Final Report

Shoreline Restoration Monitoring in Puget Sound
Grant Number PC-00J907-01

March, 2019

Prepared by:
Hannah Faulkner
Washington Department of Fish and Wildlife

Prepared for:
Puget Sound Marine and Nearshore Grant Program
Washington Department of Fish and Wildlife
Washington Department of Natural Resources

Publication Information

This project has been funded wholly or in part by the United States Environmental Protection Agency (EPA) National Estuary Program (NEP) under an assistance agreement PC-00J90701 to the Washington State Department of Fish and Wildlife (WDFW). The contents of this documents do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Contact Information

Project Manager:
Hannah Faulkner, Nearshore Biologist
Washington Department of Fish and Wildlife
1111 Washington St SE
Olympia, WA 98501
email: hannah.faulkner@dfw.wa.gov
phone: 360-902-2409

Division Lead:
Timothy Quinn, Chief Habitat Scientist
Washington Department of Fish and Wildlife
1111 Washington St SE
Olympia, WA 98501
email: timothy.quinn@dfw.wa.gov
phone: 360-902-2414

Citation

Faulkner, H.F. 2019. Shoreline Restoration Monitoring in Puget Sound: Final Report. Prepared for the Puget Sound Marine and Nearshore Grant Program. Prepared by Washington Department of Fish and Wildlife, Olympia, WA.

Acknowledgements

Phillip Dionne of Washington Department of Fish and Wildlife (WDFW) was monumental in the early development and implementation of monitoring plan. Assistance in the monitoring plan, survey design, sample collection and data management was generously provided by Jason Toft and Megan Dethier of the University of Washington (UW) (School of Aquatic and Fishery Sciences (SAFS)). Data collection and sample processing as part of this project could not have been without the assistance of the following individuals and organizations: Lisa Kaufman and Jason Morgan of Northwest Straits Foundation (and citizen science volunteers therein); Cheryl Lowe of Jefferson County MRC and WSU Extension office (and citizen science volunteers therein); Bob Oxborrow of UW (SAFS); Brian Combs of South Puget Sound Salmon Enhancement Group (SPSSEG); Jane Atha, Patrick Biondo, Erin Dilworth, Kate Olson, and Brandon Osterlund of WDFW, and; WDFW Washington Conservation Corps volunteers. I would also like to thank Kirk Krueger and Kevin Samson for their significant contribution to data management, processing and analysis.

Many thanks to the myriad of project landowners for their commitment to restoration, with a special thanks to private landowners and their public support. Finally I would like to recognize the greater restoration community (and the project developers, managers, and funding sources) for their dedication to Puget Sound nearshore resources and ecosystem health.

Contents

Puget Sound Marine and Nearshore Grant Program

Shoreline Restoration Monitoring in Puget Sound

Habitat Program – Science Division (WDFW)

Draft Final Report

1. Executive Summary

Washington State's Puget Sound Basin provides a breadth of important ecological, cultural and economic resources. The nearshore ecosystems, on which species and society rely, are intrinsically dynamic; continuously changed by a system of physical, geochemical and biotic processes (Simenstad et al. 2006). Humans are a significant force of this change, and the Puget Sound, much like other large estuarine systems, is in decline (Quinn 2010). Because the nearshore represents a critical interface between terrestrial, freshwater, estuarine and marine environments, alterations to this ecosystem have great implications to Puget Sound (Fresh et al. 2011).

Particularly, conflicts arise in the management of our naturally eroding shorelines to balance the geomorphic processes which build our beaches and both the perceived and real need to protect coastal properties (Shipman et al. 2010). Shoreline armor, in the form of hard vertical barriers such as bulkheads, seawalls, and revetments, is the most common shoreline modification in Puget Sound, intended to prevent shoreline erosion, reduce coastal flooding and protect upland development (e.g., roads, railways, homes, and agriculture). Currently, nearly a third of Puget Sound's shorelines have been armored, and construction of new armor continues (MacLennan et al. 2017). The extent and continued construction of new shoreline armoring in Puget Sound is recognized as a significant issue in shoreline management and nearshore ecosystem health (Shipman et al. 2010).

Awareness has increased concerning the critical role nearshore systems play in maintaining essential ecological functions and valued ecosystem services in Puget Sound (Shipman 2010, Williams and Thom 2001), and the adverse impacts shoreline armor has on these systems (Dethier et al. 2016, Schlenger et al. 2011). Similarly, nearshore restoration and shoreline armor removal has been identified as a potential option in repairing degraded systems (Fresh et al. 2004, Lee et al. 2018, and Simenstad et al. 2006). As advised by Brandon et al. (2013), and the restoration community, successful (restoration) projects in Puget Sound command not only the ability to alter a system but also the ability to determine outcome and effectiveness of actions through systematic monitoring.

We developed and implemented a restoration monitoring plan to assess the effectiveness of shoreline monitoring processes, and describe the effect of armor removal on nearshore condition throughout Puget Sound. Our monitoring plan was strategic in providing high-quality data to determine success, condition and effect of shoreline monitoring and restoration action, because our study design included the following key components:

(1) baseline surveys at study sites prior to armor removal and restoration;

(2) reference surveys for each study site adjacent to, but outside of the restoration footprint;
(3) spatial replication, both within a study site and throughout a broader regional framework; and
(4) extended temporal framework, including up to four years of data collection.

We observed that at sites where shoreline armor was removed, beaches were wider, had greater elevations at upper beach toe (m above MLLW) and exhibited lesser waterward encroachment of beach toe on MHHW compared to pre-restoration conditions. We also found that restored beaches accumulated greater amount and total width of marine derived logs. However, patterns of restoration effect on change in beach slope, riparian shade and wrack cover were less apparent and our data warrant further investigation.

Observations of regional variation in shoreline condition indicated potential for a broader effect of spatial setting on measured nearshore structure; where, for example, measures of physical beach condition (e.g., elevation at beach toe, relative encroachment) different among north, central and south survey sites. Further investigation into broader cumulative or threshold effects with regard to shoreline armor and nearshore restoration may be significant to understanding long-term ecosystem effects.

We are confident this study contributes to a better understanding of Puget Sound nearshore ecosystems, including the multiplicity of restoration effects on shoreline structure and the success and function of monitoring programs to capture nearshore condition. Outcomes of this study provide the nearshore and restoration communities with information to test ecological assumptions and predicted outcomes of restoration, reduce uncertainties and improve effectiveness of restoration actions, and support a need for continued investigation and empirical study into the multi-scale effects and long-term implications of shoreline armor and nearshore restoration in Puget Sound.

2. Background

Development within the Puget Sound Basin, much like other coastal areas of the United States, has been extensive (Quinn 2010, Thom et al. 1994). Data from the Puget Sound Regional Council (2010) showed that populations in Washington State's coastal regions has grown by nearly 3 million over the last half century and are expected to exceed 5 million by 2025 (as cited in Quinn 2010). As a result, substantial development has occurred along Washington's shorelines (Thom et al. 1994); often constructed too close to Puget Sound's naturally eroding coastal environment (MacDonald et al. 1994). To protect these properties, erosion control structures, such as artificial hard armoring of natural shorelines, have been constructed (Thom et al. 1994). Currently, a third of Puget Sound's shorelines have been armored, exceeding 60% along areas of heaviest urbanization (i.e. South-Central Puget Sound) (MacLennan et al. 2017. However, alterations to the shoreline can have negative implications for the structure, processes and function that create and maintain our shorelines and beaches and support the array of species, goods and services that Puget Sound provides (Thom et al. 1994).

It has been increasingly recognized in Washington State that the Puget Sound ecosystem is in decline (Quinn 2010), and efforts must be made to protect and restore functional structure and processes for both species and society alike. The goal of nearshore restoration in Puget Sound is to maintain or re-instate natural processes of a healthy ecosystem which provide and perpetuate shoreline structure and ecological function. A healthy Puget Sound ecosystem means one that can sustain the array of species, support social health and welfare, and sustain greater environmental pressures (e.g., climate change) into the future.

The Puget Sound Marine and Nearshore Grant Program (PSMNGP) is a partnership program with the Washington Departments of Fish and Wildlife (WDFW) and Natural Resources (WDNR) that funds actions to advance recovery in Puget Sound (WDFW n.d.). The PSMNGP invests in a variety of projects to implement or inform the protection and restoration of Puget Sound's threatened marine and nearshore habitats. In 2015, WDFW received funding through the PSMNGP to develop and implement a shoreline restoration monitoring plan to quantify the effects armor removal and restoration on the nearshore environment. Our project goal was to evaluate a set physical and biological parameters that define nearshore form and function in response to shoreline armor removal which: (a) captured conditions both before and after restoration; (b) utilized common and replicable sampling methods to support cohesive and comparable shoreline data, and; (c) set the stage for long-term monitoring, beyond the timeframe of our study.

2.1 Reporting Structure

Efforts of our research and information in this final report, and previously submitted reports, describe the impacts of shoreline armoring on the nearshore environment and the effectiveness of armor removal in restoring historic conditions. From 2015 to 2018, surveys were completed at a total of 14 armor removal and restoration sites throughout Puget Sound. We have provided PSMNGP with interim reports detailing individual restoration project parameters, status and preliminary monitoring data over the course of our project timeframe. This final document will not reiterate specific restoration project information, and additional details can be found in previously submitted progress reports and references therein (Faulkner 2017 and 2018). Due to the dynamic nature of shoreline restoration design, planning and implementation, not all restoration sites were surveyed every year and stage of restoration at time of survey varied annually by project. Further, not all restoration sites surveyed prior to armor removal were implemented within our monitoring timeframe; and at five of 14 sites, restoration was not accomplished in time to complete paired surveys following armor removal. Therefore, analysis of before-after change included in this report covers only those nine project where restoration implementation was completed within our monitoring timeframe.

3. Introduction

The Puget Sound is a large fjordal estuary in the northwest corner of Washington State, USA, and makes up the southern portion of the greater Salish Sea (Simenstad et al. 2011). The Salish Sea, including Puget Sound, is a greater network of inland marine waters that span international boundaries between Canada and the United States; spanning British Columbia and Washington State and connecting to the Pacific Ocean via the Strait of Juan de Fuca (Shipman 2010). Puget Sound is one of the largest estuaries in the United States, with more than 8,000 square kilometers of marine waters and estuarine environments and greater watershed footprint of approximately 33,000 square kilometers (Fresh et al. 2011). Large marine and estuarine systems, such as the Puget Sound, are incredibly dynamic environments that provide a range of critical structures and processes and sustain a diversity of ecosystems, habitats and species (Fresh et al. 2011). In Washington State, we rely on Puget Sound for the myriad of ecosystem functions, goods and services provided to species and society alike for the health and welfare of our communities and the resources on which we depend.

3.1 Human Use and Development

The Puget Sound basin is home to over 4 million people, or approximately 70% of Washington State's total population (Fresh et al. 2011). The area continues to bear urban growth, with expected populations to exceed 5 million by 2025 (Puget Sound Regional Council 2010 as cited in Quinn 2010). Much like other estuarine environments in the US, this continued population growth and associated human use and development has negatively impacted the health of Puget Sound (Fresh et al. 2011, Morley et al. 2011, Quinn 2010). In particular, the nearshore environment that brackets Puget Sound's shoreline, estuary and delta is subject to concentrated use and development.

Use and development of the nearshore area is wide-ranging, and varies with regard to residential, commercial, industrial and recreational demands. As a result, "many areas (in Puget Sound's nearshore) have experienced widespread, multiple, and compound changes", including, but not limited to: loss of River delta area and shoreline; elimination of small coastal embayments; modification of coastal beaches and bluffs, and; loss of tidal wetlands (Fresh et al. 2011). Loss of coastal beaches and bluffs dominates observed stressors in Puget Sound, and is characterized primarily by shoreline armor (Fresh et al. 2011). Shoreline armoring is a general term that defines the emplacement of artificial static structures meant to reduce or eliminate coastal erosion, stabilize shorelines, and support shoreline activities (e.g., coastal property, waterfront access) (Johannessen and MacLennan 2007, Shipman 2017). For the most part, shoreline armor involves the placement of hard vertical structures constructed of rock, cement or wood. While shoreline stabilization tactics may also take the form of "softer" approaches, by way of beach nourishment or vegetation planting for example, the presence of such structures in Puget Sound is minimal comparatively (Shipman 2017). For the purposes of our study, and this report, shoreline armor refers to hard artificial structures, unless otherwise noted.

Structures are most often placed parallel along the shoreline, intended to protect and improve upland property; be it stair landings, historic fill, residential homes or utility infrastructure (Shipman 2010). As of 2011, armor structures covered nearly a third of Puget Sound shorelines (Simenstad et al. 2011) and construction of new structures or replacement of historic structures has continued steadily (Carman et al. 2010). However, degree and character of shoreline armor varies locally in response to regional development and coastal landforms, where extent of armor exceeds 60% in the heavily developed South Puget Sound basin and represents less than 20% in the northern basins (Simenstad et al. 2011). While shoreline armor is effective in supporting shoreline activities, it also defines a fundamental alteration of the natural environment and can negatively impact coastal ecosystems (Shipman 2017).

3.2 General Ecology

The marine nearshore is a dynamic transition zone between terrestrial and aquatic environments. It encompasses the shoreline, beaches and tidal areas from the upper confines of coastal banks and bluffs to the lower limit[1] of the photic (i.e. lighted) zone (Simenstad et al. 2011). Thus, the Puget Sound nearshore is defined by a variety of ecosystem processes, which characterize a range of coastal structures and support a diversity of ecological functions and services to species and society alike.

An ecosystem is comprised of interacting physical, chemical and biological attributes which determine the condition and mechanisms of the system (Simenstad et al. 2006). Williams and Thom (2001) and Simenstad et al. (2011) simplified the concept of ecosystem processes, structure and function in the nearshore as follows: (a) different ecosystem processes (e.g., hydrology, sedimentology) control habitat structure, both biotic and abiotic; (b) habitat structure, in return, supports ecosystem processes, and; (c) both process and structure, separately and collectively, provide a diversity of ecological function (e.g., production, cycling, storage).

Likewise, the character and components of Puget Sound's nearshore ecosystem is not simply a function of any unique process, but a complex of influence that occur and vary over a broad range of spatial and temporal scales (Schlenger et al. 2011). Nearshore processes can be classified into three general

[1] The lower depth range is variable (depths as low as -10 to -30 m below Mean Lower Low Water (MLLW = 0 m) and depends on variety of water quality parameters (e.g., water clarity) (Williams and Thom 2001).

categories of influence: regional, broad and local (Schlenger et al. 2011, Simenstad et al. 2011). Schlenger et al. (2011) describes that:

> Large-scale *regional* influences, such as climate, wave exposure and geology, define the framework for broad physiographic processes. *Broad* physiographic influences are landscape-forming processes, such as sediment input, tidal flow, and physical disturbance, which are in turn imbedded in larger regional influences and within which local processes occur. *Local* geochemical and ecological processes vary within the landscape structure of nearshore ecosystems and are thus spatially and temporally complex. Local processes include, but are not limited to, nutrient cycling, productivity and food web dynamics.

3.2.1 Physical Processes. Physical processes are important to understanding the backdrop of environmental systems. For nearshore environments in particular, it is important to identify the geologic history, oceanographic setting and coastal processes that form and maintain a landscape (Finlayson 2006, Shipman 2010). The geology of Puget Sound has a profound influence on the present and future condition of the beach and nearshore, both in historic events and ongoing forces that shaped and continue to shape the environment (Finlayson 2006).

Puget Sound was formed by a history of glacial advances and retreats, which resulted in a complex series of deep basins, convoluted shorelines and steep coastal profiles (Finlayson 2006, Johannessen and MacLennan 2007). Overall, Puget Sound exhibits a widespread occurrence of high exposed bluffs, generally steep and narrow beaches, and a unique composition of mixed, glacially-derived, unconsolidated sediments (Finlayson 2006, MacDonald et al. 1994, Shipman 2010).

Puget Sound is considered a low-energy environment, driven predominantly by wave condition (Finlayson 2006). Due to the geographic isolation of Puget Sound from Pacific Ocean influence, wave condition is principally a function of local wind conditions (Shipman 2010). In turn, due to the mosaic of smaller water bodies and the complex configuration of shorelines, local wind conditions and wave generation are limited in large part by approach (i.e. orientation) and fetch distance[2] (MacDonald et al. 1994, Shipman 2010).

In general, Puget Sound is defined as a retreating landscape, as demonstrated by the widespread occurrence of eroding coastal bluffs and depositional beaches (Shipman 2010). Coastal bluffs are the major source of sediment to Puget Sound beaches (Johannessen and MacLennan 2007) and the erosion and reworking of shorelines build and maintain our beaches (Finlayson 2006). Still, the sediment composition, and mechanisms and rates of erosion can vary locally in response to site-specific factors (e.g., underlying geology, wave condition) (Finlayson 2006, Shipman 2010). Consequently, Puget Sound beaches are not defined by single sediment source or sink, but rather a complex of variable supply and

[2] The distance over water in which wind blows unimpeded and thus forms waves.

accumulation landforms, characterized by a surface of mobile sediments, low alongshore transport rates and multiple discrete drift cells[3] (Finlayson 2006, Shipman 2010).

3.2.2 Biological processes. Nearshore habitats take many forms, and support a variety of biotic communities (Dethier 2010, Williams and Thom 2001). Within nearshore ecosystems, the presence, distribution and functional interactions of plants and animals vary largely in response to physical conditions and processes (Dethier 2010, Thom et al. 1994). However, in Puget Sound, Dethier (1990) identified that nearshore habitats and species assemblages vary with regard to a limited set of predominant physical attributes including substrate character (i.e. type, depth or elevation) and wave energy.

Because marine nearshore habitats encompasses a continuum of upland terrestrial to aquatic subtidal areas, they can be defined by a range of (physical and biological) nearshore attributes such as submerged marine vegetation (e.g., eelgrass meadows, kelp beds), upland riparian vegetation (i.e. overhanging vegetation or lack thereof) and shoreline sediment composition (predominantly pebble, sand or mud (Dethier 2010)) (Dethier 1990, Thom et al. 1994). Previous work by Dethier (1990) provide extensive review of biological resources and ecological linkages in Puget Sound's nearshore that defined a catalogue of distinct habitat types and associated biota.

Different habitat types can vary dramatically in the productivity and diversity of associated biota (Dethier 2010). But, overall, nearshore habitats are identified as integral to the feeding, refuge and reproduction for many valued fish and wildlife species (Williams and Thom 2001). Particular species of concern in Washington State that uniquely rely on nearshore habitats for some portion of their life histories include juvenile salmon (Heerhartz and Toft 2015, Munsh et al. 2016), forage fish (Penttila 2007), invertebrate communities (Dethier et al. 2016, Heerhartz et al. 2015), estuarine birds (Lovvorn 1994 as cited in Thom et al. 1994), and marine algae and eelgrass (Thom et al. 1994).

Habitat and species benefits are not exclusive of one another, but are functionally related as energy and resources are transferred throughout the nearshore food web, and the broader marine food web. This is particularly true of many important biological resources in Puget Sound, as transient species (e.g., fish, birds, and invertebrates) may only spend a short period of their life history in a particular nearshore habitat (Thom et al. 1994).

<u>3.3 Human Impacts</u>

The Puget Sound nearshore is not a naturally static environment, but a continuously dynamic landscape of complex processes occurring over various temporal and spatial scales (Simenstad et al. 2006). Likewise, ecosystem processes by definition implicate a change in character or state of a system (Schlenger et al. 2011). Humans are a major force of change in environmental systems, and the Puget

[3] A section of shoreline that encompasses a distinct system of sediment input, transport and deposition (Cereghino et al. 2012).

Sound nearshore is no exception (i.e. Fresh et al. 2011, Schlenger et al. 2011, and Simenstad et al. 2011). Consequently, alternations or interruptions to historic conditions or natural processes can have serious implications for valued ecosystem functions (goods and services).

When a habitat is transformed, at even minor scales, function (i.e. resources) can be impacted (Fresh 1991). Williams and Thom (2001) define an impact to nearshore ecosystems as any unnatural disturbance to (physical or biological) processes or environmental condition (Williams and Thom 2001). Impacts to ecosystem structure and processes are generally considered direct or indirect. Direct impacts are often the explicit result of shoreline activity either temporarily (e.g., construction) or permanently (e.g., loss of beach habitat, removal of vegetation) (MacDonald et al. 1994, Thom et al. 1994, Williams and Thom 2001). Indirect impacts are secondary effects of the disturbance and are considered permanent in nature due to lasting alteration of processes (Williams and Thom 2001). Indirect permanent effects are expansive and include alteration of processes at and adjacent impact, such as downdrift sediment impoundment, substrate coarsening, and loss of habitat for fish (MacDonald et al. 1994, Williams and Thom 2001).

While a particular impact may appear small or uniquely insignificant in its effect, the cumulative impact of compounding changes to the nearshore must be an important consideration (Schlender et al. 2011). Cumulative impacts are the combined, incremental effects of two or more stressors which may accumulate over space and time and result in greater or unforeseen compounding effects to a system (Schlenger et al. 2011). However, the broader, cumulative effects of human activities on nearshore form and function remain lack clear documentation in Puget Sound, and further investigation is required (Dethier et al. 2016, Schlenger et al. 2011).

3.3.1 Shoreline armoring. The high value of coastal property, the widespread occurrence of eroding shorelines and the relatively mild wave environment make armoring both desirable and effective in Puget Sound (Shipman 2010). Consequently, the innate coastal processes which build and maintain our shoreline are often the same that drive hard armoring.

The impacts to nearshore processes and shoreline condition are varied, and often strongly related to the geologic processes that shape and maintain coastal shorelines and beach habitat (Shipman 2010). Likewise, Puget Sound's shorelines do not exist as a series of isolated and discrete habitats and processes (e.g., longshore sediment transport), but are rather functionally linked across the Basin (Fresh 1991), so that changes to local elements may effect broader functions in ecosystem input, production, cycling and more (Simenstad et al. 2006).

Shoreline structures, by design, are intended to modify coastal erosion and sediment processes (e.g., retain sediments that would otherwise be supplied to the nearshore system (Johannessen and MacLennan 2007)). Consequently, modification of the nearshore environment, can have serious implications to both physical and functionally-linked biological processes. Based on previous reviews of shoreline armor impacts on Puget Sound, Shipman (2010) (and references therein) generalized effects of shoreline armor and erosion control on Puget Sound's nearshore into five main categories:

(1) Loss of upper beach and backshore. Shoreline armor directly covers or reduces high tide beach area. This has negative implications for drift log accumulation (Dethier et al. 2016, Heerhartz et al. 2014), available forage fish habitat (Penttila 2007), and waterfront recreation.

(2) Aquatic-terrestrial connectivity. Shoreline armor is often placed at the interface of marine and terrestrial environments (Heerhartz et al. 2014). Thus modifying the natural transition of ecosystems and critical functions of the marine riparian (Brennan 2007, Brennan and Culverwell 2005). Studies have demonstrated a disruption in nutrient exchange (Heerhartz et al. 2014), beach wrack composition (Dethier et al. 2016, Heerhartz et al. 2014, Heerhartz et al. 2015), invertebrate communities (Lee et al. 2018, Toft et al. 2013), and riparian shade (Dethier et al. 2016) critical for temperature regulation of incubating forage fish eggs (Penttila 2001 and Rice 2006).

(3) Passive erosion. Shorelines are not static features, and the emplacement of armor does not address natural shore erosion waterward of the structure. Thus, natural landward migration is truncated by the presence of armoring and results in a narrowing of beach width, loss of upper beach and increased pressure under wave conditions (Johannessen and MacLennan 2007, Shipman 2010).

(4) Sediment delivery and transport. Sediment impoundment and modification of transport processes is one of the most significant nearshore impacts (Johannessen and MacLennan 2007, MacDonald et al. 1994). Shoreline armor stops natural erosion of bluffs, thereby reducing bluff material from entering the littoral system, decreasing overall sediment availability to the drift cell; and impeding longshore transport of sediments to adjacent shoreline properties.

(5) Altered wave action. The application of shoreline armor can increase erosion potential waterward of the structure, due to increased reflection of wave energy (MacDonald et al. 1994). This can result in local hydraulic impacts such as increased beach erosion and scour at or adjacent armor structure (Johannessen and MacLennan 2007, Shipman 2010).

(6) Implications to ecological linkages. The ecology of Puget Sound beaches is functionally linked to physical processes (e.g., substrate type and wave energy) (Dethier 2010). In general, biological consequences of shoreline armor include loss or modification of habitat (structure) and resources (MacDonald et al. 1994). In turn, altered nearshore habitat (structure, process and function) can echo greater implications to ecological functions (Williams and Thom 2001).

3.4 Nearshore Restoration and Monitoring

The adverse impacts of shoreline armoring has prompted considerable interest in restoring the condition of nearshore ecosystem process, structure and function in Puget Sound (Fresh et al. 2004). The National Research Council (1992, as cited in Williams and Thom 2001) defines restoration as the return of an ecosystem to its approximate condition prior to disturbance. For restoration in Puget Sound in particular, emphasis is placed on restoration of ecosystem processes that create and maintain the structure (and therefore function) of the nearshore, and not just the structure itself (Simenstad et al. 2006). Simenstad et al. (2006) asserts the relevance of this concept to Puget Sound because:

(1) The processes are inherent to desired ecological function(s).

(2) The longevity of restored structure and associated function alone (i.e. without restoring processes) are uncertain.

(3) The dynamic nature of ecosystems processes is underrepresented when only structure is considered.

Therefore, a better understanding of nearshore ecosystem processes (structure and function) contributes to a more comprehensive assessment of the (direct, indirect and cumulative) impacts of both shoreline armor and nearshore restoration (Williams and Thom 2001, Simenstad et al. 2006).

