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# Benthic Macroinvertebrate Monitoring at Seahurst Park 2008, Year 3 Post-Restoration of Seawall Removal

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## Executive Summary

This report describes year 3 post-construction restoration monitoring of benthic invertebrates at Seahurst Park, located on Puget Sound in the City of Burien. Shoreline modifications have altered many of the natural habitats in nearshore areas of Puget Sound. Efforts to restore intertidal areas have increased in recent years, with listing of Chinook salmon as threatened under the Endangered Species Act in 1999. Monitoring has been limited in many cases, leading to a lack of rigorous studies that measure effects of completed restorations and guide future efforts. Restoration completed in February 2005 at Seahurst Park removed a section of seawall and created an intertidal beach. This study describes an initial assessment of the restoration by monitoring paired project/reference sites in 2008 and comparing to previous samplings in 2004 and 2006. Benthic macroinvertebrates were used as a biological measure, due to their importance in intertidal beach ecology and prey for nearshore fish.

Ideally, the project site will one day closely match the reference site in terms of invertebrate densities, assemblages, and taxa richness. Increased densities means that the numbers of invertebrates will have increased since restoration, and improved assemblages and taxa richness means that the types and diversity of taxa will be similar to the reference beach. These improved conditions will presumably benefit juvenile salmon by providing increased prey resources for feeding.

Benthic cores were taken during three months (June, July, September) and at three tidal heights (+12, +8 and +5' MLLW), identical to previous monitoring. Results indicated that some aspects of the invertebrate community have improved since pre-restoration conditions and shifted towards those at the reference site, while others are still in development. Beach-wrack formation at high tidal elevations occurred at the project site, with development of +12 invertebrate assemblages that were typical of the reference beach and unique to those at the highest tidal elevation. Although overall densities at +8 and +5 were still not as high as the reference site, taxa richness was greater, signifying a good colonization of a diversity of invertebrates that will hopefully continue to increase in number with time. Furthermore, the previously modified seawall elevations of +12 and +8 have shown improvements compared to pre-restoration levels, as illustrated by higher densities, taxa richness, and assemblage structure. The +5 elevation seems to be most affected by the regrading of the beach, with distinct differences in invertebrate assemblages as compared to those from pre-restoration and reference beach samples. It is unknown whether this is indicative of an early restoration stage, or due to physical alterations caused by the beach regrade.

The 118 taxa sampled in this monitoring detail the diversity that can be obtained within mid to upper intertidal realms, exclusive of lower intertidal elevations. Some are important in processing organic debris, such as talitrids (beach-hoppers) at higher elevations which break down beach-wrack, and oligochaetes and nematodes which live

within sediments. Others are good potential prey items for nearshore fish, including aquatic amphipods and polychaetes which are fed upon by juvenile salmonids.

A major goal of nearshore restoration in Puget Sound should be to establish and maintain connections between terrestrial riparian and aquatic intertidal zones. When this occurs, it facilitates development of secondary responses including natural feeding processes and assemblage interactions. Monitoring in this report has shown that although there are still some differences between the restored and reference sites at Seahurst Park, the restoration has resulted in a positive initial response of the benthic invertebrate community. It will be important to continue to monitor in future years in order to assess long-term site development, especially at the +8 and +5 tidal elevations which were most affected by the beach regrade and sediment nourishment. This monitoring is currently funded for year 5 (2010) and planned for year 10 (2015). Such monitoring will be useful to help guide other restoration opportunities along shorelines of Puget Sound, including the planned restoration of the north seawall at Seahurst Park.

**Representative Invertebrates**

talitrid amphipod *Traskorchestia traskiana*

aquatic amphipod *Eogammarus confervicolus*

glycerid polychaete worm *Hemipodia simplex*

oligochaete and nematode worms

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## Introduction

Shoreline modifications have become a prevalent feature in many aquatic systems worldwide, especially in areas dominated by human populations. In Puget Sound, one third of the natural habitats in nearshore areas are modified by retaining structures, with increased levels near urban centers (Bailey et al. 1998). These retaining structures are usually composed of vertical seawalls and riprap boulder fields. Efforts to restore or enhance intertidal areas have increased in recent years, with listing of Chinook salmon as threatened under the Endangered Species Act in 1999. Endangered ocean-type juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Pacific Northwest use estuarine and nearshore habitats early in their outmigration and rearing period (Simenstad et al. 1982). Since juvenile Chinook salmon and other nearshore fishes utilize shoreline areas, the different habitat types that are represented can affect fish abundance, distribution, and behavior patterns (Toft et al. 2007), and survival of eggs in beach spawning surf smelt (Rice 2006). Additionally, removal of supralittoral vegetation correspondent with retaining structures also affects some nearshore fish species (Romanuk & Levings 2006). Negative impacts can also apply to invertebrates, which are an important prey component of many fish (Romanuk & Levings 2003; Sobocinski 2003). Nearshore habitat restoration often emphasizes improving conditions for these important invertebrates, with the goal of enhancing their production to more natural levels and increasing ecological function of the site.

Impacts of shoreline modifications on invertebrate assemblages have been shown to affect community patterns in other systems as well, predominantly in a negative way with decreased or altered assemblages, but with occasional positive interactions attributed to an increase in unique structures that can attract certain organisms (Glasby 1998: Peterson et al. 2000, Spalding & Jackson 2001; Davis et al. 2002; Chapman 2003; Chapman & Bulleri 2003; Cruz Motta et al. 2003). Underlying mechanisms for negative effects are often related to physical alterations associated with truncating and retaining the intertidal zone, such as degrading intertidal habitat and shoreline vegetation, limiting the sediment supply, and reflecting wave energy which can increase erosion and coarsen sediments (Thom et al. 1994; Douglass & Pickel 1999). Research has been lacking to test whether these altered systems can be restored towards natural conditions with removal of the modifications and enhancement of the intertidal beach.

This study describes 2008 year 3 post-restoration monitoring of the benthic invertebrates along the shoreline at Seahurst Park in the City of Burien, where restoration activities completed in February 2005 replaced a 300-m section of seawall/riprap with a more gradual and natural slope, removing the seawall by barge and importing gravel and cobble with upland plantings of riparian vegetation (Fig. 1; USCOE 2003). By incorporating a paired project/reference sampling design and comparing to pre-restoration monitoring in 2004 (Toft 2005) and year 1 post-restoration monitoring in 2006 (Toft 2007), we will be able to begin to assess the restoration effort. Benthic invertebrates in Puget Sound have been shown to be closely linked to physical characteristics in the benthos, thus making them a suitable metric for analysis (Dethier & Schoch 2005). Benthic cores were taken during three months (June, July, September) and at three different tidal heights (+5, +8 and +12' MLLW) in all years of sampling. Therefore, the main goal of this study was to compare the benthic macroinvertebrate assemblage structure at the restoration site and a nearby reference beach, in order to provide an initial measurement of restoration success.

