Maury Island Aquatic Reserve Shoreline Armoring Removal Monitoring Pre-Restoration Baseline 2016-2018




Prepared for: Maury Island Aquatic Reserve Citizen Stewardship Committee

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Cover photos clockwise from upper left: Vashon Nature Center BeachNET volunteer Hooper Havekotte conducts a beach profile at Piner Point; Lost Lake restoration site after bulkhead removal; Vashon Nature Center BeachNET volunteers measure beach wrack; Lost Lake restoration site before removal. Photos by: Bianca Perla, Maria Metler, Bianca Perla, Maria Metler.

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Abstract

This baseline report summarizes results from three years of beach surveys (2016-2018) conducted on four beaches within the Maury Island Aquatic Reserve (MIAR) before shoreline armoring was removed. Monitoring was coordinated by Vashon Nature Center and conducted by trained volunteers from the citizen stewardship committee (CSC) for MIAR. Established data collection protocols from Washington Department of Fish and Wildlife (WDFW) and University of Washington's shoreline monitoring toolbox were used to collect baseline data.

At each beach, monitoring occurred along three study treatment transects: a restoration treatment (bulkhead existing at time of study but targeted for removal); a control treatment (bulkhead which will exist throughout pre- and post- removal surveys); and a natural treatment (no bulkhead). Monitoring for beach profiles, terrestrial arthropods, shoreline vegetation, beach wrack and logs, and fish use occurred during summer months. Forage fish spawning was monitored year-round.

Study treatments differed statistically in number of logs, beach wrack composition and cover, vegetation composition and cover, and fish use (all highest on natural treatments compared to armored and restoration-armored treatments). Forage fish spawning differed more by beach site then treatment type. There were slight differences in terrestrial arthropod abundance and richness between treatments, but these were not statistically significant. Having high vegetation cover (especially overhanging) on armored treatments and being near natural shorelines may help maintain arthropod fauna levels on armored sites.

Variation associated with beach and year was high indicating that long-term and site-specific monitoring is critical to understanding effects of shoreline restoration. We recommend that monitoring is worked into restoration projects from the outset and treated as a necessary component of restoration so that managers can learn the full array of responses to their restoration activities and fine-tune methods to best accomplish restoration goals.

Beach monitoring provides a fun hands-on opportunity for local communities to take part in the stewardship and learning cycle within their aquatic reserve. Over 190 volunteers from 14-80 years of age participated in monitoring efforts during this survey period, totaling over 850 hours donated by the local community. As restoration unfolds, engaging community members in collecting data and actively learning along with project managers and scientists, is a powerful way to accomplish the fundamental goals of education, research and stewardship in Maury Island Aquatic Reserve.

Introduction

This report provides a summary and analysis of baseline conditions at four beaches within Maury Island Aquatic Reserve before shoreline armoring is removed. The report covers three years of data and is based on monitoring conducted by community science volunteers on Vashon-Maury Islands. Volunteers helped Vashon Nature Center scientists in the field as part of the Citizen Stewardship Committee for Washington Department of Natural Resources Aquatic Reserve System. Data from this shoreline armoring removal monitoring project will provide important information about how high-bank beaches in rural areas respond to restoration through armoring removal. This community science monitoring project also provides residents with opportunities to help steward and learn about Maury Island State Aquatic Reserve.

The Aquatic Reserve System

The Washington Department of Natural Resources (WDNR) Aquatic Reserves Program (AR) has established aquatic reserves throughout Puget Sound to protect high-quality native ecosystems (Figure 1). The Aquatic Reserves Program is a statewide effort to promote the preservation, restoration, and enhancement of state-owned aquatic lands that are of special educational, scientific, or environmental interest.

One benefit of the AR Program is the partnerships WDNR establishes to aid in development and implementation of site-specific aquatic reserve management plans. WDNR works with federal, state, local, tribal and non-governmental organizations and private citizens to identify and manage important resources for conservation at each reserve. An additional benefit of AR designations is that management plans can be designed to complement other protective measures within or adjacent to the reserve (WADNR 2014).

Between 2016-2018, WADNR partnered with Vashon Nature Center and Vashon Maury Island Land Trust (fiscal sponsor) in engaging community science groups in bulkhead removal monitoring surveys in MIAR. Both the Implementation and Citizen Stewardship Committees for Maury Island Aquatic Reserve chose this project for its wide-reaching implications in adding to regional understanding of nearshore ecosystem function, and for its alignment with the specific goals called out in the MIAR management plan that are listed below (from WADNR 2014):

1) Protect, enhance and restore the integrity of natural nearshore habitats and function of shoreline processes for the benefit of native plants and wildlife.

2) Gather and assess ecological and human use information to support adaptive management decisions.

3) Promote stewardship of aquatic habitats and species by providing education and outreach opportunities and promoting coordination and partnerships with other resource managers.

4) Promote sustainable management of uses in and adjacent to the reserve and minimize impacts to habitats and species.

Figure 1.0 State Aquatic Reserves including Maury Island Aquatic Reserve.

The primary focus in managing MIAR is to protect and restore the natural biological communities, habitats, processes, and the ecological services, uses and values they provide to current and future generations (WADNR 2014). This shoreline armoring removal monitoring gathers and assesses ecological and human use information to support adaptive management decisions. Promoting community engagement in science opportunities on

Maury Island shorelines brings together multiple MIAR goals stated above to promote stewardship of the aquatic reserve while contributing valuable data on the health of nearshore ecosystems.

Bulkheads and Nearshore ecosystem health

One third of Puget Sound shorelines are now armored and, although the pace of armoring is slowing, and overall armoring may be starting to decrease, numbers are still short of the 2020 targets set by Puget Sound Partnership (PSP 2018). The impacts caused by shoreline armoring to nearshore ecosystems are starting to be documented (Toft et al. 2013, Lee et al. 2018, Dethier et al. 2016). This study aims to strengthen our understanding of how rural, high-bank shorelines (characteristic of central Puget Sound) respond to armoring removal. Most new armoring construction projects occur in rural-residential areas, which makes this research timely and important (Shipman 2010).

Shoreline armoring is often put into place to prevent erosion and stabilize shorelines so that commercial and residential development can occur near marine waters. While these structures can be important for development along shorelines, armoring disrupts the connection between marine and terrestrial ecosystems along the shoreline and can decrease the availability of prey resources for juvenile salmon (Heerhartz and Toft, 2015). Armoring is also known to reduce shoreline vegetation, decrease terrestrial insect abundance and diversity, decrease wrack cover and logs, and reduce suitable spawning substrates for forage fish (Heerhartz et al. 2014; Heerhartz et al. 2016; Penttila 2007).

In addition, armoring can alter diet and feeding behavior of juvenile salmon in the nearshore. Salmon rely on shallow, productive nearshore habitats for foraging and refuge from predators when they migrate from natal streams to the sea (Heerhartz and Toft, 2015). On Vashon-Maury shorelines, salmon from as far away as the Stillaguamish River have been documented using Vashon-Maury shorelines indicating that these shorelines are a regionally important habitat for Puget Sound salmon populations (Brennan et al. 2004, pp. 3.36-3.39).

Coastal habitats in Puget Sound are facing unprecedented growth meaning that armoring in the Puget Sound is still increasing even as the pace of it slows (Gittman et al. 2015, although see also PSP 2018). Furthermore, studies local to Vashon-Maury Islands show that un-permitted armoring is occurring, further adding to shoreline armoring totals (Kinney et al. 2015). As growth continues and concerns about sea level rise come into play, understanding the complex dynamics of shoreline armoring on terrestrial, aquatic, and residential environments along the shoreline is vital for effective management of this important marine-terrestrial interface.

For the above reasons, beach restoration has become a priority in the Puget Sound region. The Puget Sound Partnership, driven by the need to protect salmon populations such as endangered populations of Chinook salmon (*Oncorhynchus tshawytscha*), has set targets for a net decrease of armored shorelines, through removal and restoration by 2020 (Puget Sound Partnership 2012).

Because beaches are such dynamic habitats, localized studies are needed to characterize local ecosystem response to armoring across the highly diverse Puget Sound region (Lee et al., 2018) because we don't know if every location will act in a similar fashion when bulkheads are removed. This study provides baseline data descriptions of 4 beach sites for 3 years prior to shoreline armoring removal. Data collected is also used to explore whether and to what extent habitat and fish use differ on armored and natural sites before restoration begins. All sites are in rural areas and contain high bank bluffs that are at the middle or at the starting point of shoreline drift cells and rated as unstable (Washington Coastal Atlas: https://fortress.wa.gov/ecy/coastalatlas/).

Methods

Study Area

The Maury Island Aquatic Reserve encompasses Quartermaster Harbor in King County including 5,530 acres of state-owned land which is adjacent to 30 miles of shoreline. The Reserve's boundary includes all of Quartermaster Harbor and stretches outside of the harbor from Neill Point to Pt. Robinson (Figure 2).

Climate and Wildlife

There are extensive micro-climates throughout the Maury Island Aquatic Reserve beaches due to variation in exposure, slope, and precipitation among other factors. Precipitation levels vary greatly by location and season. Within the reserve, average rainfall measures differ by 10 inches from the western to the eastern extent of the reserve. According to King County records, the western region of the reserve receives an average of 46 inches annually while the eastern edge at Pt. Robinson receives only 36 inches annually (KC 2013).

Seventy-eight species of birds nest and forage in and around MIAR and the reserve includes an Audubon important bird area that provides high-quality wintering grounds for Western Grebes (Swan 2013). Juvenile and adult Chinook, Coho, and Chum salmon use the sheltered bay and the eastern shoreline of Maury Island, which is an important migratory corridor for these species as they move through central Puget Sound (Brennan et al. 2004). Three species of forage fish (sand lance, Pacific herring, and surf smelt) spawn in the Reserve (WADNR 2018). Quartermaster harbor, entirely included inside reserve boundaries, is the location of one of the 21 known Pacific herring spawning populations in Puget Sound (Salish Sea Pacific Herring Assessment and Management Team 2018). The harbor's shallow and protected habitats, coupled with the heavy influence from human development, make this an important ecosystem to study.

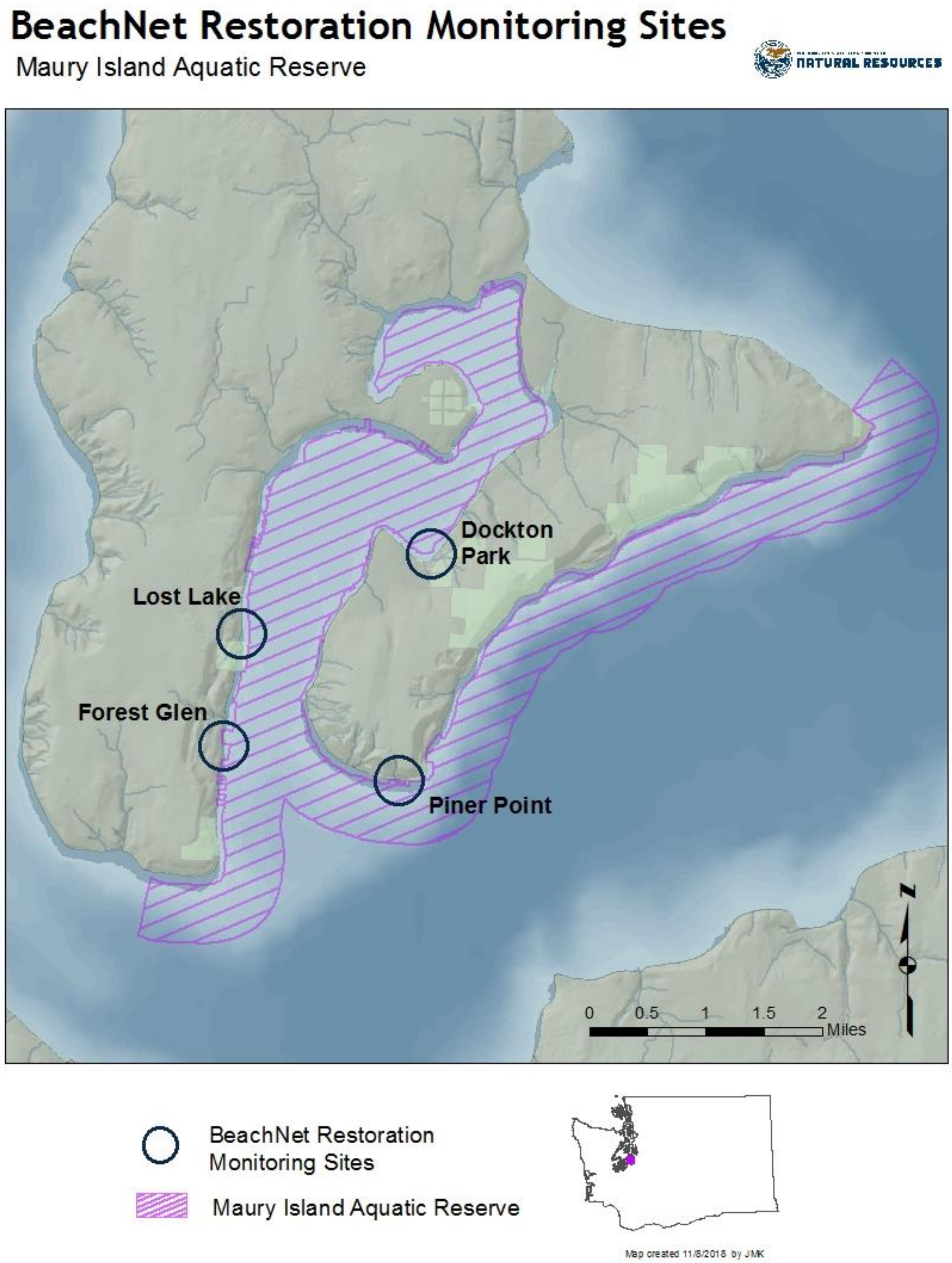


Figure 2. *Location of beach survey sites (circles) and Maury Island State Aquatic Reserve boundaries (purple hatch marks).*

Study Sites

The four study beaches are broadly distributed in Maury Island State Aquatic Reserve (Figure 2). Each beach has three study treatments: restoration, natural, and armored (Table 1). The restoration treatments on all beaches have bulkheads that are slated for removal. In addition to a restoration treatment where armoring will be removed in the future, Dockton has an additional area that has been previously restored (Table 1). The natural study treatments have no armoring and the armored treatments have bulkheads that will not be removed (Figure 3a, b, c, d).

Table 1. *Study design including beach, treatment, and transect length. All restoration treatments were armored for the full extent of this baseline survey except for one previously- restored treatment at Dockton.*

Beach Name	# of treatments	Type of treatment	Length of transect/treatment (m)
Dockton	4	Previously restored; armored; restoration (armored); natural	50
Forest Glen	3	Armored; restoration (armored); natural	50
Lost Lake	3	Armored; restoration (armored); natural	30
Piner Point	3	Armored; restoration (armored); natural	30

Beach selection for this project was determined by King County, Vashon Nature Center, and Washington Department of Natural Resources. Restoration treatment selection was constrained by where armor removal projects were occurring. Natural and armored treatments were then picked that existed within the same general area of the restoration treatment and had similar slope, aspect and substrate. When possible, armored treatments with similar bulkhead structures and materials to the restoration treatment were chosen (Perla & Metler, 2016). All study treatments at a site are contained within the same drift cell, reducing the variation in physical characteristics between treatments (Figure 5; Sobocinski, 2003). Permission to access private property was obtained by the Vashon Nature Center and King County when necessary. The sampling was overseen by Vashon Nature Center staff and conducted by trained BeachNET (Beach Nearshore Ecology Team) volunteers from the MIAR stewardship committee.

