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Olympic Sculpture Park: Results from Year 1 Post-construction Monitoring of Shoreline Habitats

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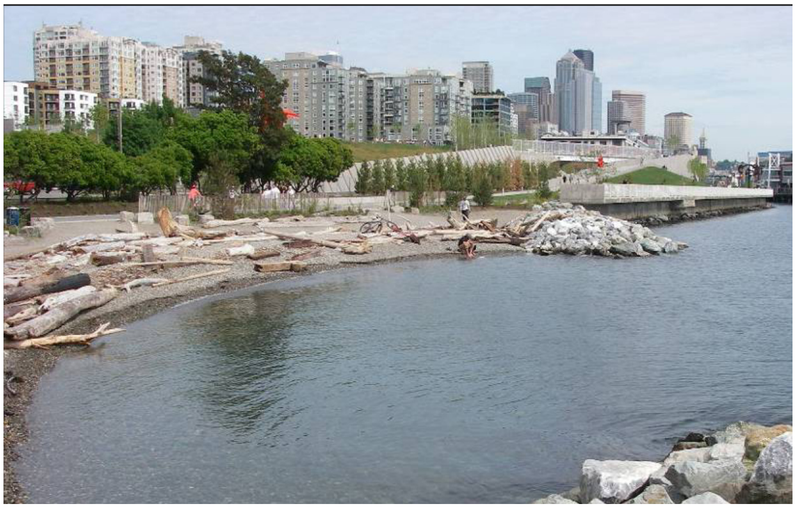

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Executive Summary

The Seattle Art Museum's Olympic Sculpture Park is located on the city of Seattle's urbanized marine shoreline. In order to provide benefits for juvenile salmon and other biota that inhabit the shoreline, a pocket beach and habitat bench were included as part of the public access area along the shoreline. Plantings occurred in the uplands, and gravel and driftwood were placed in the pocket beach. These features replaced relatively unproductive armored seawall and riprap shoreline. It is hypothesized that these created shoreline enhancements will support higher numbers and a greater diversity of fish and invertebrates than the existing urbanized shoreline.

In this study, we report initial post-construction results of monitoring the site for fish, invertebrates, vegetation, algae, and beach profiles at the habitat bench, pocket beach and in the uplands. For biological components, the newly created habitat types were also compared to adjacent seawall and riprap sites.

Overall, Olympic Sculpture Park monitoring results indicate that there has generally been a rapid development of aquatic and terrestrial biota within the newly created habitats. Many of the invertebrate and fish indicators have higher values than baseline conditions measured before construction, or adjacent sections of seawall and riprap. We recommend periodic post-construction monitoring to continue (e.g. 2, 3, 5, 10 years after construction) in order to further assess progression of biological and physical functions as the site develops. Specific monitoring results are highlighted below.

Fish

Fish were sampled to determine abundance and species composition at all of the sites. During snorkel surveys juvenile salmon were common and abundant in shallow water at the pocket beach and habitat bench, suggesting that they have the opportunity to utilize the shallow water habitats that were incorporated in the park construction. The pocket beach provides habitat specific to juvenile salmon at high tide, when they were the only abundant species observed at the beach. Snorkel observations documented high proportions of feeding behavior by juvenile salmon at the habitat bench. Potential fish predators of juvenile salmon were rare at all sites.

Juvenile Chinook salmon netted at the pocket beach consumed mainly amphipod crustaceans, fish, and insects. Chum salmon fed more on planktonic calanoid copepods and less on epibenthic harpacticoid copepods than expected, also feeding on amphipods and unidentified eggs. Coho salmon fed mainly on fish and amphipods.

Epibenthic and Benthic Invertebrates

Epibenthic invertebrates were sampled with a suction pump at 0 to +1' MLLW tidal elevation. Taxa richness increased from pre-construction sampling and was highest at the pocket beach and habitat bench sites. The habitat bench had high densities of harpacticoid copepods and overall epibenthic invertebrates, and the riprap site had high densities of amphipods, all of which are important as juvenile salmon food. The cobble/gravel substrate of the pocket beach at both +12 and 0' MLLW has been colonized by a diversity of benthic invertebrates, including several taxa of amphipods and polychaete worms that were not present before creation of the pocket beach.

Terrestrial Insects

Terrestrial insects were examined for species composition and number. All of the created habitat types (pocket beach, riparian, and vegetation swath) had significantly higher fallout insect trap densities and taxa richness than some or all of the adjacent modified shorelines (seawall and riprap), and included several taxa that are known to be juvenile salmonid prey items. Insects available to juvenile salmon as potential neustonic prey items on the surface of the water were evenly distributed among the created habitat types, and were similar to that of the adjacent riprap and seawall.

Terrestrial Vegetation and Aquatic Algae

Upland plants and aquatic algae were monitored for percent cover. The performance standard of a 10% increase in cover or a cover value of 40% was met in all backshore vegetation areas, with the exception of the dunegrass area. Changes in vegetation percent cover were greater in the understory than the overstory. SCUBA surveys documented twenty-three species of algae on the created habitat bench. Algae percent cover ranged between 46 to 74%, and kelp beds were firmly established with observed populations of kelp perch and kelp crabs.

Physical Sampling

Beach sediments were monitored for quantity and grain size. Between January 2007 and January 2008, the quantity of sediment on the pocket beach surface experienced an overall small decline. Sediment appears to have been lost due to anthropogenic causes in the summer and wave-driven causes in the fall. Much of the cross-sectional area lost came from the berm and upper foreshore. The berm material is highly mobile, and the driftwood appears to help stabilize local areas and acts as a trap for sediment. The sediment on the upper foreshore is also mobile, as can be observed by the temporary sorting of various sizes of sediment along the beach. On the lower foreshore and bench of the pocket beach, the sediment grain size is significantly coarser, and therefore the profiles are more stable in this region. The coarse, angular and well-packed sediment on the distal habitat bench is relatively invulnerable to transport, but the bench is vulnerable to being covered due to failure and repair of the riprap buttress.

The success of the pocket beach depends on sediment staying at the beach. Peak times of vulnerability to transport occur when extreme high tidal elevation is combined with storm conditions. These conditions, most likely to occur in winter, could result in major reorganization of the beach sediments. In natural systems the impacts of man on shaping beaches by down-slope sediment movement due to foot traffic and sediment removal by throwing is a minor component relative to natural wind and wave-driven transport. Preliminary indications suggest that anthropogenic impacts should be included in consideration of planned maintenance and management concerning physical beach change on the Olympic Sculpture Park pocket beach.

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

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PART I: BIOLOGICAL MONITORING

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Introduction

The Seattle Art Museum's Olympic Sculpture Park was created on 8.5 acres of undeveloped and industrialized waterfront property along Elliott Bay and, in addition to the art exhibits, it included considerable green space utilizing primarily native vegetation. The park's shoreline was also enhanced to provide beneficial habitat functions for wildlife, including threatened Chinook salmon. Juvenile Chinook and other salmon use the Seattle urban nearshore of Puget Sound including Elliott Bay 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. 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). The shoreline enhancements were intended to increase both shallow water habitat and production of juvenile Chinook prey items, such as drift insects and intertidal epibenthic crustaceans (Simenstad et al. 1982, Brennan et al. 2004). Monitoring biota at newly constructed enhanced habitat provides information to help determine how successful the site is in providing functional habitat. It is desirable to conduct biological monitoring both before and after construction and to adjacent reference sites, as was done in this study, in order to document pre-existing baseline conditions and then compare post-construction results to measure site development. Pre-construction monitoring was completed in Spring and Summer 2005 (Toft and Cordell 2006). Construction of the Olympic Sculpture Park commenced in 2006, with the official opening on January 20, 2007. In this report we describe the results of year 1 post-construction biological monitoring conducted during Spring and Summer 2007. As outlined in the preceding paragraph, data from this study will allow us to test the following overall hypothesis: *Enhancement sites along seawall and riprap provide improved habitats for juvenile Chinook salmon and other fish, as measured by invertebrate, fish, and vegetation assemblages.*

The overall ecological objectives of habitat enhancement at the Olympic Sculpture Park were to (1) restore and maintain riparian vegetation to enhance juvenile salmonid refuge functions and insect prey production, and (2) create shallow intertidal habitat to improve rearing opportunities for juvenile salmon. The shoreline was previously retained with seawall and riprap with minimal upland riparian vegetation, which severely truncated any available intertidal habitat and access to riparian habitat resources. Recent research in Sydney Harbor, Australia, has shown that seawall fauna can be much different than nearby sloping shores, and seawalls have fewer mobile species compared to natural rocky shores (Chapman 2003, Chapman and Bulleri 2003, Moreira et al. 2006). Pre-construction monitoring showed that juvenile salmon along the seawall and riprap had significantly greater densities in shallow (directly along shore, 2.3-m water depth) than in deep water (10-m from shore, 4.3-m water depth; Toft and Cordell 2006), suggesting that shoreline enhancements associated with the park would be in a location beneficial to juvenile salmon.

Two main shoreline elements were affected by construction (Figs. 1-3): at one location, a habitat bench was created along the existing end of the intact seawall north of Pier 70. The bench is located at an elevation of ~0’ MLLW. At a second location at the north end of the existing seawall, riprap armoring was removed and a pocket beach was created. The pocket beach consists of a sand/gravel beach, with surrounding vegetation. Sampling was focused on monitoring the initial development of these two stretches of shoreline. Four main biological attributes were monitored: (1) presence at the site of juvenile salmon and other fish, (2) aquatic epibenthic and benthic invertebrate fish prey, such as amphipod and harpacticoid crustaceans and polychaete worms that live on the substrates, (3) input of terrestrial insects from surrounding vegetation, and (4) development of terrestrial vegetation and aquatic algae.

Figure 1. Photograph of the Olympic Sculpture Park site before construction, showing riprap and seawall habitats.

Figure 2. Photograph of the Olympic Sculpture Park site after construction at high tide, showing inundated pocket beach and habitat bench strata.

Figure 3. Photograph of the habitat bench after construction at low tide.

Methods

Site

Photographs of the site pre- and post-construction are shown in figures 1-3, with an aerial map of main invertebrate and fish sampling locations shown in figure 4, and vegetation locations in figure 5; other photographs documenting sampling procedures and observations at the site are shown in appendices 1 and 2.

Figure 4. Aerial view of the Olympic Sculpture Park site after construction, showing main fish and invertebrate sampling locations.

Pre-construction monitoring focused on two sections of riprap and two sections of seawall; one segment of each that was planned to be modified by shoreline enhancements, and one segment that was not (e.g. restored and reference; Toft and Cordell 2006). However, in the final design, almost the entire length of the seawall at the site had the habitat bench added, except for a small portion adjacent to Pier 70. Thus, post-construction fish sampling was focused at the riprap site, pocket beach, and two sections of the habitat bench (i.e., there was no adjacent reference site for the habitat bench). The small section of unaltered seawall adjacent to Pier 70 was large enough to provide a reference site for epibenthic sampling, but seawall insect and neuston reference sampling was conducted on the south side of Pier 70. Additional fish sampling along the seawall was not conducted, as the exposed seawall south of Pier 70 was short and affected by adjacent piers. A timeline of overall pre-construction and post-construction biological monitoring is outlined in Table 1.

Table 1. Timeline of biological monitoring throughout 2005 pre-construction and 2007 post-construction samplings.

Sample	April – July 2005	Location	April – July 2007	Location
Fish - Snorkeling	**X**	Riprap, Seawall	**X**	Riprap, Pocket Beach, Habitat Bench
Fish - Enclosure Nets			**X**	Pocket Beach
Fish - Juvenile Salmon diets			**X**	Pocket Beach
Epibenthic Invertebrates	**X**	Riprap, Seawall	**X**	Riprap, Pocket Beach, Habitat Bench, Seawall
Benthic Invertebrates			**X**	Pocket Beach
Terrestrial Insects	**X**	Riprap, Seawall, Riparian	**X**	Riprap, Riparian, Pocket Beach, Vegetation Swath, Seawall
Neuston	**X**	Riprap, Seawall	**X**	Riprap, Pocket Beach, Habitat Bench, Seawall
Terrestrial Vegetation			**X**	Overlook, Backshore, Dunegrass, Uplands
Algae			**X**	Habitat Bench

Snorkel Surveys for Fish

Sampling spanned the peak juvenile salmonid outmigration period, beginning with chum salmon in April and ending with Chinook and coho salmon in June and July. Fish were surveyed weekly, coinciding with both spring tides (high tidal ranges coinciding with the new and full phases of the moon) and neap tides (low tidal ranges coinciding with the first and last quarter phases of the moon).

Surveys were conducted from 18 April to 18 July. Transects at the pocket beach spanned the entire length of 35-m, other transects were 75-m in length. Eighteen transects were sampled on each sampling date. At high tide, each of the four stretches of shoreline was sampled at a shallow and deep water depth transect (3-m and 10-m from shore), with an additional two transects in the shallow water portion of the pocket beach to account for the intertidal gradient not present at the other habitat types. This allowed surveys of the entire intertidal water depth gradient at all habitat types at high tide. This was repeated at low tide, except that the inner pocket beach was dewatered at low tide. Successful observations depended on sufficient water clarity for underwater visibility, corresponding to horizontal secchi-disk measurements exceeding 2.5-m (Toft and Cordell 2006, Toft et al. 2007). Fish numbers were standardized by transect length and water visibility: fish number/[length (m) x horizontal secchi (m)]. Data is presented as shallow and deep at each habitat type, standardized by transect length and visibility at each habitat type.

The following data were collected during snorkel transects:

- Fish identification and number.
- Approximate fish lengths (2.5-cm increments).
- Water column position of fish (surface, mid-water, bottom).
- Behavior (schooling, swam away, unaffected, fleeing, feeding, hiding; for crabs, aggressive display and mating).

- Water depth of shallow and deep transects.
- Horizontal secchi readings of underwater visibility for each snorkel surveyor.
- Salinity and temperature of water surface and bottom.

Enclosure Nets for Fish

The pocket beach was sampled for fish with an enclosure net (60-m long, 4-m deep, 0.64-cm mesh – Toft et al. 2007), five times during high Spring tides. The net was deployed at high tide across the mouth of the pocket beach, effectively enclosing the entire site, and sampled for fish as the site dewatered at low tide. Fish were removed with either a small pole seine (9.1-m. x 1.2-m., 0.64-cm mesh) or dip nets, usually starting at mid-tide a few hours after net deployment. All fish were removed before low tide. Non-salmonid fish were identified, counted, and released. Hatchery and wild status of salmon was determined by recording hatchery-clipped adipose-fins and testing with coded-wire tag readers. We refer to "hatchery" as those fish that were marked and/or tagged, and "wild" salmon to those with intact adipose fins and no coded-wire tags. Although unmarked salmon were assumed to be wild fish, incomplete marking can complicate this determination. Forklengths, weights, and diets of salmon were sampled to at least n = 5 for each species and hatchery or wild status.

The main benefits of using an enclosure net were: (1) The entire water column was sampled, providing exact density estimates; densities from techniques such as beach-seining can be compromised by varying sampling efficiencies over different substrates and water depths (Rozas and Minello 1997), and (2) the enclosure net held fish at the site for several hours, making fish diet analysis more representative of feeding at the site, instead of an "instantaneous" measure that is provided by beach seining. Numbers were converted to densities (#/1000 m^2) by standardizing catches to a estimate of the surface area sampled with the net, as calculated by digitizing the specific sampling area blocked with the enclosure net from digital orthophotos (SA = 1000 m^2).

At each net deployment, the following environmental measurements were taken: (1) surface and bottom water salinities and temperatures were recorded with a portable YSI meter, (2) total amount of time the net was deployed before complete fish sampling, and (3) maximum water depth at time of net deployment at high tide.

Diet Analysis

Diets of juvenile Chinook and coho from enclosure nets were sampled by gastric lavage. This method consisted of placing fish in a tray of seawater with a small amount of the anesthetic MS-222 for approximately 30 seconds. Each fish was removed from the tray and measured for forklength and weight. Gut contents were then removed using a modified garden pump sprayer with a custom nozzle and filtered seawater. Gastric lavage has been shown to result in 100% removal of food items and to have no adverse long-term effects on salmon (Twomey and Giller 1990). Contents were washed into a 106-µm sieve and fixed in 10% buffered formaldehyde solution. Fish were immediately placed in a bucket of seawater for recovery (approximately 2-3 minutes), and then released. Diets of juvenile chum from the enclosure nets were obtained from whole fish samples; chum were euthanized in MS-222 and preserved in 10% formalin.

In the laboratory, salmonid prey items were identified using a dissecting microscope. Small benthic and planktonic crustaceans and a few other taxa were identified to genus or species. For other major prey items such as insects, identification was only practicable to the order or family level. Each prey taxon was counted and weighed to the nearest 0.0001g.

Epibenthic Invertebrates

Epibenthic invertebrates living on top of bottom substrates were sampled twice-monthly using an epibenthic pump (16 cm diameter, 106-µm mesh size). This device suctions invertebrates from the surface layer of the benthos, in this case the cobble at the pocket beach or the surfaces of the habitat bench, seawall, or riprap sites. The pump was operated by hand, using 20 pumps for each sample. At each site, we collected seven replicate samples at the 0 to +1' MLLW tidal elevation at random points along the same 75-m transect that was used for the snorkel surveys. The samples were fixed in 10% buffered formalin in the field, and returned to the laboratory for identification of the collected invertebrates. During the peak chum outmigration (April and May) prey taxa were identified to genus and species level for taxa known to be juvenile salmon prey items; June samples were processed to order level.

Benthic Invertebrates

Benthic invertebrates living within bottom substrates were sampled twice-monthly with a benthic core 10 cm in diameter to a depth of 15 cm (Toft 2007). Cores were taken in the cobble substrate at the pocket beach, at two tidal elevations: approximately +12' and 0' MLLW, corresponding to high tide wrack depositions and low tide terrace, respectively. Seven samples were randomly collected along a transect. Large substrate was sieved in the field to retain mostly invertebrates, and the substrate was returned to the beach. Samples were fixed in 10% formalin and dyed with rose-bengal to aid in sorting and identification. Samples were sieved at 500-µm, and macroinvertebrates identified and counted.

Terrestrial Insects

Seven fall-out traps (plastic storage bins 40 x 25 cm) were placed twice-monthly at random points along a transect at each site. One transect was also sampled in the riparian zone on the north end of the pocket beach. The bottom of the traps was covered with a mild soap solution and they were deployed for 24 hours. Samples were collected by pouring the contents of the trap through a 0.106 mm sieve, washing into a sample jar, and preserving in 70% isopropanol. Samples were returned to the laboratory and identified.

Neuston

We collected three 10-m neuston tows twice-monthly along the shoreline, in order to assess insects being made available to juvenile salmon as potential neustonic prey on the water surface. A floating net (16" x 8", 130 µm) was towed by snorkeling or walking parallel to the shoreline during an ebbing high tide. This provided a comparison of insect assemblages taken by fallout traps in the riparian and shoreline zones, with those occurring on the surface of the water where they were available as prey to juvenile salmon.

Terrestrial Vegetation

Riparian vegetation was surveyed in May and July 2007. Areas surveyed were the North and South Uplands, Beach Dunegrass and Backshore, and Overlook plantings (Fig. 5). In addition to a species list, each area was divided into smaller quadrats and percent cover (over and understory) was estimated in increments of 5 percent. The canopy diameter at its widest point was recorded for every tree in the area. Each riparian area was assigned a health rating of 1 through 5 with one being all dead and 5 being vigorous (see appendix for description and photos of health categories). Photos were taken of each riparian area from a fixed point. Cover and shoot density within each of the four dunegrass patches was estimated using a 0.5 m^2 quadrat placed in five randomly selected spots, with cover estimated in increments of 1 percent. The area of each dunegrass patch was found using GIS software and patch perimeter was measured with a measuring tape and compass.

Figure 5. Aerial view of the Olympic Sculpture Park site after construction, showing vegetation sampling locations.

Algae

Algae at the habitat bench was surveyed by scuba divers on July 15 (Pema Kitaeff, UW Friday Harbor Laboratories). Seven transects perpendicular to shore were surveyed, with algae observations starting in shallow water on top of the habitat bench 0’ to -5’ MLLW, and then at -5’, -10’, -15’, and -20’ MLLW tidal elevations. Occasional observations were also taken at -25’ depth. At each elevation measurements were taken of algae percent cover by species, and number of kelp stipes (mostly *Nereocystis luetkeana* and some *Pterygophora californica*) observed at location to visibility of 10'.

Statistical Analysis

Data was entered in Microsoft Excel and analyzed using S-plus for univariate statistics. ANOVA tests (alpha = 0.05) were used to analyze log-transformed densities of Chinook/coho, chum, and total juvenile salmon from snorkel surveys at different habitat types and depths for 2007 data, as well as for comparing 2005 and 2007. Similar ANOVA tests were also used on insect and epibenthic densities. When results were significant between habitat types, the Tukey's test for multiple comparisons was used to identify specific differences between all possible pairs of means (Zar 1996).

Results

Environmental Parameters

Salinity and temperature ranges varied little with water depth, averaging 26.0 ppt and 12.2 °C at the surface, and 26.4 ppt and 11.9 °C at the bottom of intertidal sampling locations. Tidal elevations during snorkel surveys differed about 6 ft. between high and low tide transects, averaging +8.5' MLLW for high tide transects and +2.5' for low tide transects. In general, water clarity was better at high tide than low tide (Fig. 6). There was no apparent trend in increasing or decreasing water clarity over time. Values were always greater than the 2.5 m required for snorkel surveys.

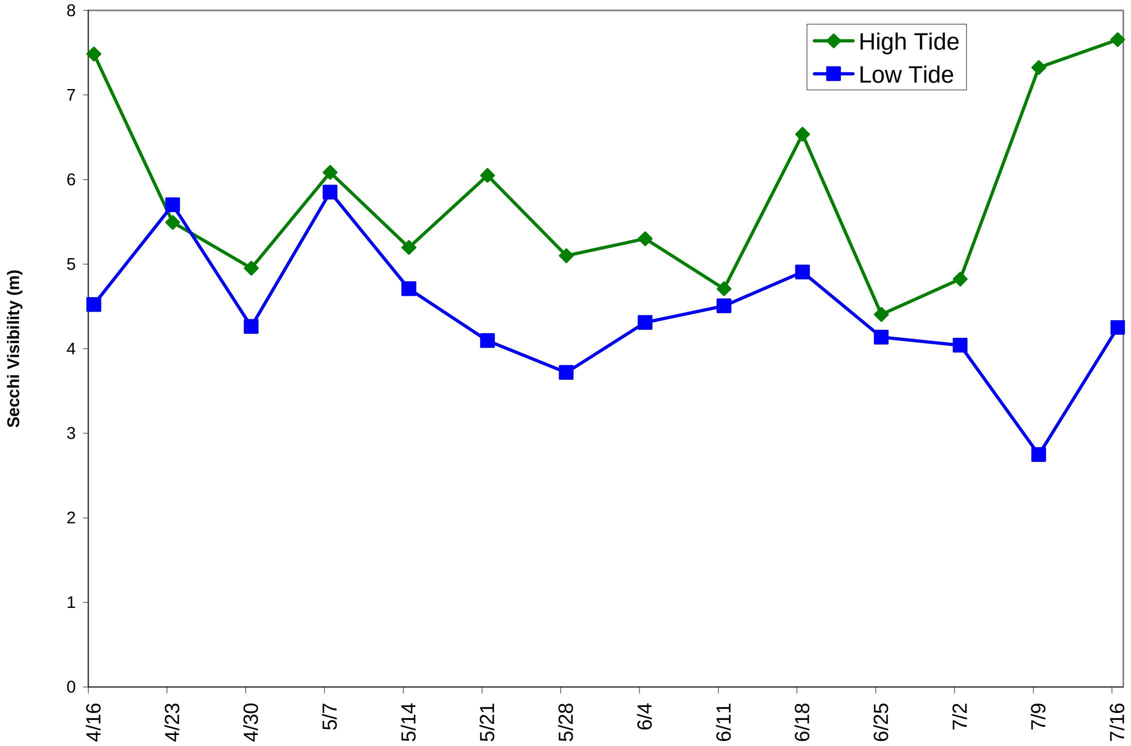

Figure 6. Average distance of underwater visibility on each snorkel survey week, at both high and low tide, based on horizontal secchi disk measurements.

Water depths during snorkel surveys varied between 1.0 and 4.0 m depending on site and tide (Table 2). In general, the span of depths surveyed was similar between sites, but the specific gradients changed due to differences in habitat morphology. The pocket beach had a more gradual gradient, especially at high tide when the entire beach was inundated. The outer beach, habitat bench, and riprap sites all had values of 2.3-2.5 m at the shallow depth and 3.7-4.0 at the deep depth during high tide. At low tide, shallow values ranged from 1.0-1.6 m and deep 2.3-2.8.

Table 2. Average water depths (m) from snorkel surveys, for high (avg +8.5' MLLW) and low (avg +2.5') tides, and shallow (3-m from shore) and deep (10-m from shore) transects.

Site	high tide	low tide
Pocket Beach Shallow 1	1.3	–
Pocket Beach Shallow 2	2.2	–
Pocket Beach Shallow 3	2.6	1.0
Pocket Beach Deep	4.0	2.3
Habitat Bench1 Shallow	2.6	1.1
Habitat Bench1 Deep	3.9	2.4
Habitat Bench2 Shallow	2.5	1.1
Habitat Bench2 Deep	4.0	2.5
Riprap Shallow	2.3	1.6
Riprap Deep	3.7	2.8

Snorkel Surveys for Fish

A total of 252 snorkel transects were conducted in 14 weeks of sampling. Twenty-one species of fish and crabs were counted during snorkel surveys (Table 3). Identification of salmon species while snorkeling was sometimes difficult because of water turbidity and short viewing time. Therefore, salmon were sometimes designated as either "unknown juvenile salmon" or grouped into one category of "Chinook/coho". Three fish species made up 93% of the overall observed fish numbers: shiner perch were most abundant (62%), followed by herring (26%), and juvenile chum salmon (5%). Crab observations were dominated by kelp crabs and red rock crabs. There were a few observations of rare fish that did not occur in 2005 (Table 3): one wolf eel was observed at the habitat bench deep site, and two clingfish were observed, one at the habitat bench deep site and one at pocket beach shallow site. Potential juvenile salmonid predators were low in abundance and included (1) three lingcod, the same number as in 2005, located at the pocket beach shallow and deep sites, and the riprap deep site, (2) four trout, at the pocket beach shallow and habitat bench deep sites, and (3) three sculpins at the habitat bench shallow site, although these were small in size (average length 10.4 cm).

Table 3. Average length estimates of fish and crabs from snorkel surveys, with total counts (not standardized by transect length or visibility). Length estimates of fish are based on total length, and crab lengths are carapace width.

Common Name	Scientific Name	Average Length (cm)	Total Number of Counted Fish
Chinook	*Oncorhynchus tshawytscha*	11.3	570
Chinook/Coho	*Oncorhynchus tshawytscha/kisutch*	11.8	611
Coho	*Oncorhynchus kisutch*	10.0	22
Chum	*Oncorhynchus keta*	7.2	2,503
Juvenile Salmon, unk.	*Oncorhynchus* spp.	10.3	284
Crab, unk.	-	11.3	2
Kelp Crab	*Pugettia* spp.	8.5	179
Red Rock Crab	*Cancer productus*	14.8	29
Fish, unk.	-	6.3	2
Gunnel	Pholidae	13.8	1
Crescent Gunnel	*Pholis laeta*	16.3	1
Longfin Gunnel	*Pholis clemensi*	12.5	2
Rockweed Gunnel	*Xererpes fucorum*	13.8	1
Herring	*Clupea harengus pallasi*	12.1	13,907
Larval Fish	-	4.6	541
Lingcod	*Ophiodon elongatus*	59.6	3
Northern Clingfish	*Gobiesox maeandricus*	11.3	2
Pacific Sand Lance	*Ammodytes hexapterus*	10.8	704
Perch, unk.	Embiotocidae	13.6	24
Kelp Perch	*Brachyistius frenatus*	10.9	61
Pile Perch	*Rhacochilus vacca*	15.1	328
Shiner Perch	*Cymatogaster aggregata*	8.8	33,966
Striped Seaperch	*Embiotoca lateralis*	16.0	864
Sculpin	Cottidae	10.4	3
Smelt	Osmeridae	8.8	5
Trout, unk.	*Oncorhynchus* spp.	16.3	3
Steelhead Trout	*Oncorhynchus mykiss*	18.8	1
Tubesnout	*Aulorhynchus flavidus*	14.5	3
Wolf Eel	*Anarrhichthys ocellatus*	51.3	1

Overall fish densities were lowest in April (Fig. 7), and the only relatively abundant fish in this month were juvenile chum salmon (Figs. 7,8). Shiner perch dominated counts in May and June, having very high peaks on May 7, May 14, and June 4 (Fig. 7). Herring were also relatively abundant in this time period and through July, especially on the June 4 sampling date. Larval fish and sand lance were relatively abundant on June 11 and July 18, respectively. Striped sea perch, pile perch, and crabs were consistently observed in low abundances.

Juvenile chum salmon were the most abundant salmonid observed; they peaked in May, and decreased to low numbers by early June (Fig. 8). Chinook and Chinook/coho categories appeared in May, and dominated salmon observations from the June 11 sampling date until the end of sampling in July. A few trout were also observed in May and early June at low abundances (4 total counted).

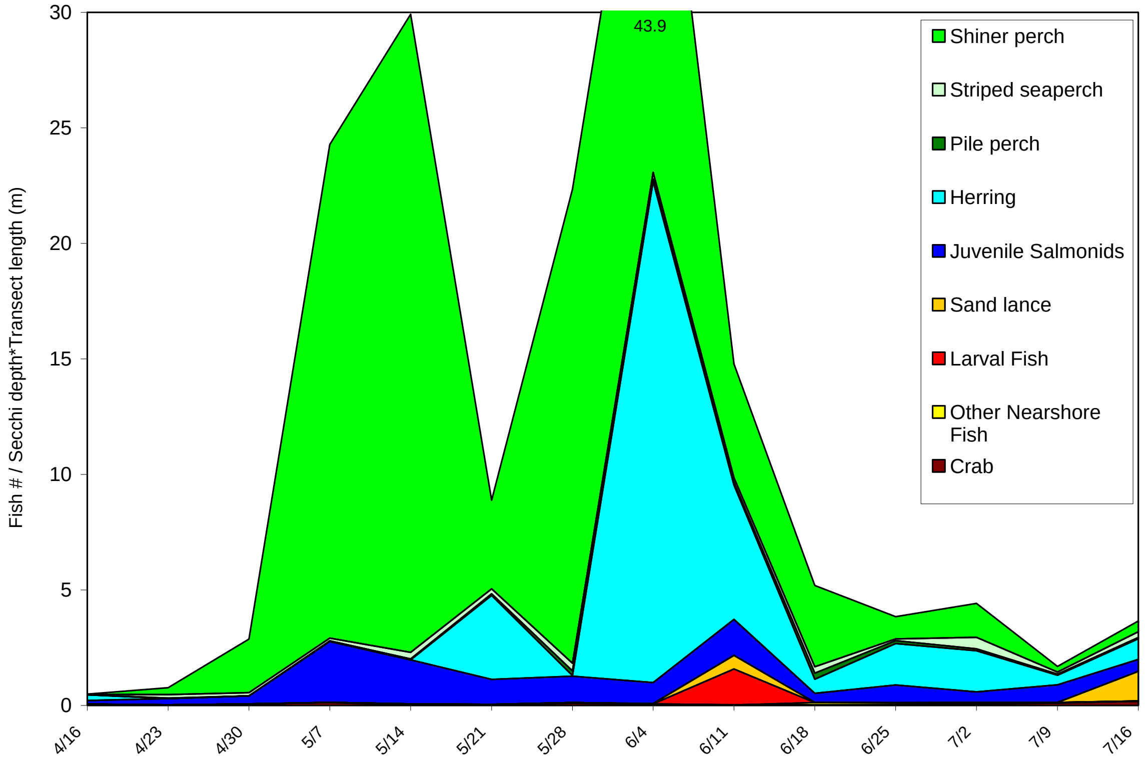

Figure 7. Total fish densities from snorkeling transects by sampling week.