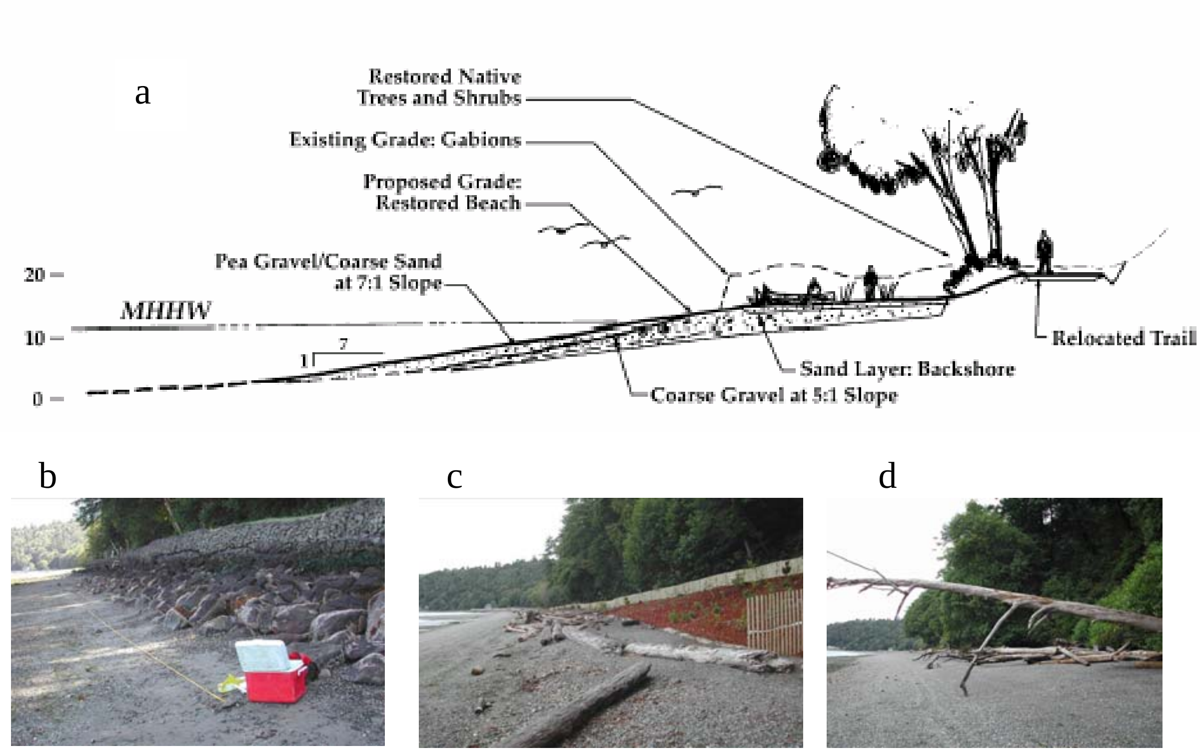



Figure 1. Typical cross section (a) of the plan for restoration at Seahurst Park (USCOE 2003), with photographs of the project site pre- (b) and post-restoration (c), and reference beach (d).

## Methods

Two sites were sampled: (1) the seawall removal project site at Seahurst Park (Proj), and (2) the reference beach (Ref) immediately south (~200-m) of Seahurst Park (Fig. 2). Sampling was conducted in June, July and September 2008, identical to past years of sampling (2004 and 2006). June and July represent peak periods of juvenile Chinook and coho (*Oncorhynchus kisutch*) salmonid migration, and September typically represents higher vegetation-wrack depositions (the accumulation of debris deposited by an ebbing tide, consisting mostly of marine algae and organic matter from terrestrial riparian sources such as wood and leaves). Invertebrates were collected at three different tidal heights that spanned the elevations affected by restoration:

(1) +12’ MLLW (hereafter +12), approximately the level of MHHW. This area is where beach-wrack is typically formed, and is at an elevation where seawall material was removed at the project site. Thus, during pre-restoration monitoring only the Reference site was sampled at +12, as there was no benthic substrate to sample at the Project site due to the seawall.
(2) +8’ MLLW (hereafter +8), the approximate elevation at the foot of the previous shoreline modification at the project site. This elevation provides comparable data where the shoreline modification interacted with the water.
(3) +5’ MLLW (hereafter +5), the low elevation of the beach regrade.


Figure 2. Location of Project and Reference transects at Seahurst Park, pre-restoration.

Seven samples were randomly collected with a benthic core along a 30-m transect at each site and tidal elevation. Benthic cores were 10 cm in diameter and taken to a depth of 15 cm. Samples were fixed in 10% formalin and dyed with rose-bengal to aid in sorting and identification. Cobble, mud, wood, and other detritus were removed to the extent possible with sieving at 500 microns, and macroinvertebrates were identified and counted using a dissecting microscope.

Data was entered into Microsoft Excel, and univariate ANOVA tests (alpha = 0.05) were used to analyze total invertebrate densities in the statistical program S-Plus (Zar 1996). Densities were log-transformed to satisfy assumptions of normality and homogeneous variances, and analyzed with a Model I ANOVA (fixed, balanced sampling design with equal replication). Taxa richness was measured as the total number of taxa recorded at each site.

Invertebrate assemblages were analyzed using multivariate statistics: nonmetric multidimensional scaling (NMDS) ordination, analysis of similarity (ANOSIM), and similarity percentage (SIMPER) analysis (Primer version 6 software, Clarke and Warwick 2001). These analyses uncover patterns in multivariate groupings of the data, which is useful when analyzing assemblage datasets with multiple species compositions. Densities were log-transformed for ordination, and species that did not account for more than 3% of the total abundance of any one sample not included. NMDS was used to graphically plot differences in species assemblages onto two-dimensional charts in multidimensional space based on a Bray-Curtis similarity matrix. ANOSIM has been used for testing hypotheses about spatial differences and temporal changes in species assemblages as well as for detecting environmental impacts (Valesini et al. 2004; Wildsmith et al. 2005). ANOSIM gives a p-value similar to an ANOVA, with values of $p < 0.05$ indicating significance. ANOSIM also generates a value of R to determine biological importance. The R value is scaled between -1 and +1, with a value of zero representing no difference among a set of samples, and the closer the value to 1 the greater the biological importance of the differences. R values above 0.4 are typically found to have biological importance. If differences were found using ANOSIM, then SIMPER analysis was used for identifying which species primarily accounted for observed differences in invertebrate assemblages between sites. SIMPER generates a ranking of the percent contribution of the species that are most important to the significant differences between factors.

## Results

General Taxa Composition

A total of 118 taxa were identified during the entire sampling regime. Graphs and analysis are grouped into major taxa groupings, with discussion of species where appropriate. General classification of sampled taxa groupings and species are listed in Table 1. For taxa grouped into general categories, the groups with the highest percent composition were oligochaetes, aquatic amphipods and isopods, terrestrial amphipods, polychaetes, nematodes, and nemertea/turbellaria (Fig. 3). Oligochaetes were the most abundant taxa, and were present at every site. Nematodes were relatively abundant at most sites, except for low percent compositions at Ref +5 2006 and Ref +12 2004 and 2008. Nemertea and turbellaria tended to have highest percent compositions at Ref +8 sites. Densities of terrestrial amphipods and isopods (mostly beachhopper amphipods in the family Talitridae) were most abundant at the +12 elevation, with lower densities at +8, and only four occurrences at +5. While juvenile talitrids usually dominated beachhopper numbers, adults of three species occurred: *Traskorchestia georgiana, Traskorchestia traskiana,* and *Megalorchestia pugettensis* (listed in order of increasing maximum size). As a group, insects (adults and larvae), arachnids (mites-acarina and spiders-araneae), and collembolans (springtails in families Hypogastruridae, Isotomidae, and Sminthuridae) had overall fairly low numbers, with insect adults and larvae mostly at higher elevations, collembola mostly at lower, and arachnids (almost all mites) evenly distributed at all elevations. As would be expected, aquatic crustaceans were most abundant at the lower +5 tidal elevations. Similar to crustaceans, almost all polychaetes had highest densities at the +5 elevation, except for the small archiannelid *Protodriloides chaetifer* which occurred mostly at +8. Mollusks also were present mostly at lower tidal elevations, although overall densities were very low compared to other taxa.