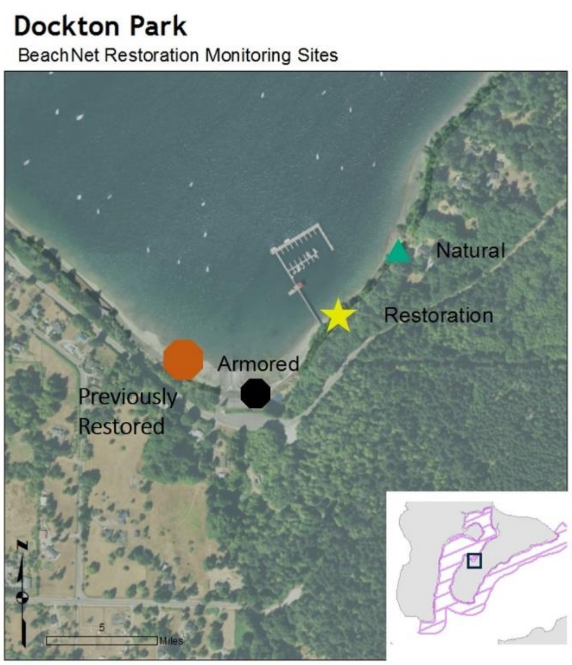
Table 2. *Number of years that each type of data was taken at each beach.*

Beach name	Profile	Logs	Wrack	Forage fish	Vegetation	Terrestrial Arthropods	Photos	Fish
Forest Glen	3	3	3	3	3	3	3	1

Beach Name	Profile	Logs	Wrack	Forage Fish	Vegetation	Terrestrial Arthropods	Photos	Fish
Dockton	2	2	2	0	2	2	1	0
Lost Lake	3	3	3	3	3	3	3	1
Piner Point	3	3	3	3	3	3	3	1

Table 2 cont'd

In total, restoration treatments represent about 300 meters of shoreline restored ranging from 35 meters to 121 meters in length. Data were taken at three beaches for three years before removal and twice at one beach (Dockton) 3- and 5-years post-removal (Table 2).



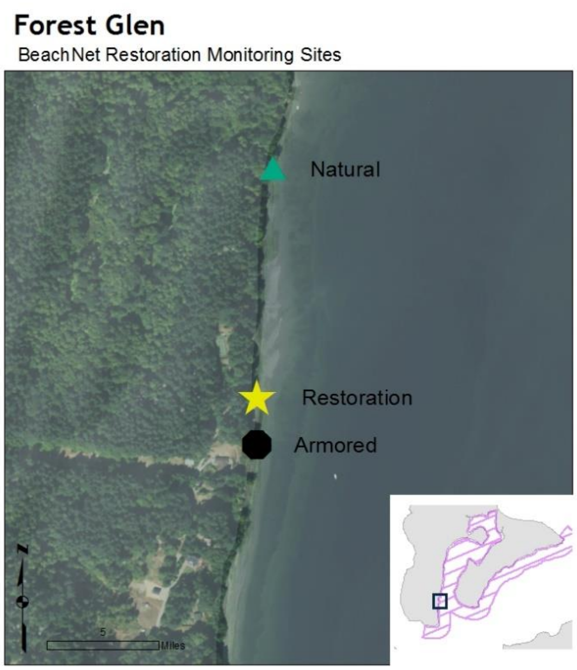


Figure 3a, b

a) Dockton beach surveyed in 2016 by the Toft lab, University of Washington in partner with Vashon Nature Center volunteers. Four treatments per site: natural= no bulkhead; armored=bulkhead; restoration= bulkhead (will be taken out in 2021); Previously Restored=this beach stretch was restored in 2013. For this report, we summarize differences between the restoration (treated as armored), restored, and natural sites.

b) Forest Glen beach surveyed in 2016-2018 through the Vashon Nature Center BeachNET program. Three treatments per site: natural= no bulkhead; armored=bulkhead; restored=bulkhead (removed after pre-surveys were completed in 2018).

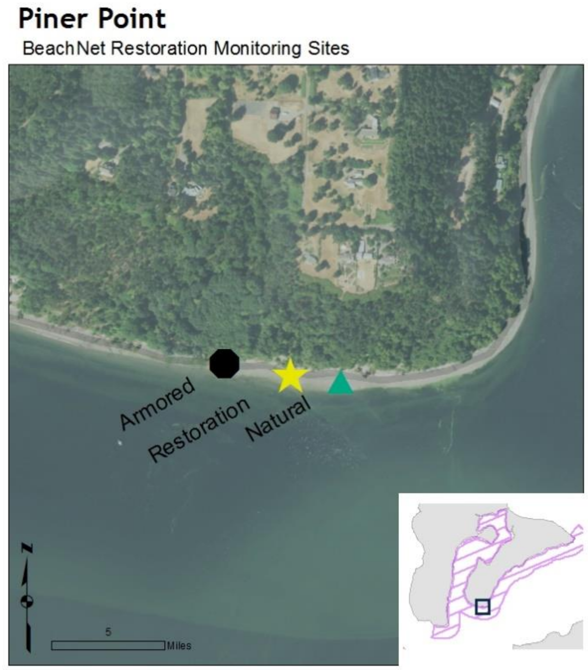


Figure 3c and d. *Lost Lake and Piner Point beaches surveyed in 2016-2018 through the Vashon Nature Center BeachNET program. Three treatments per site: natural= no bulkhead; armored=bulkhead; restored=bulkhead (removed after pre-surveys were completed in 2018).*

This armoring removal monitoring study differs from many previous studies because it is being conducted in a rural setting and concentrates on beaches that are high bank and highly erosive rather than low bank, low erosion sites (Figure 4).

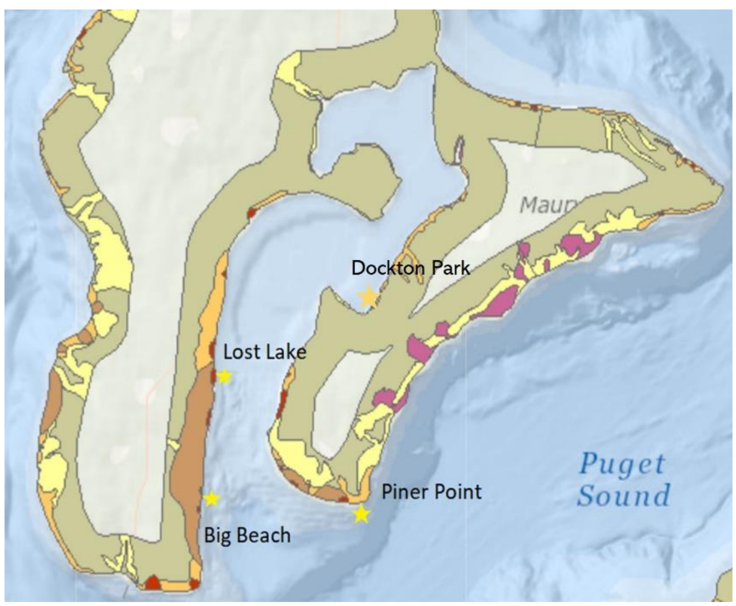


Figure 4. *Slope stability in the Maury Island Aquatic Reserve. Slopes are unstable at all sampling locations. The red indicates recent slides, brown indicates unstable slopes with old slides, orange indicates unstable slopes in general (Washington State Coastal Atlas, 2018).*

Forest Glen

Forest Glen (FG) is an east-facing, low-grade, beach with mixed cobble-sand and mud-silt substrate. This site is located near the mouth of Quartermaster Harbor. This is a residential beach, however, most of the housing is set back from the beach due to the high-bank nature of this site. The restoration treatment (-122.49166, 47.34558) is over 50 meters in length, and is comprised of a hodge-podge bulkhead made of wood and large boulders, or rip-rap and back-filled with various debris from old-growth driftwood to car tires (Figure 6a). The armored treatment is located directly adjacent to the south of the restoration treatment, and is characterized by a tall, concrete bulkhead. The natural treatment, located north of the restoration and armored treatments, is undeveloped and comprised of dense overhanging vegetation (Figure 6b). The beaches in this location are in the southern end of the same drift cell that drifts from south to north (Figure 5). The control treatment is farthest south, the restoration treatment is in the middle, and the natural treatment is north and up-drift of both (Figure 6c). The bulkhead on the restoration treatment was removed in September of 2018 after pre-restoration monitoring concluded.

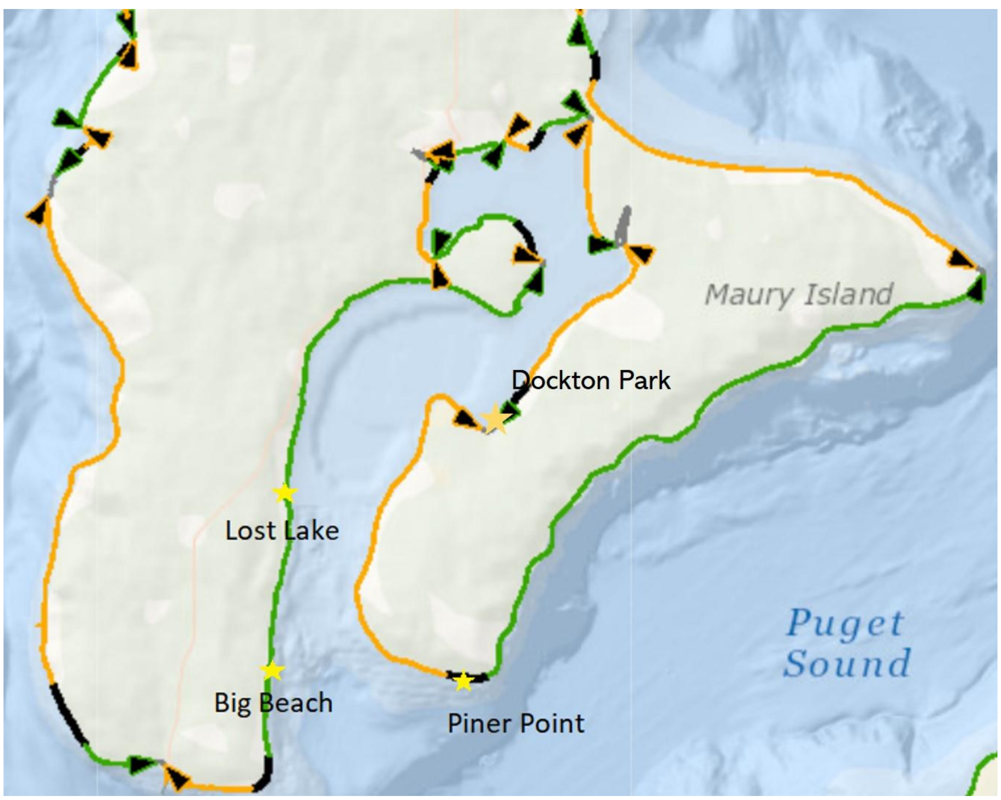


Figure 5. *Drift cells in the Maury Island Aquatic Reserve. Arrows point in the direction of the drift movement. Lost Lake and Big Beach sampling locations are in the same drift cell that drifts from south toward the north (green line). Piner Point is in a divergence zone (black line), which is generally subject to more rapid erosion (Washington State Coastal Atlas, 2018).*

Figure 6a. *Representative photo of the restoration treatment at Forest Glen 2016.*

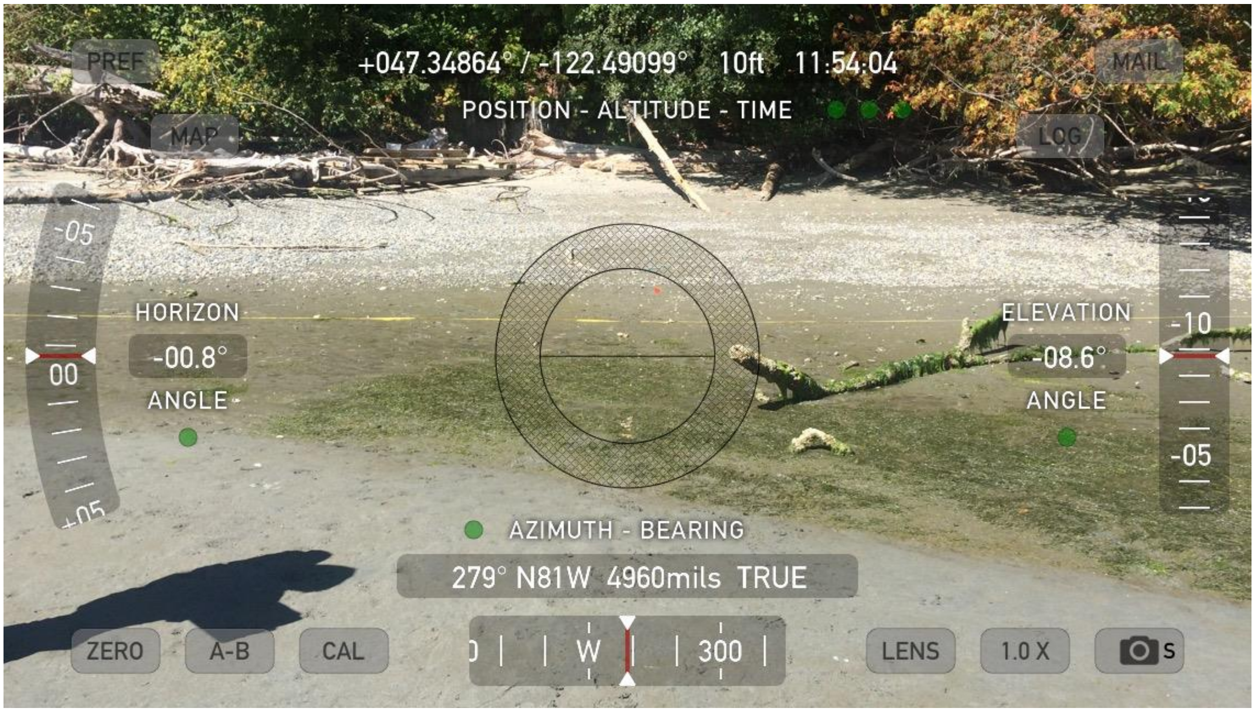


Figure 6b. *Representative photo of the natural treatment at Forest Glen 2016.*

Figure 6 c. *Representative photo of the armored treatment at Forest Glen 2016.*

Lost Lake

Lost Lake (LL) is also eastward-facing with a low-grade beach made of largely cobble and sand substrates. It exists in the middle of the same long drift cell that starts near Forest Glen (Figure 5). There is a small housing development with a few houses along the beach, placed directly above the shoreline armoring. The restoration treatment (-122.48857, 47.36060) is characterized by a 30 m wooden bulkhead with a house and a few shrubs placed directly above the armoring (Figure 7a). Armoring here extends the housing into the shoreline zone several feet. The natural treatment is directly south of the restoration treatment and has visible logs, dune grass, and overhanging trees and shrubs (Figure 7b). The armored treatment site is one of the most northern properties in the small housing development along the beach (Figure 7c). The armored treatment site has a wooden bulkhead with adjacent trees, shrubs, and a house placed at the southernmost part of the bulkhead. The bulkhead and house on the restoration treatment were both removed during restoration in September 2018 after pre-restoration monitoring concluded.

