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OLYMPIC SCULPTURE PARK: YEAR 3 MONITORING OF SHORELINE ENHANCEMENTS

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Management Summary

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In January 2007 the Seattle Art Museum's Olympic Sculpture Park (OSP) opened at a site along Seattle's urbanized Elliott Bay shoreline. The park includes enhanced shoreline features designed to benefit juvenile salmon and other organisms. A pocket beach and habitat bench were created in shallow nearshore waters, vegetation was planted in the uplands, and coarse-grained sediments and driftwood were placed on the beach. These features replaced the relatively unproductive armored seawall and riprap shoreline, with a goal of increasing the number and diversity of fish and invertebrates. Although this shoreline is in an urban, commercial setting and will not be completely restored to pre-historic conditions, the park has enhanced a publically accessible segment of shoreline that has more natural functions than it did before.

Work along OSP's seawall segment was spurred by concerns about the long-term seismic stability of the existing structure. The seawall along Seattle's waterfront needs replacement and the City of Seattle did not have plans to replace the northern section for some years. The Seattle Art Museum chose to address the seawall during the park's construction rather than experience disruption after the park was created. Construction along OSP's portion of the seawall cost $5.5 million to reinforce the existing seawall, which was cost-effective compared to the initial estimate of $50-80 million to completely replace that portion of seawall. OSP's approach made it possible to include the habitat bench which recreated shallow water habitat in front of the reinforced seawall, as well as excavate the new pocket beach from adjacent riprap.

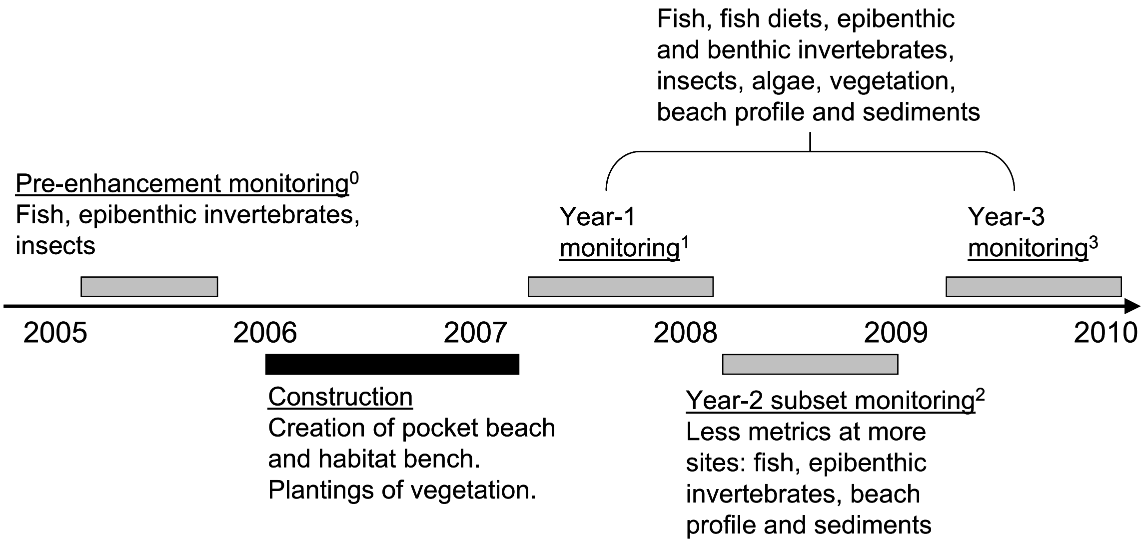
Photographs of the Olympic Sculpture Park Pre- and Post-Enhancement

(a) Riprap and seawall armoring at the site before enhancement, (b) post-enhancement pocket beach at high tide (habitat bench is under water) and (c) habitat bench at low tide showing kelp on the outer margin. The pocket beach replaced riprap armoring, and the habitat bench enhanced the existing seawall. Dunegrass and riparian vegetation were planted around the pocket beach, and a 'vegetation swath' was planted in the uplands above the habitat bench. Riprap seen in the foreground of the pocket beach in (b) and the seawall in the background of the habitat bench in (b) were sampled as reference armored sites.