Table 1. Species listing of sampled invertebrates and taxa groups, listed in descending densities within each grouping.

| Taxa Grouping | Taxa |
|---|---|
| Terrestrial amphipods | *Traskorchestia traskiana, Traskorchestia georgiana, Megalorchestia pugettensis,*and juveniles |
| Terrestrial isopods | *Detonella papillicornis*, and juveniles |
| Arachnids | Acarina, Araneae |
| Collembola | Isotomidae, Hypogastruridae, Sminthuridae |
| Insects | Staphylinidae, Coleoptera larvae, Ephydridae larvae, Chironomidae larvae, Empididae larvae, Chironomidae, Ephydridae, Empididae, Sphaeroceridae, Coleoptera, Muscidae larvae, Coccinellidae, Aphididae, Psocoptera, Chironomidae pupae, Cicadellidae, Formicidae, Hydrophilidae, Ceratopogonidae larvae |
| Aquatic amphipods | *Eogammarus confervicolus, Allorchestes angusta*, *Paramoera bousfieldi*, *Paramoera mohri*, *Monocorophium acherusicum*, *Grandidierella japonica*, *Americorophium* sp., *Photis* sp., and juveniles |
| Aquatic isopods | *Gnorimosphaeroma oregonense*, *Exosphaeroma inornata*, *Gnorimosphaeroma insulare*, *Idotea wosnesenskii*, Epicaridea, and juveniles |
| other rare Crustacea | *Hemigrapsus oregonensis*, Ostracoda, Crangonidae, *Nitokra* sp., Ectinosomatidae, *Cumella vulgaris*, Euphausiacea zoea, *Amonardia perturbata*, *Diosacchus spinatus*, *Harpacticus* sp., *Huntemannia jadensis*, Laophontidae, *Paralaophonte* sp., *Parathalestris californica*, *Amphiascus cinctus*, Porcellidium, Leptastacidae, *Zaus* sp. |
| Mollusks | *Mytilus edulis*, *Littorina scutulata*, Lottiidae, Cardiidae, and juveniles |
| Glyceridae polychaetes | *Hemipodia simplex* |
| Nereidae polychaetes | *Neanthes limnicola, Nereis vexillosa, Platynereis bicanaliculata,* and juveniles |
| Archiannelid polychaetes | *Protodriloides chaetifer, Nerilla sp.* |
| other rare Polychaetes | Capitellidae, Spionidae, Hesionidae, *Pseudopolydora kempi*, *Armandia brevis,* Phyllodocidae, *Paleanotus occidentale, Eteone californica*, *Pygospio elegans*, *Phyllodoce longipes*, Sabellidae, *Syllis elongata* and juveniles |
| General taxa groupings | Oligochaete, Nematode, Turbellaria, Nemertea, Foraminifera, Phoronida, Anthozoa |

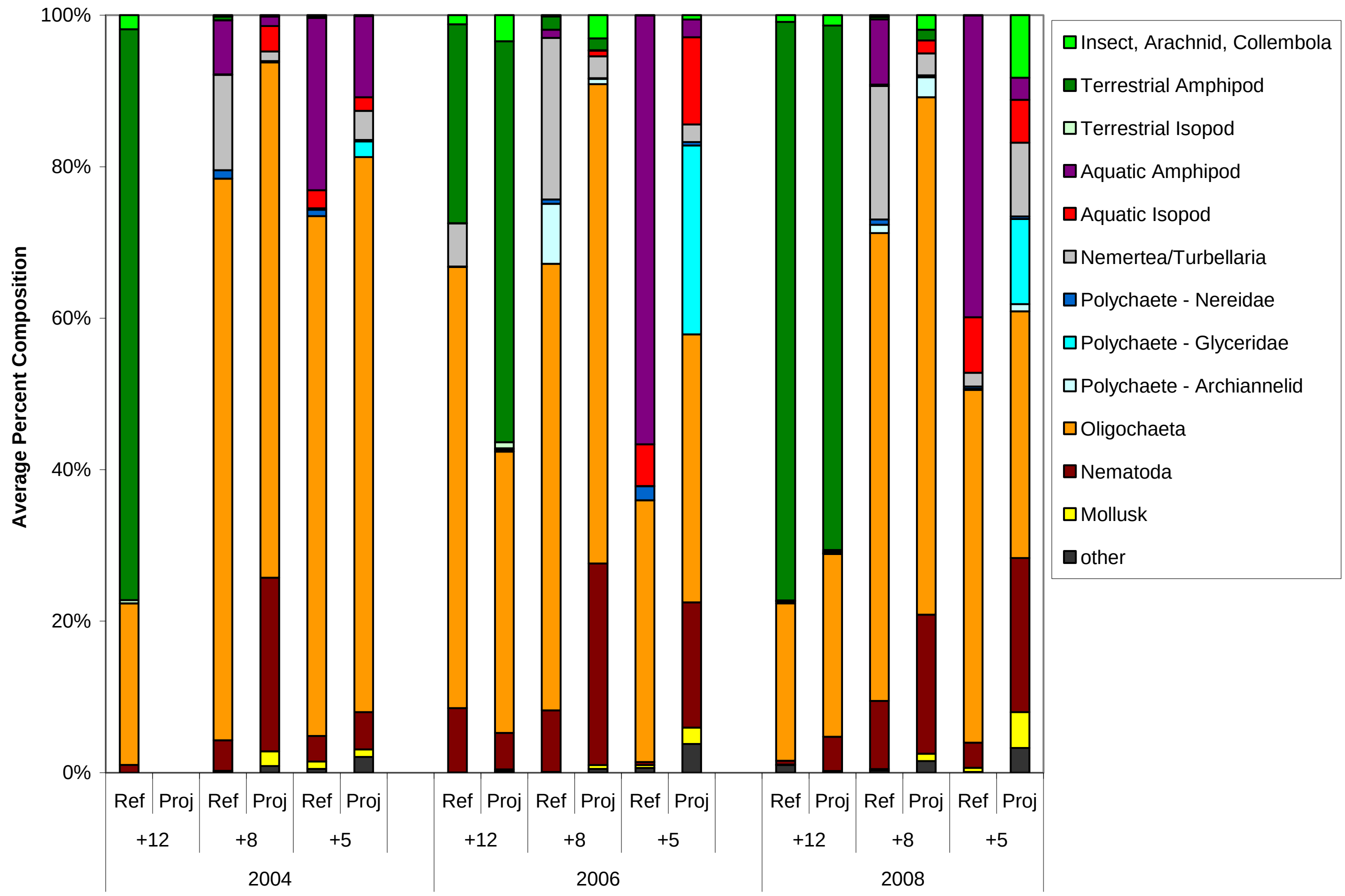



Figure 3. Numerical Percent taxa composition of all sampled invertebrates, showing major taxa groups averaged over June, July, and September for each year. Order in legend reflects that in columns, Ref = Reference, Proj = Project.