As described by Brandon et al. (2013), successful ecosystem restoration is defined not only by the alteration of said system to achieve desired state, but also by the determination of restoration outcome. In particular, by means of performance measurement or monitoring to evaluate the effectiveness of restoration actions to achieve desired objectives (e.g., restore structural or functional features of ecosystem) (Fresh et al. 2004, Brendan et al. 2013). Monitoring plans are intended to provide high-quality data on ecosystem process, structure and function, including how they respond to change, how well we can predict responses, and ultimately how we can use this information to support the development and success of ecosystem restoration (Fresh et al. 2004).

For the Puget Sound nearshore in particular, it is important that monitoring plans capture the various spatial and temporal scales at which ecosystem processes occur and are impacted. Particularly, with the goal of detecting armor-induced signals, be it presence or removal (i.e. restoration). For this reason, and as identified in previous reviews and studies by Dethier et al. (2016), Heerhartz et al. (2014), Shipman (2010), and Williams and Thom (2001), a successful monitoring plan should include:

(1) Baseline studies that describe existing conditions prior to improvement (i.e. restoration).

(2) Paired studies in target and reference areas to capture localized variability (e.g., armored, unarmored, restored sites).

(3) Extended monitoring timeframes and temporal replication to better define long-term and seasonal effects.

(4) Expanded monitoring framework (i.e. broad spatial scale) to capture regional variability.

(5) Comprehensive assessment of potential cumulative effects to identify implications to the nearshore ecosystem as a whole and detect potential threshold effects.

3.5 Project Goals and Objectives

Our primary project goal was to develop a detailed monitoring plan and sampling design that provided high-quality data describing Puget Sound's nearshore environment, was capable of identifying response of environmental condition to shoreline armor removal and nearshore restoration, and would be applicable and comparable over broader scales beyond the limits of our study. We intended our project to address three broad questions:

(1) Can we detect change in beach condition in response to shoreline armor removal and restoration?

(2) What do observations in beach condition tell us about potential ecosystem effects of shoreline armor removal and restoration?

(3) What do project findings tell us about how we should develop, implement and assess nearshore restoration monitoring in Puget Sound?

We anticipated that our observations of beach condition would align with previous studies and documents describing armor-associated impacts in Puget Sound (e.g., Dethier et al. 2016, Heerhartz et al. 2014, Toft et al. 2013, William and Thom 2001), such that armor removal and restoration may reestablish or restore the following ecosystem processes and associated structure:

(1) increased accumulation and retention of beach wrack and large woody debris;
(2) modification of beach profile and sediment dynamics, such as
    a. increase in beach toe elevation and width, and
    b. reintroduction of finer sediments; and
(3) improved backshore vegetation, such as
    a. increased marine riparian cover.

Field measures of predicted effects were intended as a first step to identify potential spatial and temporal patterns in nearshore response. Our critical project intent was not to test for the significant relationship of measured effects to structural and functional response. But rather, to address the quality and development of study plan, sampling scheme and survey method to document and describe conditions of shoreline response to armor removal and restoration across varying spatial and temporal scales. Data and observations are intended to identify potential patterns which inform understanding of nearshore ecosystem structure, inform effective monitoring efforts, and support successful restoration actions across Puget Sound.

4. Methods

4.1 Study Design

We developed an observational study to describe nearshore habitat conditions and the response of ecosystem structure to shoreline armor removal and restoration. Specifically, we designed our study to capture change in beach condition(s): (a) before and after armor removal; (b) across both spatial and temporal replicates, and; (c) with repeated measures at paired treatment (i.e. restoration) and reference locations (i.e. outside of restoration footprint).

Within the constraints of our monitoring framework, we focused survey efforts to address (predominantly physical) conditions and process that create and maintain nearshore beach habitats over a shorter time-frame (i.e. years). We sought to describe conditions of the structural beach environment at various discrete sites throughout Puget Sound to identify changes in various local and process-scale features in response to shoreline armor removal and nearshore restoration. Consequently, we acknowledge that the Puget Sound nearshore is a complex structure of individual ecosystem states represented across multiple scales of time and space (Simenstad et al. 2006) and that our monitoring efforts only address ecosystem processes in part.

One of our key objectives was to ensure methods and data from this study could be used in broader applications outside the temporal and organizational constraints of our project. Therefore, we consulted existing survey method and sampling protocol within established shoreline monitoring operations in Puget Sound. In particular, we referred to the Shoreline Monitoring Toolbox; a resource developed by University of Washington, Washington Sea Grant and Puget Sound Ecosystem Monitoring Program to encourage standardization of survey methods to monitor a selection of physical and biological parameters in Puget Sound (WSG n.d.).

4.1.1 Study sites. Study sites were chosen individually based on project phase. We sought restoration projects within the final design stages; where project implementation had not yet begun, but was set for execution within our monitoring timeframe. Consequently, location of study sites was opportunistic and individual sites varied in shoreline condition (i.e. physical and biological structure) and project design (e.g., armor dimensions, restoration design, implementation footprint). We established study sites at 14 planned locations of shoreline armor removal and restoration throughout Puget Sound, WA (Figure 4.1). Information for each restoration project is provided in the Appendix.

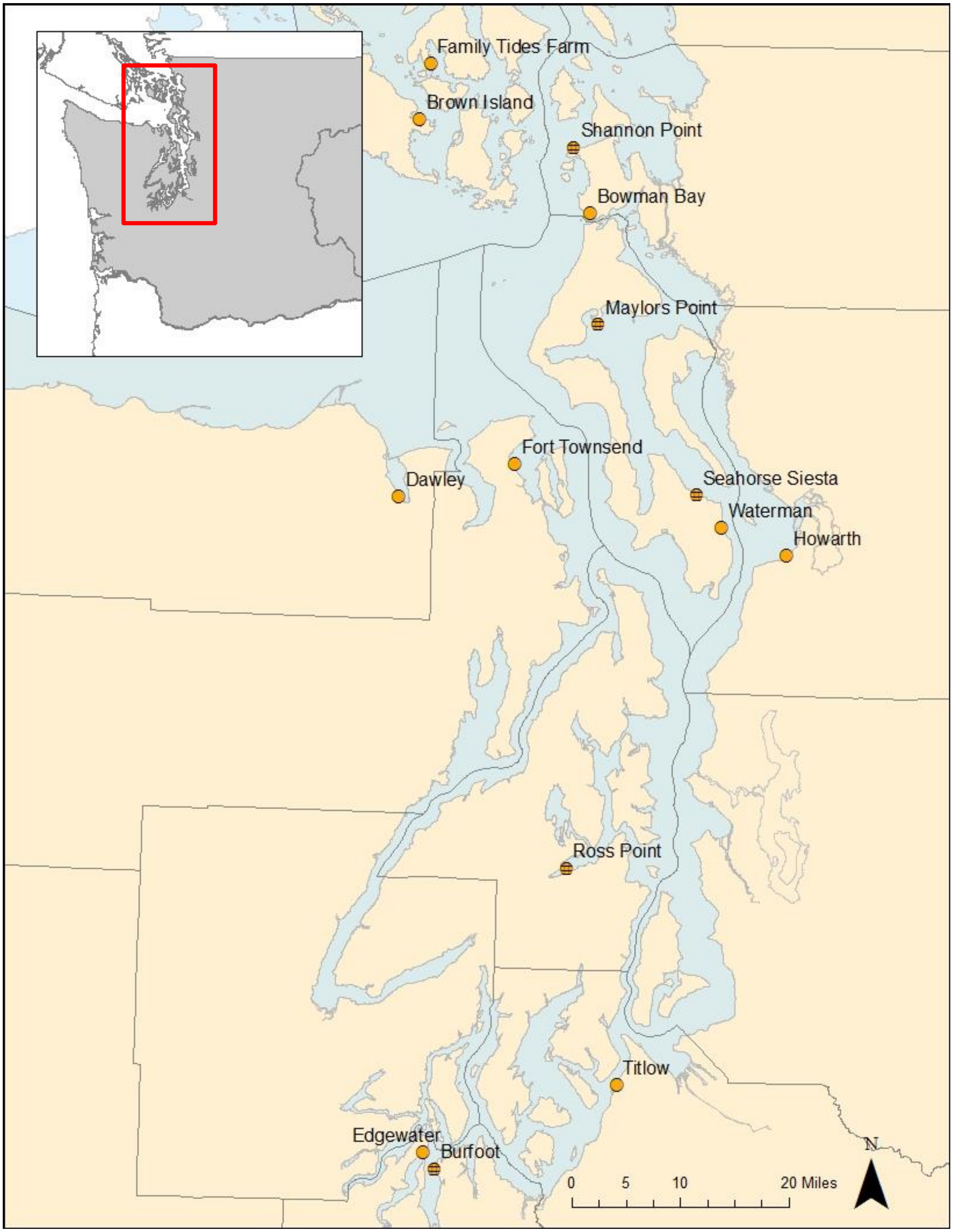


Figure 4.1. Map of shoreline restoration projects included in project monitoring in Puget Sound, Washington. Sites denoted by solid orange markers indicated surveys were completed before and after shoreline armor removal. Sites denoted by hatched orange markers indicated that armor was not removed within our project timeframe, and surveys were completed before restoration only.

4.2 Survey Methods

For every restoration project (i.e. study site) (N=14) we established a series of along-shore survey transects[4]. We established one treatment survey transect within the armor removal and restoration footprint, and up to three reference survey transects adjacent to but outside armor removal and restoration footprint. Reference transects were identified further as an unarmored reference (outside of restoration footprint along an unarmored shoreline) and an armored reference (outside of restoration footprint along an armored shoreline).However, the framework of treatment and reference transects within a study site varied among restoration project sites in response to site-specific conditions and accessibility; such that some study sites lacked both an armored and unarmored reference survey transect. For each series of survey transects within a study site, we attempted to maintain similar shoreline characteristics (e.g., beach aspect and wave exposure) and location within a common drift cell to the best of our ability. However, characteristic of many observational field studies and inherent of Puget Sound's complex shorelines, location and character of survey sites varied both within a transect series (i.e. within a restoration sites) and among restoration sites.

In total, we established 42 survey transects across 14 study sites, including: 14 treatment (i.e. restoration) transects each with at least one (and up to three) adjacent reference transect(s) located along either armored or unarmored shorelines. Location and photo documentation at center was recorded for each survey transect. Within a transect series, the mean distance between treatment and reference transects(s) was 573 m; and the maximum distance was 3.5 km (Appendix, Table 9.1a-n). Individual maps of study sites depicting location of survey transects and shoreline condition are provided in the Appendix (Figure 9.1a-n).

We conducted surveys annually, May through October during daylight, low tides. For each restoration site, we completed at least one survey event (prior to armor removal) and up to four survey events total (before and after armor removal). In total, from 2015 to 2018, 118 survey events were completed across 42 transects within 14 restoration sites. Due to the still limited timeframe of our monitoring design and the inherent uncertainty of restoration planning and implementation, three restoration projects (i.e. sites) that were initially surveyed before armor removal were indefinitely delayed or terminated, and additional survey events were not completed.

Sample locations were established relative to mean lower low water (MLLW). Local tidal datums were calculated for each survey site using Vertical Datum Transformation (VDatum), a NOAA software package designed to identify and transform coastal elevation data based on input and desired output vertical (datum) and horizontal (coordinate system) information (NOAA 2012). Mean tidal range[5] varied across survey sites from 1.33 to 3.16 m; with a minimum mean higher high water (MHHW) elevation of

[4] At restoration sites where survey locations (i.e. transects) were previously established by a project proponent, we intentionally aligned our transects within the footprint of previous efforts.
[5] Difference in height between mean low water (MLW) and mean high water (MHW).

2.30 m (above MLLW) to the north and a maximum MHHW elevation of 4.39 m (above MLLW) to the south.

4.2.1 Survey framework. Survey transects were delineated on beach using a 50 m tape pulled parallel to the shoreline equidistance from transect center location (i.e. center at 25 m tape distance). Within each 50 m transect distance three profile tapes were pulled perpendicular from beach toe (i.e. bluff, bank or armor) to lowest accessible waterline (or MLW) at each 0, 25 and 50 m transect locations. All sampling was conducted within this transect x profile framework as depicted in Table 4.1, and Figures 4.2 and 4.3.

4.2.2 Physical surveys. The physical setting of a (specific) location may strongly determine effect of shoreline armoring and armor removal. For physical processes and structure in particular removal (and restoration) of shoreline armor has implications for accessible beach area (e.g. increase in backshore width), sediment transport (e.g. change in grain size composition), and sediment dynamics (e.g. raising of beach face). Although physical processes within Puget Sound are many, we focused our monitoring to encompass several key parameters accessible within our monitoring timeframe and particularly relevant to intertidal habitats and nearshore biota including: beach profiles, sediment grain size, and surface topography.

Elevations were collected at each meter tape distance along profile length (Figure 4.2 and 4.3) from accessible beach toe (i.e. armor, bluff, or bank) waterward to at least mean low water (MLW), or accessible waterline at time. Data was collected using a Trimble Geo XH 6000 Centimeter Edition RTK GPS unit (2-10 cm vertical accuracy), or laser level and stadia rod at locations with limited satellite or cell coverage required to operate RTK GPS. Data was collected in North American Vertical Datum 1988 (NAVD 88) and converted to MLLW for analysis using VDatum. From each profile within a transect, we determined the following key physical parameters:

(1) Beach toe, elevation (m above MLLW) where beach face meets waterward terminus of bluff, bank or armor
(2) Beach width, tape distance (m) from beach toe to MLW.
(3) Beach slope, from beach toe to MLW (i.e. beach width) (m above MLLW)
(4) Backshore width, tape distance (m) from MHHW to beach toe.
(5) Relative encroachment (RE)[6], waterward encroachment of beach toe (m above MLLW) on MHHW (m above MLLW).

Characterization of beach sediments contribute to understanding of both local and broader shoreline condition and processes, such as beach profile, porosity, wave attenuation, and sediment transport. Sediment was collected at each transect to measure grain size distribution. Two samples were collected at transect center along MHW (or highest accessible location) at each surface and subsurface (see Figure 4.2 and 4.3). Surface sediments were collected from the top most layer to a depth of approximately 5

[6]Relative encroachment (RE) is a parameter developed by Dethier et al. (2016) intended to provide a consistent approach to measuring physical beach conditions across project sites with variable tidal conditions.

cm below surface, and subsurface sediments were collected to a depth approximately 10-15 cm below surface (Toft et al. 2013). Sample volume varied according to observed grain-size at site, where at least 100x the largest dominant grain-size was collected. Sediment samples were processed in the lab according to standard Wentworth (1922) grain-size classification scheme. For each sample, we estimated percent of total weight by: cobble (>6 cm), pebble (4 mm-6 cm), granule (1-4 mm) and sand (<2 mm).

Table. 4.1 Table describing survey parameter, source and function of protocols. Table is adapted from the Shoreline Monitoring Toolbox summary table of protocol purposes (WSG, n.d.)

Protocol	Parameter	Source	Function
Sediment size	Grain size composition	Shoreline Monitoring Toolbox	Beach structure
		Toft et al. 2013	Upper beach habitat
Beach profile	Beach toe elevation	Shoreline Monitoring Toolbox	Beach structure
	Backshore width	Warrick et al. 2009	
	Beach width	Dethier et al. 2016	
	Beach slope		
	Relative encroachment		
Beach wrack	Wrack composition	Shoreline Monitoring Toolbox	Marine-terrestrial connectivity
	Wrack width		Upper beach habitat
Logs and riparian vegetation	Log count	Shoreline Monitoring Toolbox	Marine-terrestrial connectivity
	Log width		Upper beach habitat
	Overhanging vegetation		
Forage fish eggs	Egg count	Moulton and Penttila 2006	Forage fish spawning habitat
	Egg species		Upper beach habitat

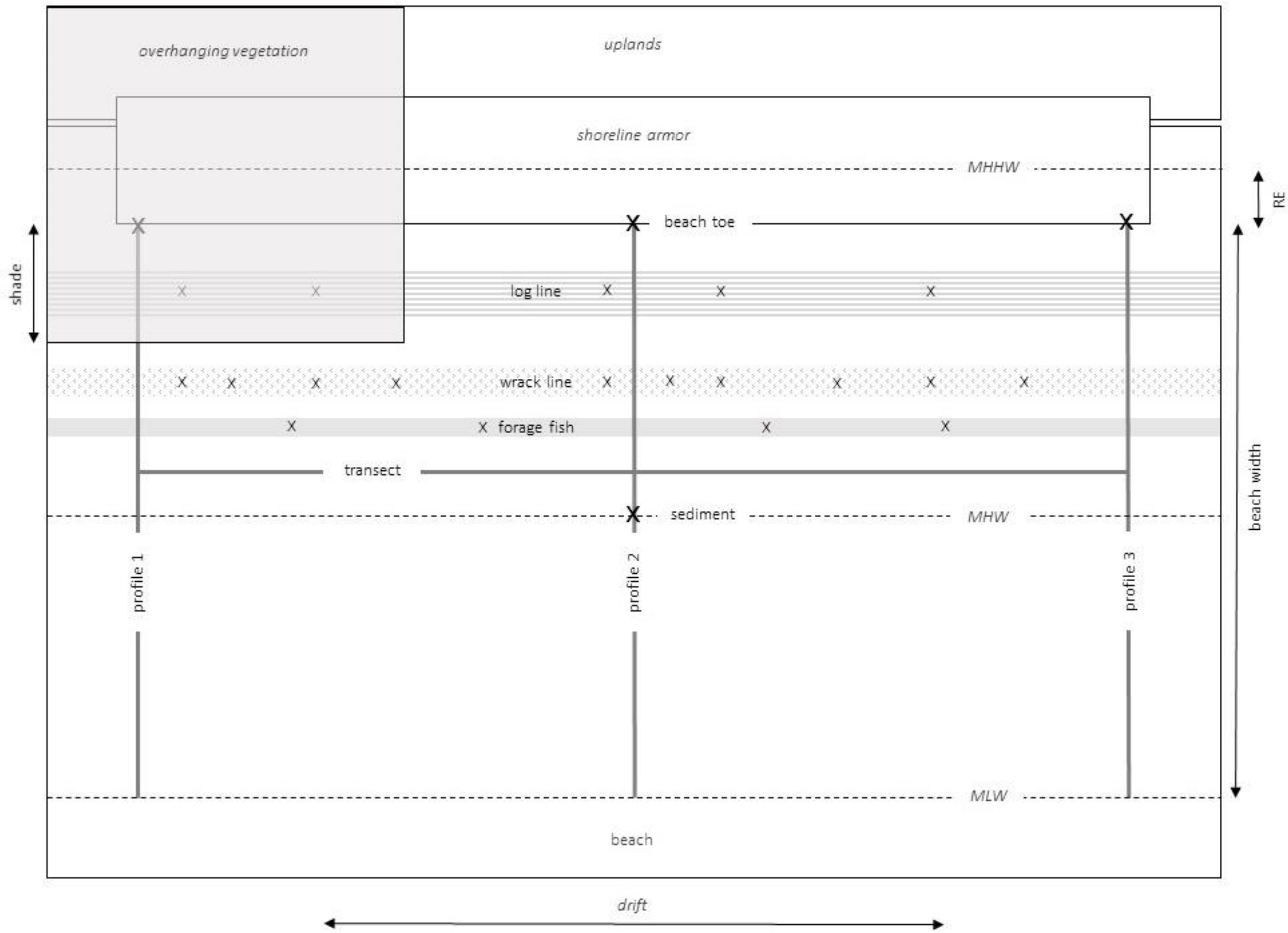


Figure 4.2. Generalized schematic of field sample design at an armored treatment (i.e. before removal and restoration) or reference transect, illustrating location of key beach features (i.e. log line, wrack line, overhanging vegetation, tidal datums), associated sample locations (denoted by '**X**') and field measures (i.e. riparian shade (% beach width overhanging vegetation), relative encroachment (RE) of beach toe on MHHW, and beach width (from toe to MLW)).

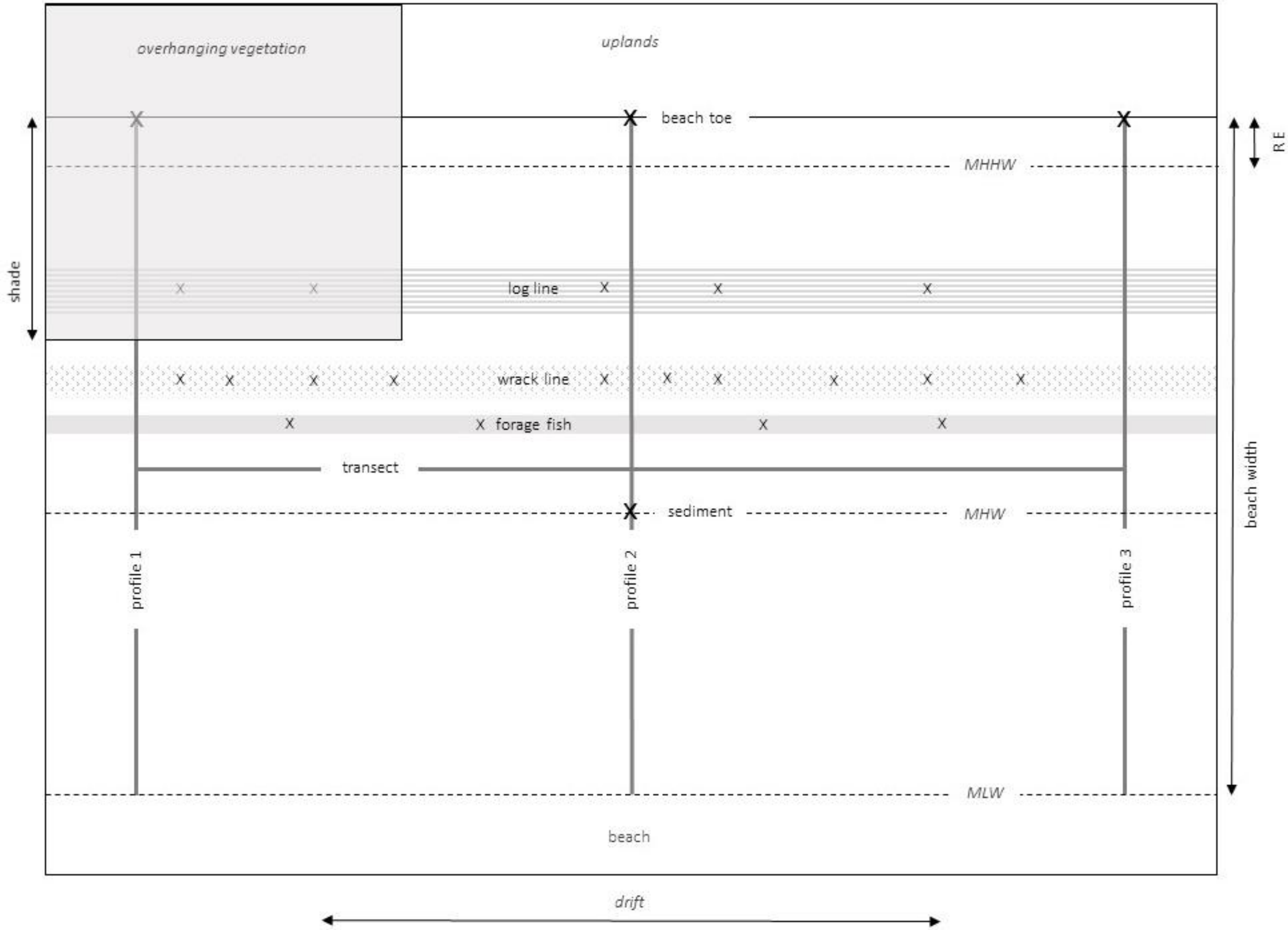


Figure 4.3. Generalized schematic of field sample design at an unarmored treatment (i.e. after removal and restoration) or reference transect, illustrating location of key beach features (i.e. log line, wrack line, overhanging vegetation, tidal datums), associated sample locations (denoted by '**X**') and field measures (i.e. riparian shade, relative encroachment (RE) of beach toe on MHHW, backshore width (from MHHW to beach toe) and beach width (from toe to MLW)).

We characterized beach surface topography at each transect by exercising a photogrammetry technique, Structure from Motion (SfM), that uses digital imagery with modeling software to create high resolution 3-D models. We collected a series of overlapping oblique convergent imagery on-site using a compact digital camera either hand-held or fixed to an extendable pole. Prior to image collection, we established a network of ground control points (GCPs), where we collected location and elevation data using Trimble RTK GPS. This enabled real-world projection of 3-D models. We processed photos using computer software AgiSoft Photoscan Professional to derive point clouds and build digital elevation models (DEM) of beach surface. We exported surface DEMs to ArcGIS for further analysis and change detection[7].

4.2.3 Biological Surveys. Biological aspects of a beach are strongly influenced by various unique and compounding physical aspects. Therefore, the biological character of a beach is affected by and informs impacts of shoreline armor and armor removal. For the purposed of our monitoring program, we focused biological surveys to the upper beach habitat (i.e. landward of MLW) and included wrack, log, riparian vegetation, and forage fish surveys

Wracks of floating debris are common within Puget Sound; deposited (as wrack lines) on exposed beach surfaces by wave and transport actions. Wrack lines are comprised largely of naturally-derived marine and terrestrial organic material, and can be transport long distances from the site of production (Thom et al. 1994). These wrack zones provide important food and habitat for an array of invertebrates, shorebirds, and nearshore fish (Heerhartz et al. 2014). We conducted wrack surveys for each site at 10 random points along the highest visible wet wrack within our 50 m transect (see Figure 4.2). At each point we measured wrack width (m from landward to waterward wrack-line limits) and composition (%). We used a 0.1m^2 quadrat to visually estimate percent total wrack cover and percent cover algae, eelgrass, and terrestrial material. We characterized algae generally by presence of *Fucu*s spp, *Ulva* spp, or broadly green, red, or brown type.