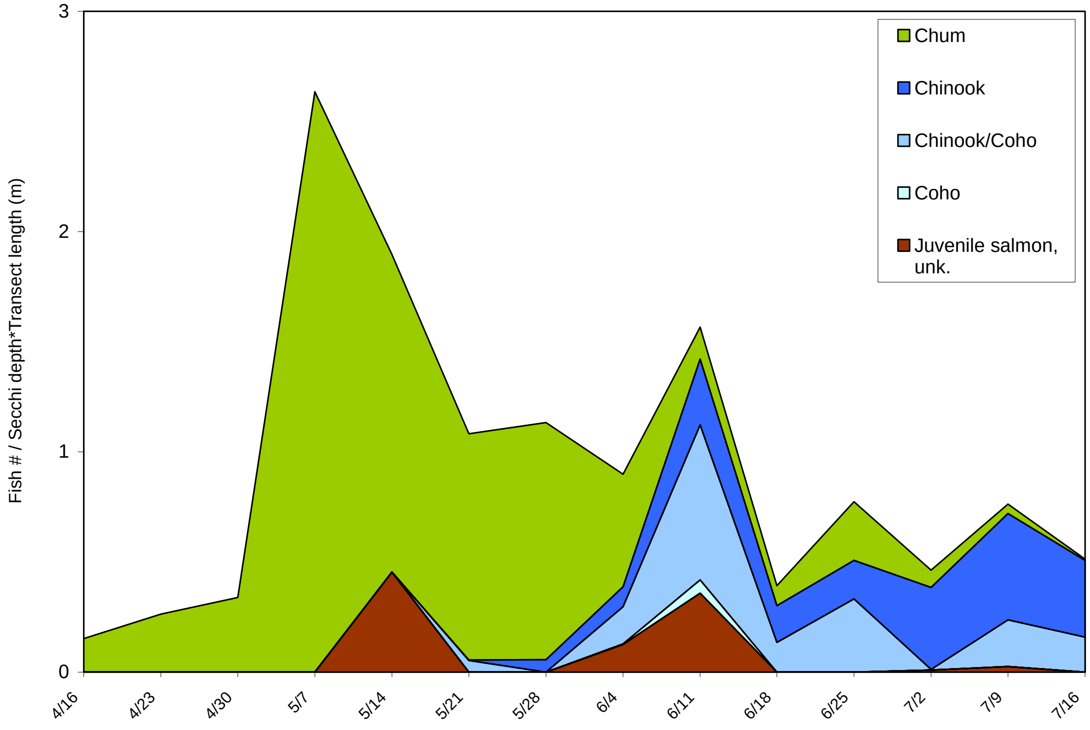

Figure 8. Juvenile salmon densities from snorkeling transects by sampling week.

At all habitat types in 2007, shiner perch and herring were more abundant at deep water transects (Fig. 9). Herring were much more abundant in 2007 than in 2005, especially at the habitat bench and riprap sites. Another difference was that juvenile salmon were more abundant at shallow riprap sites than deep riprap sites in 2005, but the opposite was true in 2007. This was due to Chinook and coho being more abundant at the deep transect at the riprap site: chum were more abundant at the shallow water transect (Figs. 9-10). Unidentified juvenile salmon occurred almost exclusively at deep water transects, consisting of fast-moving schools that precluded specific identifications. There were differences in fish assemblages and densities at the pocket beach based on if the survey was conducted at high or low tide. At high tide the shallow transect occurred within the pocket beach, and was accessed mainly by juvenile salmon, with relatively few other species (Fig. 11).

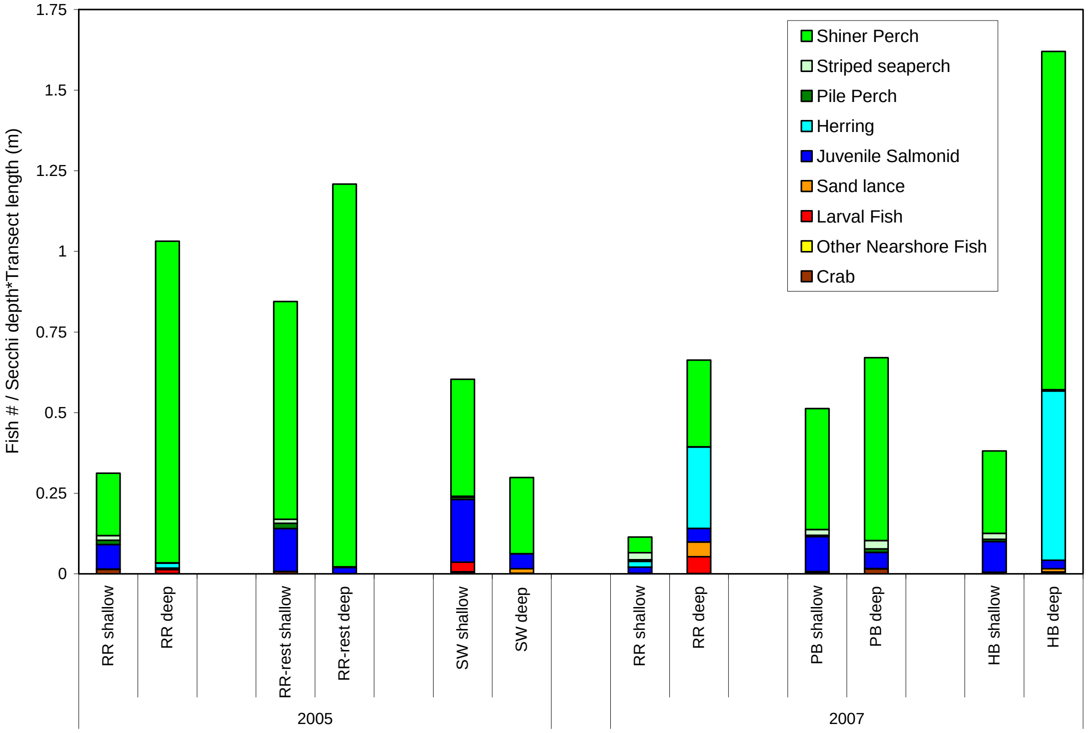

Figure 9. Average total fish densities at shallow and deep transects by habitat type and year. RR = Riprap, RR-Rest = Riprap at location where pocket beach was later restored, SW = Seawall at location where habitat bench was created, PB = Pocket Beach, HB = Habitat Bench.

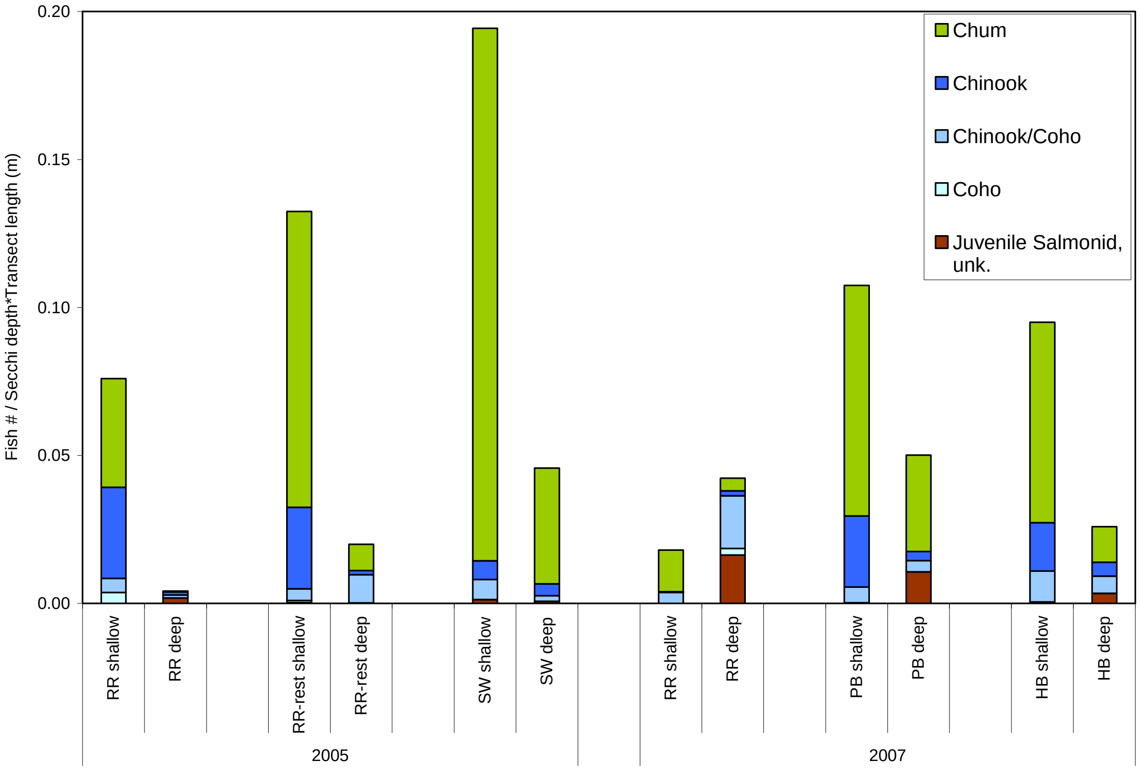

Figure 10. Average juvenile salmon densities at shallow and deep transects by habitat type and year.

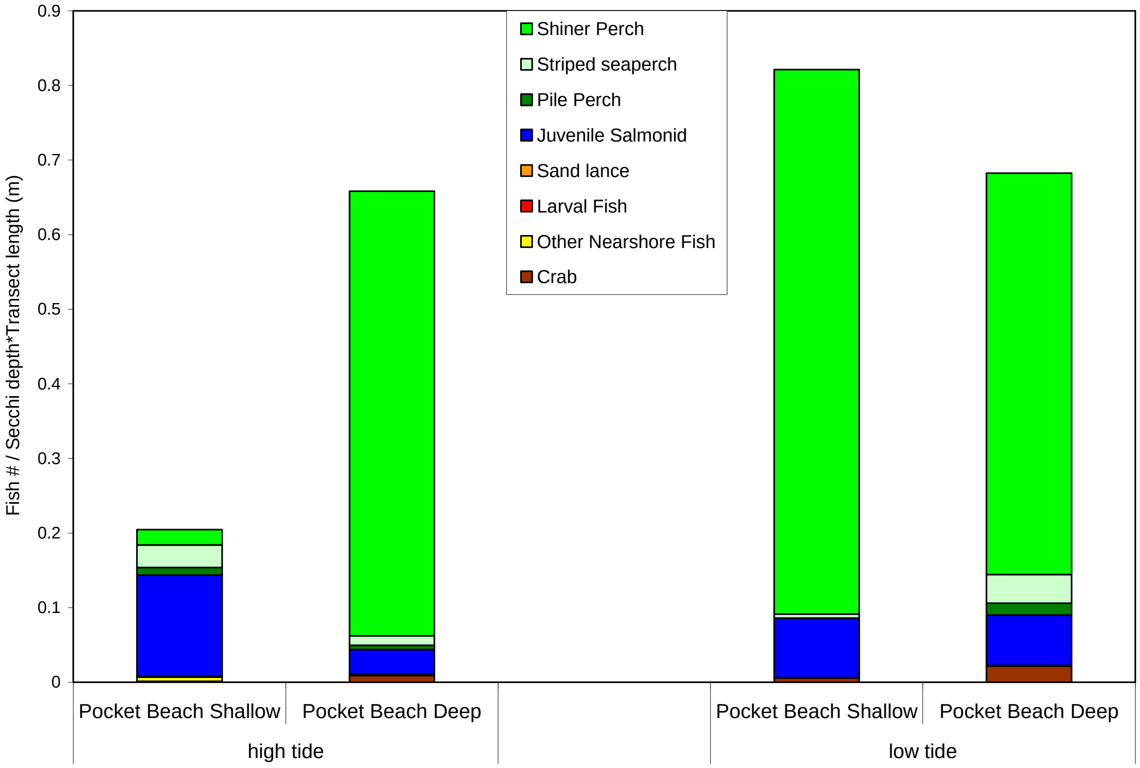

Figure 11. Average juvenile salmon densities from snorkeling transects at the pocket beach shallow and deep transects separated by high and low tide.

For 2007 data, one-way ANOVAs indicated significant differences in juvenile salmon densities between habitat types at shallow depths (Table 4). The habitat bench and pocket beach had greater densities than the riprap site for both total juvenile salmonid and Chinook/coho categories, and the habitat bench also had higher densities than riprap for chum salmon. There were no significant results at deep depths.

For 2007 versus 2005 data, one-way ANOVAs identified significant differences between specific habitat types and years for the riprap shallow and deep sites, but not for any of the created habitat types at the habitat bench and pocket beach (Table 4). At the riprap site, densities of all juvenile salmon categories were significantly higher in shallow water in 2005, but the reverse was true in 2007, when total juvenile salmon and Chinook/coho categories were significantly less abundant in shallow water, and all salmonid categories were significantly more abundant in deeper water.

Table 4. Results of ANOVA on snorkel-survey fish densities, significant results ($p < 0.05$) are in bold.

2007		p-value	tukey
Shallow	juvenile salmon	**0.0000003**	habitat bench & pocket beach > riprap
	chinook/coho	**0.002**	habitat bench & pocket beach > riprap
	chum	**0.0002**	habitat bench > riprap
Deep	juvenile salmon	0.54	–
	chinook/coho	0.30	–
	chum	0.61	–

2005 & 2007	juvenile salmon	chinook/coho	chum
RR shallow	**0.026** (05 > 07)	**0.0037** (05 > 07)	0.74
RR deep	**0.028** (07 > 05)	**0.048** (07 > 05)	**0.037** (07 > 05)
RR-rest/PB shallow	0.26	0.40	0.48
RR-rest/PB deep	0.33	0.85	0.28
SW/HB shallow	0.10	0.16	0.19
SW/HB deep	0.25	0.09	0.45

Water column position and behavior varied by species (Table 5). For salmon, main water column positions were middle and surface for Chinook and coho salmon, and surface for chum salmon; no salmon were observed in the bottom portion of the water column. Most other fishes occurred at middle to bottom depths, and crabs were away from the bottom only if climbing on kelp. The most common behaviors were swimming away, schooling, unaffected, and feeding. Most observations of feeding were for juvenile salmon, herring, and perch species.

Table 5. Number of observations of fish and crabs in categories of water column position and behavior.

	Water column position			Behavior								
Fish Species	Bottom	Middle	Surface	Feeding	Fleeing	Hiding	Injured	Schooling	Swam Away	Unaffected	Aggressive display	Mating
Chinook		53	41	35			1	28	28	2		
Chinook/Coho		39	16	19				18	18			
Coho		3		2					1			
Chum		23	121	53				54	34	3		
Juvenile Salmon, unk.		6	2	2				4	2			
Crab, unk.	1		1							2		
Kelp Crab	140	14	3	4		3			3	147		
Red Rock Crab	24	1							1	18	2	4
Fish	1									1		
Gunnel	1									1		
Crescent Gunnel	1									1		
Longfin Gunnel	2					1				1		
Rockweed Gunnel	1									1		
Herring	2	33	4	24	1			12		2		
Larval Fish		2	1					2	1			
Lingcod	3									3		
Northern Clingfish	2									2		
Pacific Sand Lance		5			2			2		1		
Perch, unk.	14	1		2	2			2	5	4		
Kelp Perch	10	4		6		1		2		5		
Pile Perch	118	10		17				10	82	19		
Shiner Perch	183	107	2	31	4	2	1	162	33	59		
Striped Seaperch	360	19		96	3	5		21	137	117		
Sculpin	3								1	2		
Smelt		1		1								
Trout, unk.		2						1	1			
Steelhead Trout			1	1								
Tubesnout	1	2							1	2		
Wolf Eel	1			1								

Percentage of observations of juvenile salmon in categories of water column position and behavior were fairly consistent between strata, with Coho/Chinook salmon occupying both middle and surface positions, and chum salmon occurring mostly in the surface position (Table 6). Exceptions to these general findings were (1) at the pocket beach deep site Chinook and coho were observed more at the surface than in the middle of the water column; (2) the riprap deep site was the only site that had more chum salmon in the middle than at the surface. Observations of feeding were higher at the habitat bench than at all other sites for Chinook, coho, and chum. Also, all juvenile salmon schooled most at the riprap shallow site and least at the habitat bench deep site.

Table 6. Percentage of observations of juvenile salmonids in categories of water column position and behavior.

		Water column position		Behavior					
Fish Species	**Site**	Middle	Surface	Feeding	Injured	Schooling	Swam Away	Unaffected	Total Number of Observations
Chinook and Coho	Riprap Shallow	67%	33%	33%		50%	17%		6
	Riprap Deep	83%	17%	28%		39%	33%		18
	Pocket Beach Shallow	62%	38%	24%	3%	34%	38%		29
	Pocket Beach Deep	43%	57%	29%		29%	43%		7
	Habitat Bench Shallow	54%	46%	40%		30%	29%	2%	63
	Habitat Bench Deep	72%	28%	52%		17%	28%	3%	29
Chum	Riprap Shallow	25%	75%	13%		63%	25%		8
	Riprap Deep	56%	44%	22%		33%	44%		9
	Pocket Beach Shallow	13%	88%	25%		54%	13%	8%	24
	Pocket Beach Deep	17%	83%	17%		33%	50%		6
	Habitat Bench Shallow	8%	92%	41%		37%	20%	1%	75
	Habitat Bench Deep	27%	73%	55%		14%	32%		22

Other observations noted during snorkel surveys were: (1) jellyfish became very abundant by the first week in June, (2) up to 50% of herring observed in June had lamprey wounds, and some herring had lampreys attached, (3) some Chinook, coho, and chum salmon also had lamprey wounds, starting in the first week of June, (4) kelp perch were observed to be abundant in the kelp beds, mostly in water deeper than our snorkel transects, and (5) a juvenile seal pup was occasionally observed hauled out on the beach when we arrived for early morning fieldwork.

Example underwater videos of fish from the Olympic Sculpture Park snorkel surveys can be found online at: http://staff.washington.edu/tofty/jvideo.html

Enclosure Nets for Fish

On average, the enclosure net was deployed for 2.9 hours at the pocket beach, with a maximum water depth of 2.5 m at time of net deployment. Fish composition in the net was mainly juvenile salmon, accounting for 94% of the total catch with an average count of 53 per net (Fig. 12). Chum were the most abundant species, followed by hatchery and wild Chinook, with relatively few coho. Average forklength and weight of salmon were: Chinook 91.2 mm and 8.7 g, coho 106.3 mm and 12.2 g, and chum 68.3 mm and 4.2 g. Most non-salmonid species were small, and were not considered to be predators on juvenile salmon: average length of sculpins was 43 mm, shiner perch 74 mm, sand lance 105 mm, and one starry flounder was 132 mm.

Two snorkel transects were done inside the net immediately after each deployment, in order to compare observed fish counts with the net catches to account for any fish that escaped the net and for any fish not observed by snorkeling. Average counts from the two methods were very similar (Fig. 13). Relative counts of juvenile salmon were consistent between techniques, with snorkel counts slightly lower than the net counts. Conversely, perch counts were higher in snorkel surveys and presumably were able to sometimes escape the net. Snorkel surveys did not observe rare demersal species that were captured in the net (1 starry flounder, 1 red rock crab, 8 sculpins). Juvenile salmon were observed to remain schooled within the net and did not try to actively escape. Other fish such as sand lance and perch actively attempted escape (sand lance by attempting to swim through the mesh, perch by trying to swim underneath the lead-line).

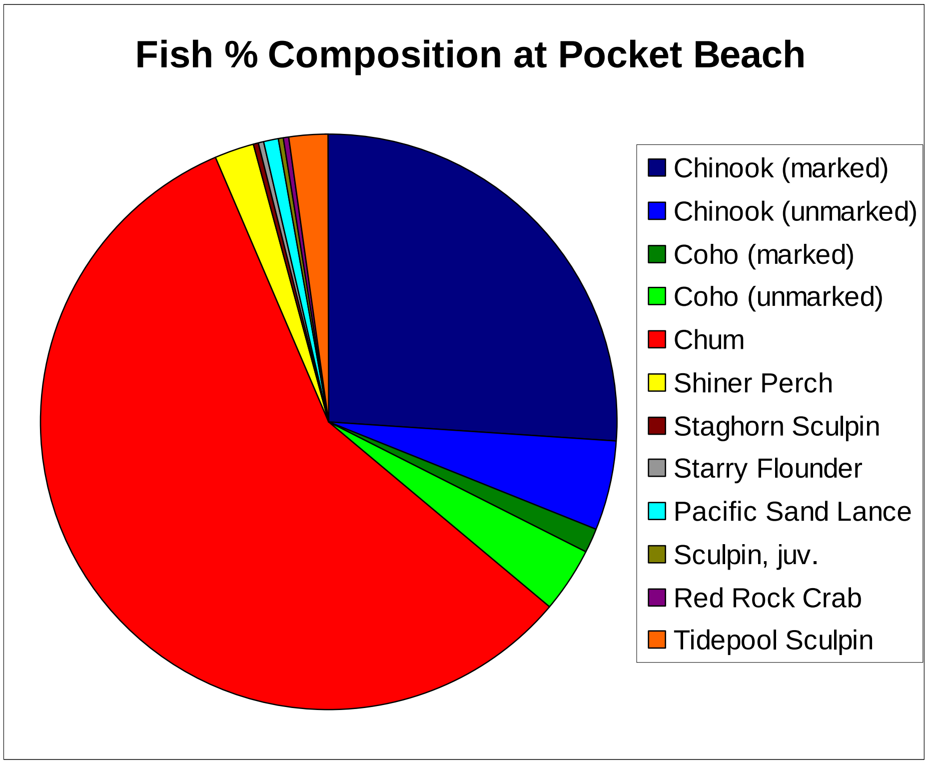

Figure 12. Numerical percent composition of fish captured by enclosure net at the Pocket Beach (n = 5; average 53 juvenile salmon).

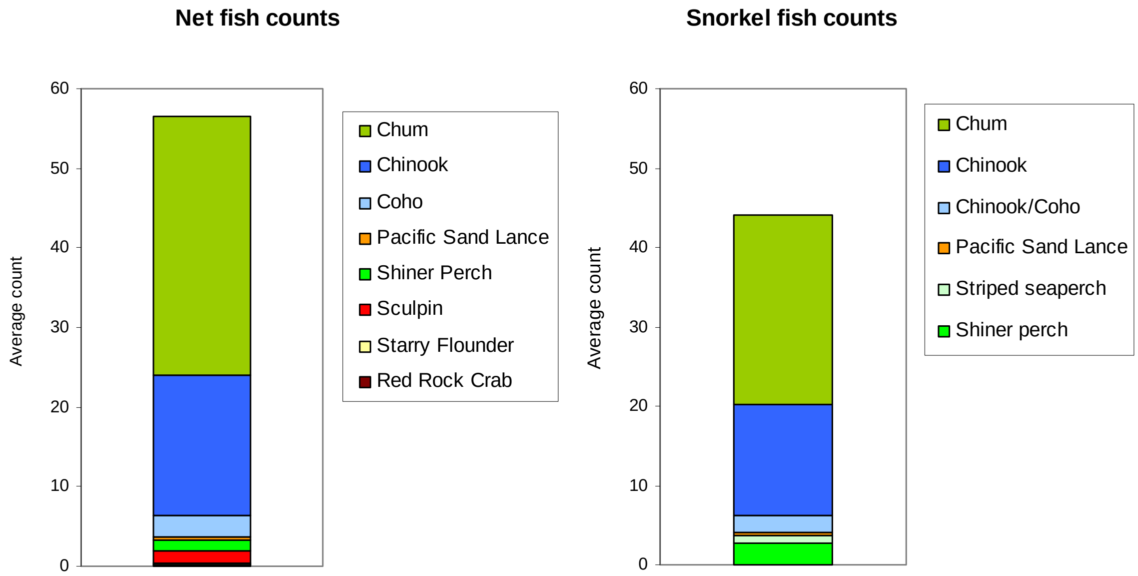

Figure 13. Average counts of fish captured in the enclosure net and fish observed inside the net by snorkel surveys.

Diet Analysis

Diet samples from 19 Chinook, 34 chum, and 13 coho salmon were analyzed from the pocket beach enclosure netting (Fig. 14, Table 7). Chinook salmon diet biomass was dominated by fish in May (92% of prey weight, consisting of fish larvae, unknown heavily digested fish, and one occurrence of a juvenile chum), and amphipods in June and July. Most of the remaining prey items consisted of dipteran flies (May, June), ostracods (June), and hymenopteran insects (July). Chum salmon fed mostly on amphipods and calanoid copepods except on the 18 June sample date, when unidentified eggs were the main prey item. They also had consistently small amounts of dipteran insects and harpacticoid copepods. Smaller chum salmon captured in April and May tended to eat more small prey items such as calanoid copepods, while larger chum captured in June and July consumed more amphipods and unidentified eggs. Coho had less diverse diets compared with the other salmon species, eating almost exclusively fish in May and amphipods in July.

Since juvenile salmon were held at the beach for an average of 2.9 hours per enclosure net, we assumed that undigested prey items mostly represented taxa fed on at the pocket beach. Main prey taxa within each taxa grouping were sometimes similar to those sampled in invertebrate samples from the site (Table 7). For example the main prey amphipods were Calliopiidae and *Paramoera mohri*, both common in benthic and epibenthic samples. However, there were some prey items that did not occur in our benthic and epibenthic invertebrate samples, such as other amphipods that are pelagic or associated with algae (*Themisto pacifica, Accedomoera vagor*), and calanoid copepods which are planktonic in the water column. These prey were probably consumed in habitats that weren't sampled for invertebrates (algae, zooplankton) or before the fish were enclosed at the pocket beach.

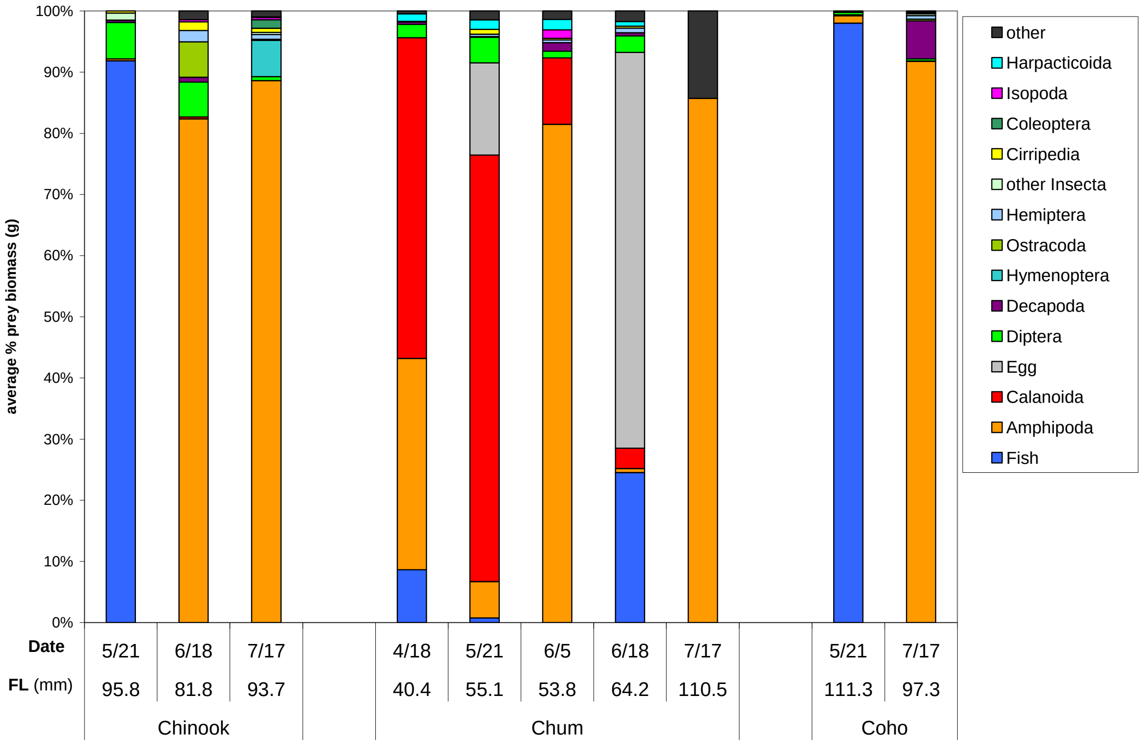

Figure 14. Average percent weight composition of juvenile salmon prey, by date and average fish forklength (mm) of Chinook, chum and coho.

Table 7. Prey taxa occurring in juvenile salmon diets, listed in descending order in each category by overall weight in the diets.

Taxa Grouping	Taxa
Amphipod crustaceans	Calliopiidae, *Paramoera mohri*, *Themisto pacifica*, *Ampithoe dalli*, *Allorchestes* sp., *Accedomoera vagor*, *Desdimellita californica*, *Paramoera* sp., Hyperiidae, *Caprella* sp., *Jassa* sp., *Dulichia* sp., *Americorophium salmonis*, *Aoroides* sp.
Calanoid copepods	*Aetidius divergens, Epilabidocera longipedata, Pseudocalanus* sp., *Paracalanus* sp., *Calanus* sp., *Centropages abdominalis*, Epilabidocera copepodid
Cirripedia (barnacles)	Cirripedia, Cirripedia exuvia, Cirripedia nauplii, Cirripedia cyprid
Coleoptera (beetles)	Coccinellidae, Coleoptera larvae
Cumacea crustaceans	*Eudorella pacifica, Cumella vulgaris*
Decapoda	Cancridae megalopa, Cancer megalopa, Paguridae megalopa, Porcellanidae zoea/megalopa, Brachyura zoea, Caridea zoea
Diptera insects	Brachycera, Chironomidae, Chironomidae larvae, Brachycera larvae, Chironomidae pupae, Tipulidae, Empididae, Psychodidae pupae, Ceratopogonidae, Chamaemyiidae, Sciaridae, Brachycera pupae, Diptera pupae, Psychodidae
Egg	Egg, Fish egg, Egg case
Fish	Chum, Sand lance, Fish, Fish larvae

Table 7 continued

Harpacticoid copepods	*Tisbe* sp., *Diosaccus spinatus, Amphiascopsis cinctus, Harpacticus* sp., *Harpacticus septentrionalis, Harpacticus uniremis, Harpacticus obscurus group,* Laophontidae, *Parathalestris* sp., *Amonardia perturbata, Coullana canadensis, Dactylopusia crassipes, Harpacticus* copepodid
Hemiptera insects	Cicadellidae, Aphididae
Hymenoptera insects	Formicidae
Isopoda crustaceans	*Idotea* sp.
Ostracoda	*Euphilomedes producta, Euphilomedes carcharodonta*
Polychaeta worms	Hesionidae, Spionidae
Psocoptera insects	Psocoptera
General Taxa Groupings	Araneae, Euphausiacea, Acari, Pteropod, Collembola (Hypogastruridae), Cyclopoida, Diatoms

Epibenthic Invertebrates

Taxa Richness in epibenthic samples was higher in 2007 than 2005 at all of the sites (Fig. 15). The largest between-year differences were at the pocket beach and habitat bench sites. In 2007 the pocket beach had the highest taxa richness, followed by the habitat bench, both of which were greater than at the adjacent riprap and seawall sites.