<u>2008 Post-Restoration Invertebrates</u>

Results from a 2-way site x month ANOVA with interactions on log-transformed total densities at each elevation showed significantly greater Reference densities at the +8 and +5 elevations, with no site differences at +12 (Table 2, Fig. 4). Although there were also significant site x month interaction differences at +5, separate ANOVAs for each month still showed significantly greater densities at Reference. Month was significant at all elevations, illustrating some seasonal differences in densities. In contrast, the Project site exceeded the Reference site in taxa richness for every elevation (Fig. 5).

Multivariate analysis of the 2008 benthic invertebrate assemblages based on densities proved to be a “useful” model according to statistical guidelines, showing a NMDS ordination 2-d stress of 0.18 (Fig. 6a). The three different elevations grouped distinctly, with separation between the Reference and Project sites at +5, some overlap between the sites at +8, and more overlap at +12. Further analysis with a 1-way ANOSIM on site showed significant overall results on the Global test, with significant meaningful differences between the Reference and Project sites at the +5 and +8 elevations (Table 3). Although the p-value was also significant at the +12 elevation between Reference and Project, the R-value was low (well below 0.4) showing little biological importance. The subsequent SIMPER analysis details the taxa differences for these significant results (Table 4): (1) at +8 elevation, greater densities of turbellaria, nemertea, and the amphipod *Paramoera* sp. at Ref, with also minor increases in densities of oligochaetes and nematodes at Ref, and (2) at the +5 elevation, greater densities of the amphipods *Eogammarus confervicolus* and *Allorchestes* sp. at Ref, and the Glyceridae polychaete *Hemipodia simplex* at Proj, with minor differences in oligochaetes and nematodes.

As an example of these post-restoration invertebrate assemblage characteristics, the same ordination plot in Figure 6a is shown with bubble plots of the densities of four key taxa identified in SIMPER results (juvenile Talitridae, turbellaria, aquatic amphipod *Eogammarus confervicolus*, and the Glyceridae polychaete *Hemipodia simplex;* Fig. 6b). There is a clear separation at +5 between *E. confervicolus* at Reference and Glyceridae at Project. The +8 elevation shows most of the turbellaria inhabiting Reference sites. And, at +12 juvenile Talitridae amphipods are distributed among both Reference and Project sites.

<u>2004/2008 Pre- and Post-Restoration Invertebrates</u>

Results from a 1-way ANOVA of log-transformed total densities on year for comparable Project +8 and +5 sites from each month showed two months at +8 where 2008 was greater than 2004 (June and September), and two months at +5 where 2004 was greater than 2008 (July and September; Table 2; Fig. 4). Taxa richness was much higher post-restoration at Proj +8, and slightly higher at Proj +5 (Fig. 5).

Multivariate analysis of the benthic invertebrate assemblages pre- and post restoration based on densities proved to be a “useful” model according to statistical guidelines, showing a NMDS ordination 2-d stress of 0.18 (Fig. 7). The three different elevations grouped distinctly, using Project sites from both 2004 and 2008 and Ref +12 from 2004, as there wasn’t a comparable +12 Project site pre-restoration. Proj +12 2008 clustered similar to Ref +12 2004 and away from the pre-restored highest elevation Proj +8 2004. The +5 elevation clustered apart between years, but there was a fair amount of overlap at +8. Further analysis with a 1-way ANOSIM on site showed significant overall results on the Global test (Table 3). At Proj +12, there was no significant differences compared to Ref +12 pre-restoration, but there was compared to the pre-restored highest elevation Proj +8 2004. Proj +8 had few differences 2008 compared to 2004 (low R-value), and Proj +5 had moderately meaningful differences (R-value close to 0.4). The subsequent SIMPER analysis details the taxa differences for these significant results (Table 4), summarized as: (1) much higher densities of Talitrids at Proj +12 2008 compared to the pre-restored highest elevation Proj +8 2004, and (2) at +5, more oligochaetes and juvenile amphipods in 2004, and more of the Glyceridae *Hemipodia simplex* in 2008.

Table 2. Summary ANOVA p-values of total invertebrate significant density differences, p < 0.05 in bold.

***2008***

*2-way ANOVA on site x month*

| Elevation | Month | Site | Interaction |
|---|---|---|---|
| 12' | **0.008** | 0.13 | **0.002** |
| 8' | **0.0002** | **1.0E-08** (Ref > Proj) | 0.35 |
| 5' | **0.000002** | **1.0E-09** (Ref > Proj) | **0.005** |

***Project 2004 and 2008***

*1-way ANOVA on site*

| Elevation | Month | |
|---|---|---|
| Proj +8' | June | **0.0001** (2008 > 2004) |
| | July | 0.73 |
| | Sept | **0.001** (2008 > 2004) |
| Proj +5' | June | 0.24 |
| | July | **0.0000009** (2004 > 2008) |
| | Sept | **0.003** (2004 > 2008) |

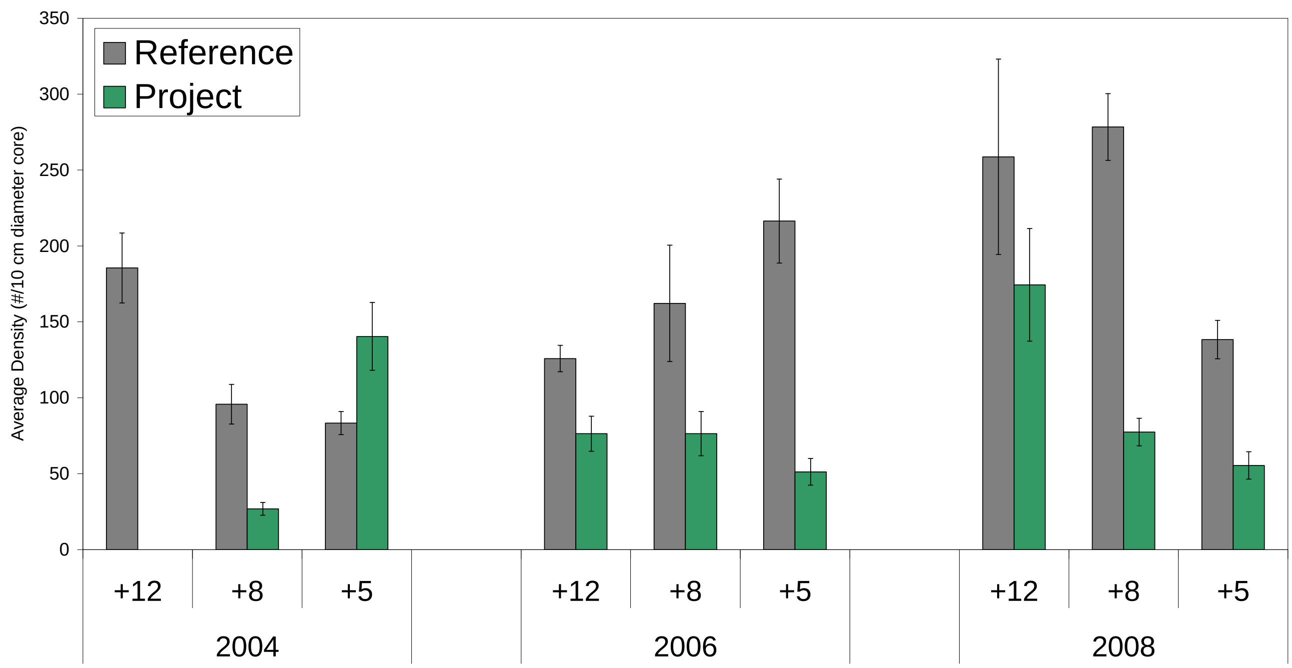



Figure 4. Total average invertebrate densities for all sites in 2004 (pre-restoration), 2006 and 2008 (years 1 and 3 post-restoration). Error bars represent Standard Error.

