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Olympic Sculpture Park: Year 2 Fish, Epibenthos, and Physical Monitoring, Including Additional Beaches

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Executive Summary

This report on year 2 post-construction monitoring during the 2008 field season investigates the role of the pocket beach and habitat bench at the Olympic Sculpture Park (OSP) as compared to other beaches, in order to better evaluate the benefit and function of created habitats in this system. Year 2 research was initiated to address questions and conditions not covered by the established OSP monitoring plan during years 1, 3, 5, and 10 that is specific to the OSP habitats. A subset of components was monitored, including physical beach profiles and sediment composition, epibenthic invertebrates living on bottom substrates, and fish assemblages. Sampling for fish during an even year was additionally useful to assess the alternate year pink salmon outmigration.

Six beaches with different sediment and slope characteristics were surveyed. Beach profiles aligned into three groupings: 1) OSP and Seacrest beaches (steep, high berm, well sorted coarse sediment); 2) Myrtle Edwards and Seahurst-middle (moderately steep slope, variable sediment), and; 3) Seahurst north and south, 32nd St, and Smith Cove (flatter lower foreshore, break in slope to upper foreshore, generally coarser and more variable sediment). With regard to the relationship between active beach slopes and median sediment grain size, the beaches fell into two categories in their response to natural processes. The first category included beaches composed of coarse sediment that can maintain a range of slopes (e.g., OSP, Seacrest, Seahurst-north, and 32nd St). These beaches were relatively stable at slopes up to 0.22 and show little response to natural processes. The second category contained beaches composed of finer grain sizes (e.g., Myrtle Edwards and Seahurst-south and middle). These beaches are more responsive to natural processes and slopes are controlled by sediment grain size and wave conditions.

Epibenthic invertebrates consisted mainly of harpacticoids and amphipods, two types of crustaceans that can be important prey items for nearshore fish including juvenile salmonids. Characteristics of assemblages were related specifically to physical parameters on the lower foreshore or low tide terrace where sampling occurred (~0 to +0.3 m MLLW). Epibenthic invertebrate taxa richness was greater at Smith Cove and Seahurst where there were more varied sediment types and more available habitat at the wide, low-gradient beaches. These habitats also had larger percentages of harpacticoids. The created OSP Habitat Bench was similar to these beaches in having high taxa richness, perhaps due to other factors such as algal growth since there were few interstitial spaces between pebble/cobble sediments on the bench. The created OSP Pocket Beach was similar in invertebrate taxa composition to the more natural beaches, indicating that it provided some natural functions despite its steep gradient and less diverse sediment types. Both of the created OSP sites had harpacticoid densities similar to the Smith Cove and Seahurst sites, whereas other sites in Elliott Bay had lower densities. Epibenthic assemblages at riprap sites were composed almost exclusively of amphipods; densities of amphipods at the OSP Habitat Bench, Seahurst, and Seacrest beach sites were similar to the riprap sites, illustrating that amphipods can be abundant at a variety of beach structures. Myrtle Edwards had the lowest values in all metrics (taxa richness, harpacticoid and amphipod densities), suggesting that relatively fine sediments and a steep gradient is not as supportive of the epibenthos as other beach types.

Important fish groupings at intertidal beaches were juvenile salmon, forage fish, and larval/post-larval fish (mostly forage fish, typically smelt, that were too small to identify to species with snorkel observations). Juvenile pink and chum salmon comprised the vast majority (98%) of juvenile salmonid observations in April and May; Chinook salmon observations were extremely low compared to previous years, and peaked in July. Larval fish and forage fish were abundant in June and especially in July; sand lance were the dominant forage fish in 2008, whereas herring were dominant in 2007.

Seahurst and Seacrest had the highest percent composition of juvenile salmon, while Smith Cove had very few observations of juvenile salmon; the OSP habitat sites were in the middle of the distribution. This suggests that local topography and position of specific beaches can influence fish assemblages: Seahurst and Seacrest beaches differ morphologically, and although Smith Cove was similar to Seahurst in terms of structure and epibenthic invertebrates, its fish assemblage was different. The OSP Pocket Beach and Habitat Bench had the highest observed larval fish compositions. Small larval fish may use these beaches as refuge habitats, since these shorelines are the closest shallow water habitats on the north side of the Seattle seawall from the Duwamish Waterway, and it is possible the larval fish hatched at the site. Spatial and temporal distributions of pink salmon, larval fish, and forage fish were somewhat variable, in part due to their patchy distribution and large school sizes (often greater than 1,000 individuals). Fish behaviors were also suggestive of beach function, as percent of juvenile salmon observed feeding was highest (90%) at Seahurst, an un-armored, wide, low-gradient beach. This beach also has a vegetated shoreline and high harpacticoid copepod densities. The OSP Habitat Bench had the second highest observed percentage of feeding, and feeding percent was also relatively high at OSP Riprap and Seacrest sites, so feeding behaviors occurred at a diversity of habitat types. Feeding percentage at the OSP Pocket Beach was between that of other similar beaches in Elliott Bay (Seacrest was higher, Myrtle Edwards lower).

In summary, the OSP Habitat Bench and Pocket Beach appear to have biological functions that are often similar to older created and more natural beaches, even though their physical structures are somewhat different. Most measurements of epibenthic invertebrates and fish were comparable to other beaches, and were never at a depleted level. While natural beach types with low gradient intertidal zones and a variety of substrate types are often most biologically productive, our monitoring has shown that within a highly urbanized bay, enhanced habitat types that mimic more natural conditions can increase overall diversity and taxa richness of the system. Potential areas of improvement where data values were at slightly lower levels than the measured potential were amphipod densities and observed juvenile salmon feeding at the OSP Pocket Beach. Since this data was collected in year 2 post-restoration, these could be compared to future monitoring to see if they improve as the site develops. Upcoming year 3 monitoring will be identical to that conducted pre- and year 1 post-construction, and will specifically address the rate of change in form and function through these first few years of development. Continued analysis will seek to inform management decisions and design criteria, in order to further progress our knowledge of beach restoration processes.

TABLE OF CONTENTS

Introduction 1
Methods 3
Sites 3
Epibenthic Invertebrates 6
Snorkel surveys for fish 6
Statistical Analysis 6
Physical beach profiling and sediment characterization 6
Results and Discussion 8
Description of physical beach characterization 8
Beach profile variation (morphology & grain size) 17
Epibenthic Invertebrates 20
Snorkel Surveys 27
Conclusions 38
Acknowledgements 39
References 39
Appendix 1: Photographs of Sites and Methods 40
Appendix 2: Additional Data 45
Glossary 51

List of Figures

Figure 1. OSP after construction at high tide, showing inundated pocket beach and habitat bench. 2
Figure 2. Aerial view of the Olympic Sculpture Park site after construction, showing general sampling locations. 4
Figure 3. Location map of the beaches sampled for fish, epibenthos, and physical properties. 5
Figure 4a. Location map for OSP beach transects and Myrtle Edwards Park transect, with profile and grain-size histograms for Myrtle Edwards Park shown below the map. 9
Figure 4b. Beach profiles and grain-size histograms for OSP north and south transects. 10
Figure 5a. Location map for Seacrest Park beach transects, with profile and grain-size histograms for Seacrest north shown below the map. 11
Figure 5b. Beach profiles and grain-size histograms for Seacrest middle and south transects. 12
Figure 6a. Location map for Seahurst Park beach transects, with profile and grain-size histograms for Seahurst north shown below the map. 13
Figure 6b. Beach profiles and grain-size histograms for Seahurst middle and south transects. 14
Figure 7. Location map for Smith Cove beach transects, with profile and grain-size histograms shown below the map. 15
Figure 8. Location map for 32nd St. Park beach transects, with profile and grain-size histograms shown below the map. 16
Figure 9. Beach profiles for the study sites in Summer 2008 (or Summer 2007, if applicable) aligned so that +0.0 MLLW falls on a common location in the horizontal. 18
Figure 10. Relationship between active beach slope and median sediment grain size on the Puget Sound beaches studied, site color codes are the same as in Figure 9. 19
Figure 11. Overall taxa richness (number of species) of epibenthic invertebrates at all sites listed in descending number. 21
Figure 12. Average percent numerical composition of epibenthic invertebrate orders at all sites. 22
Figure 13. Average densities of harpacticoid copepods at all sites, listed in descending order. 23
Figure 14. Average percent numerical composition of main harpacticoid species at all sites, listed in descending densities as in Figure 13. 24
Figure 15. Average densities of amphipods at all sites, listed in descending order. 25
Figure 16. Average percent numerical composition of main amphipod species at all sites, listed in the same order as in Figure 15. 26
Figure 17. Densities of major fish groups averaged over all sites for each week. 31
Figure 18. Average weekly density of juvenile salmon across all sites. 32
Figure 19. Average weekly density of forage fish across all sites. 33
Figure 20. Overall composition of major fish groups by habitat, listed in descending percent of juvenile salmon. 34

Figure 21. Overall densities of juvenile salmon by habitat, listed in descending order. .. 35
Figure 22. Overall densities of forage fish (including larval fish) by habitat, listed in descending order. 36
Figure 23. Percentage of juvenile salmon observed feeding at each habitat. 37

List of Tables

Table 1. Biological and physical monitoring conducted at each site in 2008..................... 4
Table 2. Landward locations of beach morphology transect lines...................................... 7
Table 3. Summary of all observed fish and crab species and classification into different functional groups. 30

Introduction

The Olympic Sculpture Park (OSP) was created by the Seattle Art Museum on 8.5 acres of waterfront property along Elliott Bay. A main design goal was to improve habitat along the shoreline that would provide public access and benefit wildlife resources, including outmigrating juvenile salmon. Past biological and physical monitoring has documented the initial development of OSP in relation to pre-construction levels and to adjacent shorelines of riprap and seawall (Toft et al. 2008). Results indicated that although there is significant public use, the beach is relatively stable and there has generally been a rapid development of aquatic and terrestrial biota within the newly created habitats. However, one missing aspect of the baseline monitoring has been assessment of how created habitats at OSP function in relation to other shoreline habitats at the larger scale of Elliott Bay. This report on year 2 monitoring specifically investigates the role of the pocket beach and habitat bench at OSP as compared to other beaches, in order to better evaluate the benefit and function of created habitats.

The overall ecological objectives of habitat enhancement along the shoreline at OSP were to (1) create a pocket beach and habitat bench, in order to increase shallow-water intertidal habitat for juvenile salmonid rearing and aquatic invertebrate prey production, and (2) plant and maintain shoreline vegetation to enhance juvenile salmonid refuge functions and insect prey production. Before OSP was constructed, the shoreline consisted of seawall and riprap with minimal upland riparian vegetation, which severely truncated available intertidal habitat and access to riparian habitat resources. The habitat bench was created along the existing north end of the downtown Seattle seawall, and the pocket beach was excavated from riprap adjacent to the south end of Myrtle Edwards Park (Fig. 1). Both features extend from shore down to a tidal elevation of ~0.0 m MLLW. Dunegrass and riparian vegetation were planted along the shore of the pocket beach, and riparian vegetation was also planted along the walkway above the habitat bench.

These habitat enhancement features at OSP were incorporated because juvenile salmonids use the Seattle urban nearshore of Puget Sound for rearing and migration (Toft et al. 2007), with the nearby Green/Duwamish Waterway being the closest source for both wild and hatchery juvenile salmon. Improved habitat for Chinook salmon is often a focus for shoreline restoration in the region, because Puget Sound Chinook are listed as threatened under the Endangered Species Act. Research has shown that shoreline habitat types can affect nearshore fish distribution and abundance patterns (Valesini et al. 2004, Rice 2006, Toft et al. 2007), and that the nearshore can be an important source of juvenile Chinook prey items, such as drift insects and intertidal epibenthic crustaceans (Simenstad et al. 1982, Brennan et al. 2004). Monitoring beach structure and biota at constructed habitats that were designed to help “restore” the shoreline can provide information on how functional those designed beaches are in providing beneficial habitat. Monitoring to date at OSP has progressed on the following timeline, as related to construction in 2006 and opening in January 2007: pre-construction monitoring on fish and invertebrates in Spring and Summer 2005 (Toft and Cordell 2006), and year 1 post-construction monitoring on fish, invertebrates, algae, vegetation, and physical structure in 2007 (Toft et al. 2008).

Year 2 monitoring was initiated as an alternate-year addition to the original monitoring plan of years 1, 3, 5, and 10 post-construction, in order to address questions and conditions not covered by the original monitoring plan. The main goals of year 2 monitoring were twofold: (1) place the OSP restoration work in context of a variety of beach types in Elliott Bay in order to more fully understand the value of created habitats in this system, and (2) assess the pink salmon outmigration and any other factors that may be unique to 2008 and even-years.

These two main goals were investigated by sampling with a subset of the typical methods at an increased spatial scale of ten habitat types: the four main shoreline habitats at OSP (pocket beach, habitat bench, riprap, seawall), five comparison shoreline habitats within Elliott Bay (four beaches and one other riprap), and one reference beach outside Elliott Bay at Seahurst Park along central Puget Sound. During Spring-Summer 2008 we conducted weekly snorkel surveys at these sites during high tides for fish and monthly pump samples at low intertidal elevations for epibenthic invertebrates. Concurrently, beach profiles were monitored and sediment samples collected to characterize the beaches based on their geomorphology.

Figure 1. OSP after construction at high tide, showing inundated pocket beach and habitat bench.

Methods

Methods are briefly described below for techniques used in past monitoring (see Toft et al. 2008 for full methods descriptions); methods unique to 2008 fieldwork are described in more detail. Sampling locations are mapped in Figures 2 and 3, and an overview of the sampling regime is detailed in Table 1. Additional photographs of sites and methods are shown in Appendix 1.

Sites

At OSP, sampling locations were identical to past monitoring (Fig. 2). A group of new sites was added in 2008 (Fig. 3):

- Seacrest: Located on the south side of Elliott Bay opposite of OSP, Seacrest is a series of three created gravel/cobble pocket beaches. Beach morphology was evaluated at all three beaches. Biological parameters were sampled at Beach #3, the northern-most beach, as was a stretch of adjacent riprap on the north side of this beach. Seacrest was similar to the OSP Pocket Beach in that the beaches are created small pocket beaches that are bordered on either side by riprap.
- Myrtle Edwards: The sand/gravel beach at Myrtle Edwards Park is northwest of OSP on the same stretch of shoreline. The beach there creates a gap in the riprap shoreline similar to OSP, and has been allowed to evolve naturally over time.
- Smith Cove: The mixed sediment beach at Smith Cove is west of Terminal 91 and east of the Elliott Bay Marina. The historic natural cove has been filled-in and developed; the sampled stretch of beach is a south-facing linear gravel shoreline backed by riprap.
- 32nd St.: The coarse-grained Magnolia beach is at the 32^{nd} Ave W street end park. Biological data was not collected at this site.
- Seahurst Park: The mixed sediment beach at Seahurst Park is in the City of Burien, south of Elliott Bay along central Puget Sound. Physical characterization occurred at three sections of beach that ranged from beaches backed by retained riprap and seawall in the north to a more natural beach in the south. Biological sampling occurred along the more natural south side of the park, where there are presently no shoreline retaining structures.

Figure 2. Aerial view of the Olympic Sculpture Park site after construction, showing general sampling locations.

Table 1. Biological and physical monitoring conducted at each site in 2008.

Site	Fish - Snorkeling	Epibenthic Invertebrates	Beach Profiling	Sediments
Olympic Sculpture Park				
Habitat Bench	X	X	X	X
Beach	X	X	X	X
Riprap	X	X		
Seawall		X		
Seacrest				
Beach	X	X	X	X
Riprap		X		
Myrtle Edwards				
Beach	X	X	X	X
Smith Cove				
Beach	X	X	X	X
32nd St				
Beach			X	X
Seahurst Park				
Beach	X	X	X	X

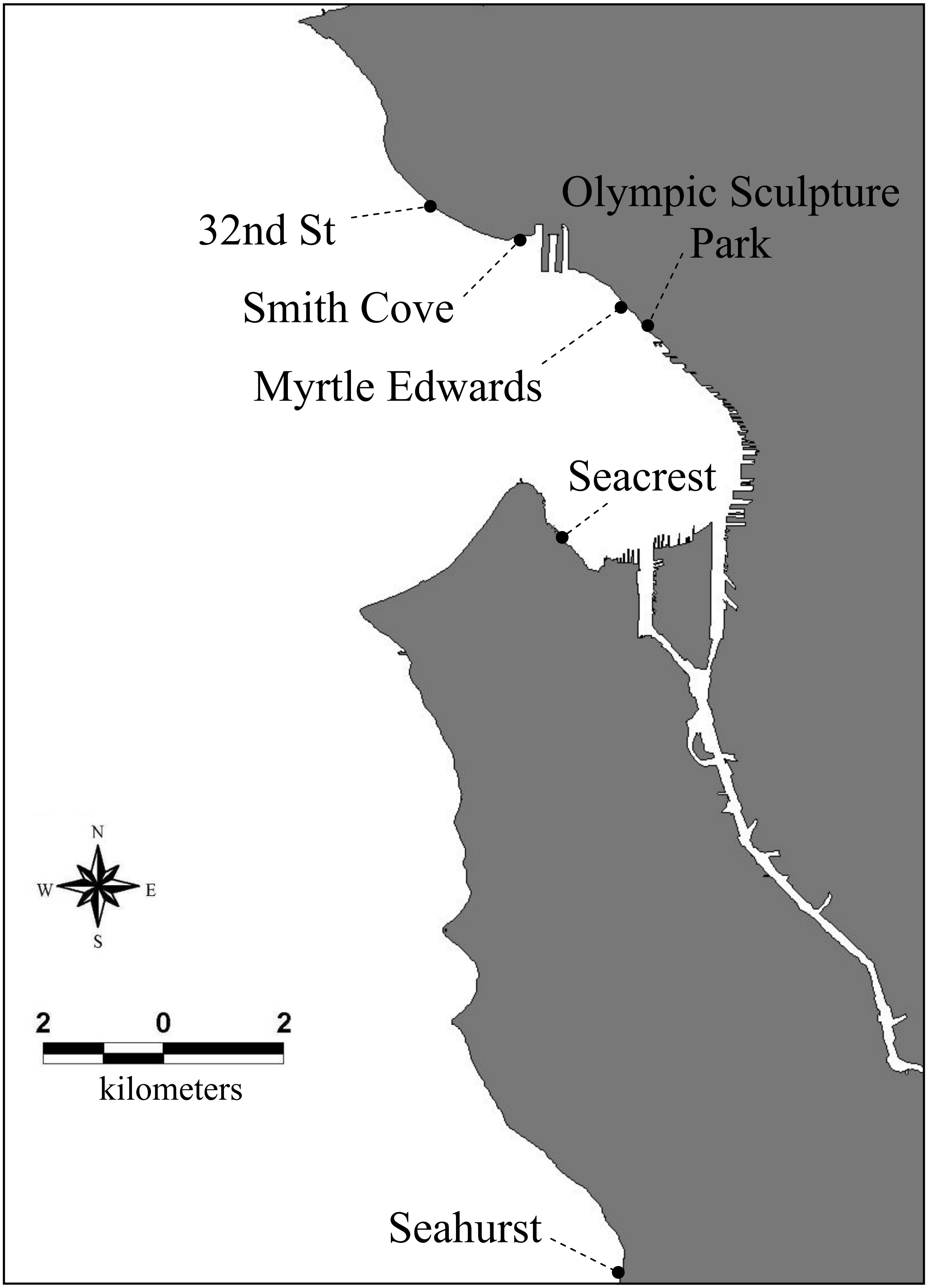


Figure 3. Location map of the beaches sampled for fish, epibenthos, and physical properties.