Accumulations of logs, tree roots and branches are common along upper beaches of Puget Sound. These collections of large woody debris are important to stabilize the shoreline, provide habitat structure for birds and fish, and provide organic material to the nearshore system (Thom et al. 1994). We differentiated log surveys by input source: marine (i.e. driftwood) and terrestrial (i.e. fallen). We measured marine log input at 5 random points along 50 m transect (see Figure 2). We recorded count of logs (by diameter and length), log width (m from landward to waterward log-line limit), and any defining characteristics (e.g., human-modified, terrestrial growth). We measured terrestrial log input as total count of fallen trees (by diameter and length) within the entire length of our 50 m sample transect.

We estimated riparian cover (i.e. overhanging vegetation) at each profile location within our 50 m transect (Figure 2). Along each profile, we recorded the waterward extent (m) from toe (of bluff, bank or

---

[7] This pilot effort demanded greater resources than expected (e.g., post-processing and data management) and change detection was not wholly completed within our monitoring timeframe. Consequently, no results will be included for the purposes of this report.

armor) and overhanging vegetation type (evergreen or deciduous). For each profile, we estimated amount of overhanging vegetation as percent of total beach width. At each 0, 25, and 50 m transect location, we also recorded presence of backshore vegetation by type (pickleweed, beachgrass, herbaceous, shrub, tree, and modified).

We conducted forage fish spawn surveys to assess egg presence and abundance for surf smelt (*Hypomesus pretiosus*) and Pacific sand lance (*Ammodytes hexapterus*) along each survey transect. We conducted surveys consistent with WDFW standard methods (Moulton and Penttila 2006) and processed sediment samples according to revised WDFW protocols (Dionne 2015). Due to our limited field capacity, we completed forage fish egg surveys at each site once annually – with the exception of one site whose close proximity to our central office enabled monthly forage fish sampling for limited project duration. Additional forage fish surveys may have been conducted by other project proponents (e.g., Northwest Straits Foundation, Snohomish County, Point No Point Treaty Council), but are not reported here.

4.3 Analysis

For the purposes of this project report, no statistical analyses were completed to test significance of shoreline armor removal and restoration in determining measured effects. Rather, our intention was to collect high-quality, quantitative data which communicate nearshore condition, inform study design, and advise future monitoring and analysis

Data and observations presented in this report are intended to describe the effect of armor removal and restoration on beach condition, identify variable scales of observed response(s), and characterize possible sources of "noise" in monitoring data. Therefore, we quantified a suite of physical and biological structural components that describe nearshore process and function; with particular interest in ecosystem components affected by shoreline armoring. Key parameters of physical structure included: beach toe, beach width, relative encroachment, beach slope, and sediment grain size composition. Key parameters of biological structure included: marine log input, wrack cover, and riparian shade (i.e. overhanging vegetation). Further, because we collected data before and after restoration action, at various spatial locations, annually (up to four years), we explored shoreline response as a function of varying scales of temporal and spatial effect.

4.3.1 Treatment effect. Shoreline armoring has demonstrated apparent Sound-wide effects on nearshore condition (Dethier et al. 2016, Heerhartz et al. 2014, Lee et al. 2018). Analysis of treatment effect can identify influence of armor removal and restoration on shoreline condition, despite spatial and temporal differences. To describe the effect of armor removal, we summarized change in key structural components (beach toe, beach width, relative encroachment, beach slope, marine log input, wrack cover, riparian shade) measured before (1-2 years) and after (1-3 years) restoration at each treatment and reference transect within a study site (N=14).

A threshold response identifies a non-linear relationship where an impact may not be experienced or detected until a critical turning point is reached. Previous work by Dethier et al. (2016) identified that threshold effects may explain particular shoreline responses as a function of relative encroachment. Therefore, we explored the relationship between relative encroachment and two key structural dimensions (identified in Dethier et al. 2016): number of logs and total wrack cover.

4.3.2 Regional effect. There are regional differences in the physical condition and processes that define Puget Sound's nearshore, and consequently influence of shoreline armor on structural components can vary by location (Dethier et al. 2016). Analysis of treatment effect as a function of regional differences can identify variability in observed response as a function of broader physical conditions. To describe treatment effect as a function of regional variation, we summarized structural response data by transect status as armored, unarmored, or restored (i.e. after armor removal) within each geographic region as south (south of the Tacoma Narrows), central (north of the Tacoma narrows to Admiralty Inlet), and north (north of Admiralty Inlet). We examined only a selection of structural components that illustrated regional responses in previous efforts (Dethier et al. 2016), including beach toe, relative encroachment, marine log input, riparian shade, beach wrack composition, and sediment grain size composition.

4.3.3 Site-scale influence. Because our study design encompassed a series of sample transects (i.e. treatment and reference transects) per restoration site, our data allowed for consideration of site-scale variability and the local effect of restoration over time. However, for the purposes of this report, we present only an example of site-scale variation of relative encroachment from select restoration sites that encompass our study maximum four-year time frame.

5. Results

5.1 Treatment Effect

The effect of restoration treatment (i.e. before-after armor removal) was measured at 9 of 14 study sites where armor was removed within our survey timeframe[8]. Observations of change from pre-restoration conditions describe that, in general, restored beaches were wider, exhibited greater elevations at upper beach toe and lesser encroachment onto MHHW. Overall, restored beaches also accumulated more marine derived logs, and exhibited greater width of log line. However, the observed effect of restoration on change in beach slope, riparian shade and total wrack cover was less consistent across study sites (Figure5.1c, e and f, and Table 5.1).

[8] Restoration sites Burfoot Park (BF), Maylor's Point (MP), Ross Point (RP), Seahorse Siesta (SH), and Shannon Point (SP) were all removed from examination of treatment effect because armor removal and restoration action was not implemented within our monitoring timeframe and therefore, no post-restoration survey (i.e. after armor removal) could be conducted.

5.1.1. Physical parameters. Across all survey sites measured before and after restoration (N=9), we measured an increase in beach toe elevation (m above MLLW) at treatment transects following armor removal and restoration (Figure 5.1a, Table 5.1). Mean change in measured elevation of beach toe at treatment transects ranged from 0.19 m above MLLW to 1.37 m above MLLW (Table 5.1). Mean change measured at both armored and unarmored reference transects varied across study sites, where an increase in beach toe elevation was observed in 4 unarmored and 1 armored reference transects, and a decrease in elevation was observed in 8 unarmored and 2 armored transects (Figure 5.1a and Table 5.1). The overall amount of change in beach toe elevation measured at treatment transects was greater than measured at (armored or unarmored) reference transects within a study site.

Similarly, we observed that relative encroachment (of beach toe elevation on MHHW (m above MLLW)) decreased at treatment transects across all study sites (Figure 5.1d). The measured extent of beach toe on MHHW lessened by 0.19 m to 1.37 m following armor removal (Table 5.1). A decrease in relative encroachment was also observed at 2 armored and 3 unarmored reference transects. Of the remaining 10 reference transects, that exhibited an increase in relative encroachment (i.e. waterward advance of beach toe on MHHW), one was armored (Figure 5.1d). Within each study site, we observed that the amount of change in relative encroachment was greater at all treatment transects compared to (armored or unarmored) reference transects.

We observed that change in beach width ((m) distance from beach toe to MLLW) was not as consistent across study sites, where width increased at only 7 of 9 treatment transects (range = 1.13m – 8.82 m (Table 5.1)) (Figure 5.1b). Of our 15 reference transects, two armored and 5 unarmored also increased in beach width, and 1 armored and 7 unarmored decreased in beach width (Figure 5.1b). Dissimilar to change in beach toe and relative encroachment, the amount of change in beach width (regardless of directionality) was greatest at treatment transects for 8 of 9 study sites.

5.1.2. Biological parameters. At treatment transects across all study sites, both count and width of marine derived logs increased following armor removal and restoration (Figure 5.1g and h). Width of log line at treatment transects increased up to 1.65 m (Table 5.1). However, we observed that count and width of log line differed across reference transects and study sites. Of our 15 reference transects, 6 (unarmored) showed an increase in log count and 3 showed an increase in beach width. Conversely, 6 unarmored and 2 armored reference transects showed a decrease in log line count, and 2 armored and 9 unarmored showed a decrease in log line width (Figures 5.1 g and h).

5.1.3. Threshold effect. Data indicate that change over time was not only observed at treatment transects across study sites, but also occurred at adjacent reference transects outside the restoration footprint. In alignment with previous analysis by Dethier et al (2016), we briefly explored the potential for threshold responses of several beach parameters (i.e. log line count, beach slope, wrack cover) as a result of relative encroachment of beach toe (armored, unarmored and restored) on local MHHW. Appearance of scatterplots indicate a tendency for beaches (i.e. transects) with greater relative encroachment values to exhibit a reduction in number of logs and total wrack cover; and that greater RE values were commonly associated with armored beaches (Figures 5.2 and 5.3). Moreover, unarmored and restored beaches, which generally exhibited lesser RE values, appear to have greater spread in number of logs and total wrack cover. Patterns were less apparent in a scatterplot of beach slope to RE (Appendix, Figure 9.2).

5.2 Regional Variability

We explored the same suite of beach structure parameters for indication of potential regional variation (i.e. north, central and south Puget Sound) across survey transects. The bar graphs (Figures 5.4a-h) and associated data (Appendix, Table 9.3) indicate a difference in beach structure among regions across armored (armored reference transects and test transects prior to armor removal), unarmored (unarmored reference transects), and restored (test transects after armor removal) transects.

For the majority of physical beach parameters, data described a pattern of shoreline condition where measures were least (e.g., lowest elevation at beach toe) at armored sites, second at restored sites, and greatest at unarmored sites. However, comparisons of data at armored, restored and unarmored sites across regions illustrate that north transects were most distinguished from central and south sites; and south transects often mirrored north transects in extent and direction of beach attribute. The amount of regional difference was most pronounced for relative encroachment (Figure 5.4d). Across armored, unarmored and restored sample transects, relative encroachment of beach toe on MHHW was least at north transects (mean RE=-0.55 m) compared to central (mean RE=0.11 m) and south (mean RE=0.01 m). This was predominantly represented by measures at unarmored (reference) transects (mean RE=-0.89 m) and followed closely by restored transects (mean RE=-0.73 m). Likewise, however not as defined, north beaches exhibited the lowest elevations at beach toe (mean = 2.93 m above MLLW) and narrowest beach widths (mean=19.19 m) compared, in greatest contrast, to south transects (mean = 4.20 m above MLLW, and 30.48 m, respectively) (Appendix, Table 9.3).

Overall, measures of total wrack cover were greatest at north transects compared to central and south transects (Figure 5.6b). However, armored transects consistently measured the least in total wrack cover compared to both unarmored and restored beaches across all three regions. Within each north, central, and south regions, wrack cover was predominantly comprised of algae species; and remaining proportions of terrestrial and seagrass varied by region (e.g.. north sites measured the greatest proportion terrestrial wrack) and transect (e.g., south beaches measured the least proportion seagrass) (Figure 5.4f).

Beach slope (toe to MLW) displayed the least apparent distinction among sample regions (Figure 5.4c), with a mean 0.12, 0.09 and 0.11 m in each north, central and south transects, respectively (Appendix, Table 9.3). Similarly, riparian shade (% beach width overhanging vegetation) was measured at a mean 10.06%, 10.99%, and 11.23% of total beach width within each north, central and south regions, respectively (Appendix, Table 9.3). However, of north beaches, restored transects exhibited the greatest extent riparian shade; of central beaches, unarmored transects exhibited greatest extent, and; of south beaches, armored sites exhibited the greatest extent of overhanging vegetation (Figure 5.4e). Understandably, such observations may be a result of site-specific beach conditions. For example, at one south site, Edgewater, overhanging vegetation was prevalent at the test transect despite armor (mean=53.0% of beach width), and following the armor removal, much of the vegetation shifted on beach with the newly formed bluff and eliminated presence of riparian shade (mean=9.4% of beach width (Appendix, Table 9.2e)).

Sediment samples at armored, unarmored and restored transects did not exhibit obvious differences in grain size composition among regions. Of four general grain size categories, sand (<2 mm), granule (2-4 mm), pebble (4 mm – 6 cm) and cobble (>6 cm), all samples across north, central and south transects were dominated by sand (mean=.48.2%, 51.0% and 47.5%, respectively) and pebbles (mean=37.6%, 38.0%, 44.2%, respectively) (Appendix, Table 9.4). While this pattern was apparent in both surface and sub-surface samples (Figures 5.5a and b), sub-surface samples showed stronger proportion of sand (mean=51.7%, 56.8%, 46.8% at north, central and south regions, respectively). When evaluated on a finer scale, transects across all regions exhibited the greatest proportions of medium sand (0.25-0.5 mm), but varied in sub-dominant grain size (Figures 5.5c and d, and Appendix, Table 9.4). At north transects, sediment samples were dominantly comprised of medium sand (24.4%) and fine gravel (4-8 mm) (14.5%); at central transects, sediments samples were dominantly comprised of medium sand (23.7%) and coarse sand (0.5-1 mm) (16.8%), and; at south transects, sediment samples were dominantly comprised of medium sand (24.5%) and coarse gravel (1.6-3.2 cm) (17.9%) (Appendix, Table 9.4).

5.3 Site-scale Variability

For each transect within a study site, we collected replicate measures of key beach structure parameters each survey year (see Methods, and Figures 4.2 and 4.3). We observed that beach structure parameters within a transect exhibited both spatial and temporal variability in replicate measures collected. Box plots comparing measures of relative encroachment (RE) collected each survey year (Figure 5.6a-d) illustrate potential span of within-transect field measures. We observed that the range of values within a transect was minor for some (e.g. Bowman Bay treatment transect (Figure 5.6a)), and more sizable for other (e.g. approx. 1 m range at Fort Townsend (Figure 5.6b) and Edgewater (Figure 5.6c) treatment transects.

While discrete measures of site-specific variability may be negligible with regard to broader nearshore processes, measures of annual variability may provide clarity in short-term versus long-term effects of restoration. For example, at Bowman Bay change in measure of RE year one after armor removal (2016) appear different from year two (2017) and year three (2018) across all three transects (Figure 5.6a). Consequently, a determination of restoration effect on RE (or other beach parameter) may vary by any single survey year. In comparison, data from Howarth Park depicted in Figure 5.8d illustrate our scope of effort in the event of a reduction (i.e. single measures taken at each transect center in 2016) and gap (i.e. no field surveys conducted at reference transects 2 and 3) in monitoring effort. In this instance, box plots illustrating spatial and temporal range of field measures within a transect depict potential limitations in a reduced survey design.

5.4 Forage Fish

No analysis of forage fish sample data were completed due to limited confidence in the resolution of sample results (Appendix, Table 9.5) to demonstrate causative patterns in egg detection for the following reasons:

(1) Poor timing. Surveys were conducted in common during summer months only, as part of restoration surveys. We did not individually implement surveys with regard to regional peak spawn times.

(2) Narrow spatial scale. Samples were collected along a single elevation within the beach profile (most visibly suitable band of spawning substrate) (Moulton and Penttila 2001).

(3) Limited temporal replication. Sampling was conducted once annually (during restoration surveys)

However, at one site in south Puget Sound, Edgewater, we were able to sample (treatment and reference) transects monthly over an extended timeframe. Results from monthly survey validate our hesitations (of limited annual surveys), and illustrate temporal variability in egg detections across survey transects. Data show that while spawning occurs year round, greatest peaks were exhibited during winter months (Nov-Mar) (Figure 5.7a-b). However, peak timing was not consistent annually and egg counts were highly variable.

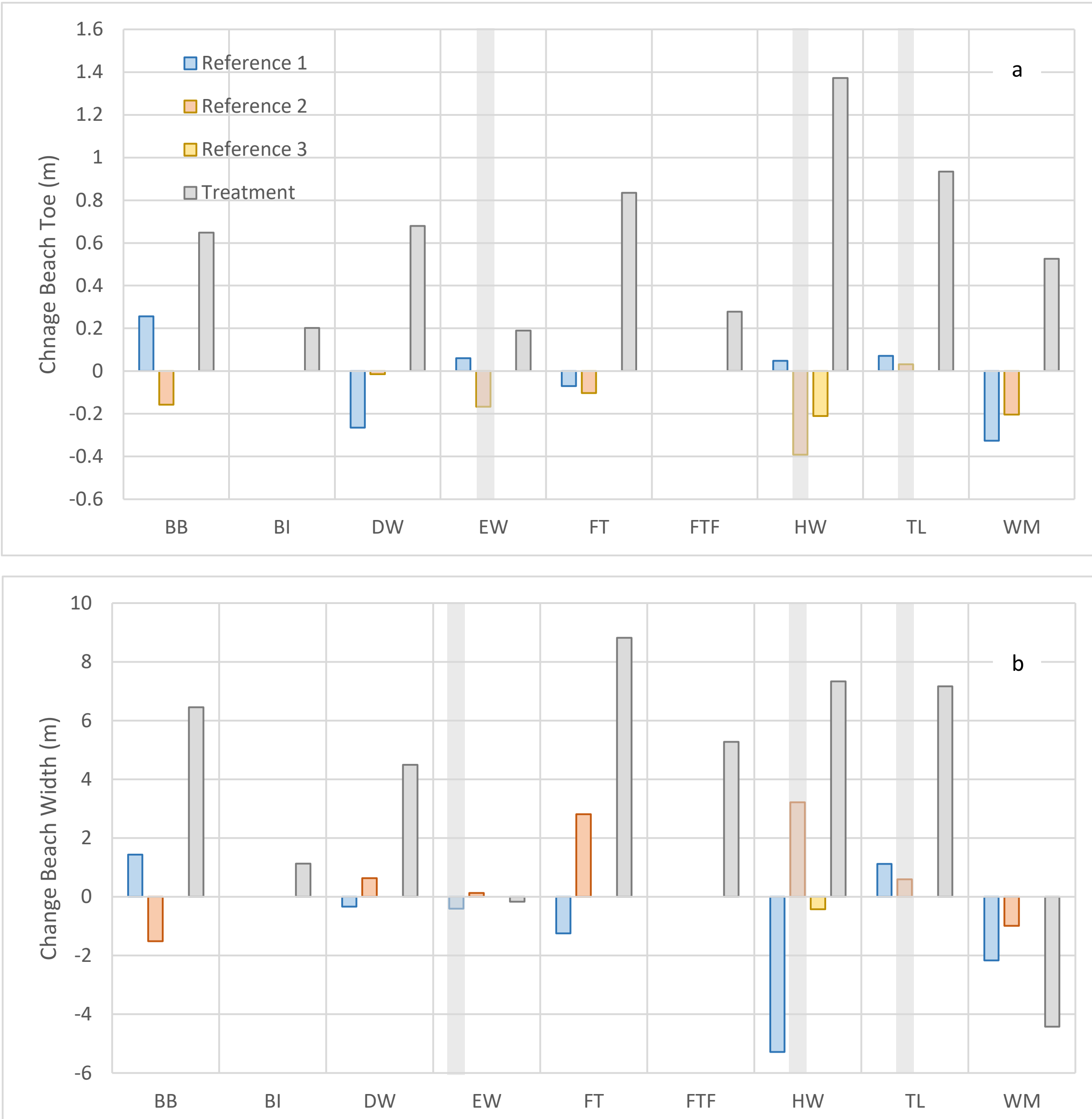


Figure 5.1a-b. Comparison of mean change from pre-restoration conditions, measured at each treatment (N=9), armored reference (shaded bars) (N=3) and unarmored reference (N=12) transect within a study site[9]. Change is calculated as the difference of values measured before restoration and after restoration. A positive value in (a) change beach toe (m) represents an increase in elevation (m above MLLW) after restoration, and a positive value in (b) change beach width (m) represents an increase in beach width (m) after restoration. See Table 5.1 for site codes and sample size.

[9] No pre-restoration surveys were conducted at Brown Island (BI) and Family Tides Farm (FTF) reference transects. No post-restoration surveys were conducted at Burfoot Park (BF), Maylor Point (MP), Ross Point (RP), Seahorse Siesta (SH), and Shannon Point (SP) test and reference transects due to project delay.

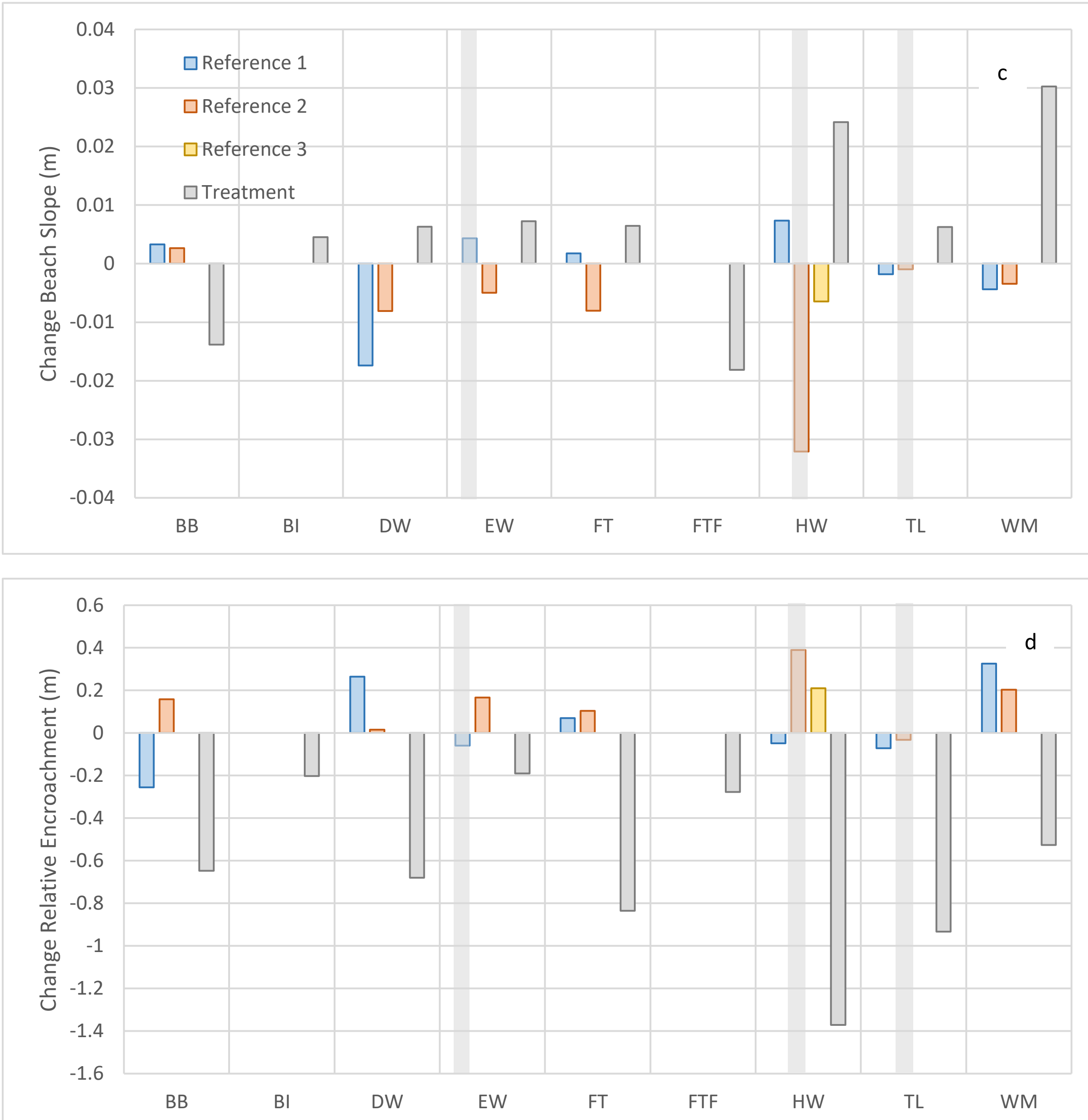
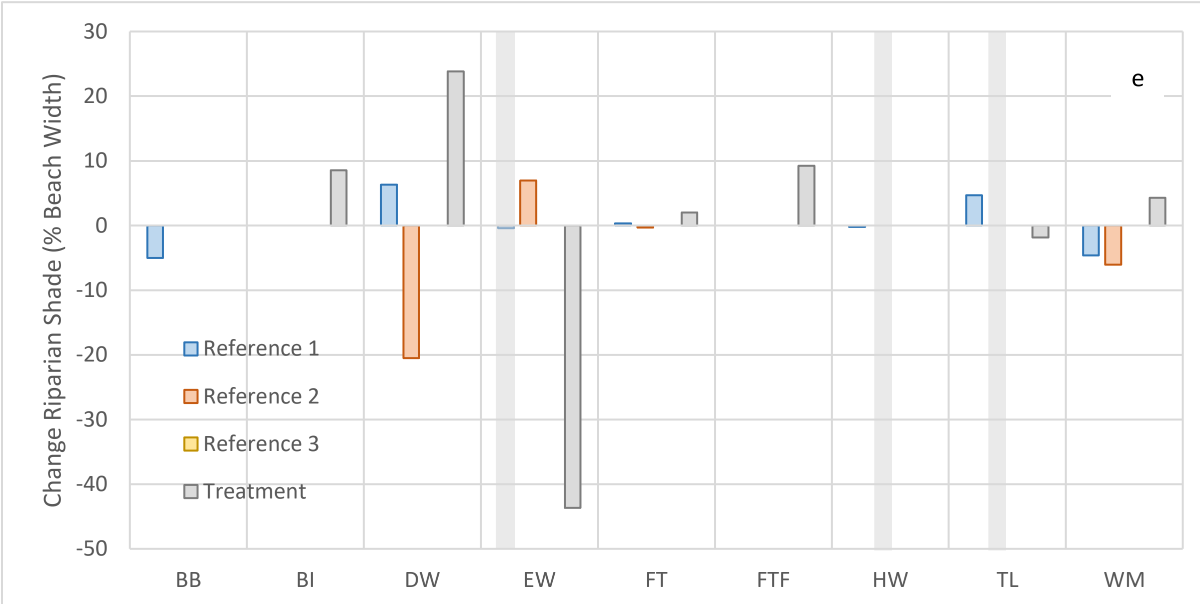


Figure 5.1c-d. Comparison of mean change from pre-restoration conditions, measured at each treatment (N=9), armored reference (shaded bars) (N=3) and unarmored reference (N=12) transect within a study site[10]. Change is calculated as the difference of values measured before restoration and after restoration. A positive value in (c) change beach slope (m) represents an increase in beach grade (i.e. steeper) after restoration, and a positive value in (d) change relative encroachment (m) represents a waterward advance of beach toe on MHHW after restoration. See Table 5.1 for site codes and sample size.