Monitoring of the site has been conducted to measure the status and development of the shoreline enhancements, and also to generate data that will inform future restoration efforts along this and other regional urbanized shorelines. The main goal of monitoring is to test if *nearshore enhancement at the Olympic Sculpture Park has improved habitat for biota as compared to adjacent armored shorelines.* Sampling focused on providing information specific to juvenile Chinook salmon, which are listed under the Endangered Species Act as threatened in Puget Sound. We collected data on assemblages of *fish, invertebrates, algae, and vegetation,* and conducted *sediment surveys and beach profiling.* Monitoring results will help us determine if shoreline enhancements along the urban waterfront provide beneficial habitat for nearshore biota, and if the physical structures (e.g., pocket beach) will remain intact without frequent beach sediment nourishment or stabilization efforts.

Results from three years of monitoring indicate that the beach structure is relatively stable and there has been a rapid development of aquatic and terrestrial biota. Many of our indicators of invertebrate and fish use measured in years 1 and 3 post-enhancement have higher values (abundance, diversity, assemblages) when compared to the baseline conditions measured before enhancement, or the adjacent sections of seawall and riprap. Monitoring is currently planned for years 5 and 10 post-enhancement to continue to assess biological and physical functions at the developing site.

Overall Timeline of Monitoring Activities at the Olympic Sculpture Park



Reports

0 Toft, J.D., and J. Cordell. 2006. Olympic Sculpture Park: results from pre-construction biological monitoring of shoreline habitats. Technical Report SAFS-UW-0601, School of Aquatic and Fishery Sciences, University of Washington. Prepared for Seattle Public Utilities, City of Seattle. 36 pp.

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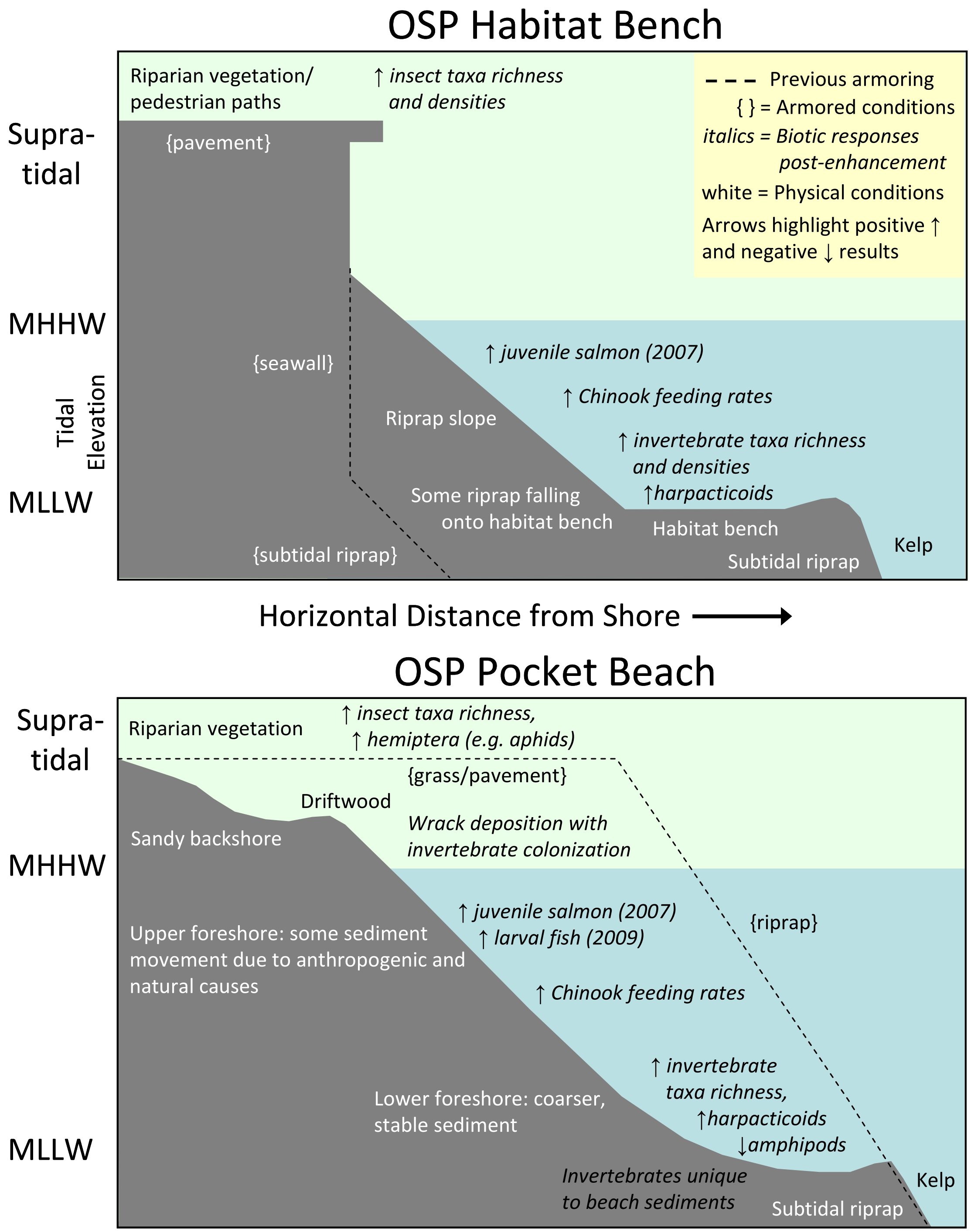
This report summarizes 2009-10 data, and builds on past pre-enhancement and post-enhancement monitoring conducted in 2005 and 2007. Specific monitoring results are highlighted in the conceptual model below, followed by additional details for each category, and a table summarizing the results.

