Protecting & Restoring
Puget Sound & the Northwest Straits

LARGE-SCALE PATTERNS IN LARGE WOODY DEBRIS AND UPLAND VEGETATION AMONG ARMORED AND UNARMORED SHORELINES OF PUGET SOUND, WA.

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EXECUTIVE SUMMARY:

Low altitude aerial surveys were conducted along King County and Vashon/Maury Island shorelines (within WRIA 9) in February of 2007. Photos were analyzed for patterns in the abundance and areal extent of large woody debris (LWD) along natural shorelines and those armored with vertical bulkheads or riprap revetments. Shoreline vegetation and upland development along armored and unarmored shorelines was also noted.

Approximately 72% of the shoreline segments we analyzed were armored with either vertical bulkheads (38%) or riprap revetments (35%). Both low-resolution analysis of 289 photos and high-resolution analysis of a subset of 16 photos revealed that unarmored, natural shorelines appear to accumulate the most LWD. We found significantly lower abundance of large and small logs along armored beaches than natural shorelines and significantly lower areal coverage of LWD where the shoreline had been reinforced with vertical bulkheads. Not surprisingly, bulkheads were often associated with development, and houses, lawns, and manicured vegetation were most common along armored shorelines. Perhaps most striking was the relationship between housing setbacks and armoring. In the photos we analyzed, every house placed within 100 ft of the shore was reinforced with vertical bulkheads or riprap revetments, while all houses that occurred along natural shorelines were set back from the beach. Trees and natural vegetation were also markedly lower along armored shorelines, and overhanging vegetation rarely occurred where shorelines were armored with riprap or bulkheads.

1.1. INTRODUCTION

Puget Sound nearshore environments, which include supratidal, intertidal, and photic subtidal zones, are some of the most productive marine habitats in the region. Marine and terrestrial systems are inextricably linked along the shoreline interface through a variety of biotic and abiotic processes including hydrogeological, detrital, and nutrient cycles. Within the nearshore environment terrestrial vegetation and geology combine with oceanic processes to produce a mosaic of unique habitats that are critical to the life-history of a variety of species (Simenstad et al. 1979; Simenstad 1983; additional technical reports can be found at www.pugetsoundnearshore.org). Many species in Puget Sound (including federally listed stocks of threatened Steelhead trout and Chinook and Chum salmon) utilize nearshore habitats at one time or another as spawning areas, nursery habitats, foraging grounds, or migratory stopovers.

The soft dissipative beaches characteristic of Puget Sound are formed through natural erosion of high bluffs in the region (also known as "feeder bluffs") primarily composed of glacial deposits. Wind derived wave action slowly transports eroded material along sedimentary drift cells towards accretion beaches (Finlayson 2006, Johannessen and MacLennan 2007). On natural beaches, large woody debris (LWD) is also transported along shorelines and typically accumulates in the high intertidal during flood tides. The wood acts to physically stabilize shoreline banks and reduce wave erosion (Williams and Thom 2001, Zelo and Shipman 2000, MacDonald et al. 1994) and may also be important complex habitats for fishes that use the material as refuge from predators while foraging on prey items residing on or around LWD (e.g., juvenile salmonids feed on amphipods and insects in high intertidal habitats; Toft et al. 2004, Sobocinski 2003, Williams and Thom 2001). Additionally, forage fish (such as sand lance and surf smelt) lay their eggs on high intertidal beaches and survival of eggs depends in part on low intra-sediment temperatures and higher moisture levels commonly found in shade beneath overhanging riparian vegetation or under wrack and woody debris on natural beaches (Pentilla 2001; Rice 2006).

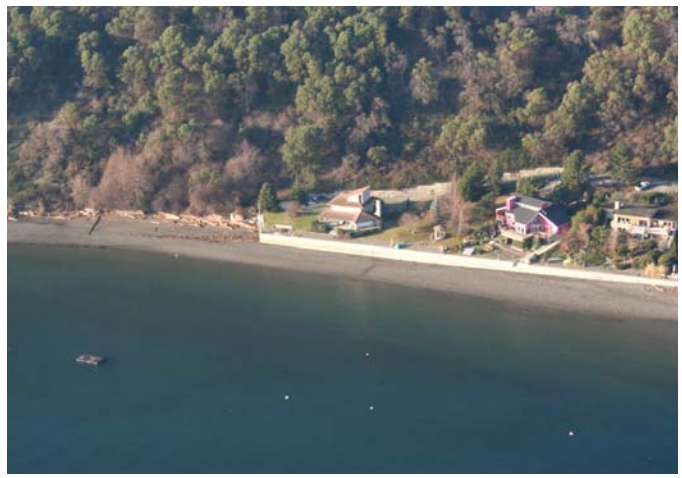

Figure 1. Image of natural (on left) and armored (right) shorelines.