---

[10] No pre-restoration surveys were conducted at Brown Island (BI) and Family Tides Farm (FTF) reference transects. No post-restoration surveys were conducted at Burfoot Park (BF), Maylor Point (MP), Ross Point (RP), Seahorse Siesta (SH), and Shannon Point (SP) test and reference transects due to project delay.



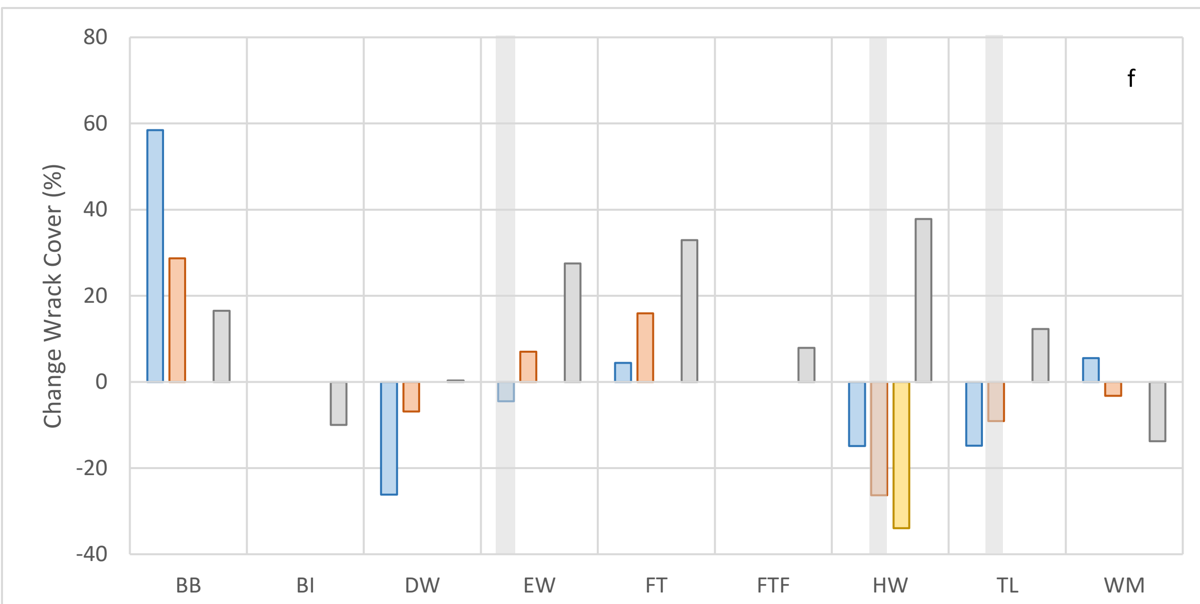


Figure 5.1e-f. Comparison of mean change from pre-restoration conditions, measured at each treatment (N=9), armored reference (shaded bars) (N=3) and unarmored reference (N=12) transect within a study site[11]. Change is calculated as the difference of values measured before restoration and after restoration. A positive value in (e) change riparian shade (% beach width (m)) represents an increase in extent of overhanging vegetation after restoration, and a positive value in (f) change wrack cover (%) represents an increase in total wrack cover after restoration. See Table 5.1 for site codes and sample size.

[11] No pre-restoration surveys were conducted at Brown Island (BI) and Family Tides Farm (FTF) reference transects. No post-restoration surveys were conducted at Burfoot Park (BF), Maylor's Point (MP), Ross Point (RP), Seahorse Siesta (SH), and Shannon Point (SP) test and reference transects due to project delay.

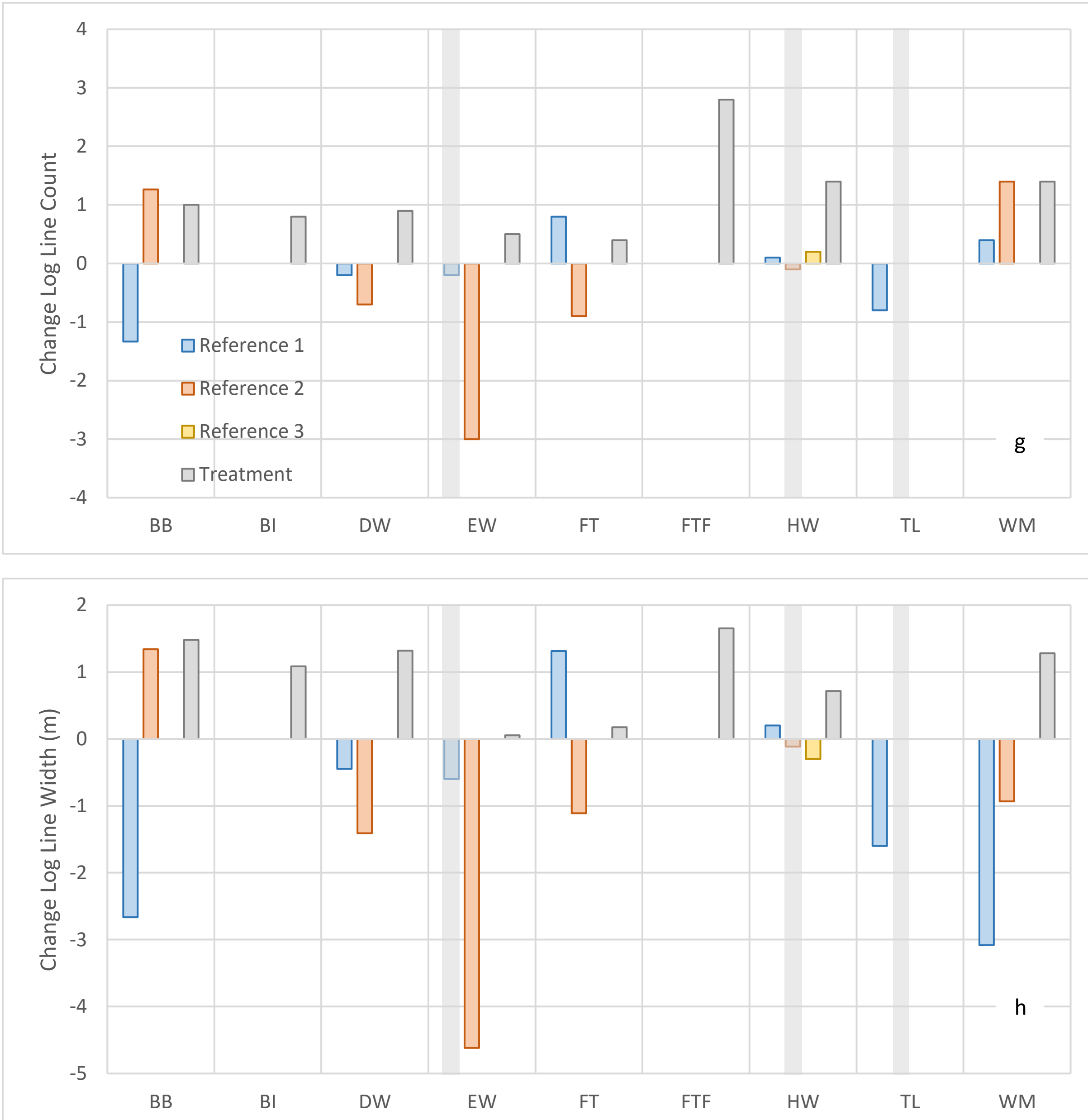


Figure 5.1g-h. Comparison of mean change from pre-restoration conditions, measured at each treatment (N=9), armored reference (shaded bars) (N=3) and unarmored reference (N=12) transect within a study site[12]. Change is calculated as the difference of values measured before restoration and after restoration. A positive value in (g) change log line count represents an increase in number of marine derived logs after restoration, and a positive value in (h) change log line width (m) represents an increase in the total width of log line after restoration. See Table 5.1. for site codes and sample sizes.

---

[12] No pre-restoration surveys were conducted at Brown Island (BI) and Family Tides Farm (FTF) reference transects. No post-restoration surveys were conducted at Burfoot Park (BF), Maylor Point (MP), Ross Point (RP), Seahorse Siesta (SH), and Shannon Point (SP) test and reference transects due to project delay.

Table 5.1. Mean change from pre-restoration conditions, measured for key survey parameters. Values are averaged by transect, within each study site[13], where: R1=reference 1, R2=reference 2, R3=reference 3, and T=treatment transect. Shaded columns designate armored reference transects. Bolded values highlight greatest within-site change per parameter. See Figure 5.1a-h for additional illustration.

	Bowman Bay (BB)			Brown Island (BI)			Dawley (DW)			Edgewater (EW)			Fort Townsend (FT)		
Parameter	R1	R2	T	R1	R2	T	R1	R2	T	R1	R2	T	R1	R2	T
Beach Toe (m)	0.26	-0.16	**0.65**			0.20	-0.26	-0.01	**0.68**	0.06	-0.17	**0.19**	-0.07	-0.10	**0.84**
Beach Width (m)	1.43	-1.51	**6.45**			1.13	-0.34	0.63	**4.50**	**-0.41**	0.13	-0.17	-1.24	2.81	**8.82**
Beach Slope (m)	**0.003**	0.003	-0.014			0.005	**-0.017**	-0.008	0.006	0.004	-0.005	**0.007**	0.002	**-0.008**	0.006
RE (m)	-0.26	0.16	**-0.65**			-0.20	0.26	0.01	**-0.68**	-0.06	0.17	**-0.19**	0.07	0.10	**-0.83**
Shade (%)	**-5.01**	0.00	0.00			8.55	6.33	-20.48	**23.85**	-0.40	6.94	**-43.66**	0.33	-0.31	**1.99**
Wrack cover (%)	**58.48**	28.66	16.52			-9.98	**-26.15**	-6.85	0.35	-4.45	7.05	**27.52**	4.39	15.95	**32.95**
Log Count	**-1.33**	1.27	1.00			0.80	-0.20	-0.70	**0.90**	-0.20	**-3.00**	0.50	0.80	**-0.90**	0.40
Log Width (m)	**-2.66**	1.34	1.48			1.09	-0.45	**-1.41**	1.32	-0.60	**-4.62**	0.06	**1.32**	-1.11	0.18
Pre *n*	3	2	3	0	0	3	3	3	3	6	6	6	6	6	6
Post *n*	9	6	9	9	9	9	6	6	6	6	6	6	6	6	6

Table 5.1. Continued.

	Family Tides Farm (FTF)		Howarth (HW)				Titlow (TL)			Waterman (WM)		
Parameter	R1	T	R1	R2	R3	T	R1	R2	T	R1	R2	T
Beach Toe (m)		0.28	0.05	-0.39	-0.21	**1.37**	0.07	0.03	**0.93**	-0.33	-0.20	**0.53**
Beach Width (m)		5.28	-5.28	3.22	-0.42	**7.34**	1.12	0.60	**7.17**	-2.17	-0.99	**-4.42**
Beach Slope (m)		-0.018	0.007	**-0.032**	-0.006	0.024	-0.002	-0.001	0.006	-0.004	-0.003	**0.030**
RE (m)		-0.28	-0.05	0.39	0.21	**-1.37**	-0.07	-0.03	**-0.93**	0.33	0.20	**-0.53**
Shade (%)		9.25	**-0.23**	0.00	0.00	0.00	**4.71**	0.00	-1.87	-4.62	**-6.07**	4.29
Wrack cover (%)		7.88	-14.90	-26.30	-33.93	**37.85**	**-14.80**	-9.10	12.30	5.50	-3.25	**-13.75**
Log Count		2.80	0.10	-0.10	0.20	1.40	**-0.80**	0.00	0.00	0.40	**1.40**	**1.40**
Log Width (m)		1.65	0.20	-0.11	-0.30	**0.72**	**-1.60**	0.00	0.00	**-3.08**	-0.94	1.28
Pre *n*	0	3	4	4	4	4	3	3	3	3	3	3
Post *n*	6	9	6	3	3	6	6	6	6	6	6	6

[13] No pre-restoration surveys were conducted at Brown Island (BI) and Family Tides Farm (FTF) reference transects. No post-restoration surveys were conducted at Burfoot Park (BF), Maylor Point (MP), Ross Point (RP), Seahorse Siesta (SH), and Shannon Point (SP) transects due to project delay.

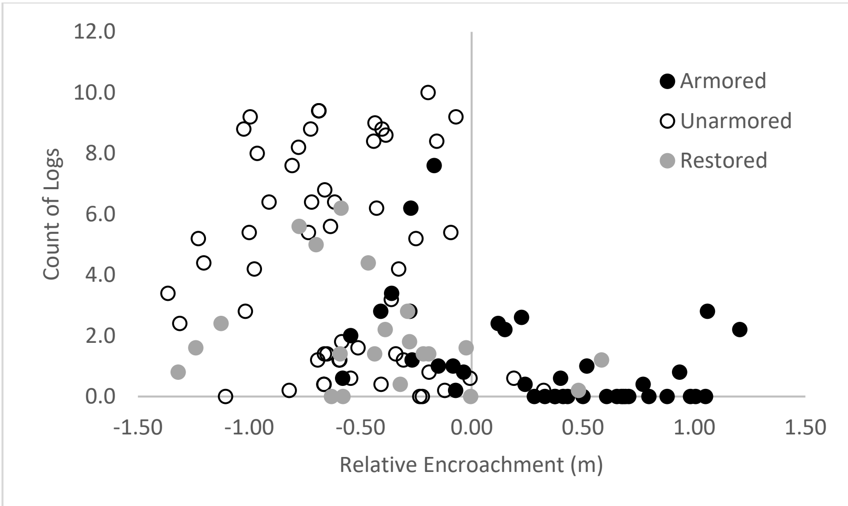


Figure 5.2. Scatterplot of mean log counts relative to encroachment of beach toe on local MHHW, measured at each survey transect. Transects are differentiated by shore status as armored (including treatment transects before armor removal) (n=40), unarmored (unarmored reference transects only) (n=55), and restored (treatment transects after armor removal) (n=21).

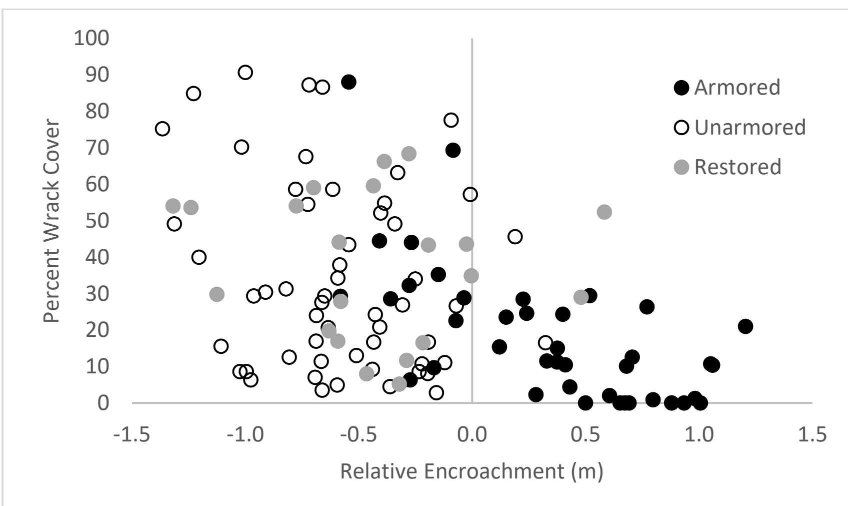


Figure 5.3. Scatterplot of mean wrack cover (%) relative to encroachment of beach toe on local MHHW, measured at each survey transect. Transects are differentiated by shore status as armored (including treatment transects before armor removal) (n=40), unarmored (unarmored reference transects only) (n=55), and restored (treatment transects after armor removal) (n=21).

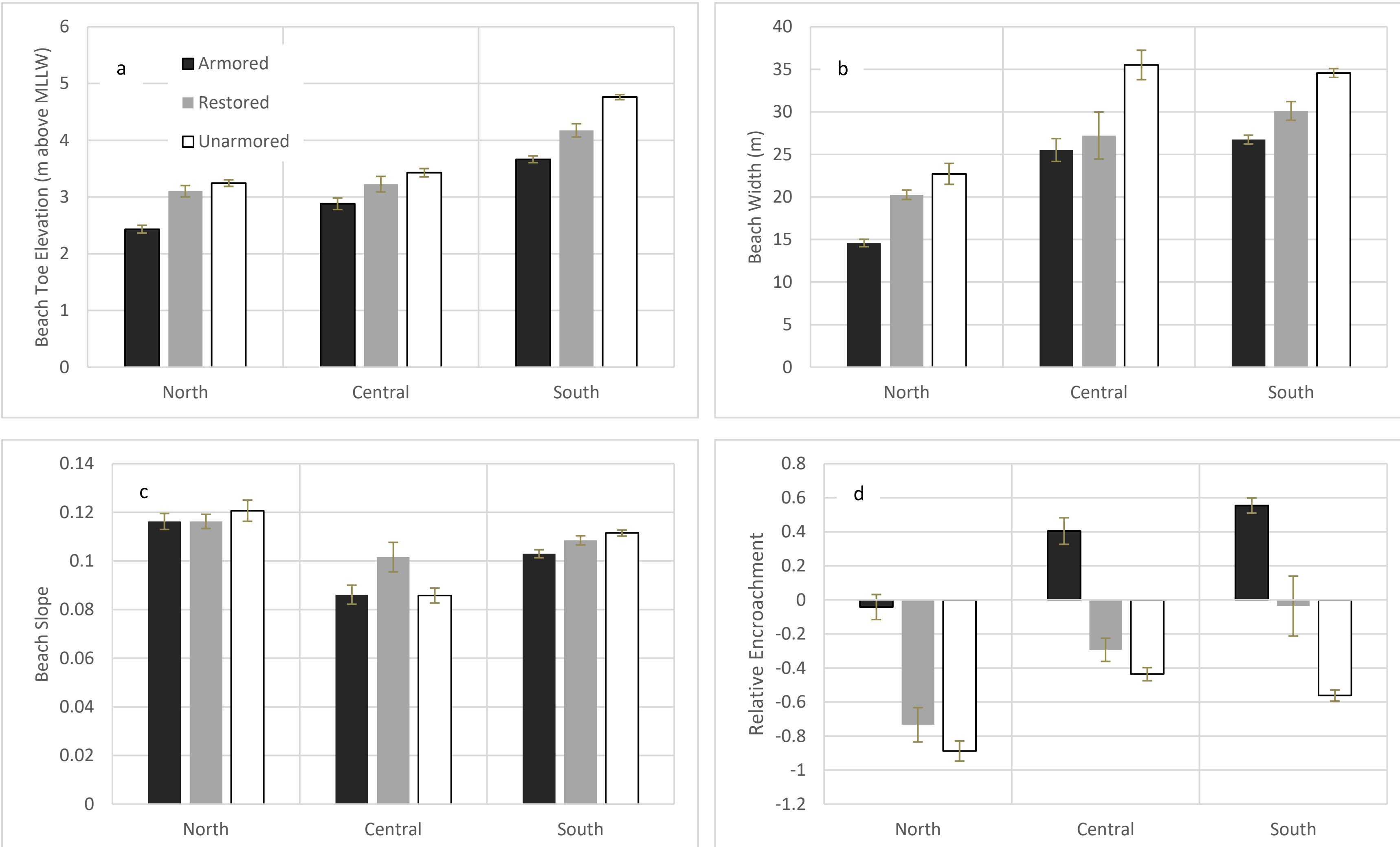


Figure 5.4a-d. Comparison of mean values (+/- SE) for key beach parameters: (a) beach toe elevation (m above MLLW), (b) beach width (toe to MLW (m)), (c) beach slope (m), and (d) relative encroachment (m). Bars compare values measured at each armored (armored reference and armored treatment prior to restoration) (black), unarmored (unarmored reference) (grey), and restored (treatment after armor removal) (white) transect within north (N=4), central (N=7) and south (N=3) study regions of Puget Sound, WA.

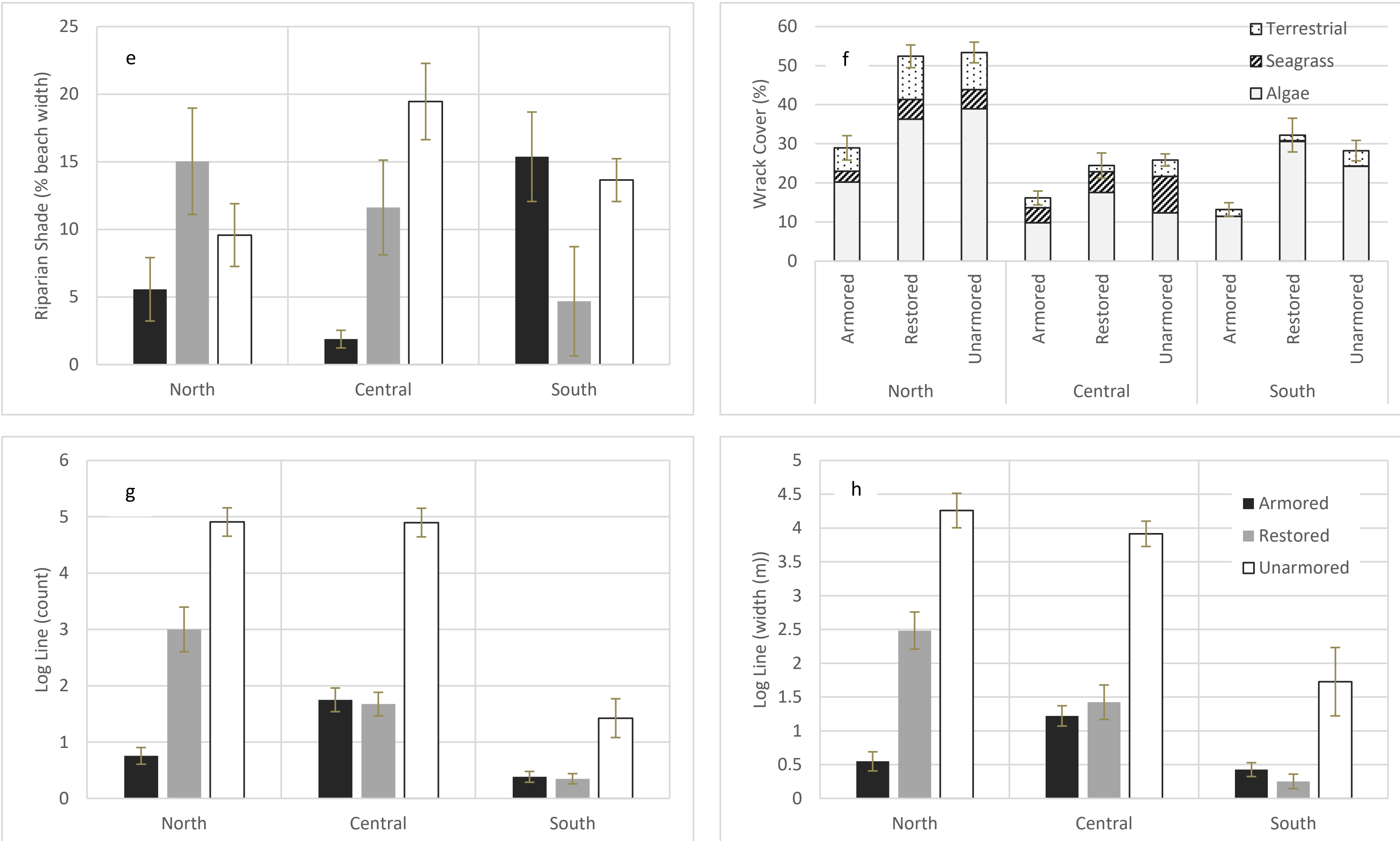


Figure 5.4e-h. Comparison of mean values (+/- SE) for key beach parameters: (e) riparian shade (% beach width overhanging vegetation), (f) total wrack cover by proportion terrestrial, seagrass and algae, (g) log line count (i.e. number of marine logs), and (h) log line width (m). Bars compare values measured at each armored (armored reference and armored treatment prior to restoration) (black), unarmored (unarmored reference) (grey), and restored (treatment after armor removal) transect within north (N=4), central (N=7), and south (N=3) study regions of Puget Sound, WA.

