 7.7 percent for bluff-backed beaches and nearly 12.0 percent for barrier beaches, as many transitioned to artificial shorelines.

Conceptually, the mechanisms that could cause transitions from a barrier beach to a bluff-backed beach include loss of significant sediment budget as a consequence of armoring and the trapping of sediments updrift of overwater structures that would make the downdrift beach more erodible. Likewise, the updrift beaches that are now trapping sediment would be mapped as barrier beaches by the change analysis methodology. Massive landslides within the period of analysis could also transform a bluff-backed beach to a barrier beach.

Because of the dynamic, directional nature of drift cells, we should expect that barrier beach shoreforms could move from one place to another over time. This would register in the change analysis methodology as two transitions: from barrier beach to bluff-backed beach at the historic location of the barrier beach and from bluff-backed beach to barrier beach directly adjacent and down drift. If that is the case with any of these transitions, we would expect an equal number of each kind of transition to explain this phenomenon.

Many of these transitions are small (< 1 km in length). Thus, the probability of mapping registration errors between the two time periods used in the change analysis causing a “false positive” is high. However, where mapping confidence is higher, we can extrapolate the relative rate at which sediments moved from one position to the next. Each transition must, therefore, be looked at individually in this way and in the context of how stressors like overwater structures and armoring could affect sediment budget and movement (see examples, figs. 4 and 5).

Figure 4. Example data source discrepancy due to shorezone mapping of current shoreline being landward of barrier.

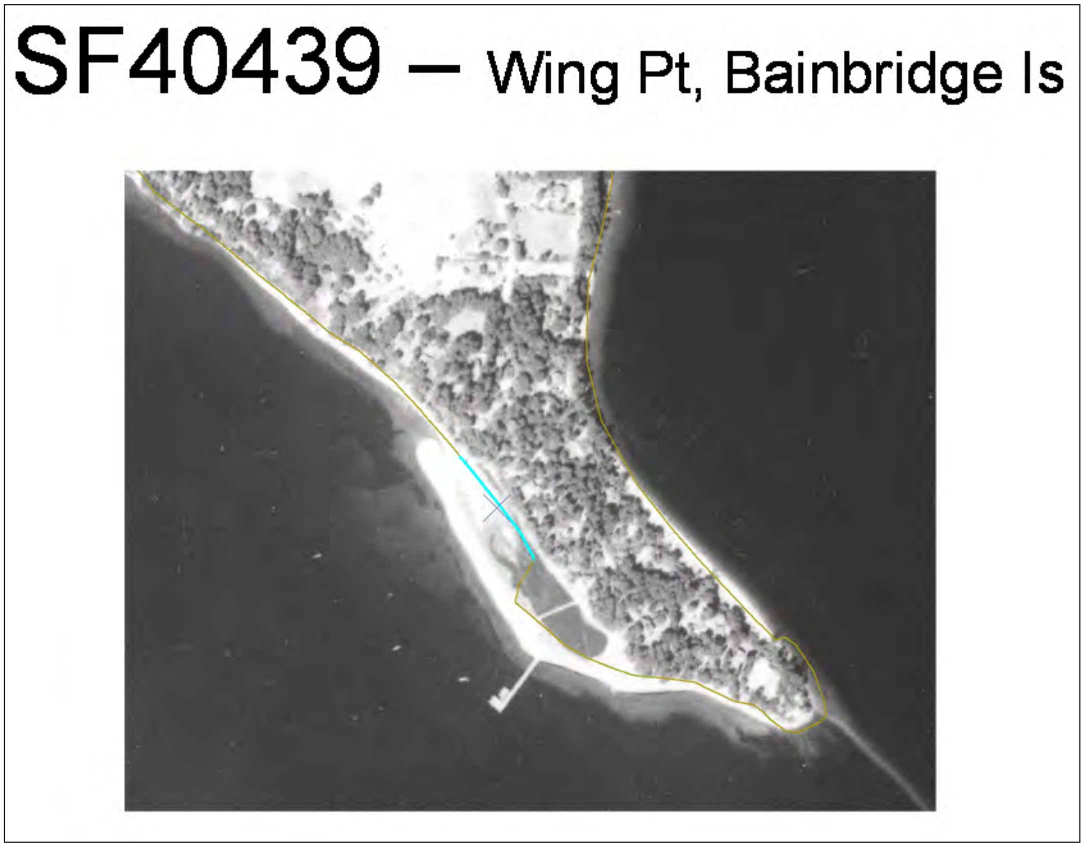

Figure 5. Example real transition with barrier apparent in this 1945 image.

In the South Central Puget Sound Subbasin, 10 such transitions were investigated in a case study comparing the transitions signaled in the change analysis geodatabase with ancillary aerial photographs of interim time periods between the historical and current endpoints to reveal that 5 were likely to be real transitions or loss of barrier beach and the other 5 were mapping discrepancies. At the scale of a subbasin restoration strategy, this information would be useful to screen potential locations for the bulkhead removal or beach nourishment management measures. Once a "real transition" is detected, additional information, such as the co-occurrence and adjacency of certain stressors with the observed shoreform transition, can be consulted. For example, armoring co-occurs on 33 percent of bluff-backed beaches by length, representing the most common co-occurrence with a natural shoreform. If armoring conceptually linked to the disruption of sediment supply and transport) is commonly found adjacent to and updrift of a shoreform transition, it could be thought to have a role in that transition happening.

Conclusion

The PSNERP Change Analysis and Strategic Needs Assessment begins to put the driver of nearshore armoring into context with the landscape disruptions it causes and in relation to other stressors. These diagnostic tools will inform restoration strategies to maximize the benefits of armoring removal as a restoration management measure.

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