Nearshore areas of Puget Sound are particularly vulnerable to human alterations. Throughout the region riprap revetments and vertical bulkheads have been installed extensively along shorelines, ostensibly to slow erosion and stabilize shoreline banks. Previous analysis of aerial photos from 2000 and 2002 revealed that nearly 63% of shorelines are armored (Higgins et al. 2005). Recent studies have also shown that the architecture of riprap revetments and vertical bulkheads greatly alters hydrodynamic processes on beaches during tidal inundation in ways that accentuate benthic scour and paradoxically cause failure of armoring structures, subsequent local bank destabilization, and erosion of adjacent beaches (Institution of Civil Engineers 1985; Silvester and Hsu 1993; Williams and Thom 2001).

Since bulkheads generally interrupt natural processes along shorelines, including bank erosion and sloughing of terrestrial vegetation (Williams and Thom 2001), they may also interfere with essential allochthonous terrestrial inputs (e.g., fine sediments, insects, detritus) to the marine ecosystem. Studies from other systems have shown that vertical bulkheads and riprap revetments can negatively impact the diversity and abundance of bivalve, fish, and crab species, by interrupting the transport of allochthonous nutrients from marsh habitats to intertidal food webs (Seitz et al. 2006). Similarly, armored beaches in Puget Sound have markedly lower densities of marine and terrestrial macroinvertebrates that are important prey items for salmonids, possibly as the result of lower abundances of LWD as well as reduction in allochthonous riparian (e.g., detritus and insects) and marine (e.g., wrack) inputs (Sobocinski 2003). Toft et al. (2004) found that unarmored sites had twice as many terrestrial prey items for Chinook salmon than armored beaches, and Romanuk (2003) similarly found that the abundance of aquatic and terrestrial arthropods in the supratidal zone of Howe Sound (BC) was markedly lower at sites with residential development than shorelines with intact vegetation. Recent comparative studies of fish assemblages along armored and natural shorelines have also revealed that intertidal riprap affects demersal fish assemblages, particularly flatfish species, which were found at significantly lower densities at riprap sites than unarmored sand beaches (Toft et al. 2007).

Increased scour rates and wave energy on armored beaches may preclude the accumulation and retention of LWD and wrack material since LWD presence is less frequent at bulkheaded versus non-bulkheaded beaches (Sobocinski 2003, Higgins et al. 2005). Residential development and clearing of shrubs and trees from backshore and slope areas is also often associated with installation of shoreline armoring (Gabriel and Terich 2005; Higgins et al. 2005) and the absence of LWD or overhanging vegetation may contribute in part to low survival of forage fish eggs along armored shorelines in Puget Sound (Martin and Swiderski 2001, Penttila 2001, Rice 2006).

Despite observations of less LWD along armored beaches (Sobocinski 2003, Higgins et al. 2005), no studies to date have specifically explored differences in the number of logs or the area occupied by LWD between natural shorelines and shorelines armored with vertical bulkheads or riprap revetments. Structurally, riprap revetments may differ from both vertical bulkheads and natural shorelines and may differentially impact LWD accumulation on shorelines. The goal of the present study was to explore large-scale patterns in the abundance of LWD across a range of natural and armored beaches in Water Resource Inventory Area (WRIA) 9 in Puget Sound, WA, in order to determine if shoreline armoring affects LWD distribution.

2. MATERIALS AND METHODS

2.1. Data Collection

Aerial photographs were collected during low altitude surveys of nearshore beaches in WRIA 9 on December 29, 2006 (Fig. 2). WRIA 9 includes the Green/ Duwamish and Central Puget Sound Watershed, and this study focused on over 141 miles of shoreline (Higgins et al. 2005) along Seattle, Burien, Normandy Park, Des Moines, Federal Way, and also Vashon, and Maury Islands. Oblique photographs were taken at 1500 ft using a high-resolution handheld digital SLR camera. Spatial information (latitude and longitude) was collected with a handheld GPS (Garmin Map 60C). Photos were post-processed using GIS software and analyzed to estimate the abundance of LWD and collect corresponding information on upland characteristics. A subsequent survey was also conducted on February 12, 2007 to collect ortho-like photos for GIS analyses; these analyses are ongoing and will not be described in this report.

Figure 2. WRIA 9 study area (yellow). Surveys sampled shorelines of Seattle, Burien, Normandy Park, Des Moines, Federal Way, as well as Vashon and Maury Islands.

2.2. Broad-Scale Analysis

In order to collect broad-scale information on patterns of LWD distribution and upland characteristics, 289 individual photos were coarsely analyzed for presence of natural shoreline ("natural"), riprap revetments or vertical bulkheads ("armored"), or a mix of these characteristics ("mixed natural"). For each photo we noted upland characteristics (trees, shrubs, or grass), qualitative LWD abundance (none, low, medium, high), and the presence of houses, roads, and vegetation overhanging the upper intertidal zone ("overhanging trees").

2.3. High Resolution Analysis

A subset of sixteen photographs were randomly selected for more detailed analysis of variation in patterns of the number of logs, area covered by LWD, and other upland characteristics across a range of shorelines with various types of shoreline armoring. In order to allow for within photo comparisons, only high-resolution photos were selected that had at least two of three types of armoring along shorelines in the photo; vertical bulkheads ("bulkhead"), riprap revetments ("riprap"), or no armoring ("natural").