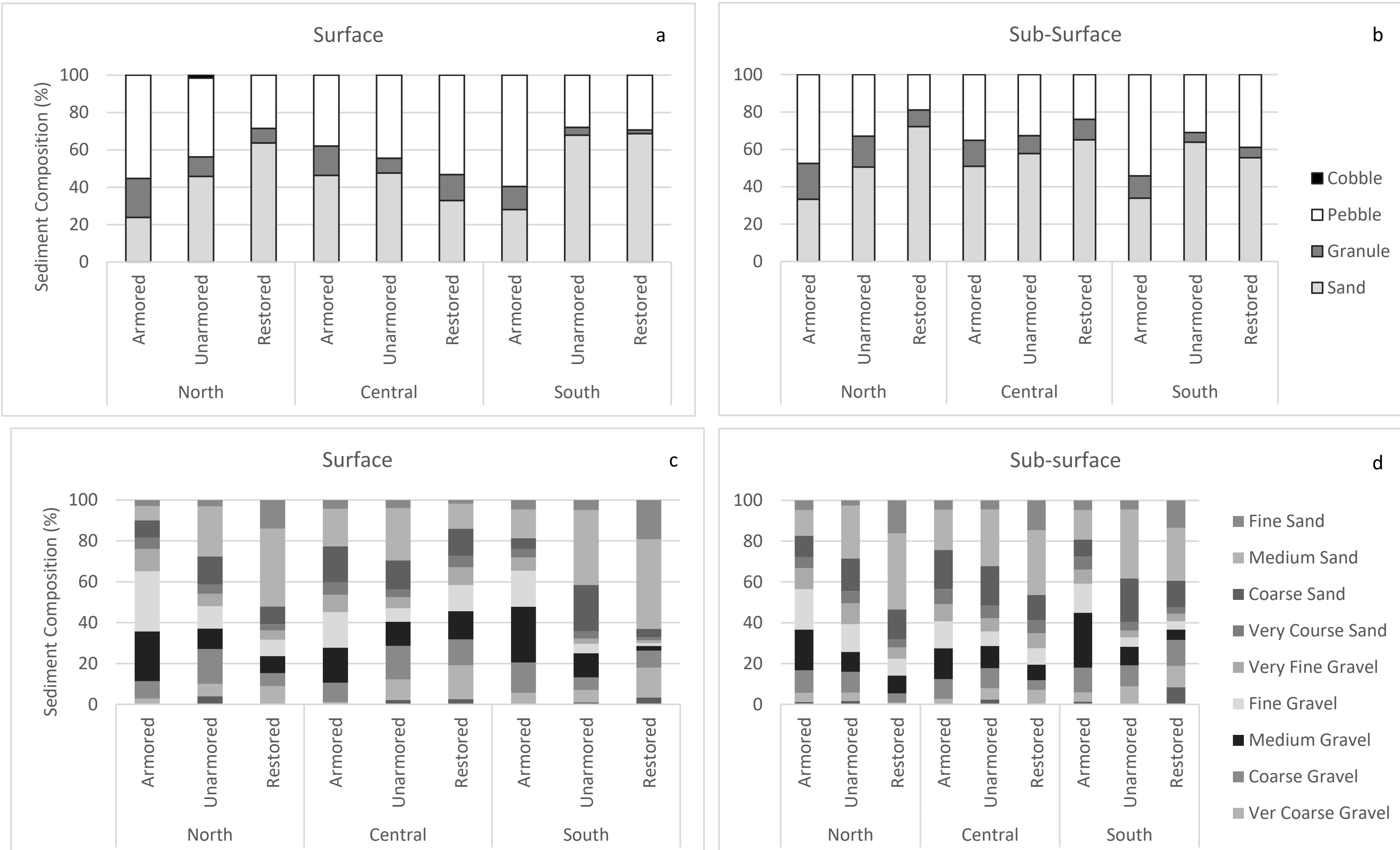


Figure 5.5a-d. Regional comparison of average sediment grain size distributions (% total by weight) for surface and sub-surface samples (collected within same beach footprint) collected at each armored (armored reference and armored test prior to restoration) (*n*=37), unarmored (unarmored reference) (*n*=54), and restored (test transect after armor removal) (*n*=21) transect within north (*n*=33), central (*n*=55) and south (*n*=24) Puget Sound, WA. Sediment distributions are depicted broadly in figures (a) and (b) and more detailed in figures (c) and (d) for both surface (a, c) and sub-surface (b, d) samples.

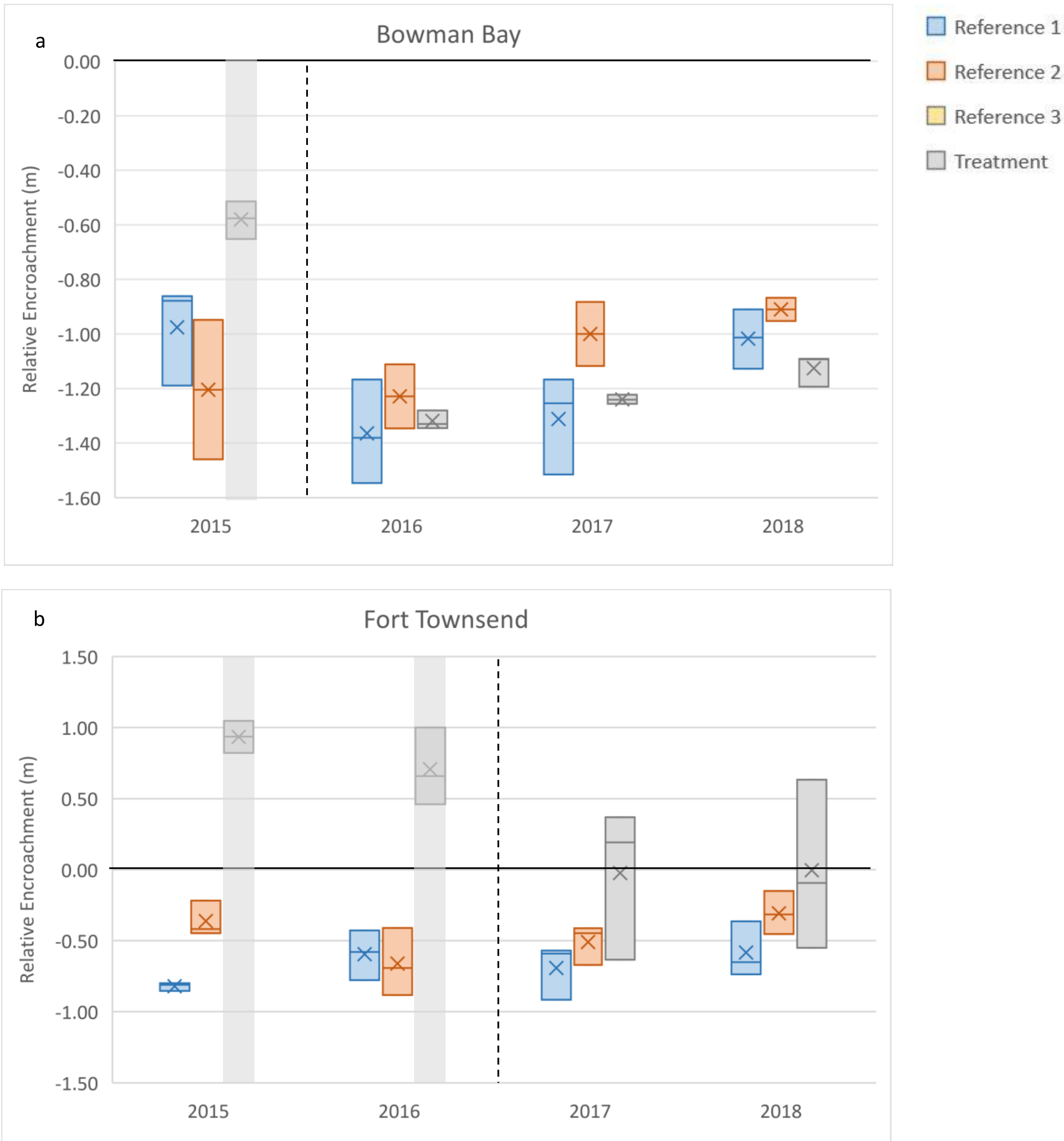


Figure 5.6a-b. Comparison of relative encroachment (RE) (waterward advance of beach toe on MHHW) measured at (a) Bowman Bay and (b) Fort Townsend. Box plots illustrate within-transect range and mean (denoted by X) of RE measured at each treatment and reference transects within a study site over time. Shaded bars identify armored transects (i.e. armored reference and armored treatment prior to restoration). Dash line marks event of armor removal. Note varying RE scales.

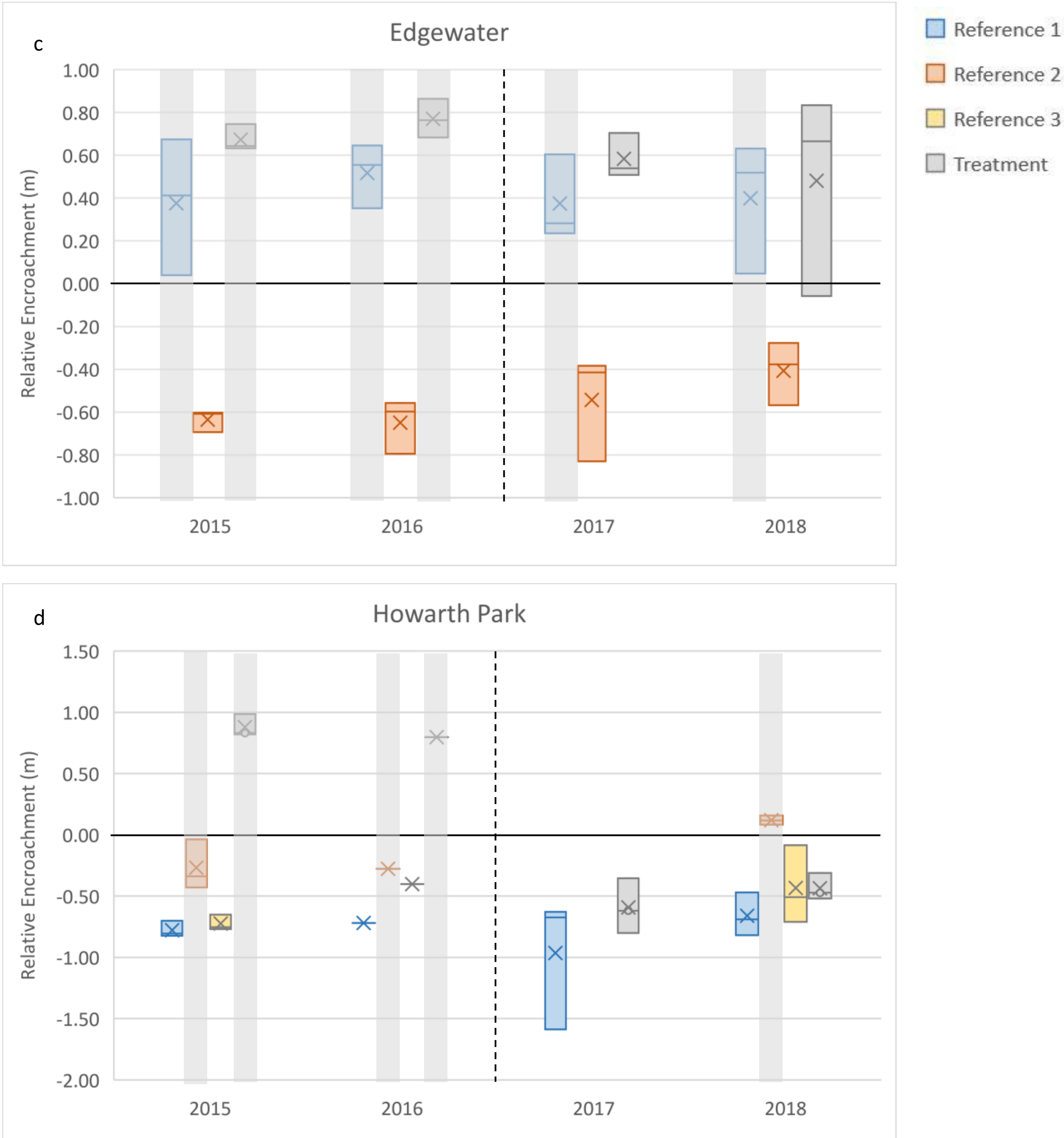
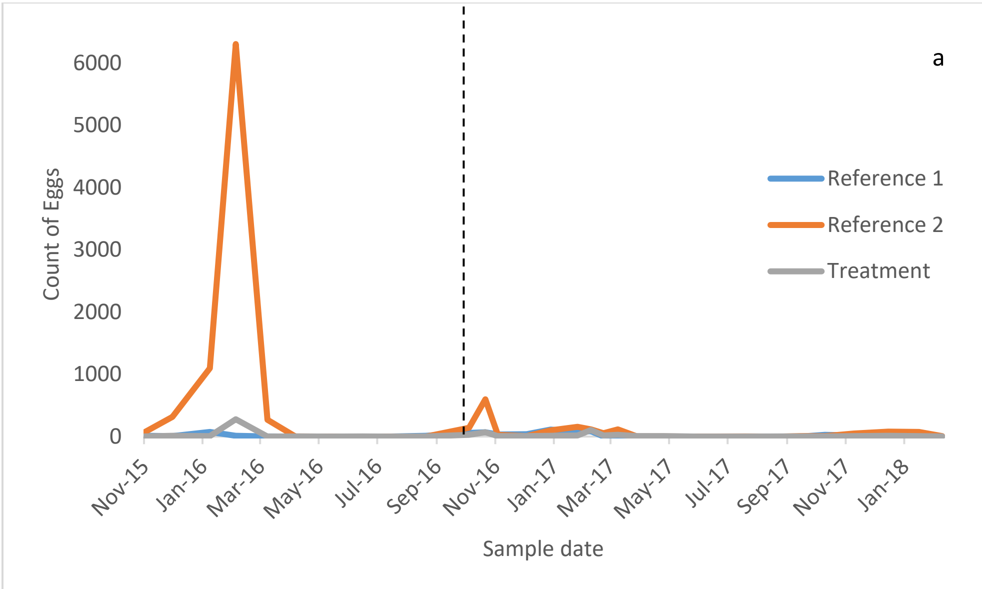


Figure 5.6c-d. Comparison of relative encroachment (RE) (waterward advance of beach toe on MHHW) measured at: (c) Edgewater and (d) Howarth Park[14]. Box plots illustrate within-transect range and mean (denoted by X) of RE measured at each treatment and reference transects within a study sites over time. Shaded bars identify armored transects (i.e. armored reference and armored treatment prior to restoration). Dash line marks event of armor removal. Note varying RE scales.

[14] In 2016, only one measure was taken from center transect and in 2017 only the treatment and reference 1 transect were surveyed.



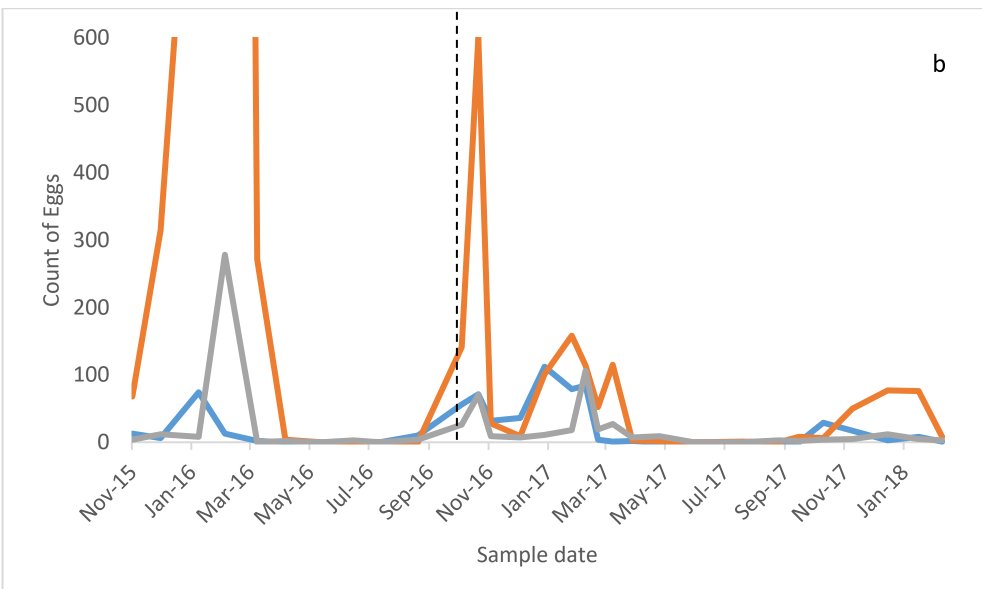


Figure 5.7a-b Count of surf smelt eggs detected in bulk sediment samples conducted monthly at treatment, reference 1 (armored) and reference 2 (unarmored) transects at Edgewater Beach, Eld Inlet, WA. Upper and lower figures plot same data on different y-axis, where upper plot (a) illustrates complete scale of egg count and lower plot (b) illustrates reduced scale. Vertical dash line marks event of armor removal

6. Discussion

6.1 Measured Effects

Due to the complex nature of nearshore ecosystems, impacts of restoration occur and vary across multiple spatial and temporal scales as both regional and local site-scale effects impart varying levels of influence. Therefore, effects of shoreline restoration may be detected and defined within and among multiple scales of incidence and influence. We identified varying trends and magnitudes of change in beach structure measured across a number of study sites before and after shoreline armor removal and restoration; some changes were more apparent than others.

6.1.2 Treatment effects. Many of our findings mirror results from previous studies in Puget Sound evaluating armor-induced impacts to nearshore structure and function. For example, where results in Dethier et al. (2016) and Heerhartz et al. (2014) found an overall reduction in riparian shade, log accumulation and wrack cover at armored beaches, our data illustrated an overall increase in riparian shade, log line accumulation and width, and total wrack cover with armor removal. In particular, it's been documented that shoreline armoring exhibits significant impacts to beach profile as a result of direct displacement (of upper beach), such as: lower elevation at beach toe, decrease in beach width, and increase of relative encroachment (of beach toe) on MHHW (Coyle and Dethier 2010, Dethier et al. 2016, Heerhartz et a. 2014). Accordingly, our measurements of beach profile at restored beaches, where armoring was removed, exhibited an overall increase in elevation at beach toe, extension of beach width and decrease in relative encroachment.

6.1.3 Regional and local effects. There are fundamental differences in the geomorphic setting of our broad sample area that can exert influence on beach parameters at multiple scales regardless of restoration effect. Although restoration (i.e. treatment) transects overall displayed greater (and often opposing) extent of change compared to armored or unarmored reference transects, there were some instances where regional or local effect regardless of transect treatment appeared to exert measurable influence. Measures of beach slope, for example, did not illustrate a uniform response from restoration treatment. Previous assessments of armor impacts with regard to broad-scale variation found several processes more descriptive of regional or geomorphic setting than armor-specific effect (e.g., Dethier et al. 2016, Heerhartz et al. 2014). This may be particularly true for measures of beach slope. For low-energy beaches, as those generally described in Puget Sound, beach slope may not change drastically to site-specific influence (e.g., Toft et al. 2013), but rather to broader scale wave and sediment processes such as proportion drift cell armored (i.e. cumulative sediment impoundment) (Dethier et al. 2016). In a similar vein, the sediment character of Puget Sound beaches are defined by complex geological history and dynamic transport processes, so that variation in size and composition reflect larger drift scale processes (Dethier et al. 2016, Heerhartz et al. 2014), seasonal wave energy, and local movement patterns (Toft et al. 2013). The results from sediment samples exhibited strong proportions of sand and gravel Sound-wide, but no apparent difference in mean composition as a result of restoration treatment.

The complex shorelines of Puget Sound introduce opportunity for unique site-specific response to armor removal. For example, at Edgewater Beach in south Puget Sound, local beach conditions at this site were distinctive in presence and extent of overhanging vegetation, despite the emplacement of shoreline armor. At this site in particular, the removal of shoreline armor (and associated fill) resulted in a shallow collapse of the upland vegetated bluff, and drastically reduced the extent overhanging vegetation (i.e. riparian shade).

6.1.4 Temporal scales. Our monitoring efforts describe only the first few years of shoreline condition following (restoration) impact. More comprehensive measurements of annual variability within a restoration site can provide insight regarding the temporal scale at which systems respond to impact (or removal of impact), and therefore the timescales at which change can be measured (see Dethier et al. 2016).. This may be critical for discrete restoration actions (such as armor removal), where the initial change following an action is often accelerated (Brandon et al. 2013). As such, a single measurement at any given location or time may not accurately represent short or long-term effects. Our forage fish sampling design and data illustrate this concept. We lacked confidence in results from spatially and temporally discrete surveys (within a site) to indicate true presence of eggs or suitability of spawning habitat. This uncertainty was supported by the monthly variation observed at one south Puget Sound site. In a study by Quinn et al. (2012) assessing the pattern of intertidal spawn use of surf smelt in Puget Sound, the findings emphasized that "failure to detect eggs in a few samples remains poor evidence of absence of (smelt) spawning just as relatively low abundance of eggs in a few samples at a site may not be indicative of the importance of that site over an annual cycle."

<u>6.2 Shoreline Monitoring</u>

For the purposes of this monitoring report, we did not test for the relationship(s) between the suite of observed response and predictor variables. Therefore, definitive determinations of significant cause and effect were not established and interpretation of our findings must be made conservatively. Still, we are confident that data provides invaluable insights into the multi-scale spatial and temporal effect of nearshore restoration and impact of shoreline armor. This document is intended to provide a functional source of data on shoreline condition and monitoring design that can then be used to evaluate assumptions of nearshore ecosystems, measure effectiveness of restoration action, and reduce uncertainties in future conservation and management actions. Our monitoring plan and study design was effective in providing high-quality data on beach condition and potential restoration effects for the following key reasons:

(1) Baseline surveys. At each restoration location (i.e. study site) we completed at least one year of baseline surveys prior to armor removal and restoration. Before-after monitoring designs can increase scale of inference and aid interpretation of restoration effects (Lee et al. 2018). Baseline surveys allowed for more robust investigation of shoreline change as a result of restoration. Although not all restoration projects were implemented within our monitoring timeframe, with baseline surveys, we incorporated flexibility into our study design and created potential for future survey efforts.

(2) Reference sites. In many cases, beach dynamics are driven largely by external factors (i.e. local geology, wave exposure, tidal range) (Brandon at el. 2013). At each restoration site, we surveyed paired reference transects (armored and/or unarmored) within a similar geomorphic setting but outside of direct restoration impact. Paired treatment and reference transects enabled distinction of alternative effects (e.g., natural variability) on a system apart from or in concert with restoration effect.

(3) Spatial framework. Because the geomorphic setting and landscape processes in Puget Sound vary and overlap across and within any given region, this innate heterogeneity of nearshore condition should be reflected in monitoring design (Brandon et al. 2013). Study sites encompassed the full reach of Puget Sound and represented each north, central and southern regions: from the unique structure of the San Juan Islands, to the western reaches of Port Townsend Bay, along the most-heavily developed central Puget Sound, and to the southern extent of Eld Inlet in south Puget Sound.

(4) Temporal framework. Nearshore processes (structure and function) occur and are impacted along a spectrum of temporal scales (days, season, years, decades). Similar to the complex spatial framework of Puget Sound, the dynamic temporal scales of ecosystem processes must be incorporated in monitoring design. Surveys were completed annually during summer months 2015 to 2018 to capture both near-term and long-term response. However, a comprehensive understanding of lasting effects may require monitoring up to 10 years and beyond (Brandon et al. 2013, Lee et al. 2018).

(5) Structure, consistency and repeatability. Standard proven survey methods were used consistently across our monitoring framework (e.g., UW Shoreline Toolbox) before and after restoration, within both test and reference sites, and across restoration locations. This allows for more direct comparison of monitoring parameters (Brandon et al. 2013), and insures applicability and repeatability beyond the limits of our study and this report.

There is always more which remains to be investigated, particularly as our knowledge of comprehensive and long-last effects of ecosystem degradation and nearshore restoration is limited still. While our study design and monitoring data can offer the restoration community a breadth of valuable information, we acknowledge several challenges of our survey method and monitoring design and offer opportunities for improvement in future (internal and external) effort:

(1) Sample size. Increase spatial and temporal spread and replication across multiple scales (e.g., at least 5 sites within each region) to capture innate variability in shoreline condition (i.e. different local and regional processes) and effectively quantify both short-term and long-term effects. Measurements and assessments should appropriately encompass predicted timeframes for measured structural and functional system response (Brandon et al. 2013) (e.g., temporal and spatial scales of detectable armor impacts provided in Dethier et al. (2016)).

(2) Cumulative and threshold impacts. Quantify effect of restoration with regard to broader scale cumulative impacts. Cumulative impacts are the result of collective ecosystem degradation (e.g.,

percent drift cell armored (Dethier et al. 2016)). There is still little known with regard to cumulative impacts, but it is likely that impacts to shoreline condition far extend the physical effects, and include changes to geological, chemical and biological systems within the nearshore (Coyle and Dethier 2010). Additional to cumulative effects, threshold impacts occur when a critical limit is breached, and an ecosystem effect is triggered. One potential threshold impact in nearshore systems is the relative encroachment of beach toe (armored or unarmored) on local MHHW and its effect on critical structure responses such as log accumulation (Dethier et al. 2016). Quantifying both cumulative and threshold effects is important to identifying potential indirect or latent effects to an ecosystem.

(3) Ecological linkages. Draw functional relationships between restoration impacts to nearshore ecosystem and resulting ecological function and biological resources. The nearshore environment is critical to a multitude of important Puget Sound species; it defines a functional interface between terrestrial and marine systems, and represents a critical link in marine food web dynamics (i.e. forage fish (Penttila 2007, juvenile salmon (Heerhartz and Toft 2015, Toft et al. 2013) and wrack invertebrates (Heerhartz et al. 2015)). While the ecosystem effects of nearshore degradation are inevitable, empirical evidence linking biological effects are limited and the ecological consequences are not wholly understood (Coye and Dethier 2010, Rice 2010, Williams and Thom 2001). Therefore, the functional response of biological components to nearshore restoration is equally limited, and quantitative studies at multiple scales (e.g., local, regional, cumulative) must be implemented. Of particular interest is the success of armor removal and restoration in repairing degraded or displaced forage fish spawning habitat. Surf smelt and sand lance are obligate intertidal spawners (Penttila 2007), and their spawning success relies on several functional beach attributes impacted by shoreline armor including beach access, riparian shade, and physical beach conditions (e.g., beach slope, sediment grain size) (Quinn et al. 2012 and references therein). Accordingly, the removal of impact and restoration of habitat structure may have beneficial effects on forage fish species, but results and mechanisms demand empirical study.

(4) Statistical analysis. Raw data describing monitoring metrics (i.e. process indicators, structural responses and functional implications) should be processed and converted into actionable information for statistical analysis (Brandon et al. 2013) to better support, validate and defend interpretations.

Ecosystem restoration is an ever-evolving process of development, implementation and monitoring (Fresh et al. 2004). For ecosystem restoration to be successful, we must continually adapt practices to new and advancing knowledge of dynamic nearshore processes. We must prioritize detailed, quantitative studies that encompass multi-scale processes of and impacts to the Puget Sound ecosystem. This will be particularly important as broader spatial and temporal effects come to light, such as the collective effects of growing coastal development, to effectively identify, implement and evaluate of successful restoration actions.