Epibenthic Invertebrates

An epibenthic pump was used for sampling invertebrates living at the water-sediment interface at 0 to +0.3 m MLLW, as in past monitoring (Toft et al. 2008). Samples were collected monthly in April, May, and June. During the peak chum/pink outmigration period (April and May), prey taxa were identified to genus and species level; June samples were processed to order level.

Snorkel surveys for fish

Sampling spanned the peak juvenile salmonid outmigration period, beginning with chum and pink salmon in April and ending with Chinook and coho salmon in June and July. Monitoring in 2008 was different from previous years since it captured the pink salmon outmigration which mainly occurs on even years in this region. Fish were surveyed weekly from April 15 to July 23, using previously developed snorkel methods that allowed for calculating densities and behaviors (Toft et al. 2008). Methods in 2008 differed from previous sampling in that surveys were only conducted at high tides when beach habitats were completely inundated, and the entire intertidal beach habitat at each site was surveyed. Standard snorkel transects were 75 m in length, with the exception of the OSP Pocket Beach which was 35 m in total length. Fish numbers were standardized by transect length and water visibility: fish number/(transect length x horizontal secchi disk measurement). Shore-parallel transects were surveyed at 10 m increments from shore until the depth corresponding with the -0.6 m MLLW tidal elevation was reached. Thus, the number of transects surveyed at a given habitat depended on the depth gradient. Snorkel surveys covered the entire intertidal range so that density estimates for the overall intertidal fish assemblage could be compared among sites.

Statistical Analysis

Biological data was entered in Microsoft Excel and analyzed using S-plus. ANOVA tests (alpha = 0.05) were used to analyze log-transformed densities of fish and invertebrate data, because transformed data better satisfied the assumptions of normality and heterogeneity of variances. When results were significant among habitat types, the Tukey's test for multiple comparisons was used to identify specific differences between all possible pairs of means (Zar 1996).

Physical beach profiling and sediment characterization

Beach morphology at the study sites was obtained during low spring tides so that the sediment-covered portion of the beach (generally from +4.3 m to <0.0 m MLLW) was exposed and could be measured. Techniques used were similar to those in past OSP monitoring. The location and number of transects were chosen based on site variability, and 1-3 transects were evaluated per site (see Table 2 for the landward endpoint of each transect). Transects at four of the study sites were monitored in summer 2007, winter 2007/08, and summer 2008 (OSP, Seahurst, Seacrest, and Myrtle Edwards), while transects at Smith Cove and 32nd St were only monitored in summer 2008. Active and average slopes (see defining figure in Appendix 2), berm/maximum sediment elevation, and beach width were computed from the measured profiles.

Sediment samples were obtained from the foreshore and berm areas. The number of samples was dictated by the variability of sediment, and in areas where sediment was too large for traditional grain-size analysis, visual estimates were made to characterize the zone. Surface samples were scraped from the sediment surface to a depth of approximately one diameter or 5 cm (whichever was greater), as this upper sediment layer overlapped with the strata of epibenthic invertebrate sampling. Samples were analyzed in the lab using standard sieve techniques (finer than -4 phi) and measurement of individual grains (coarser than -4 phi).

Table 2. Landward locations of beach morphology transect lines.

Site		Landward Pt. of Transect
Myrtle Edwards		47° 38.790' N 122 22.376' W
OSP	No. Transect	47° 37.003' N 122 21.483' W
	So. Transect	47° 37.046' N, 122° 21.501' W
Seacrest	No. Beach	47° 35.399' N 122 22.894' W
	Mid. Beach	47° 35.317' N 122 22.802' W
	So. Beach	47° 35.234' N 122 22.667' W
Seahurst	No. Transect	47° 28.878' N 122 21.682' W
	Mid. Transect	47° 28.783' N 122 21.719' W
	So. Transect	47° 28.631' N 122 21.848' W
32nd Street	West Transect	47° 37.939' N 122 23.916' W
	East Transect	47° 37.922' N 122 23.860' W
Smith Cove	West Transect	47° 37.888' N 122 23.216' W
	East Transect	47° 37.892' N 122 23.146' W

Results and Discussion

Physical data are treated first, to give context to the pertinent biological results (e.g., relationships between sediment characteristics and epibenthic invertebrate assemblages). For each section expanded figure/table captions are used to detail results and discussion on the same page.

Description of physical beach characterization

Location maps, beach profiles and descriptions of the surface sediment size of the six study sites are shown in Figures 4 to 8. Beaches can be generally characterized as follows:

1. OSP. A steep, pebble to cobble grained beach. The sediment was well sorted with a berm developed at the top of the profile.
2. Myrtle Edwards. A moderately steep, mixed grain-size beach with well sorted sandy upper foreshore, and sand/pebble lower foreshore. This beach was backed by an older riprap wall at an elevation of approximately +3.8 m.
3. Seacrest. The three beaches had steep slopes, and generally consisted of very well sorted coarse pebble to cobble-sized sediment. On the upper foreshore of the south beach, sand was present. All are backed by a seawall above ~+4.2 m.
4. Seahurst. This site had a range of conditions, both in morphology and sediment size. The north section of the beach consisted of a steep upper foreshore, and broad flat low-tide terrace. The north section was backed by a riprap wall, and sediment cover was poorly sorted with variable sand and pebble material across the transect. The middle and south transects were less steep, and had sandy upper foreshores and pebble lower foreshores. The broad low-tide terrace on all transects was composed of sand.
5. Smith Cove. A broad beach with variable sediment. The riprap backing truncates upper beach sediments at ~+2.1 m. The steep lower foreshore was cobble and sand, and the flat, broad low-tide terrace had bands of sand and coarse cobble.
6. 32nd St. A moderate sloped beach with coarse pebble to cobble sediment. Local seawalls exist to the east, truncating the upper beach profile.

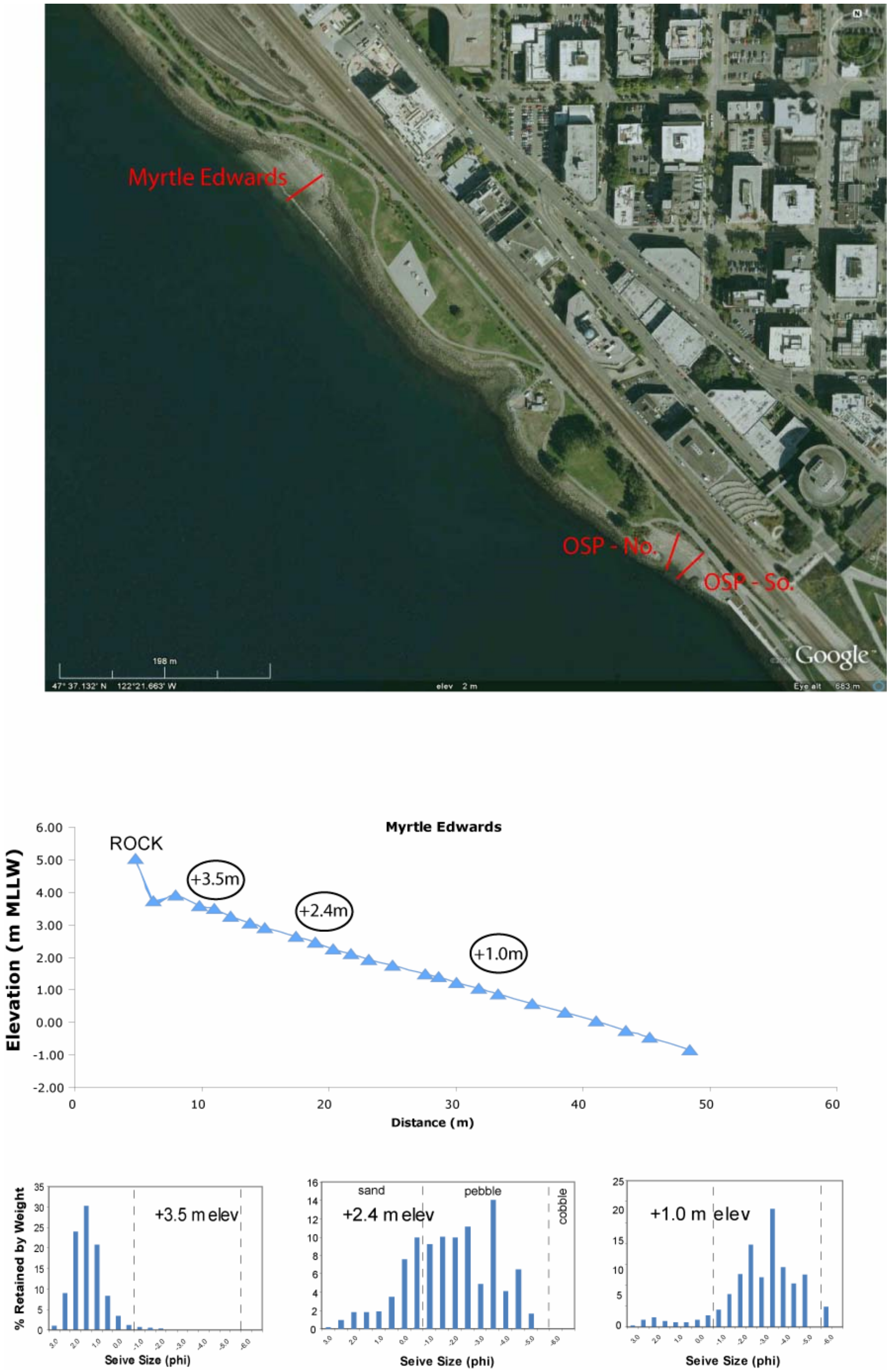


Figure 4a. Location map for OSP beach transects and Myrtle Edwards Park transect, with profile and grain-size histograms for Myrtle Edwards Park shown below the map.

The upper foreshore of Myrtle Edwards beach was predominantly sand, and the lower foreshore was dominated by pebble-sized sediment. The profile is backed by large rock retaining material.

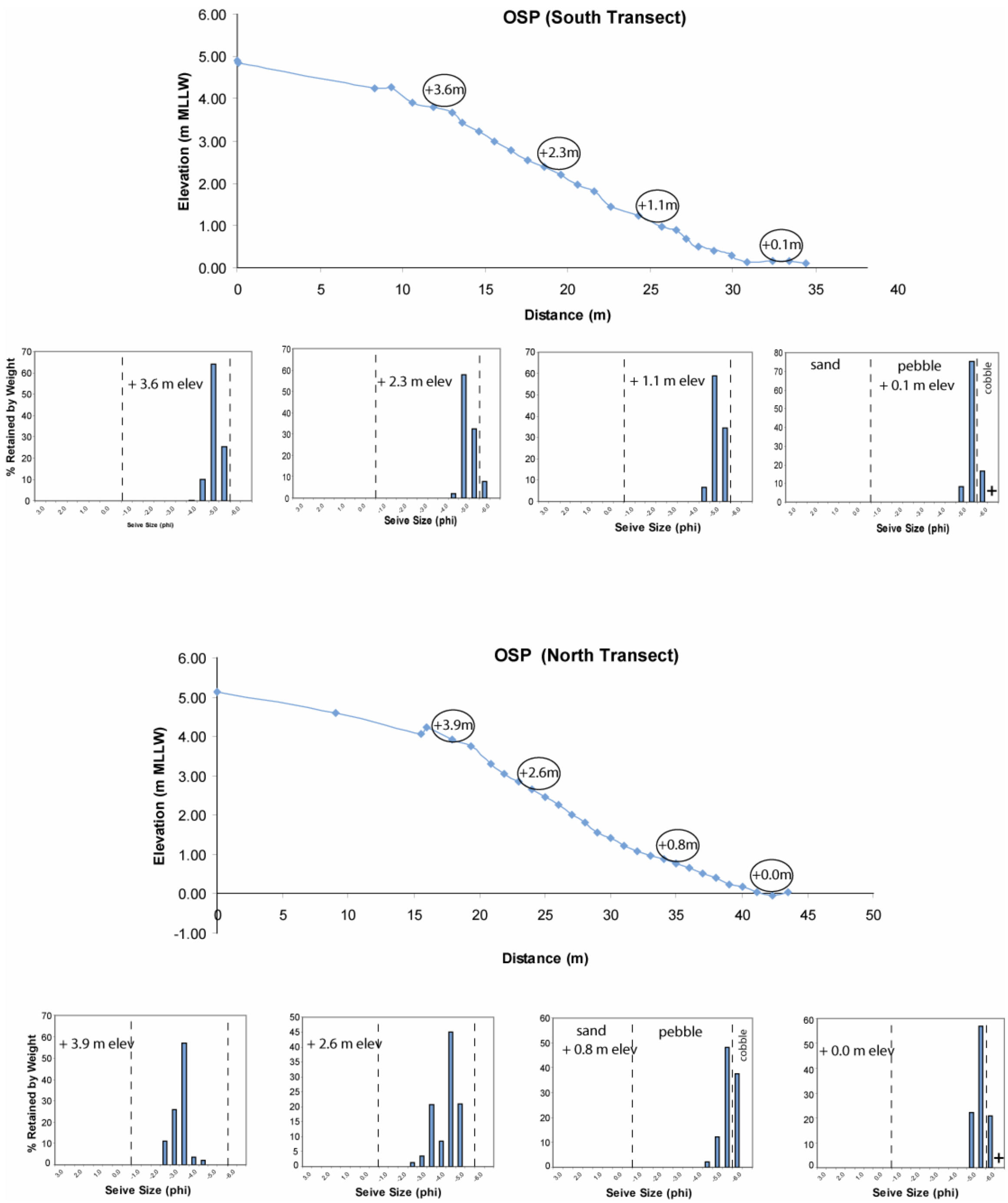


Figure 4b. Beach profiles and grain-size histograms for OSP north and south transects.

The surface sediment at OSP was generally well-sorted, of coarse pebble to cobble size, with the exception of smaller pebble material on the upper foreshore of the OSP-north transect.

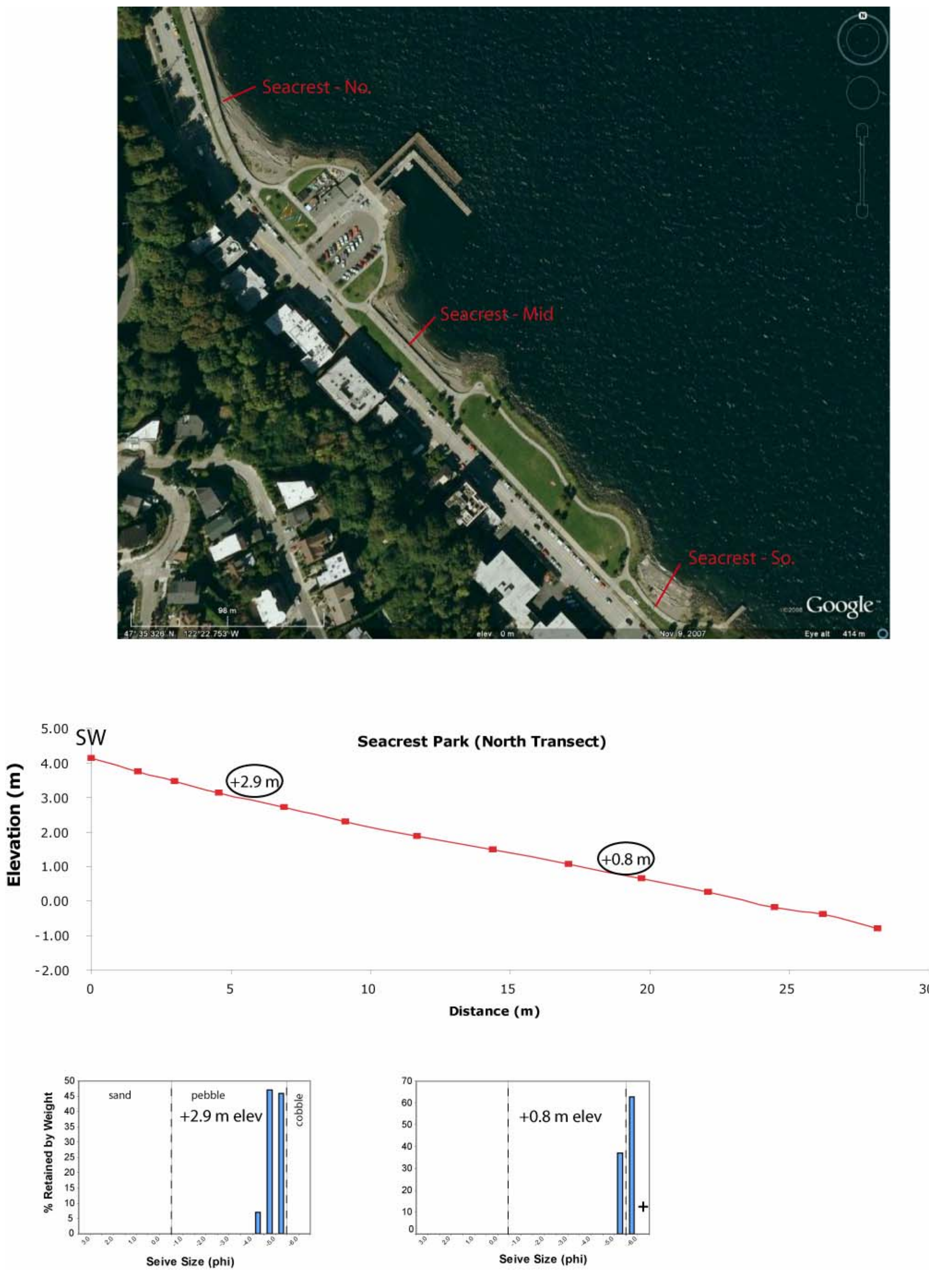


Figure 5a. Location map for Seacrest Park beach transects, with profile and grain-size histograms for Seacrest north shown below the map.