For each photograph, standardized values for the total number of logs per shoreline type ($\hat{N}_a$) were calculated as:

$$\hat{N}_a = \frac{\sum N_{ai}}{\sum L_{ai}}$$

where N_{ai} is total number of logs counted along each shoreline segment (i) with a shoreline type (a) and L_{ai} is the total length in pixels of the shoreline segment (i) with a shoreline type (a; Fig. 3). Similarly, standardized values for the area occupied by LWD ($\hat{A}_a$) was calculated as:

$$\hat{A}_a = \frac{\sum A_{ai}}{\sum L_{ai}}$$

where A_{ai} is total number of logs counted along each shoreline segment (i) with a shoreline type (a) and L_{ai} is the total length in pixels of the shoreline segment (i) with a shoreline type (a). Logs were also characterized as small or large and their position relative to the shoreline was noted (parallel, at an angle, or perpendicular to the shore). In addition, the following upland characteristics were also recorded; the number and placement of houses relative to the shoreline ("set back" or "on shore"), the presence of lawns ("grass"), and natural or landscaped vegetation. Data were square- root transformed to meet model assumptions of normality and analyzed with a type 2, one-way ANOVA (each photo was treated as a replicate). Additionally, Tukey's HSD post-hoc tests were used to conduct pairwise comparisons (Zar 1999).

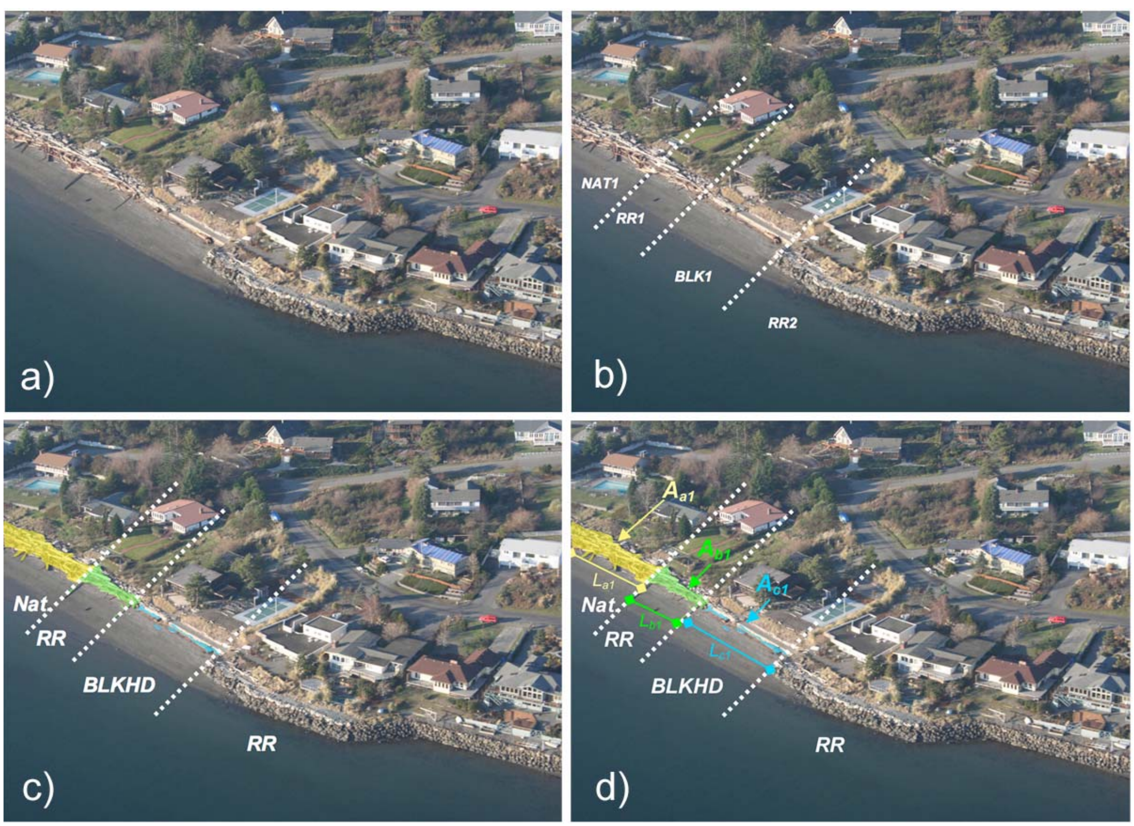

Figure 3. High resolution analysis methodology; a) photo is imported into ARC GIS, b) the visible shoreline is divided into discrete shoreline segments based on changes in shoreline type (natural, riprap revetments, vertical bulkheads), c) polygons are created that encompass the beach area covered by LWD, d) the segment length and log area (pixels and square pixels respectively) is calculated for each segment within the photograph.