Figure 7a. *Lost Lake restoration treatment representative photo 2016.*

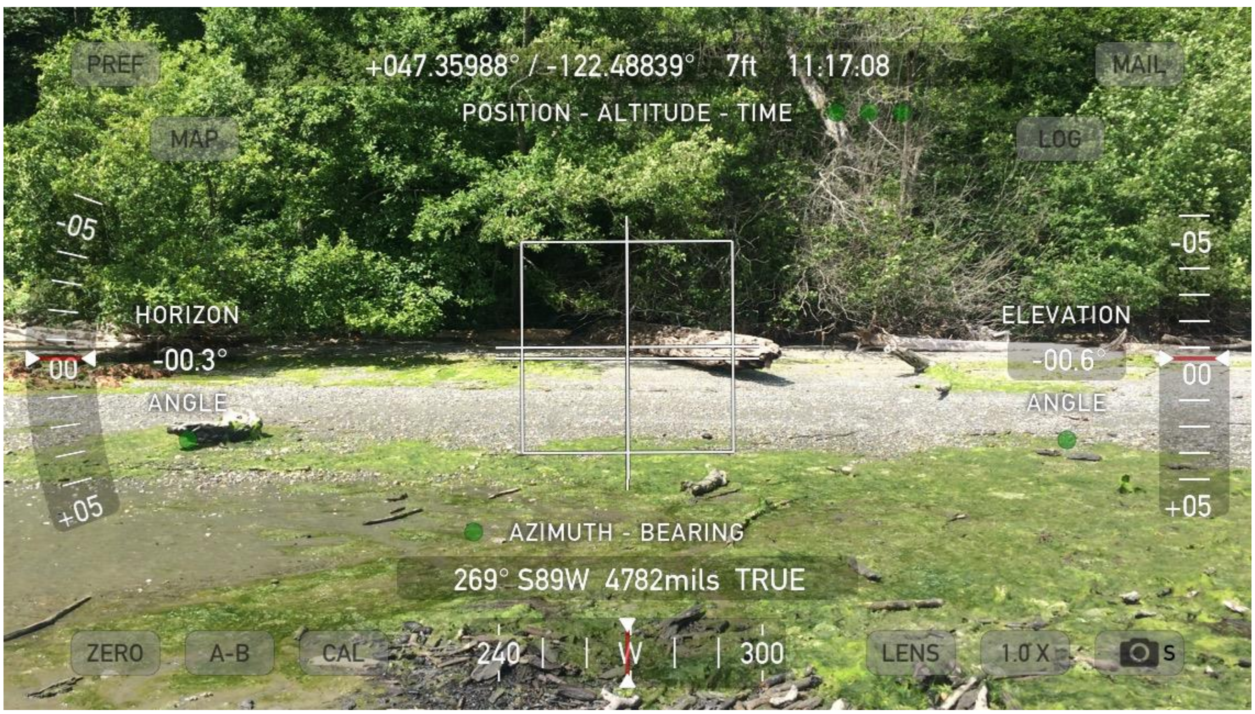


Figure 7b. *Lost Lake natural site representative photo 2016.*

Figure 7c. *Lost Lake armored site representative photo 2016.*

Piner Point

Piner Point (PP) is a south-facing, low-grade beach with cobble and sand substrates. It is in outer Quartermaster Harbor at the south tip of Maury Island and gets much more wave action than the other two beaches. This is a highly erosive, high-bank beach. The restoration treatment (-122.45894, 47.34329) is a 30 meter, failing wooden bulkhead (Figure 8a). The bulkhead was removed at the end of August 2018 after pre-restoration monitoring had concluded. The uplands consist of trees and shrubs that have been subjected to recent landslides. The armored treatment is located toward the west of the restoration treatment and is a wooden structure with a house placed directly above the shoreline armoring and with several overhanging trees and shrubs (Figure 8c). The natural treatment is directly east of the restoration treatment, with a visibly eroding high sand bank, accumulated logs, and some overhanging trees and shrubs that have been subjected to landslides (Figure 8b). The treatments at this location are in a divergence zone, which is subject to more rapid erosion (Shipman 2008). This beach zone feeds beaches both west into the inner Quartermaster harbor and east along the southern edge of Maury Island (Figure 5).

Dockton Park

Dockton Park (DP) is a north-easterly facing, low grade beach with gravel to mud-clay substrate. It is on the eastern shore of inner Quartermaster harbor and is very sheltered. Dockton Park has a public boating dock, boat launch and play area backed by road and forest. The restoration treatment (47.371520, -122.452630) is a heavy and tall concrete bulkhead to the northeast of the boat dock (Figure 9a). This bulkhead will likely be removed by 2022. The uplands are forested and contain many trees that overhang the bulkhead. The armored treatment is to the west on the other side of the boat dock (Figure 9c). It is also concrete and in good repair. The uplands are highly modified for public use and topped with a cement walkway. The armored treatment contains very little overhanging vegetation. The natural treatment is northeast and adjacent to the restoration site. The uplands consist of mixed-coniferous deciduous forest (Figure 9b).

There is an additional previously restored treatment that was surveyed in 2016 (restored in 2013; Figure 9d). In this report we compare the natural, restoration (armored) and previously restored treatments. There was not enough data available to include the armored treatment in our analysis.

Dockton Park is located at the convergence of two drift cells but much of the shoreline along both drift cells is armored. Shoreline toolbox monitoring was conducted on Dockton Park in 2016 and 2018 but no forage fish data were collected. Dockton Park is included in this report for informational purposes on a post-restoration site. But, because data were not taken consistently for some factors at this location, Dockton Park was not included in statistical analysis that explored differences between armored and unarmored treatments.

Figure 8a. *Piner Point restoration site representative photo 2016.*

Figure 8b. *Piner Point reference site representative photo 2017.*

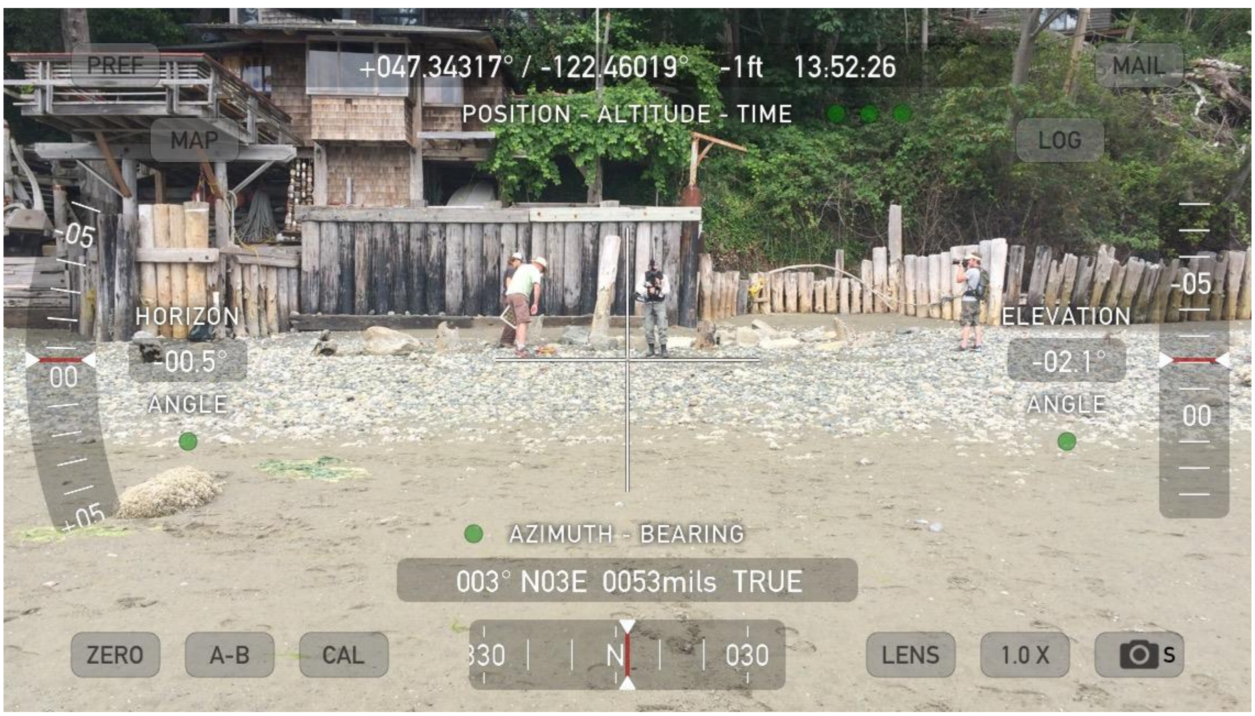


Figure 8c. *Piner Point armored study treatment representative photo 2016.*

Figure 9a. *Dockton Park restoration treatment representative photo 2018.*

Figure 9b. *Dockton Park natural treatment representative photo 2018.*

Figure 9c. *Dockton Park armored treatment representative photo 2018.*

Figure 9d. *Previously restored treatment at Dockton, 2018. This treatment was restored in 2013.*

Field Surveys

Monitoring for terrestrial invertebrates, shoreline vegetation, logs, beach profiles, beach wrack, forage fish spawning, and fish use occurred during 2016-2018. For terrestrial invertebrates, shoreline vegetation, logs, beach wrack, and beach profiles, sampling occurred during summer low tides for maximum accessibility and to standardize with other survey efforts taking place in the Puget Sound. Sampling was performed over two consecutive days and each category of data was collected on the same day across all treatments for consistency.

Snorkel surveys measuring fish use were conducted in 2017. Data were collected over a single day for all treatments on the same beach during the high tide. Data collection occurred at Lost Lake and Forest Glen in July and Piner Point in August.

Forage fish spawning data was collected by community science volunteers every other month at each beach (except for Dockton Park), except during June, July, August, when one site was sampled each month at the same time as the suite of shoreline surveys. Forage fish spawning samples were collected and recorded separately on each of the three study treatments at each beach.

This project used standard field protocols adapted from the Washington Sea Grant's Nearshore Monitoring Toolbox, a collection of simple, standardized monitoring protocols that can be used to evaluate the impacts of shoreline armoring across the Puget Sound (Shoreline Monitoring Toolbox, 2017). Data will eventually be stored on the shoreline monitoring toolbox database which is currently in creation by the Toft lab at University of Washington. A full description of methods, including datasheets used, and printed copies of detailed protocols from the shoreline toolbox is available in the QAPP report for this study and outlined in less detail below (Perla and Metler 2016).

Beach Wrack Survey Methods

At ten random points along a 30 or 50 m transect parallel to shore, a 0.1 m^2 quadrat was placed on the beach surface and a visual estimate of the percent composition of deposited dead algae, eelgrass, terrestrial plant material, and trash was conducted. Transect length was determined by the length closest to the length of bulkhead slated for removal on the restoration treatment at each beach (Table 1). The quadrat was divided with string into 25 6 x 6 cm small squares to facilitate these estimates – each square equaled roughly 4%. If possible, the algal type was specified (e.g., red, green, brown, or species). Two transects were established: (1) at the most recent high tide line that has fresh wrack deposition, and (2) just above MHHW in older wrack. The most recent high tide line targeted mobile wrack, whereas the higher elevation sample targeted the more stable wrack layer. If there was a bluff or shoreline armoring, elevation was sampled at the base. Samples were taken on an ebbing tide when the upper beach +6' MLLW and above was exposed.

Vegetation Survey Methods

A plant species list for each beach was generated and compiled by treatment, noting native and introduced species, estimated the percent cover of canopy (trees) and understory (e.g., dune grass, salal) vegetation in increments of 5% at different areas in 3, 5x5 meter plots located at the beginning, middle and end of the transect. Width of overhanging canopy was measured at the widest point for each tree along the transect and these width measurements were totaled and divided by total transect length to get a quantitative measurement of overhanging vegetation along each transect. Each vegetation area was assigned a health rating between 1 (dead) and 5 (vigorous growth), noting specific plants/trees that were characteristic of the rating.

At patches of dune grass, a transect was established parallel to shore along the dune grass patch length, or for 50 m if the patch was very long. There was only one patch of dune grass present on the Lost Lake natural treatment, so these data were not included in the results. However, it will be interesting to track whether this dune grass patch grows and disperses up drift to colonize the restoration treatment as bulkheads are removed. At five random points along the transect, the width of the dune grass patch was measured and shoot density was counted. Vegetation was sampled in summer months when it was lush and at its height.

Beach Profile Survey Methods

A transect was established perpendicular to shore, starting from above MHHW at the top of the berm or toe of the bluff at natural beaches, or at the base of armoring if there was bulkhead or riprap. The transect extended down to MLLW or waterline, whichever was longest. Key elevation or transition areas were marked with wired flags (such as at the wrack line, or an obvious change in beach profile or sediment grain size). Elevation measurements were taken using a level and stadia rod at all flagged areas and every 2 meters along the transect, more frequently if the topography greatly varied, and less frequently if there was an extensive low tide terrace with not much change in gradient. Elevation at the water line was recorded and the time was noted so that data can be corrected to actual elevations measured at NOAA stations. Summer daytime low tides allowed sampling down to MLLW.

Terrestrial arthropods Survey Methods and Lab analysis

Plastic storage bins (40 x 25 cm) filled with 5 cm of soapy water were used as fallout traps. Five replicate bins were placed randomly along a 30 m or 50 m transect (Table 1) parallel to shore. A few drops of natural odorless dishwashing soap were poured in the bottom, and the tub was filled with about 5 cm of sieved water. The dishwashing soap relieves surface tension so that insects will remain trapped, and sieving the water ensures that there are no invertebrates that could contaminate the sample from the marine or freshwater source used to fill the tubs. Bins were left in place for 24 hours. To collect the insects, each bin was drained through a 106-micron mesh sieve, and insects were placed into a sample jar. Samples were fixed in in 70% ethyl alcohol and the jar labeled. Sampling was conducted in

June-July when juvenile Chinook salmon are feeding along the shoreline, and vegetation and insect communities are developed.

Lab analysis was conducted by UW labs for terrestrial invertebrate samples. This lab analysis was not funded by the NEP grant. Microscope identification of insects was conducted by University of Washington Toft lab. Chironomidae flies and aphids are two key juvenile salmon prey items that were identified at the Family taxonomic level. Other insects such as Hymenoptera and Lepidoptera were identified at the Order level. Processing at a consistent taxonomic level allows calculation of diversity measurements (e.g., taxa richness, the number of different taxa in the sample). Counts were converted to density (#/m2) based on the surface area of the bin. Taxonomic keys and laboratory expertise were used to identify insects (full protocol available here: https://sites.google.com/a/uw.edu/toolbox/protocols/insects).

Forage Fish

Forage fish protocols were taken directly from standard Washington Department of Fish and Wildlife protocols (Moulton and Penttila 2001).

Beach substrate samples were collected by VNC BeachNET volunteers at each treatment at each beach. A 100 foot transect tape was placed parallel to the shore at each study treatment in sandy-gravel substrates. Tidal elevation of the transect is determined by measuring the distance from the transect to an identified landmark, such as upland toe of the beach, the last high tide mark, or the water's edge. Two transects were identified, one existing within the surf smelt spawning zone and a lower transect was conducted to catch sand lance spawning zones. Along the established transect tape, bulk substrate samples were collected by scooping the top 5-10 cm of sediment (about two-foot-long scoops) at 4 evenly spaced locations.

Substrate samples were wet-screened through a set of 4 mm, 2 mm, and 0.5 mm sieves using hoses with nozzles. The material from the 0.5 mm sieve was placed into a whirlpool and winnowed into subsamples of forage fish egg-sized material using the reverse gold pan method. Winnowing consists of whirlpooling the sample for a standard time to cause lighter material to rise to the surface, and in short, suspend any forage fish eggs to the top of the sediment sample. Egg subsamples were collected by scooping the top layer of lighter sediment material (and any eggs) into a 16 oz jar. Sub-samples were sent to the Washington Department of Natural Resources Aquatic Reserve Program's laboratory to be analyzed for spawning presence/absence and total number of eggs.

Fish observations

Fish observations were conducted by Kirsten Miller in 2017 and methods detailed in this section are directly from her thesis (Miller 2018).