7. Conclusions

The process, structure and function of nearshore ecosystems across Puget Sound have been significantly degraded and resulted in substantial impacts to many important biological, social and cultural resources (Fresh et al. 2004). It is believed that recovery of these systems can be achieved through strategic, effective, process-based restoration action (Cereghino et al. 2012). The fundamental assumption of ecosystem recovery and process-based restoration is that if the source of significant or sustained impact to a system is removed, then the system will be able to re-establish or significantly improve fundamental form and function (Fresh et al. 2004). This concept, along with previous studies of ecosystem processes and impact effects, suggests that removal of prevalent and widespread shoreline armor may reverse negative impacts to nearshore systems and restore or re-establish critical ecosystem process, structure and function.

Successful ecosystem restoration is defined by not only the action, but the ability to determine the effect on nearshore condition. While restoration actions are based on well-informed assumptions, they involve uncertainties inherent to ecosystem restoration (Brandon et al. 2013). Monitoring provides an effective tool to enhance understanding of nearshore ecosystems, and investigate the innate assumptions and uncertainties of complex systems, reduce uncertainties an increase effectiveness in conservation and management actions, and support the restoration community, and community at large, in Puget Sound (Brandon et al. 2013).

The issue and importance of nearshore restoration will grow exponentially as coastal development and shoreline modification continues to advance in Puget Sound, particularly as we accelerate cumulative impacts, breach threshold effects, and encounter predicted advance of sea levels on coastal structure. Making informed decisions about how, where and whether to armor (or restore) shorelines will be especially important in coming decades, to address conflicting concerns of shoreline protection (i.e. protection of developed shorelines from increased sea levels, storm damage and potential erosion) and shoreline restoration of critical ecosystem function (Shipman 2010).

8. References

Brandon, T., Gleason, n., Simenstad, C., and Tanner, C. 2013. Puget Sound nearshore ecosystem restoration project monitoring framework. Prepared for the Puget Sound Nearshore Ecosystem Restoration Project. Published by Washington Department of Fish and Wildlife, Olympia, WA, and U.S. Army Corps of Engineers, Seattle, WA.

Brennan, J.S. and Culverwell, H. 2005. Marine Riparian: An assessment of riparian functions in marine ecosystems. Published by Washington Sea Grant Program, Seattle, WA.

Brennan, J.S. 2007. Marine riparian vegetation communities of Puget Sound. Prepared for Puget Sound Nearshore Partnership Report No. 2007-02. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Carman, R., Taylor, K., and Skowlund, P. 2010. Regulating shoreline armoring *in* Puget Sound in Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., Dinicola, R.S. (Eds.). 2010. Puget Sound shorelines and the impacts of armoring: proceedings of a state of the science workshop, May 2009. U.S. Geological Survey, Reston, VA

Cereghino, P., Toft, J., Simenstad, C., Iverson, E., Campbell, S., Behrens, C., and Burke, J. 2012. Strategies for nearshore protection and restoration in Puget Sound. Prepared for the Puget Sound Nearshore Ecosystem Restoration Project. Published by Washington Department of Fish and Wildlife, Olympia, WA, and U.S. Army Corps of Engineers, Seattle, WA.

Coyle, J.M. and Dethier, M.N. 2010. Review of shoreline armoring literature *in* Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., Dinicola, R.S. (Eds.). 2010. Puget Sound shorelines and the impacts of armoring: proceedings of a state of the science workshop, May 2009. U.S. Geological Survey, Reston, VA

Dethier, M.N. 1990. A marine and estuarine habitat classification system for Washington State. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA

Dethier, M.N. 2010. Overview of the ecology of Puget Sound beaches *in* Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., Dinicola, R.S. (Eds.). 2010. Puget Sound shorelines and the impacts of armoring: proceedings of a state of the science workshop, May 2009. U.S. Geological Survey, Reston, VA

Dethier, M.N., Raymond, W.W., McBride, A.N., Toft, J.D., Cordell, J.R., Ogston, A.S., Heerhartz, S.M., Berry, H.D. 2016. Multiscale impacts of armoring on Salish Sea shoreline: evidence for cumulative and threshold effects. Estuarine, Coastal and Shelf Science, 175, 106-117.

Dionne, P. 2015. Vortex method for separation of forage fish eggs from beach sediment: addendum to 2006 revision of Field Manual for Sampling Forage Fish Spawn in Intertidal Shore Regions. Washington Department of Fish and Wildlife, Olympia, WA.

Faulkner, H.F. 2017. Shoreline Restoration Monitoring in Puget Sound: Pre-restoration Report. Prepared for the Puget Sound Marine and Nearshore Grant Program. Prepared by Washington Department of Fish and Wildlife, Olympia, WA.

Faulkner, H.F. 2018. Shoreline Restoration Monitoring in Puget Sound: Post-restoration Report. Prepared for the Puget Sound Marine and Nearshore Grant Program. Prepared by Washington Department of Fish and Wildlife, Olympia, WA.

Finlayson, D.P. 2006. The geomorphology of Puget Sound beaches. Ph.D. dissertation. University of Washington, Seattle, WA.

Fresh, K. 1991. Washington Coastal Currents. Washington Department of Fisheries, XVI (6): 15 *cited in* MacDonald, K., Simpson, D., Paulson, B., Cox, J. and Gendron, J. 1994. Shoreline armoring effects on physical coastal processes in Puget Sound, Washington: Coastal erosion management studies volume 5. Washington Department of Ecology, Olympia, WA.

Fresh, K., Simenstad, C., Brennan, J., Dethier, M., Gelfenbaum, G., Goetz, F., … Tanner, C. 2004. Guidance for protection and restoration of the nearshore ecosystems of Puget Sound. Published for Puget Sound Nearshore Partnership Report No. 2004-02. Published by Washington Sea Grant Program, Seattle, WA.

Fresh, K., Dethier, M., Simenstad, C., Logsdon, M., Shipman, H., Tanner, C., … Newton, J. 2011. Implications of observed anthropogenic changes to the nearshore ecosystems in Puget Sound. Prepared for the Puget Sound Nearshore Ecosystem Restoration Project. Published by Washington Department of Fish and Wildlife, Olympia, WA, and U.S. Army Corps of Engineers, Seattle, WA.

Heerhartz, S.M., M.N. Dethier, J.D. Toft, J.R. Cordell, and A.S. Ogston. 2014. Effects of Shoreline Armoring on Beach Wrack Subsidies to the Nearshore Ecotone in an Estuarine Fjord. Estuaries and Coasts 37:1256-1268.

Heerhartz, S.M. and Toft, J.D. 2015. Movement patterns and feeding behavior of juvenile salmon (*Oncorhynchus spp*.) along armored and unarmored estuarine shoreline. Environmental Biology of Fishes. doi: 10.1007/s10641-015-0377-5

Johannessen, J. and MacLennan, A.2007. Beaches and Bluffs of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Johannessen, J., MacLennan, A., Blue, A., Waggoner, J., Williams, S., Gerstel, W., … Shipman, H. 2014. Marine shoreline design guidelines. Washington Department of Fish and Wildlife, Olympia, WA.

Lee, T.S., Toft, J.D., Cordell, J.R., Dethier, M.N., Adams, J.W., and Kelly, R.P. 2018. Quantifying the effectiveness of shoreline armoring removal on coastal biota of Puget Sound. PeerJ. doi: 10.7717/peerj.4275

Leschine, T.M. and Petersen, A.W. 2007. Valuing Puget Sound's Valued Ecosystem Components. Puget Sound Nearshore Partnership Report No. 2007-07. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

MacDonald, K., Simpson, D., Paulson, B., Cox, J. and Gendron, J. 1994. Shoreline armoring effects on physical coastal processes in Puget Sound, Washington: Coastal erosion management studies volume 5. Washington Department of Ecology, Olympia, WA.

MacLennan, A., Rishel, B., Johannessen, J., Lubeck, A., and Øde, L. 2017. Beach Strategies Phase 1 Summary Report: identifying target beaches to restore and protect. Prepared for the Puget Sound Nearshore Ecosystem Restoration Project. Published by Washington Department of Fish and Wildlife, Olympia, WA.

Morley, S.A., Toft, J.D., and Hanson K.M. 2012. Ecological effects of shoreline armoring on intertidal habitat of Puget Sound urban estuary. Estuaries and Coasts, 35, 774-784.

Moulton, L., and Penttila, D. 2001. San Juan County forage fish assessment project field manual for sampling forage fish spawn in intertidal shore regions. First edition. MJM Research, Lopez Island, WA, and Washington Department of Fish and Wildlife, Olympia, WA.

Munsch, S.H., Cordell J.R., and Toft, J.D. 2016. Fine-scale habitat use and behavior of a nearshore fish community: nursery function, predation avoidance, and spatiotemporal habitat partitioning. Marine Ecology Progress Series. 557:1-15

National Oceanic and Atmospheric Administration (NOAA). 2012. Vertical Datum Transformation Tool, VDatum, Version 3.3 (http://vdatum.noaa.gov)

Penttila, D. 2007. Marine Forage Fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-03. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Quinn, T. 2010. An Environmental and Historical Overview of the Puget Sound Ecosystem *in* Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., Dinicola, R.S. (Eds.). 2010. Puget Sound Shorelines and the Impacts of Armoring: Proceedings of a State of the Science workshop, May 2009. U.S. Geological Survey, Reston, VA

Quinn, T., Krueger, K., Pierce, K., Penttila, D., Perry, K., Hicks, T., and Lowry, D. 2012. Pattern of surf smelt, *Hypomesus pretiosus*, intertidal spawning habitat use in Puget Sound, Washington State. Estuaries and Coasts 35(5):1214-1228.

Rice, C.A. 2006. Effects of shoreline modification in northern Puget Sound: beach microclimate and embryo survival in summer spawning surf smelt (*Hypomesus pretiosus*). Estuaries and Coasts 29(1):63-71.

Rice, C.A. 2010. Biological Effects of Shoreline Armoring in Puget Sound: Past Studies and Future Directions for Science *in* Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., Dinicola, R.S. (Eds.). 2010. Puget Sound Shorelines and the Impacts of Armoring: Proceedings of a State of the Science workshop, May 2009. U.S. Geological Survey, Reston, VA

Schlenger, P., MacLennan, A., Iverson, E., Fresh, K., Tanner, C., Lyons, S., … Wick, A. 2011. Strategic needs assessment: Analysis of nearshore ecosystem process degradation in Puget Sound. Prepared for the Puget Sound Nearshore Ecosystem Restoration Project, Washington.

Shipman, H. 2010. The Geomorphic Setting of Puget Sound: Implications for Shoreline Erosion and the Impacts of Erosion Control Structures *in* Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., Dinicola, R.S. (Eds.). 2010. Puget Sound Shorelines and the Impacts of Armoring: Proceedings of a State of the Science workshop, May 2009. U.S. Geological Survey, Reston, VA

Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., Dinicola, R.S. (Eds.). 2010. Puget Sound shorelines and the impacts of armoring – Proceedings of a State of the Science workshop, May 2009. U.S. Geological Survey, Reston, VA

Shipman, H. 2017. The use of soft shoreline techniques: implications for the shoreline armor vital sign. Prepared for the Puget Sound Partnership. Prepared by Washington State Department of Ecology, Lacey, WA.

Simenstad, C., Logsdon, M., Fresh, K., Shipman, H., Dethier, M., and Newton, J. 2006. Conceptual model for assessing restoration of Puget Sound nearshore ecosystems. Prepared for Puget Sound Nearshore Partnership Report No. 2006-03. Published by Washington Sea Grant Program, Seattle, WA

Simenstad, C.A., Ramierz, M., Burker, J., Logsdon, M., Shipman, H., Tanner, C., … MacLennan, A. 2011. Historical change of Puget Sound shorelines: Puget Sound nearshore ecosystem project change analysis. Prepared for the Puget Sound Nearshore Ecosystem Restoration Project, Washington.

Thom, R.M, Shreffler, D.K., and MacDonald, K. 1994. Shoreline armoring effects on coastal ecology and biological resources in Puget Sound, Washington: Coastal erosion management studies volume 7. Washington Department of Ecology, Olympia, WA.

Toft, J.D., Ogston, A.S., Heerhartz, S.M., and Cordell, J.R. 2013. Ecological response and physical stability of habitat enhancements along an urban armored shoreline. Ecological Engineering 57:97-108

Washington Department of Fish and Wildlife (WDFW). n.d. Puget Sound Marine and Nearshore Grant Program (PSMNGP). Retrieved from https://wdfw.wa.gov/grants/ps_marine_nearshore/

Washington Department of Fish and Wildlife (WDFW). 2016. Forage fish spawning data accessed from the Spawning Location Map. Retrieved from http://wdfw.wa.gov/conservation/research/projects/marine_beach_spawning/

Washington Department of Natural Resources (DNR). 2001. Washington ShoreZone Inventory Data Dictionary. Olympia, WA: Nearshore Habitat Program.

Washington Sea Grant (WSG). Shoreline monitoring toolbox. Retrieved from wsg.washington.edu/toolbox

Washington State Department of Ecology (WA DOE). 2014. Shoreline data accessed from the Washington State Coastal Atlas. Retrieved from https://fortress.wa.gov/ecy/coastalatlas/

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377-392.

Williams, G.D. and Thom, R.M. 2001. Marine and estuarine shoreline modification issues. Prepared for the Washington Department of Fish and Wildlife, Washington Department of Ecology and Washington Department of Transportation, Washington.

9. Appendix.

9.1 Bowman Bay

Sponsor: Northwest Straits Foundation
Location: Anacortes, Skagit County, WAl
Approx. 155 m of sloping riprap removed in 2015.

Table 9.1a. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Bowman Bay (BB)		
Transect	Treatment	Reference 1	Reference 2
Armor Type	SR	N	N
Bank type	D	D	D
Latitude	48.4157959	48.4169968	48.4150010
Longitude	-122.6508352	-122.6521474	-122.6505402
Drift Cell Name	SK-G-1.1 / D-3	SK-G-1.1 / D-3	SK-G-1.1 / D-3
Drift Cell Direction	NAD	NAD	NAD
Landform Type	NAD-B	NAD-B	NAD-B

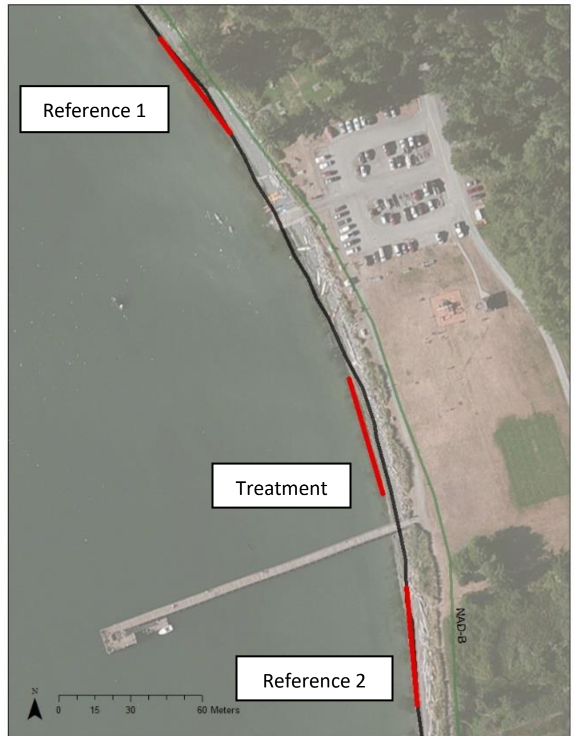


Figure 9.1a. WDFW restoration monitoring survey transects (red lines) established at Bowman Bay project site. See Appendix, Table 9.1 for additional details

Table 9.2a Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Bowman Bay (BB)					
	Site Status (survey year(s))	Pre (2015)			Post (2016, 2017, 2018)		
	Site Transect (shoreline status)	R1 (U)	R2 (U)	T (A)	R1 (U)	R2 (U)	T (R)
Physical Parameter	*n*	3	3	3	9	9	9
	Beach Toe (m above MLLW)	3.32	3.55	2.93	3.58	3.39	3.58
	Beach Width (m)	19.93	20.93	14.89	21.37	19.41	21.35
	Beach Slope (m to MLW)	0.130	0.134	0.147	0.133	0.136	0.133
	Relative Encroachment (m)	-0.98	-1.20	-0.58	-1.23	-1.05	-1.23
	Riparian Shade (% beach width)	22.9	0.0	0.0	17.9	0.0	0.0
Biological Parameter	*n*	10	10	10	30	30	30
	Wrack Cover (%)	6.4	40.0	29.3	64.8	68.7	45.8
	Wrack Width (m)	0.77	1.12	1.10	2.61	1.46	1.85
	Log Line (count)	4.2	4.4	0.6	2.9	5.7	1.6
	Log Line (width (m))	5.42	3.85	0.08	2.76	5.19	1.56

9.2 Brown Island

Sponsor: Friends of the San Juans

Location: Friday Harbor, San Juan County, WA

Approx. 90 m of vertical rock removed in 2015.

Table 9.2b Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Brown Island (BI)			
	Site Status (survey year(s))	Pre (2015)	Post (2016, 2017, 2018)		
	Site Transect (shoreline status)	T (A)	R1 (A)	R2 (U)	T (R)
Physical Parameter	*n*	3	9	9	9
	Beach Toe (m above MLLW)	2.43	2.45	3.00	2.64
	Beach Width (m)	17.01	14.82	34.00	18.14
	Beach Slope (m to MLW)	0.104	0.120	0.074	0.109
	Relative Encroachment (m)	-0.08	-0.09	-0.68	-0.29
	Riparian Shade (% beach width)	27.3	4.7	1.1	35.9
Biological Parameter	*n*	10	30	30	30
	Wrack Cover (%)	69.3	28.9	47.7	59.3
	Wrack Width (m)	1.59	1.14	1.58	1.75
	Log Line (count)	1.0	0.7	7.1	1.8
	Log Line (width (m))	0.31	0.46	6.34	1.40

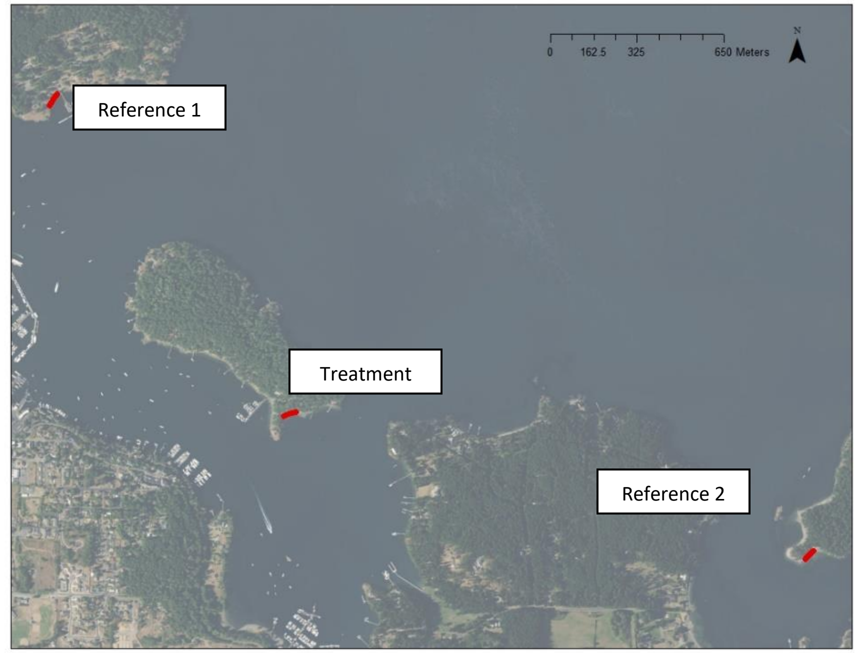


Figure 9.1b. WDFW restoration monitoring survey transects (red lines) established at Brown Island project site

Table 9.1b. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Brown Island		
Transect	Treatment	Reference 1	Reference 2
Armor type	VR	VR	N
Bank type	D	D	VB
Latitude	48.5353129	48.5456016	48.5311110
Longitude	-123.0007394	-123.0132387	-122.9741290
Drift cell name	BR-1	SJ-2 / 3	TU-1
Drift cell direction	NAD	NAD	RtoL
Landform type	MOD	NAD-B	AS

9.3 Burfoot Park

Sponsor: South Puget Sound Salmon Enhancement Group
Location: Olympia, Thurston County, WA
Approx. 94 m of sloping riprap proposed for removal.

Table 9.1c. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Burfoot Park (BF)		
Transect	Treatment	Reference 1	Reference 2
Armor type	VR	N	VC
Bank type	D	VB	VB
Latitude	47.1321543	47.1340573	47.1301284
Longitude	-122.9055991	-122.9059570	-122.9041304
Drift cell name	TH-6-1	TH-6-1	TH-6-1
Drift cell direction	RtoL	RtoL	RtoL
Landform type	MOD	FB	MOD, TZ

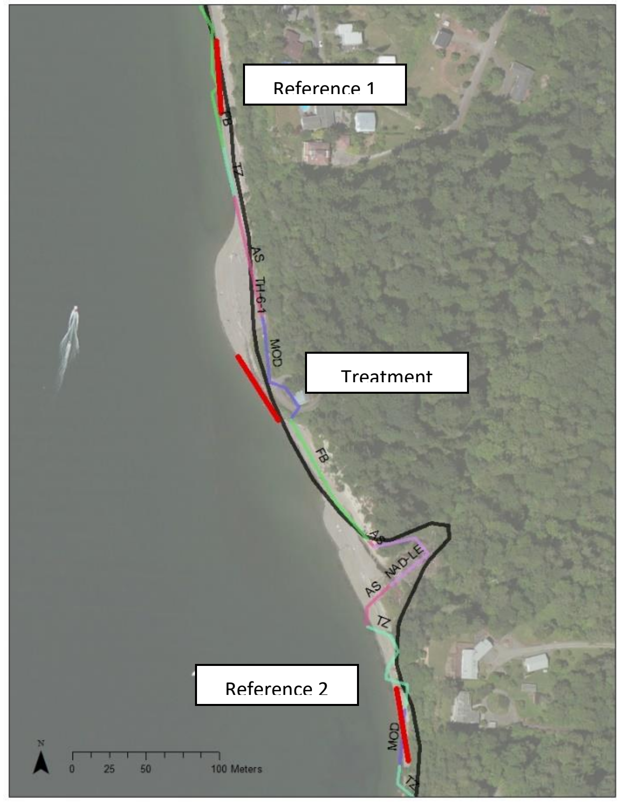


Figure 9.1c. WDFW restoration monitoring survey transects (red lines) established at Burfoot Park project site

Table 9.2c Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Burfoot Park (BF)		
	Site Status (survey year(s))	Pre (2016)		
	Site Transect (shoreline status)	R1 (U)	R2 (A)	T (A)
Physical Parameter	n	3	3	3
	Beach Toe (m above MLLW)	4.73	4.16	3.38
	Beach Width (m)	31.78	30.60	27.55
	Beach Slope (m to MLW)	0.119	0.105	0.090
	Relative Encroachment (m)	-0.34	0.22	1.01
	Riparian Shade (% beach width)	22.5	14.3	0.0
Biological Parameter	n	10	10	10
	Wrack Cover (%)	49.1	28.5	0.0
	Wrack Width (m)	0.41	0.30	0.00
	Log Line (count)	1.4	2.6	0.0
	Log Line (width (m))	0.89	2.62	0.00

9.4 Dawley

Sponsor: US Fish and Wildlife Service
Location: Blyn, Clallam County, WA
Approx. 60 m of vertical concrete removed in 2016.

Table 9.1d. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Dawley (DW)		
Transect	Treatment	Reference 1	Reference 2
Armor type	VC	N	N
Bank type	D	VB	VB
Latitude	48.0302091	48.0286808	48.0310445
Longitude	-123.0173970	-123.0158799	-123.0187070
Drift cell name	JF-17-3	JF-17-3	JF-17-3
Drift cell direction	RtoL	RtoL	RtoL
Landform type	MOD	FB, TZ	FB

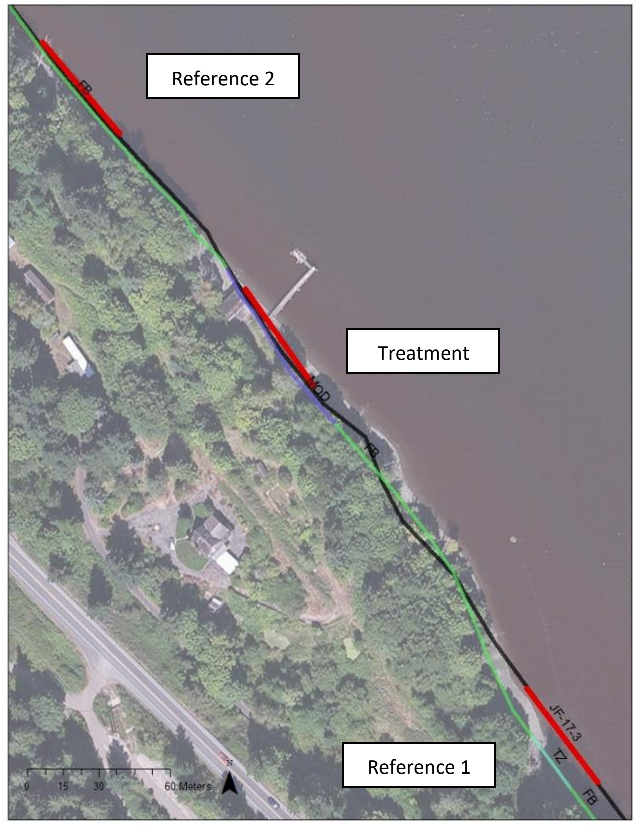


Figure 9.1d. WDFW restoration monitoring survey transects (red lines) established at Dawley project site

Table 9.2d Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Dawley (DW)					
	Site Status (survey year(s))	Pre (2016)			Post (2017, 2018)		
	Site Transect (shoreline status)	R1 (U)	R2 (U)	T (A)	R1 (U)	R2 (U)	T (R)
Physical Parameter	*n*	3	3	3	6	6	6
	Beach Toe (m above MLLW)	2.30	2.49	1.88	2.04	2.47	2.56
	Beach Width (m)	13.85	12.29	8.06	13.51	12.92	12.55
	Beach Slope (m to MLW)	0.111	0.141	0.137	0.094	0.133	0.143
	Relative Encroachment (m)	-0.01	-0.19	0.41	0.26	-0.18	-0.27
	Riparian Shade (% beach width)	50.4	88.8	4.3	56.7	68.3	28.1
Biological Parameter	*n*	10	10	10	20	20	20
	Wrack Cover (%)	57.2	16.7	10.5	31.1	9.9	10.9
	Wrack Width (m)	0.32	0.28	0.16	0.32	0.74	0.20
	Log Line (count)	0.6	0.8	0.0	0.4	0.1	0.9
	Log Line (width (m))	0.92	1.54	0.00	0.47	0.13	1.32

9.5 Edgewater

Sponsor: South Puget Sound Salmon Enhancement Group
Location: Olympia, Thurston County, WA
Approx. 215 m of vertical concrete removed in 2016.