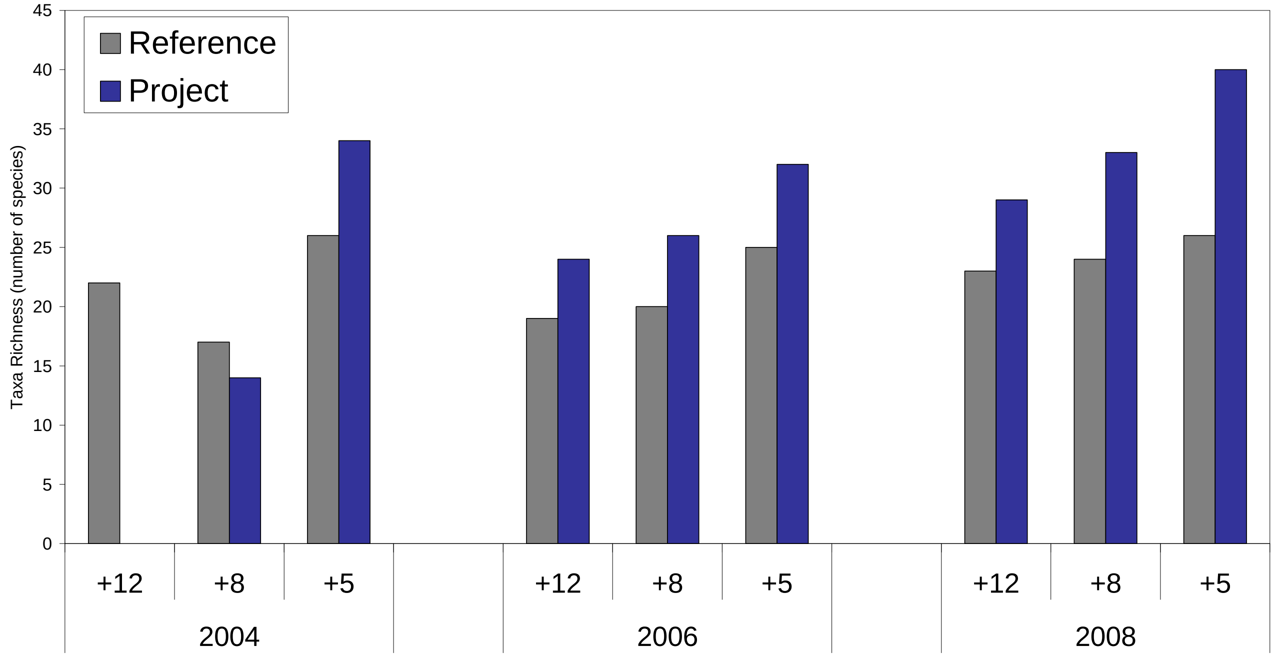
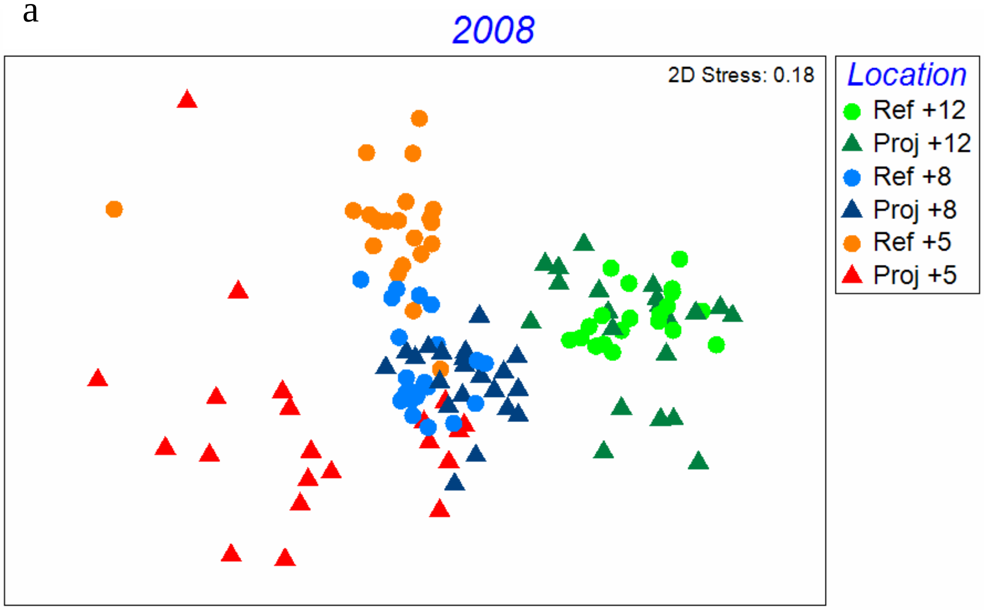


Figure 5. Overall taxa richness for all sites and years.