The surface sediment at Seacrest north was coarse pebble and cobble, with slightly coarser sediment on the lower foreshore than on the upper foreshore. A seawall (SW) backs this profile.

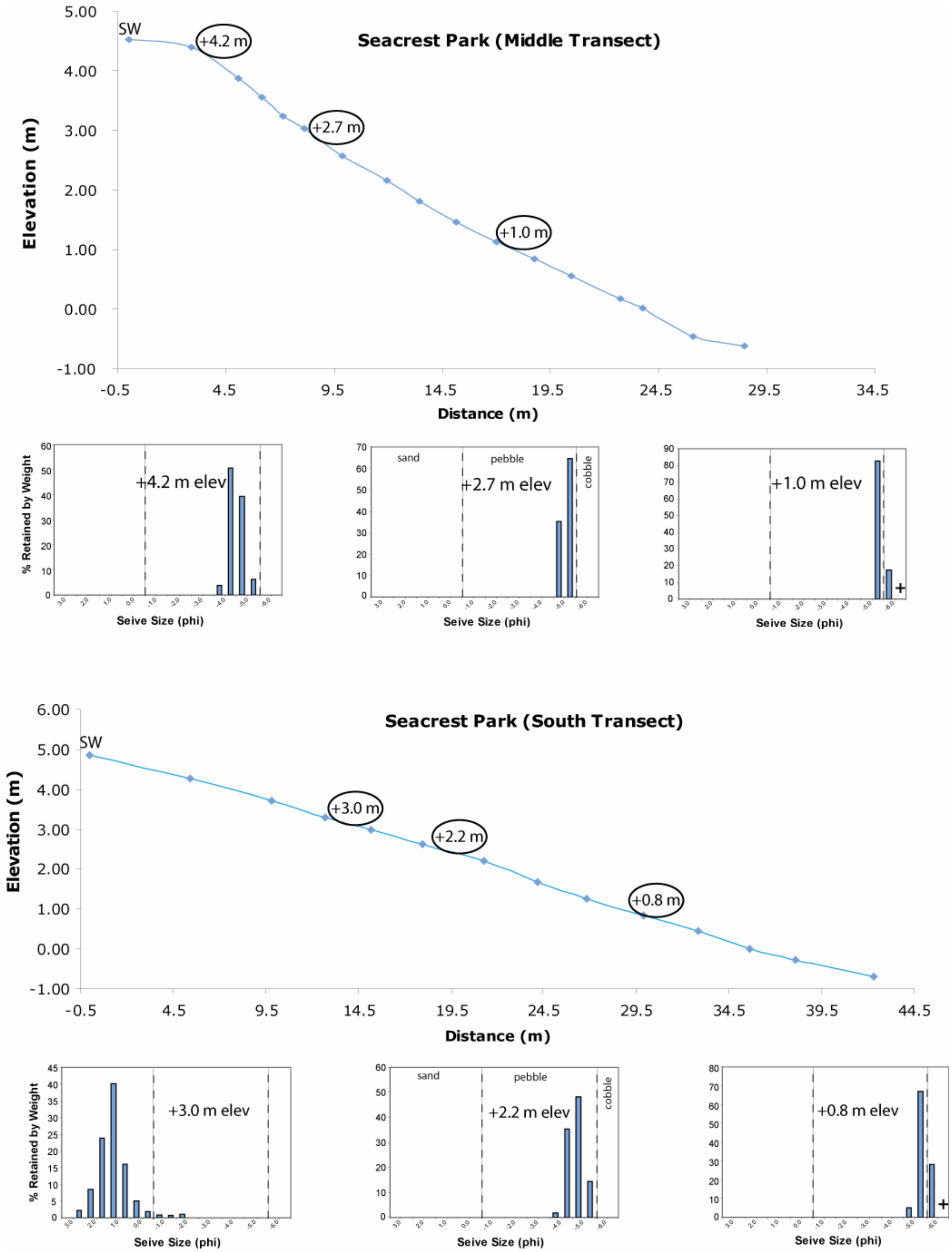


Figure 5b. Beach profiles and grain-size histograms for Seacrest middle and south transects.

Similar to the north transect, the surface sediment was well-sorted coarse pebble and cobble. On the upper foreshore of the south transect, there was a surface sand layer. Seawalls (SW) back these profiles at elevations greater than +4.4 m.

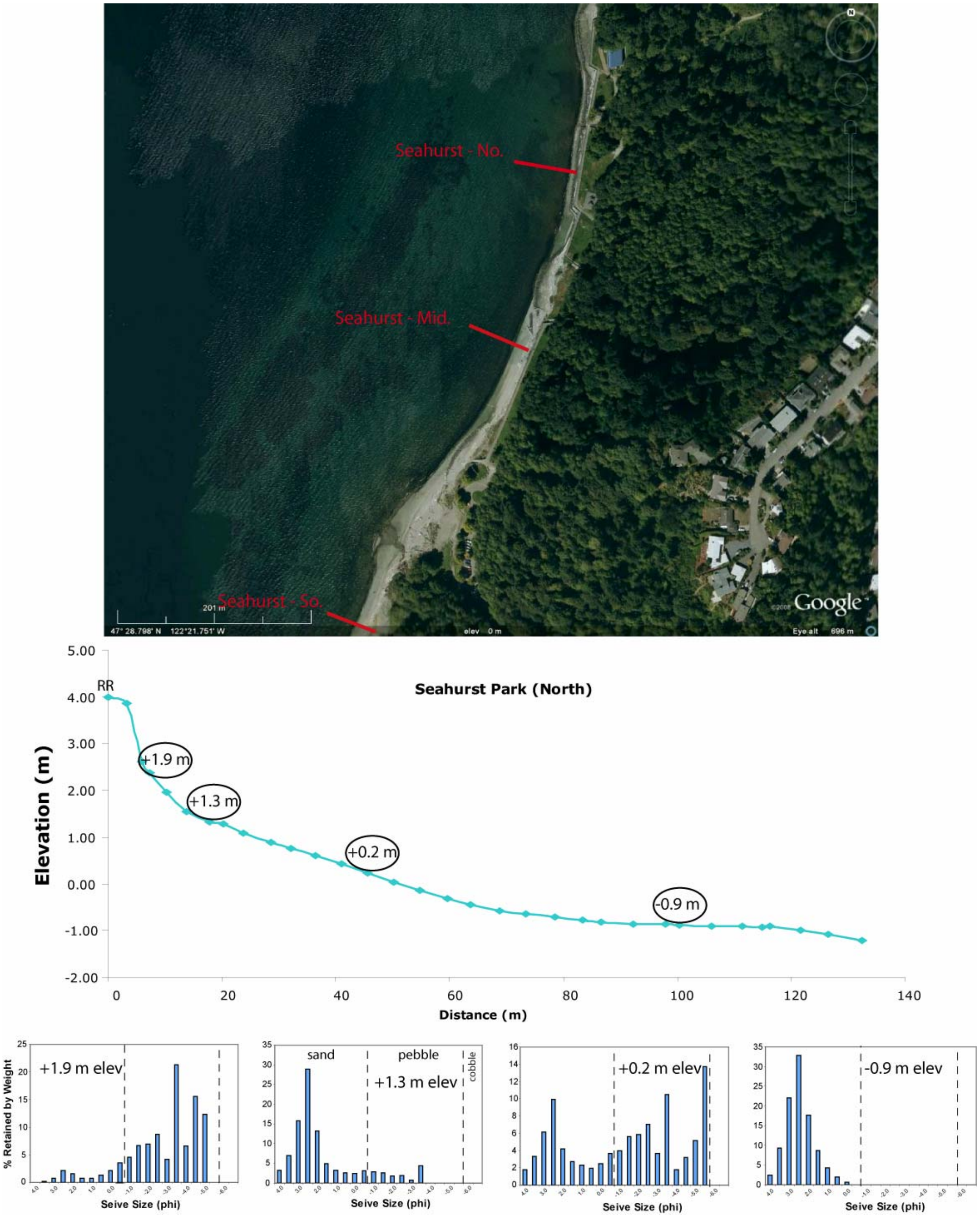


Figure 6a. Location map for Seahurst Park beach transects, with profile and grain-size histograms for Seahurst north shown below the map.

The beach sediment consists of spatially segregated mix of sand and pebble on the upper foreshore and a broad sandy low-tide terrace. This profile was backed by a riprap wall (RR).

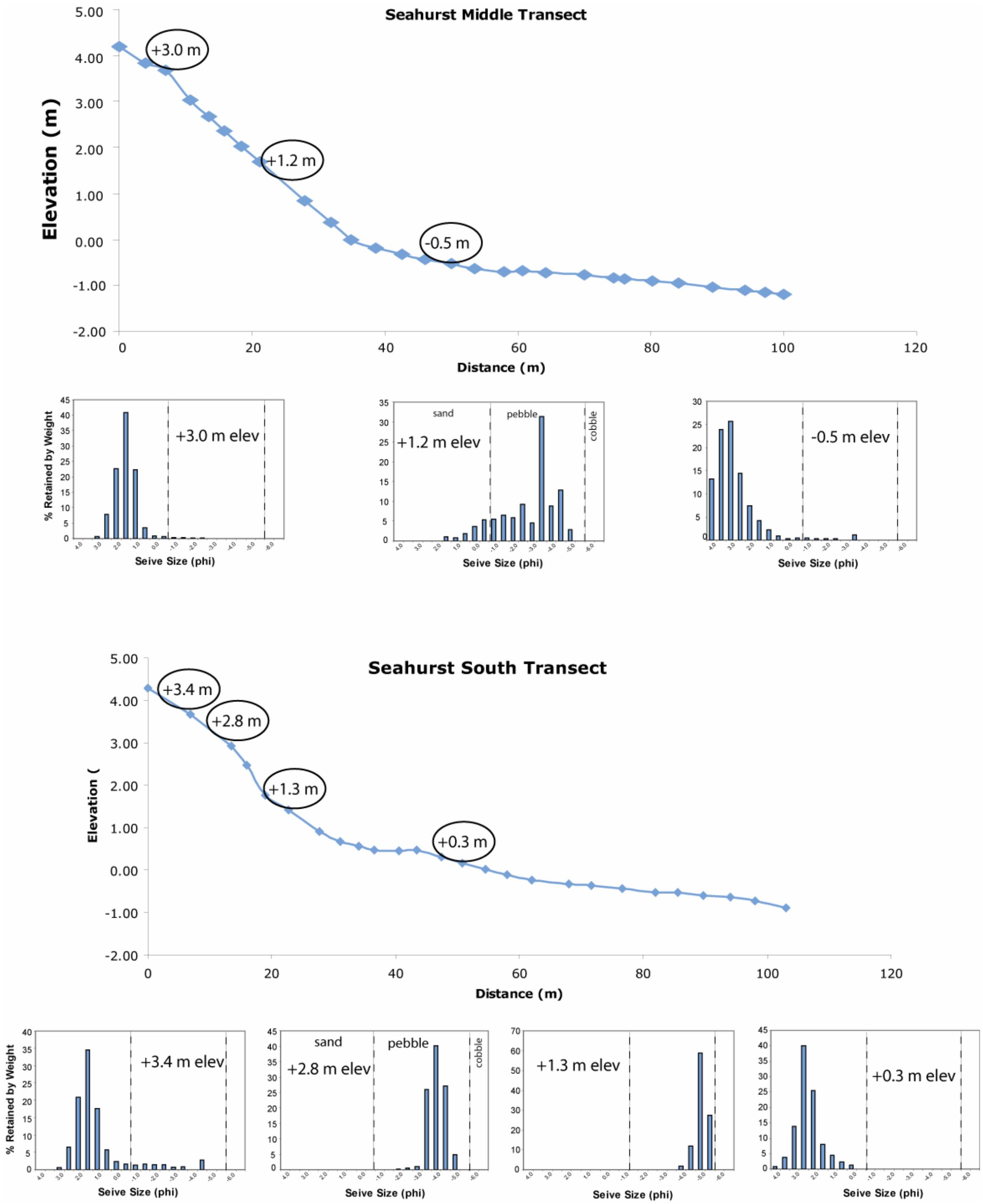


Figure 6b. Beach profiles and grain-size histograms for Seahurst middle and south transects.

Both transects had a sandy upper foreshore, pebble/mixed middle foreshore and broad sandy low-tide terrace.

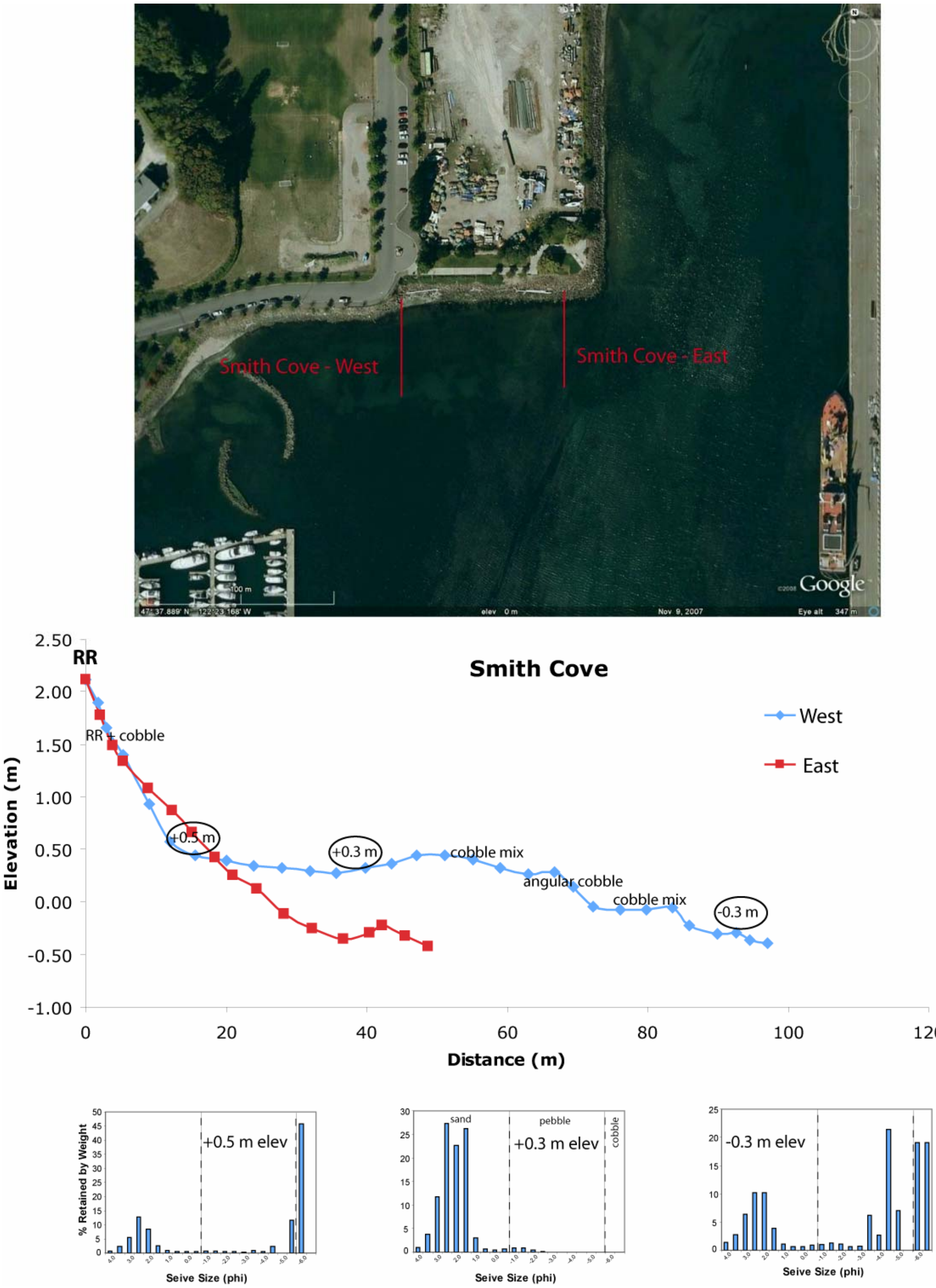


Figure 7. Location map for Smith Cove beach transects, with profile and grain-size histograms shown below the map.

On the west side of the cove, a broad low-tide terrace exists, and the beach sediment was highly variable with patches of poorly sorted sand, sandy cobble, and pebble/cobble mix. Much of the terrace was too coarse too sample.