3. RESULTS:

3.1 Broad Scale Analysis

Of the 289 photos we evaluated, 70% contained shorelines with either riprap revetments or vertical bulkheads. Natural features including abundance of LWD, nearshore vegetation, and overhanging trees also varied markedly between photos characterized by natural or armored shorelines. LWD abundance indices were greatest in photos with natural shorelines indicating that LWD is most abundant on natural shorelines and least abundant on armored shorelines (Fig. 4). Overhanging

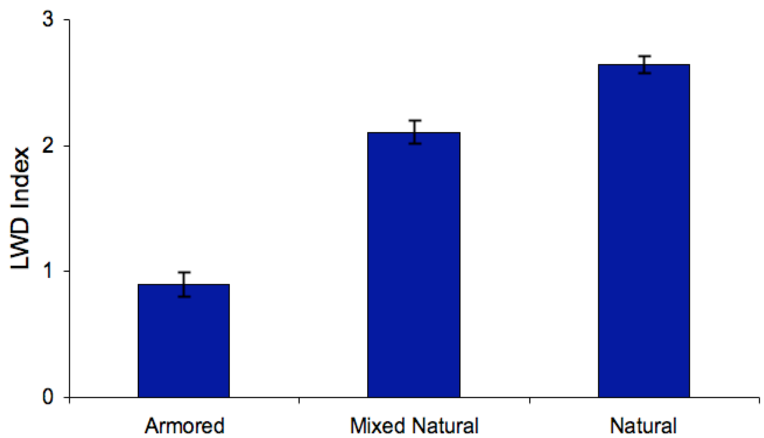

Figure 4. Mean abundance indices (Low=1, Med=2, High=3) of large woody debris (LWD) in photos with shorelines characterized by riprap revetments or vertical bulkheads (Armored), natural and armored shorelines (Mixed Natural), and unarmored shorelines (natural). Error bars represent standard error of the mean.

vegetation was most frequently observed in photos characterized by natural shorelines and rarely observed in photos where shorelines where completely armored (Fig. 5). Patterns in upland characteristics were strongly correlated with shoreline armoring. More than 60% of photos characterized by unarmored shorelines were dominated by trees and shrubs (Fig. 6, 7). In contrast, less than 5% of photos with extensive armoring were dominated by trees and shrubs, in these photos most upland areas were dominated by lawns ("grass") and semi-manicured landscapes (Fig. 6, 7).

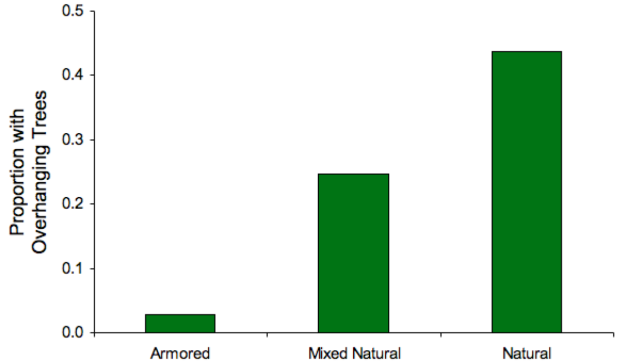

Figure 5. Proportion of all photographs with shorelines characterized by riprap revetments or vertical bulkheads ("armored"), natural and armored shorelines ("mixed natural"), and unarmored shorelines ("natural") that contained trees overhanging the upper intertidal zone.

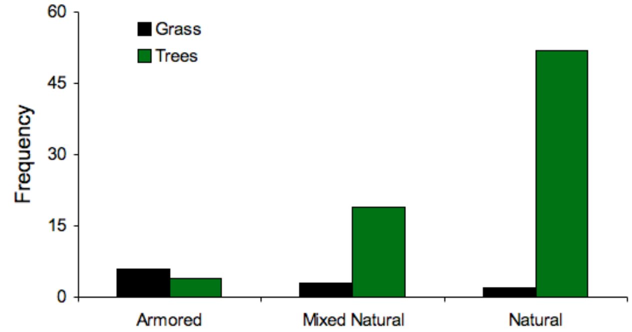

Figure 6. Frequency of photos with shorelines characterized by riprap revetments or vertical bulkheads ("armored"), mixed natural and armored ("mixed natural"), and unarmored shorelines ("natural") where upland areas were dominated by trees or lawns ("grass").

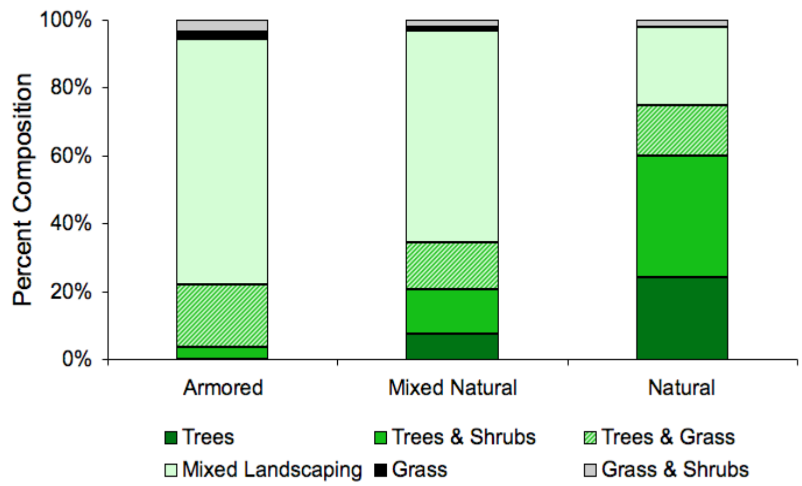

Figure 7. Percent composition of upland areas for photographs where the predominate shoreline type was riprap revetment or vertical bulkhead ("armored"), armored and natural shorelines ("mixed natural"), or unarmored shorelines ("natural").