During the highest tide of the day, two 50 meter transects were established parallel to the shore for each beach treatment. One transect was established at 1.5 m depth, about 20 meters from the shore. The second transect was established at approximately 2.0 meters depth and approximately 30 meters from the shore.

Observers started by measuring underwater visibility. Ideally, surveys should only occur when visibility exceeds 2.5 m to maximize the accuracy of observations and minimize effects of observed on fish behavior (Toft et al., 2007). The shallow water depth was measured at 1.5 m using a weighted line. The second water depth was measured 10 m away (away from the beach) at the beginning of the second transect using a weighted line. The second depths varied but were consistently around 2 m of depth. Transects ran parallel to the shore.

Observers recorded the following variables for each fish species encountered: species, a visual estimate of length to the nearest centimeter, number of individual fishes, and water column position of the fish. When fish were not identifiable to the species level, names of lower taxonomic resolution were used to describe their identity (e.g. unknown forage fish). Water column positions were described in thirds: top, middle, and bottom. Feeding behavior (i.e. darting to the surface) was recorded when applicable. Number of fish and observations were averaged by treatment type (armored, natural, and pre-restoration). Taxa richness was calculated by averaging the number of species by treatment type.

Due to proximity, Forest Glen and Lost Lake sites were sampled during the same day in July. Piner Point was sampled a month later in August.

Data Compilation and Analysis

Before researchers left the field, one researcher was assigned to scan all datasheets for completeness and clarity. All completed datasheets were photographed in the field for immediate back-up of all field collected data. Upon completion of field collection, data was entered in excel spreadsheets.

Statistical analysis was conducted in Excel and JMP 12 including summary statistics, checks for normal distribution of model residuals, and ANOVA tests or non-parametric equivalents.

Summary statistics for shoreline survey variables are presented in tables detailed by each beach and further by each treatment within each beach for comparison with post-restoration figures. Average value across three years along with standard errors are reported to provide a figure that considers natural variation between years.

In addition to summary statistics, the following question was examined statistically: After accounting for variation due to beach location and year, are there any variables that are statistically different between treatments? For all analyses, the independent variable was treatment type (armored, restoration, and natural) with year and beach as co-variables. The following variables were compared between treatment type and examined for interaction across year and beach:

- Vegetation (percent overstory, percent understory, native vs. non-native species)

- Wrack (total percent cover, percent marine, percent terrestrial, percent eelgrass)
- Insects (taxa richness, density)
- Forage fish spawning (spawning events, number of eggs)
- Fish (number of fish, taxa richness, number of observations)
- Beach profile (slope, beach width, number of slope changes)

Statistical analysis was not performed when sample sizes or sampling frequency was low as in the fish data. All data was checked for violations of normality in residual plots and was transformed if violations were detected. Continuous data was log transformed. Arcsine transformations were applied (p'=ASIN(SQRT(p)) to proportional datasets. Transformed data was then reassessed to ensure no violations persisted. Statistical analysis was conducted on the transformed dataset. If the dataset still violated assumptions of normality and skewness upon transformation, non-parametric statistical tests were used.

Analysis of variance (nested: treatment within beach and year within treatment) was used to analyze differences between treatment type (armored, natural, restoration) among all beach sites. Model outputs include interactions with beach and year. Post-hoc tests were used to further examine differences using the Tukey test. The critical p-value in assigning statistical significance was α=0.05.

The Friedman's test or Kruskall-Wallis were used as non-parametric equivalents to the mixed-design ANOVA. Post-hoc tests were not calculated for the Friedman's test, as methods for this remain relatively uncommon (Wobbrock et al., 2011). Wilcoxon tests were used as post-hoc tests for Kruskall-Wallis. The critical p-value in assigning statistical significance was α=0.05.

Results and Discussion

Volunteers

Overall, we engaged 74 community volunteers and 175 high school students in our beach survey and forage fish field data collection between 2016-2018. This totaled 850 volunteer hours put in by the local community. Efficiency in shoreline armoring removal monitoring improved between 2017 and 2018 with surveys taking 272 hours the first summer compared with 156.6 hours in 2018 (a difference of 115.4 hours). This was mostly due to having a more experienced cadre of volunteers that could help VNC staff direct new volunteers. We also scheduled two days/beach instead of one which decreased the length of each field day for volunteers and kept everyone fresher and more efficient.

VNC staff audits of datasheets showed high consistency of measurement and completeness of data entry. For example, in-field datasheet checks rarely found missing values and, during analysis, factors that we would not expect to change much from year to year (like large logs or canopy cover) were consistently similar even when taken by different groups.

It is likely that having heavy oversight of all crews during beach surveys by the same VNC staff members as well as in field trainings each year helped with this consistency. UW Shoreline monitoring toolbox protocols and WDFW forage fish collection protocols were also well designed to encourage consistency and ease of collection. For example, beach wrack plots were divided into sub-squares and volunteers were asked to count the amount of each square filled rather than entering coverage percent. Two volunteers would work together to come to consensus on coverage metrics. This likely made readings more consistent between observers.

Overall, survey protocols were appropriate to level of volunteer experience and capacity. The one exception to the good accuracy and completeness of data collected was the 2018 beach wrack data taken at Dockton Park (collected by 10th grade students) which was not usable due to multiple errors in recording and thus was dropped from the analysis. If students are used in the future, more staff and adult volunteer oversight would help correct this. Every other metric measured with students in the field from logs to beach profile was useable.

Ecological Metrics

Although there were some clear differences between natural treatments compared to armored and restoration treatments, there was high variability between beaches and between years for many metrics. These findings underscore the fact that beaches are highly variable environments. Because of this high natural variability, it is important to conduct long-term monitoring of restoration projects, and to monitor multiple sites. What is learned in one location or one year may not necessarily be applicable at another location or year.

Logs

Differences in the amount and area of woody debris showed the strongest and most consistent difference between treatment sites in all years. Natural sites had significantly more large and small woody debris as well as wider log lines than both restoration and armored sites (ANOVA nested by beach and year: natural treatments significantly differed from the other two treatments: width of log line: F-value-87.001, p-value<.00001, no interaction with year and beach; LWD: F-value-48.7, p-value<.00001, no interaction with year and beach; SWD: F-value-22.7, p-value<.0001, positive interaction with year, p=.03, but not beach; there was no significant difference between restoration and control treatments: F-value<.327, p-value>.327).

More large woody debris on natural treatments indicates that these treatments provide important habitat for both terrestrial and marine invertebrates and good cover for foraging juvenile salmon at high tides in contrast to armored and restoration treatments (Figure 10, Table 3). Although small woody debris was also more plentiful along natural treatments, it varied with survey year indicating that smaller wood may be more mobile and therefore change more frequently (Figure 10, Table 3). The log line was also wider on natural treatments compared to the other treatments indicating that logs provide more habitat area on natural shorelines (Figure 10, Table 3).

Table 3. *Average values of log counts and log line width over three years of study. X=Mean and (SE=standard error). Results are organized by beach and then by treatment. Under each metric, significant differences (p<.05) are listed between treatments (ANOVA). P-values are also listed for whole model interactions with beach and year. FG=Forest Glen; LL=Lost Lake; PP=Piner Point.*

Metric and model (p)	Beach	Natural X(SE)	Armored X (SE)	Restoration (armored) X (SE)
Log Line Width (m)	FG	5.3 (1.5)	.40 (.25)	0 (0)
Natural-Armored, p<.0001	LL	4.15 (.59)	0 (0)	1.56 (.31)
Beach (p)=.0017	PP	3.22 (.40)	.5 (.29)	2.12 (.56)
Year (p)=.79				
Large Logs (count)	FG	4.5 (1.04)	.14 (.09)	0 (0)
Natural-Armored, p<.0001	LL	5.12 (.99)	0 (0)	1.32 (.23)
Beach (p)=.048	PP	3.95 (.53)	0 (0)	3.22 (1.17)
Year (p)=.52				
Small Logs (count)	FG	2 (.71)	.21(.14)	0 (0)
Natural-Armored, p=.0004	LL	1.52 (.30)	0 (0)	.5 (.15)
Beach (p)>.09	PP	1.3 (.20)	.2 (.12)	.78 (.29)
Year (p)=.03				

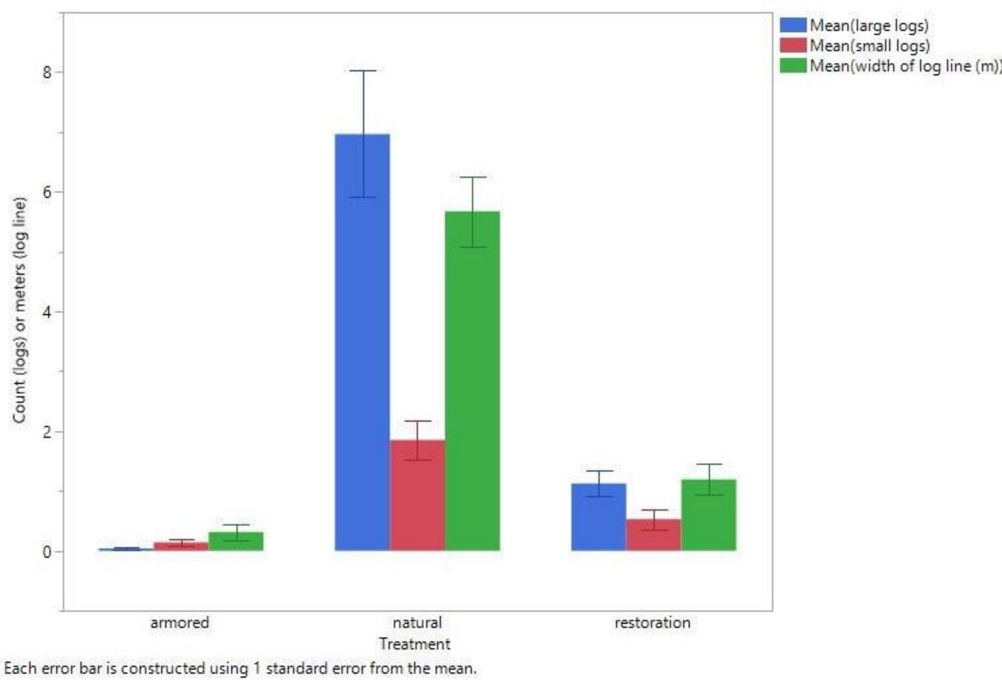


Figure 10. *Log counts and log line width (m) are higher/wider on natural treatments compared with armored and restoration treatments. Mean value per treatment. Error bars=1 std error.*

Vegetation

Natural treatments had significantly more canopy cover compared with armored and restoration treatments (ANOVA nested by beach and year: F=5.4, p=.01; no significant differences between year (p=.8) or beach, p=.09; natural treatments had significantly higher canopy cover than other treatments p=.003, no difference between armored and restoration treatments, p=.56; Figure 11). The percentage of overhanging vegetation was also higher on natural treatments compared to armored and restoration treatments (ANOVA nested by beach and year: F=12.2, p<.0002; no difference between armored and restoration treatments p=.296; significant interaction with beach p=.012; but not year, p=.67, Figure 11).

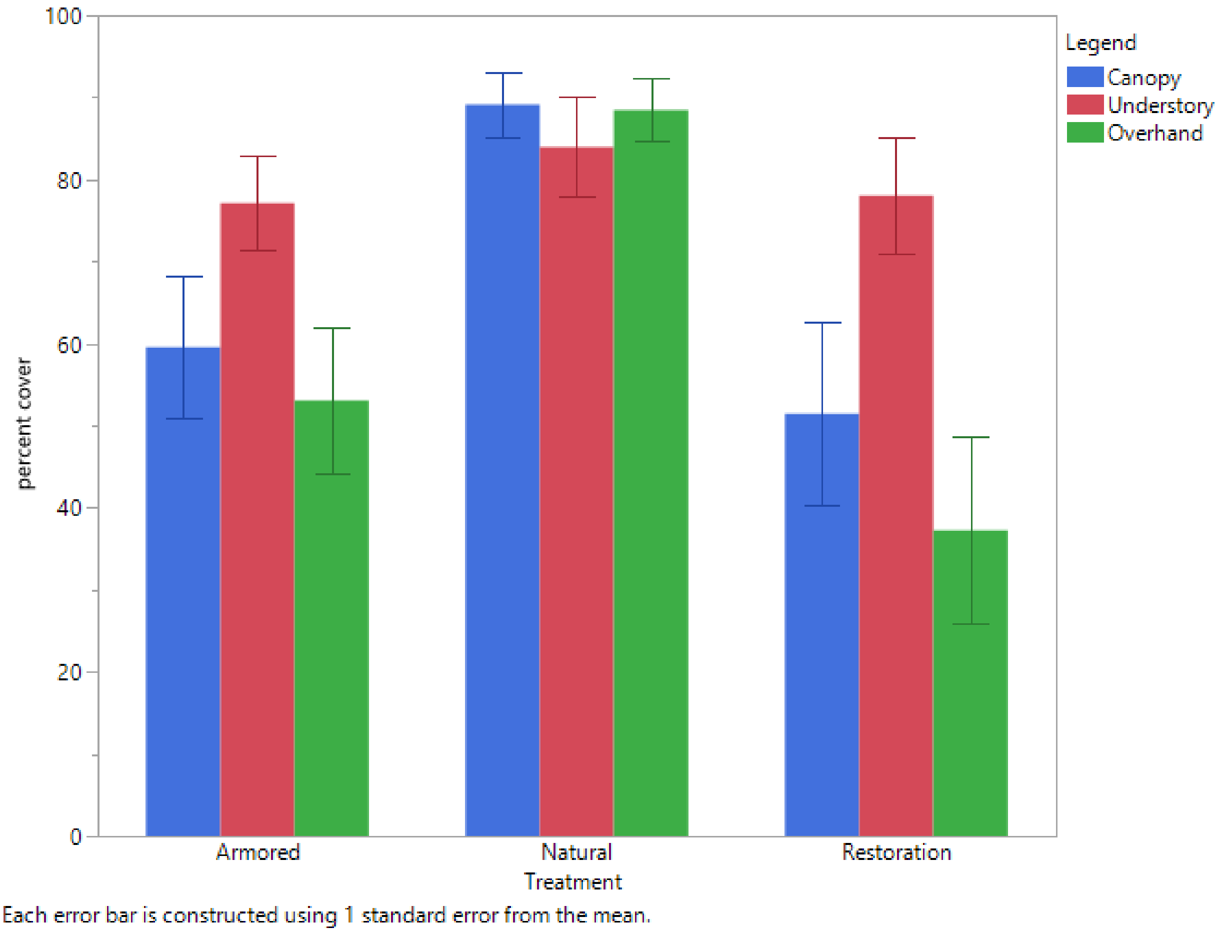


Figure 11. *Natural treatments had significantly higher percentages of canopy and overhanging vegetation than armored or restoration treatments. Understory canopy cover measurements did not significantly differ between treatments. Bars represent mean values for treatment type across 3 years and error bars are one standard error from the mean.*

In contrast, understory cover did not differ between treatments (ANOVA nested by beach and year; F=.46, p=.6, there was an interaction with beach p=.01, but not with year p=.8, Figure 11).

Plant species lists from Lost Lake, Piner Point, and Forest Glen were coded by native or non-native status. Of all species existing along natural treatments, 80% were native and 20% were non-native. In contrast, 50% of the species occurring along armored treatments and 56% of the species occurring along restoration sites were non-native (Appendix). The high proportion of non-native species on armored and restoration treatments indicates that plant communities differ widely between natural and armored treatments. This could potentially lead to differences in higher trophic levels from terrestrial arthropods to birds to fish.