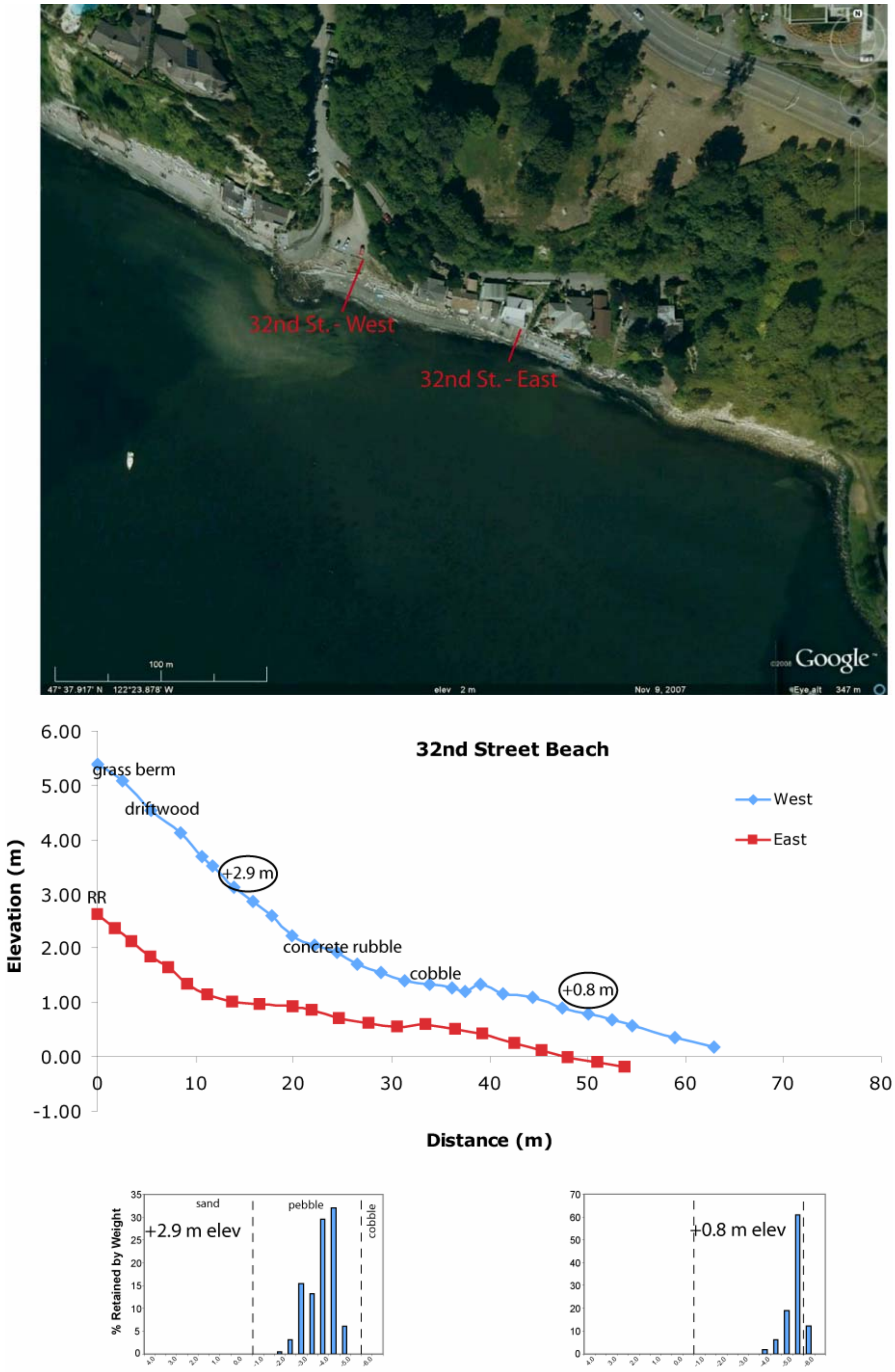


Figure 8. Location map for 32nd St. Park beach transects, with profile and grain-size histograms shown below the map.

On the west transect, a broad low-tide terrace exists, and the beach sediment was highly variable with patches of pebble, cobble, and concrete rubble. To the east, riprap seawalls truncate the upper beach profile.

Beach profile variation (morphology & grain size)

Plotted together, the beach morphologies were compared among the sites (Fig. 9) and groupings made of beaches that appeared to have similar physical form and function. Average profile slopes of the study sites ranged from -0.056 to -0.208 and active profile slopes were between -0.075 and -0.205 (summary data in Appendix 2). All beaches were relatively stable through time, although a slight seasonal variation between surveys was observed at OSP south, Myrtle Edwards and Seahurst middle and south. Berm elevations reached +4.42 m (relative to MLLW) and in general varied between the multiple surveys at each site where a berm could form. The beaches backed by riprap or a seawall had less sediment cover at higher intertidal elevations due to truncation of the upper profiles. The differences in observed beach slope and berm heights led to a differing general beach morphology and differing beach width between MHHW and MLLW.

Relationships between the beach slope and sediment grain size allowed us to evaluate whether the beaches studied are responding to natural processes as predicted in the literature (see e.g., Komar 1998), although few studies have been performed on coarse-grained beaches (McLean and Kirk 1969; Jennings and Shulmeister 2002). The present study shows two different beach types that have been restored (Fig. 10), those that are built for stability (coarse grained, not responsive to natural forcing) and those that are built to mimic natural processes (variable grain size, more responsive to natural forcing).

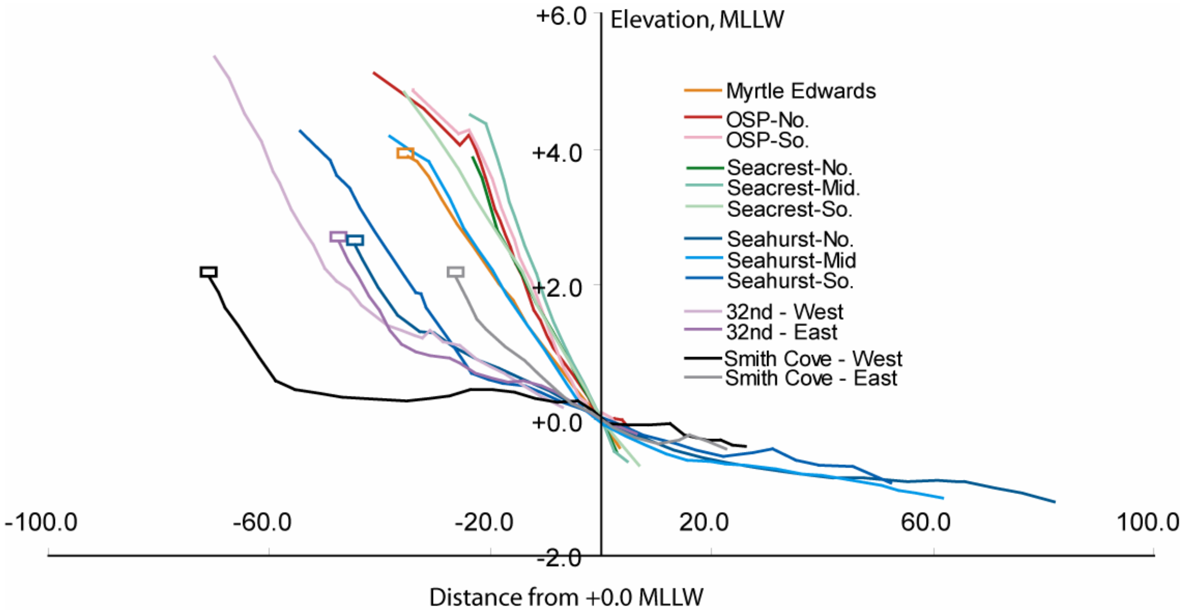


Figure 9. Beach profiles for the study sites in Summer 2008 (or Summer 2007, if applicable) aligned so that +0.0 MLLW falls on a common location in the horizontal.

Transects that had riprap located below +4.0 m MLLW are indicated with a box at the shoreward end of the profile. Note that the profiles fall in three groupings: 1) OSP and Seacrest beaches (steep, high berm, well sorted coarse sediment); 2) Myrtle Edwards and Seahurst-middle (moderately steep slope, variable sediment), and; 3) Seahurst-north and south, 32nd St, and Smith Cove (flatter lower foreshore, break in slope to upper foreshore, coarser more variable sediment). This third group of beaches exhibits a broad zone between +0.0 and +0.9 m MLLW and a change in slope between the upper and lower foreshore, and thus the active slope on the upper foreshore at all the beaches is relatively similar (see Beach Morphology Table in Appendix 2).

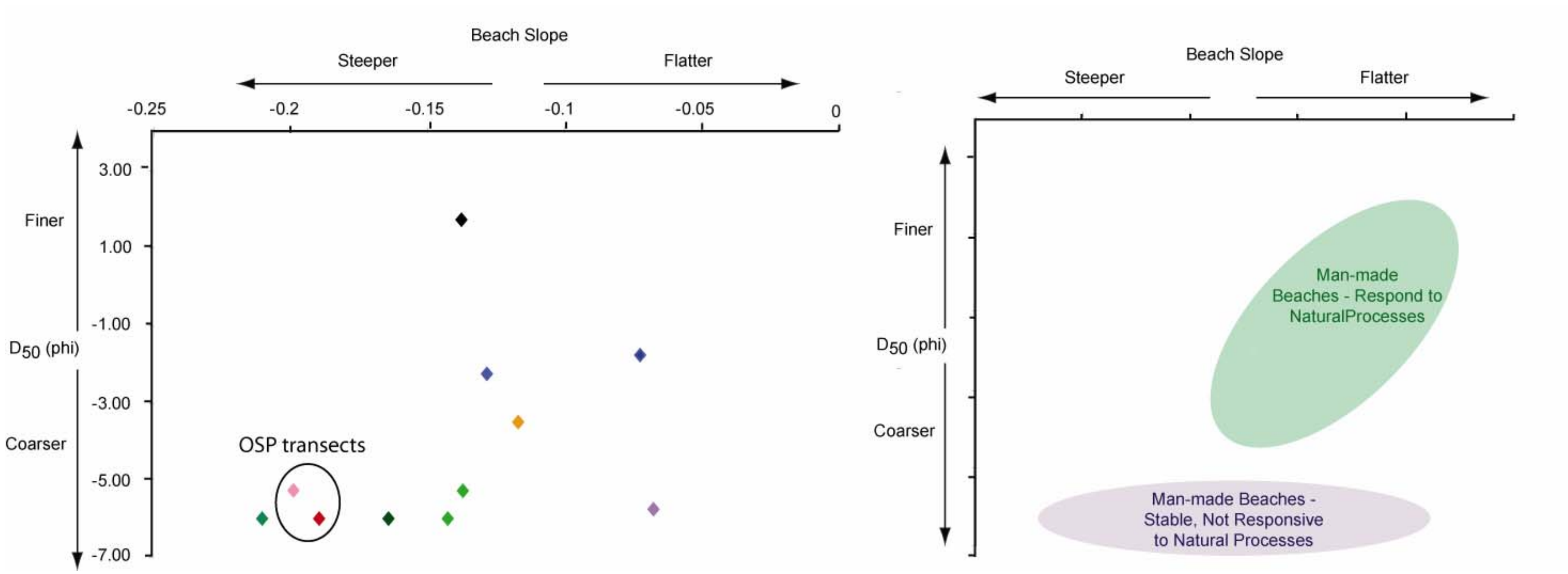


Figure 10. Relationship between active beach slope and median sediment grain size on the Puget Sound beaches studied, site color codes are the same as in Figure 9. Note that the point for Smith Cove indicates fine-grained sediment due to the truncation of the profile and patch of sand near the riprap wall, which is not representative of the sediment on the active slope.

The beaches fall into two categories. In the first category, beaches were composed of coarse sediment that can maintain a range of slopes (e.g., all Seacrest beaches, Seahurst-north, and 32nd St). These beaches were relatively stable at slopes up to 0.22 and show little response to natural processes. The OSP beach transects fall within this group. The second group contains beaches that were composed of smaller grain sizes (e.g., Myrtle Edwards and Seahurst-south and middle). These beaches are more responsive to natural processes and their slopes are controlled by the sediment grain size and wave conditions for the area.

Epibenthic Invertebrates

In general epibenthic invertebrates consisted mainly of harpacticoid copepods and gammarid amphipods, which are both crustaceans that are preyed on by nearshore fish including juvenile salmonids. Therefore, these two groups were a focus of analysis both for their prominence in the invertebrate assemblage and their importance as fish prey. Harpacticoids are usually smaller than 0.5 mm in length, and amphipods are larger shrimp-like crustaceans typically around 1-5 mm in length in our samples.

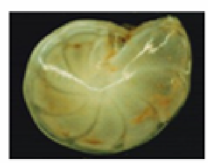
In the following results and discussion, we relate densities and composition of epibenthic invertebrate assemblages to physical characteristics where applicable, in order to illustrate the underlying physical features that influence these factors. Figures 11-16 show epibenthic invertebrate data, with descriptions and summary statistics detailed below the figure captions. Error bars on density graphs represent Standard Error, and complete statistics are listed in Appendix 2. Photographs of some common epibenthic invertebrates are shown below:

Amphipod (*Paracalliopiella pratti*)

Harpacticoid (*Harpacticus* sp.)

Cumacea

Ostracod



Foraminifera

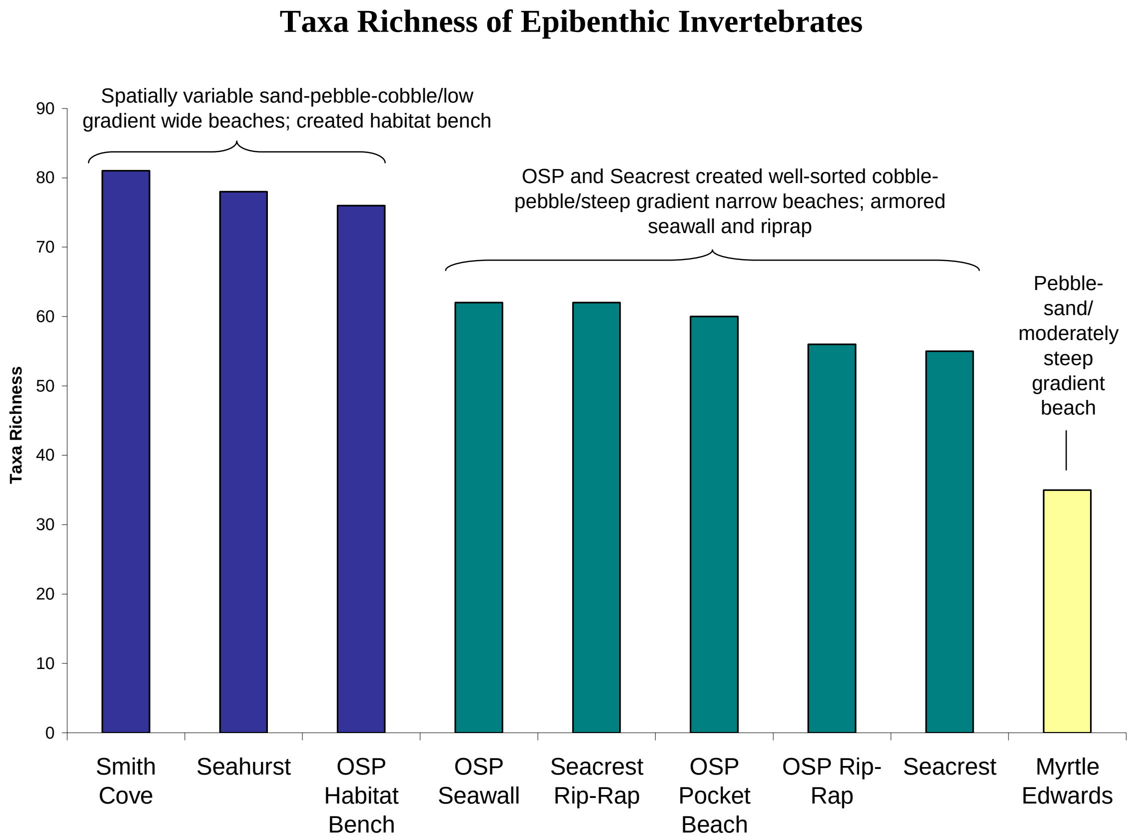


Figure 11. Overall taxa richness (number of species) of epibenthic invertebrates at all sites listed in descending number.

The OSP Habitat Bench had high taxa richness and grouped with Smith Cove and Seahurst, both sites that had variable sediment types and were low gradient wide beaches. The created OSP Pocket Beach and Seacrest beach had medium levels of taxa richness, and grouped with modified riprap and seawall shorelines in Elliott Bay. These created steep gradient, narrow beaches had well-sorted cobble/pebble sediment types that were fairly uniform in structure. Myrtle Edwards had the lowest taxa richness, potentially due to its smaller sediment size and steep gradient. Overall, taxa richness of epibenthic invertebrates was greater at beaches with diverse sediment types and low gradients. The created OSP Habitat Bench had similar measurements as these more diverse beaches, although there were no rounded beach sediments and little pore space on the bench. These results are probably due to other factors related to the packed-sediment bench that are different from those with more naturally occurring beach sediment.