3.2 High Resolution Analysis

Of the 16 individual photos analyzed, 12 had stretches of natural shoreline, 11 had shorelines modified by riprap revetments, and 14 had shorelines armored with

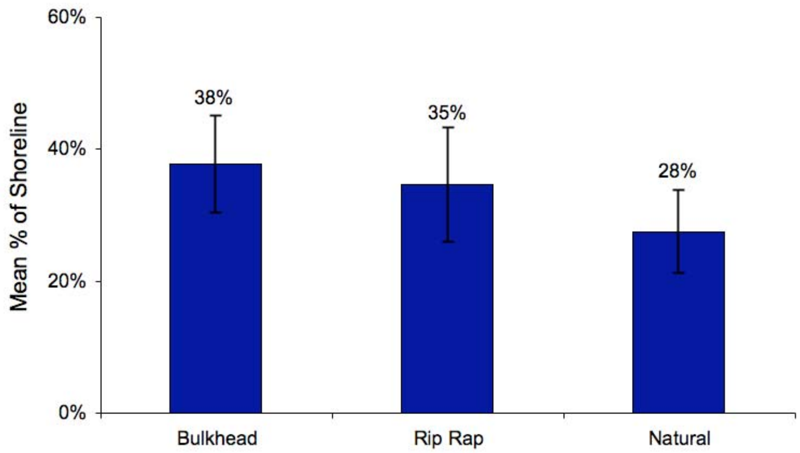

Figure 8. Percent of total shoreline measured in the 16 selected WRIA 9 photos taken December 2006 that were characterized by vertical bulkheads ("bulkhead"), riprap revetments ("riprap"), or unarmored shorelines ("natural"). Error bars represent the standard error of the mean.

vertical bulkheads. More than 70% of shorelines were equally armored with riprap revetments or vertical bulkheads and, of the shorelines we measured, only 28% were unaltered (Fig. 8). Logs were significantly more abundant on unarmored shorelines ($F_{2,34} = 12.9$, $P < 0.001$) and least abundant on beaches with vertical bulkheads (Fig. 9).

Patterns in log position relative to the shoreline were only slightly influenced by shoreline armoring; although logs were most often positioned at oblique angles on bulkheaded shores (43%), on riprap-armored and natural shorelines most logs were positioned parallel to the shoreline (57-65%), followed by logs at oblique angles. Only 8-12 % of observed logs were perpendicular to the shore (Fig. 9). Both small and large logs were significantly more abundant on unarmored shorelines ($F_{2,34} = 12.0, P < 0.001$, and $F_{2,34} = 12.9, P < 0.001$ respectively; Fig. 10). Small logs composed the majority of LWD on beaches and accounted for 70 – 78% of logs at each shoreline type; large logs were proportionately more abundant on unarmored shorelines than bulkheaded or riprap armored shores (Fig. 10). Lastly, the area occupied by LWD was significantly higher on natural shorelines than armored shorelines ($F_{2,34} = 5.3$, $P=0.01$), and was most variable along shorelines with vertical bulkheads (Fig. 11).

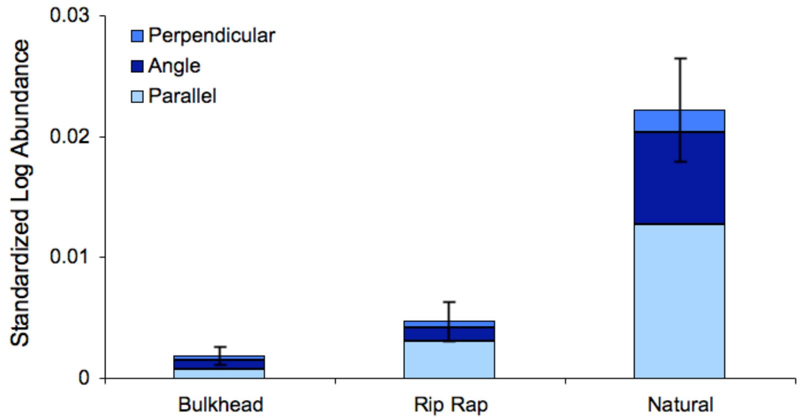

Figure 9. Mean standardized log abundance (logs per segment length) of shorelines characterized by vertical bulkheads ("bulkhead"), riprap revetments ("riprap"), or unarmored shorelines ("natural"); mean abundances are shown for logs positioned perpendicular to the shoreline (med blue), at an angle to the shoreline (dark blue), or parallel to the shoreline (light blue). Error bars represent the standard error of total mean abundance. Data are from analysis of 16 selected WRIA 9 photos taken December 2006.