In 2007, epibenthic invertebrate taxa composition was dominated by harpacticoid copepods at the pocket beach, habitat bench, and seawall sites, and by amphipods at the riprap site (Fig. 16). Harpacticoids were particularly abundant at the pocket beach and habitat bench sites. Harpacticoids were not dominated by any one species. The top five taxa by numerical percentages were *Heterolaophonte longisetigera* (18%), *Tisbe* sp. (12%), *Paralaophonte perplexa* group (9%), *Ameira* sp. (9%), and *Harpacticus septentrionalis* (8%). Similar to 2005, the amphipod numbers were dominated by *Paracalliopiella pratti* (70%), with smaller contributions by a number of other species such as *Desdimelita californica* (9%), *Calliopius* sp. (2%), *Pontogeneia rostrata* (1%), and *Hyale* sp. (1%). The habitat bench also had higher numbers of other taxa groups compared to the other sites, such as foraminifera, annelid worms, and nematodes, and had a much higher total invertebrate abundance. All taxa groupings were more abundant in 2007 than 2005, with the exception of Cirripedia (barnacles). Overall listings of 2007 epibenthic invertebrates and taxa groups are in Table 8.

ANOVA conducted on 2007 total invertebrate data indicated significantly higher densities at the habitat bench than all other habitat types (Table 9). ANOVA was also conducted for amphipods and harpacticoid copepod densities, the two most abundant orders of epibenthic juvenile salmonid prey. Results showed that harpacticoid densities were significantly higher at the habitat bench compared to the other sites and that amphipods were significantly more numerous at the riprap site than all other sites. The habitat bench also had significantly higher amphipod densities than the seawall site.

ANOVA on each 2007 habitat type compared to its pre-enhancement 2005 habitat indicated that densities of total invertebrates, harpacticoids, and amphipods were significantly higher at all habitat types in 2007, with the exception that there was no significant difference in amphipod densities between years at the seawall habitat.

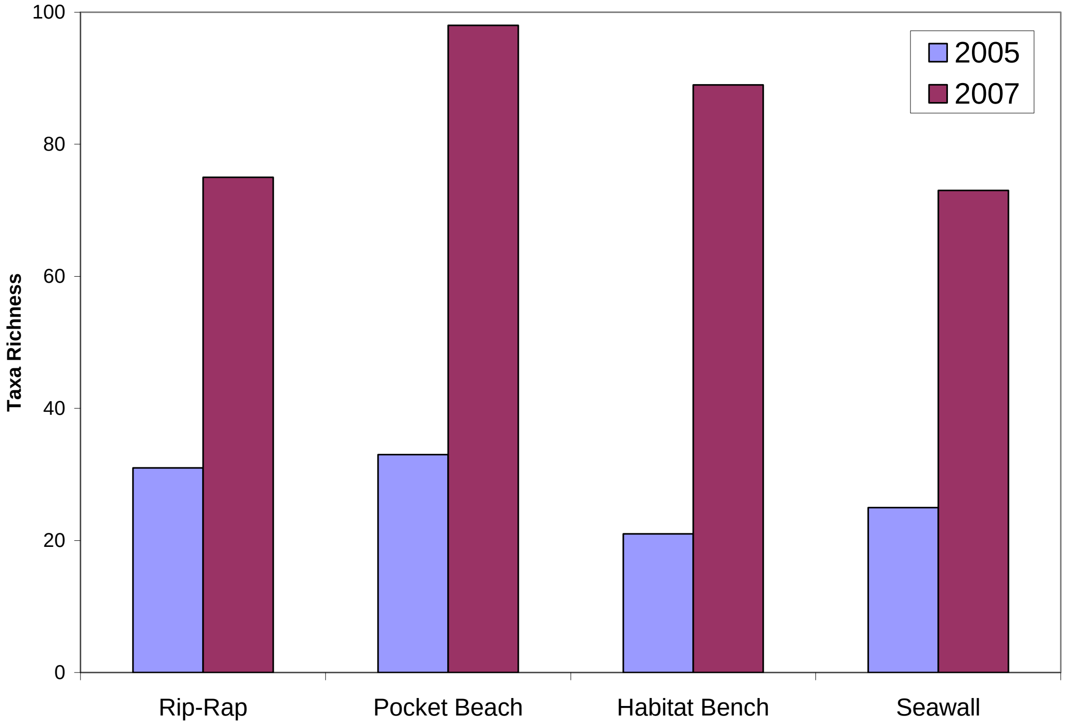

Figure 15. Overall taxa richness (# of taxa) of epibenthic invertebrates by year and site. Sites are labeled by post-construction habitat: in 2005, pocket beach was riprap, and habitat bench was seawall.

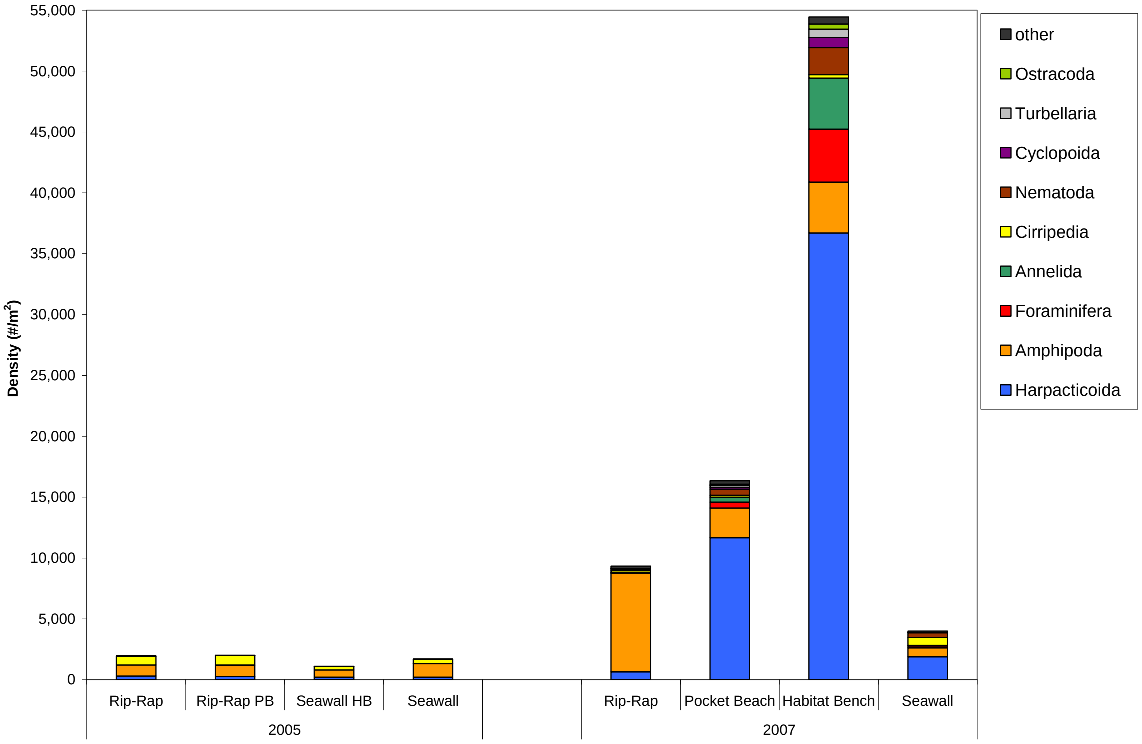

Figure 16. Average densities and taxa composition of epibenthic invertebrates by habitat type and year.

Table 8. Detailed list of taxa from epibenthic pump samples, by major taxonomic categories.

Taxa Grouping	Taxa
Amphipoda	*Allorchestes* sp., *Ampithoe* sp., *Aoroides* sp., Calliopiidae juvenile, *Calliopius* sp., *Caprella laeviscula*, *Desdimelita* sp., *Desdimelita californica*, Gammaridea juvenile, *Hyale frequens*, *Hyale* sp., Hyalidae, Hyperiidea, *Ischyrocerus* sp., *Paracalliopiella pratti*, *Paramoera* sp., *Pontogeneia rostrata*, *Pontogeneia* sp.
Archiannelida	Archiannelida, *Nerilla* sp.
Bivalvia	Bivalvia, Mytilidae
Calanoida	*Aetidius* sp., *Stephos* sp.
Cirripedia	Cirripedia, Cirripedia cyprid, Cirripedia nauplii
Cumacea	Cumacea, *Cumella vulgaris*
Decapoda	Brachyura zoea, *Cancer productus* zoea, Caridea, Decapoda, Paguridae megalopa, Pinnotheridae zoea, *Pugettia* sp.
Diptera	Ceratopogonidae larvae, Chironomidae, Chironomidae larvae, Chironomidae pupae, Diptera larvae
Gastropoda	Gastropoda, Gastropoda larvae, *Littorina scutulata* egg case, Patellogastropoda
Harpacticoida	Ameira sp., Ameiridae, *Amonardia normani*, *Amonardia perturbata*, *Amonardia* sp., *Amphiascoides* sp., *Amphiascopsis cinctus*, *Amphiascus* sp., Ancorabolidae, D*actylopusia crassipes*, *Dactylopusia* sp., *Dactylopusia vulgaris*, *Danielssenia typica*, *Diarthrodes* sp., *Diosaccus spinatus*, *Echinolaophonte* sp., Ectinosomatidae, Harpacticoida, Harpacticoida copepodid, Harpacticoida nauplii, *Harpacticus* copepodid, *Harpacticus obscurus* group, *Harpacticus septentrionalis*, *Harpacticus* sp. A, *Harpacticus uniremis*, *Heterolaophonte longisetigera*, *Heterolaophonte* sp., *Idomene purpurocincta*, *Laophonte cornuta*, *Laophonte elongata*, Laophontidae, *Longipedia* sp., *Mesochra pygmaea*, *Mesochra* sp., *Microsetella* sp., *Orthopsyllis illgi*, *Paradactylopodia* sp., *Paralaophonte perplexa* group, *Paralaophonte* sp., *Parastenhelia spinosa*, *Parathalestris* sp., Peltidiidae, *Porcellidium* sp., *Pseudonychocamptus* sp., *Rhynchothalestris helgolandica*, *Scutellidium* sp., *Stenhelia* sp., Tegastidae, *Tisbe* sp., *Zaus* sp.
Isopoda	*Dynamenella sheareri*, *Epicaridea* sp., *Epicaridea microniscus*, *Exosphaeroma* sp., *Idotea* sp.., Isopoda, *Pentidotea wosensenskii*
Ostracoda	*Euphilomedes producta*, Ostracoda
Polychaeta	Aphroditoidea, *Armandia brevis*, Nereidae, Phyllodocidae juvenile, Polychaeta juvenile, Polychaeta larvae, *Polydora socialis*, *Prionospio* sp., Spionidae, Spionidae larvae, Syllidae
Tanaidacea	*Leptochelia dubia*
General Taxa Groupings	Acari, Cladocera, Cnidaria, Collembola (Isotomidae), Cyclopoida, Echinoderm larvae, Egg, Foraminifera, Hydrozoa, Insect larvae, Insect pupae, Nematoda, Nudibranch, Oligochaeta, Turbellaria

Table 9. Results of ANOVA on epibenthic invertebrate densities, significant results ($p < 0.05$) are in bold. All significant results between 2005 & 2007 are for higher densities in 2007.

2007	p-value	tukey
Overall densities	**5.4E-11**	habitat bench **>** riprap, seawall, & pocket beach
Harpacticoida	**5.7E-12**	habitat bench **>** riprap, seawall, & pocket beach
Amphipoda	**2.4E-08**	riprap **>** seawall, habitat bench, & pocket beach habitat bench **>** seawall

2005 & 2007	Overall densities	Harpacticoida	Amphipoda
Riprap	**0.00004**	**0.006**	**0.00002**
Pocket Beach	**5.0E-10**	**4.5E-10**	**0.00007**
Habitat Bench	**6.9E-07**	**1.0E-06**	**4.5E-11**
Seawall	**0.004**	**0.014**	0.094

Benthic Invertebrates

Taxa richness was 45 for the 0' MLLW elevation benthic core invertebrates and 20 for +12'. The 0' tidal elevation benthic samples were dominated by the amphipod *Desdimelita californica*, with secondary contributions by Chironomidae larvae, the amphipod *Paramoera mohri*, and juvenile amphipods (Fig. 17). The +12' stratum was dominated by the semi-terrestrial talitrid amphipod *Traskorchestia traskiana* along with talitrid juveniles, with most of the remainder consisting of *Paramoera mohri* and acarinid mites. Complete taxa listings are in Table 10.

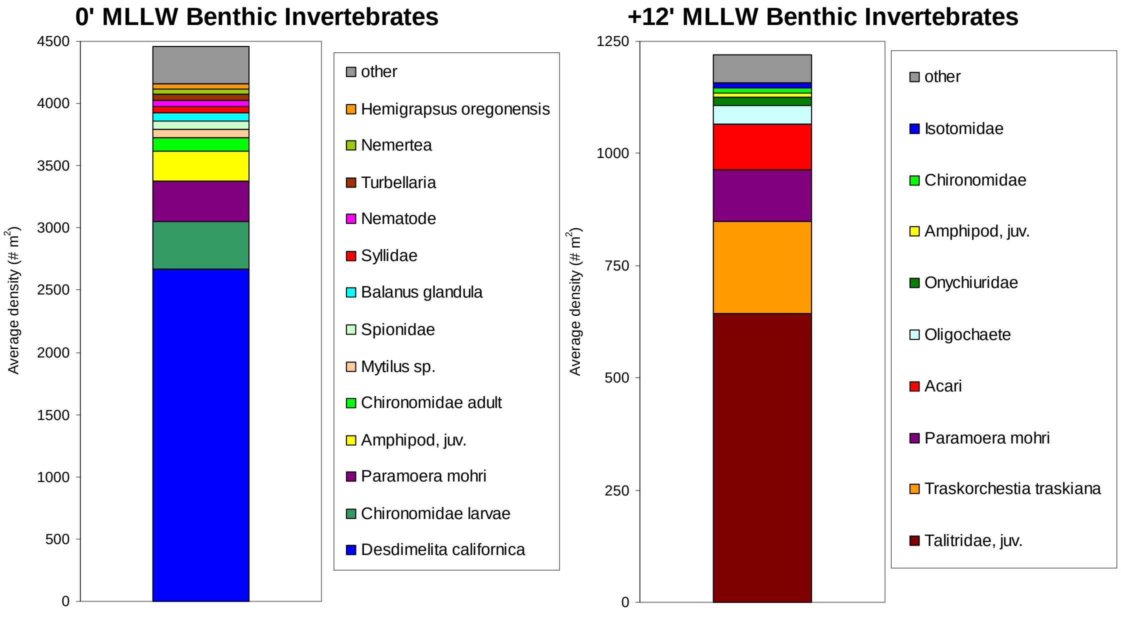

Figure 17. Average densities and taxa composition of benthic invertebrates at the pocket beach by tidal elevation.

Table 10. Detailed list of taxa from benthic core samples, by major taxonomic categories.

Taxa Grouping	Taxa
Amphipod	Corophiidae, *Desdimelita californica*, *Eogammarus* sp., *Hyale* sp., *Monocorophium insidiosum*, *Paracalliopiella pratti*, *Parallorchestes* sp., *Paramoera mohri*, *Traskorchestia traskiana*, juvenile Hyalidae, juvenile Talitridae, juvenile Amphipod
Bivalve	*Mytilus* sp., juvenile Bivalve, juvenile Mussel
Cirripedia	*Balanus glandula*, Balanomorpha
Collembola	Isotomidae, Onychiuridae
Crab	*Hemigrapsus oregonensis*, Majidae, Paguroidea, juvenile Crab, Brachyura megalopa, Pinnotheridae zoea
Insect	Aphididae, Chironomidae, Chironomidae larvae, Chironomidae pupae, Coleoptera larvae, Formicidae, Mymaridae
Isopod	*Gnorimosphaeroma oregonensis, Idotea wosnesenskii, Idotea* sp.
Ostracod	*Euphilomedes producta*
Polychaete	*Platynereis bicanaliculata*, *Nereis vexillosa*, Ophelidae, Orbiniidae, Polynoidae, Spionidae, Syllidae, Terebellidae, juvenile Nereidae, juvenile Polychaete
General Taxa Groupings	Acari, Nematode, Nemertea, Oligochaete, Polycladida, Turbellaria, Pseudoscorpion

Insects

As compared to 2005 results, taxa richness in fall-out traps increased the most at the pocket beach backshore, and decreased at the seawall site (Fig. 18). At the other sites, taxa richness was similar across the sampling years. The riparian area had the highest taxa richness in both years, and the riprap and seawall habitats had relatively low taxa richness in both years.

In 2007, dipterans had lower densities and comprised less of the percent composition than at the corresponding sites in 2005 (Fig. 19). Also, at four of the five paired sites, total invertebrate densities were higher in 2005. Conversely, mites (Acari), collembolans, and hemipterans were more abundant in 2007. Diptera consisted mostly of Chironomidae (85%), and hemipterans were dominated by Aphididae (68%). Low numbers of other orders, such as Psocoptera, Hymenoptera, and Coleoptera were most abundant at the riparian site. Overall listings of 2007 fall-out trap invertebrates and taxa groups are in Table 11.

ANOVA conducted on 2007 data indicated that total invertebrate densities were significantly higher at the pocket beach and vegetation swath than the riprap and seawall sites, and that the riparian site had significantly higher numbers than the seawall site (Table 12). For two important orders of juvenile salmon prey taxa, diptera and hemiptera, ANOVA showed dipteran densities significantly higher at the vegetation swath than the seawall, riprap, and pocket beach sites. Hemipteran densities were significantly higher at the riparian and pocket beach sites than the riprap and seawall sites, and were also significantly higher at the vegetation swath than the seawall site.

Similar ANOVA tests were used on 2005 and 2007 data separated for each 2007 habitat type compared to its suitable pre-restoration 2005 habitat location (Table 12). It is clear that all diptera densities were less in 2007, as every habitat had significantly less than in 2005. Hemiptera densities increased at the pocket beach and vegetation swath, compared to the pre-restored riprap and seawall, respectively. Overall densities were less at the new riparian site than the previous established 2005 riparian site, and densities at the seawall decreased as well.

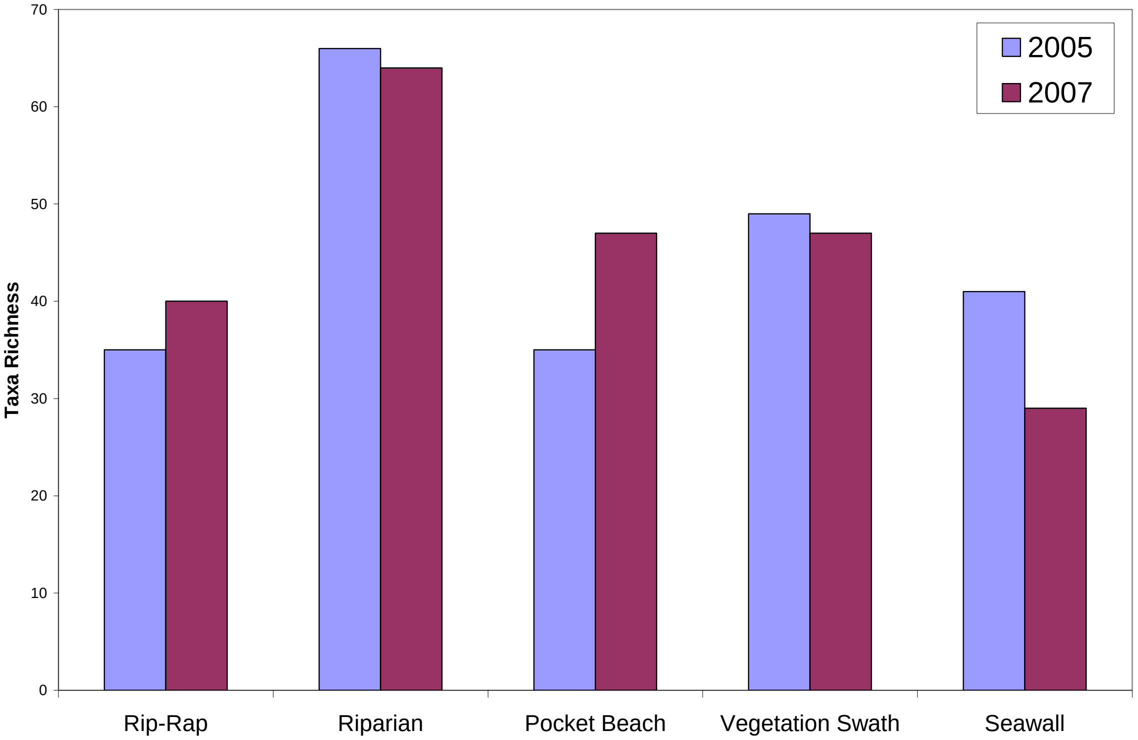

Figure 18. Overall taxa richness (# of taxa) of insects by year and site. Sites are labeled by post-construction habitat: in 2005, pocket beach was riprap, and vegetation swath was seawall.

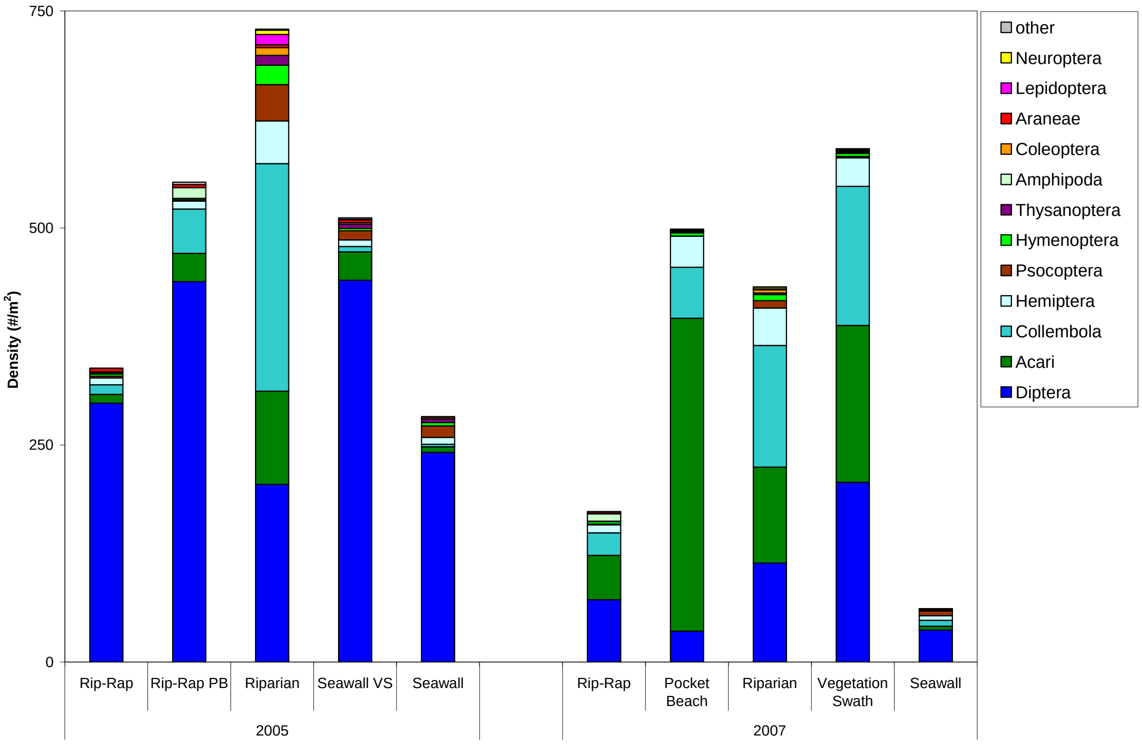

Figure 19. Average densities and general taxa composition of insects by habitat and year.

Table 11. Detailed list of taxa from insect fallout traps, by major taxonomic categories.

Taxa Grouping	Taxa
Diptera	Acalypterate muscoid, Anthomyiidae, Calliphoridae, Carnidae, Cecidomyiidae, Ceratopogonidae, Chironomidae, Chloropidae, Dolichopodidae, Dryomyzidae, Empididae, Ephydridae, Heleomyzidae, Lauxaniidae, Muscidae, Mycetophilidae, Nematocera, Phoridae, Piophilidae, Psilidae, Psychodidae, Sarcophagidae, Scathophagidae, Scatopsidae, Sciaridae, Sphaeroceridae, Tethinidae, Tipulidae, Syrphidae larvae, Psychodidae larvae, Ephydridae larvae, Chironomidae larvae, Ceratopogonidae larvae, Cecidomyiidae larvae
Hemiptera	Aleyrodidae, Anthocoridae, Aphididae, Auchenorrhyncha, Cercopidae, Cicadellidae, Coccoidea, Delphacidae, Eriosomatidae, Lygaeidae, Miridae, Nabidae, Pentatomidae, Psyllidae, Reduviidae, Hemiptera immature, Sternorrhyncha immature
Hymenoptera	Aphelinidae, Apidae, Braconidae, Chalcidoidea, Cynipidae, Diapriidae, Encyrtidae, Eulophidae, Figitidae, Formicidae, Hymenoptera, Ichneumonidae, Megaspilidae, Mymaridae, Perilampidae, Platygasteridae, Proctotrupidae, Proctotrupoidea, Pteromalidae, Scelionidae, Sphecidae, Tenthredinidae, Torymidae

Table 11 continued

Coleoptera	Carabidae, Cerambycidae, Chrysomelidae, Coccinellidae, Cryptophagidae, Curculionidae, Elateridae, Latridiidae, Hydrophilidae, Byrrhidae, Staphylinidae, Throscidae, Scarabaeidae, Ptiliidae, Anobiidae, Coccinellidae larvae, Coleoptera larvae
Lepidoptera	Lepidoptera, Microlepidoptera, Tortricidae
Thysanoptera	Aeolothripidae, Phlaeothripidae, Thripidae, Thysanoptera
Collembola	Entomobryidae, Hypogastruridae, Isotomidae, Sminthuridae
Amphipoda	Talitridae, *Traskorchestia* sp., *Traskorchestia traskiana, Megalorchestia pugettensis*
General Taxa Groupings	Araneae, Acari, Chilopoda, Dermaptera, Gastropoda (slug, snail), Psocoptera, Trichoptera, Tardigrada, Pseudoscorpiones, Neuroptera, Thysanura

Table 12. Results of ANOVA on fall-out trap insect densities, significant results ($p < 0.05$) are in bold.

2007	p-value	tukey
Overall densities	**0.0000001**	pocket beach, vegetation swath **>** riprap & seawall; riparian **>** seawall
Diptera	**0.00003**	vegetation swath **>** riprap, seawall, pocket beach
Hemiptera	**0.00001**	riparian, pocket beach **>** riprap & seawall vegetation swath **>** seawall

2005 & 2007	Overall densities	Diptera	Hemiptera
Riprap	0.067	**0.01** (05 > 07)	0.72
Pocket Beach	0.73	**0.0007**(05 > 07)	**0.0002** (07 > 05)
Riparian	**0.013** (05 > 07)	**0.0005** (05 > 07)	0.65
Vegetation Swath	0.52	**0.003** (05 > 07)	**0.002** (07 > 05)
Seawall	**5.2E-11** (05 > 07)	**2.8E-11** (05 > 07)	0.20

Neuston

Neuston tows had lower replication than the other sampling methods (replication of three 10-m tows per habitat/date), and were characterized by high variability. Although invertebrate densities were highest at pocket beach and seawall, the results were not significant for total densities (one-way ANOVA on habitat type, $p > 0.05$; Fig. 20). ANOVAs on diptera and Hemiptera showed that the seawall site had significantly higher numbers than the riprap site ($p < 0.05$ with Tukey-test for multiple comparisons). There were no differences between the pocket beach and habitat bench sites and the adjacent riprap and seawall sites. The neuston tows also contained invertebrates that were not from terrestrial habitats, such as aquatic invertebrates that were sampled in the epibenthic sampling (e.g. the amphipod *Paracalliopiella pratti* and harpacticoid copepods) as well as exuvia from insect larvae.

In terms of percent composition, neuston tows and fallout trap samples were similar for Diptera, Collembola, and Hemiptera (Fig. 21). Fallout traps had much higher contributions of Acari, and neuston tows had more Hymenoptera, Coleoptera, Psocoptera, and Thysanoptera.

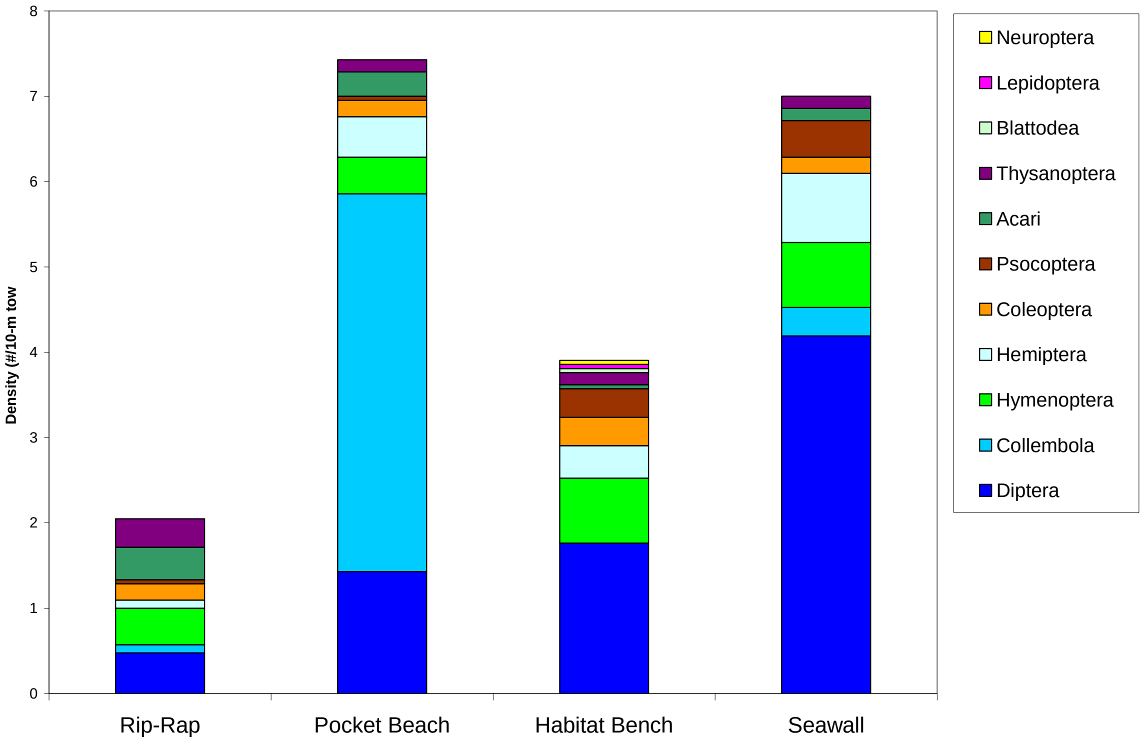

Figure 20. Average overall densities and taxa composition of neuston by habitat type in 2007.