Percent Composition of Epibenthic Invertebrates

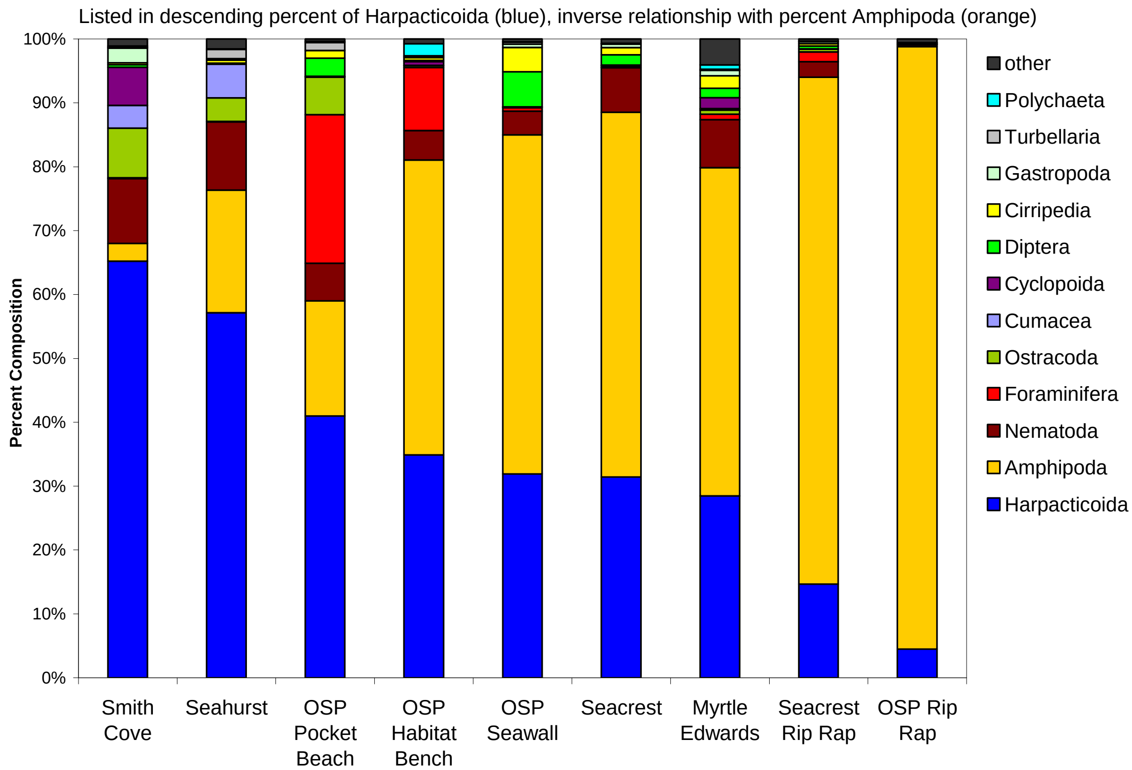


Figure 12. Average percent numerical composition of epibenthic invertebrate orders at all sites.

Percent of harpacticoids and amphipods followed an approximate inverse relationship. Smith Cove and Seahurst had the highest percentages of harpacticoids and also had the highest taxa richness values. The OSP Pocket Beach was closest to these two sites in percentages of amphipods, harpacticoids, and ostracods (a small bivalve-like shelled crustacean). Other sites in Elliott Bay were more similar to each other with around 50% amphipods and 30% harpacticoids. Sites with riprap were dominated almost exclusively by amphipods. Similar to the trends in taxa richness, this shows that beaches such as Smith Cove and Seahurst with diverse sediments and wide, low-gradient beaches had larger percentages of harpacticoids. The created OSP Pocket Beach had similar results, but had lower percentages of some taxa such as cumaceans (another small crustacean), perhaps due to its steep gradient and lower diversity of sediment types. The two created habitat types at OSP had the largest percentages of foraminifera (a small shelled protist), which may be indicative of an early colonizer of new habitats.

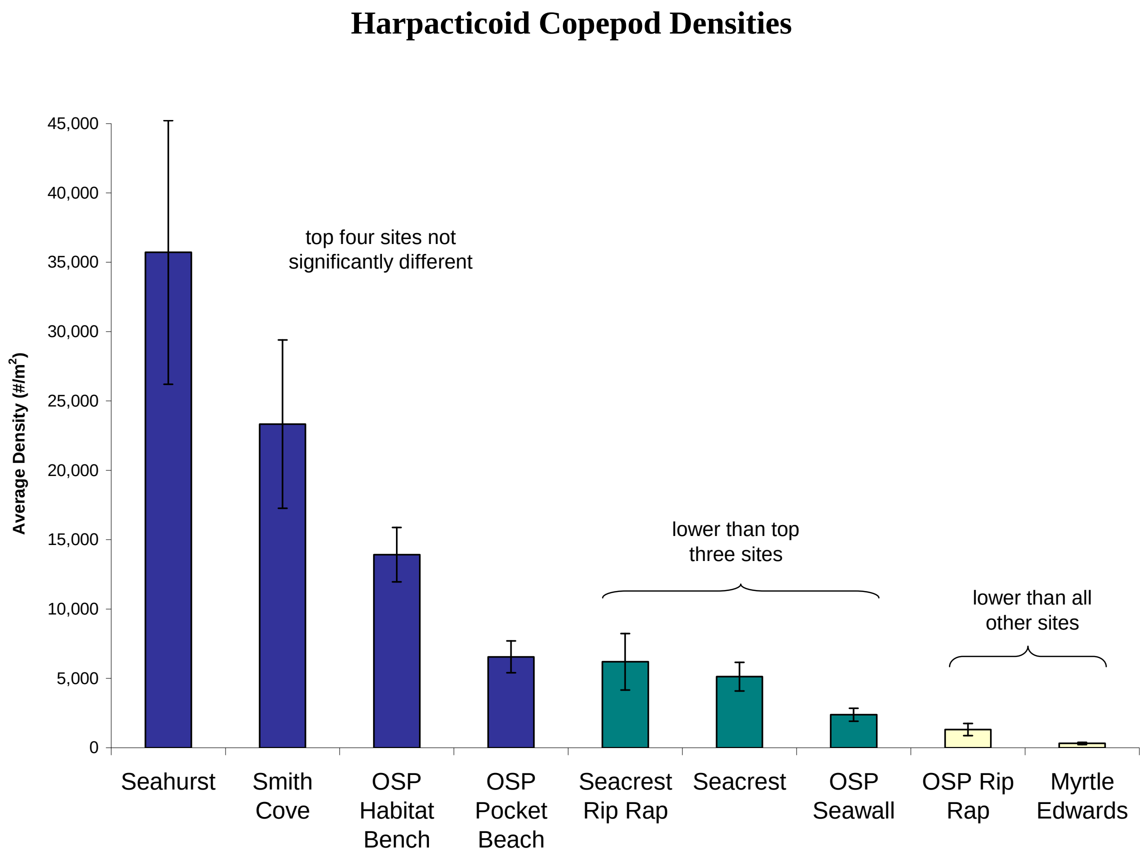


Figure 13. Average densities of harpacticoid copepods at all sites, listed in descending order.

Log-transformed densities were significantly different ($p < 0.05$), with general site groupings based on statistical results outlined in colors (overall statistical results are detailed in Appendix 2). Similar to the trends in percent composition, Seahurst and Smith Cove had the highest densities of harpacticoids, and there were no significant differences between these two sites and the created OSP Pocket Beach and Habitat Bench. The remaining sites within Elliott Bay had significantly lower densities than Seahurst and Smith Cove. Thus, the created habitats at OSP support similar densities of harpacticoids as more natural wide gradient beaches with diverse sediment types, whereas other Elliott Bay beaches and retained shorelines support lower harpacticoid densities.

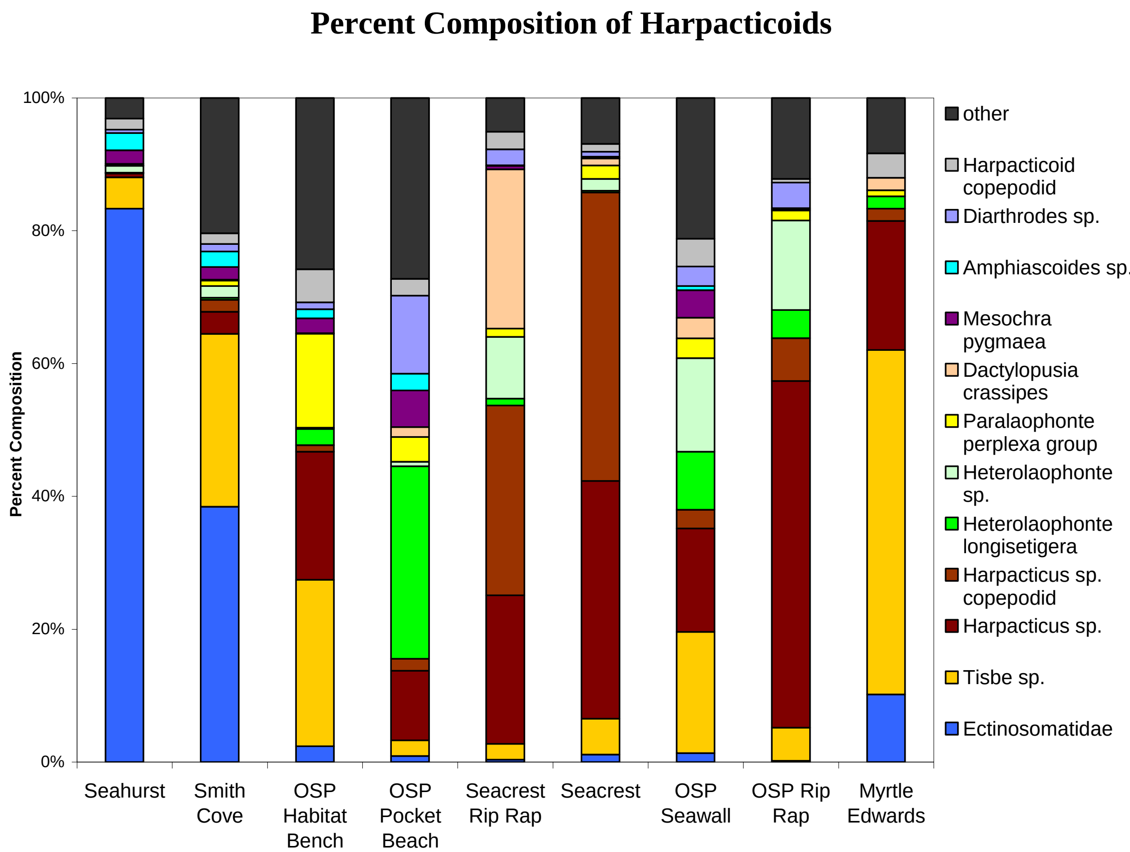


Figure 14. Average percent numerical composition of main harpacticoid species at all sites, listed in descending densities as in Figure 13.

There was a high number of taxa and considerable variation among sites in dominant taxa (the figure illustrates the top 12 taxa out of a total of 60, leaving a noticeable percentage in the "other" category). Seahurst and Smith Cove, which had the highest densities, had high percentages of Ectinosomatidae. *Tisbe* spp. were most prominent at Myrtle Edwards (although this site had very low overall densities). *Harpacticus* spp. comprised medium to high percentages at most of the Elliott Bay sites (including juvenile copepodid stages). The OSP sites all had around 20% *Heterolaophonte* sp., except for the Habitat Bench which had a similar percentage of *Paralaophonte perplexa*. Differences among the sites in presence of low percentage taxa also occurred, for example the sites with the top four densities all had higher percentages of *Amphiascoides* sp. The variance in taxa across all the sites points to the importance of having a diversity of sediment types and beach structure, that in turn support a wide array of harpacticoids. Although specific fish diets at all the sites were not taken, it is generally known that species such as *Harpacticus* and *Tisbe* spp. are good juvenile salmon prey items. Therefore, although the sites on the right side of the graph from Seacrest Riprap to Myrtle Edwards had overall lower densities, their species compositions still show good juvenile salmon prey items.

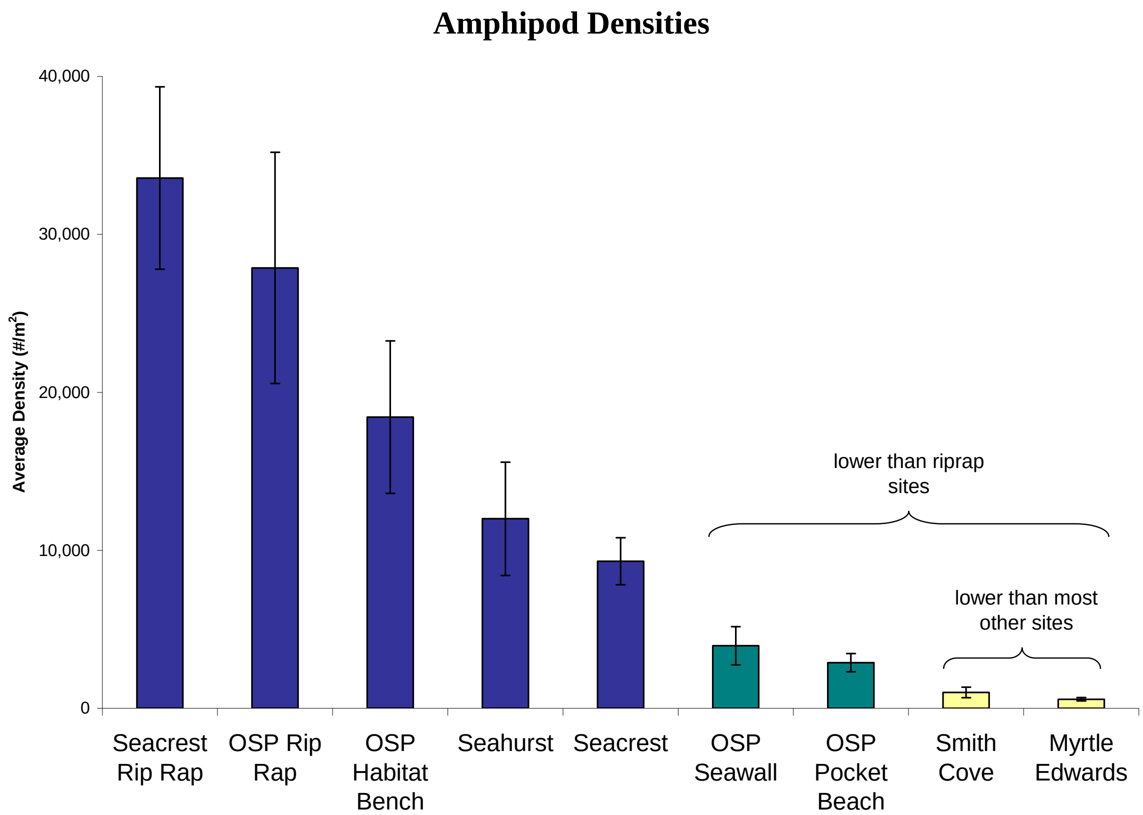


Figure 15. Average densities of amphipods at all sites, listed in descending order.

Log-transformed densities were significantly different ($p < 0.05$), with site groups that differed from each other based on statistical results outlined in colors (overall statistical results are detailed in Appendix 2). Similar to percent composition results in Figure 12, the two riprap sites had the highest densities of amphipods. The OSP Habitat Bench and Seacrest sites inside Elliott Bay and the Seahurst site were the only sites with densities similar to the riprap sites. All other sites had significantly lower densities than the riprap sites, with Smith Cove and Myrtle Edwards having the lowest densities. Thus, riprap sites supported high numbers of amphipods, but so did the created OSP Habitat Bench and two other beaches with differing physical structures. Algae can be a productive habitat for amphipods, and it may have contributed to the relatively high densities at the OSP Habitat Bench because this site had mostly harder substrates that could provide attachments for algae.

Percent Composition of Amphipods

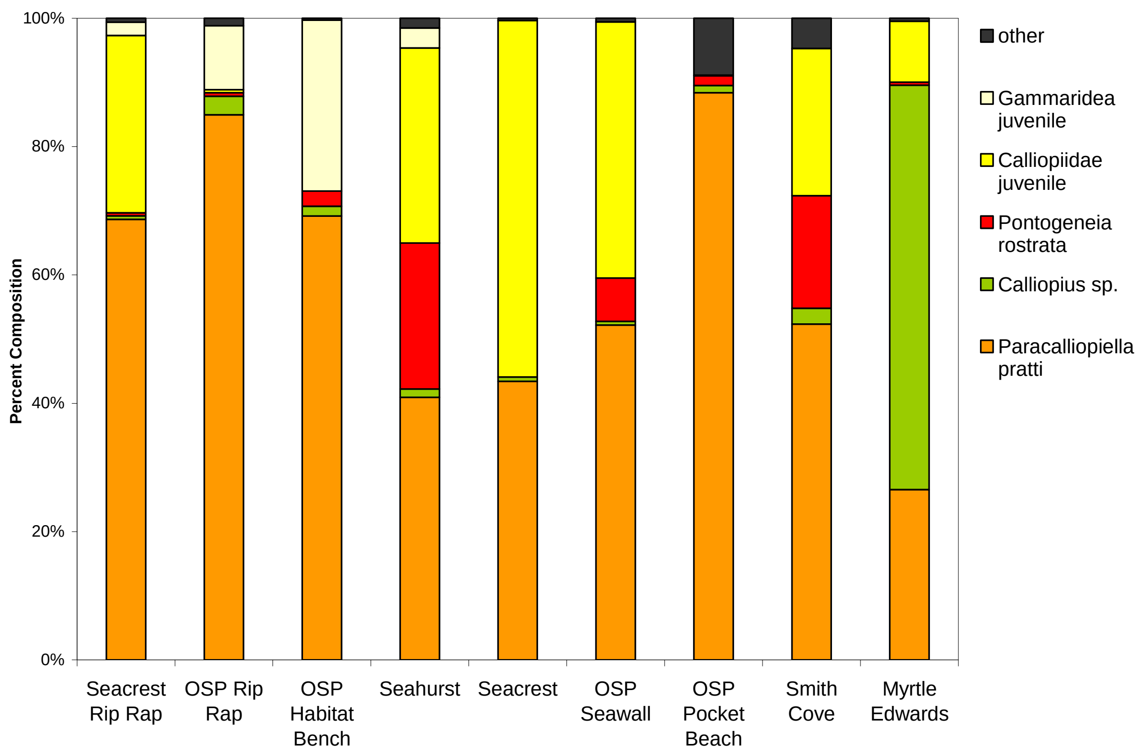


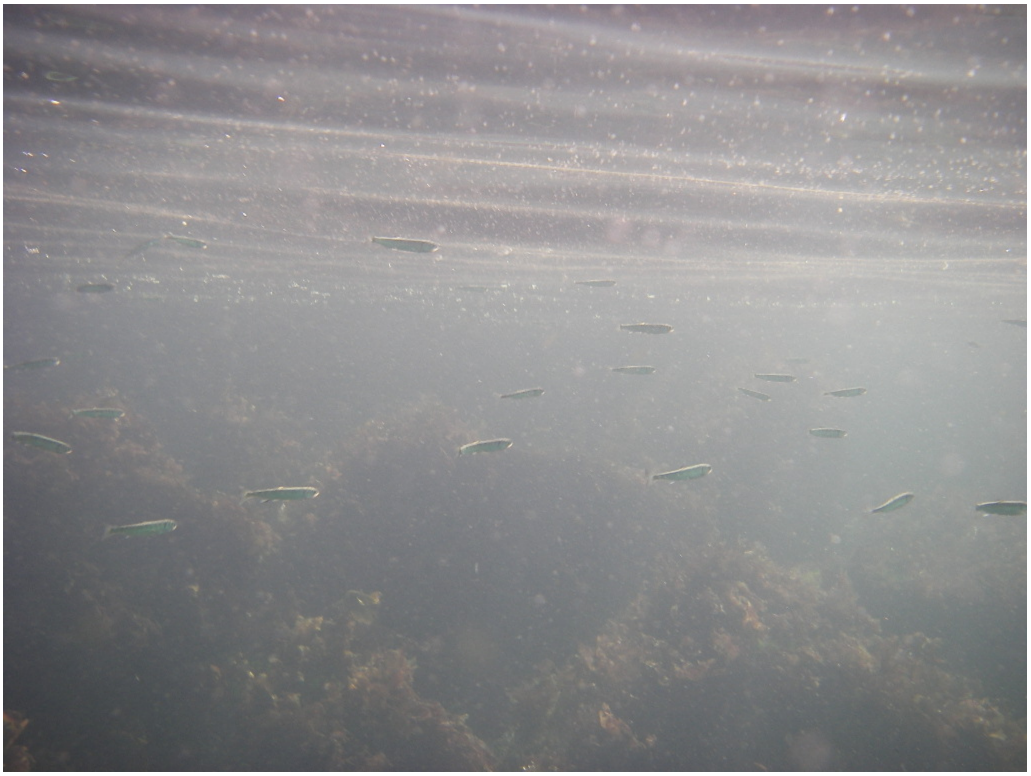
Figure 16. Average percent numerical composition of main amphipod species at all sites, listed in the same order as in Figure 15.