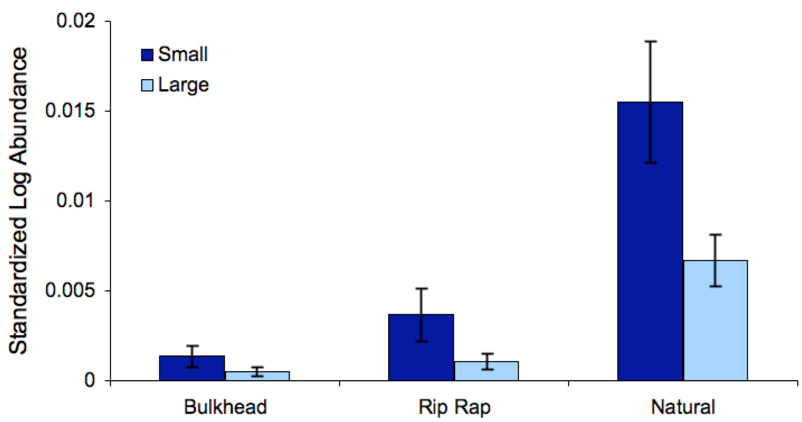

Figure 10. Mean standardized log abundance (logs per segment length) of small (blue) and large (light blue) logs observed along shorelines characterized by vertical bulkheads ("bulkhead"), riprap revetments ("riprap"), or unarmored shorelines ("natural"). Error bars represent the standard error of the mean. Data are from analysis of 16 selected WRIA 9 photos taken December 2006.

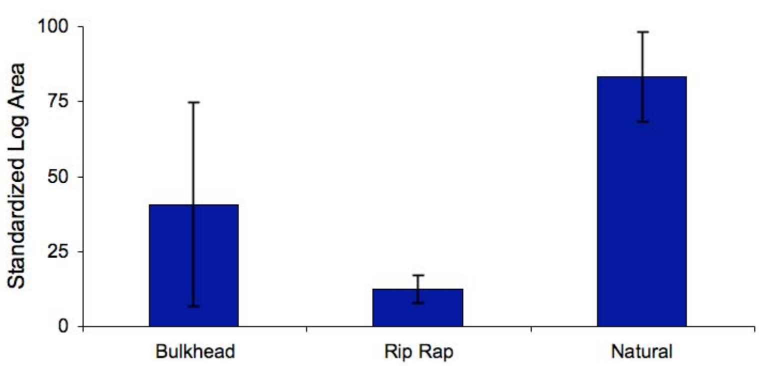

Figure 11. Mean LWD area standardized by shoreline segment length along shorelines characterized by vertical bulkheads ("bulkhead"), riprap revetments ("riprap"), or unarmored shorelines ("natural"). Error bars represent the standard error of the mean. Data are from analysis of 16 selected WRIA 9 photos taken December 2006.

Every shoreline segment armored with riprap had at least one house upland from or adjacent to the shore, as did 96% of shoreline segments armored with vertical bulkheads and 58% of unaltered shoreline segments. The majority of residential houses and buildings were observed along armored shorelines, with only 19% of houses observed along natural shorelines (Figure 12). In addition, every house observed along natural unarmored shorelines was set back from the shore; houses that occurred in close proximity to the shore always had vertical bulkheads or riprap revetments.

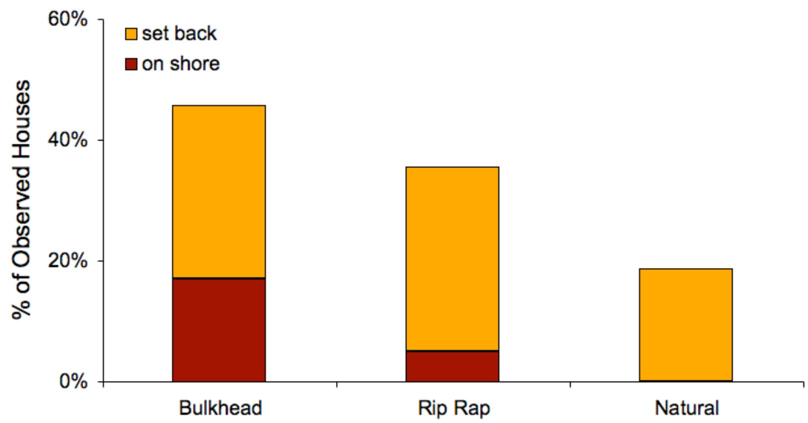

Figure 12. Percentage of all observed houses either directly adjacent to the shoreline ("on shore"; red) or located in the upland behind the shoreline ("set back"; orange) that occurred along shorelines characterized by vertical bulkheads ("bulkhead"), riprap revetments ("riprap"), or unarmored shorelines ("natural"). Data are from analysis of 16 selected WRIA 9 photos taken December 2006.