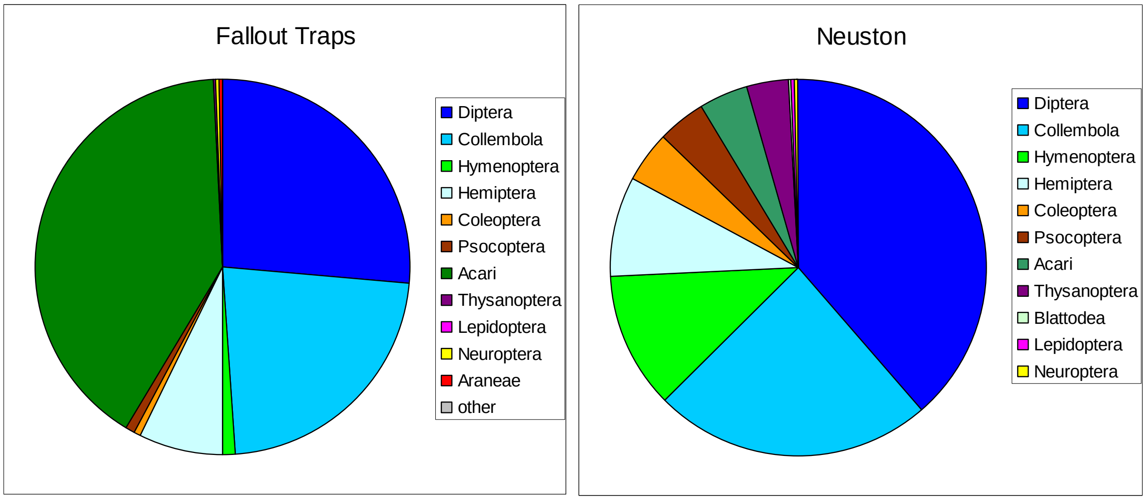

Figure 21. Numerical percent composition of invertebrates from fallout traps and neuston tows.

Terrestrial Vegetation

Riparian plantings were completed in early 2007 and our May 2007 survey serves as the as-built (year 0) survey. Some planting continued throughout the spring, and some trees that had not survived were replaced. Our July survey took place at the height of the growing season and future surveys should also be conducted in July for comparability. A species list is provided in Table 13. There were no major changes in species composition between the May and July surveys. There was some colonization of the beach backshore area by Dunegrass (*Elymus mollis*) and some spread of Beach Strawberry (*Fragaria chiloensis*) into the dunegrass area. All other changes were due to ongoing plant maintenance activities.

From May to July the percent cover of both overstory and understory increased in all areas (Figs. 22-23; Table 14). The average canopy diameter of each tree species also increased from May to July with the exception of the Garry Oaks in the North Uplands (Table 15). The area of each dunegrass patch was as follows; Patch 1 (40.7 m^2), Patch 2 (97.6 m^2), Patch 3 (17.5 m^2), Patch 4 (21.8 m^2), numbered north to south along the beach backshore.

Health ratings were assigned separately to the overstory and understory plants (Table 16). All areas were in relatively good health and the ratings generally improved or stayed the same between the two survey dates. Damage to *Alnus rubra* leaves in the Backshore area was observed in July but the source of the damage was not identified. Pedestrians use the driftwood logs as benches and the Dunegrass on the beach side of the logs was extensively trampled. Dunegrass growing closer to and behind the driftwood did not suffer the same damage. Photographs of all surveyed areas were taken from the same vantage point in May and July. Examples are in the appendix, and copies are available upon request.

Table 13. Plant species present in each of the five riparian areas in May 2007 and July 2007.

Site	May-07	Jul-07
North Uplands	*Carex obnupta*	*Carex obnupta*
	Descampsia caespitosa	*Descampsia caespitosa*
	Elymus glaucus	*Festuca idahoensis*
	Festuca idahoensis	*Fragaria chiloensis*
	Fragaria chiloensis	*Gaultheria shallon*
	Garrya elliptica	*Oemleria cerasiformis*
	Gaultheria shallon	*Pinus contorta*
	Mahonia aquifolium	*Picea sitchensis*
	Oemleria cerasiformis	*Quercus garryana*
	Pinus contorta	*Rosa* sp.
	Picea sitchensis	*Salix* sp.
	Quercus garryana	*Spirea douglasii*
	Rosa sp.	*Symphoriocarpus albus*
	Salix sp.	Juncaceae
	Spirea douglasii	Cyperaceae
	Vaccinium ovatum	*Vaccinium ovatum*
	Viburnum edule	*Viburnum edule*

Table 13 continued

South Uplands	*Arctostaphylus columbiana* *Descampsia caespitosa* *Elymus glaucus* *Festuca idahoensis* *Fragaria chiloensis* *Garrya elliptica* *Mahonia aquifolium* *Pinus contorta* *Picea sitchensis* *Quercus garryana* *Thuja plicata* *Vaccinium ovatum*	*Arctostaphylus columbiana* *Descampsia caespitosa* *Elymus glaucus* *Festuca idahoensis* *Fragaria chiloensis* *Garrya elliptica* *Mahonia aquifolium* *Mahonia nervosa* *Picea sitchensis* *Quercus garryana* *Thuja plicata* Poaceae Juncaceae *Vaccinium ovatum*
Overlook	*Alnus rubra* *Elymus mollis* *Fragaria chiloensis* *Fragaria virginiana* *Gaultheria shallon* *Holodiscus discolor* *Mahonia aquifolium* *Pinus contorta* *Picea sitchensis* *Pseudotsuga menziesii* *Rosa* sp. *Symphoriocarpus albus* *Thuja plicata*	*Alnus rubra* *Elymus mollis* *Fragaria chiloensis* *Fragaria virginiana* *Gaultheria shallon* *Holodiscus discolor* *Mahonia aquifolium* *Pinus contorta* *Picea sitchensis* *Rosa* sp. *Salix* sp. *Symphoriocarpus albus* *Thuja plicata*
Backshore	*Alnus rubra* *Fragaria chiloensis* *Fragaria virginiana* *Gaultheria shallon* *Holodiscus discolor* *Mahonia aquifolium* *Pinus contorta* *Rosa* sp. *Symphoriocarpus albus*	*Alnus rubra* *Elymus mollis* *Fragaria chiloensis* *Fragaria virginiana* *Gaultheria shallon* *Holodiscus discolor* *Mahonia aquifolium* *Pinus contorta* *Rosa* sp. *Symphoriocarpus albus*
Dunegrass	*Elymus mollis* *Fragaria virginiana* *Grindelia integrifolia*	*Elymus mollis* *Fragaria chiloensis* *Fragaria virginiana* *Grindelia integrifolia*

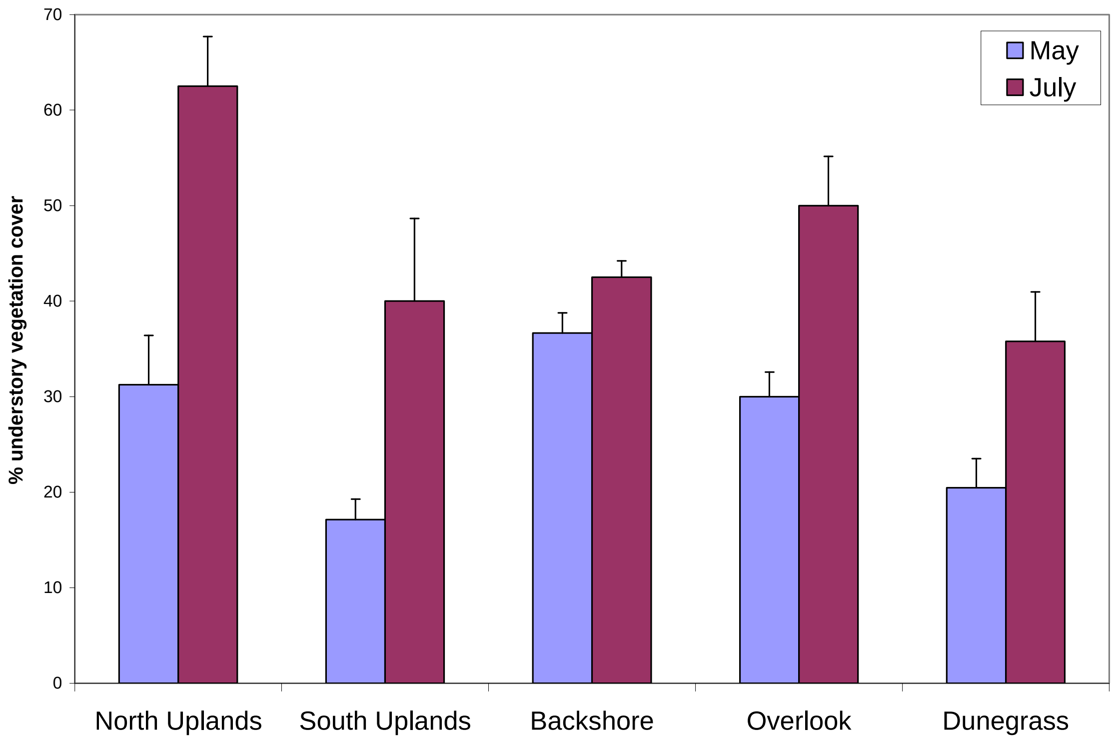

Figure 22. Average percent cover of understory vegetation at shoreline habitats.

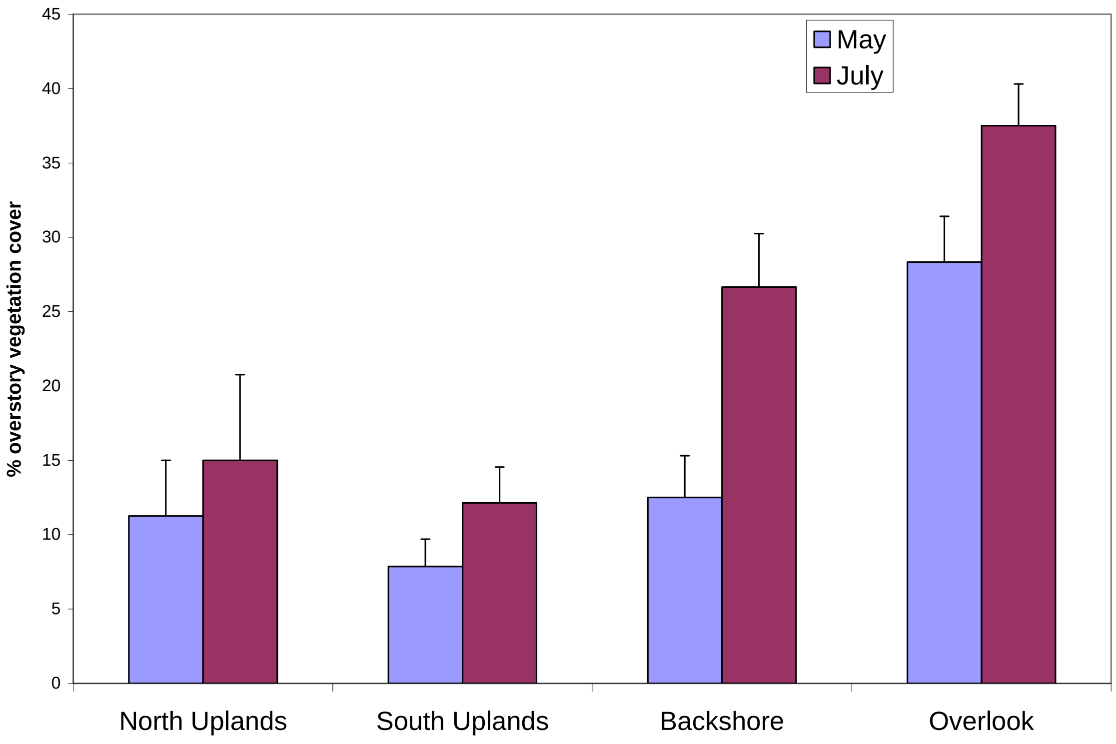

Figure 23. Average percent cover of overstory vegetation at shoreline habitats.

Table 14. Average change in percent cover at all vegetation areas.

Vegetation Type	Site	Average change % Cover
Overstory	North Uplands	3.8
	South Uplands	4.3
	Backshore	14.2
	Overlook	9.2
Understory	North Uplands	31.3
	South Uplands	22.9
	Backshore	5.8
	Overlook	20.0
	Dunegrass	15.4

Table 15. Average change in canopy diameter (m) of tree species.

Species	Site	Average change diameter
Pinus contorta	North Uplands	0.19
	South Uplands	0.23
	Overlook	0.14
	Backshore	0.28
Alnus rubra	Overlook	0.46
	Backshore	0.41
Quercus garryana	North Uplands	-0.17
	South Uplands	0.11
Picea sitchensis	North Uplands	0.3
	South Uplands	0.7
	Overlook	0.21
Salix sp.	North Uplands	0.44
Thuja plicata	South Uplands	0.05
	Overlook	0.15

Table 16. Average health ratings for each vegetation area.

Vegetation Type	Site	May	July
Overstory	North Uplands	3.8	4.3
	South Uplands	4.5	4.3
	Backshore	3.3	3.7
	Overlook	3.3	3.8
Understory	North Uplands	3.5	4.0
	South Uplands	3.7	4.1
	Backshore	4.0	4.0
	Overlook	4.0	4.0
	Dunegrass	3.3	4.3

Algae

Twenty-three species of algae were observed between tidal elevations of 0’ to -25’ MLLW at the habitat bench (Table 17). Four species occurred on the habitat bench (0’ to -5’), with the remainder occurring in shallow subtidal waters off the edge of the habitat bench between -5 to -20’. Beds of the bull kelp (*Nereocystis luetkeana*) occurred between -5 and -20’, with greatest numbers of stipes at -10’ (Table 17). Small numbers of the stalked kelp *Pterygophora californica* were also present at -10, -20, and -25’. At the habitat bench and the -5’ elevation, average percent composition was dominated by *Ulva fenestrata* (Fig. 24). *Saccharina latissima* was consistently abundant across tidal elevations from -5’ to -25’, being highest at -15’. *Desmarestia ligulata* was also present across those same tidal elevations, and was the most abundant species at -10’. A high diversity of red algae was present at all tidal elevations, with no single species dominating the composition. Overall percent algae cover ranged from 46 to 74%, depending on the elevation.

Table 17. Species list of algae and occurrences at each tidal elevation (feet below MLLW), with average number of stipes within 10' for Bull and Stalked Kelp.

Algae Type	**Species**	**habitat bench (0 to -5')**	**-5**	**-10**	**-15**	**-20**	**-25**
Brown	Bull Kelp (*Nereocystis luetkeana)*		9.3	14.5	5.6	0.6	
	Stalked Kelp *(Pterygophora californica)*			0.2		0.3	0.3
	Sugar Kelp *(Saccharina latissima)*		X	X	X	X	X
	Flat Desmarestia *(Desmarestia ligulata)*		X	X	X	X	X
	Seersucker kelp *(Costaria costata)*			X			
	Stringy Desmarestia (*Desmarestia viridis*)			X			
	Seive kelp *(Agarum fimbriatum)*			X			
	Sargassum muticum		X				
Green	Sea Lettuce *(Ulva fenestrata)*	X	X	X	X	X	
	Green Ribbon *(Enteromorpha intestinalis)*	X					
Red	Hidden Rib Red (*Cryptopleura ruprechtiana*)		X	X	X	X	X
	Branching Palmaria (*Palmaria callophylloides)*			X	X	X	X
	Sea Comb *(Plocamium cartilagineum)*		X	X	X	X	X
	Gracilaria pacifica			X	X	X	X
	Fine Branching Reds (*Ceramium pacificum*)		X				X
	Flat Palmaria (*Palmaria mollis*)			X	X	X	
	Turkish Towel *(Chondracanthus exasperatus)*		X		X	X	
	Turkish Washcloth *(Mastocarpus papillatus)*	X					
	Purple laver *(Porphyra perforata)*	X					
	Fuzzy Reds (*Polysiphonia* sp.)		X	X		X	
	Splendid iridescent seaweed *(Mazzaella splendens)*		X		X		
	Small Delesseria (*Delesseria decipiens*)		X	X			
	Red Islet Silk *(Sparlingia pertusa)*				X		

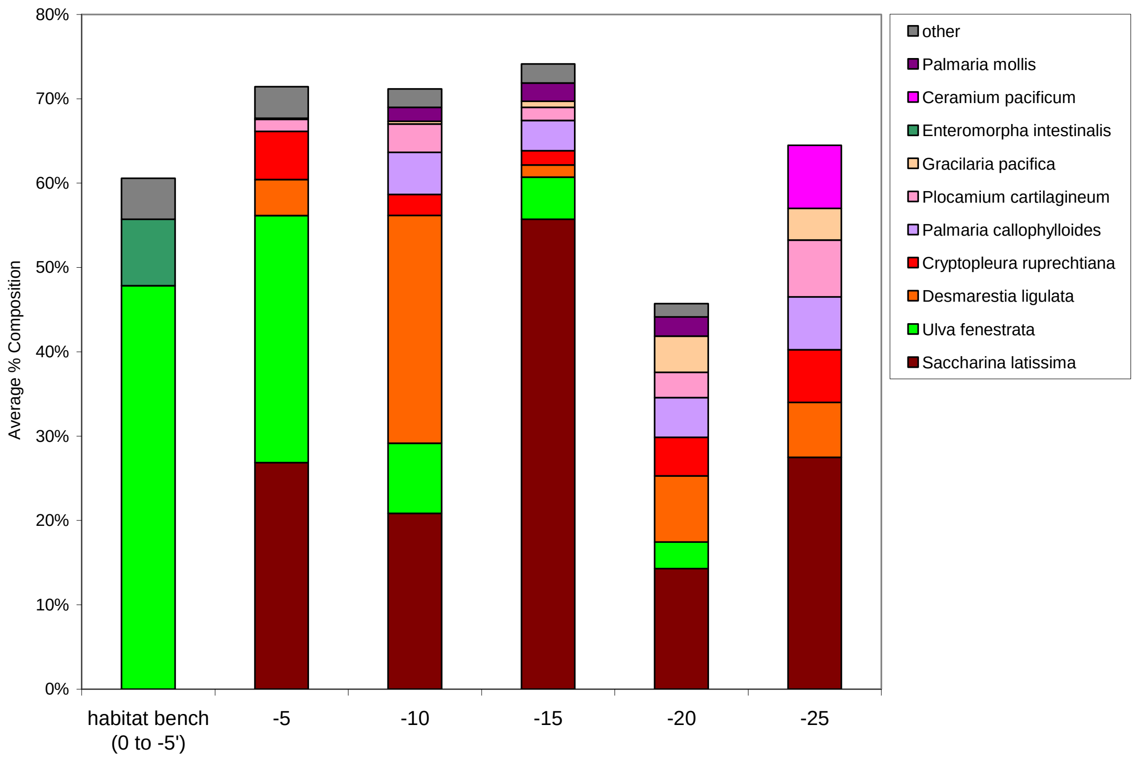

Figure 24. Average percent algae composition by tidal elevation (feet below MLLW).

Discussion and Conclusions

Fish

Results of pre-construction monitoring indicated that benefits resulting from created habitat in the Olympic Sculpture Park should be available for juvenile salmon, because the salmon occurred in relatively high numbers in shallow water at and near the sites (Toft and Cordell 2006). The results from 2007 monitoring further suggest this, because juvenile salmon were significantly more abundant at the shallow water strata of the habitat bench and pocket beach sites than the adjacent riprap site. Also, the fact that shallow water salmon densities decreased only at the riprap site between 2005 and 2007, may have resulted from fish being attracted to the adjacent shallow water habitats at the created pocket beach and habitat bench sites. Our data showed that the pocket beach was regularly occupied by juvenile salmon which were the dominant species there at high tide. Additionally, during snorkel surveys there was high observed feeding by schools of juvenile salmon at the habitat bench of 40 to 55%, compared to 0 to 25% at the previous seawall site (Toft and Cordell 2006).

Some 2007 findings on fish assemblages were similar to pre-construction monitoring in 2005, such as the numerical domination by shiner perch, especially in deeper transects. However, there was also interannual variation, such as more abundant herring at the habitat bench and riprap sites in 2007. The herring increase in 2007 is probably not attributable to the shoreline enhancements, as they are primarily water column dwellers, but the created shoreline habitat may provide some prey resources for herring occupying the shoreline, and may also provide substrata (algae) for herring spawning. Continued sampling at the sites will help to assess differences in annual variation and to pinpoint factors influencing fish abundances and distribution.

When new intertidal habitat is created for juvenile salmon, concern is sometimes expressed about the potential of the site for attracting predators. In this study we rarely observed fish predators likely to eat juvenile salmon such as sculpins, steelhead trout, and lingcod, and we observed no increases in predators at the created habitat types as compared to 2005 results.

Although difficult to observe with our snorkel surveys, wolf eel and clingfish were two fish species at the pocket beach and habitat bench that were rarely observed but that were not documented pre-enhancement in 2005. This may be attributed to the novelty of the created habitats mimicking natural shorelines in an urbanized landscape; future monitoring will better assess if these rare species increase with time at the site, or if they were a chance occurrence. Additionally, juvenile gunnels were frequently observed underneath cobble at the pocket beach during the process of taking benthic cores.

Enclosure netting at the pocket beach verified that snorkel surveys accurately estimate fish numbers at the netted site, because juvenile salmon counts were consistent between the two techniques. Minor differences were observed, such as snorkeling yielding slightly lower counts and lack of larger perch species in the nets, as has been found in previous studies (Toft et al. 2007).

Juvenile salmon netted at the pocket beach consumed a diversity of prey. For Chinook salmon, diets consisted mostly of amphipods, fish, and insects. This finding is similar to diet results from other nearshore habitats in central Puget Sound, where Chinook salmon have been found to contain prey associated with multiple habitats including bottom substrates and algae, the water column, and on the water's surface (Brennan et al. 2004). Chum salmon diets overlapped somewhat with Chinook salmon diets, but fed more on smaller prey such as copepods, eggs, and fish larvae. The preponderance of planktonic calanoid copepods in small early-outmigrating chum salmon diets was not typical, as these fish usually prey on harpacticoid copepods (Kaczynski et al. 1973; Sibert et al. 1977; Sibert 1979; Simenstad et al. 1980; Landingham 1982; Cordell 1986; Webb 1991). The reasons for this are unknown, but could include relatively low abundances of prey harpacticoids at the pocket beach habitat, change in chum salmon behavior while in the net, or particularly high abundances of calanoid copepod prey occurring on the 2007 sampling dates. Similar to other results from Puget Sound (Brennan et al. 2004), coho salmon fed mainly on more water-column associated prey such as fish and decapod larvae.

In terms of both habitat access and aquatic prey resources (see below), the created habitats associated with the Olympic Sculpture Park have increased biological functions for juvenile salmon when evaluated against the armored shoreline that previously existed at the site. Because juvenile salmon were the main species found at the pocket beach, prey resources at the site are probably utilized mainly by juvenile salmon as opposed to other fish species. Thus, the created habitat at the pocket beach may provide more benefits to salmon rather than to their competitors, which are rare at the site. For example, shiner perch, which overlap in diet composition with juvenile salmon (they feed mostly on small crustaceans and algae; Bane and Robinson 1970) are very abundant in deeper habitats but scarce in pocket beach net samples.

Epibenthic/benthic Invertebrates

Created habitats at the pocket beach and habitat bench have been colonized by a diversity of epibenthic invertebrates. As found elsewhere (Chapman 2003), the new, more complex habitats had higher taxa richness and densities of taxa that were not previously seen at armored sites (in this case the seawall and riprap sites). The habitat bench in particular had high densities of harpacticoids and other epibenthic invertebrates. Total invertebrate densities were higher than 2005 baseline levels, except for amphipods at the seawall habitat which showed no change. The riprap site did have higher densities of amphipods that may have been associated with established algae attached to the rocks (this site had not been disturbed by construction).

Creation of a cobble/gravel beach has provided habitat for benthic invertebrates where there was previously no interstitial benthic substrate. The main amphipods – *Desdimelita californica* at 0’ and talitrid beach-hoppers at +12’ MLLW – are different from the amphipods that were sampled in 2005, when the more epibenthic *Paracalliopiella pratti* dominated the 0’ elevation and there was no high intertidal beach wrack zone for talitrids to inhabit. The amphipod *Paramoera mohri* was also common in benthic cores at both tidal elevations: this species migrates up and down the beach with the rise and fall of the water table (Staude 1986, 1995), and is able to utilize most of the intertidal habitat created at the pocket beach. *Paramoera mohri* was the second-most abundant amphipod prey item in salmon diets from this study, and has also been observed to be an important prey item for several sculpin species (including tidepool sculpins, which have been observed at the pocket beach) and saddleback gunnels (Staude 1986). Taxa such as chironomid midges also use the created habitats. Chironomid larvae were found in benthic core samples, and adults were common in insect fall-out traps: while we do not know if the larvae and adults were of the same species, this may demonstrate a linkage between the aquatic and upland habitats at the site. A number of polychaete worm taxa that were not previously recorded at the site were also found at the pocket beach. Seven families of polychaetes occurred there as opposed to two in the 2005 epibenthic samples. Polychaetes were of overall moderate to low abundance in the benthic samples, but some constituted the largest individuals in the samples, such as the Terebellids and Nereids which sometimes were 5 to 10 cm long.

Insects

All of the created habitat types (pocket beach, riparian, and vegetation swath) had significantly higher fallout insect trap densities than some or all of the adjacent modified shorelines (seawall and riprap sites). They also all had higher values for taxa richness. While we do not know how this translates into overall biomass of prey taxa, it suggests that insect production has increased as a result of plantings of shoreline vegetation and other site enhancements. Some of the increases in insects were taxa that are known to be juvenile salmonid prey items (Brennan et al. 2004), such as hemipterans that are often vegetation oriented (e.g. aphids), and dipterans (e.g. chironomids at the vegetated area).

Interannual differences were evident in the insect trap results, especially for dipterans, which decreased at all sites in 2007 compared to 2005 levels. This made pre- and post-enhancement evaluations difficult for insect samples. Post-enhancement increases were most notable at the pocket beach as compared to the pre-construction riprap, as taxa richness increased as well as hemiptera densities. Hemiptera densities also increased at the vegetation swath, compared to the pre-construction seawall. The newly planted riparian site was similar in taxa richness and only slightly lower in densities than the mature riparian site measured in 2005, signifying initial colonization by a diversity of taxa.

Data from neuston samples taken at the water's surface differed little among the enhanced and reference habitats. Potential salmon prey in the neuston appeared to be distributed evenly along sections of shoreline associated with the Sculpture Park. The only statistically significant finding of higher numbers of dipterans and hemipterans at the seawall site than the riprap site might be attributed to differences in wave and wind patterns associated with the two shoreline segments, or to the fact that the seawall site was separated from the other sites by a pier.

Our results show that many of the taxa captured in fallout trap samples were also available to juvenile salmon as neuston. These consisted mainly of diptera, collembola, and hemiptera, all of which are known to occur in the diets of juvenile chum and Chinook salmon. The extent to which the invertebrates captured in the neuston net were actually produced at the sculpture park sites is unknown, because drift insects could have originated from outside the area. Also, some taxa, such as mites, hymenoptera, coleoptera, psocoptera, and thysanoptera had greater relative abundances in the neuston than in fallout samples. However, it is clear from our study that the types of insects found in salmon diets and neuston samples are being produced at the enhanced habitat sites. Other studies have shown insect communities to be significantly reduced where shoreline vegetation has been removed in association with armoring (Romanuk and Levings 2003, Sobocinski 2003), and continued development of the vegetation communities along the shoreline will probably increase the input of these riparian insects.

Vegetation and Algae

Performance standards for the year 1 percent vegetative cover require either a 10% increase in cover or a cover value of 40%, whichever is larger (as developed by Anchor Environmental). This standard was met in all areas with the exception of the dunegrass area where there was an average increase of 15.35% but the threshold of 40% was not reached. The dunegrass patch area will be an informative measure of future performance. All other riparian areas are contained within fixed borders while the dunegrass is free to spread across the upper beach and changes in patch size will reflect growth and vigor that might be missed by measurements of percent cover alone.

Changes in cover were greater in the understory than the overstory, and in the north and south uplands were partly due to additional plantings made after our May survey. Cover values also increased due to the spreading growth of Beach Strawberry and vigorous growth of grasses. We recommend that future surveys be conducted in July when plant canopies are at their maximum.

The created habitat bench has been colonized with a diverse, dense growth of kelps and other algae, with 23 species of green, red, and brown algae. Algae percent cover ranged between 46 to 74%, and kelp beds appeared to be firmly established with observed resident populations of kelp perch and kelp crabs.

Conclusions and Future Monitoring

Overall, results from year 1 monitoring of the shoreline enhancements at the Olympic Sculpture Park indicate that there has been rapid development of aquatic and terrestrial biota, based on measurements from the created habitat bench, pocket beach, and shoreline vegetation. Many of the invertebrate and fish indicators have higher values compared to both the baseline conditions measured before construction of the Sculpture Park, as well as to current reference sections of seawall and riprap.

We recommend periodic post-construction monitoring to continue (e.g. 2, 3, 5, 10 years after construction) in order to assess additional development of biological functions at the site. More frequent monitoring during the first few years will detail early changes in development and stabilization of biological and physical processes, with long-term trends determined in later years. Maintaining the sampling design and methodologies used in this study will increase the likelihood of detecting changes associated with the created habitats. In addition to the attributes measured in this initial post-construction study, the following additional sampling should be considered in future monitoring:

- Comparative sampling at different habitats within Elliott Bay, to put the functions of the habitats at the Olympic Sculpture Park more in context with its surroundings. This could focus on fish, invertebrate, and physical conditions of other natural and created sand and cobble beaches (note: some of these attributes are being measured in 2008).
- Interannual variability of fish assemblages, as measured during year 2 monitoring and compared to previous years. All previous fish sampling was done in odd years (2005 and 2007), so 2008 fish sampling would address not only inter-annual variability but also the presence of alternate year fish species such as juvenile pink salmon that only out-migrate on even years.
- Movement and residence time of juvenile salmon among different shoreline habitats, in order to evaluate time spent in certain areas and potential habitat-specific behaviors.
- Sampling of invertebrates and fish that are associated with beds of kelp growing in deeper water on the habitat bench. This would document specific sources of invertebrates that are associated with kelp blades, as potential prey items for

nearshore fish, and identify if juvenile salmon and important non-salmonids (e.g., juvenile rockfish) are using the kelp.