Because of the high levels of vegetation cover on all treatments regardless of armoring, one unexpected short-term outcome of shoreline armoring removal could be a depression in both vegetation cover, shade, and terrestrial arthropod abundance due to vegetation disturbance during bulkhead removal activities. If, as part of the restoration process, restoration treatments are cleared of non-native vegetation, they will go through a period of lower than baseline recorded vegetation cover until native vegetation planted along the restoration treatments grows to maturity. This could cause short-term decreases in many factors from fish use to forage fish spawning to insect fall out rates. Only a long-term monitoring program will be able to measure whether this initial "disturbance" to the shorelines of restoration sites results in improvement over initial conditions in the long-term as restoration plantings mature.

The vegetation present at these sites, regardless of armoring, supports the vital connection between terrestrial and aquatic ecosystems. Terrestrial vegetation fosters habitat for insects and provides natural beach function, such as shading and moisture retention. More riparian vegetation contributes to the input of terrestrial insects in the nearshore (Toft et al., 2013). Terrestrial insects, such as dipterans (flies), can be carried by wind from terrestrial ecosystems onto the water surface and provide food for juvenile Chinook salmon (Munsch et al., 2016). Therefore, encouraging landowners to vegetate behind bulkheads may help to support the connection between terrestrial and marine systems on armored sites that shoreline armoring usually destroys. In addition, introducing native riparian vegetation after armoring removal may improve the marine-terrestrial connectivity and facilitate a rapid response from terrestrial macroinvertebrate assemblages and fish that prey on them like juvenile chinook (Toft et al. 2014; Lee et al. 2018).

Beach Wrack

When both fresh and old wrack were looked at together, natural treatments had significantly more total wrack cover compared to both restoration and armored treatments (Figure 12; ANOVA nested by beach and year on transformed data (arcsine square root): Total cover between all treatments differed with $p<.01$, significant variability with beach and year $p<.0003$). Natural treatments also had higher percent cover of marine algae, terrestrial debris, and eel grass in wrack (Figure 12; ANOVA nested by beach and year on transformed data (arcsine square root): percent cover eel grass natural- armored treatments, $p=.0013$, significant site and year effects $p<.001$; marine algae cover, natural-armored p=.001, significant site p<.032, but not year effects p>.08; terrestrial cover higher on natural compared to armored and restoration, p<.0001, armored-restoration p=.05, significant year and site effect p<.001; human debris cover, p>.26 for all).

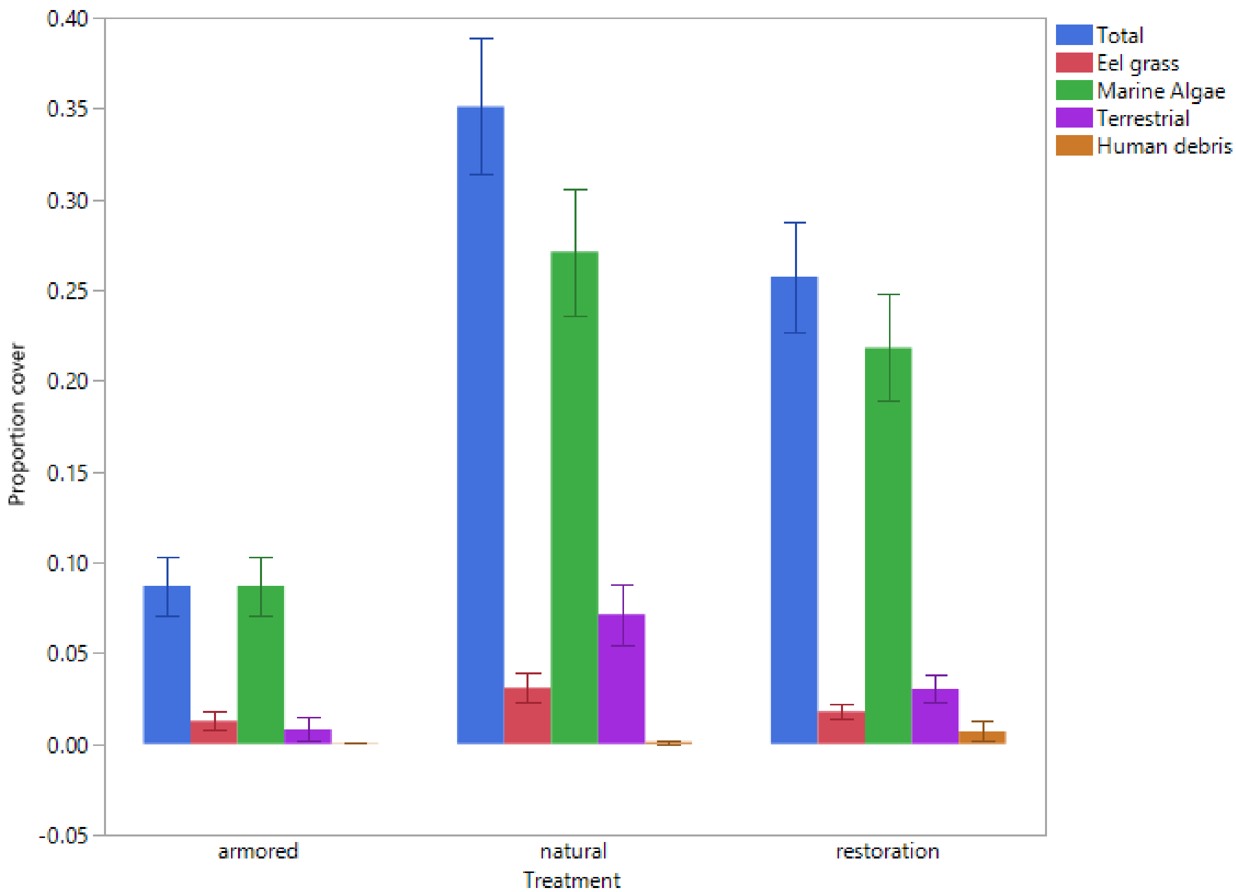


Figure 12. *Beach wrack total cover, terrestrial cover, marine algae and eel grass cover were higher on natural sites compared to armored sites. Total wrack cover and terrestrial cover was higher on natural sites than restoration sites. Data analysis was conducted on arcsine square root transformed data to comply with normality constraints of ANOVA but data depicted here is untransformed so that actual cover proportions can be derived from the graph. Bars represent mean values for treatment type. Error bars are one standard error.*

Wrack depth and width also differed between treatments. Data remained non-normally distributed after log transforming so Kruskall-Wallis tests with Wilcoxon post-hoc tests were used. Wrack depth differed between all treatments (Kruskall Wallis chi-square 45.15, p<.0001). Wrack width was narrower on armored compared to natural treatments but there was no difference between natural and restoration treatments (Kruskall-Wallis chi-square 7.71, p=.02, armored-natural, p=.01, natural-restoration, p=.064, there were significant differences between site and year p<.01). The fact that natural treatments had deeper wrack overall suggests that beach wrack may be a more concentrated resource along natural shoreline (Figure 13). Anecdotal observations also showed that beach wrack on armored and restoration sites tended to be widely dispersed and patchier in distribution perhaps scattered by high tides hitting the bulkheads and bouncing back. However, this was not directly quantified apart from the high variability in wrack cover readings on armored treatments.

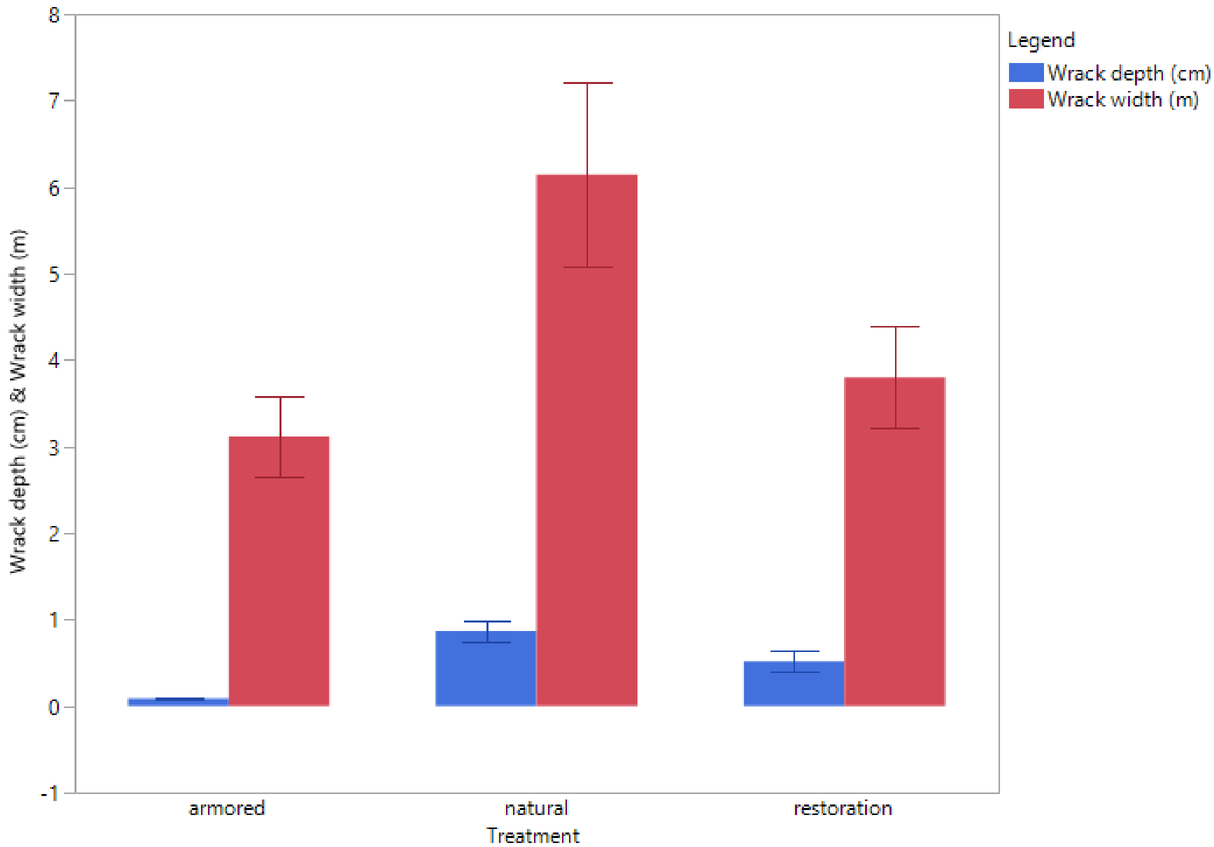


Figure 13. *Beach wrack depth (cm) and width (m) was significantly greater on natural compared to armored treatments. There was a trend for natural treatments to have deeper wrack and wider wrack lines than restoration treatments, but this was statistically significant only for depth. Bars represent mean values and error bars are one standard error from the mean.*

Despite differences found between treatments, both variation between years on the same beach and variation between beaches in the same year was high for all wrack variables measured (Table 4). This suggests that wrack coverage likely depends on many different factors in the environment and may be distributed patchily between locations and years.

Natural treatments had significantly more old wrack cover than restoration or armored treatments (Figure 14, ANOVA nested by beach and year: $F>15.3$, $p<.0013$; no significant interactions with beach and year). In addition, while fresh wrack contained more marine algae, old wrack tended to contain more terrestrial cover than fresh wrack suggesting that the resources for decomposers and other macroinvertebrates and biota differ between old and fresh wrack. Terrestrial wrack also may degrade more slowly than marine-derived wrack. Thus, natural shorelines may contain an important extra resource for beach biota that does not occur as regularly on the other armored shorelines.

The placement of each beach in relation to on-shore drift cells likely caused some of the variation seen between beaches. Location in a drift cell can affect the direction of drift (e.g. longshore currents, estuarine outflow) and can affect biological response variables like accumulation of wrack. For example, total percent cover of wrack was higher at both Forest Glen and Lost Lake, located in the same drift cell, compared to Piner Point, which is located within a diverging drift cell where net shore drift goes in either direction and less accumulation occurs (Washington State Coastal Atlas, 2018).

Table 4. *Means (X) and Standard errors (SE) of beach wrack variables averaged over 3 years for each treatment. Values are shown as percentages on untransformed data. Due to high skewness of data, arcsine square root transformations were conducted on proportional data before statistical analysis. Significant differences and beach, year interactions are noted under each metric. FG=Forest Glen; LL=Lost Lake; PP=Piner Point.*

Metric and model (p)	Beach	Natural X(SE)	Armored X (SE)	Restoration (armored) X (SE)
Total cover %	FG	31 (6)	8 (3)	35 (5)
Natural-Armored-Restoration p<.01	LL	57.4 (4.8)	6.1 (2.9)	29.9 (4.9)
Beach and Year p<.003	PP	16.5 (3.7)	12.2 (3.1)	12.7 (2.9)
Eel grass cover %	FG	.6 (.38)	3.5 (1.2)	.8 (.44)
Natural-Armored, p=.013	LL	6.9 (1.9)	.2 (.5)	3.5 (1.2)
Beach and Year p<.001	PP	1.7 (.6)	.1 (.2)	1 (.4)
Marine Algae %	FG	30.4 (5.6)	7.9(3.5)	34 (5.2)
Natural-Armored, p=.001	LL	40.6 (5.1)	5.9 (2.7)	20.7 (4,5)
Beach, p=.032, no year effect	PP	10.3 (3.1)	12.3 (2.8)	10.6 (2.6)
Terrestrial cover %	FG	.84 (.3)	2.1 (1.9)	.86 (.3)
Natural-restor, armor p<.0001	LL	17.2 (3.8)	.1 (.1)	6.4 (2.3)
Beach and Year p<.001	PP	3.4 (1.1)	.17 (.24)	1.8 (.49)
Human debris %	FG	.01 (.01)	.05 (.02)	.08 (.07)
Natural, armor, rest, p=.26	LL	.3 (.3)	.01 (.17)	1.7 (1.6)
Beach and Year p<.001	PP	0 (0)	.1 (.04)	.37 (.27)