a




b

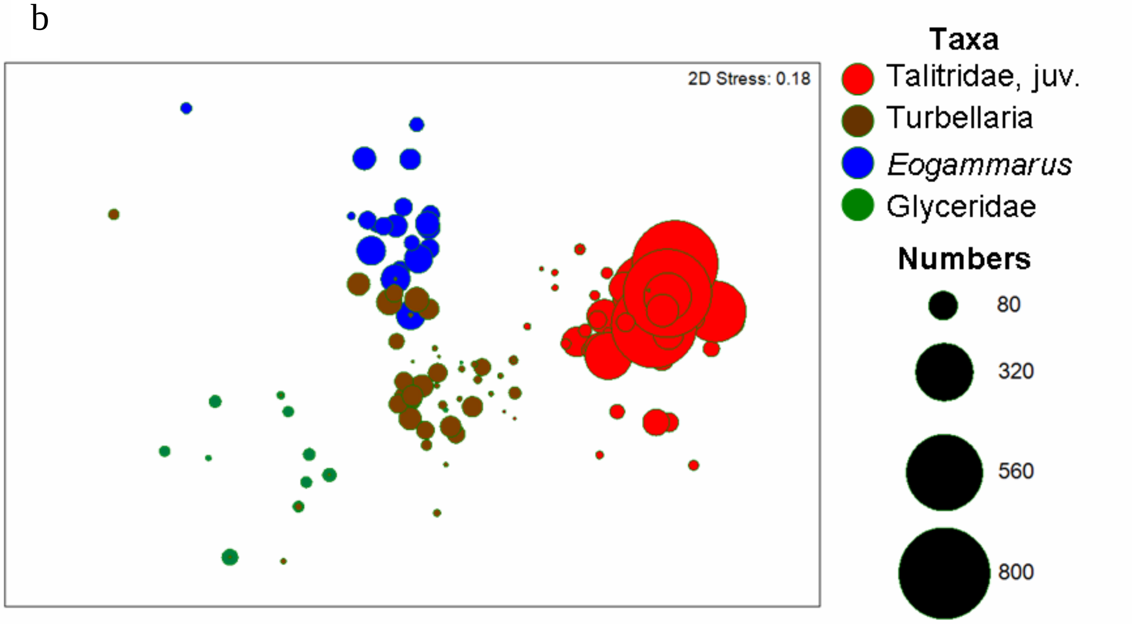



Figure 6. Multivariate analysis using NMDS ordination of the benthic invertebrate data (each symbol represents the invertebrate assemblage in a single sample) in (a) 2008, and (b) corresponding bubble plot of numbers of representative taxa, positions of bubbles correspond to points on 2008 NMDS ordination. Taxa: juvenile terrestrial amphipods (Talitridae), flatworms (Turbellaria), aquatic amphipods (*Eogammarus confervicolus*), and the polychaete *Hemipodia simplex* (Glyceridae).

Table 3. Summary ANOSIM statistics using multivariate analysis on invertebrate assemblages. ANOSIM is equivalent to a univariate ANOVA, with high biological importance illustrated by $R > 0.4$ and significant differences $p < 0.05$.

| ***2008*** | | |
|---|---|---|
| Site Comparison | R-value | p-value |
| Global test | 0.68 | 0.001 |
| **+12** Proj & Ref | 0.08 | 0.022 |
| **+8** Proj & Ref | 0.68 | 0.001 |
| **+5** Proj & Ref | 0.57 | 0.001 |

| ***Project 2008 and 2004*** | | |
|---|---|---|
| Site Comparison | R-value | p-value |
| Global test | 0.53 | 0.001 |
| **Proj+12** 2008 & Ref +12 2004 | 0.001 | 0.387 |
| **Proj+12** 2008 & Proj +8 2004 | 0.65 | 0.001 |
| **Proj+8** 2008 & 2004 | 0.21 | 0.001 |
| **Proj +5** 2008 & 2004 | 0.38 | 0.001 |

Table 4. Summary SIMPER statistics using multivariate analysis on invertebrate assemblages. SIMPER analyzes the taxa that have the largest contributions to statistical differences (top 5 in each category included).

| ***2008*** | Average log-densities | | |
|---|---|---|---|
| **+8 Proj & Ref** (avg. dissimilarity 48.5) | **Project** | **Reference** | % Contribution |
| Turbellaria | 0.69 | 3.39 | 20.2 |
| Nemertea | 0.11 | 2.28 | 16.6 |
| Oligochaeta | 3.79 | 5.07 | 10.0 |
| *Paramoera* sp. | 0 | 1.2 | 7.5 |
| Nematoda | 2.52 | 2.77 | 7.3 |
| **+5 Proj & Ref** (avg. dissimilarity 71.1) | | | |
| *Eogammarus confervicolus* | 0.12 | 3.35 | 17.1 |
| Oligochaeta | 1.83 | 3.89 | 13.1 |
| *Hemipodia simplex* | 1.28 | 0.05 | 7.1 |
| *Allorchestes* sp. | 0.47 | 1.11 | 6.5 |
| Nematoda | 2.08 | 1.38 | 6.4 |

Table 4 continued

| ***Project 2008 and 2004*** | Average log-densities | | |
|---|---|---|---|
| **Proj+12 2008 & Proj +8 2004** (avg. dissimilarity 69.1) | **2008** | **2004** | % Contribution |
| Talitridae, juv. | 3.56 | 0 | 29.2 |
| *Traskorchestia traskiana* | 1.9 | 0 | 14.9 |
| Oligochaeta | 2.96 | 2.52 | 14.5 |
| Nematoda | 0.99 | 1.51 | 12.8 |
| *Traskorchestia georgiana* | 1.13 | 0 | 8.3 |
| **Proj +5 2008 & 2004** (avg. dissimilarity 70.2) | | | |
| Oligochaeta | 1.83 | 3.66 | 15.4 |
| *Hemipodia simplex* | 1.28 | 0.49 | 7.6 |
| Nematoda | 2.08 | 1.42 | 7.6 |
| Amphipod, juv. | 0 | 1.42 | 7.5 |
| Turbellaria | 0.9 | 1.4 | 7.4 |

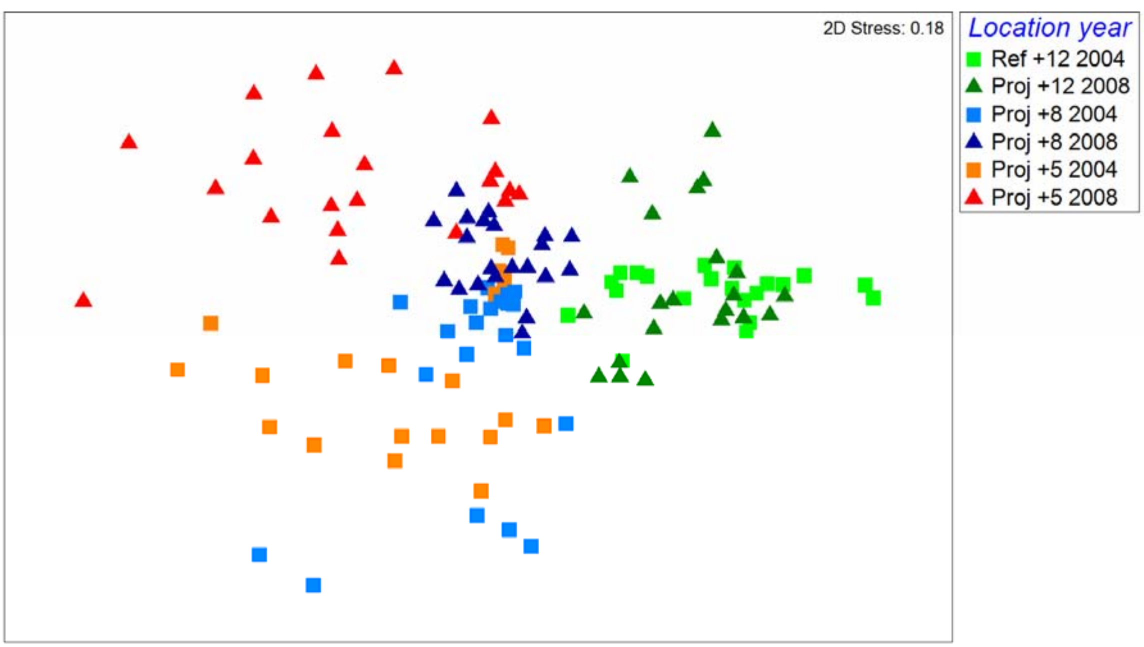



Figure 7. Multivariate analysis using NMDS ordination of the benthic invertebrate data for Project sites in 2008 (post-restoration) versus 2004 (pre-restoration), with Ref +12 2004 as a comparison since no Proj +12 site existed pre-restoration.