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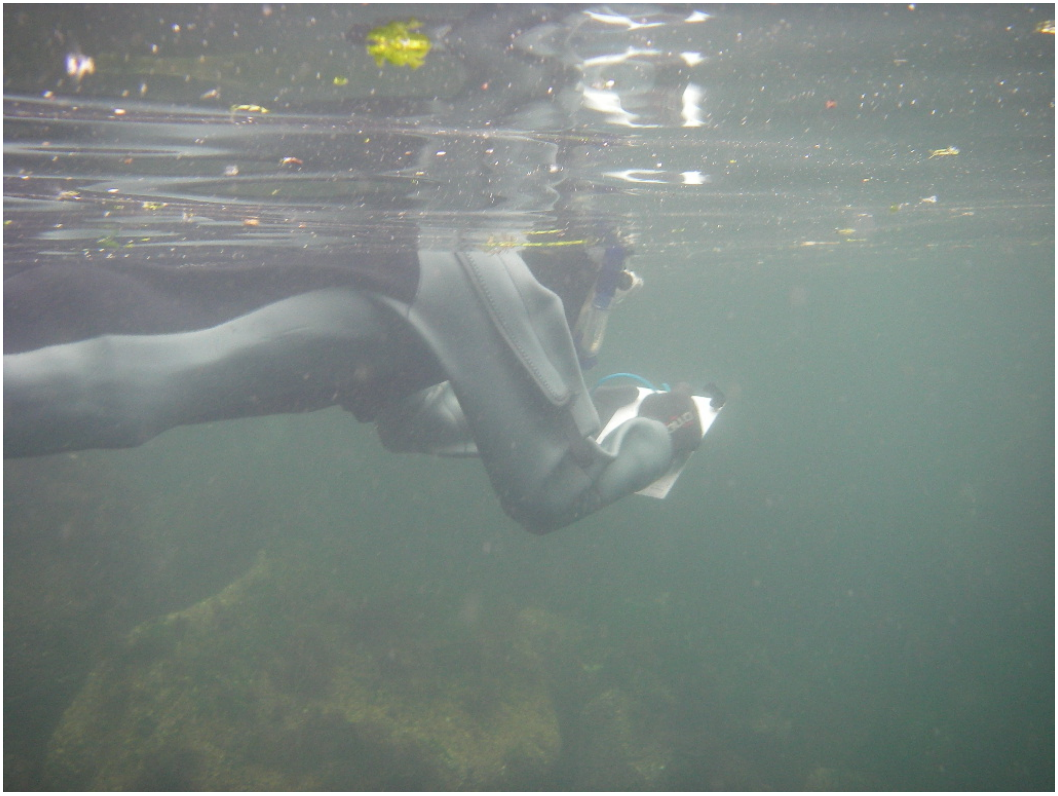
Appendix 1: Photographs of Methods

Snorkel surveys being conducted at shallow and deep transects.



Snorkeler with underwater writing tablet.


Setting the enclosure net at the pocket beach at high tide.

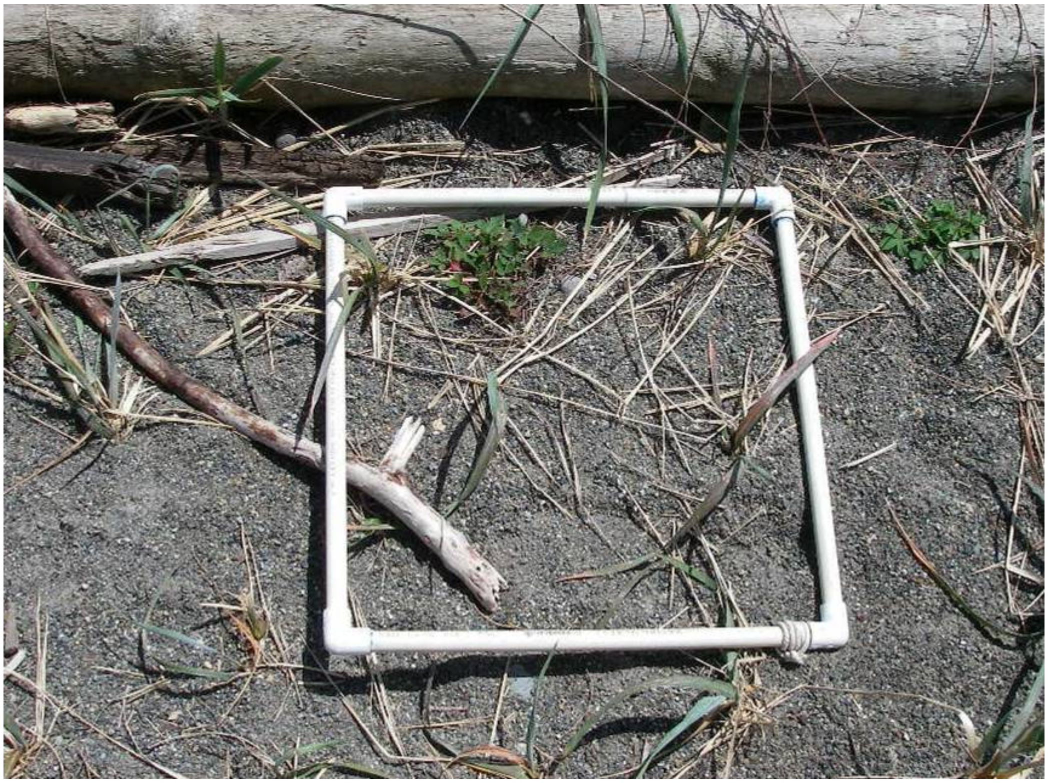

Pole-seining within the pocket beach enclosure net at low tide.


Epibenthic pump sampling of aquatic invertebrates on riprap.


Benthic sampling of invertebrates at the pocket beach.


Insect traps deployed at the pocket beach.

Neuston sampling at the seawall site.



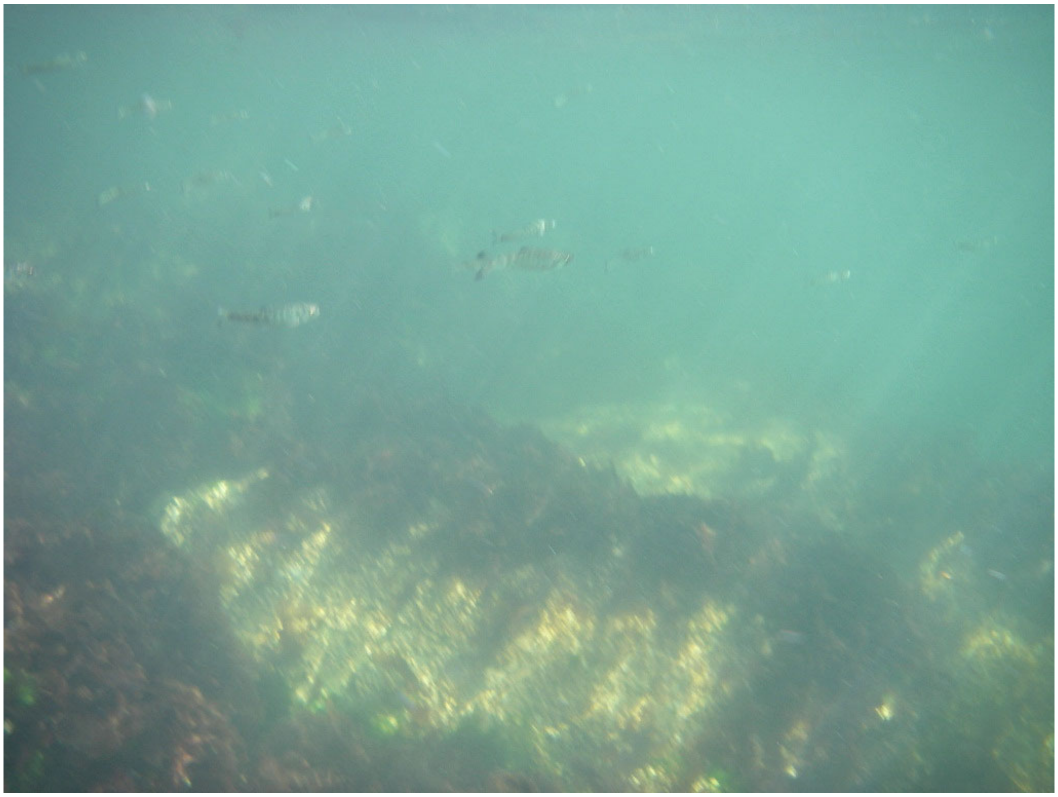
Quadrat in a patch of dunegrass.

Appendix 2: Photographs of Animals and Plants

Seal pup at the pocket beach. Picture also shows accumulated drift wood.

Juvenile chum salmon at the waters surface.

A school of juvenile chum salmon.



A school of juvenile Chinook salmon.

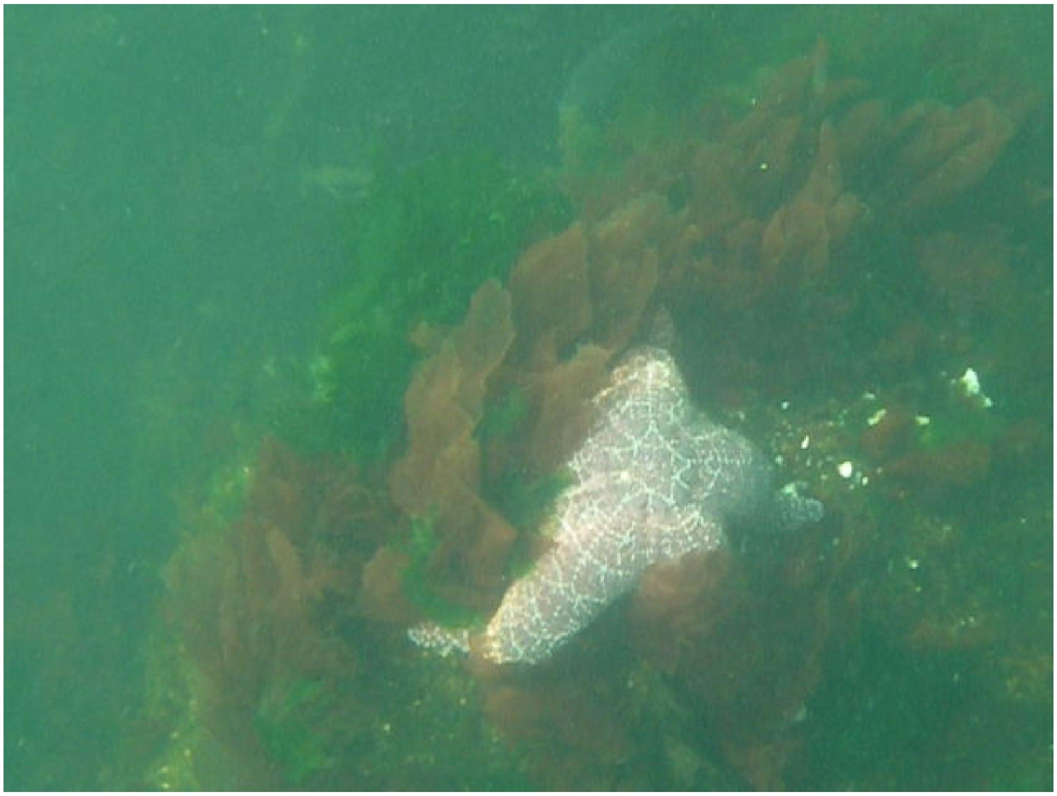
A gunnel found in the cobble at the pocket beach.

Jellyfish, common in the water column by early June.

Lamprey wound on a sampled juvenile Chinook salmon.

Kelp crabs, clinging to kelp that has colonized the site.

Kelp perch, inhabiting kelp forests at the site.



Algae and starfish on the habitat bench.

The gammarid amphipod *Paracalliopiella pratti*.

The harpacticoid copepod *Harpacticus uniremis.*

Adult midge (Order Diptera, family Chironomidae).

Springtail (Order Collembola).

Backshore vegetation plantings at the pocket beach.

View of the vegetation swath leading down towards the pocket beach (north uplands).

Dune grass planted at the pocket beach.

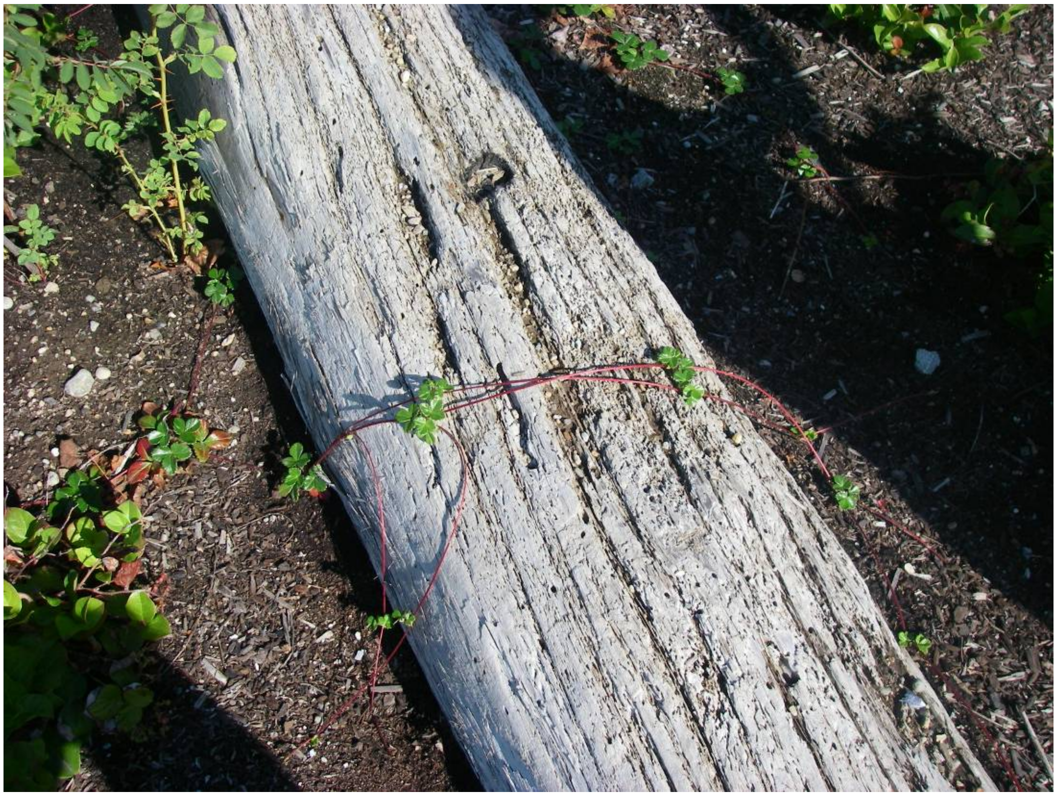
Health rating 1 – dead (*Pseudotsuga menziesii*).

Health rating 2 – significant dieback (*Gaultheria shallon*).

Health rating 3 – little to no dieback (*Pinus contorta*).

Health rating 4 – appears healthy (*Pinus contorta*).

Health rating 5 – healthy with apparent new growth (*Mahonia aquifolium*).



Creeping of Beach Strawberry (*Fragaria chiloensis*) in the dunegrass area.

A section of the Northern Uplands, looking south in May.

The same section of Northern Uplands, looking south in July.

PART II: PHYSICAL MONITORING

Andrea Ogston and Emilie Flemer

Introduction

Coarse-grained beaches are widespread at mid to northern latitudes, where the sources for the littoral system are composed of mixed sediment (e.g., sand-sized to cobble-sized sediment) (Osborne 2005). In Puget Sound most of the beach substrate comes directly from the glacial tills incorporated in nearby bluffs. These supply an abundant source of sands, pebbles, and cobbles for subsequent reworking by long- and short-term physical processes (Terich 1987, Mason and Coates 2001). The mixed-sediment composition of these beaches makes them morphologically distinct from sand or gravel beaches (Kirk 1980, Mason and Coates 2001).

As beach replenishment/nourishment (e.g., soft forms of shoreline stabilization) continues to become the encouraged coastal engineering solution for shoreline stabilization in the U.S. and Puget Sound, understanding the geomorphic response of coarse-grain beaches to physical and anthropogenic processes will become increasingly important (Mason and Coates 2001, Shipman 2001). Although coarse-grained (e.g., gravel) beaches are an efficient form of protection against shoreline erosion (Powell 1990), the modes, mechanisms, and rates of bedload transport for pebble and cobble beaches and mixed-sand-and-gravel beaches are not constrained as well as those of sandy beaches (Osborne 2005). More high-quality field data from coarse-grained beaches is needed to validate the model predictions of coarse-grained sediment transport and mobility (Bradbury and McCabe 2003). Without field data collection and monitoring of physical beach properties, models will continue to be limited in their successful prediction of beach erosion and accretion. The behavior of coarse-grained beaches is not only of interest for basic research on sediment transport and beach morphodynamics but also for coastal engineering and shoreline management as well.

In addition to the riparian and aquatic vegetation and salmonid utilization and prey monitoring plan and results outlined in Part I of this report, the physical beach-profile monitoring provides the unique opportunity to begin addressing some of the problems and uncertainty faced by managers today [e.g., determining the sensitivity of the beach cross-shore profile and area to changes in sediment distributions and patterns (Mason and Coates 2001]. The goals of the physical monitoring are to evaluate the stability over time of the restored pocket beach and habitat bench at OSP. The success of the beach and bench relies on their form to serve their function. An important part of the monitoring effort includes investigating the causes (natural and human) of change in the sediments and profiles of the beach and bench. The general approach for the physical beach-profile monitoring includes: (a) measurement of beach profile transects in the tidal embayment and along the habitat bench, (b) substrate size sampling, and (c) monitoring of wave activity at the beach. Between the detailed year 0 and year 1 surveys, beach profile surveys were performed monthly throughout the year to document the impact of energetic winter conditions on the beach profile, seasonal variability in the profile, and potential anthropogenic impacts to the beach profile. Results from this work will not only help assist in future beach renourishment planning in Puget Sound but also evaluate the impacts and performance of the Seattle Art Museum's Olympic Sculpture Park (OSP) marine nearshore habitat enhancement project and the interdisciplinary approach to long-term monitoring.

Methods

Timeline

A timeline of field activities and other events that influence the evolution of the beach is contained in Table 1. Combined fieldwork was planned to start in autumn 2006 (year 0) to provide a post-construction baseline survey for the physical beach profiling and riparian vegetation, but construction delays caused initiation of monitoring to be postponed. An initial survey was accomplished in December 2006, but subsequent construction activities limit the value of those data. In the following we consider surveys in January and March of 2007 as baseline year 0 (for the beach and bench, respectively) and January and March of 2008 as year 1 (for the beach and bench, respectively). As the physical beach monitoring has become the thesis topic of a graduate student, we have conducted monthly surveys and plan to continue the surveys through the summer of 2008.

Monthly Profile Surveys

Two cross-shore transects (Fig. 1) were selected for monthly monitoring. On the landward end of each transect, a nail was placed in the sidewalk surrounding the beach. On the seaward end, a mark was placed on a piece of toe riprap that is assumed to be immobile:

South transect (BS).
    Landward endpoint location: 47° 37.003' N, 122° 21.483' W
    Seaward endpoint location: 47° 37.011' N, 122° 21.506' W
North transect (BN).
    Landward endpoint location: 47° 37.046' N, 122° 21.501' W
    Seaward endpoint location: 47° 37.018' N, 122° 21.515' W

At the base of the pocket beach, a sub-section of the habitat bench, referred to here as the central bench, was monitored for elevation changes as part of the monthly profile surveys. Along this section of the bench, two transect lines were run at approximately one third and two thirds of the bench width (Fig. 1). Horizontal control was limited on the bench, so these surveys were analyzed for variability, not absolute change.

Monthly profile surveys (Table 1) were performed at low spring tide to capture the full beach profile. The elevations were determined using a laser leveler and direct rod measurements (Fig. 2a and b). A known point on the habitat bench (partially buried construction debris) was monitored during each monthly survey to determine the accuracy of vertical measurements. The vertical precision is estimated to be +/- 4 cm. Mean Lower-Low Water (MLLW) is used as the vertical datum, and survey data was converted to MLLW using the measured water-surface elevation and NOAA tidal observations.

Table 1. OSP's beach and bench habitat physical monitoring timeline for year 0 – year 1.

Date	Beach Survey Performed	Bench Survey Performed	Sediment Samples Collected	Wave Gauge	Other Activities
September 2006					Lower Beach Repaired
December 2006	X		X		Backshore Construction Completed
January 2007	X (Year 0)	X	X	Alec-P Deployed	OSP's Opening Weekend
February 2007	X	X	X		Failed Riprap Repaired
March 2007	X	X (Full-Year 0)		Alec-P Retrieved & Deployed	
April 2007	X			Alec-P Retrieved	Ecological Monitoring Begins (Year 0)
May 2007	X			Alec-P Deployed & Not Retrieved	
June 2007	X	X			
July 2007	X	X			Seattle's 4th of July Fireworks
August 2007	X	X	X		Seattle's Hempfest Held at Myrtle Edwards Park
September 2007	X	X			
October 2007	X (Two Times)	X (Two Times)			
November 2007	X	X		DOBIE Deployed & Retrieved	Denny Way CSO Sediment Clean up Begins
December 2007	X	X	X	DOBIE Deployed	
January 2008	X (Year 1)	X			Denny Way CSO Sediment Cleanup Ends
April 2008	X	X (Full-Year 1)		DOBIE Retrieved	

<u>Bench Surveys</u>

The entire (~286 m-long) habitat bench was surveyed in March 2007 for the year 0 database and again in April 2008 for the year 1 database (Table 1). These surveys provide a basis for comparison and evaluation of change. Two transect lines were laid out along the full length of the bench (see Fig. 1b and 2c) along which elevations were measured using the same survey equipment as for the beach profiles. For sections of the bench, the approximate width of the bench between the intertidal sea-wall buttress and the subtidal riprap base at the toe of the bench was also estimated.

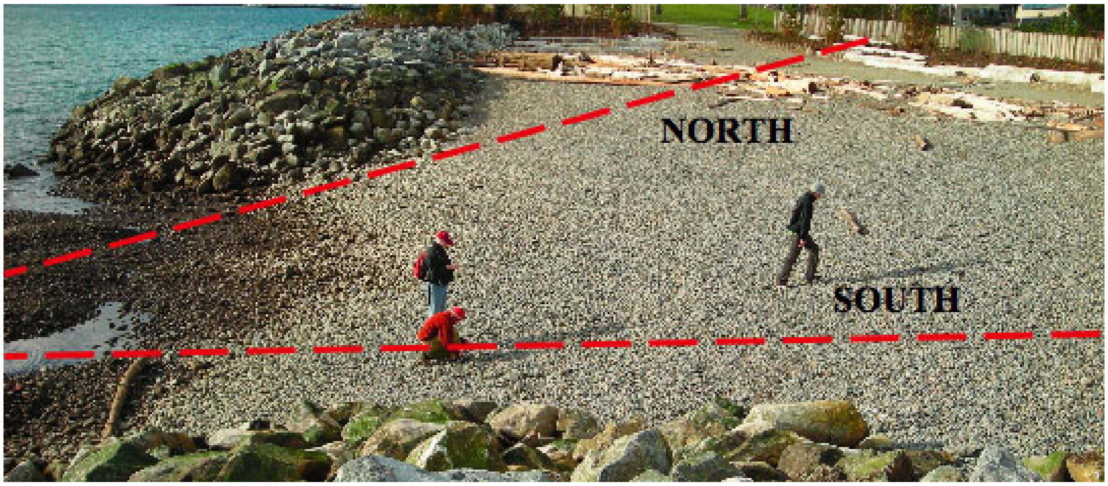


Figure 1a. Cross-shore beach profile surveys at the Olympic Sculpture Park (OSP) pocket beach were performed monthly along North (BN) and South (BS) transect lines.

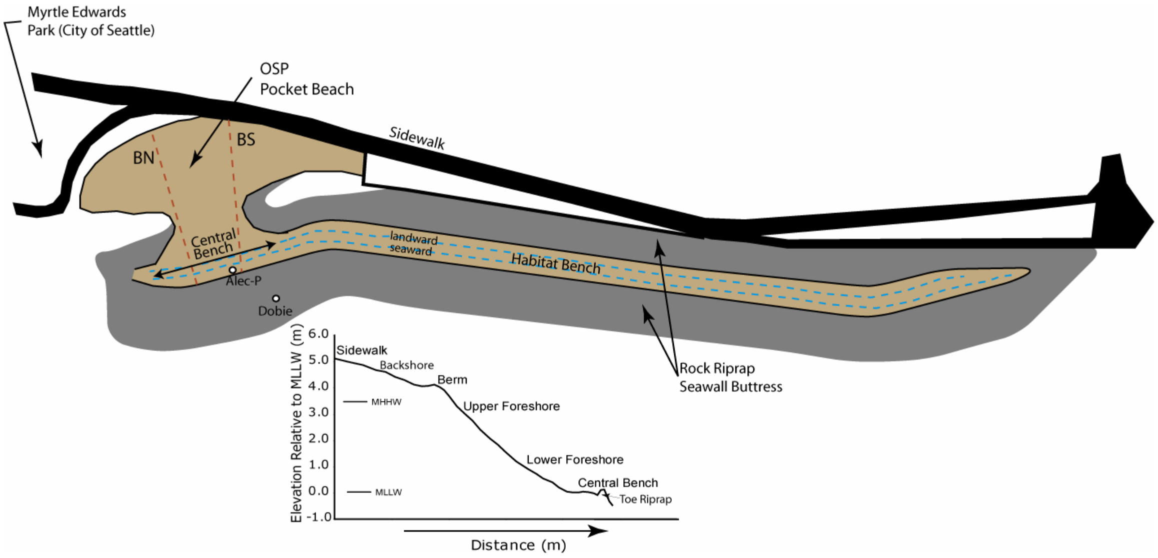


Figure 1b. Plan view drawing with approximate locations of the BN and BS transect lines (red) within the beach, and seaward and landward transect lines (blue) within the habitat bench. The two transect lines on the bench are spaced ~1/3 of the bench's width from each other. Where the bench is too narrow only one transect line (seaward) was used. The circles (labeled Alec-P and Dobie) indicate the locations of the wave gauge deployments.

Figure 2a. The pocket beach and habitat bench were surveyed using high precision, laser survey equipment. Beach surveys were performed monthly during spring low tides.

Figure 2b. Beach profile measurements were obtained between a landward endpoint location (i.e., a nail on the sidewalk) to a seaward endpoint location (i.e., a marker on the top of the riprap at the seaward side of the central bench).

Figure 2c. Complete bench profile measurements were obtained annually from the northern end of the central bench to the southern end of the habitat bench (see Fig. 1).

Beach Topography

Beach topography for the OSP tidal embayment/pocket beach was collected in March 2008, using a Trimble R3 receiver with an L1 antenna (see Fig. 3a) that was provided by Dr. C. Chickadel, Applied Physics Laboratory at the University of Washington. Data was collected by walking along East – West transect lines spaced at 2 m. These were then intersected by North – South transect lines spaced at ~2 – 4 m (Fig. 3b). This provided a data density of ~2 points/m^2. The data was then interpolated to a regular grid using a LOES interpolation scheme with ~5-m horizontal smoothing (Plant et al. 2002) and stored as UTM, WA state plane north (see Fig. 3b).

Sediment Sampling

Sediment samples were obtained from the beach foreshore and berm, sampling both the surface and subsurface (Fig. 4). The surface sample was scraped to a depth of approximately one diameter of the surface material (~5 cm). If the sediment below was visually noted to be of the same grain size as the surface, no subsurface sample was taken. If not, a sample of the subsurface material was collected (~10-15 cm). All samples were collected above +0.0 MLLW. Sediment at lower elevations was always coarser and size estimates were noted.

Sediment samples were analyzed using standard grain-size analysis methods for coarse sediment. The smaller fraction of sediment (smaller than -4 phi, see Table 2 for grain-size scale) was sieved through progressively finer sieves, and the coarser grains were individually measured on the intermediate axis. The Wentworth (1922) grain-size classification scale is used here (Table 2). The median grain size (D_{50}) was obtained from the grain-size distribution and sorting estimates were obtained from the widths of grain-size distribution histograms. A small amount of fine-grained sediment (silt and clay) was retained and although in no sample was there enough to impact the distribution of sediment, the samples will be stored in our labs for potential future investigation.

Natural Forcing

Tidal Observations

Water-surface elevations for Seattle, WA were provided by the Center for Operational Oceanographic Products and Services' (CO-OPS) NOS station 9447130. Located at the downtown ferry terminal (47° 36.3' N, 122° 20.3' W), the tide gauge records primary and backup water-level variations every six minutes. Primary water-level observations from December 1, 2006 through January 31, 2008 were retrieved and small data gaps (e.g., <24 min) were interpolated. Observations were then converted to the MLLW datum, so the tidal data could be coupled with wind and wave gauge data (recorded at West Point and the OSP pocket beach, respectively) to reconstruct the natural forcing mechanisms acting on OSP's beach.

Figure 3a. Beach topography was collected using a Trimble R3 GPS receiver and an L1 antenna. Data was collected by walking along transect lines in the North-South and East-West directions. This grid provided a data density of ~2 pts/m^2.

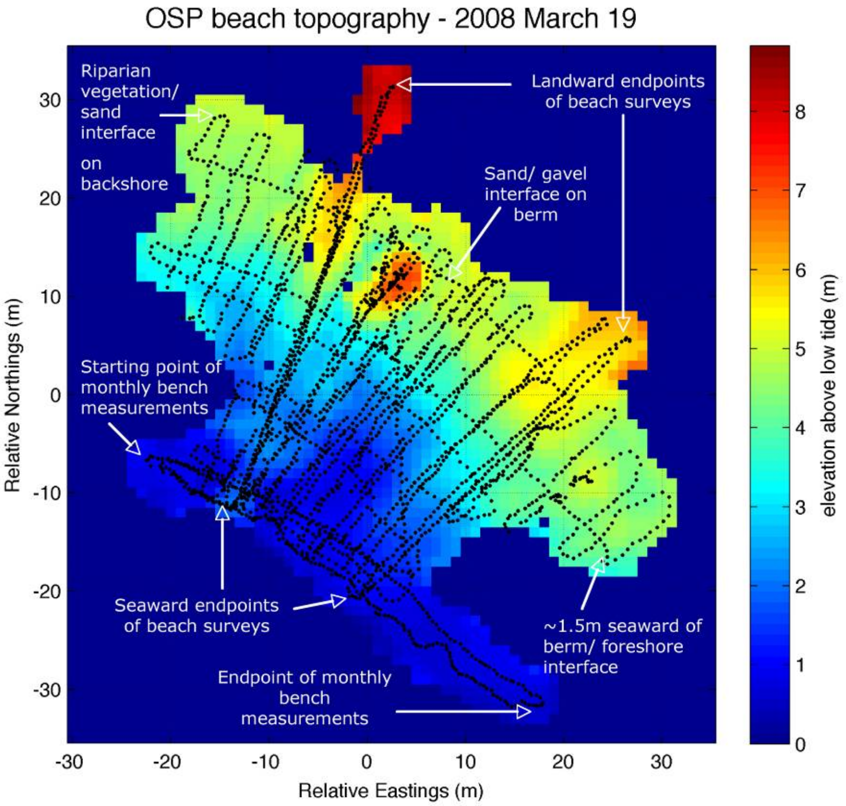


Figure 3b. The topography of the pocket beach was obtained on March 19, 2008. Black dots indicate data collection points and other features are noted. Note: variability in the berm and upper foreshore is due to the driftwood in those areas and elevations are relative to MLW.