Table 9.1e. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Edgewater (EW)		
Transect	Treatment	Reference 1	Reference 2
Armor type	VC	VC	N
Bank type	VB	VB	EB
Latitude	47.1533311	47.1522962	47.1550676
Longitude	-122.9294300	-122.9302728	-122.9281315
Drift cell name	TH-8-5	TH-8-5	TH-8-5
Drift cell direction	LtoR	LtoR	LtoR
Landform type	MOD	MOD, FB	FB

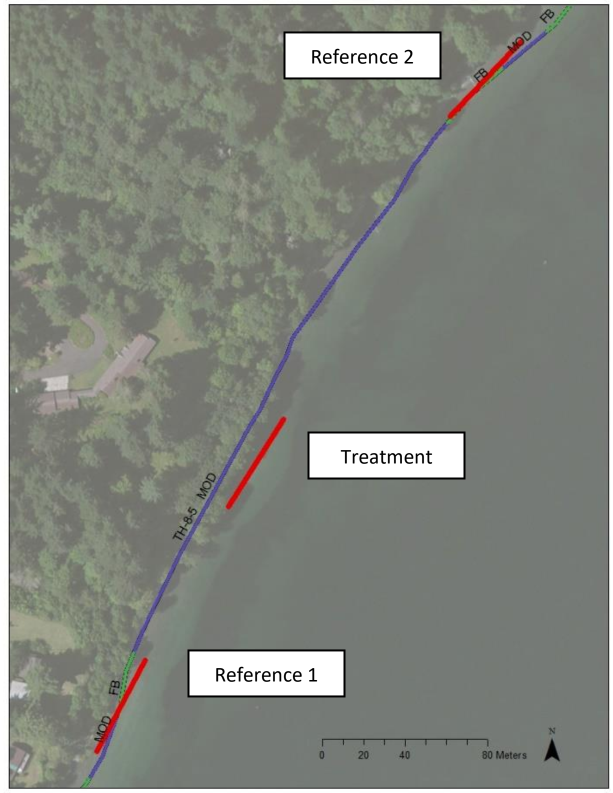


Figure 9.1e. WDFW restoration monitoring survey transects (red lines) established at Edgewater project site

Table 9.2e Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Edgewater (EW)					
	Site Status (survey year(s))	Pre (2015, 2016)			Post (2017, 2018)		
	Site Transect (shoreline status)	R1 (A)	R2 (U)	T (A)	R1 (A)	R2 (U)	T (R)
Physical Parameter	*n*	6	6	6	6	6	6
	Beach Toe (m above MLLW)	3.92	5.01	3.65	3.98	4.84	3.84
	Beach Width (m)	27.71	36.60	26.89	27.30	36.73	26.72
	Beach Slope (m to MLW)	0.108	0.112	0.101	0.112	0.107	0.109
	Relative Encroachment (m)	0.45	-0.64	0.72	0.39	-0.48	0.53
	Riparian Shade (% beach width)	15.8	9.4	53.0	15.4	16.3	9.4
Biological Parameter	*n*	20	20	20	20	20	20
	Wrack Cover (%)	22.2	25.1	13.2	17.8	32.1	40.7
	Wrack Width (m)	0.93	1.69	0.86	3.56	3.72	5.87
	Log Line (count)	0.5	3.5	0.2	0.3	0.5	0.7
	Log Line (width (m))	0.70	4.97	0.45	0.10	0.35	0.51

9.5 Family Tides Farm

Sponsor: Friends of the San Juans
Location: Eastsound, San Juan County, WA
Approx. 45 m of sloping riprap removed in 2015.

Table 9.1f. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Family Tides Farm (FTF)	
Transect	Treatment	Reference 1
Armor type	SR	N
Bank type	D	D
Latitude	48.6109080	48.6104938
Longitude	-122.9810333	-122.9813197
Drift cell name	OR-15 / 16	OR-15 / 16
Drift cell direction	NAD	NAD
Landform type	NAD-B	NAD-B

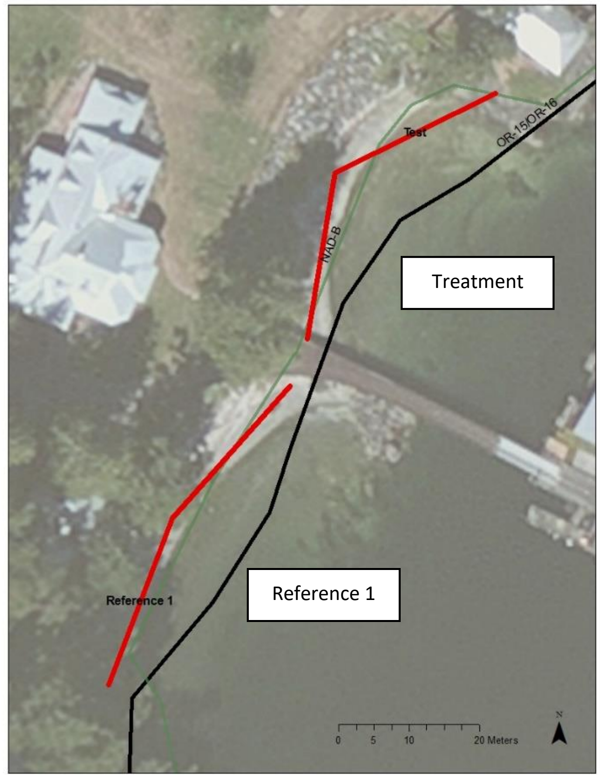


Figure 9.1f. WDFW restoration monitoring survey transects (red lines) established at Family Tides Farm project site

Table 9.2f Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Family Tides Farm (FTF)		
	Site Status (survey year(s))	Pre (2015)	Post (2016, 2017, 2018)	
	Site Transect (shoreline status)	T (A)	R1 (U)	T (R)
Physical Parameter	*n*	3	9	9
	Beach Toe (m above MLLW)	2.81	2.67	3.09
	Beach Width (m)	16.02	13.51	21.30
	Beach Slope (m to MLW)	0.126	0.144	0.108
	Relative Encroachment (m)	-0.41	-0.27	-0.69
	Riparian Shade (% beach width)	0.0	17.5	9.2
Biological Parameter	*n*	10	30	30
	Wrack Cover (%)	44.5	65.2	52.4
	Wrack Width (m)	0.76	1.31	1.49
	Log Line (count)	2.8	6.1	5.6
	Log Line (width (m))	2.78	3.81	4.43

9.6 Fort Townsend State Park

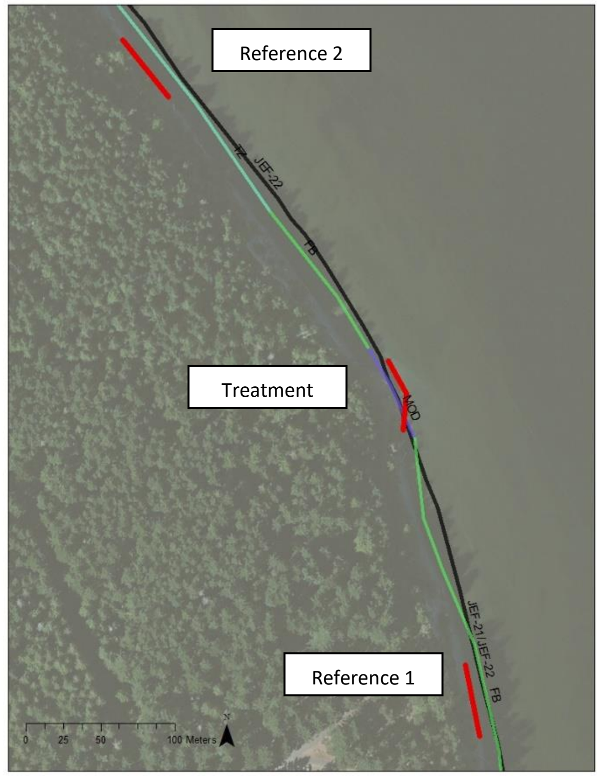


Figure 9.1g. WDFW restoration monitoring survey transects (red lines) established at Fort Townsend project site

Sponsor: Northwest Straits Foundation

Location: Port Townsend, Jefferson County, WA

Approx. 320 m of sloping riprap removed in 2016.

Table 9.1g. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Fort Townsend (FT)		
Transect	Treatment	Reference 1	Reference 2
Armor type	SR	N	N
Bank type	D	EB	EB
Latitude	48.0779633	48.0760643	48.0798573
Longitude	-122.7878747	-122.7872374	-122.7903244
Drift cell name	JEFF-22	JEF-21 / 22	JEFF-22
Drift cell direction	LtoR	DZ	LtoR
Landform type	MOD	FB	TZ

Table 9.2g Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Fort Townsend (FT)					
	Site Status (survey year(s))	Pre (2015, 2016)			Post (2017, 2018)		
	Site Transect (shoreline status)	R1 (U)	R2 (U)	T (A)	R1 (U)	R2 (U)	T (R)
Physical Parameter	*n*	6	6	6	6	6	6
	Beach Toe (m above MLLW)	3.37	3.17	1.84	3.30	3.07	2.68
	Beach Width (m)	27.04	57.93	12.20	25.80	60.74	21.02
	Beach Slope (m to MLW)	0.096	0.046	0.087	0.098	0.038	0.094
	Relative Encroachment (m)	-0.71	-0.51	0.82	-0.64	-0.41	-0.01
	Riparian Shade (% beach width)	0.3	5.5	0.0	0.6	5.2	2.0
Biological Parameter	*n*	20	20	20	20	20	20
	Wrack Cover (%)	18.1	4.0	6.3	22.5	20.0	39.3
	Wrack Width (m)	0.78	0.43	0.33	0.63	0.93	1.15
	Log Line (count)	0.7	2.3	0.4	1.5	1.4	0.8
	Log Line (width (m))	0.48	3.13	0.48	1.79	2.02	0.65

9.7 Howarth Park

Sponsor: Snohomish County

Location: Everett, Snohomish County, WA

Approx. 90 m of sloping riprap removed in 2016

Table 9.1h. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Howarth Park (HW)			
Transect	Treatment	Reference 1	Reference 2	Reference 3
Armor type	SR	N	VR	N
Bank type	D	D	D	D
Latitude	47.9641190	47.9644167	47.9607454	47.9598821
Longitude	-122.2410322	-122.2399499	-122.2463866	-122.2482734
Drift cell name	SN-1	SN-1	SN-1	SN-1
Drift cell direction	RtoL	RtoL	RtoL	RtoL
Landform type	MOD	MOD	MOD	MOD

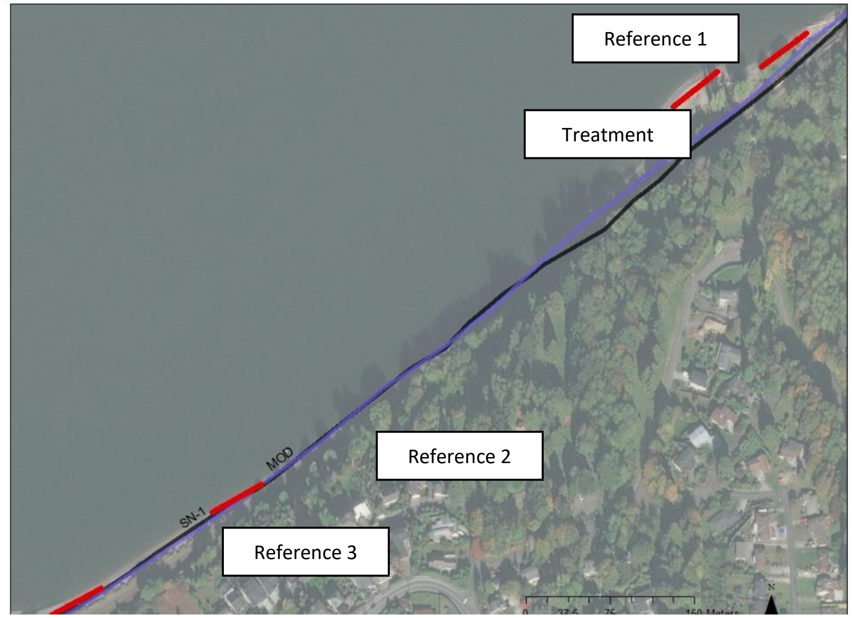


Figure 9.1h. WDFW restoration monitoring survey transects (red lines) established at Howarth Park project site

Table 9.2h Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Howarth Park (HW)							
	Site Status (survey year(s))	Pre (2015, 2016)				Post (2017, 2018)			
	Site Transect (shoreline status)	R1 (U)	R2 (A)	R3 (U)	T (A)	R1 (U)	R2 (A)	R3 (U)	T (R)
Physical Parameter	*n*	4	4	4	4	6	6	6	6
	Beach Toe (m above MLLW)	4.14	3.65	4.02	2.52	4.19	3.26	3.81	3.89
	Beach Width (m)	59.31	21.72	35.76	38.53	54.03	24.94	35.33	45.86
	Beach Slope (m to MLW)	0.056	0.129	0.092	0.044	0.064	0.097	0.085	0.068
	Relative Encroachment (m)	-0.76	-0.27	-0.64	0.86	-0.81	0.12	-0.43	-0.51
	Riparian Shade (% beach width)	3.7	0.0	0.0	0.0	3.5	0.0	0.0	0.0
Biological Parameter	*n*	20	20	20	20	20	20	20	20
	Wrack Cover (%)	72.9	38.1	53.3	0.5	58.0	11.8	19.4	38.3
	Wrack Width (m)	1.54	0.76	2.08	0.23	3.54	3.13	7.76	0.73
	Log Line (count)	7.3	2.0	8.8	0.0	7.4	1.9	9.0	1.4
	Log Line (width (m))	6.98	1.46	5.84	0.00	7.18	1.35	5.54	0.72

9.8 Maylor Point

Sponsor: Northwest Straits Foundation

Location: Oak Harbor, Island County, WA

Approx. 460 m of mixed material armor removed in 2018.

Table 9.1i. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Maylor Point (MP)		
Transect	Treatement	Reference 1	Reference 2
Armor type	VW	N	VC
Bank type	EB	VB	D
Latitude	48.2682534	48.2967401	48.2970019
Longitude	-122.6286389	-122.6101200	-122.6088455
Drift cell name	WHID-15 / 16	WHID-17	WHID-17
Drift cell direction	DZ	RtoL	RtoL
Landform type	MOD	AS	AS

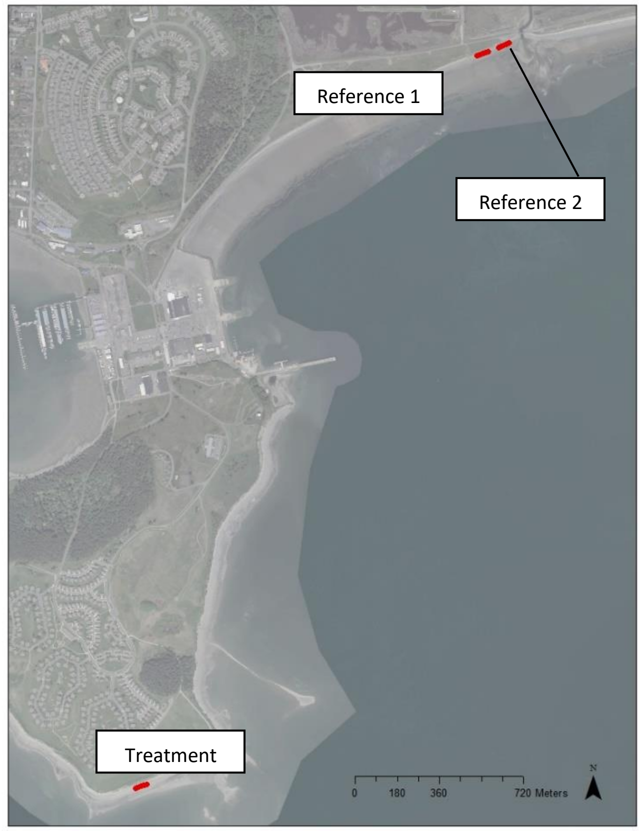


Figure 9.1i. WDFW restoration monitoring survey transects (red lines) established at Maylor Point project site.

Table 9.2i Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Maylor Point (MP)		
	Site Status (survey year(s))	Pre (2016, 2017)		
	Site Transect (shoreline status)	R1 (U)	R2 (A)	T (A)
Physical Parameter	*n*	6	6	6
	Beach Toe (m above MLLW)	4.54	3.73	3.97
	Beach Width (m)	35.73	38.74	36.13
	Beach Slope (m to MLW)	0.103	0.076	0.086
	Relative Encroachment (m)	-1.00	-0.20	-0.45
	Riparian Shade (% beach width)	0.0	0.0	0.0
Biological Parameter	*n*	20	20	20
	Wrack Cover (%)	8.6	8.0	58.3
	Wrack Width (m)	0.35	0.33	0.45
	Log Line (count)	9.0	6.9	2.7
	Log Line (width (m))	9.07	4.61	1.69

9.10 Ross Point

Sponsor: Washington Department of Fish and Wildlife
Location: Port Orchard, Kitsap County, WA
Approx. 20 m of vertical concrete proposed for removal.

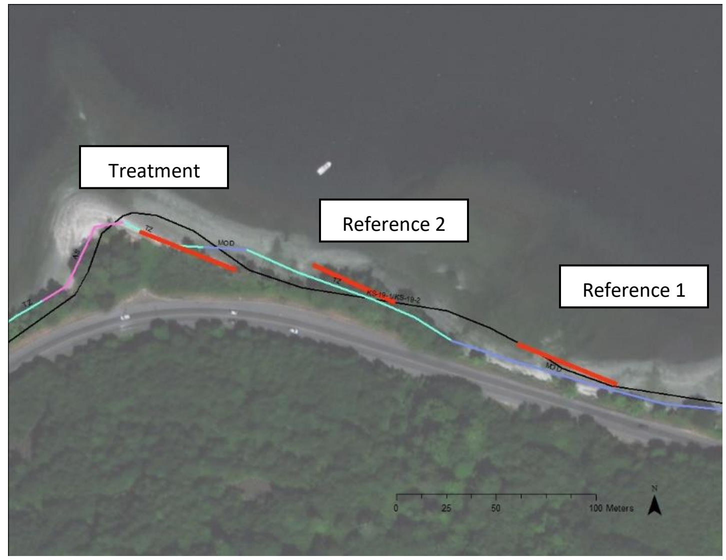


Figure 9.1j. WDFW restoration monitoring survey transects (red lines) established at Ross Point project site.

Table 9.1j. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Ross Point		
Transect	Treatment	Reference 1	Reference 2
Armor type	VC	VR	N
Bank type	D	D	D
Latitude	47.5396300	47.5390660	47.5395180
Longitude	-122.6613170	-122.6587860	-122.6602400
Drift cell name	KS-19-1 / 2	KS-19-1 / 2	KS-19-1 / 2
Drift cell direction	NAD	NAD	NAD
Landform type	MOD, TZ	MOD	TZ

Table 9.2j Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Ross Point (RP)		
	Site Status (survey year(s))	Pre (2018)		
	Site Transect (shoreline status)	R1 (A)	R2 (U)	T (R)
Physical Parameter	*n*	3	3	3
	Beach Toe (m above MLLW)	2.92	3.80	3.08
	Beach Width (m)	23.39	21.97	17.71
	Beach Slope (m to MLW)	0.091	0.134	0.125
	Relative Encroachment (m)	0.65	-0.22	0.50
	Riparian Shade (% beach width)	4.8	24.7	0.0
Biological Parameter	*n*	10	10	10
	Wrack Cover (%)	0.0	10.7	0.0
	Wrack Width (m)	0.00	0.21	0.00
	Log Line (count)	0.0	0.0	0.0
	Log Line (width (m))	0.00	0.00	0.00

9.11 Shannon Point

Sponsor: Northwest Straits Foundation

Location: Anacortes, Skagit County, WA

Approx. 145 m of sloping riprap proposed for removal.

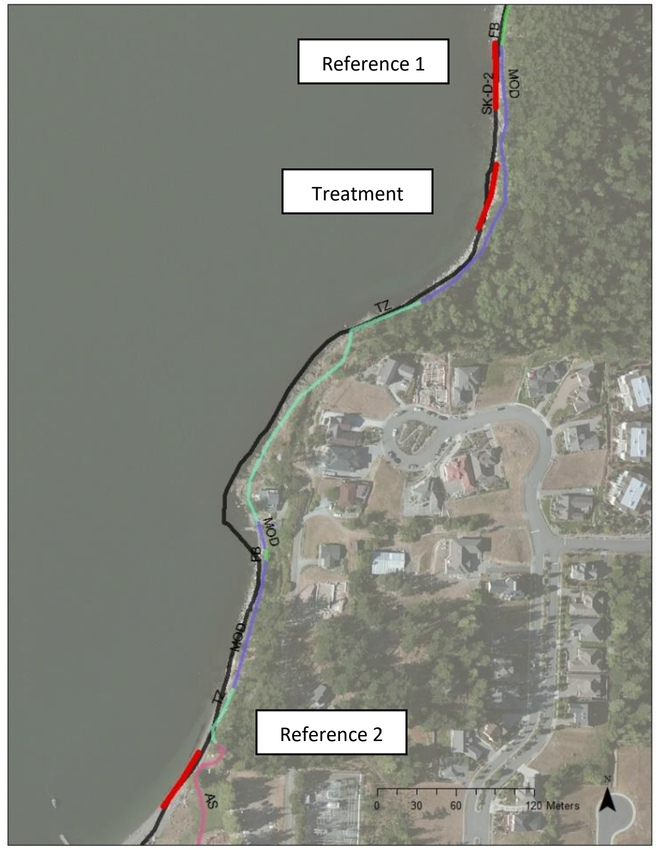


Figure 9.1k. WDFW restoration monitoring survey transects (red lines) established at Shannon Point project site.

Table 9.1k. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Shannon Point		
Transect	Treatment	Reference 1	Reference 2
Armor type	VR	VR	N
Bank type	VB	VB	D
Latitude	48.5048596	48.5056612	48.5007055
Longitude	-122.6885327	-122.6885404	-122.6915225
Drift cell name	SK-D-2	SK-D-2	SK-D-2
Drift cell direction	RtoL	RtoL	RtoL
Landform type	MOD	MOD	AS

Table 9.2k Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Shannon Point (SP)		
	Site Status (survey year(s))	Pre (2015, 2016)		
	Site Transect (shoreline status)	R1 (A)	R2 (U)	T (A)
Physical Parameter	*n*	3	3	6
	Beach Toe (m above MLLW)	2.20	3.54	2.09
	Beach Width (m)	14.20	21.89	12.38
	Beach Slope (m to MLW)	0.101	0.127	0.105
	Relative Encroachment (m)	0.24	-1.11	0.36
	Riparian Shade (% beach width)	0.5	6.6	4.2
Biological Parameter	*n*	10	10	20
	Wrack Cover (%)	24.6	15.6	3.4
	Wrack Width (m)	1.04	0.70	0.28
	Log Line (count)	0.4	0.0	0.0
	Log Line (width (m))	0.40	0.00	0.00

9.12 Seahorse Siesta

Sponsor:
Northwest Straits Foundation
Location:
Langley, Island County, WA
Approx. 40 m of vertical concrete proposed for removal.

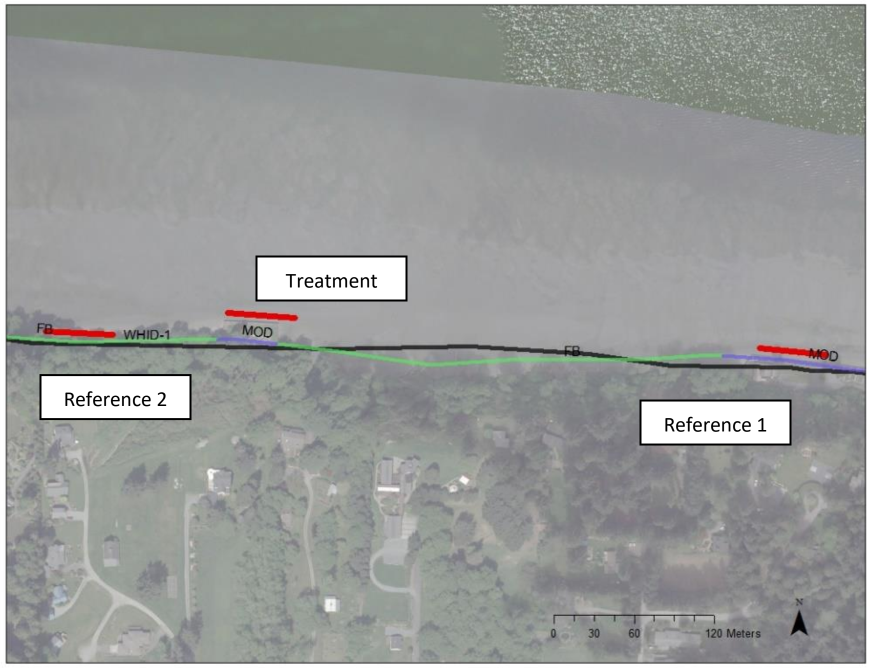


Figure 9.1l. WDFW restoration monitoring survey transects (red lines) established at Seahorse Siesta project site.