This pattern may also have contributed to distinct differences in upland characteristics between armored and unarmored shorelines. In general, features associated with residential landscaping including lawns ("grass"), removed trees, and landscaped vegetation, were most common along armored shorelines (Fig. 13). Not surprisingly, natural upland vegetation was highest on shorelines that had no armoring; however, numerous upland areas along armored shorelines also supported natural vegetation (Fig. 13).

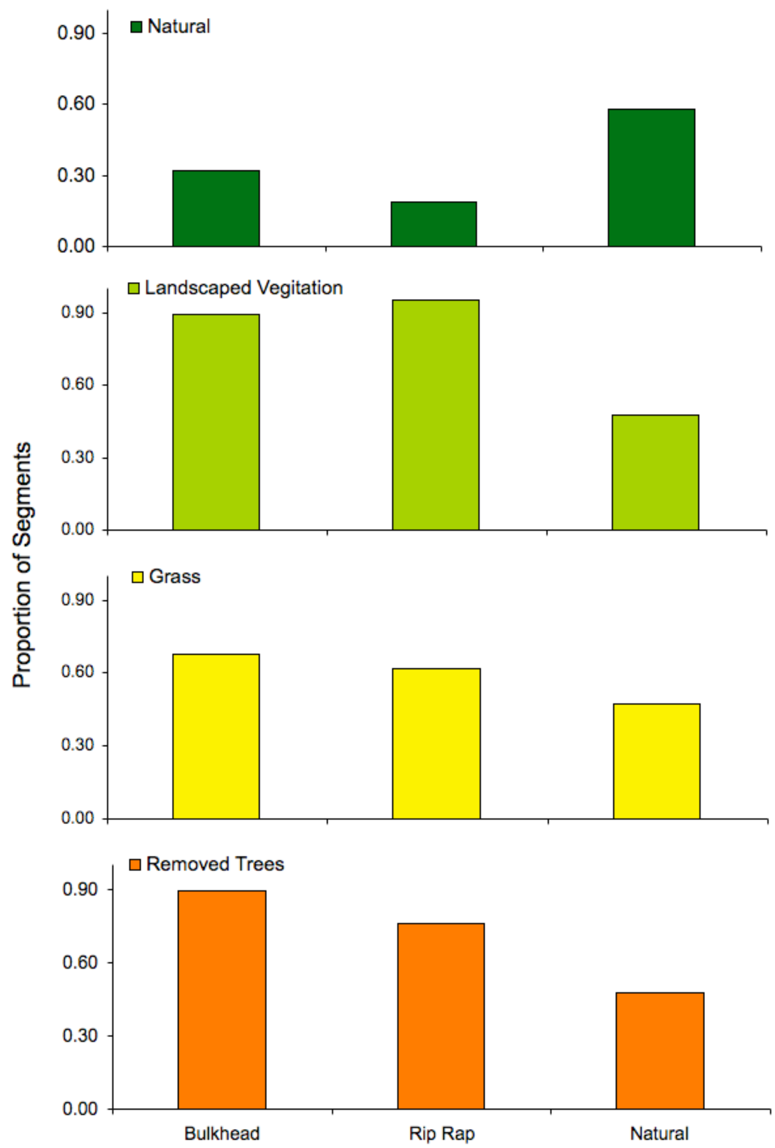

Figure 13. Proportion of shoreline segments characterized by vertical bulkheads ("bulkhead"), riprap revetments ("riprap"), or unarmored shorelines ("natural") where upland areas had natural vegetation (dark green), landscaped vegetation (light green), lawns or grass (yellow), and removed trees (orange). Data are from analysis of 16 selected WRIA 9 photos taken December 2006.

4. DISCUSSION:

The results of this study demonstrate that like other sheltered coastlines, rivers, and streams, shoreline armoring in Puget Sound is associated with the loss of riparian vegetation and lower abundances of large woody debris (LWD) in nearshore areas (Schmetterling 2001, Benoit 2007, Brauns and Garcia 2007). Nearly three-quarters (72%) of the shoreline segments we analyzed were armored with vertical bulkheads (38%) or riprap revetments (35%). The results of this study are similar to those of Higgins et al. (2005) who found that 63% of shorelines in WRIA 9 were armored in 2002 and that the presence of LWD was more common along natural shorelines. Gabriel and Terich (2005) also found that 72% of shorelines in South Puget Sound were armored by 1998 (a 5- to 20-fold increase from 1953). Although site-specific factors (e.g., direction of exposure, scour rates, along-shore drift, proximity to river mouths) appear to influence local patterns of accumulation of LWD, we generally found significantly lower abundances of both large and small logs along armored beaches than natural shorelines, and significantly lower areal coverage of LWD where the shoreline had been reinforced with vertical bulkheads. These results corroborate previous observations of lower LWD presence along armored shorelines (Higgins et al. 2005, Sobosinki 2003, Toft 2004) and indicate that shoreline armoring has negative impacts on critical processes of LWD recruitment and retention along Puget Sound shorelines.