## Discussion

It is clear that after the third year of beach restoration at Seahurst Park that some aspects of the invertebrate community have improved since pre-restoration conditions and shifted towards those at the reference site, while others are still in development. Before restoration, the seawall truncated the supratidal and high intertidal zone, causing lack of shoreline riparian vegetation and preventing formation of beach-wrack deposition that is typical of a natural gradual sloping beach. By removing the seawall and restoring the natural beach gradient along with plantings of terrestrial vegetation, the processes that were negated by the presence of the seawall can begin to re-develop. Beach-wrack formation at high tidal elevations now occurs at the project site, with development of invertebrate assemblages that are typical of the reference beach and unique to those at the highest tidal elevation. Although overall densities at lower tidal elevations are still not as high as the reference site, taxa richness is greater, signifying a good initial colonization of a diversity of invertebrates that will hopefully continue to increase in number with time.

Results of the invertebrate sampling can best be discussed in relation to the different tidal elevations characterized by the restoration activities at each elevation. At the +12 elevation, there was previously a seawall that prevented wrack formation and a benthic assemblage prior to restoration. Since restoration, an initial colonization of invertebrates has occupied this site with high taxa richness and similar invertebrate assemblages to the Reference site, with equal densities. Terrestrial amphipods (beachhoppers in the family Talitridae) are typical of this elevation, thriving on beach wrack deposition. This wrack-dependent community has been found to be unique in other systems as well, with important links to terrestrial zone productivity (Dugan et al. 2003; Ince et al. 2007). Overall, invertebrate assemblages at this elevation have been restored to the conditions at the reference beach, progressing to this status since the initial year 1 monitoring (Toft 2007).

The +8 elevation was previously the location at the base of the seawall, and therefore subject to physical alterations in sediments and wave activity that altered the invertebrate community. Taxa richness was low, and invertebrate assemblages were different than comparable elevations at the Reference site, with lower densities (Toft 2007). Invertebrates have occupied this elevation since restoration, resulting in high taxa richness that was almost double that of pre-restoration levels and higher than the reference site. However, even though two of the months had higher densities than pre-restoration levels, the densities are still lower than the Reference site. Hopefully these encouraging initial trends will continue to develop in future years, mainly in numbers of amphipods and other invertebrates.

The +5 elevation was below the base of the seawall, at the low level of the regrade of the restored beach. There were no major significant differences between densities or assemblages before restoration, with taxa richness actually being highest at the project site. This could possibly be due to invertebrate colonization being hindered by physical alterations at the base of the seawall at Proj +8 and thereby occupying lower tidal elevations, additionally supported by sediment samples which showed higher sediment sizes (gravel) at the project site than at the reference site (medium sand; Sobocinksi 2003). The necessary regrade of the beach at this elevation as part of the restoration affected the invertebrate community, leading to reduced densities and a dramatic shift in invertebrate assemblages, albeit with high taxa richness. The restored site had less amphipods and oligochaetes and more Glyceridae polychaete worms in both years of monitoring post-restoration. The reasons for these alterations in the invertebrate community are unknown, and could be indicative of an early restoration stage. However, the differences could also be the result of different habitat qualities specific to the restored and reference sites, such as physical alterations caused by the beach regrade and changes in sediment size. Physical properties sampled at the beach have shown that beach profiles and sediments are similar between the restored and reference beaches, with minor changes over time (Johannessen and Waggoner 2008). The same report noted that this elevation is at the upper extent of freshwater seepage, so interchange between freshwater and saltwater environments may be different between the two sites. Future sampling could help to explain these types of differences: if invertebrate communities converge with time, or if more physical data can be collected at this elevation.

It is important to acknowledge that these initial responses have occurred in just a few years – baseline monitoring in 2004, seawall removal and restoration in 2005, and post-restoration monitoring in 2006 and now 2008. A five-year timeline has been suitable for measuring effects of the seawall and early development of the site after beach restoration, but it is clear that long-term monitoring will be necessary to completely gauge aspects of restoration success or failure especially at the +8 and +5 elevations. However, it does appear that after a relatively short post-restoration recovery period an invertebrate community can partially recruit and establish on a restored beach, with questions remaining on the stability of those communities and their development through time.

Initial responses of nearshore beach restoration may be comparable to those of beach nourishment, in which sediment is added to beaches in order to prevent erosion of coastal habitats. Research on impacts of beach nourishment has shown mixed results (Nordstrom 2005), with effects on sediments and invertebrates being linked to local conditions (Colosio et al. 2007). It remains unknown whether beach restorations such as at Seahurst Park will require additional beach nourishment over time, or if sediments and beach slope will remain stable. However, physical monitoring has indicated that beach renourishment should not be required in the near future based on current rates of sediment transport (Johannessen and Waggoner 2008).

Since the removal of the seawall, presumably both benthic invertebrates and terrestrial insects have been made more available to juvenile salmonids and other nearshore fish as potential prey items. The type of indirect measure of productivity measured with invertebrate assemblages in our study can be said to increase the "opportunity" that juvenile salmon have to access and benefit from the site (Simenstad & Cordell 2000).

Although insects have not been sampled since restoration, previous efforts showed that the Seahurst reference site had a productive riparian zone, with greater taxa richness and differences in density and diversity of insects as compared to the pre-restoration seawall (Sobocinksi 2003). Studies from other systems have shown similar results of reduced supralittoral insect communities in association with armoring (Romanuk & Levings 2003). Datasets from fish netting in the surrounding area have shown major prey items of juvenile Chinook salmon to be epibenthic/benthic invertebrates and terrestrial insects (Brennan et al. 2004), with a decrease in riparian insect feeding when shorelines have artificial retainments (Toft et al. 2007). This entire context places emphasis on restoration of nearshore processes, in order to increase the opportunity of nearshore feeding by juvenile salmonids.

Two large scale organizations have recently been initiated to help guide the restoration of Washington State's Puget Sound waters: The Puget Sound Partnership (PSP), and the Puget Sound Nearshore Ecosystem Restoration Partnership (PSNERP). Both list shoreline armoring as a major threat to the health of Puget Sound. The goal of PSP is to create a comprehensive action agenda to restore Puget Sound by the year 2020, and they list shoreline armoring as one of the major threats to ecosystem processes in Puget Sound (PSP 2009). PSNERP also is creating guidelines and conceptual models at the ecosystem processes level, and they further state that shoreline armoring is a source of stress to the nearshore and that bulkhead removal should be a focus of restoration actions (Simenstad et al. 2006). It is clear that a more complete understanding of shoreline armoring removal and restoration of the nearshore will add greatly to the knowledge of whether the goals of these programs can be reached.

In summary, it becomes apparent that a major goal of nearshore restoration in Puget Sound should be to establish and maintain connections between terrestrial riparian and aquatic intertidal zones. When this occurs, it facilitates development of secondary responses including natural feeding processes and assemblage interactions. Monitoring in this report has shown that although there are still some differences between the restored and reference sites at Seahurst Park, the restoration has resulted in a positive initial response of the benthic invertebrate community. It will be important to continue to monitor in future years in order to assess long-term site development, currently funded for year 5 (2010) and planned for year 10 (2015). Such monitoring will be useful to help guide other restoration opportunities along shorelines of Puget Sound, including the planned restoration of the north seawall at Seahurst Park.