Three amphipod species and juvenile stages accounted for the majority of taxa, with a small percentage of "other" category (28 total counted taxa). *Paracalliopiella pratti* dominated at all sites except Myrtle Edwards, the site with smaller sediment sizes and a steep gradient, which had a high percentage of *Calliopius* sp. *Pontogeneia rostrata* accounted for around 20% of the amphipods at Seahurst (at high densities) and Smith Cove (at low densities); again, these are the two sites that had variable sediments and low gradient wide beaches. All three of these species are juvenile salmon prey items.

Snorkel Surveys

Table 3 summarizes all fish observed during snorkel surveys, followed by figures 17-22 describing densities by week and habitat, and figure 23 showing feeding behavior of juvenile salmon. “Larval fish” were a combination of all fish that were too small to identify to species level by snorkel observation; in cases where we could verify identifications these were mostly post-larval forage fish, typically smelt. Statistics on density were done on groupings of overall juvenile salmonids and larval fish to account for differing taxonomic observations due to visibility (e.g. observations recorded as “juvenile salmonid unknown” if visibility was too turbid to identify to species). Both of these nearshore fish groupings are a restoration focus of shallow water habitat. Additional tables showing physical characteristics of visibility, temperature, and salinity are in Appendix 2. Photographs of some of the major fish types are shown below:

School of juvenile salmon smolts (Chinook/coho)



School of juvenile salmon smolts (chum/pink)

School of sand lance

School of larval fish (small smelt)

Table 3. Summary of all observed fish and crab species and classification into different functional groups. Average lengths were calculated from estimates of total body length for fish and carapace width for crabs. Overall, 28 distinct species or taxa groups of fish and crabs were identified from snorkel surveys. Total fish counts were dominated by sand lance, larval fish, and pink salmon.

Functional group	Common name	Scientific name	Total counted	# of observations	Average school size	Average length (cm)
Crab	Cancer sp.	*Cancer sp.*	5	5		13.75
	Dungeness Crab	*Cancer magister*	39	35		15.11
	Hemigrapsus sp.	*Hemigrapsus sp.*	61	57		3.52
	Kelp Crab	*Pugettia producta*	46	39		8.24
	Red Rock Crab	*Cancer productus*	92	87		14.61
Flatfish	English sole	*Parophrys vetulus*	1	1		21.25
	Flatfish		4	4		12.50
	Sole	*Pleuronectidae*	8	8		19.69
	Starry Flounder	*Platichthys stellatus*	4	4		27.50
Forage fish	Forage fish		50	1	50	6.25
	Pacific Herring	*Clupea pallasii*	5000	1	5000	6.25
	Pacific Sand Lance	*Ammodytes hexapterus*	21706	17	2411	8.82
	Surf Smelt	*Hyposmeus pretiosus*	6809	10	857	5.38
Gunnel	Gunnel	*Pholididae*	3	3		11.33
	Penpoint Gunnel	*Apodichthys flavidus*	1	1		26.25
	Saddleback Gunnel	*Pholis ornate*	1	1		13.75
Juvenile salmon	Chinook	*Oncorhynchus tshawytscha*	560	45	76	10.06
	Chinook/Coho	*O. tshawytscha/O. kisutch*	163	7	60	10.54
	Chum	*O. keta*	4822	58	147	5.97
	Chum/Pink	*O. keta/O. gorbushca*	7425	33	239	4.51
	Juvenile Salmon	*Oncorhynchus spp.*	1687	15	140	7.75
	Pink	*O. gorbuscha*	15526	65	315	4.43
	Sockeye	*O. nerka*	1	1	16	11.25
	Trout	*Oncorhynchus spp.*	2	1		16.25
Larval fish	Larval Fish		16463	32	658	3.02
Other demersal fish	Lingcod	*Ophiodon elongatus*	4	4		76.25
	Northern Clingfish	*Gobiesox meandricus*	2	2		3.75
	Sculpin	*Cottidae*	10	10		10.75
	Tidepool Sculpin	*Oligocottus maculosus*	7	7		8.39
	Whitespotted greenling	*Hexagrammos stelleri*	4	4		20.00
Other nearshore fish	Bay Pipefish	*Syngnathus leptorhynchus*	2	2		13.75
	Threespine Stickleback	*Gasterosteus aculeatus*	1	1		6.25
	Tubesnout	*Aulorhynchus flavidus*	74	12	12	14.06
Surfperch	Kelp Perch	*Brachyistius frenatus*	26	18	4	8.89
	Perch	*Embiotocidae*	8	4		10.63
	Pile Perch	*Damalichthys vacca*	209	92	5	14.48
	Shiner Perch	*Cymatogaster aggregata*	6675	24	605	8.44
	Shiner/Kelp Perch		49	5		9.25
	Striped Seaperch	*Embiotoca lateralis*	238	133	5	16.20
Unidentified fish	Fish, unident.		21	2	20	11.25

Average Weekly Density of Major Functional Groups (all sites)

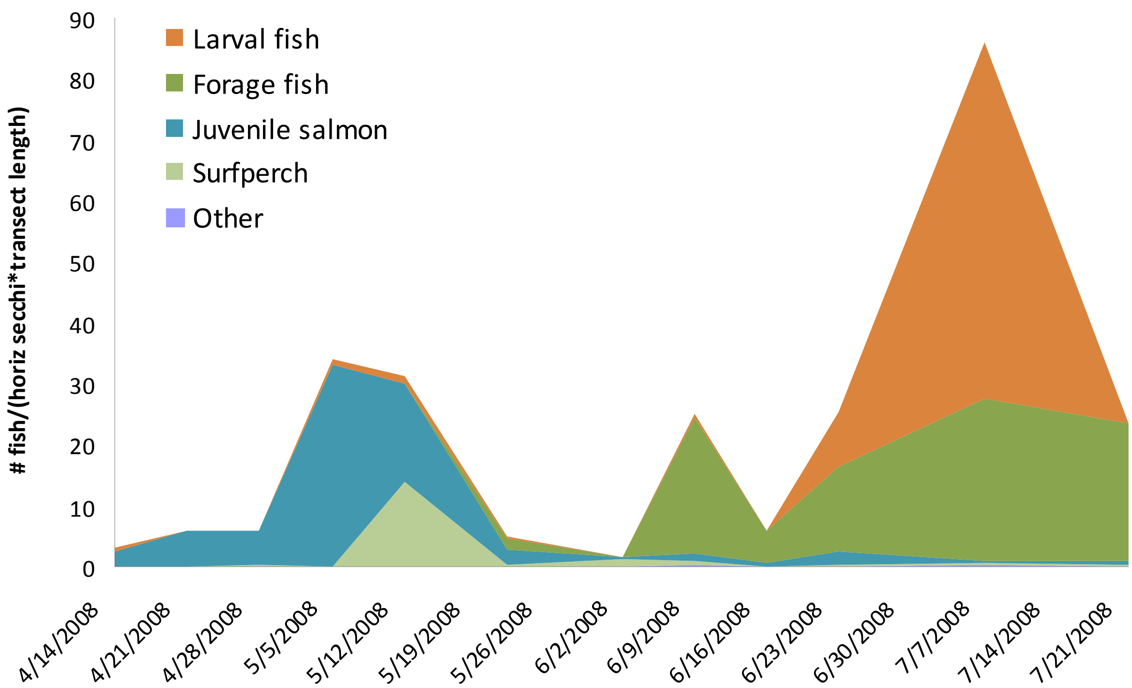


Figure 17. Densities of major fish groups averaged over all sites for each week.

Juvenile salmon and surfperch were the most abundant fish observed in April and May, while forage fish and larval fish were the dominant groups later in the season. The high observed densities of juvenile salmon in April and May were driven by large numbers of outmigrating juvenile pink and chum. In general, surfperches were observed throughout the sampling period at consistently low levels; their peak densities in May were driven by a few observations of relatively large schools of shiner perch. Larval fish included small (< 2.5 cm in length) post-larval fish and slightly larger (2.5 – 5 cm in length) juvenile forage fish, most likely surf smelt. Larval fish and adult forage fish, particularly surf smelt and Pacific sand lance, were observed in large schools (hundreds to thousands of individuals) near shore in June and July.

Average Weekly Density of Juvenile Salmon (all sites)

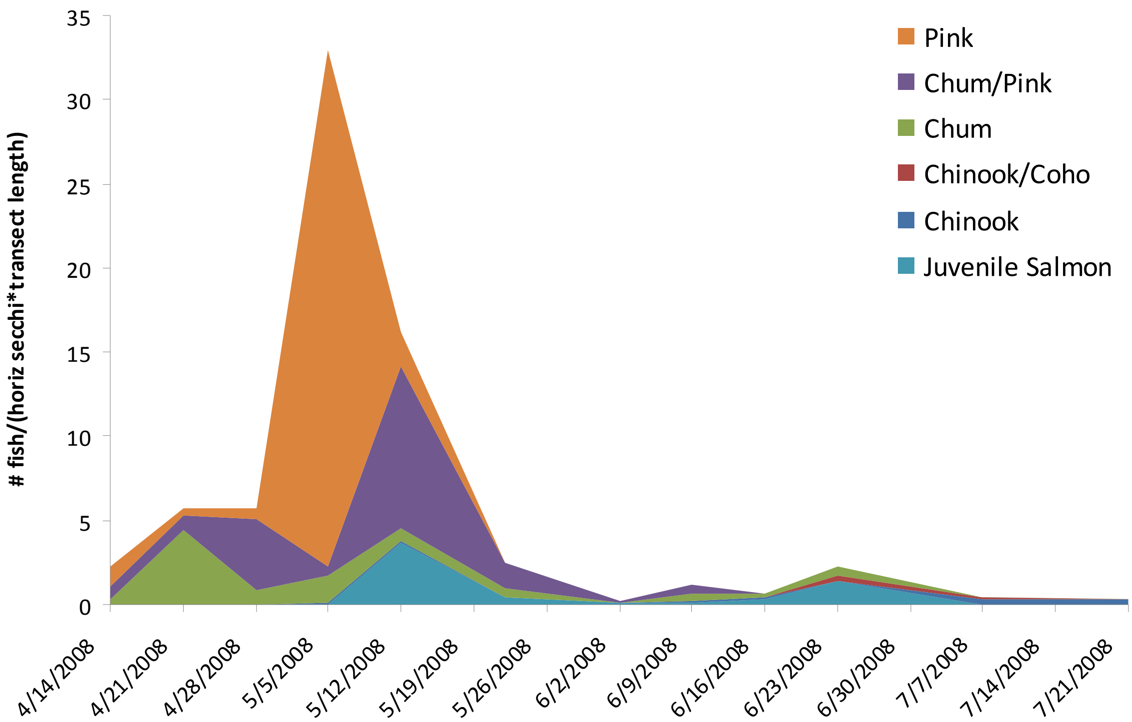


Figure 18. Average weekly density of juvenile salmon across all sites.

Fish were identified as pink/chum, Chinook/coho, or juvenile salmon when complete differentiation was not possible (i.e. due to poor visibility or distance between the observer and the fish). Overall, juvenile pink salmon were the most abundant salmonid. They were observed in highest densities in early May and were absent from all study sites after the end of May. In general, peak abundances of juvenile chum and pink salmon overlapped, however chum salmon observations continued into June and July. Juvenile Chinook and Chinook/coho were first observed in May and reached their highest densities in July. The vast majority of observations were of pink and chum; Chinook observations were extremely low compared to previous years. Similarly low Chinook numbers in 2008 were found by several other projects in Puget Sound (Salmon Habitat Conference, Salmon Recovery Funding Board, April 15-16, 2009, Shelton, WA). This may have been due to three contributing factors: (1) differing weather patterns and physical conditions, as there were severe floods during the Winter of 2007/2008 which could effect winter survival and timing of outmigration, (2) competition with pink salmon in shallow water, as previous samplings were not during years of juvenile pink salmon outmigration (Ruggerone and Goetz 2004), and (3) low visibilities in June and July during the typical peak in Chinook outmigration, resulting in difficulty viewing and identifying salmonids at times (see secchi disk readings in Appendix 2).

Average Weekly Density of Forage Fish (all sites)

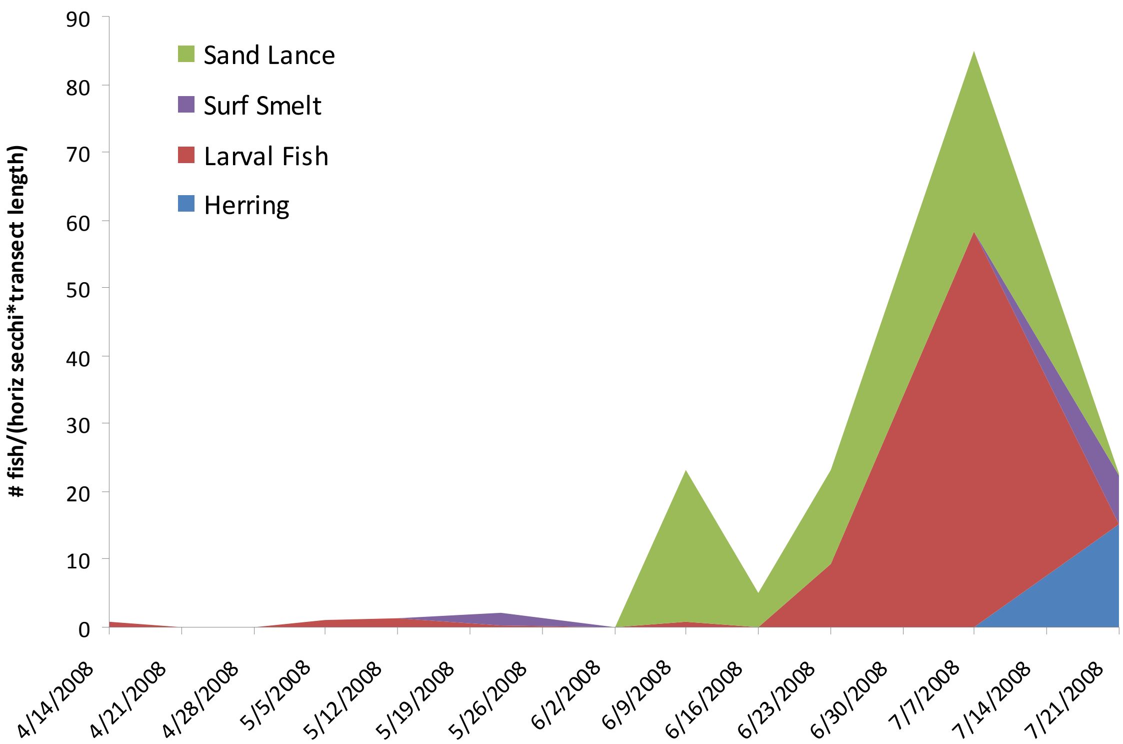


Figure 19. Average weekly density of forage fish across all sites.

Larval fish are included because they were most likely post-larval or juvenile forage fish (probably surf smelt). Sand lance were the most consistently observed forage fish and the dominant species in this group in June. Larval fish, which had the highest densities observed overall, reached highest densities in July. Herring were represented by only a single observation at Smith Cove in July, which contrasted to 2007 when they were the most abundant forage fish observed at OSP.