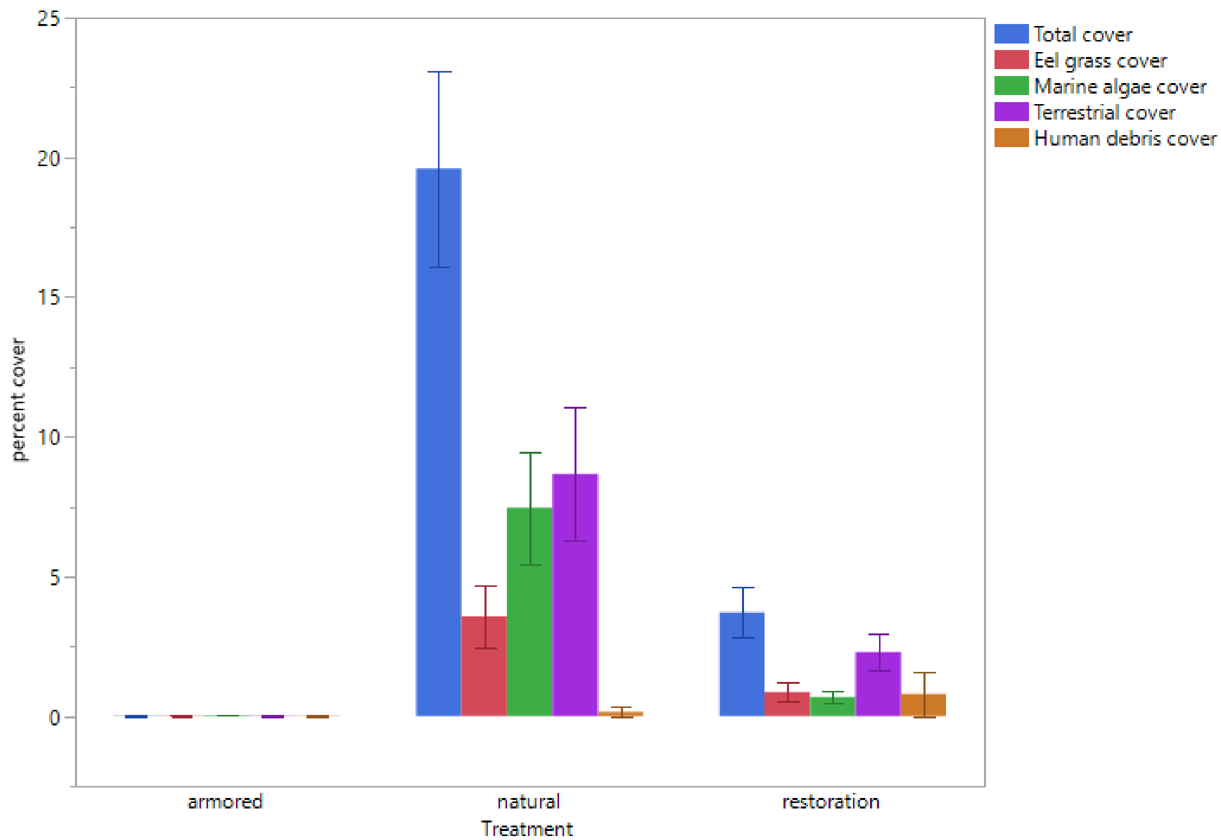


Figure 14. *Natural treatments had significantly higher cover of old beach wrack compared to both armored and restoration treatments and this difference was statistically significant for marine algae, total wrack cover, eel grass and terrestrial debris cover. Error bars represent one std error and bars are mean values.*

Terrestrial arthropod fall-out

Densities of terrestrial arthropods ranged from 70-2100 arthropods/m^2 across all beaches and treatments. We found no clear pattern in terrestrial arthropod abundance and richness between treatments. Miller (2018) found higher proportions of Diptera, a preferred salmon food, in natural treatments in our 2017 surveys but this pattern did not hold up for all three years. There was significant variation between beaches that swamped any differences between treatments (Table 5; Figure 15, 16). Although there were trends for natural treatments to have a higher overall abundance and higher proportion of salmon preferred taxa, results were not statistically significant (ANOVA nested by beach and year on log or arcsine (for proportions) transformed data, $p<.1$ for all, significant interaction with site and year $p<.03$).

This contrasts to other studies that have found direct negative impact of shoreline armoring on insect supply (Dethier et al. 2017). Due to the high understory and overhanging vegetation cover on armored treatments in this rural study area, it is possible that the vegetation differences between natural treatments and armored treatments in this study area are not significant enough to influence insect populations. Having any type of vegetation might be enough to attract similar quantities and richness of insects in rural areas regardless of treatment type.

Table 5. *Means (X) and Standard errors (SE) of terrestrial arthropod metrics averaged over 3 years for each treatment. Values are shown are untransformed data. Due to non-normality of residuals, data were log_{10} transformed before statistical analysis. This table shows untransformed data. FG=Forest Glen; LL=Lost Lake; PP=Piner Point. Salmon preferred taxa= sum of all Diptera, Hemiptera, Hymenoptera, Lepidoptera.*

Metric and model	Beach	Natural X(SE)	Armored X (SE)	Restoration (armored) X (SE)
Abundance/m2	FG	1113 (975)	339 (38.6)	359.5 (147.4)
	LL	219 (45.5)	387.1 (51)	340.2 (9.6)
	PP	659.8 (67.5)	340.2 (199.7)	319.6 (129.5)
Taxa Richness/m2	FG	62 (4.1)	100.6 (12.4)	90.9 (11.0)
	LL	91 (11)	95 (17.9)	84 (4.1)
	PP	108.8 (9.6)	79.9 (5.5)	93.7 (19.3)
Salmon preferred taxa/m2	FG	79.9 (5.5)	217.6 (16.5)	147.4 (12.4)
	LL	92.3 (20.7)	155.6 (4.13)	139.1 (28.9)
	PP	433.9 (210.7)	75.8 (15.2)	186 (101)
Proportion of Salmon preferred taxa/treatment	FG	.33 (.29)	.65 (.12)	.48 (.16)
	LL	.46 (.19)	.41 (.06)	.41 (.10)
	PP	.63 (.26)	.38 (.27)	.54 (.09)

Alternatively, armored treatments in this study are surrounded by long stretches of natural shoreline that could act as source habitats that supplement insect populations on armored areas. Thus, armored treatments that are surrounded by natural habitat and that have at least a bit of vegetation that insects can inhabit might attract a greater abundance of insects than if they were surrounded by more urban shorelines. All study treatments in MIAR, independent of whether they were armored or not, contained at least some vegetation for insects to inhabit and were located adjacent to natural shorelines.

Lastly, terrestrial arthropod variation between beach locations could also have something to do with different micro-climates at different beaches. For example, each beach had slightly different exposures (Lost Lake and Forest Glen are east-facing, while Piner Point, which had the highest densities of insects, was south-facing).

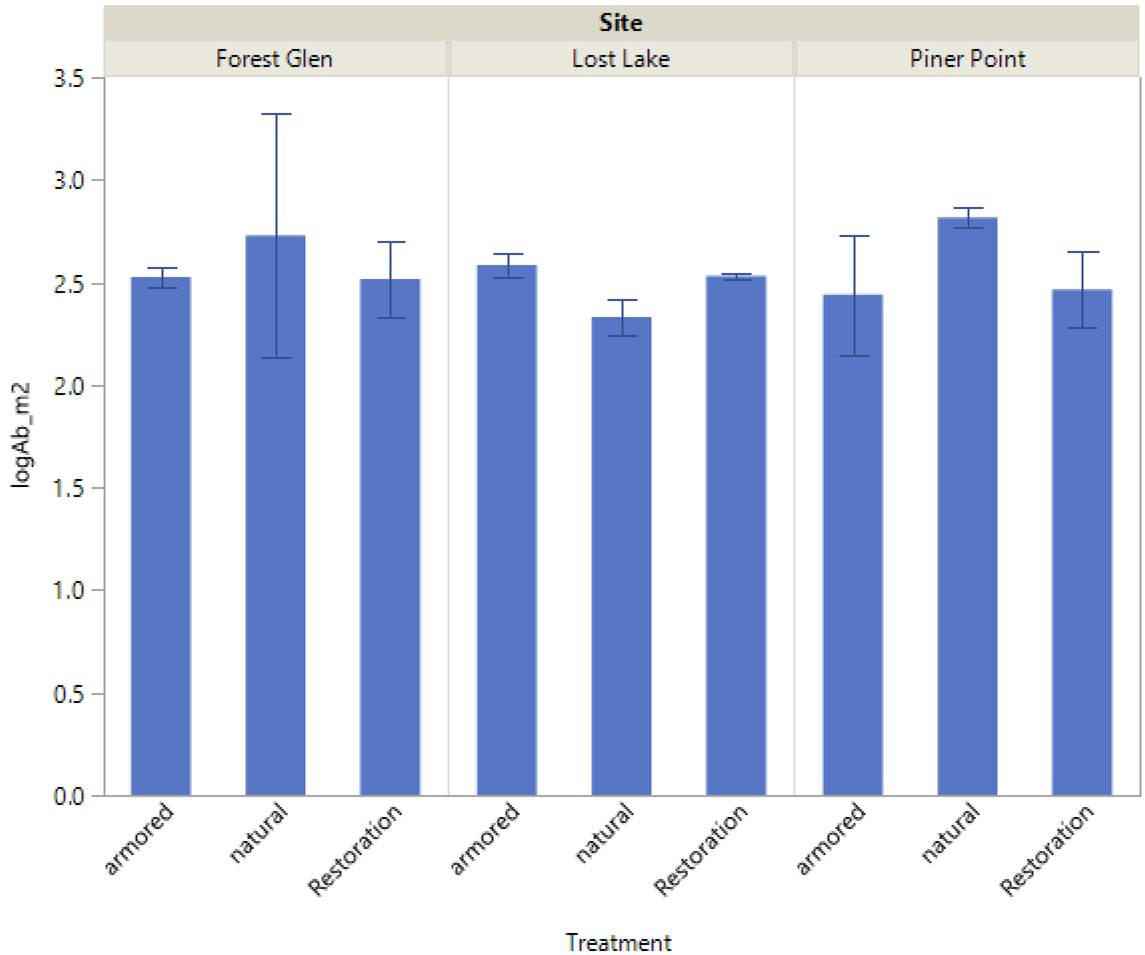


Figure 15. *Terrestrial arthropod fall-out abundance (number/m²) compared between study treatment and beach site. Although there were trends indicating natural treatments had higher arthropod abundance and richness, the variation between beaches and years was high enough that trends were not significant at the treatment level. Therefore, we show data separated by beach (and year Fig. 16). Graph depicts log transformed data. Bars are mean densities and error bars represent 1 Std error from the mean.*

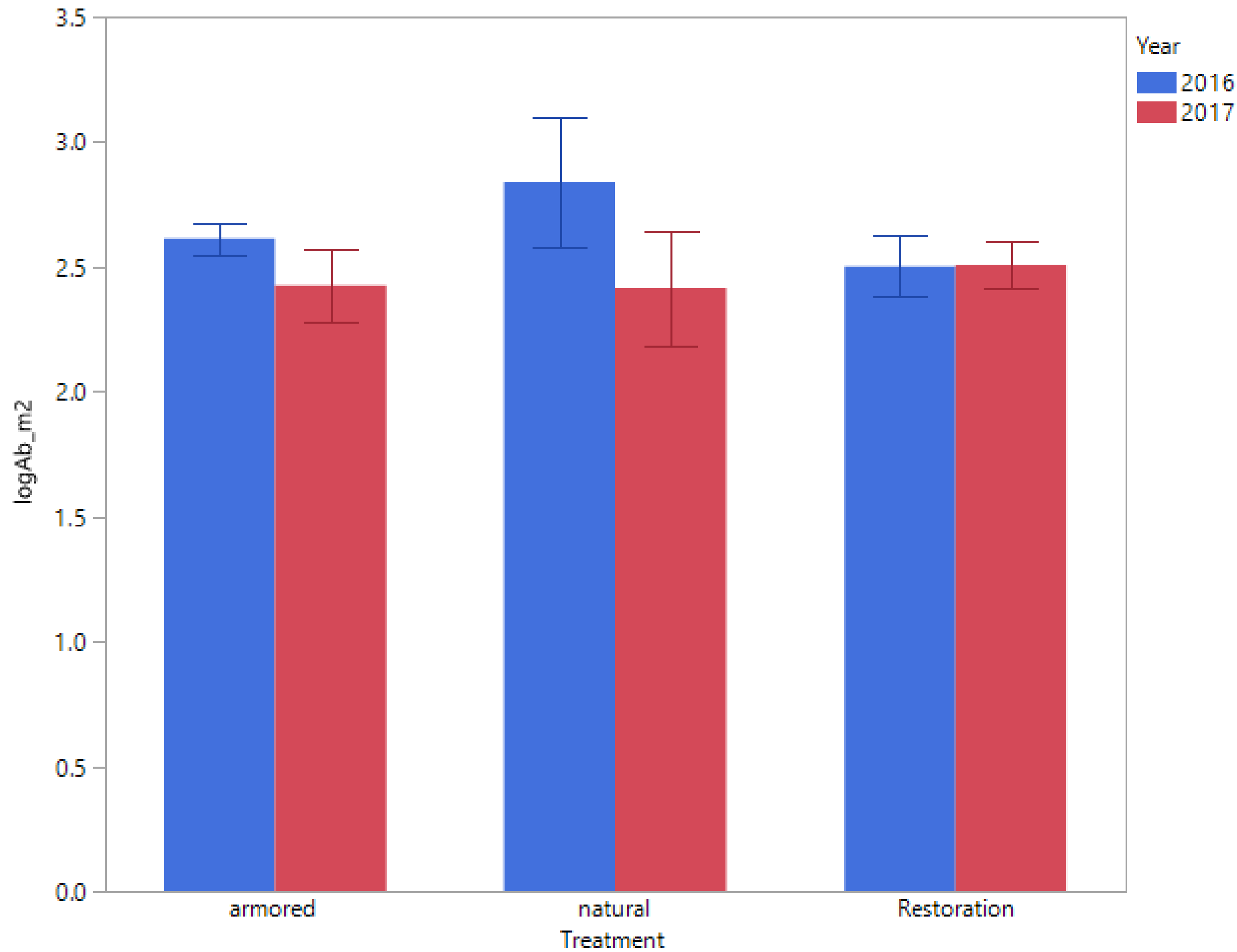


Figure 16. *Variation in arthropod data between years and beaches (Figure 15) were high enough that results were not significant at the treatment level. Therefore, we show data separated by year and beach (Fig. 15). While 2016 years had a trend towards higher terrestrial arthropod abundance on natural treatments, this same pattern was not apparent in 2017. 2018 samples have not yet been processed. Graph depicts log transformed numbers as untransformed data. Bars are mean densities and error bars represent 1 Std error from the mean.*

When dealing with entire complex communities of multiple species, summary statistics like density and taxa richness are not always a complete enough measure to detect differences. It is possible that other components of community composition are different between treatments even if summary metrics like taxa richness and total abundance don't appear to differ. A multi-variate multi-dimensional analysis like NDMS or principal components analysis could be used to explore community composition more widely. This could be a beneficial analysis to plan for when comparing pre-restoration and post-restoration communities.

Forage fish

Because spawning differed so much from month to month throughout the year, egg counts were summed across each treatment site to give a 3-year composite for each treatment at each beach and statistical analysis was run on these collapsed figures. In general, surf smelt trended towards spawning in larger numbers on armored treatments and sand lance tended to prefer natural treatments, but these differences were not statistically significant because they varied by beach location (ANOVA on square-root transformed data: p>.08 for all, significant interaction with beach p=.01; Figure 17). Rock sole numbers were too low to see meaningful trends (6 total eggs found). However, it is interesting to note that rock sole eggs were never found on armored treatments. There was negligible surf smelt, sand lance, or rock sole spawning at Forest Glen (Figure 17).