Figure 4. Sediment samples were taken seasonally along the two beach survey transects (BS and BN). Samples were collected from the upper 5 cm where changes in size and sorting and/or changes in topographic features were observed. Subsurface samples were taken where the sediment below the surface clearly differed in size from the surface layer (as seen here).

Table 2. 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	-1.50	2.83
	-2.00	4.00
Pebble	-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

Wind Observations and Wave Monitoring

The National Data Buoy Center (NDBC) station WPOW1 (47° 39.44’ N 122° 26.09’ W) at West Point provided hourly wind direction and speed data from December 1, 2006-Janurary 31, 2008. Similar to the tidal data, data gaps smaller than 4 hrs were interpolated. Based on wind directions, wind speeds were then categorized into 16 directional bins (e.g., N, NNE, NE, ENE, E, etc.), so that an empirical wave hindcast method outlined in the *Shore Protection Manual* (SPM) (Coastal Engineering Research Center 1984) could be performed.

The deep-water wave height estimates in the SPM require a mean fetch length and average wind speed. Fetch was calculated by taking an average of 10 fetch lengths measured within a 30-degree wind bin (e.g., N, NNE, NE, ENE, E, etc.) and average wind speeds were provided by WPOW1. The resulting wave height (H_s) estimates were then used to reconstruct the wave climate between wave gauge deployments at OSP beach.

An Alec-P wave gauge (Fig. 5) was deployed at the base of the beach’s foreshore (47° 37.014' N, 122° 21.507' W) from January 20, 2007 to March 21, 2007, and from March 22, 2007 to April 19, 2007 to measure wave heights, wave periods and tidal effects acting on the beach’s foreshore and habitat bench during the winter storm season. The gauge was sampled to collect high-resolution data on waves with 4-7 sec periods (typical for Puget Sound). Following it’s third deployment on May 5, 2007 the instrument was not recovered and a DOBIE wave gauge was redeployed further seaward (47° 37.014' N, 122° 21.483' W) from November 1, 2007 – November 23, 2007 and again on December 4, 2007. Similar to the Alec-P wave gauge, the DOBIE wave gauge (Fig. 5) was sampled to collect high-resolution data on waves with 4-7 sec periods. This instrument was last recovered on April 11, 2008.

(Alec-P Wave Gauge)

(DOBIE Wave Gauge. Photo courtesy of http://www.niwa.cri.nz/rc/instrumentsystems/dobie).

Figure 5. An Alec-P wave gauge (top photo) and Dobie wave gauge (bottom photo) were deployed at the base of the beach's foreshore to measure water-surface elevation, and wave heights and periods that act on the beach's foreshore and habitat bench. The gauges were sampled to collect high-resolution data on waves with periods of 4-7 s (typical for Puget Sound). See Table 1 for the timeline of Alec-P and Dobie deployments, and Figure 1 for deployment locations.

Results

The complete set of monthly survey profiles of the beach and the habitat bench are shown together in Figures 6 and 7. In the following sections only the winter profiles are discussed so that comparisons of change can be drawn between the year 0 and year 1 conditions.

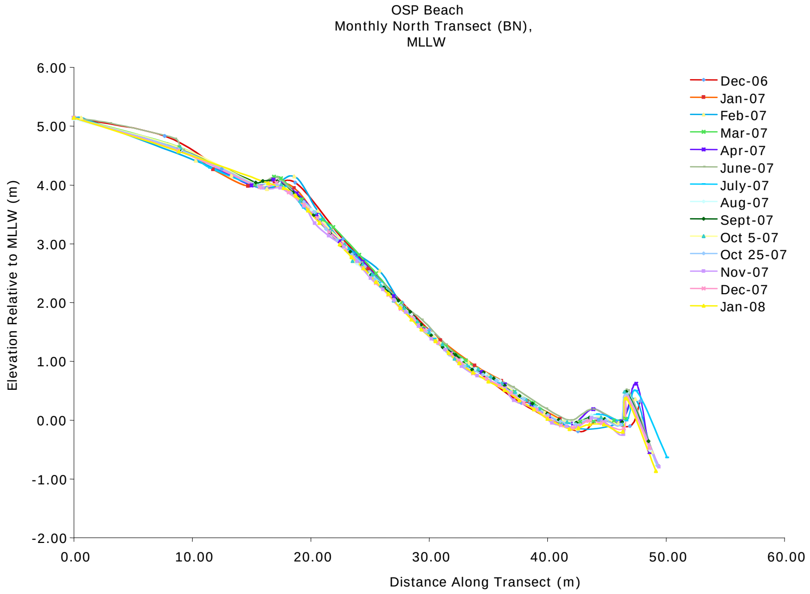
Initial Beach Profiles (year 0)

The initial (year 0) winter beach profiles were measured in January 2007 and February 2007. Although a survey was performed in December 2006, construction between December 2006 and January 2007 caused changes that are noted in the following. The discussion of the beach is divided into geomorphic units, as defined in Table 3 and shown in Figure 1b, consisting of the backshore, berm, upper foreshore, lower foreshore and central bench.

The surveys that make up the year 0 winter period (Fig. 8) showed significant temporal variations. On the north survey line, BN, between December 2006 and January 2007, the backshore, berm and upper foreshore all saw reduction in elevation. Construction activities were likely the cause of these changes. Between January and February 2007, natural processes acted to raise the berm by ~25 cm and moved it seaward by 2 m. Much of the upper foreshore was raised in elevation by about ~10-20 cm. The lower foreshore was relatively stable.

On the south survey line, BS (Fig. 8), major changes occurred in the backshore as the plantings were finished. Construction equipment was observed on the backshore, and continued construction was undoubtedly the cause of the upper beach changes. There was less change between January and February 2007. The berm increased in elevation between December 2006 and January 2007 (+15 cm) and decreased again between January and February 2007 (-20 cm) but stayed relatively stable in the horizontal direction. The upper foreshore increased in elevation by ~20 cm between January and February 2007. The lower foreshore also increased in elevation between December 2006 and January/February 2007 but to a lesser extent. There was little change over the winter in the central bench area at the base of the pocket beach.

Although the December 2007 survey occurred before most of the winter storms, it is not a good baseline survey. There were many changes observed between this survey and the January 2007 survey, but it is not possible to determine whether the changes were a result of the construction activities or natural processes. The multiple winter surveys indicate that elevations on the berm can change with variability of ~25 cm, and the berm crest location can shift horizontally by a couple of meters. Natural processes appear to have moved sediment onto the foreshore through the winter. Because the riprap limits the potential for the seaward transport of sediments, the origin of this sediment must be from the berm or from the side areas of the pocket beach. A small amount may have originated in the lower foreshore, but the lack of elevation change here makes it unlikely as the major source.



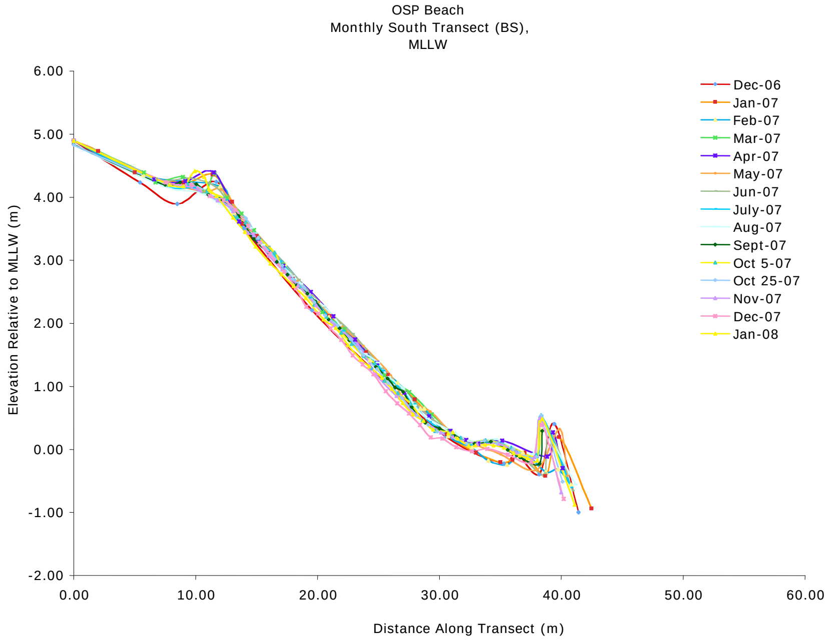


Figure 6. Monthly cross-shore profiles along the BN and BS transects of the pocket beach show elevation changes over the year. Each profile was measured from a fixed landward endpoint location on the sidewalk to the top of the riprap (transect length of ~48 m for BN and ~38 m for BS). Changes have primarily occurred in the berm location and along the foreshore of the beach. At the base of the lower foreshore on the central bench, mounds of coarse nourishment material were added post-construction (see Fig. 10). Slight changes in transect orientation cause variability in elevations of the nourishment mounds in this view. Note: datum is MLLW for all cross-shore and habitat bench profiles.

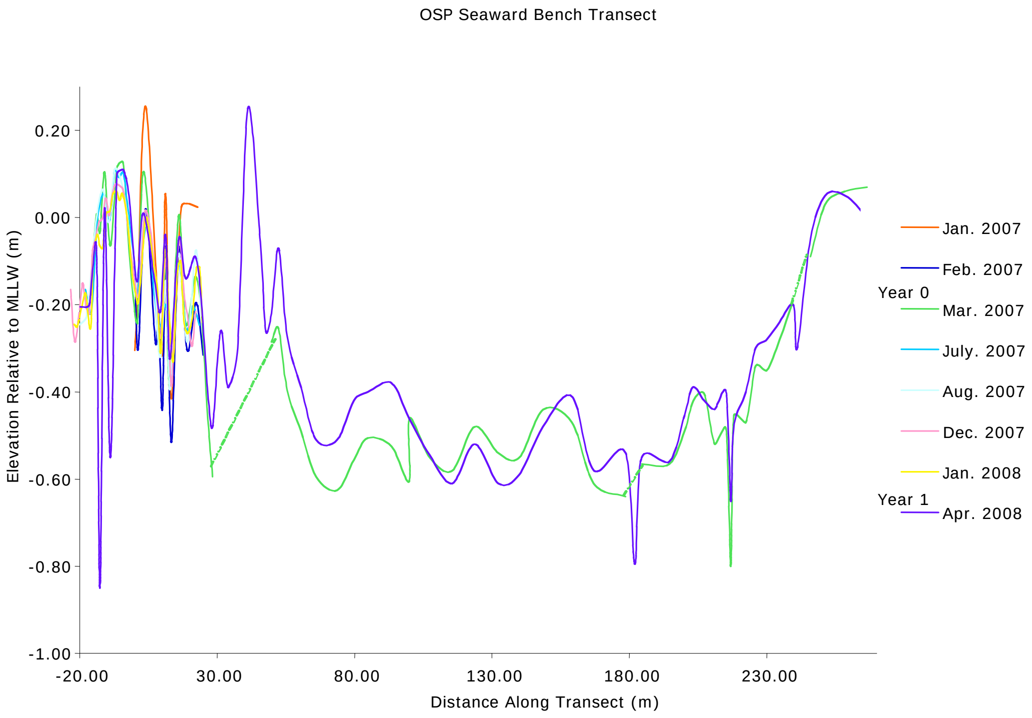


Figure 7. Alongshore profiles of the habitat bench. Full bench surveys were accomplished in March 2007 (year 0) and April 2008 (year 1) and partial surveys of the central bench coincided with monthly beach surveys (when possible). The full-length survey begins at the north base of the beach's foreshore to end of the bench (~286 m).

Table 3. Geomorphic units used to describe different regions of the beach profile at OSP.

Beach Profile Terminology	**Geographic Location on BN Transect**	
	Approximate Distance from Landward Endpoint Location (m)	**Approximate Elevation (Relative to MLLW) (m)**
Backshore	0 - +15.0	+5.1 – +4.0
Berm	+15.0 – +20.0	+4.0 – +3.6
Upper Foreshore	+20.0 - +32.0	+3.6 – +1.0
Lower Foreshore	+32.0 - +42.0	+1.0 – -0.2
Central Bench	+42.0 - +46.0	~-0.2

Beach Profile Terminology	**Geographic Location on BS Transect**	
	Approximate Distance from Landward Endpoint Location (m)	**Approximate Elevation (Relative to MLLW) (m)**
Backshore	0 - +8.0	+4.9 – +4.2
Berm	+8.0 - +13.0	+4.2 – +3.8
Upper Foreshore	+13.0 - +26.0	+3.8 – +1.0
Lower Foreshore	+26.0 - +32.0	+1.0 – +0.1
Central Bench	+32.0 - +38.0	~+0.1

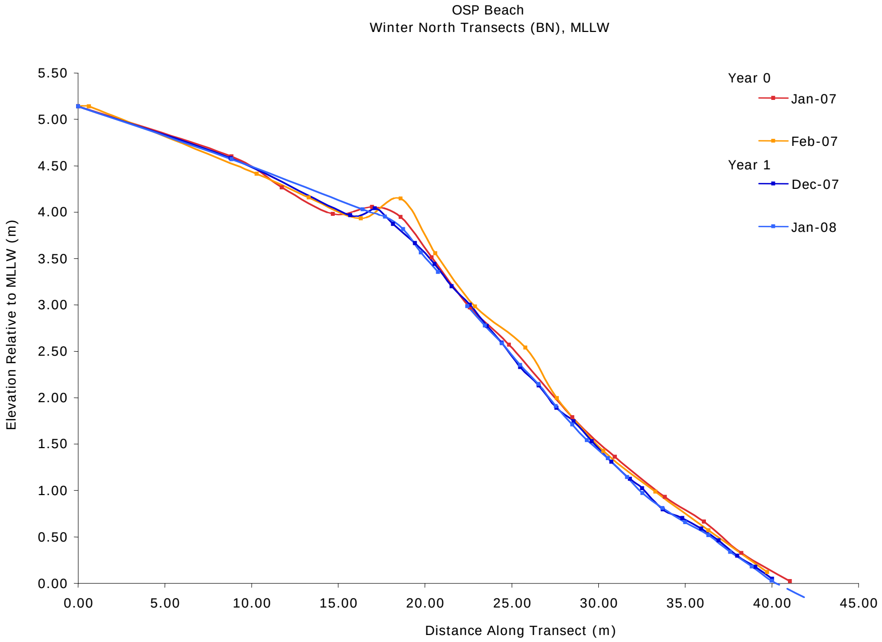


Figure 8. Winter cross-shore profile comparisons along BN and BS for the first winter season (year 0—January and February 2007) and second winter season (year 1—December 2007 and January 2008).

Beach Profile Changes (year 0 – year 1)

Comparison of the winter surveys between year 0 and year 1 show that the most significant changes in the beach profile occurred on the berm and upper foreshore. On the north survey line, BN, changes in the backshore were within the range of variability of the year 0 surveys (Fig. 8), but the berm moved landward by 1-2 m and was lowered by 10-20 cm. On the upper foreshore, there was an elevation reduction of ~10 cm throughout. Small-scale variations (e.g., mounding and development of banding of sediment grain sizes) were on the order of 2-3 cm, and although these variations are within the survey accuracy, they were clearly noted during surveys and were associated with grain-size variations (for example, see Fig. 2b).

On the south survey line, BS (Fig. 8), backshore changes were minimal, but the berm moved approximately 2 m landward of the berm location in the previous year. The elevation was initially at -0.5 m in year 0, and decreased in January 2008 to -0.7 m. The upper foreshore showed reduced elevations of ~10 cm relative to the previous year, and the lower foreshore was lower by ~15 cm. Between the winter surveys of January 2008 and March 2008, sediment was removed from the upper foreshore and supplied to the lower foreshore.

Initial Bench Survey (year 0)

The initial habitat bench survey was performed in March 2007. This was the first opportunity to access the bench during negative tides and daylight hours. The bench is ~286 m in expanse, and distances were measured from a point mid-width of the bench on transect line BS. The habitat bench generally ranged in elevation between -0.6 m and + 0.2 m (Fig. 9). There were some points (holes) on the south end of the bench that were lower in elevation where it appears that the habitat bed material was not placed level or settled following the installation. These holes extended down to -0.9 m depth. The habitat bench at the base of the pocket beach had an elevation that averages +0.05 m, and the rest of the bench to the south of the beach averaged -0.3 m in elevation. The width of the habitat bench (as defined by the distance between the riprap slope and the riprap toe) was estimated to range between ~0.9 m and ~5.4 m and averaged approximately ~3.5 m (see Fig. 1b).

Bench Profile Changes (year 0 – year 1)

The year 1 habitat bench survey was performed in April 2008. The range of elevation observations south of the pocket beach is similar for the year 1 survey as for the year 0 survey, indicating little change in the habitat bench elevation at distances of +50 m and greater along the transect (Fig. 9). The greatest observed changes occurred on the bench below the pocket beach (see below) and a section directly to the south (+30 m to +60 m, Fig. 9) where new riprap material was placed in February 2007. The riprap material covered much of the habitat bench over >30 m of distance. Differences at locations to the south of the repair area are likely due to minor differences in horizontal control on the irregular surface (i.e., whether or not the survey rod was placed on a locally high or low area of the irregular topography).

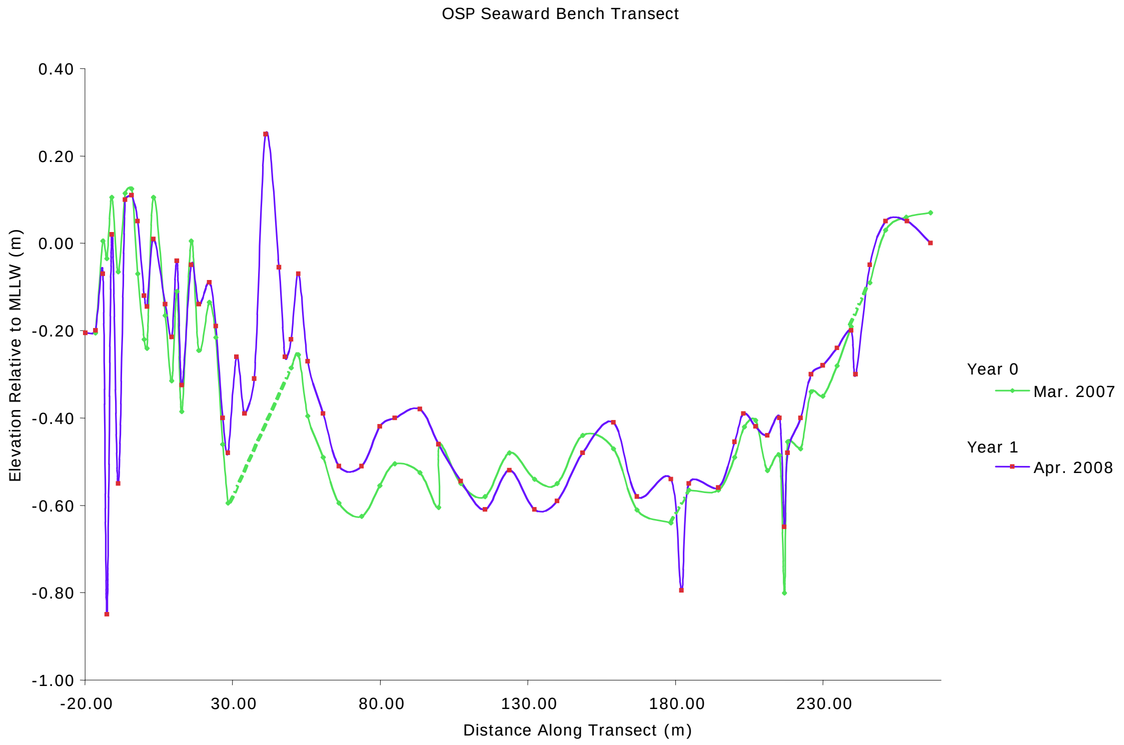


Figure 9. Alongshore profile comparison along the seaward transect of the habitat bench. Following the 2006-07 winter storm season, the riprap north of the seawall failed and 400 tons of riprap were added to the site. The March 2007 profile changed dramatically on the bench as a result of the riprap failure.

Changes in the central bench directly below the pocket beach were monitored monthly as part of the profile surveys (Fig. 10). These initial surveys showed relatively steeps mounds of sediment placed at the base of the beach. Over the summer, these mounds generally decreased in elevation. This can be seen in the temporal comparison of the height of the mounds, determined by differencing the elevation between the peaks and troughs of the four major mounds (Table 4).

Initial Sediment Grain Size Analysis (year 0)

Sediment samples were obtained in year 0, winter and summer, and year 1 winter. Data from the year 0 winter samples are difficult to evaluate due to continued construction and maintenance activities that occurred in winter 2006-07. Eight locations (four on BS and four on BN) provide consistent data for temporal comparison (Tables 5 and 6). Other sites sampled in year 0 winter provide insight into rapid post-construction changes.

On the surface of BN, initial sediment size on the upper foreshore in December 2006 ranged from –5.75 to –4.0 phi (D_{50} ~ 35 mm), and was relatively well sorted at profile locations designated as +22 m and +27 m (Fig. 11). Following the construction and storm activity in January 2007, the sediment at these locations was on average smaller (D_{50} ~ 11 mm), consisting of material between –5.75 and –2.5 phi and less well sorted. No samples were taken lower in the profiles.

Surface sediment at BS on the berm, and upper and lower foreshore in December 2006 was similar to that at BN, ranging from –5.75 to –4.5 phi (D_{50} ~ 37-43 mm), at profile locations designated +12 m, +18 m and +34 m (Fig.12). In January and February 2007, following construction and storm activity, the sediment at the berm and upper foreshore locations (+12 m and +17.5 m) was generally smaller (D_{50} ~ 12-29 mm), consisting of material between –6.0 and –2.5 phi. At all locations, grain size did not significantly change between January and February, but on the berm and upper foreshore, sorting increased.

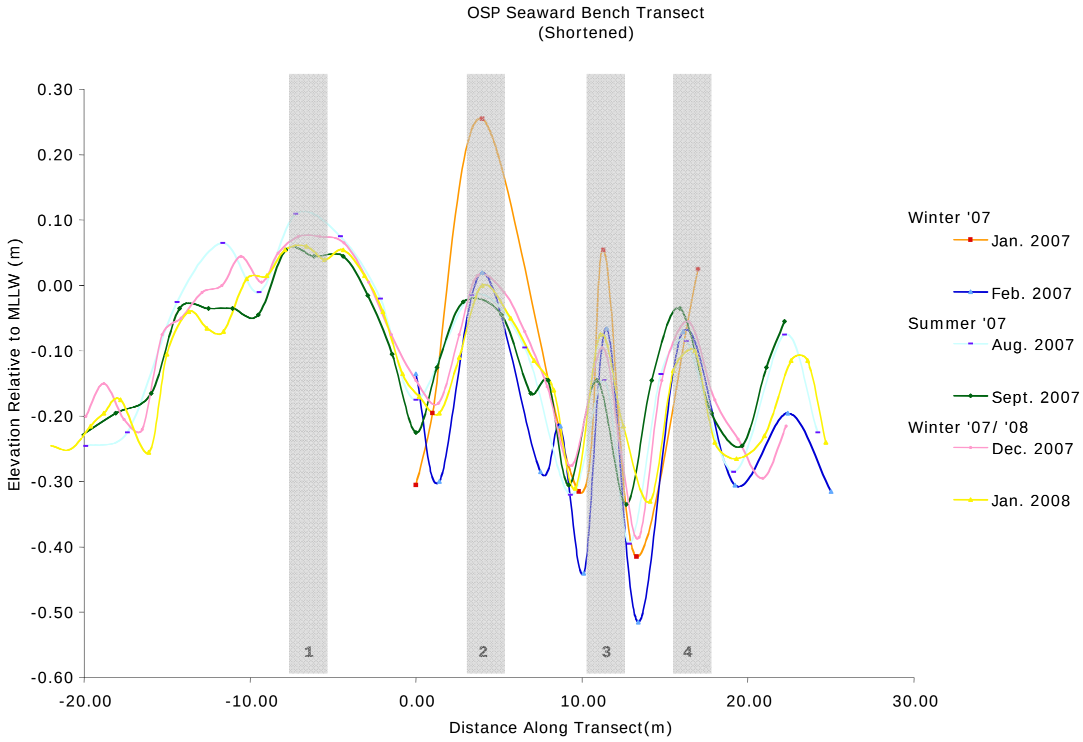


Figure 10. Alongshore profile comparison of the seaward transect on the central habitat bench. As highlighted by the grey bars, four mounds of sediment were added to the base of the beach's foreshore following construction of the pocket beach. In general, it can be seen that over time these mounds of sediment have flattened. (See Table 4 for changes in the height of the sediment mounds). Slight changes in transect orientation cause variability in the absolution elevation of the nourishment mounds in this view.

Table 4. Vertical change in the magnitude of the nourishment mounds on the Central Bench - Seaward transects. Mound heights are measured from the base of a mound's trough to the crest of the mound of sediment. Variations occur between surveys due to horizontal control of the survey line, but the trend is toward reduced height.

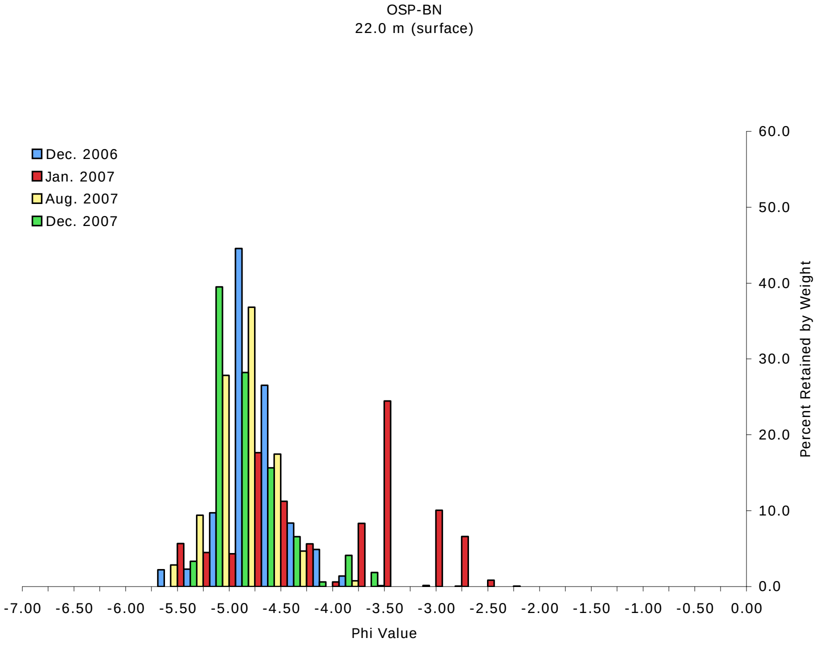
Mound	Date	Alongshore Distance (m)	Height of Mound along Survey Line (m)
1	August 2007	-7.2	0.34
	September 2007	-6.2	0.27
	December 2007	-7.1	0.30
	January 2008	-6.6	0.17
2	January 2007	+4.0	0.55
	February 2007	+4.0	0.25
	August 2007	+3.4	0.10
	September 2007	+2.9	0.27
	December 2007	+3.7	0.31
	January 2008	+4.0	0.30
3	January 2007	+11.3	0.44
	February 2007	+11.5	0.32
	August 2007	+11.4	0.54
	September 2007	+10.9	0.24
	December 2007	+11.2	0.29
	January 2008	+11.1	0.31
4	January 2007	+17.0	0.35
	February 2007	+16.1	0.26
	August 2007	+16.3	0.24
	September 2007	+15.9	0.29
	December 2007	+16.4	0.27
	January 2008	+16.8	0.23

Table 5. Sediment grain-size parameters from year 0 (December 2006, and January and February 2007) through year 1 (December 2007) for BN transect. The position of the sediment sample is relative to the landward endpoint of the transect, and upper and lower refer to the upper and lower foreshore. For temporal comparison purposes, spatial groups of samples were given a sample designation.

		Position on profile (m) and geomorphic unit	**Designation (m)**	**Sample Type**		**D_{50} (mm)**
				Surface	**Sub-surface**	
Year 0	Dec. 6, 2006	22.4 upper	+22	X		33.1
		27.2 upper	+27	X		38.7
	Jan. 20, 2007	17.6 berm		X		33.0
		21.7 upper	+22	X		15.9
	Feb. 15, 2007	20.3 berm		X		26.6
		24.3 upper		X		8.0
		27.7 upper	+27	X		31.5
	Aug. 10, 2007	22.0 upper	+22	X		30.5
		22.0 upper			X	6.9
		27.5 upper	+27	X		32.1
		27.5 upper			X	8.5
		35.0 lower	+35	X		49.8
		44.0 lower	+43	X		45.3
Year 1	Dec. 11, 2007	21.0 upper	+22	X		30.6
		21.0 upper			X	19.2
		26.5 upper	+27	X		36.4
		26.5 upper			X	7.3
		34.0 lower	+35	X		52.4
		34.0 lower			X	13.4
		43.0 lower	+43	X		66.8
		43.0 lower			X	47.1

Table 6. Sediment grain-size parameters from year 0 (December 2006, and January and February 2007) through year 1 (January 2007) for BS transect. The position of the sediment sample is relative to the landward endpoint of the transect, and upper and lower refer to the upper and lower foreshore. For temporal comparison purposes, spatial groups of samples were given a sample designation.