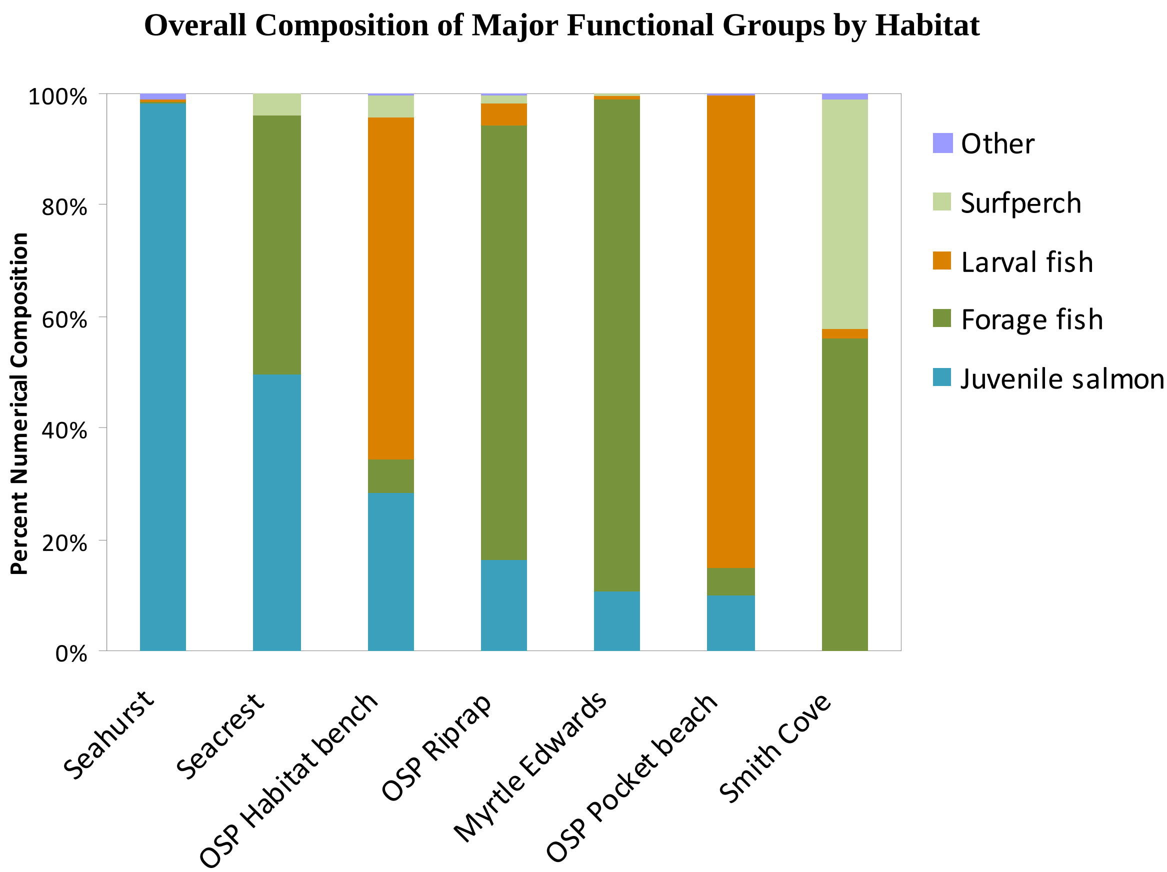


Figure 20. Overall composition of major fish groups by habitat, listed in descending percent of juvenile salmon.

Seahurst and Seacrest had the highest percentages of juvenile salmon, which made up almost all of the observations at Seahurst, while at Smith Cove very few juvenile salmon were observed. The OSP Pocket Beach and Habitat Bench had the highest proportions of larval fish. These small larval fish may have been attracted to this area as a refuge habitat because it is the first shallow water habitat located to the north of downtown Seattle at the end of the seawall, and it is possible the larval fish hatched at the site. Other small beaches in Elliott Bay at Myrtle Edwards and Seacrest did not have high percentages of larval fish, even though their beach slopes were similar, and the sediment types at Seacrest were similar to the OSP Pocket Beach. These larval fish were most likely small forage fish; larger forage fish that could be identified had high compositions at Myrtle Edwards and OSP Riprap, and medium levels at Seacrest and Smith Cove.

Overall Density of Juvenile Salmon by Habitat

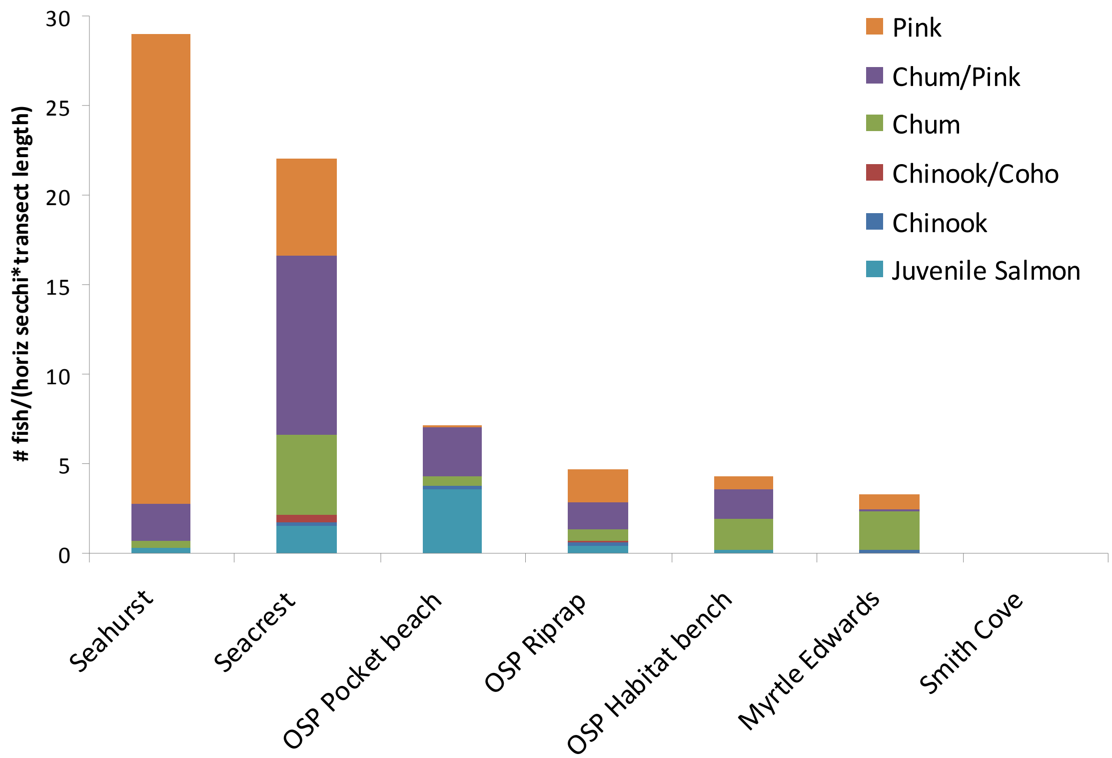


Figure 21. Overall densities of juvenile salmon by habitat, listed in descending order.

Highest densities of juvenile salmon were observed at Seahurst and Seacrest. At most habitats, the majority of juvenile salmon were represented by a mix of pink and chum, although pink salmon dominated the observations at Seahurst. The OSP habitats and Myrtle Edwards were similar in overall juvenile salmon densities. The only habitat that was significantly different in overall juvenile salmon density was Smith Cove, where only 2 salmonids were observed during the study. This was in contrast to the Smith Cove epibenthic invertebrate results and beach physical properties (variable sediments, low-gradient profile) which were more similar to those at Seahurst. Again, the high counts of pink/chum juvenile salmon (98% of total counts) compared to those of Chinook were different from previous years; pink and chum prefer very shallow water, which may override other habitat preferences. Additionally, pinks formed variably sized schools often ranging into the 1000s, which caused variability in statistical analyses.

Overall Density of Forage Fish by Habitat

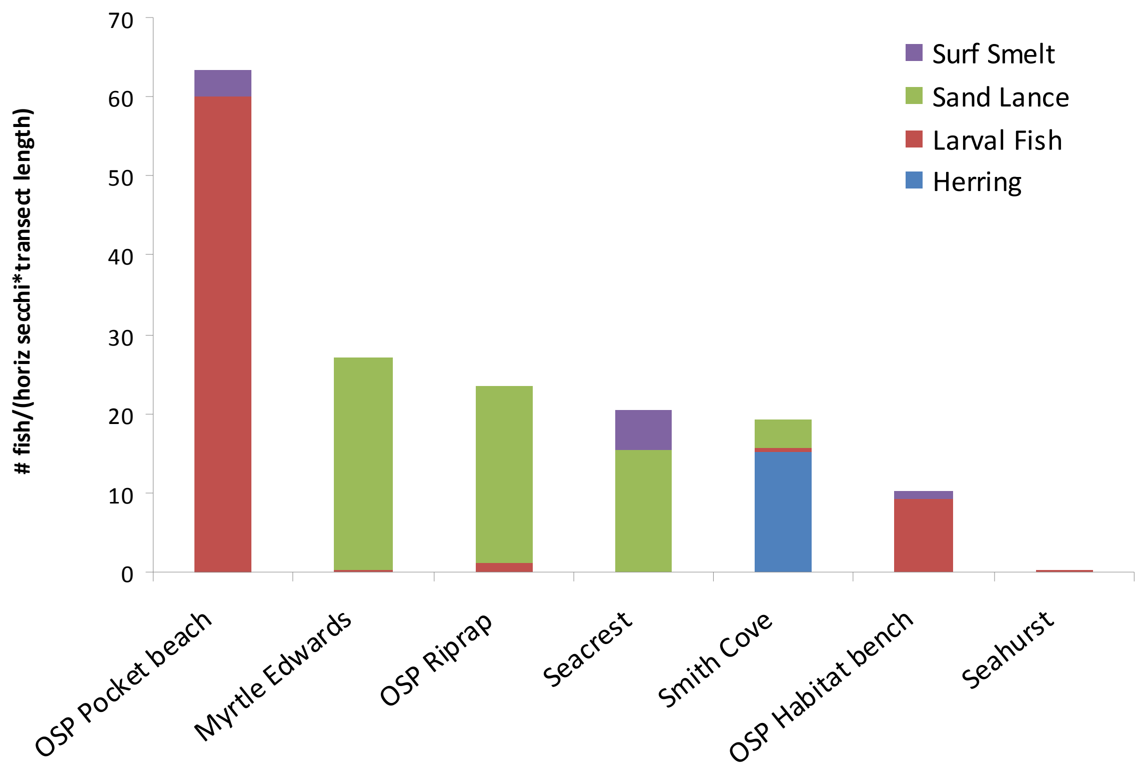


Figure 22. Overall densities of forage fish (including larval fish) by habitat, listed in descending order.

Larval fish and surf smelt dominated forage fish observations at the OSP created habitats. At other surveyed habitats sand lance were the most abundant forage fish observed, except at Smith Cove where a single large school of 5000 herring were observed. Forage fish were rarely observed at Seahurst during snorkel transects, possibly due to the open shoreline and relatively gentle gradient that made observations of patchily distributed schooling species more difficult; we did observe forage fish at Seahurst several times when data was not being collected. Because of the patchy nature and high variability of the schooling species data, we did not detect any statistical differences in densities; therefore the data represent non-significant trends of nearshore use by forage fish. Species of forage fish also varied by year: in 2007 herring were the most abundant forage fish observed at OSP, as compared to 2008 when larval fish and sand lance dominated.

Percent of Juvenile Salmon Observed Feeding at each Habitat

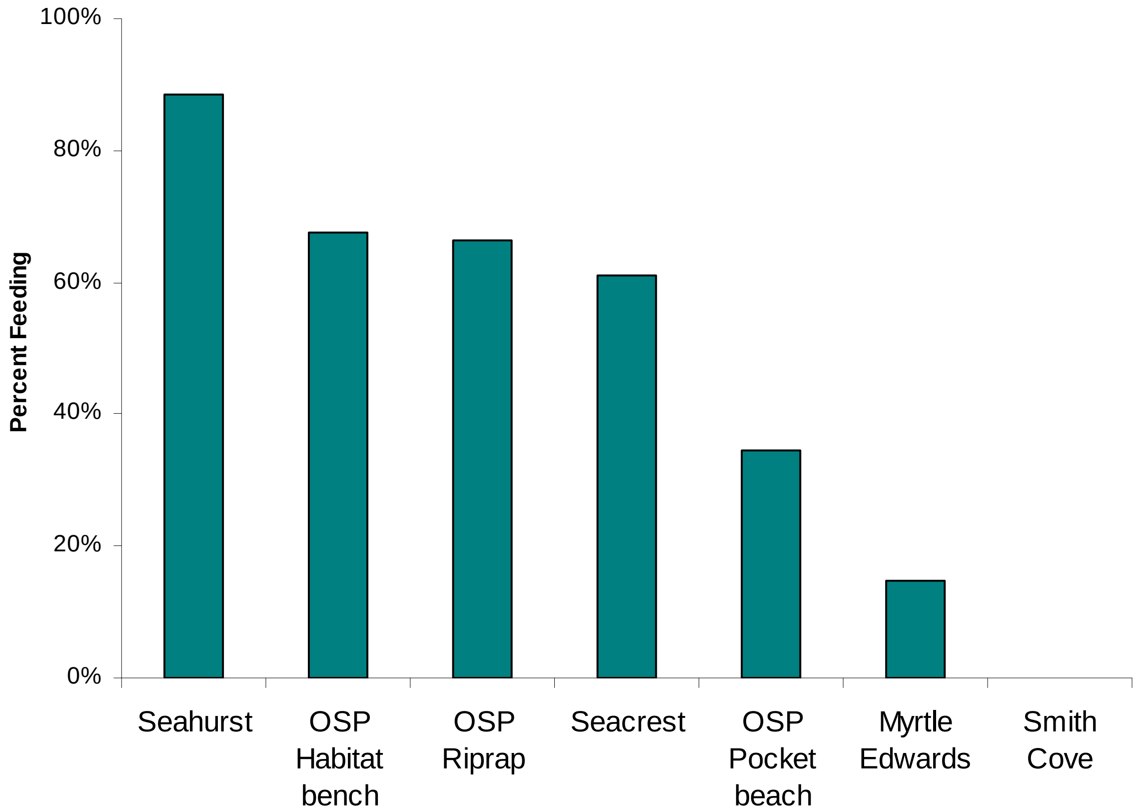


Figure 23. Percentage of juvenile salmon observed feeding at each habitat.

Within Elliott Bay, greater than 50% of juvenile salmon observed were feeding at OSP Habitat Bench, OSP Riprap, and Seacrest. Nearly 90% of the juvenile salmonids (mostly pink salmon) observed at Seahurst were feeding. This may be related to availability of juvenile salmon prey at this site, which has an unretained, wide, low-gradient beach and a vegetated shoreline. Harpacticoid copepods, a common prey item for juvenile chum and pink salmon, were abundant and diverse in the epibenthos at Seahurst and were presumably available for consumption at the site. The OSP Pocket Beach was intermediate in salmon feeding compared to other similar beaches in Elliott Bay, signifying that although feeding behavior is at a medium level there still may be room for improvement as the site continues to develop in its biological communities. No feeding was observed at Smith Cove, but only two salmonids were recorded at that site.

Conclusions

Results from physical and biological monitoring such as that conducted in this study can be useful in formulating nearshore restoration designs. For example, the results suggest that detailed descriptions of physical beach structure can be important in understanding patterns of juvenile salmon and their epibenthic invertebrate prey. Beaches that either had a diversity of substrate types or a wide, low gradient beach often had higher invertebrate densities. Even though their physical structures are different than those of other beaches, the OSP Habitat Bench and Pocket Beach appear to have biological functions similar to the more natural beaches. We found a general pattern of amphipods being more associated with riprap and harpacticoids with more natural/created beaches, and one interpretation of this is that a diversity of habitat types supports more types of biotic assemblages. For instance, within the highly modified Seattle shoreline amphipods were very prevalent and mostly consisted of one species. Incorporating small, diverse segments of shoreline into a restoration plan could increase the overall biotic diversity and taxa richness of the system. This integrative approach may help to reach management goals such as those detailed by the Puget Sound Partnership, which state that restoration is needed to alleviate the threat of shoreline armoring to ecosystem processes in Puget Sound (PSP 2008).

Previous monitoring at the Olympic Sculpture Park has detailed initial development from pre-construction to year 1 post-construction (Toft et al. 2008). At the OSP habitat sites, juvenile salmon were significantly more abundant in the shallow water strata of the habitat bench and pocket beach sites than at the adjacent riprap site. Data collected during 2008 has added information from a year of pink salmon outmigration. Pink salmon dominated the observations, and numbers of Chinook were extremely low compared to past years. Pink salmon were abundant at most nearshore habitat types sampled, with particularly large schools and high numbers at Seahurst and low numbers at Smith Cove; the OSP habitat sites fall in the middle of the distribution. Small post-larval forage fish comprised a high proportion of the fish observed at both the OSP Pocket Beach and Habitat Bench. This suggests that providing refuge for these fish may be an added benefit of creating shallow water beach types in a highly modified urban setting, where the majority of the shoreline has a truncated steep intertidal zone. Feeding rate of juvenile salmonids was high at the OSP Habitat Bench during both odd and even years of juvenile salmon outmigration, while the OSP Pocket Beach was slightly lower; it will be interesting to address feeding behaviors in future years to see if this improves as the biological community develops.

Monitoring at OSP is scheduled for year 3 post-construction, identical to the pre- and year 1 post-construction. Research activities in the next year will provide an important assessment of site conditions, as there will have been a greater period of time for physical and biotic processes to develop. Additional data and analysis related to the present year 2 report will also be available in the upcoming year as part of the graduate school Masters theses of two of the co-authors, Sarah Heerhartz and Emilie Flemer.