Similar to Higgins et al. (2005) and Gabriel and Terich (2005), we found that shoreline armoring was often associated with development; houses, lawns, and manicured vegetation were most common along armored shorelines. Moreover, we observed a relationship between housing setbacks and armoring. In the photos we analyzed every house placed within 100 ft of the shore was reinforced with vertical bulkheads or riprap revetments; all houses that occurred along natural shorelines were set back from the beach. Trees and natural vegetation occurred less frequently along armored shorelines, and overhanging vegetation rarely occurred where shorelines were armored with riprap or bulkheads. Gabriel and Terich (2005) similarly analyzed upland vegetation and placement of houses on shorelines in South Puget Sound and found that 78-87 % of upland vegetation was residential lawn or garden.

Despite widespread structural alteration of soft-sediment shorelines throughout Puget Sound, only a handful of studies have examined how armoring alters important features such as accumulation of large woody debris (LWD) along Puget Sound shorelines. Although there is some disagreement about the mechanisms through which armoring affects physical processes, most authors to date agree that armoring can have the following cumulative effects: 1) interruption of terrestrial sediment inputs, which in combination with accelerated longshore transport of beach sediments can result in erosion of “downstream” unarmored shorelines; and 2) accentuation of wave energy that increases scour, reduces sediment accretion at the toe of the artificial structure, increase beach slope, reduces intertidal area, reduces LWD and marine wrack recruitment, and winnows away fine sediments (silt, clay, sand, and small gravel) leaving behind large gravel and bedrock (Silvester and Hsu 1993; MacDonald et al. 1994, Terich et al. 1994).

These physical changes have both direct and indirect consequences for intertidal and nearshore biological communities. In the case where intertidal soft sediment habitats are replaced by riprap or vertical bulkheads, there is generally a shift from soft bottom, demersal and infaunal species to fouling organisms that typically occupy hardened structures or rocky marine environments (e.g., Cheney et al. 1994). Cumulative physical changes to microhabitat features such as sediment grain size, wrack and LWD accumulation, and tidal elevation can result in shifts in associated biological assemblages from those typical of fine sediments to those of cobble and mixed sediments. Shoreline armoring can also affect the accumulation of organic matter (Macdonald et al. 1994, Williams et al. 2001, Rice 2006), which provides allochthonous nutrient subsidies to intertidal areas and partially fuels intertidal food webs. In addition, the loss of overhanging nearshore vegetation associated with shoreline armoring appears to reduce terrestrial allochthonous subsidies such as terrestrial detritus or terrestrial insects that are important prey items for juvenile salmonids and other fishes. Loss of overhanging vegetation may also intensify the effects of solar radiation on exposed beaches, leading to increased surface water temperatures during high tides and desiccation and reduction of intra-sediment moisture of high intertidal beaches during low tides (Rice 2006). All of these conditions may be further degraded by the reduction in LWD along armored beaches; LWD may engineer supratidal habitats through increased retention of marine and terrestrial detritus, providing microhabitats for fish at high tide and physical refuge for important macroinvertebrate during low tide (Williams and Thom 2001).

Yet despite empirical evidence that shoreline armoring negatively impacts nearshore ecosystems, structural reinforcement of shoreline properties continues at an increasing rate. Removal of shoreline vegetation and installation of riprap revetments or vertical bulkheads have been identified by numerous sources as among the most severe and widespread disturbances to Puget Sound (Shipman and Canning 1993; Williams and Thom 2001). In part this may be the result of discrepancies between the perceived protection of armoring (resulting from short-term immediate erosion control) versus actual negative impacts that can take years to materialize. Gabriel and Terich (2005) found that 65% of landowners installed shoreline armoring to “protect” backshore uses and properties from perceived risk of erosion or damage. This is in direct contrast to empirical investigations showing increased sediment transport and scour along armored shorelines that lead to eventual failure of armoring structures; “failure by toe-scour is probably one of the most common causes of failure for vertical or near vertical walls” (Institution of Civil Engineers 1985; Silvester and Hsu 1993). Furthermore, cumulative effects of shoreline modifications may be disproportionate to small-scale, site-specific impacts making it difficult to estimate the comprehensive influence of shoreline armoring on nearshore and marine communities and habitats. While there are legislative mandates (e.g., Engrossed Senate Bill 6128; Gabriel and Terich 2005) to consider structural and nonstructural methods of shoreline erosion control, little empirical evidence specific to Puget

Sound exists that can help inform alternative options (but see Gerstel and Brown 2006). As a result, permits continue to be issued to private landowners for bulkheads and riprap revetments, despite a lack of evidence that such armoring will have the desired effect at a specific site. Additional studies are needed that focus on the large-scale mechanistic impact of shoreline modifications as well as reciprocal effects on subsequent biological communities. In light of increasing anthropogenic pressure in the region, such information is vital for shoreline management decisions predicated on sound science and aimed at long-term sustainability of the Puget Sound ecosystem.

Acknowledgments

We would like to thank Pat Pressentin for intellectual input on project design and analysis as well as Miles Logsdon, Daniel Schwartz, Robin Clark, and P. Sean McDonald for assistance in conducting the aerial surveys, collecting data, and analyzing survey results. The report was greatly improved with comments from Julia Parrish and P. Sean McDonald. Funding for the project was generously provided through a King County Conservation District grant.

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