		Position on profile (m) and geomorphic unit	**Designation (m)**	**Sample Type**		**D_{50} (mm)**
				Surface	**Sub-surface**	
Year 0	Dec. 6, 2006	8.5 berm		X		8.5
		11.6 berm	+12	X		36.6
		19.6 upper	+17.5	X		41.9
		30.5 lower	+34	X		43.8
	Jan. 20, 2007	13.0 berm	+12	X		12.0
		17.7 upper	+17.5	X		29.2
		24.4 upper	+24.4	X		36.4
	Feb. 15, 2007	13.5 berm	+12	X		11.4
		17.7 upper	+17.5	X		32.0
		22.6 upper	+24.4	X		40.8
	Aug. 10, 2007	12.0 berm	+12	X		20.2
		18.5 upper	+17.5	X		35.5
		18.5 upper			X	9.5
		25.5 upper	+24.4	X		48.0
		25.5 upper			X	7.9
		35.0 lower	+34	X		44.9
Year 1	Dec. 11, 2007	11.0 berm	+12	X		39.2
		11.0 berm	+12		X	24.8
		17.5 upper	+17.5	X		31.3
		17.5 upper			X	6.9
		21.5 upper	+17.5	X		39.5
		21.5 upper			X	7.6
		34.0 upper	+34	X		50.8
		34.0 upper			X	37.6



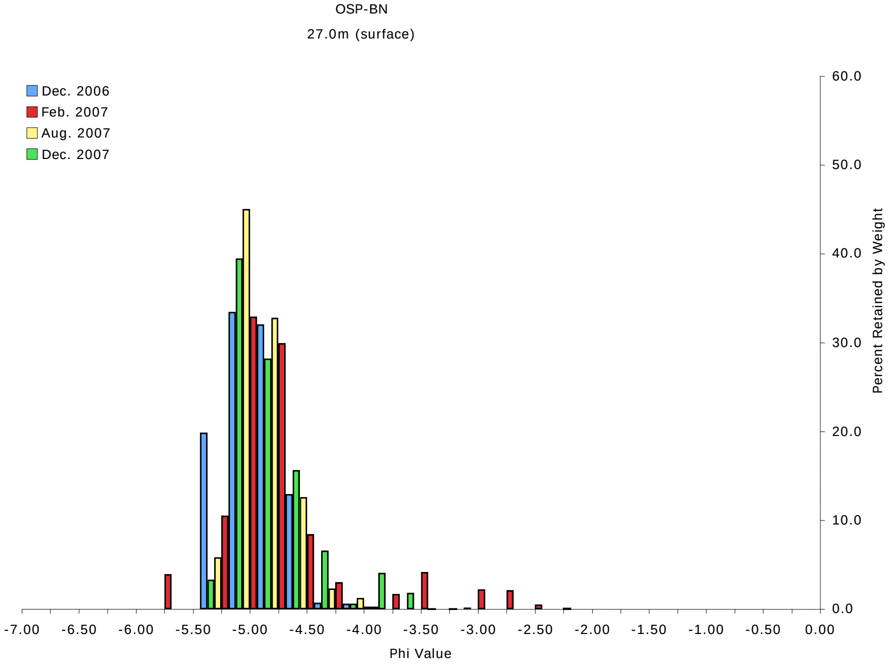
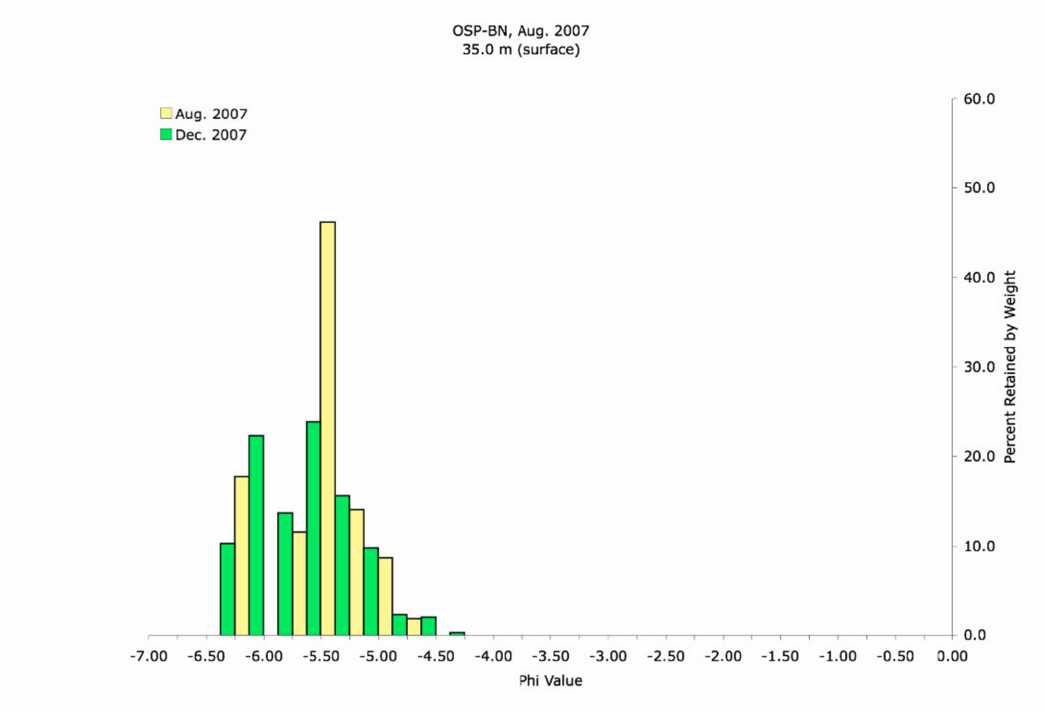
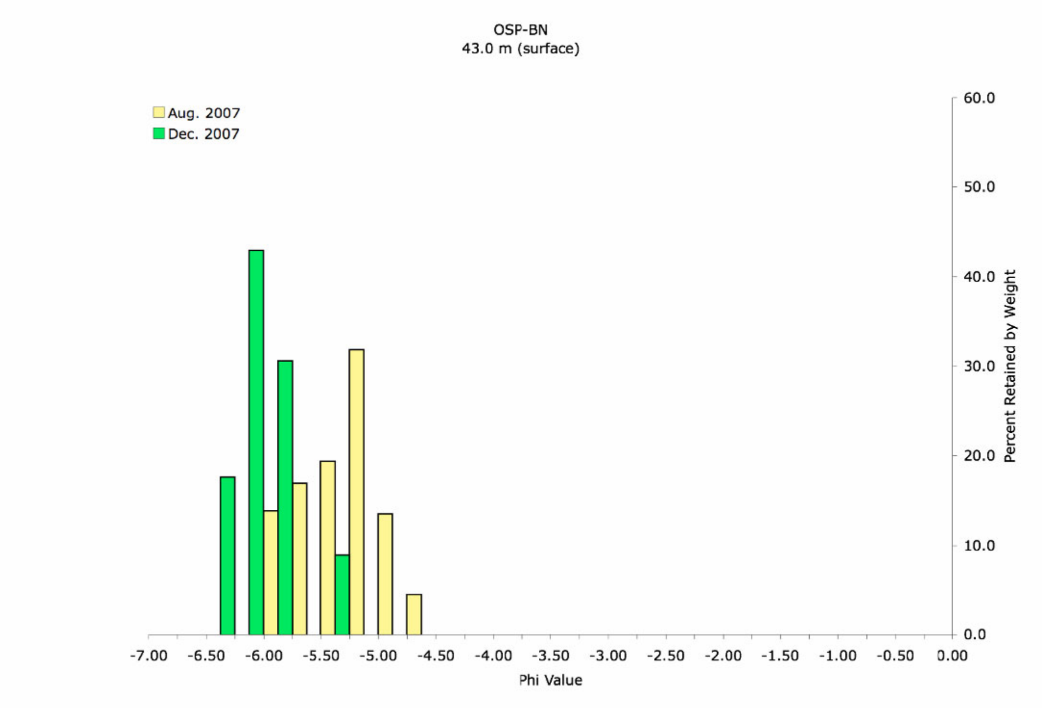
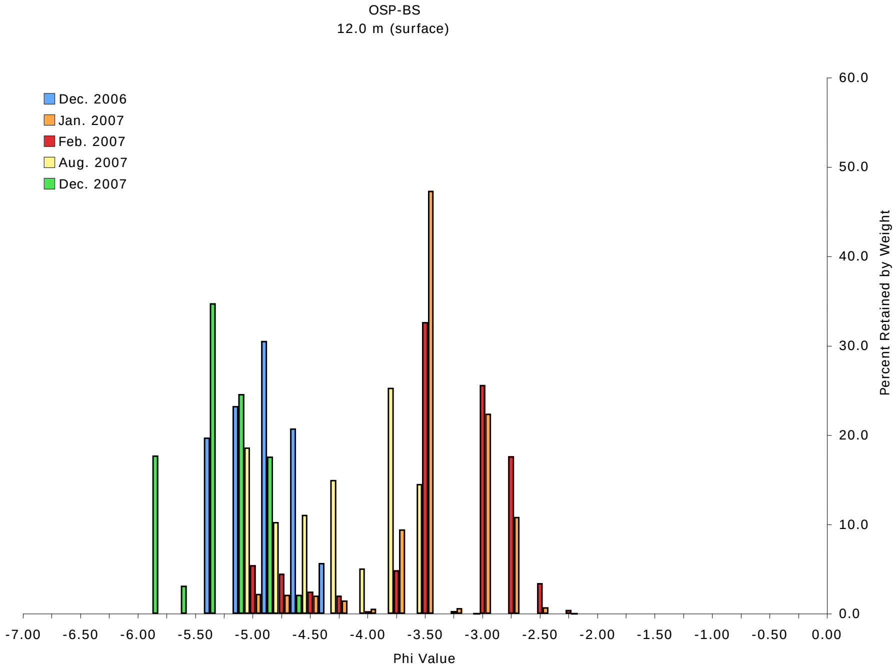


Figure 11. Surface sediment grain-size distributions along the BN transect of the pocket beach. Sediment samples were collected from the upper 5 cm where changes in size and sorting and/or variations in topographic features were observed.

(Figure 11 cont).







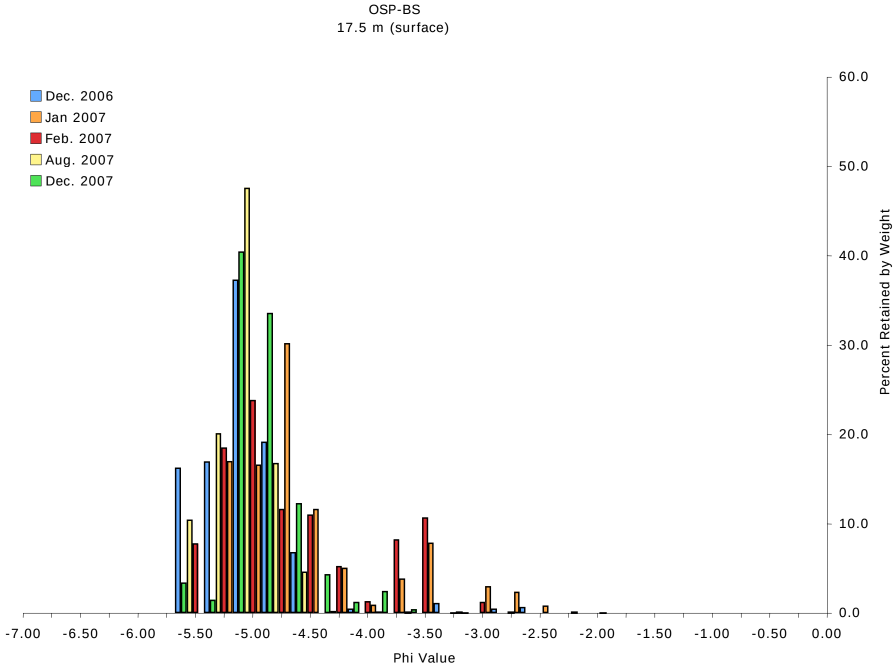
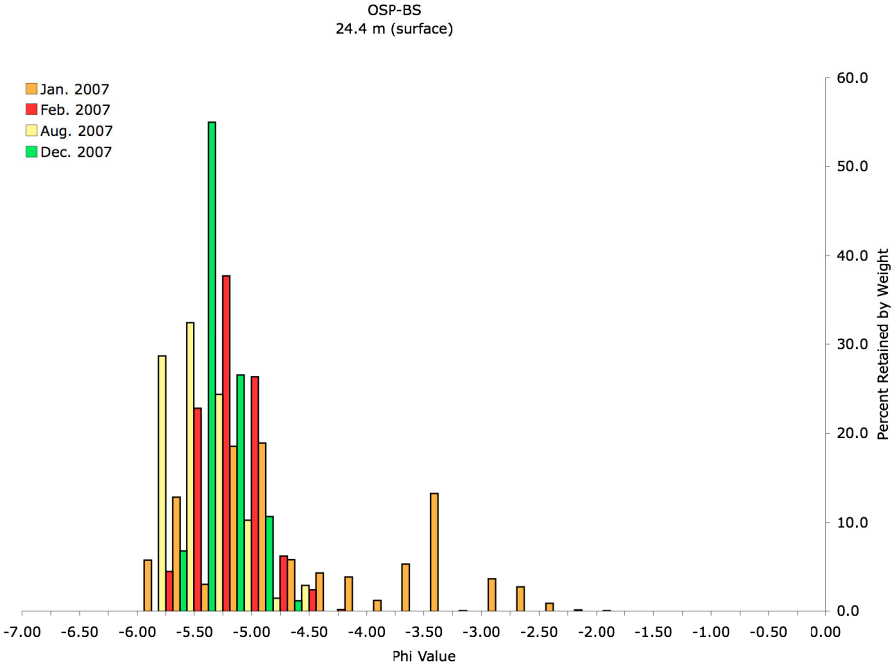
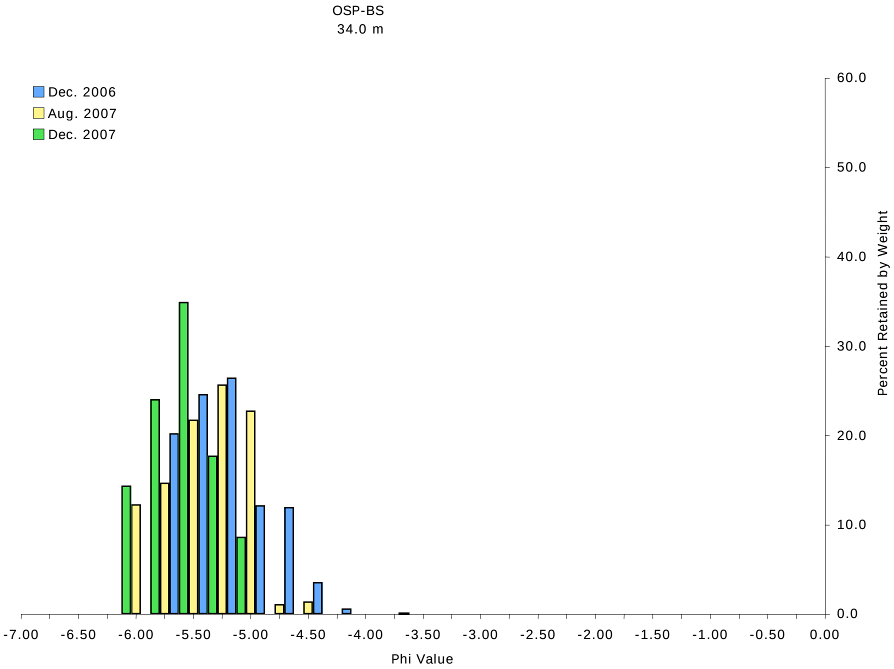


Figure 12. Surface sediment grain-size distributions along the BS transect of the pocket beach. Sediment samples were collected from the upper 5 cm where changes in size and sorting and/or variations in topographic features were observed.

(Figure 12 cont).





Grain Size Changes (year 0 – year 1)

Surface Sediment

Over the following summer and into the winter of 2007-2008, grain size changes were monitored. Temporally variable banding in grain size on the upper foreshore were evident during the monthly surveys, indicating active reorganization of surface sediment.

On the upper foreshore of BN, the sediment size distribution became better sorted over the summer and into the winter of year 1. The smaller particles were lost from the surface sediment. At the upper location (+22 m), the sediment became significantly coarser, creating a relatively consistent grain-size distribution across the upper foreshore (Fig. 11).

On the berm (+12 m) of BS, the grain size changed significantly between year 0 and year 1 (Fig. 12) with evolution from the finer grain sizes ($D_{50} \sim 12$ mm) in the post construction period (January/February 2007) to a coarser grain size ($D_{50} \sim 39$ mm) in the winter of year 1 (December 2007). On the upper foreshore the grain size was slightly coarser and better sorted over the 2007 summer months, losing the finer pebble-sized sediment and generally becoming less coarse into winter of year 1. On the lower foreshore, the grain size appeared to have coarsened between year 0 and year 1. Visual observations have noted that the surface sediment on the upper foreshore, although remaining fairly consistent in grain size, has become thinner.

Sub-surface Sediment

The sub-surface sediment was distinctly different from the surface sediment on the upper foreshore, but not on the berm or lower foreshore (Fig. 13 and 14). On the upper foreshore, the sub-surface was smaller in grain size ranging from -4.0 to -1.5 phi ($D_{50} \sim$ 7-9 mm) where sorting was higher (Tables 5 and 6). Where a sub-surface grain-size change was observed on the lower foreshore, the sub-surface material appeared to be finer than the surface sediment, but more mixed with coarser particles, creating a sub-surface grain-size distribution that was coarser on average, and less well sorted. Temporal change is difficult to evaluate, but did not appear to be significant.

Natural Forcing

Tidal Observations

Tides in Puget Sound are mixed semidiurnal and are characterized by diurnal (24 hour) and semidiurnal (12.4 hour) components. This relationship produces two nearly equal high water levels and two unequal low water levels each day. The average tidal range between MLLW and mean higher high water (MHHW) is 5.88 m (http://tidesandcurrents.noaa.gov/). Differences in the high and low water levels are larger during spring tides (e.g., when the tidal range is at its greatest) and smaller during neap tides and vary with a fortnightly cycle. During December and June (i.e., winter and summer solstices, respectively) extreme tidal elevations are at a maximum. Over time, the cumulative interaction between the tidal components produces an upward skew in the distribution of water level observations (Fig. 15) (see also Finlayson 2006), significantly impacting the duration of time different beach elevations are subject to wind- and wave-driven processes.

Wind Observations and Wave Monitoring
The wind intensity and direction in Puget Sound also have seasonal cycles. During the winter months of this study (October-March), winds dominated from the S, SSE, and SSW, and during the summer months (April- September) winds dominated from the NNE, N, and NE directions (Fig. 16 and 17, respectively). Because southerly winds (winds from the south) are generated by low pressure systems from the Pacific Ocean, the wind speeds are higher than for the northerly winds (winds from the north) that are generated from high pressure systems (e.g., fair-weather conditions) in NW Canada or Northern California and Oregon (Finlayson 2006). In the Sound these seasonal wind patterns are an important natural forcing mechanism on the local wave climate.

Because Puget Sound is protected from the Pacific Ocean, there is no long-period ocean swell, and waves are tightly coupled to the wind speed and directions. As a consequence, waves are fetch-limited and lower energy than open ocean waves. At the OSP beach the waves are controlled by the beach's orientation and the physiographic constraints of Elliot Bay and dominate from the SE-SW directions (Fig. 16 and 17). Because of the smaller fetch lengths, observed wave heights were low (e.g., ranged from 0 to 0.4 m) and increased when winds were energetic along the beach's longer fetch lengths (e.g., WNW, W, WSW, and SW directions). This was observed five times during the January 2007 deployment of the Alec-P wave gauge and once during the March 2007 deployment of the Alec-P wave gauge (Fig. 18). When winds were relatively calm, wave heights were generally observed to be 0.2 m or less. These values have a contribution from non-wind-driven waves such as vessel wakes.

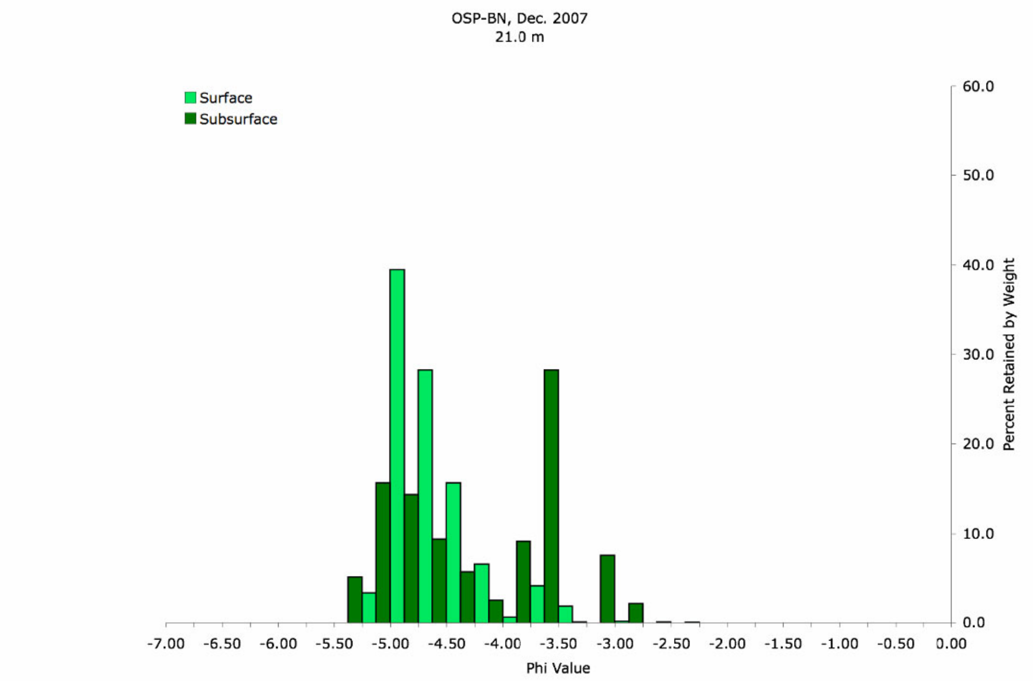
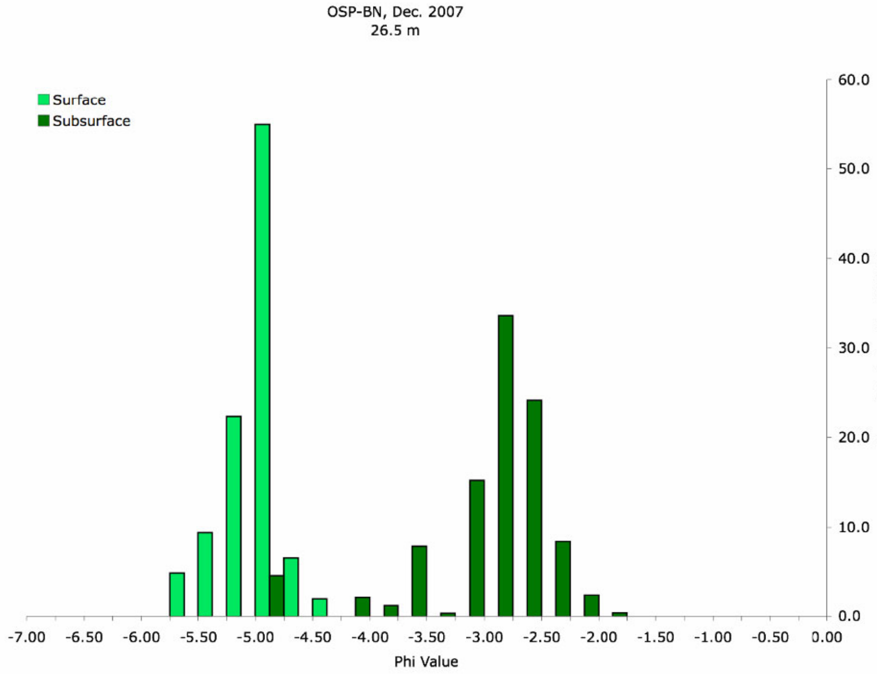
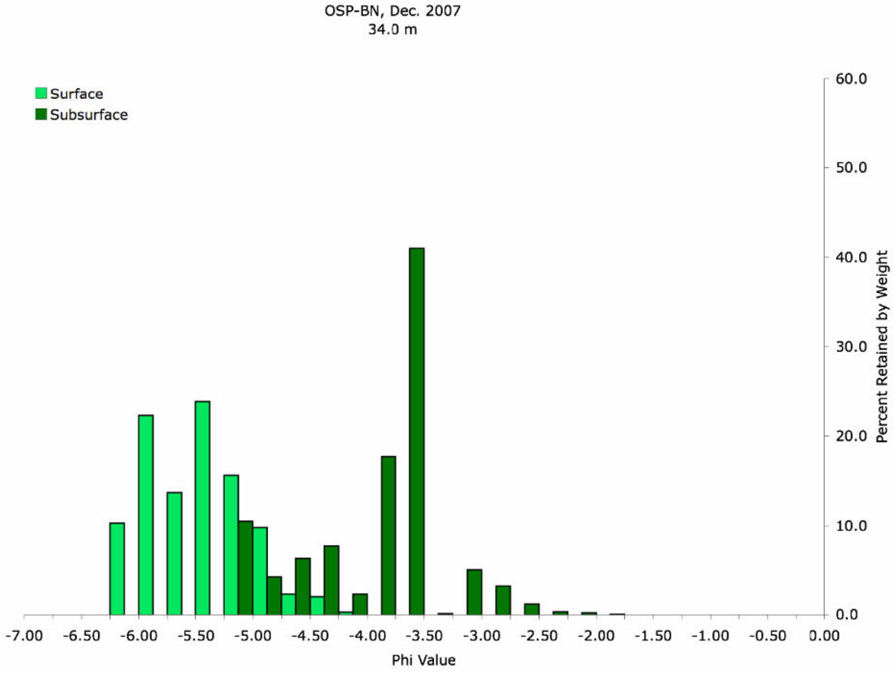
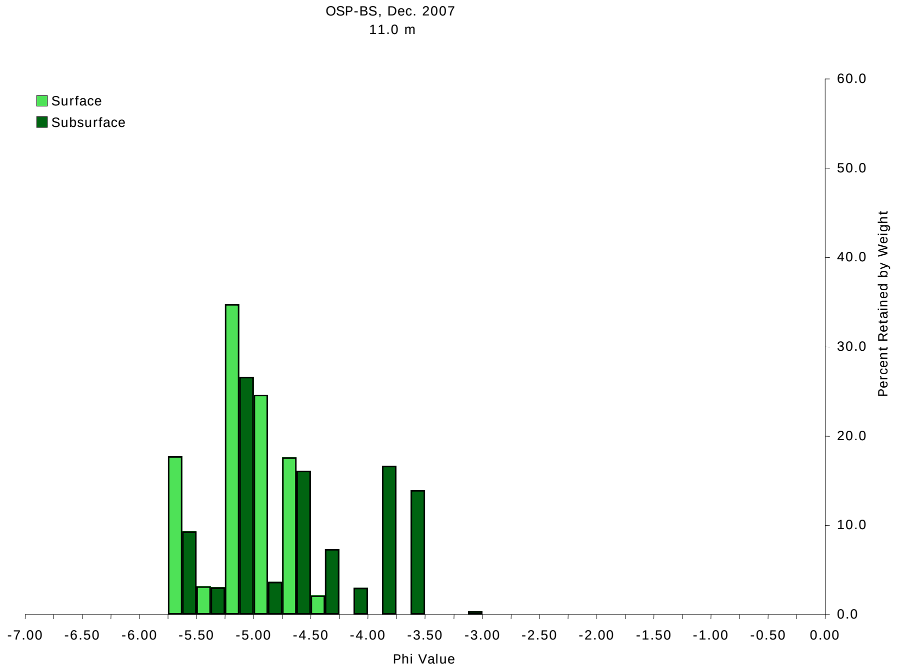


Figure 13. Surface and subsurface grain-size sediment distributions along the BN transect of the pocket beach. Sediment samples were collected from the upper 5 cm (surface) and ~10-15 cm (subsurface) where changes in size and sorting and/or variations in topographic features were observed.

(Figure 13 cont).







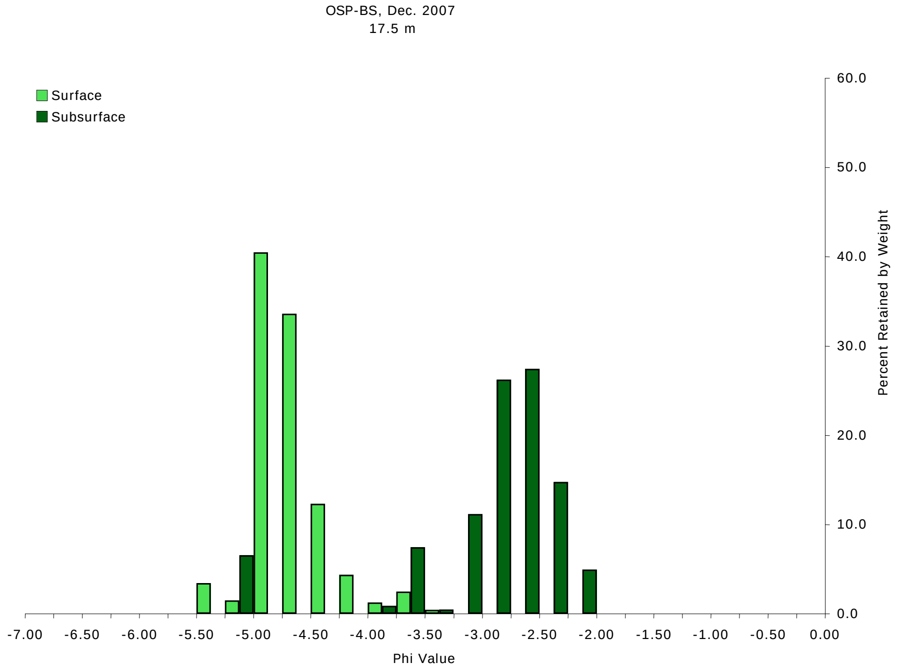
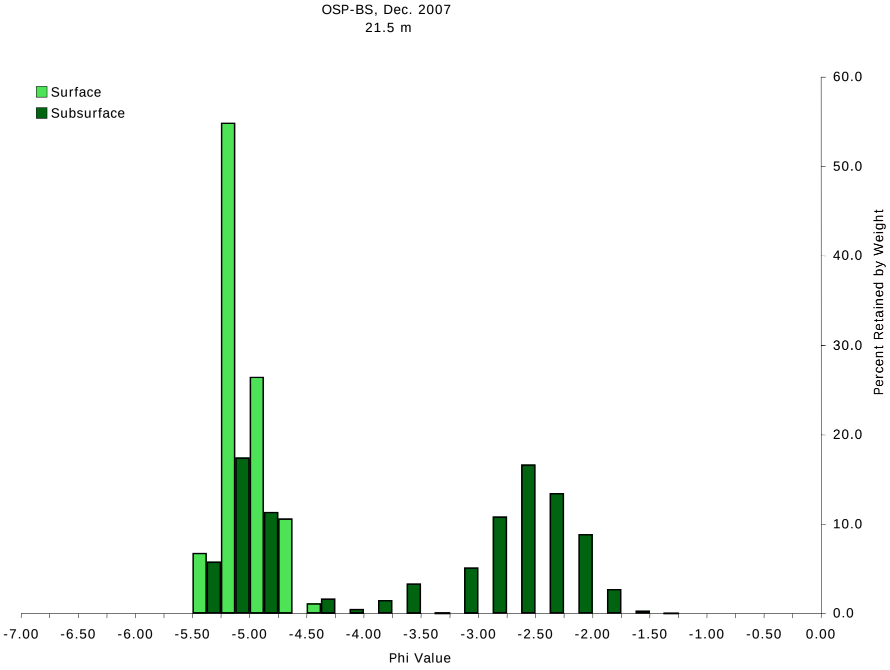
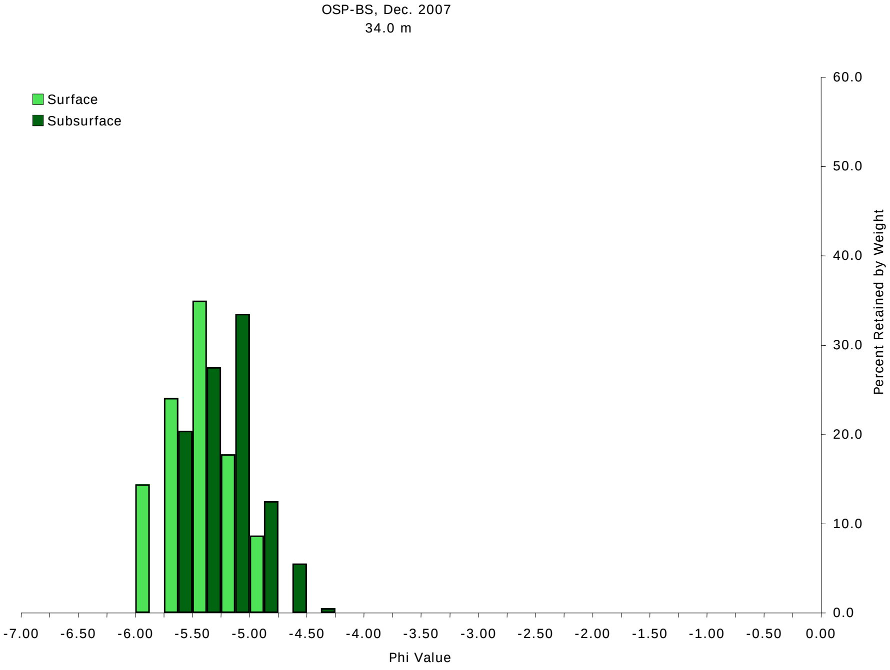


Figure 14. Surface and subsurface grain-size sediment distributions along the BS transect of the pocket beach. Sediment samples were collected from the upper 5 cm (surface) and ~10-15 cm (subsurface) where changes in size and sorting and/or variations in topographic features were observed.