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Appendix 1: Photographs of Sites and Methods

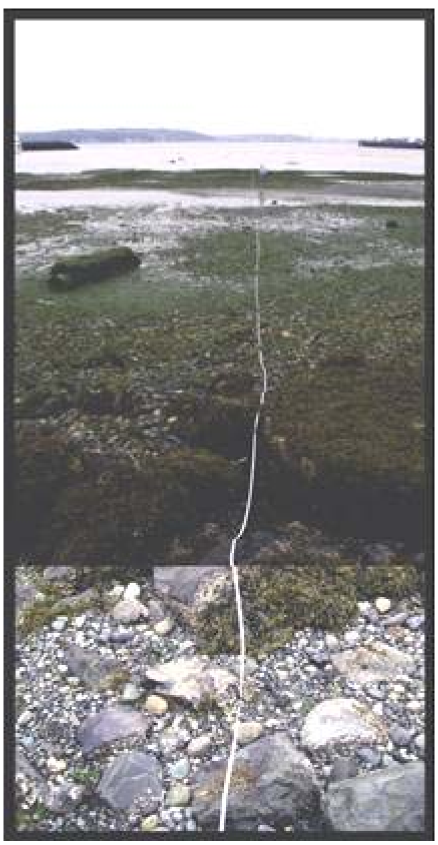
The Olympic Sculpture Park pocket beach and habitat bench at high tide.

The habitat bench after construction at low tide.

Coarse-grained pebble/cobble beach at Seacrest (north transect).

Coarse-grained pebble/cobble beach at 32nd St, also showing parallel snorkel transects.

Sand/pebble mix beach at Myrtle Edwards Park.



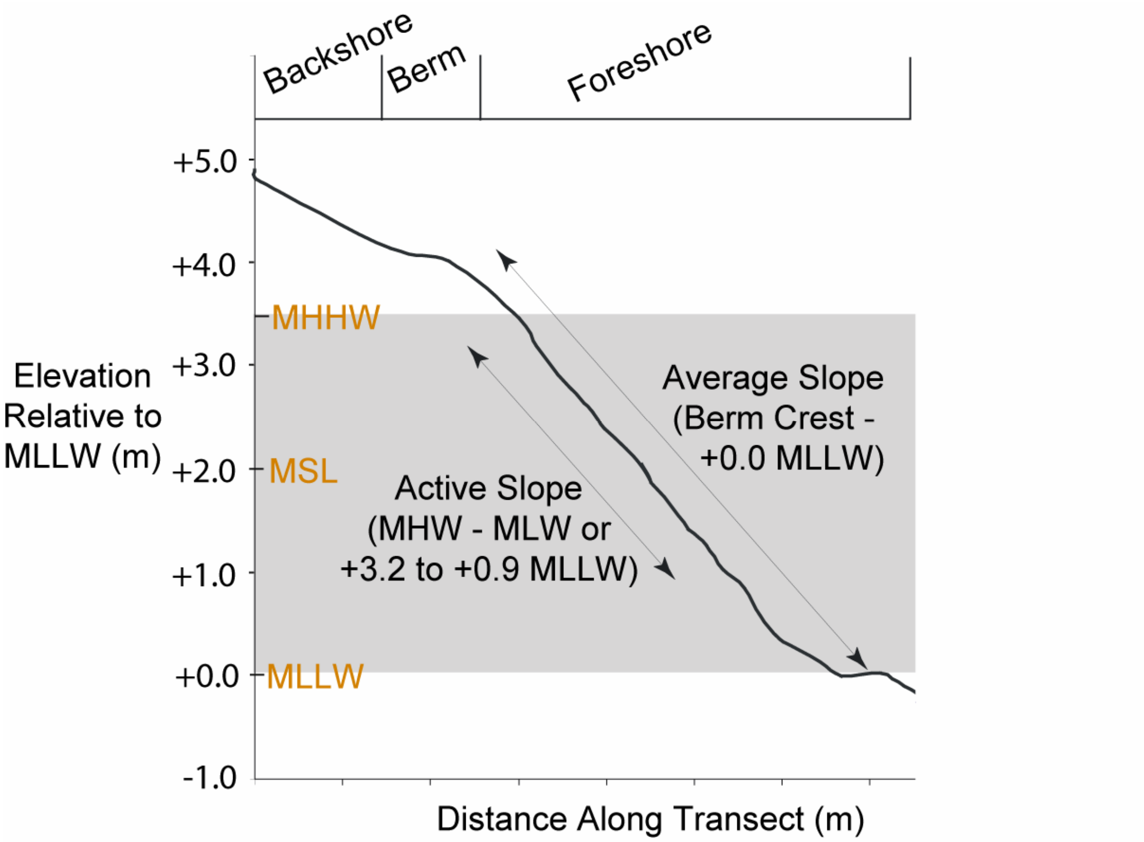
Coarse sediment beach at Smith Cove.

Pebble beach at Seahurst Park.

Parallel snorkel transects at Seahurst Park.

Pump sampling for epibenthic invertebrates.

Appendix 2: Additional Data



Beach profile at OSP defining the terms used to calculate active and average slopes at all the beaches.

Sediment grain-size parameters estimated at +4.0, +3.0, +2.0, +1.0, +0.0, -1.0 m MLLW. Data was compiled from surface sediment samples obtained in summer 2007 and 2008.

		~4.0 m Elevation (MLLW)			~3.0 m Elevation (MLLW)			~2.0 m Elevation (MLLW)			~1.0 m Elevation (MLLW)			~0.0 m Elevation (MLLW)			~-1.0 m Elevation (MLLW)		
		D-50 (phi)	Sorting (phi)	% Sand	D-50 (phi)	Sorting (phi)	% Sand	D-50 (phi)	Sorting (phi)	% Sand	D-50 (phi)	Sorting (phi)	% Sand	D-50 (phi)	Sorting (phi)	% Sand	D-50 (phi)	Sorting (phi)	% Sand
Myrtle Edwards		1.25	0.65	99.4	1.25	0.65	99.4	-2.25	1.65	32.4	-3.50	1.56	9.9	-3.50	1.56	9.9	---	---	---
OSP	No. Transect	-3.75	0.72	0.0	-3.50	0.38	0.0	-5.00	0.24	0.0	-6.00	0.28	0.0	-5.75	0.34	0.0	RR	---	---
	So. Transect	-5.25	0.30	0.0	-5.25	0.28	0.0	-5.25	0.20	0.0	-5.25	0.24	0.0	-5.75	0.20	0.0	RR	---	---
Seacrest	No. Beach (Alki)	-5.75	0.18	0.0	-5.75	0.18	0.0	-5.75	0.18	0.0	-6.00	0.20	0.0	-6.00+	---	---	-6.00+	---	---
	Middle Beach	-5.00	0.24	0.0	-5.50	0.30	0.0	-5.50	0.30	0.0	-6.00	0.20	0.0	-6.00+	---	---	-6.00+	---	---
	So. Beach (Port)	-5.25	0.34	0.0	-5.25	0.34	0.0	-5.75	0.28	0.0	-6.00	0.10	0.0	-6.00+	---	---	-6.00+	---	---
Seahurst	No. Transect	RR	---	---	RR	---	---	-2.00	1.14	19.9	-1.75	2.77	46.7	-5.75	2.48	14.7	2.25	0.75	98.9
	Middle Transect	1.00	0.65	98.9	1.00	0.65	98.9	-2.25	1.33	25.5	-2.25	1.33	25.5	2.50	0.93	86.9	2.50	0.93	86.9
	So. Transect	1.25	1.09	90.5	1.25	1.09	90.5	-4.25	0.44	0.0	-5.25	0.28	0.0	2.00	0.59	0.0	2.00	0.59	0.0
32nd Street	West Transect	-4.50	0.58	0.0	-4.50	0.58	0.0	concrete rubble	---	---	-5.75	0.38	0.0	-5.75	0.38	0.0	-6.50+	---	---
Smith Cove	West Transect	RR	---	---	RR	---	---		---	---	1.75	0.65	97.6	-6.00	3.43	37.6	-6.50+	---	---

--- above sediment line (+4.0 and +3.0 m), or no data (-1.0 m)
RR - rip rap material

Beach morphology (Average slope, Active Slope, Beach Width, Berm Elevation) for the three spatial sampling efforts (Summer 2007, Winter 2008, Summer 2008) where applicable. Slopes were calculated over the sediment covered portion of the beach only, and do not include the riprap backed portion of the beach in the active or average profile.

		Average Slope (berm - MLLW, if no berm observed, start of beach sediment - MLLW) (error, ± 0.007)			Active Slope (MHW - MLW) (error, ± 0.007)			Beach Width, m (start of beach sediment - MLLW) (error, ± 2 m)			Berm Elevation (MLLW), m (error, ± 0.04)		
		S-07	W-08	S-08	S-07	W-08	S-08	S-07	W-08	S-08	S-07	W-08	S-08
Myrtle Edwards		-0.113	-0.101	-0.106	-0.122	-0.101	-0.117	31.4	35.4	32.4	3.91*	3.67*	3.89*
OSP	No. Transect	-0.170	-0.176	-0.172	-0.199	-0.199	-0.190	28.6	23.6	24.4	3.97	3.95	4.16
	So. Transect	-0.167	-0.172	-0.165	-0.204	-0.202	-0.199	25.7	27.5	31.1	4.15	4.41	4.28
Seacrest	No. Beach	-0.166	-0.176	-0.172	-0.158	-0.166	-0.164	24.5	23.3	23.3	3.89*	4.14*	4.11*
	Middle Beach	-0.208	-0.210	-0.212	-0.205	-0.213	-0.210	23.8	24.0	24.5	4.40	4.42	4.42
	So. Beach	-0.142	-0.141	-0.138	-0.144	-0.148	-0.143	35.7	35.1	35.6	---	3.84	---
Seahurst	No. Transect	-0.056	-0.053	-0.055#	-0.075	-0.073	-0.072#	44.3	48.8	44.3	2.61*	2.64*	2.48*
	Middle Transect	-0.122	-0.109	-0.117	-0.130	-0.124	-0.128	34.9	38.7	38.7	3.68	---	3.84
	So. Transect	-0.078	-0.077	N/A	-0.137	-0.122	N/A	54.6	52.6	N/A	2.93	---	N/A
32nd Street	West Transect	N/A	N/A	-0.063	N/A	N/A	-0.068	N/A	N/A	27.3	N/A	N/A	---
	East Transect	N/A	N/A	-0.055#	N/A	N/A	-0.063#	N/A	N/A	49.9	N/A	N/A	2.63*
Smith cove	West Transect	N/A	N/A	-0.029#	N/A	N/A	-0.137#	N/A	N/A	71.0	N/A	N/A	2.11*
	East Transect	N/A	N/A	-0.081#	N/A	N/A	-0.105#	N/A	N/A	26.0	N/A	N/A	2.11*

N/A no data.

incomplete profile for slope calculation

--- no berm observed.

* elevation of sediment next to abuttment (rip-rap).

Wentworth (1922) size classification scheme used for sediment analysis.

Sediment Type	Grade Limits	
	Phi Size	Intermediate Diameter (mm)
Fine Sand	2.00	0.25
Medium Sand	1.50	0.35
	1.00	0.50
	0.50	0.71
	0.00	1.00
Coarse Sand	0.50	0.71
	0.00	1.00
Very Coarse Sand	-0.50	1.41
	-1.00	2.00
Granule (Very Fine Gravel)	-1.50	2.83
	-2.00	4.00
Pebble (Gravel)	-2.50	5.66
	-3.00	8.00
	-3.50	11.31
	-4.00	16.00
	-4.50	22.63
	-5.00	32.00
	-5.50	45.25
	-6.00	64.00
Cobble	-6.50	90.51
	-7.00	128.00

Inman (1952) measurement scale of dispersion (sorting).

Sorting	Description
less than 0.35	very well sorted
0.35 – 0.50	well sorted
0.50 – 1.00	moderately sorted
1.00 – 2.00	poorly sorted
2.00 – 4.00	very poorly sorted
greater than 4.00	extremely poorly sorted

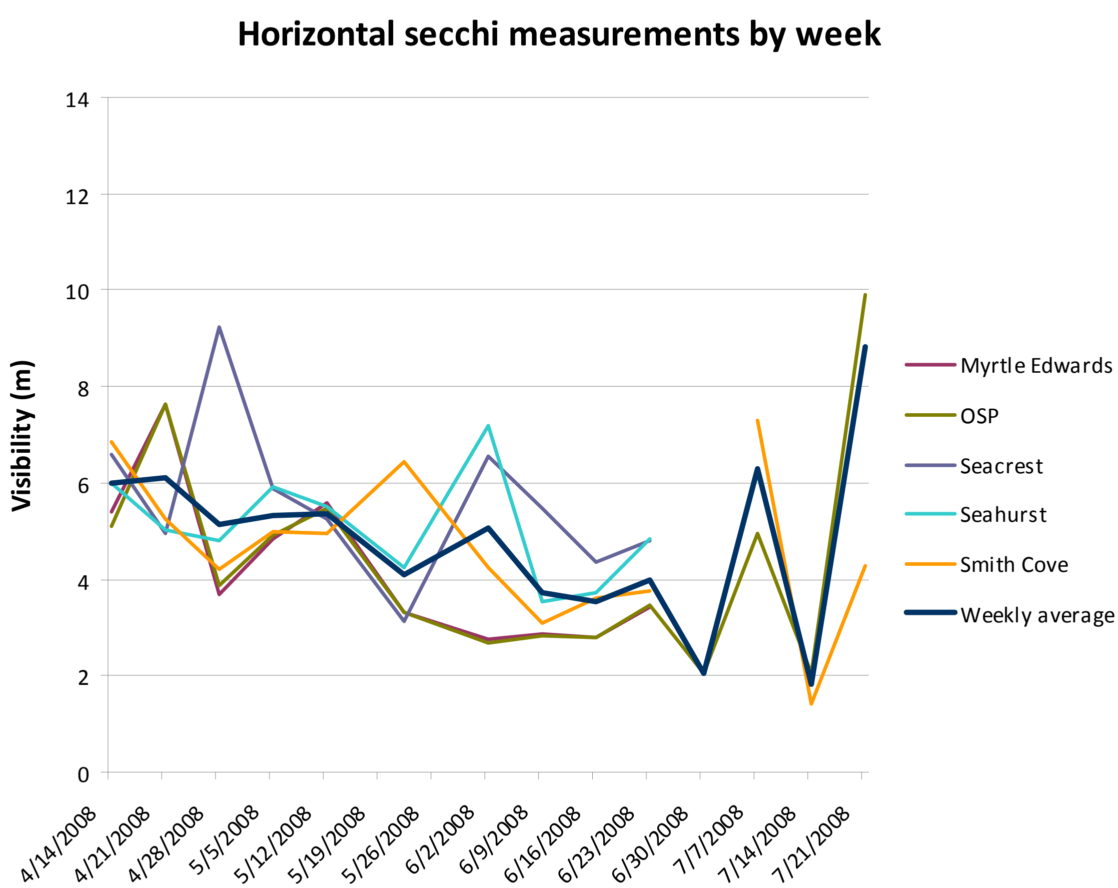
ANOVA results of significant differences in log-transformed densities of Amphipods and Harpacticoids. Site p-values for both are significant ($p < 0.05$), with specific differences between sites outlined in the matrix (using Tukey's test for multiple comparisons).

Harpacticoids p < 1.0E-12

	Seahurst	Smith Cove	OSP Habitat Bench	OSP Pocket Beach	Seacrest Rip Rap	Seacrest	OSP Seawall	OSP Rip Rap	Myrtle Edwards
Seahurst					X	X	X	X	X
Smith Cove					X	X	X	X	X
OSP Habitat Bench					X		X	X	X
OSP Pocket Beach								X	X
Seacrest Rip Rap								X	X
Seacrest								X	X
OSP Seawall								X	X
OSP Rip Rap									
Myrtle Edwards									

Amphipods p < 1.0E-12

	Seacrest Rip Rap	OSP Rip Rap	OSP Habitat Bench	Seahurst	Seacrest	OSP Seawall	OSP Pocket Beach	Smith Cove	Myrtle Edwards
Seacrest Rip Rap				X		X	X	X	X
OSP Rip Rap						X	X	X	X
OSP Habitat Bench						X		X	X
Seahurst								X	X
Seacrest						X		X	X
OSP Seawall									
OSP Pocket Beach								X	X
Smith Cove									
Myrtle Edwards									



Average physical characteristics recorded during snorkel surveys.

Habitat	Average of Tide ht (ft)	Average Surface Temp (ºC)	Average Bottom Temp (ºC)	Average Surface Salinity (‰)	Average Bottom Salinity (‰)
OSP Habitat bench	8.03	11.14	10.96	22.35	24.08
Myrtle Edwards	7.75	10.59	10.45	22.60	23.70
OSP Pocket beach	8.25	10.63	10.54	22.43	23.60
OSP Riprap	8.07	10.70	10.58	22.67	24.04
Seacrest	8.34	10.50	10.39	26.92	27.23
Seahurst	7.10	11.48	11.38	27.59	27.66
Smith Cove	7.75	11.13	11.02	24.44	24.58

Glossary

Active beach slope – the slope of the beach between MHW and MHL.
Amphipoda – A taxonomic Order of shrimp-like crustaceans.
Average beach slope – the slope of the beach between the berm and MLLW.
Backshore – The part of the shore lying between the berm crest and the vegetation, affected by waves only during severe storms.
Berm – a nearly horizontal plateau on the beach formed on the upper part of the foreshore by the deposition of beach material.
Diurnal – having a period of a tidal day, i.e., about 24.84 hours.
Epibenthic Invertebrates – Invertebrates that live just above bottom substrates.
Foreshore – The part of the shore, lying between the berm crest and the ordinary low water mark, which is ordinarily traversed by the uprush and backwash of the waves as the tides rise and fall.
Harpacticoid Copepods – An Order of small crustaceans that are mainly epibenthic.
Median grain size (D_{50}) – the diameter of sediment which marks the division of a given sample into two equal parts by weight, one part containing all the grains larger than that diameter and the other part containing all grains smaller.
MLLW – Mean Lower Low Water of tidal elevation.
Phi size scale – the diameter of individual grains of sediment. Size ranges define limits of classes that are given names in the Wentworth scale. The phi (φ) scale, is a logarithmic scale computed by the equation: $\phi = \log_2(D)$ where φ is the phi scale, and D is the diameter of the particle in mm.
Riprap – Large pieces of rock used to armor shorelines.
Sediment sorting – indicates the distribution of grain size of sediments. Poorly sorted indicates that the sediment sizes are mixed (large variance); whereas well sorted indicates that the sediment sizes are similar (low variance).