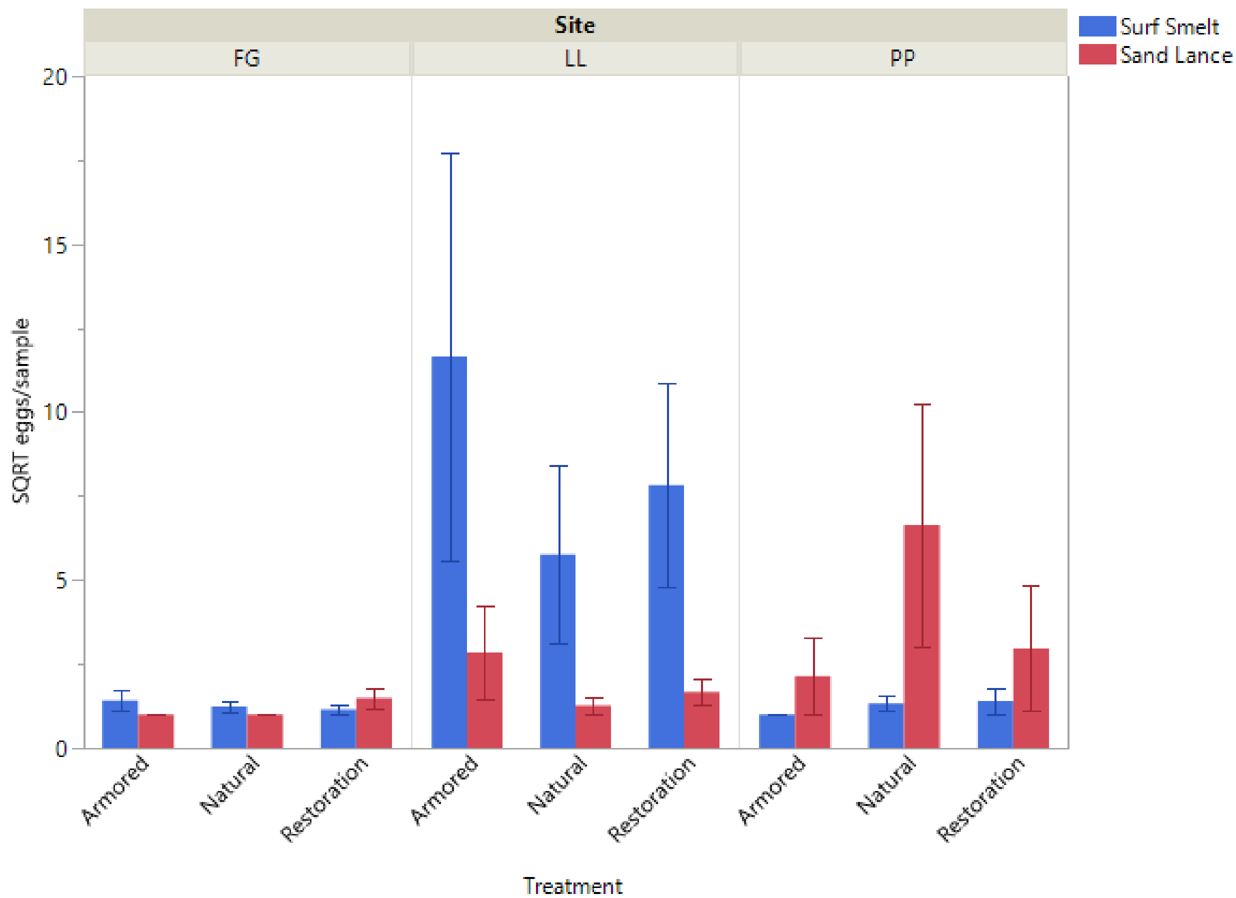


Figure 17. *Square root transformed counts of Surf smelt (blue) and sand lance (red) eggs divided by site and treatment. FG=Forest Glen; LL=Lost Lake; PP= Piner Point. Bars are average/eggs per sample and error bars are 1 std error from the mean. No statistically significant differences were found between treatments within each site however there were significant differences between sites with Piner Point having more sand lance eggs and Lost Lake having more surf smelt eggs. Thus, results are depicted separated by site.*

In general, differences in spawning were more beach and season oriented than treatment oriented. Different beaches had different patterns of spawning between natural, restoration, and armored treatments (Figure 17). For example, Piner Point tended to be the hot spot for sand lance spawning while Lost Lake tended to have the most surf smelt spawning. Spawning for all forage fish occurred between October through April with a very small occurrence of eggs being picked up at select sites in May. This is important information to know as north of Vashon-Maury spawning can stretch into summer months, and south of Vashon-Maury spawning has been shown to peak in winter months. This study confirms that Vashon-Maury spawning populations align in timing with South Puget Sound stocks (Penttila 2007). No eggs of any kind were found between June and September in any year (Figure 18).

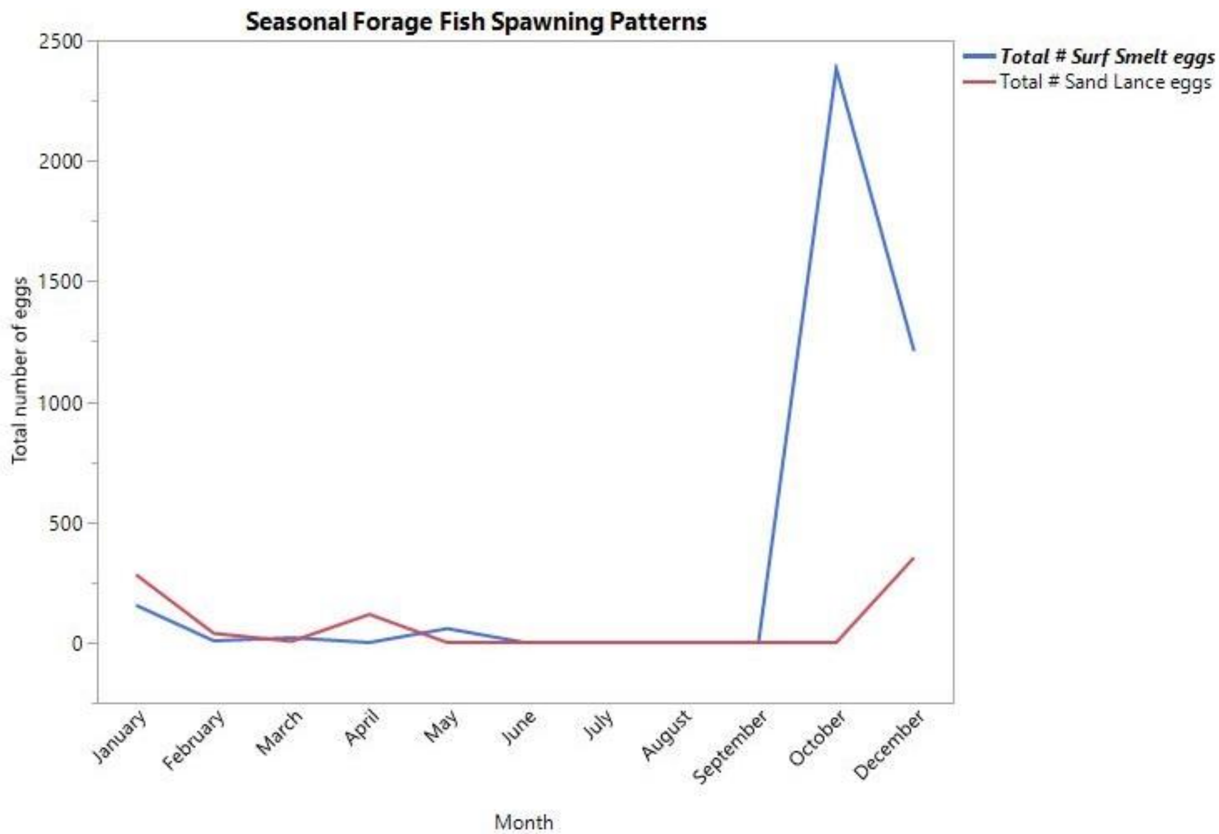


Figure 18. *Seasonal trends in sand lance (red) and surf smelt (blue) across all beaches and study treatments. No eggs were found between June and September. Sand Lance peaked at Piner Point in December and January and at Lost Lake in April and May suggesting two separate populations.*

Sand lance spawning peaked at different times on different beaches. Piner Point sand lance spawning events occurred in December and January (Figure 18). In contrast, sand lance spawning at Lost Lake peaked between February and April. This may suggest two separate populations of sand lance utilize these different beaches.

Fish

The following information, figures and tables on fish were collected and analyzed by Kirsten Miller for her M.S. thesis and reprinted here with permission.

The number of observations (how many individual times fish were spotted) were averaged across treatments. In general, there were more observations of fish on average at natural sites (3 fish) compared to the armored (1.33 fish) and pre-restoration (0.33 fish) sites (Figure 19).

Taxa richness of fish was averaged across treatments for all sites. Taxa richness was higher at natural sites (2.67 species) compared to armored (1.33 species) and pre-restoration sites (0.33 species) (Figure 20).

The total number of fishes found were averaged across treatments for all sites. There was a higher average total number of fish at natural sites (92.33 fish) compared to the armored (68.33 fish) and pre-restoration (0.33 fish) sites.

At Forest Glen there were two species of fish observed at the natural site: unknown forage fish and anchovy (approximately 200 fish). There were no observations at the armored or restoration sites (Table 6). At Lost Lake, there were more total observations, total fish, and number of species at the natural site (Table 6). At Piner Point, there were more total observations and number of fish species at the natural site. However, there were more overall fish (200 unknown species of forage fish) observed at the armored site (Table 6).

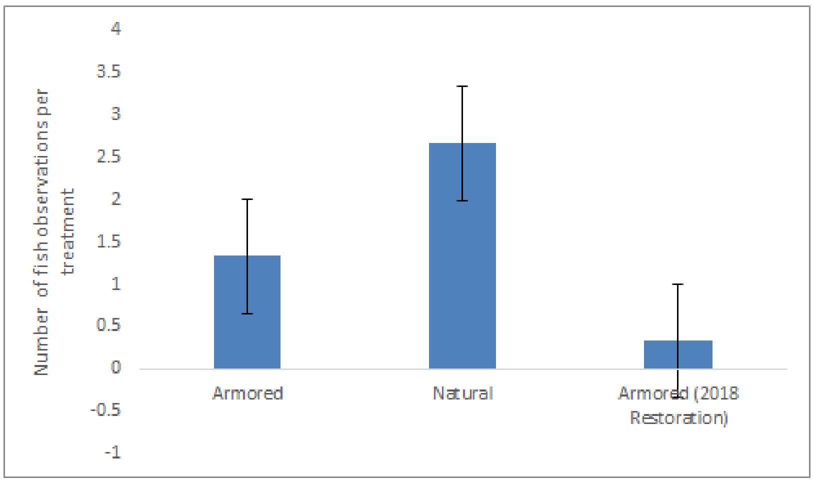


Figure 19: *Number of times fish were observed. Error bars are standard deviation.*

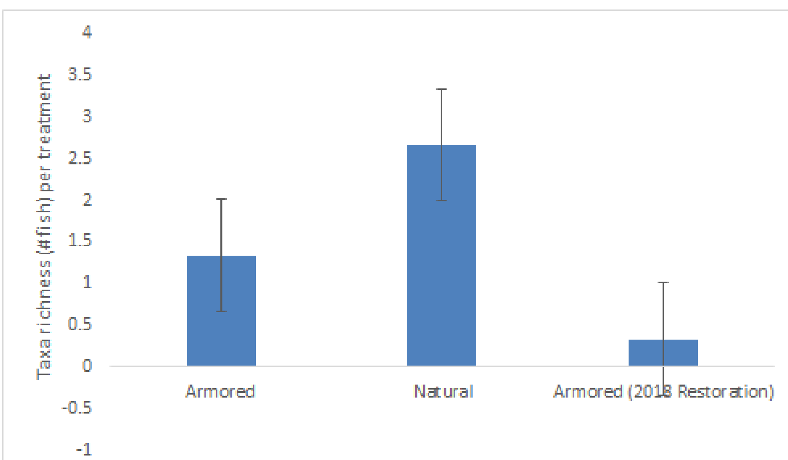


Figure 20: Average taxa richness of fish per study treatment. Error bars are standard deviation.

Table 6: *Fish observations.*

Site	Treatment	Total observations	Total fish	Number of species	Species type
Forest Glen	Armored	0	0	0	N/A
Forest Glen	Natural	2	101	2	Forage fish (unknown), anchovy
Forest Glen	Restoration	0	0	0	N/A
Lost Lake	Armored	2	4	2	Sculpin, rock sol
Lost Lake	Natural	4	6	3	Shiner perch, sculpin, trout (unknown)
Lost Lake	Restoration	1	1	1	Saddleback gunnel
Piner Pt	Armored	2	201	2	Sculpin, forage fish (unknown)
Piner Pt	Natural	3	170	3	Surf smelt, salmon (unknown), forage fish (unknown)
Piner Pt	Restoration	0	0	0	N/A

Beach Profile

We analyzed beach profiles for the most recent year surveyed (2018) for all 3 study beaches on all study treatments (armored, natural, and restoration). The 2018 beach profile measured beach slopes, lengths and other attributes within weeks of when shoreline armoring was removed and thus give the most recent baseline for these beaches from which to measure change.

We generated summary statistics from these beach profiles including:

- Beach width: the length of the beach measured in meters from the toe of the armoring or beach bluff (natural sites), down to the Mean Low Water line (MLW).
- Beach slope: calculated as the slope from MLW to bulkhead or bluff toe.
- Back beach width: the length of the beach above MHHW to the bulkhead toe or bluff toe.
- Elevation of native eel grass: in feet referenced to MLLW.

Natural beaches trended towards wider beach widths, less steep beach slopes, and wider back beach width compared to restoration and armored treatments (Table 7) but back beach width was the only variable that was statistically significant (ANOVA, F=22.22, p=.0068 natural-armored, restoration; no difference between armored-restoration; Figure 21).

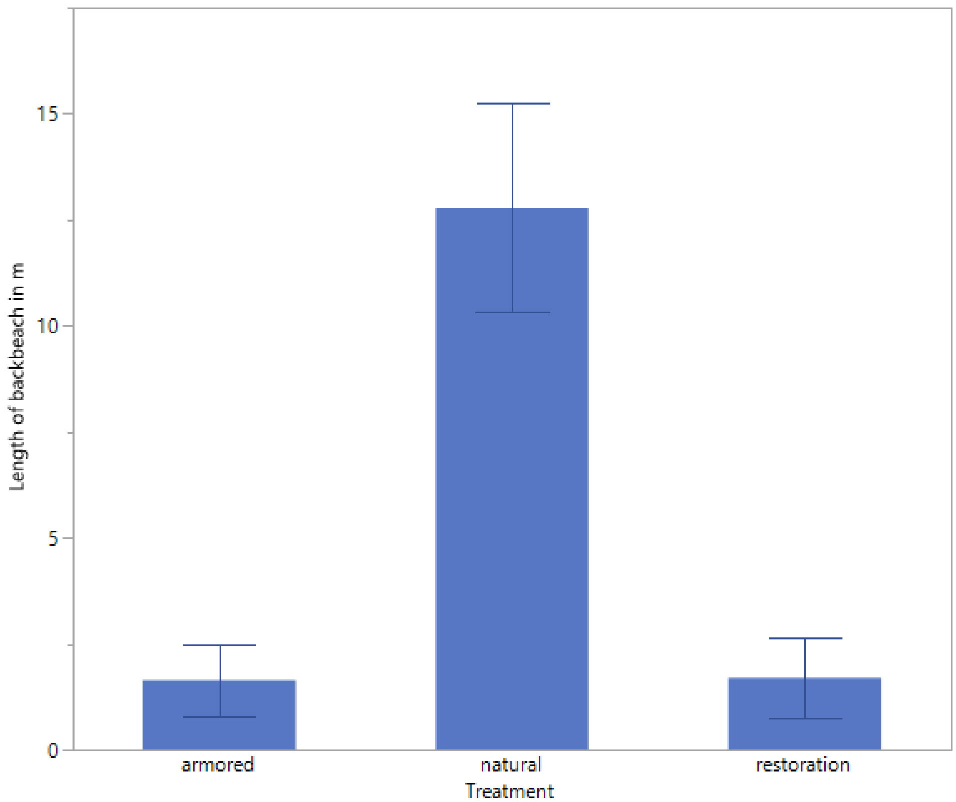


Figure 21. *The length of the back beach (beach above MHHW) was calculated from the most current beach profiles surveyed in 2018 for n=3 beaches: Lost Lake, Forest Glen, and Piner Point. Bars are means by treatment and error bars are one standard error from the mean.*

It's interesting to note that the elevation of native eel grass, although not statistically different between treatments, had higher variance around the mean for both restoration and armored treatments compared to a very low variance on natural treatments (Table 7 as seen by looking at SE of means). This means that native eel grass starts at a very predictable elevation on natural sites centered around 2 feet above MLLW. However, on armored or restoration sites the start of the native eel grass band can vary considerably in elevation from 0 to 3.3 feet above MLLW. This may have habitat consequences for the many species that use eel grass for spawning, hiding, and feeding if the start of the eel grass bed occurs too high or too low in the intertidal for their needs.