(Figure 14 cont).





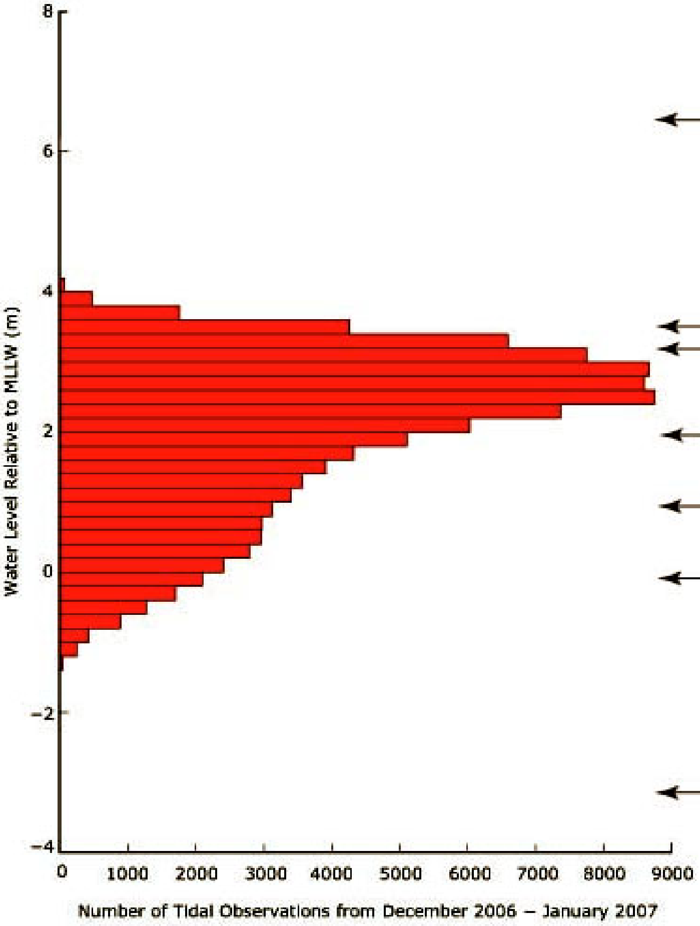


Figure 15. Surface water-level histogram and associated tidal datum for Seattle, WA (CO-OPS NOS Station 9447130) from December 2006 – January 2008. Tidal datum is relative to MLLW.

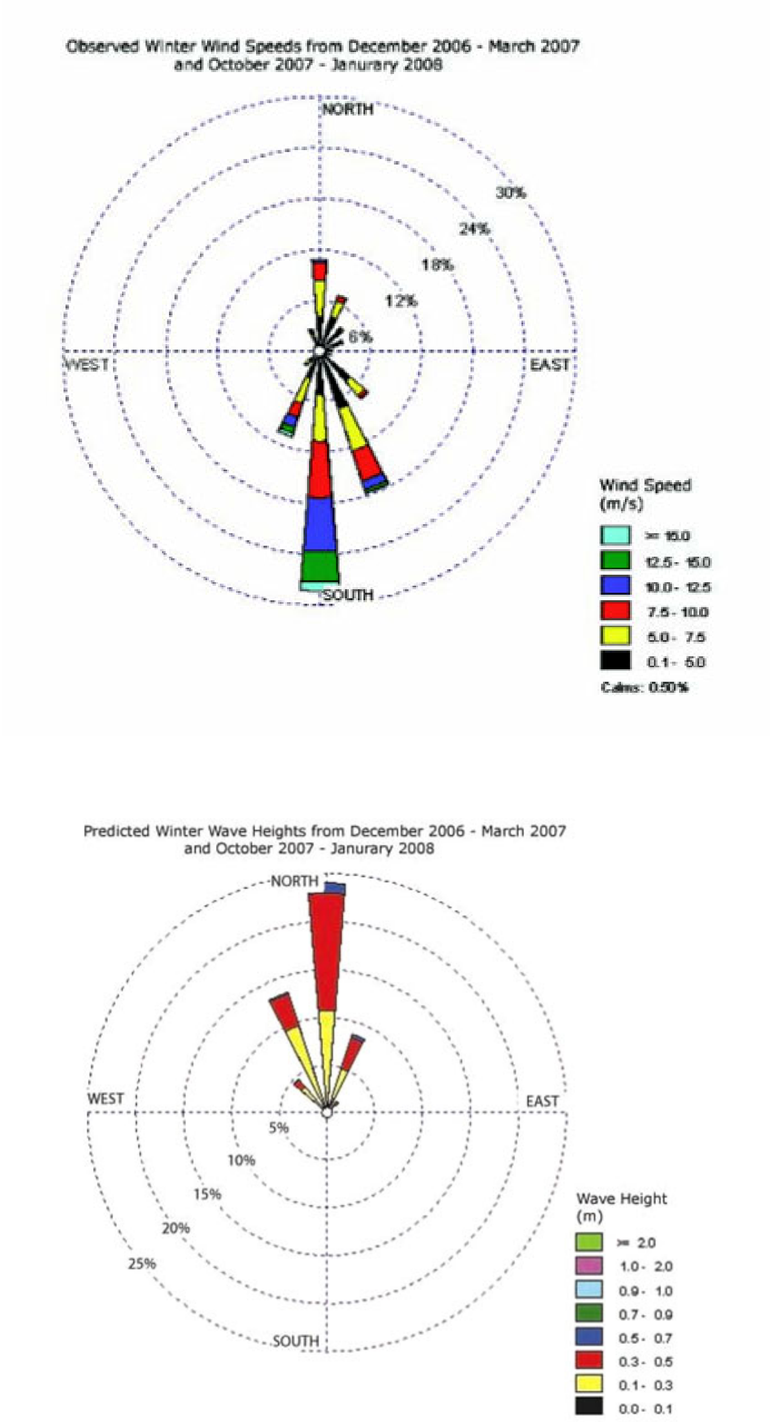
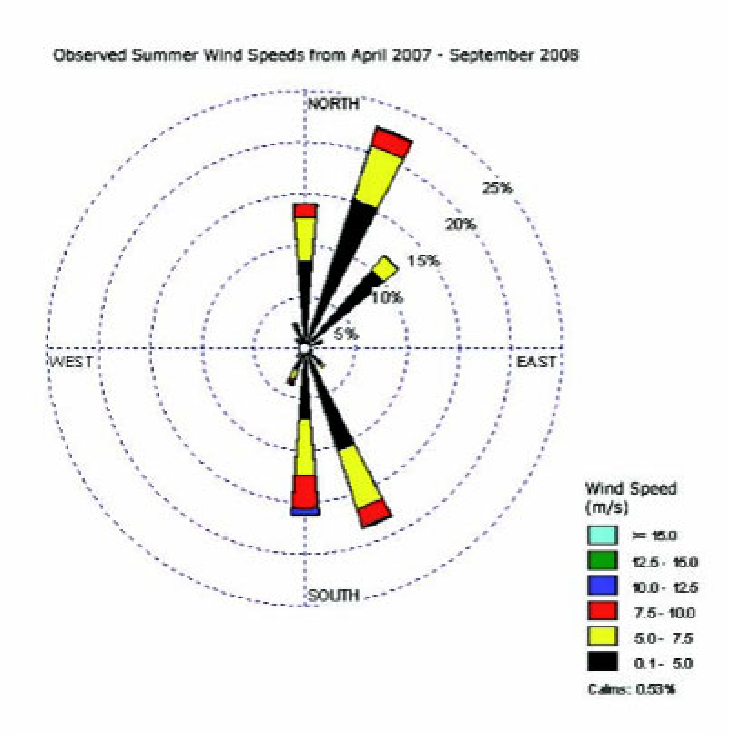


Figure 16. Rose diagram of winter winds and winter waves. The wind conditions were obtained from National Data Buoy Center (NDBC) station WPOW1 at West Point, and wave heights were predicted from the observed wind data and measured fetch. Note that the strongest and most frequent winds and waves come from the south.



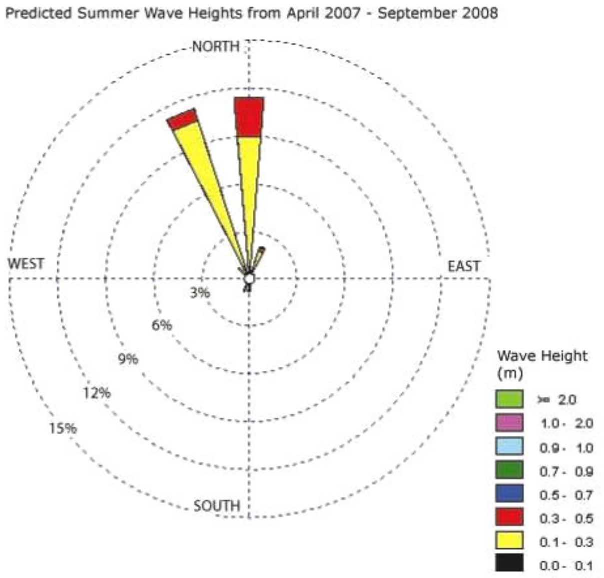


Figure 17. Rose diagram of summer winds and waves. The wind data and wave calculations were obtained in the same manner as for Figure 16. Note that in the summer, winds are generally weaker from both the south and the north where the fetch is near zero for the OSP pocket beach. This results in low wave heights through most of summer.

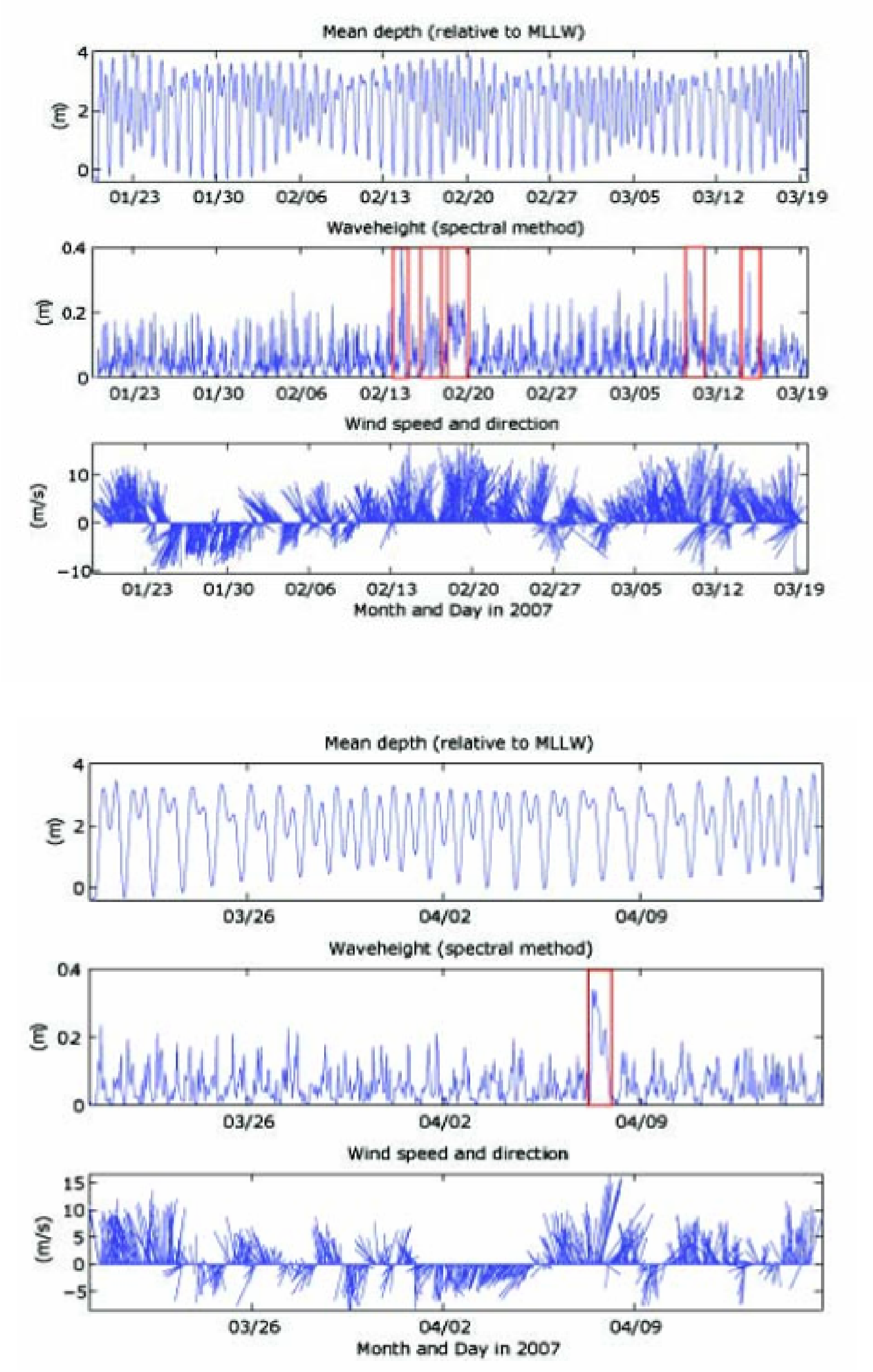


Figure 18. Data collected from an Alec-P wave gauge deployed at OSP. The tides are mixed semidiurnal. The magnitudes of the wave heights are affected by the speed and duration of the winds and the water-surface elevation over the wave gauge. Storm periods (highlighted in the red boxes) increase the wave heights at the beach. Wave periods are typically short, ranging from 1.4 to 3 s.

Discussion and Conclusions

Analysis of Beach Profile Change

The analysis of the change in cross-sectional area on transects BS and BN were obtained by differencing the subsequent beach profile surveys. Overall (between year 0 and year 1 surveys), the volume of sediment along these two transects has declined (Table 7 and 8, and Fig. 19). Survey datum errors probably contribute significantly to the vertical rate of change between any two surveys, but the trend over the year of data collection (Fig. 19) is robust. In both beach survey transects, sediment appears to have been lost after June 2007 and again in October – November 2007. We interpret these changes to be associated with anthropogenic (June 2007) and wave-driven causes (October – November 2007), which are discussed below.

Table 7. Vertical rate of change (m^2/survey) for OSP-BN transect, relative to previous profile survey. Positive numbers indicate accretion, negative numbers indicate erosion. Large differences between individual surveys may result from datum ambiguity, but the long-term trends are toward a reduction in cross-sectional area of the beach. Area calculations extend from the sand/pebble interface of the backshore (+15.0 m) seaward to +0.0 MLLW.

	Date	**Area (m^2)**	**Vertical Rate of Change (m^2/survey)**	**Cumulative Rate of Change Since Initial Survey (m^2)**
Year 0	Dec. 6, 2006	150.16	0.00	0.00
	Jan. 20, 2007	---	---	---
	Feb. 15, 2007	150.10	-0.06	-0.06
	Mar. 22, 2007	150.51	0.41	0.35
	Apr. 21, 2007	149.29	-1.22	-0.87
	May 19, 2007	---	---	---
	June 19, 2007	150.62	1.33	0.47
	July 11, 2007	148.82	-1.80	-1.34
	Aug. 10, 2007	149.23	0.41	-0.93
	Sept. 7, 2007	149.29	0.06	-0.87
	Oct. 5, 2007	149.30	0.01	-0.86
	Oct. 25, 2007	148.63	-0.67	-1.53
	Nov. 23, 2007	147.09	-1.54	-3.07
	Dec. 11, 2007	147.79	0.70	-2.37
Year 1	Jan. 21, 2008	147.83	0.04	-2.33

Table 8. Vertical rate of change (m^2/survey) for OSP-BS transect, relative to previous profile survey. Positive numbers indicate accretion, negative numbers indicate erosion. Large differences between individual surveys may result from datum ambiguity, but the long-term trends are realistic. Area calculations extend from the sand/pebble interface of the backshore (+8.0 m) seaward to +0.0 MLLW.

	Date	**Area (m^2)**	**Vertical Rate of Change (m^2/survey)**	**Cumulative Rate of Change Since Initial Survey (m^2)**
	Dec. 6, 2006	110.46	---	---
Year 0	Jan. 20, 2007	114.24	0.00	0.00
	Feb. 15, 2007	113.87	-0.37	-0.37
	Mar. 22, 2007	---	---	---
	Apr. 21, 2007	114.84	0.98	0.60
	May 19, 2007	114.50	-0.34	0.26
	June 19, 2007	115.05	0.54	0.81
	July 11, 2007	112.97	-2.08	-1.27
	Aug. 10, 2007	113.22	0.25	-1.02
	Sept. 7, 2007	112.65	-0.57	-1.59
	Oct. 5, 2007	112.49	-0.16	-1.43
	Oct. 25, 2007	112.72	-4.08	-1.52
	Nov. 23, 2007	111.93	-0.80	-2.3
	Dec. 11, 2007	110.17	-1.76	-4.07
Year 1	Jan. 21, 2008	111.21	1.04	-3.03

Profile Vulnerability

Different regions on the cross-sectional profiles are more or less vulnerable to sediment transport on the beach surface and therefore have differing amounts of sediment loss or gain. The berm is highly mobile and shows change between surveys on the order of 10-20 cm in elevation and horizontal movement of the crest of a few meters. Consistent with other studies (e.g., Finalyson 2006), the driftwood on the berm appears to help stabilize local areas and acts as a trap for sediment that is moved from the foreshore during extreme tidal and storm surge conditions. The driftwood is likely an active participant in maintaining sediment storage in the berm (see Fig. 20a).

Much of the cross-sectional area lost between year 0 and year 1 came from the berm and upper foreshore. The sediment on the upper foreshore is highly mobile, as seen in the temporary sorting of sediments (banding of sediment grain size, see Fig. 20b and 20c). This is the zone where water-surface elevations in Puget Sound occur most frequently due to the tidal components (Fig. 15) and is therefore the zone that experiences processes associated with the swash zone, such as active wave breaking, runup, and groundwater discharge.

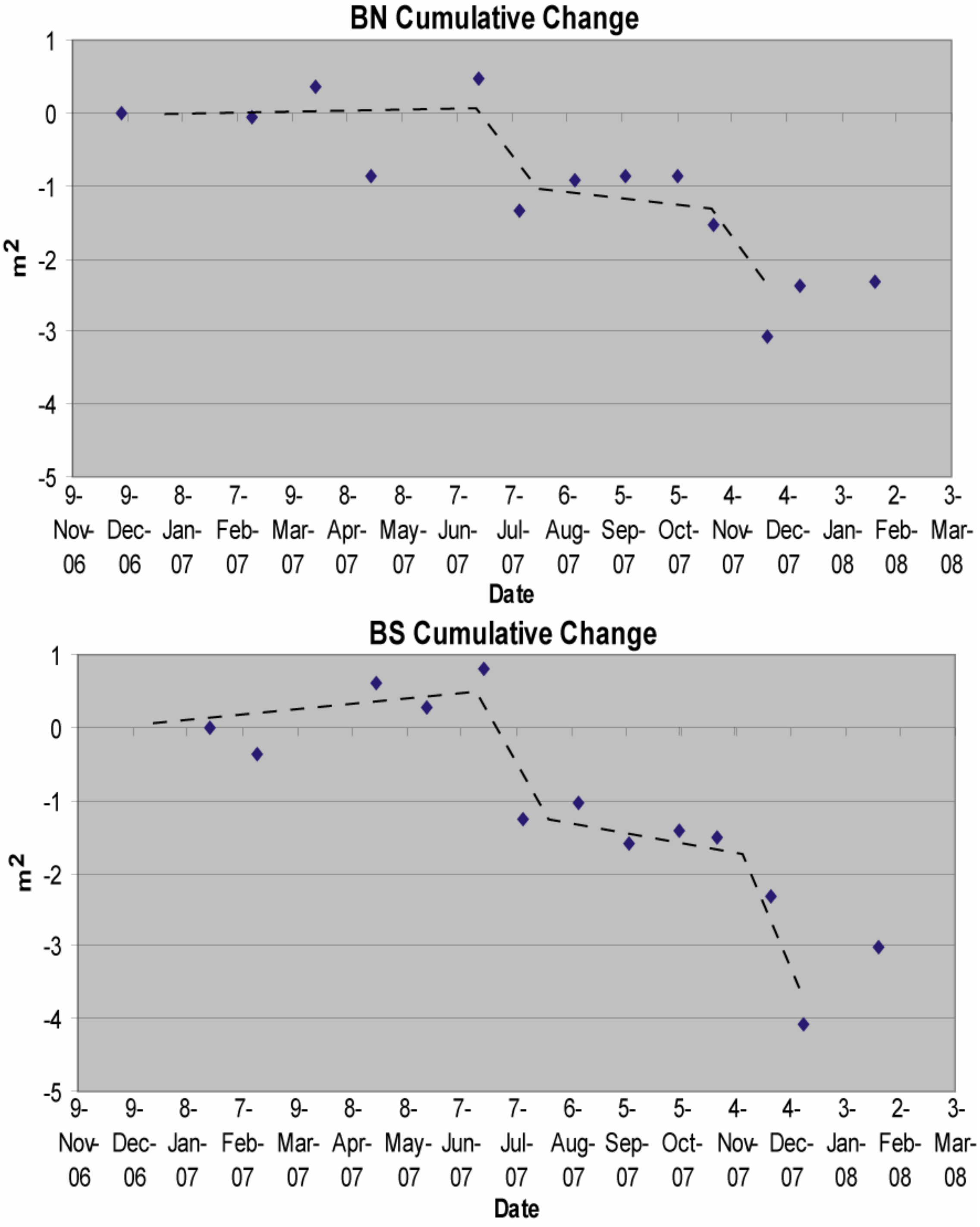


Figure 19. Cumulative rate of change of cross-sectional area of the beach at BN and BS. Although comparison between any two individual surveys may be subject to datum errors, the net trend is robust. The dashed line indicates conceptual steps in beach change and is not a statistical fit to the data.

Figure 20a. Driftwood aids in retaining sediment on the berm, but logs loose on the beach can focus wave energy causing local scour.

Figure 20b and c. In these photos, the temporally varying “striping” of the beach sediments can be seen on the upper foreshore. Note the slight undulating variations in elevation, and spatial sorting of sediment grain size.

On the lower foreshore and central bench below the pocket beach, the sediment grain size is significantly coarser (Tables 5 and 6), and swash processes occur less frequently. Therefore, the profiles were more stable in this region. Little, if any sediment loss was observed in this section over the year of surveys. The central bench experienced significant sediment reworking in the summer of 2007 in the form of flattening of the mounds that existed there in the previous winter (Table 4). Summer tides provide lower water-surface elevations to occur in the daytime when park visitors utilize the beach, and it is likely that foot traffic caused the nourishment mounds to flatten.

Sediment on the overall habitat bench is relatively invulnerable to transport. The tidal elevation infrequently reaches these lower levels, and therefore swash processes have limited impact. Access to pedestrians is limited and uninviting. The coarse, angular and well-packed sediment on the habitat bench does not show sign of movement. The habitat bench is vulnerable to failure of the riprap buttress. For example, in February 2007 (Table 1), a failure of the riprap was repaired by adding more boulders. This repair involved placing large riprap over the habitat bench (see Fig. 9, region between distances of ~30 m and ~60 m).

Sediment Grain Size Changes

Most of the observed grain-size changes occurred on the berm and upper foreshore, the regions that are most vulnerable to sediment transport. In general, the surface sediment became well sorted between year 0 and year 1 with the exception of the period following construction activities, which appeared to mix the subsurface and surface sediments.

The surface sediment thickness is highly variable across the beach and has been visually observed to be thinning. There are patches where the smaller sub-surface sediment is exposed on the upper foreshore. Although this has not been associated with major loss of sediment from the beach, the exposed finer sediment could become more vulnerable to storms in the coming years and should be monitored. Local disturbances can also create zones where the subsurface sediment is exposed (e.g., submerged log in Fig. 20c).

Wave-Driven Forcing of Sediment Transport

Storms in Puget Sound occur during the winter season and winds generally blow from the south and southwest directions (Fig. 16). These bring the largest waves that impact the transport of sediment on the beach. The recorded events during the winter reached wave heights of ~0.4 m and were generally of short wave periods due to the relatively protected location of OSP beach within Elliott Bay. The shorter wave periods mean that the wave energy cannot penetrate deeply into the water column, and the major impact of the waves is within the swash zone. Additionally, persistent vessel-wake action may play a role in the transport of sediment throughout the year.

On the lower foreshore, the coarser sediments are within the swash zone infrequently and are generally too large to be moved by the small waves. On the upper foreshore however, the loose material moves with the uprush and backwash during energetic conditions. The continued swash motion on the upper foreshore acts to maintain a well-sorted seabed. As the volume of surface sediment is reduced, the swash action contributes to sediment grain-size sorting in bands along the beach (Fig. 20b and 20c) (Buscombe et al. 2006).

The combination of tidal elevation and energetic wave conditions will determine the net amount of sediment transport on the beach. These peak transport conditions occur during periods of extreme high tidal elevation combined with storm conditions. If these conditions occur early in the winter season , a major reorganization of the beach sediments could occur, similar to or greater than those seen in the profile area changes in October – November 2007(Fig. 19).

Anthropogenic Forcing of Sediment Transport

The trend in sediment cross-sectional area implies that anthropogenic forcing has also impacted erosion and deposition of sediment, particularly of the berm and upper foreshore of the pocket beach. Although exact usage estimates are difficult to obtain for OSP, media reports, "Area restaurants and retailers see customers in the 600,000 people expected to visit the public park during its first year" (Holtzman 2007), and on the opening weekend in January 2007 alone, there were an estimated 35,000 visitors (http://www.visitseattle.org/).

During our monthly surveys, significant numbers of people on beach and children throwing rocks (Fig. 21) were observed. In natural systems the impacts of down-slope sediment motion due to foot traffic and sediment removal due to throwing on the net sediment transport would be a minor component relative to the overall natural wind and wave-driven transport. In the case of OSP beach, they may not be. The profile change estimates (Fig. 19) exhibit a notable shift in the amount of material on the beach in the first month where low daytime tides and summer weather conditions occurred. No wind events that would have driven wave-driven transport were observed in this time period. Continued seasonal monitoring is recommended to allow evaluation of both wave and human-driven transport.

Summary of Findings

Physical monitoring suggests that over the first year of implementation, the beach has been successful in terms of providing public access to the shoreline and maintaining its form (both in profile shape and sediment grain size). The design of the beach appears to have been successful over the first winter in resisting major changes due to erosion from winter storms. Yet, it must be realized that since there is no source of sediment (e.g., an eroding bluff) in this urban setting (http://www.ecy.wa.gov/programs/sea/SMA/atlas_home.html), there is no possible mechanism to replace sediment that is carried off the foreshore. We predict that every winter a small amount of sediment could be lost from the system due to natural wave-driven transport. The public reaction to the beach has been extremely positive, and the enthusiastic use of the beach likely also contributes to sediment loss. We predict that there will be a need to renourish the beach as these natural and anthropogenic forces continue to remove sediment from the pocket beach. It is too early to tell the necessary frequency of renourishment. The habitat bench with coarse-grained sediment and at an elevation below most wave activity and direct human impact likely will not experience change as a result of sediment-transport processes. Success of the bench is only threatened by failure of the riprap buttress, which can cover the relatively narrow bench.

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Figure 21. Anthropogenic activities at the beach may contribute to the movement of the beach sediments. Pedestrians can move sediment downslope with their feet, and rock throwing on this heavily used beach may contribute to the net sediment removal.

Glossary

Amphipoda – A taxonomic Order of shrimp-like crustaceans.
Backshore – The part of the shore lying between the berm crest and the vegetation, affected by waves only during severe storms.
Benthic Invertebrates – Invertebrates that live in bottom substrates.
Berm – a nearly horizontal plateau on the beach (see Figure 1 of Part II).
Clay – A fine-grained sediment with a typical grain size less than 0.004 mm.
Copepod – A group of small crustaceans including the orders Harpacticoida (mainly epibenthic) and Calanoida (mainly planktonic).
Diptera – A taxonomic Order of flies, including Chironomids (non-biting midges).
Diurnal – having a period of a tidal day, i.e., about 24.84 hours.
Epibenthic Invertebrates – Invertebrates that live just above bottom substrates.
Fetch – The length of unobstructed open sea surface across which the wind can generate waves.
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.
Hemiptera – A taxonomic Order of insects, including aphids and planthoppers.
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.
Neuston – Organisms that are on the surface of the water.
Phi size scale – the diameter of individual grains of sediment. Size ranges define limits of classes that are given names in the Wentworth scale (see Table 2 of Part II). 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.
Polychaeta – A taxonomic Class of annelid worms, including Nereids and Spionids.
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).
Silt – sediment particles with a grain size between 0.004 mm and 0.062 mm.
Swash zone – The zone of wave action on the beach, which moves as water levels vary, extending from the limit of run-down to the limit of run-up (the rush of water up a beach on the breaking of a wave).
Wave hindcast – The calculation from historic synoptic weather charts or wind records of the wave characteristics that probably occurred at some past time.