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## References


Bailey, A., H. Berry, B. Bookheim, and D. Stevens. 1998. Probability-based estimation of nearshore habitat characteristics. Proceedings of Puget Sound Research '98 Conference, Seattle, WA. *http://www.dnr.wa.gov/Publications/aqr_nrsh_hab_estimate98.pdf*

Brennan, J. S., K. F. Higgins, J. R. Cordell, and V. A. Stamatiou. 2004. Juvenile salmon composition, timing distribution, and diet in marine nearshore waters of central Puget Sound in 2001-2002. King County Department of Natural Resources and Parks, Seattle, Washington. *http://green.kingcounty.gov/marine/reports/nearshore.aspx*

Chapman, M.G. 2003. Paucity of mobile species on constructed seawalls: effects of urbanization on biodiversity. Marine Ecology Progress Series **264**:21-29.

Chapman, M.G. and F. Bulleri. 2003. Intertidal seawalls – new features of landscape in intertidal environments. Landscape and Urban Planning **62**:159-172.

Clarke, K.R., and Warwick, R.M. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation, Second ed. PRIMER-E, Plymouth Marine Laboratory, UK.

Colosio, F., M. Abbiati, and L. Airoldi. 2007. Effects of beach nourishment on sediments and benthic assemblages. Marine Pollution Bulletin **54**:1197-1206.

Cruz Motta, J. J., A. J. Underwood, M. G. Chapman, F. Rossi. 2003. Benthic assemblages in sediments associated with intertidal boulder-fields. Journal of Experimental Marine Biology and Ecology **285-286**:383-401.

Davis J. L. D., L. A. Levin, S. M. Walther. 2002. Artificial armored shorelines: sites for open-coast species in a southern California bay. Marine Biology **140**:1249–1262.

Dethier, M.N., and G.C. Schoch. 2005. The consequences of scale: assessing the distribution of benthic populations in a complex estuarine fjord. Estuarine, Coastal and Shelf Science **62**:253-270.

Douglass, S. and B. Pickel. 1999. The tide doesn't go out anymore – the effect of bulkheads on urban bay shorelines. Shore and Beach **67**:19-25.

Dugan, J.E., D.M. Hubbard, M.D. McCrary, and M.O. Pierson. 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. Estuarine, Coastal, and Shelf Science **58S**:25-40.

Glasby, T.M. 1998. Differences between subtidal epibiota on pier pilings and rock reefs at marinas in Sydney, Australia. Estuarine, Coastal and Shelf Science **48**:281-290.

Ince, R., G.A. Hyndes, P.S. Lavery, and M.A. Vanderklift. 2007. Marine macrophytes directly enhance abundances of sandy beach fauna through provision of food and habitat. Estuarine, Coastal, and Shelf Science **74**:77-86.

Johannessen, J., and J. Waggoner. 2008. Seahurst Park, South – physical beach monitoring: year 3 post restoration, Fall 2008. Coastal Geologic Services, Inc, Bellingham, WA, prepared for Burien Parks. 26 pp.

Nordstrom, K.F. 2005. Beach nourishment and coastal habitats: research needs to improve compatibility. Restoration Ecology **13**:215-222.

Peterson, M.S., B.H. Comyns, J.R. Hendon, P.J. Bond, and G.A. Duff. 2000. Habitat use by early life-history stages of fishes and crustaceans along a changing estuarine landscape: differences between natural and altered shoreline sites. Wetlands Ecology and Management **8**:209-219.

Puget Sound Partnership (PSP). 2009. Puget Sound Action Agenda: protecting and restoring the Puget Sound ecosystem by 2020. 209 pp. *http://www.psp.wa.gov*

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

Romanuk, T.N., and C.D. Levings. 2003. Associations between arthropods and the supralittoral ecotone: dependence of aquatic and terrestrial taxa on riparian vegetation. Environmental Entomology **32**:1343-1353.

Romanuk, T.N., and C.D. Levings. 2006. Relationships between fish and supralittoral vegetation in nearshore marine habitats. Aquatic conservation: marine and freshwater ecosystems **16**:115-132.

Simenstad, C.A., K.L. Fresh, and E.O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific Salmon: an unappreciated function. Pages 343-364 in V. S. Kennedy, editor. Estuarine comparisons. Academic Press, New York.

Simenstad, C.A. and J.R. Cordell. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering **15**:283-302.

Simenstad, C., M. Logsdon, K. Fresh, H. Shipman, M. Dethier, and J. Newton. 2006. Conceptual model for assessing restoration of Puget Sound nearshore ecosystems. Puget

Sound Nearshore Partnership Report No. 2006-03. Published by Washington Sea Grant Program, University of Washington, Seattle, WA. *http://pugetsoundnearshore.org*

Sobocinski, K.L. 2003. The impact of shoreline armoring on supratidal beach fauna of central Puget Sound. M.S. Thesis. University of Washington, Seattle.

Spalding, V.L., and N.L. Jackson. 2001. Field investigation of the influence of bulkheads on meiofaunal abundance in the foreshore of an estuarine sand beach. Journal of Coastal Research **17**:363-370.

Thom, R.M., D K. Shreffler, and K. MacDonald. 1994. Shoreline armoring effects on coastal ecology and biological resources in Puget Sound, Washington. Coastal Erosion Management Studies Volume 7. Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia.

Toft, J.D. 2005. Benthic macroinvertebrate monitoring at Seahurst Park 2004, pre-construction of seawall removal. Technical Report SAFS-UW-0502, School of Aquatic and Fishery Sciences, University of Washington. Prepared for City of Burien. 18 pp. *https://digital.lib.washington.edu/researchworks/handle/1773/3783*

Toft, J.D. 2007. Benthic macroinvertebrate monitoring at Seahurst Park 2006, post-construction of seawall removal. Technical Report SAFS-UW-0702, School of Aquatic and Fishery Sciences, University of Washington. Prepared for City of Burien. 40 pp. *https://digital.lib.washington.edu/researchworks/handle/1773/3783*

Toft, J.D., J.R. Cordell, C.A. Simenstad, and L.A. Stamatiou. 2007. Fish distribution, abundance, and behavior along city shoreline types in Puget Sound. North American Journal of Fisheries Management **27**:465-480.

USCOE. 2003. Draft Environmental Assessment for Nearshore Restoration at Seahurst Park, Burien, Washington.

Valesini, F.J., I.C. Potter, and K.R. Clarke. 2004. To what extent are the fish compositions at nearshore sites along a heterogeneous coast related to habitat type? Estuarine, Coastal and Shelf Science **60**:737-754.

Wildsmith, M.D., I.C. Potter, F.J. Valesini, and M.E. Platell. 2005. Do the assemblages of benthic macroinvertebrates in nearshore waters of Western Australia vary among habitat types, zones and seasons? Journal of the Marine Biological Association of the United Kingdom **85**:217-232.

Zar, J.H. 1996. Biostatistical Analysis, 3rd edition. Prentice Hall, New Jersey.