Table 9.1l. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Seahorse Siesta		
Transect	Treatment	Reference 1	Reference 2
Armor type	VC	VC	N
Bank type	VB	D	VB
Latitude	48.0436491	48.0434900	48.0434844
Longitude	-122.4227096	-122.4173672	-122.4245488
Drift cell name	WHID-1	WHID-1	WHID-1
Drift cell direction	RtoL	RtoL	RtoL
Landform type	MOD	MOD	FB

Table 9.2l Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Seahorse Siesta (SH)		
	Site Status (survey year(s))	Pre (2016, 2017)		
	Site Transect (shoreline status)	R1(A)	R2 (U)	T (A)
Physical Parameter	*n*	6	6	6
	Beach Toe (m above MLLW)	2.42	4.18	2.30
	Beach Width (m)	25.27	33.67	20.26
	Beach Slope (m to MLW)	0.062	0.099	0.072
	Relative Encroachment (m)	1.02	-0.75	1.13
	Riparian Shade (% beach width)	4.5	22.7	0.0
Biological Parameter	*n*	20	20	20
	Wrack Cover (%)	6.0	18.3	15.7
	Wrack Width (m)	0.36	0.86	1.38
	Log Line (count)	0.0	8.5	2.5
	Log Line (width (m))	0.00	5.44	1.78

9.13 Titlow Park

Sponsor: South Puget Sound Salmon Enhancement Group
Location: Tacoma, Pierce County, WA
Approx. 50 m of vertical concrete and rock removed in 2018.

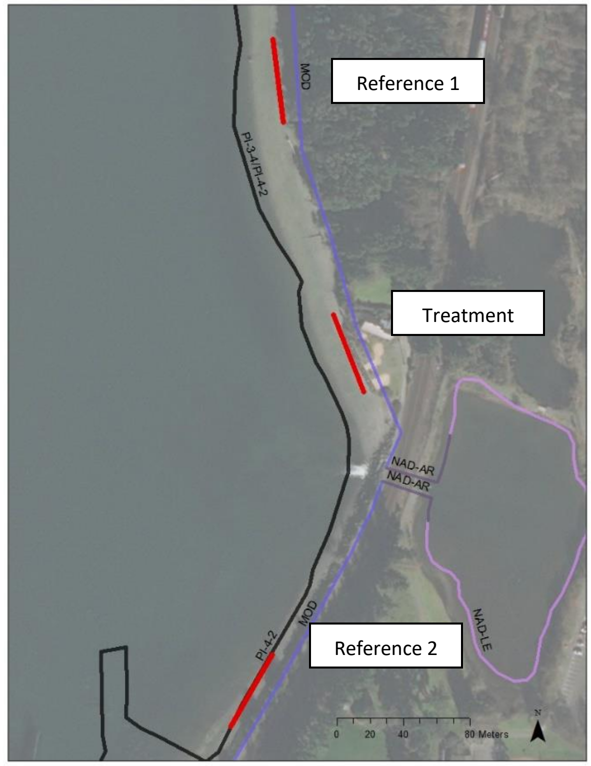


Figure 9.1m. WDFW restoration monitoring survey transects (red lines) established at Titlow Park project site.

Table 9.1m. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Titlow Park		
Transect	Treatment	Reference 1	Reference 2
Armor type	VC, SR	N	VR
Bank type	D	EB	D
Latitude	47.2494500	47.2481090	47.2481090
Longitude	-122.5521000	-122.5524600	-122.5524600
Drift cell name	PI-4-1	PI-4-1	PI-4-2
Drift cell direction	DZ	DZ	LtoR
Landform type	MOD	MOD	MOD

Table 9.2m Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Titlow Park (TL)					
	Site Status (survey year(s))	Pre (2016)			Post (2017, 2018)		
	Site Transect (shoreline status)	R1 (U)	R2 (A)	T (A)	R1 (U)	R2 (A)	T (R)
Physical Parameter	*n*	3	3	3	6	6	6
	Beach Toe (m above MLLW)	4.50	3.23	3.58	4.57	3.26	4.51
	Beach Width (m)	31.95	23.84	26.33	33.07	24.43	33.50
	Beach Slope (m to MLW)	0.113	0.099	0.102	0.111	0.098	0.108
	Relative Encroachment (m)	-0.59	0.68	0.33	-0.66	0.65	-0.60
	Riparian Shade (% beach width)	8.6	0.0	1.9	13.4	0.0	0.0
Biological Parameter	*n*	10	10	10	20	20	20
	Wrack Cover (%)	34.3	10.1	11.6	19.5	1.0	23.9
	Wrack Width (m)	0.46	0.23	0.43	0.35	0.04	0.32
	Log Line (count)	1.2	0.0	0.0	0.4	0.0	0.0
	Log Line (width (m))	1.83	0.00	0.00	0.23	0.00	0.00

9.14 Waterman

Sponsor: Whidbey Camano Land Trust
Location: Clinton, Island County, WA
Approx. 135 m of vertical wood removed in 2016.

Table 9.1n. Project site information by survey transect, including: armor type (sloping riprap (SR), vertical wood (VW), vertical riprap (VR), vertical concrete (VC), none (N)); bank type (eroding bank (EB), developed (D), vegetated bank (VB)); transect location (latitude, longitude); drift cell name and direction (no appreciable drift (NAD), right to left (RtoL), left to right (LtoR), divergent zone(DZ)), and; landform type (no appreciable drift-bedrock (NAD-B), modified (MOD), accretion (AS), feeder bluff (FB), transport zone (TZ)[a]. [a]Defined by WA Department of Ecology (2014).

Study Site	Waterman (WM)		
Transect	Treatment	Reference 1	Reference 2
Armor type	VW	N	N
Bank type	VB	VB	VB
Latitude	48.0001770	47.9980095	48.0023810
Longitude	-122.3718146	-122.3710634	-122.3719019
Drift cell name	IS-1	IS-1	IS-1
Drift cell direction	LtoR	LtoR	LtoR
Landform type	MOD	FB	FB

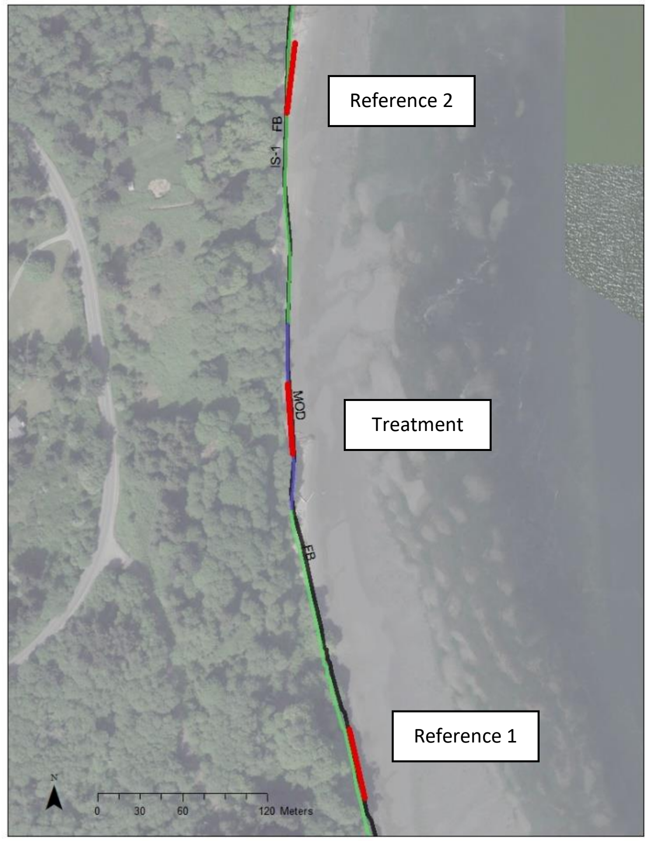


Figure 9.1n. WDFW restoration monitoring survey transects (red lines) established at Waterman project site.

Table 9.2n Value of key beach structure parameters measured at each survey transect within a study site, before and after shoreline armor removal and restoration. Table includes: site name and code; site status (pre, post) at survey year(s), and; site transect designation (R1=reference 1, R2= reference 2 and T=treatment) and shoreline status (A=armored, U=unarmored, R=restoration). Values listed are averaged within a transect and across survey years (where applicable). Sample size (*n*) included.

Study Site	Restoration Site (code)	Waterman (WM)					
	Site Status (survey year(s))	Pre (2016)			Post (2017, 2018)		
	Site Transect (shoreline status)	R1 (U)	R2 (U)	T (A)	R1 (U)	R2 (U)	T (R)
Physical Parameter	*n*	3	3	3	6	6	6
	Beach Toe (m above MLLW)	3.84	35.95	33.87	3.51	3.62	3.78
	Beach Width (m)	44.91	0.08	0.07	42.73	34.96	29.45
	Beach Slope (m to MLW)	0.067	-0.427	0.150	0.063	0.079	0.102
	Relative Encroachment (m)	-0.44	0.13	0.12	-0.11	-0.22	-0.38
	Riparian Shade (% beach width)	23.7	13.1	12.1	19.0	7.0	16.4
Biological Parameter	*n*	10	10	10	20	20	20
	Wrack Cover (%)	9.2	24.3	23.6	14.7	21.1	9.9
	Wrack Width (m)	0.08	0.24	0.22	6.78	0.42	1.32
	Log Line (count)	8.4	6.2	2.2	8.8	7.6	3.6
	Log Line (width (m))	7.65	5.23	1.73	4.57	4.30	3.01

9.15 Other Tables and Figures

Table 9.3. Average value (and sample size *n*) of key beach parameters measured at each armored (armored reference and armored test prior to restoration), unarmored (unarmored reference), and restored (test transect after armor removal) transect within north, central and south regions of Puget Sound, WA. Mean values are calculated across sample transects for each parameter.

		Transect			
Region	Parameter	Armored	Unarmored	Restored	Mean
North	*n*	27	45	27	99
	Beach Toe Elevation (m)	2.43	3.24	3.10	2.93
	Beach Width (m)	14.59	22.72	20.26	19.19
	Beach Slope	0.116	0.121	0.116	0.118
	Beach RE (m)	(0.04)	(0.89)	(0.73)	(0.55)
	Riparian Shade (% beach width)	5.57	9.58	15.04	10.06
	Log Line (count)	0.76	4.91	3.00	2.89
	Log line (width (m))	0.55	4.26	2.48	2.43
	Total Wrack Cover	28.97	53.37	52.39	44.91
	Percent Algae Wrack Cover	69.70	73.08	69.29	70.69
	Percent Seagrass Wrack Cover	9.74	9.07	9.59	9.47
	Percent Terrestrial Wrack Cover	20.57	17.85	21.12	19.85
Central	*n*	56	95	24	175
	Beach Toe Elevation (m)	2.88	3.43	3.23	3.18
	Beach Width (m)	25.52	35.51	27.22	29.42
	Beach Slope	0.086	0.086	0.102	0.091
	Beach RE (m)	0.40	(0.44)	(0.29)	(0.11)
	Riparian Shade (% beach width)	1.88	19.46	11.62	10.99
	Log Line (count)	1.75	4.90	1.68	2.77
	Log line (width (m))	1.22	3.91	1.42	2.19
	Total Wrack Cover	16.15	25.86	24.46	22.16
	Percent Algae Wrack Cover	60.81	47.73	71.76	60.10
	Percent Seagrass Wrack Cover	23.96	36.15	21.65	27.26
	Percent Terrestrial Wrack Cover	15.22	16.12	6.59	12.65
South	*n*	36	24	12	72
	Beach Toe Elevation (m)	3.66	4.76	4.17	4.20
	Beach Width (m)	26.75	34.57	30.11	30.48
	Beach Slope	0.103	0.111	0.108	0.108
	Beach RE (m)	0.55	(0.56)	(0.04)	(0.01)
	Riparian Shade (% beach width)	15.37	13.64	4.68	11.23
	Log Line (count)	0.38	1.43	0.35	0.72
	Log line (width (m))	0.43	1.73	0.25	0.80
	Total Wrack Cover	13.18	28.25	32.23	24.56
	Percent Algae Wrack Cover	86.80	85.84	94.92	89.19
	Percent Seagrass Wrack Cover	0.16	0.31	0.67	0.38
	Percent Terrestrial Wrack Cover	13.04	13.85	4.41	10.43

Table 9.4. Mean sediment grain size distributions (% total by weight) for each surface and sub-surface sample (collected within same beach footprint) collected at armored (armored reference and armored test prior to restoration) (*n* =37), unarmored (unarmored reference) (*n* =54), and restored (test transect after armor removal) (*n* =21) transects within north (*n* =33), central (*n* =55) and south (*n* =24) Puget Sound, WA. Total percent values are averaged across sample region. See Wentworth scale for size class designations (Appendix, Figure 9.3).

				Gravel					Sand			
Region	Sample	Transect	Cobble	Very Coarse	Coarse	Medium	Fine	Very Fine	Very Coarse	Coarse	Medium	Fine
North	Surface	Armored	0.00	2.82	8.54	24.33	29.43	10.94	5.40	8.54	6.98	3.01
		Unarmored	3.95	6.16	17.00	10.02	10.87	6.13	4.53	13.76	24.44	3.14
		Restored	0.00	8.94	6.32	8.40	7.99	4.60	2.89	8.77	38.10	14.00
	Sub-surface	Armored	1.13	4.43	11.17	19.86	19.92	10.22	5.43	10.49	12.65	4.69
		Unarmored	1.64	4.09	10.22	9.70	13.72	10.14	5.93	16.06	25.92	2.58
		Restored	0.00	0.89	4.49	8.73	8.26	5.47	4.05	14.63	37.34	16.15
Central	Surface	Armored	0.00	0.98	9.54	17.23	17.30	8.58	6.02	17.66	18.49	4.19
		Unarmored	2.22	9.96	16.46	11.78	6.63	5.38	3.82	14.26	25.45	4.05
		Restored	2.59	16.48	12.68	13.81	12.91	8.56	5.65	13.34	12.14	1.84
	Sub-surface	Armored	0.00	2.68	9.70	15.11	13.19	8.38	7.36	19.30	19.68	4.61
		Unarmored	2.27	5.61	9.75	11.06	7.08	6.53	6.01	19.50	27.70	4.49
		Restored	0.00	7.02	4.84	7.63	8.00	7.42	6.35	12.42	31.70	14.62
South	Surface	Armored	0.00	5.66	14.82	27.32	17.67	6.46	3.99	5.34	14.09	4.65
		Unarmored	0.94	6.03	6.25	11.80	4.56	2.51	3.76	22.54	36.69	4.93
		Restored	3.36	14.61	8.37	2.19	1.43	1.37	1.39	4.28	43.71	19.29
	Sub-surface	Armored	1.25	4.65	12.00	27.06	14.17	6.93	6.37	8.31	14.55	4.70
		Unarmored	0.00	8.76	10.32	9.12	4.61	3.34	4.36	21.16	33.89	4.43
		Restored	8.43	10.41	12.69	5.08	4.15	3.69	3.15	12.96	25.98	13.46
Total	Surface	Armored	0.00	3.15	10.97	22.96	21.47	8.66	5.13	10.51	13.19	3.95
		Unarmored	2.37	7.39	13.24	11.20	7.35	4.67	4.03	16.85	28.86	4.04
		Restored	1.99	13.34	9.12	8.13	7.44	4.84	3.31	8.80	31.32	11.71
	Sub-surface	Armored	0.79	3.92	10.96	20.68	15.76	8.51	6.39	12.70	15.63	4.67
		Unarmored	1.30	6.16	10.10	9.96	8.47	6.67	5.44	18.91	29.17	3.83
		Restored	2.81	6.10	7.34	7.14	6.80	5.53	4.52	13.34	31.67	14.74

Table 9.5. Count of Surf smelt and Sand Lance eggs detected in bulk sediment samples at each transect within a study site each year 2015 – 2018. Dash (-) indicates that no sample was collected (i.e. no restoration survey completed). Note that results do not include results from previous surveys (WDFW, 2016) or results from other organizations (e.g., Northwest Straits Foundation).

		2015		2016		2017		2018	
Site	Transect	Surf Smelt	Sand Lance	Surf Smelt	Sand Lance	Surf Smelt	Sand Lance	Surf Smelt	Sand Lance
BB	Ref 1	0	0	0	0	0	0	0	0
BB	Ref 2	0	0	0	0	0	0	0	0
BB	Test	0	0	0	0	0	0	0	0
BF	Ref 1	-	-	0	0	-	-	-	-
BF	Ref 2	-	-	0	0	-	-	-	-
BF	Test	-	-	0	0	-	-	-	-
BI	Ref 1	-	-	0	0	0	0	0	0
BI	Ref 2	-	-	0	0	0	0	0	0
BI	Test	0	0	0	0	0	0	0	0
DW	Ref 1	-	-	0	1	0	0	0	0
DW	Ref 2	-	-	1	2	0	0	0	0
DW	Test	-	-	0	0	0	0	0	0
EW	Ref 1	10	0	0	0	0	0	0	0
EW	Ref 2	6	0	13	0	1	0	0	0
EW	Test	71	0	0	0	0	0	0	0
FT	Ref 1	0	0	0	0	0	0	0	0
FT	Ref 2	0	0	0	0	0	0	0	0
FT	Test	0	0	0	0	0	0	0	0
FTF	Ref 1	-	-	0	0	0	0	1	0
FTF	Test	0	0	0	0	0	0	0	0
HW	Ref 1	28	0	-	-	0	0	6	0
HW	Ref 2	11	0	-	-	0	0	0	0
HW	Ref 3	0	0	-	-	0	0	0	0
HW	Test	0	0	-	-	0	0	0	0
MP	Ref 1	-	-	128	0	0	0	-	-
MP	Ref 2	-	-	4	0	0	0	-	-
MP	Test	-	-	0	0	0	0	-	-
RP	Ref 1	-	-	-	-	-	-	0	0
RP	Ref 2	-	-	-	-	-	-	0	0
RP	Test	-	-	-	-	0	0	0	0
SP	Ref 1	-	-	-	-	-	-	-	-
SP	Ref 2	0	0	-	-	-	-	-	-
SP	Test	0	0	-	-	-	-	-	-
SS	Ref 1	-	-	0	0	0	0	-	-
SS	Ref 2	-	-	0	0	0	0	-	-
SS	Test	-	-	0	0	0	0	-	-
TL	Ref 1	-	-	0	0	0	0	0	0
TL	Ref 2	-	-	0	0	0	0	0	0
TL	Test	-	-	1	0	0	0	0	0
WM	Ref 1	-	-	0	0	0	0	0	0
WM	Ref 2	-	-	0	0	0	0	0	0
WM	Test	-	-	0	0	0	0	0	0

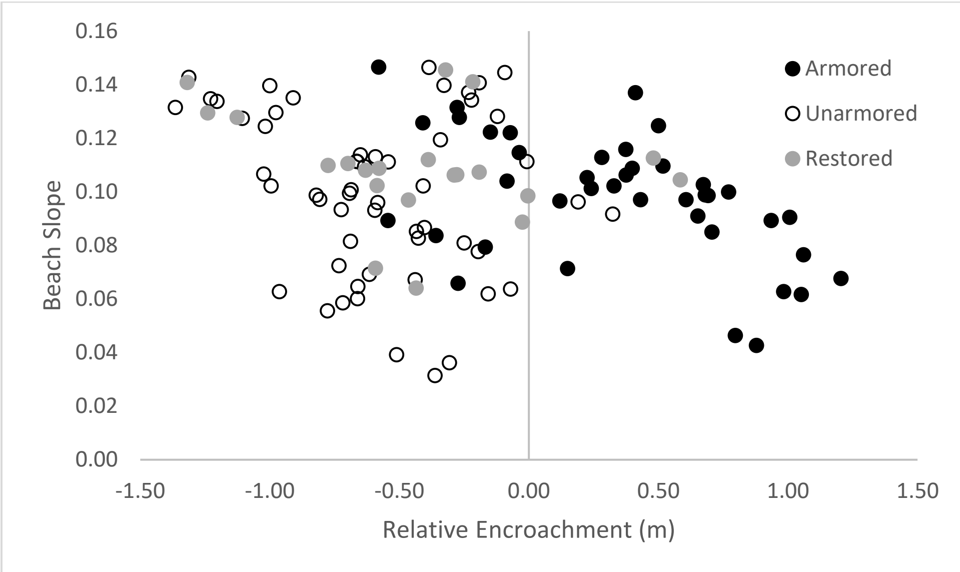


Figure 9.2 Scatterplot of mean beach slope measured at a transect relative to encroachment of beach toe on local MHHW. Transects are differentiated by shore status as armored (including test transects before armor removal) (*n*=40), unarmored (unarmored reference transects only) (*n*=55), and restored (test transects after armor removal) (*n*=21).

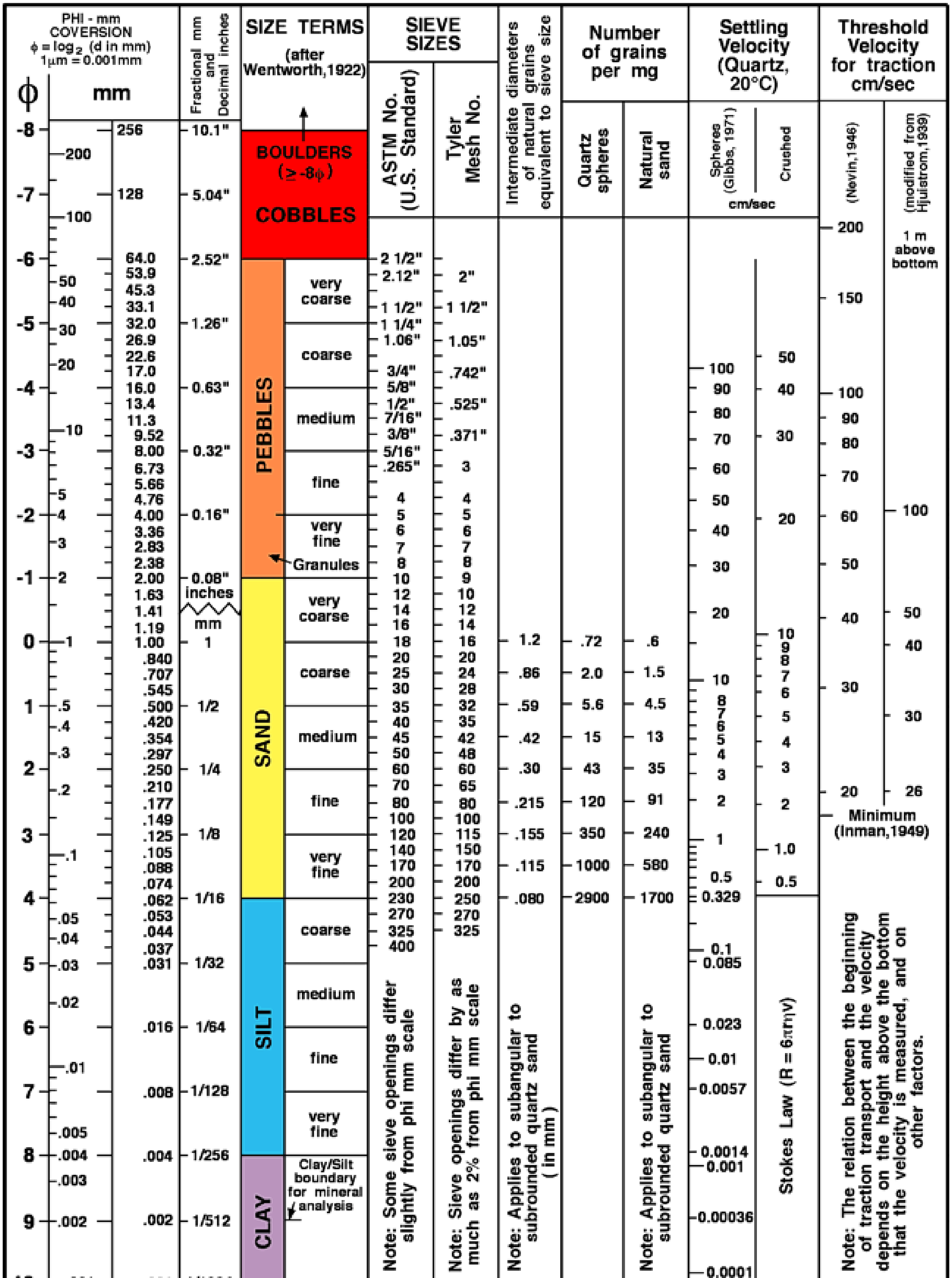


Figure 9.3. Classification scheme for sediment texture distributions as standardized to the scale by Wentworth (Wentworth, 1922)

10. Material and Data Availability.

Additional data and site specific details are available upon request to:

Hannah Faulkner
Nearshore Biologist
Science Team, Habitat Program
Washington Department of Fish and Wildlife
Olympia, WA 98501
Phone: 360-902-2409
Email: hannah.faulkner@dfw.wa.gov

It is our intention to upload data to Shoreline Monitoring Database: a community resource to upload data from standardized protocols to monitor shorelines in Puget Sound, WA. The database in currently in development and testing; funded by U.S. Environmental Protection Agency, Washington Sea Grant Program and Washington Department of Fish and Wildlife. For further information, please contact database managers:

Jason Toft
Senior Research Scientist
UW School of Aquatic and Fishery Sciences
tofty@uw.edu

Karen Morrill-McClure
Computer Systems Administrator
Washington Sea Grant GDPR Point of Contact
karenmmc@uw.edu