Back beach width is important habitat for both nearshore and terrestrial organisms. Armored and restoration (armored) sites had little to no beach exposed above MHHW however, natural sites had as much as 12 meters of beach exposed above MHHW (Table 8). This "extra" beach not only increases the edge zone between terrestrial and marine environments but adds resilience to change by giving intertidal zones room to move up beach as ocean levels rise due to global warming. Width of back beach will be an important component to measure as restoration proceeds on these sites.

Table 7. *Summary statistics by beach of beach profiles in 2018.*

Site	Year	Treatment	Beach width (m)	Beach slope	Backbeach (m)	Native eel grass tidal elevation (ft)
Piner Point	2018	natural	58.58	-0.07	10.35	2.20
Lost Lake	2018	natural	148.80	-0.02	17.70	2.30
Forest Glen	2018	natural	98.73	-0.04	10.29	2.10
Piner Point	2018	armored	23.98	-0.07	0.00	-1.70
Lost Lake	2018	armored	62.39	-0.04	2.00	3.36
Forest Glen	2018	armored	92.46	-0.03	2.92	1.75
Piner Point	2018	restoration	54.06	-0.05	1.76	0.27
Lost Lake	2018	restoration	85.80	-0.03	3.32	3.14
Forest Glen	2018	restoration	45.00	-0.06	0.00	1.22

Table 8. *Beach profile summary statistics for the most recent year 2018. Natural treatments had more back beach (length of beach above the Mean high high water level-MHHW) than the other two treatments. All other metrics had no significant difference between treatment.*

Treatment	Beach width (m) X (SE)	Beach slope X (SE)	Back beach (m) X (SE	Eel grass elevation X (SE)
Armored	59.6 (19.8)	-.05 (.01)	1.64 (.86)	1.1 (1.5)
Natural	102 (26)	-.043 (.01)	12.8 (2.5)	2.2 (.05)
Restoration	61.6 (12.4)	-.048 (.01)	1.7 (.95)	1.5 (.84)

Dockton Park Post-Restoration Analysis

In contrast to the other beach sites, Dockton Park has a beach treatment that was restored in 2013. We include a short analysis of data (surveyed in 2016) at natural, restoration (armored), and the previously restored treatments at Dockton to explore what variables may change most post-restoration on the other 3 beach sites. Vashon Nature Center volunteers helped the Toft lab at University of Washington sample this site in 2016 as part of an in-field training. Because there was no pre-restoration data taken at this site, we compare differences between treatments after restoration has occurred.

Natural treatments had significantly more logs, wider log line width, more canopy cover, and a greater density and richness of terrestrial arthropods than the restoration (armored) and previously restored treatments at Dockton (ANOVA F>19.5 and p<.001 for all).

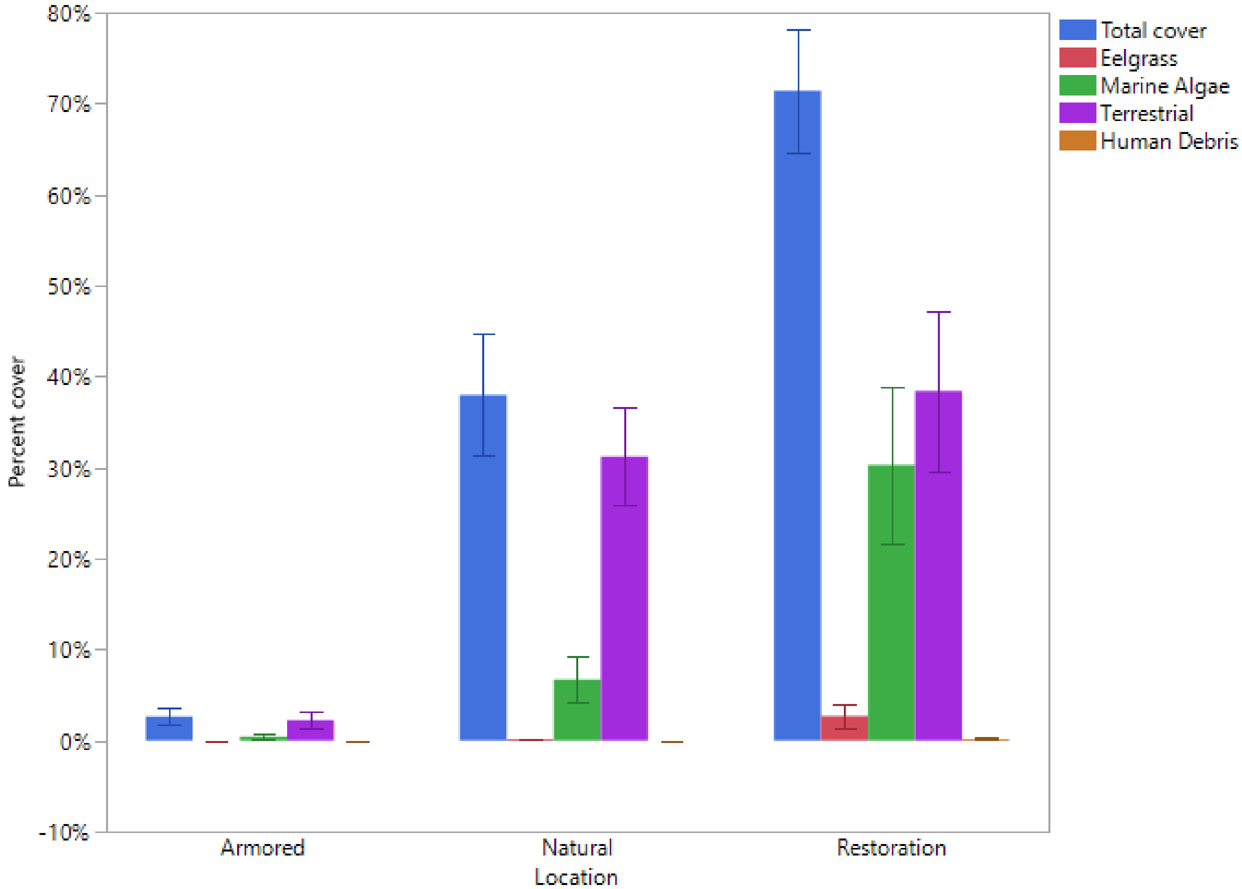


Figure 22. *Beach wrack metrics at Dockton Beach study site year 2016. The restoration site was restored in 2013 so these are post-restoration figures. Restoration sites had more total, marine algae, and terrestrial cover compared to both armored and natural treatments. Bars are mean values and error bars are one standard error.*

Three years after restoration, the biggest difference between previously-restored and other treatments was in beach wrack accumulation (Figure 22). The previously-restored treatment had significantly more total beach wrack cover even then the natural site (ANOVA, F=27.5, p<.0001, all treatments significantly differed). The previously restored treatment also had more marine algae cover than the other two treatments (F=4.7, p=.02) and more terrestrial cover in the wrack than restoration (armored) but not natural treatments (F=5.18, p=.01). Beach wrack was also significantly deeper and wider on the previously restored treatment compared to the other treatments (F>29.01 and p<.001 for both).

Because no surveys were done before restoration, we cannot be confident that this difference is due to a change post-restoration or whether the previously restored treatment had higher values of beach wrack than other treatments at the outset. However, it will be interesting to see if this same response is recorded post-restoration on the other 3 beaches surveyed.

Table 9. *Post-restoration beach profile summary statistics for Dockton Park. Restoration treatment had longer beach length (defined as the distance between mean low water (MLW) the natural beach toe or bulkhead) and more back beach (length of beach above the mean high high water level (MHHW)) than both natural and armored study treatments.*

Treatment	Beach width (m)	Beach slope	Back Beach (m)
Armored	37.3	-.06	0
Natural	30.7	-.100	6.47
Restoration	55.9	-.07	2.41

Beach profiles revealed that the previously-restored site had more beach above MHHW (back beach) and longer beach widths overall than the armored site indicating more habitat available for both intertidal and terrestrial species (Table 9).

Summary

The following key points became clear during this three-year study:

- Beach locations differ considerably in their response to ecological variables connected with shoreline armoring.
- The same beach site can vary considerably from year to year.
- Despite this variation, there are some variables that clearly differ between armored treatments and natural treatments regardless of variation due to beach location and year. These variables include both habitat structure characteristics and actual species use differences.
- High variability due to beach and year suggests that each restoration treatment will respond in different ways to shoreline armoring removal. Therefore, it is essential to monitor over a long period of time and at multiple sites if a true understanding of the effect of restoration is wanted.
- Presence of vegetation behind bulkheads that are close to natural shorelines may help maintain terrestrial arthropod abundance and diversity on armored sites and support connection between terrestrial and marine systems that shoreline armoring usually destroys.
- Monitoring takes a lot of time and people power, especially as shoreline restoration projects increase in quantity. However, shoreline toolbox monitoring protocols are robust enough that local community members can help. This allows for local

communities to be involved in stewarding and learning about their local State Aquatic Reserve in a hands-on way, which is one of the fundamental goals of the MIAR management plan (WDNR 2014).

After bulkheads are removed on the restoration sites, we can predict that the variables that showed the most difference between natural and armored treatments should experience the most change. The variables that statistically differed between restoration and natural sites and thus are expected to change the most with shoreline armoring removal are:

- number of large logs and log line width
- overhanging vegetation and total canopy cover
- total beach wrack cover, terrestrial input to beach wrack, presence and coverage of old beach wrack, and beach wrack depth
- width of back beach (the width of the beach falling above MHHW)
- Overall fish use including juvenile salmon, forage fish etc. and possible increase in sand lance spawning depending on site.

As restoration proceeds, this report will provide a baseline for comparing trends in change along study treatments--natural, armored, and restored, at each beach location. Starting in 2019, we will be able to start answering post-restoration questions like: how do variables change on restoration sites compared to pre-restoration numbers? Do the effects of restoration go beyond restoration treatment boundaries and cause changes on adjacent armored and natural treatments? How long does it take for changes to occur and on what magnitude do they occur?

We thank the local community, the landowners who offered permission, and our partners for collaborating on this effort and for putting so much time and goodwill into this work. We look forward to following change on these beaches with all of you into the future.

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Appendix

Plant Species List

Scientific name	Common Name	Form	Forest Glen (nat)	Forest Glen (arm)	Forest Glen (rest)	Lost Lake (nat)	Lost Lake (arm)	Lost Lake (rest)	Piner Point (nat)	Piner Point (arm)	Piner Point (rest)
Artemisia spp?	Artemisia	ground							1		
Lathyrus japonicus	Beach Pea	ground								1	
Corylus cornuta	Beaked Hazelnut	shrub	1			1				1	
Acer macrophyllum	Bigleaf Maple	tree	1	1	1				1	1	1
Pteridium aquilinum	Bracken Fern	ground	1		1						
Cirsium vulgare	Bull Thistle	ground		1	1			1	1		
Cirsium arvense	Canada Thistle	ground									1
Prunus spp?	Cherry	tree								1	
Galium aparine	Cleavers	ground				1					
Trifolium spp?	Clover spp?	ground					1				
Cotoneaster spp?	Cotoneaster	shrub		1							
Populus balsamifera	Cottonwood	tree					1				
Taraxacum officinale	Dandelion	ground		1	1			1			
Pseudotsuga menziesii	Douglas Fir	tree	1	1							1
Elymus mollis	Dune grass	ground				1	1				
Sambucus racemosa	Elderberry	shrub	1			1					
Hedera helix	English Ivy	ground		1				1	1	1	1
Festuca spp?	Fescue spp?	ground			1						
Epilobium angustifolium	Fireweed	ground			1						
Digitalis purpurea	Foxglove	ground		1							
Tellima grandiflora	Fringecup	ground	1								
Fuchsia spp?	Fuchsia	shrub						1			

Scientific name	Common Name	Form	Forest Glen (nat)	Forest Glen (arm)	Forest Glen (rest)	Lost Lake (nat)	Lost Lake (arm)	Lost Lake (rest)	Piner Point (nat)	Piner Point (arm)	Piner Point (rest)
Geranium spp?	Geranium	ground		1							
Vitis spp?	Grape (domestic)	ground								1	
Poacea spp?	Grass spp?	ground		1	1		1	1	1	1	
Rubus armeniacus	Himalayan Blackberry	shrub		1	1		1	1	1	1	1
Lonicera ciliosa	Honeysuckle	ground						1	1		
Equisetum arvense	Horsetail	ground		1	1		1	1		1	1
Oemleria cerasiformis	Indian Plum	shrub									1
Iris spp?	Iris (domestic)	ground						1			
Athyrium filix-femina	Lady Fern	ground	1								
Lupinus spp?	Lupine	ground							1		
Arbutus menziesii	Madrona	tree							1		
Malvacea spp?	Mallow spp?	shrub						1			
Convolvulus arvensis	Morning Glory	ground					1	1			
Brassica spp?	Mustard spp?	ground						1			
Rosa nutkana	Nootka Rose	shrub									1
Holodiscus discolor	Ocean Spray	shrub	1		1				1	1	
Atriplex spp?	Orache	ground			1			1			1
Dactylis glomerata	Orchard Grass	ground			1						
Vinca minor	Periwinkle	ground			1						
Rhus diversiloba	Poison Oak	shrub							1		
Alnus rubra	Red Alder	tree	1	1	1	1		1	1	1	1
Phalaris arundinacea	Reed Canary Grass	ground			1						
Juncus spp?	Rush spp?	ground			1		1				
Gaultheria shallon	Salal	shrub	1								

Scientific name	Common Name	Form	Forest Glen (nat)	Forest Glen (arm)	Forest Glen (rest)	Lost Lake (nat)	Lost Lake (arm)	Lost Lake (rest)	Piner Point (nat)	Piner Point (arm)	Piner Point (rest)
Rubus spectabilis	Salmonberry	shrub	1	1		1					
Saxifragacea spp?	Saxifrage	ground				1					
Cytisus scoparius	Scotch Broom	shrub		1	1				1		
Salix scouleriana	Scouler's Willow	shrub/tree									1
Carex spp?	Sedge	ground					1		1		
Pinus contorta var. contorta	Shore Pine	tree									1
Salix stichensis	Sitka Willow	shrub/tree							1		
Spp?	small white flower	ground					1				
Sonchus arvensis	Sow Thistle	ground			1						
Urtica dioica	Stinging Nettle	ground	1	1	1			1			
Polystichum munitum	Sword fern	ground	1			1				1	
Senecia jacobaea	Tansy Ragwort	ground		1	1						
Rubus parviflorus	Thimble berry	shrub	1		1	1		1			
Rubus ursinus	Trailing Blackberry	ground	1	1	1	1		1			
spp?	Unknown (domestic)	shrub					1	1			
spp?	Unknown groundcover (cultivated)	ground		1							
spp?	Unknown rosette	ground			1						
spp?	Unknown weed	ground						1			
Vicia spp?	Vetch	ground			1						
Acer circinatum	Vine Maple	shrub/tree		1							1

Scientific name	Common Name	Form	Forest Glen (nat)	Forest Glen (arm)	Forest Glen (rest)	Lost Lake (nat)	Lost Lake (arm)	Lost Lake (rest)	Piner Point (nat)	Piner Point (arm)	Piner Point (rest)
Thuja Plicata	Western Red Cedar	tree									1
Salix spp?	Willow	shrub/tree						1			
Asteracea spp?	Yellow Composite	ground							1	1	