Conceptual Model of Olympic Sculpture Park Monitoring Results



Mean Higher High Water (MHHW): approximate high-tide line
Mean Lower Low Water (MLLW): approximate low-tide elevation

Fish

Snorkel surveys: Juvenile salmonids were most abundant in shallow waters, where feeding behavior occurred in a high proportion of observations (range 36-82% across sites/species). Densities were equal at all sites in 2009, as opposed to 2007 when the habitat bench and pocket beach had significantly higher densities than riprap. Larval fish in 2009 were much more abundant at the pocket beach and habitat bench, and were significantly more abundant in shallow waters at the pocket beach as compared to past years and other sites. The larval fish category contained both larval and post-larval forage fish (e.g., smelt) and demersal fish (e.g., sculpin) types. Like juvenile salmon, larval fish may benefit from refuge areas in the nearshore that are created by habitat enhancement. Potential fish predators of juvenile salmon were rare at all sites.

Enclosure nets: Juvenile salmonids accounted for 91% of the fish captured at the pocket beach. Chinook consumed mainly amphipod crustaceans, crab larva, and insects. Chum fed similarly, but also fed on epibenthic harpacticoid copepods.

Aquatic Invertebrates

Epibenthic invertebrates: Taxa richness in pump samples on top of the substrate from the low intertidal zone increased after enhancement and was highest at the pocket beach and habitat bench. The habitat bench had high densities of harpacticoid copepods, amphipods, and overall epibenthic invertebrates, and the pocket beach also had high densities of harpacticoids. Harpacticoids and amphipods are crustaceans that are generally important prey for juvenile salmon. The riprap site had more amphipods than the seawall and pocket beach, although 95% of the amphipods at riprap were of one species that was not very abundant in juvenile salmon diets.

Benthic Invertebrates: Pocket beach sediments have been colonized by diverse benthic invertebrates, including several taxa of amphipods and polychaete worms that were not present before creation of the pocket beach. Taxa richness from core samples was higher in 2009 than 2007. There were more chironomid fly larva but fewer amphipods in the low intertidal, both of which are important prey for juvenile salmon.

Terrestrial Insects

Fallout traps: All of the enhanced vegetation areas (pocket beach, riparian, and vegetation swath) had greater taxa richness and hemiptera densities (mostly aphids) than the adjacent armored shorelines (seawall and riprap). These metrics have also increased at the pocket beach and vegetation swath since pre-enhancement armored conditions. This suggests that production of certain juvenile salmonid prey that are associated with vegetation have increased, whereas other prey items such as dipterans (flies, e.g., chironomid midges) have not increased since enhancement.

Neuston tows: Insects available to juvenile salmon as potential neustonic prey items on the surface of the water were evenly distributed among the created beach types, and were similar to that of the adjacent riprap and seawall. Many of the taxa captured in insect fallout trap samples were also in the neuston, and consisted mainly of the orders diptera, psocoptera, and hemiptera, all of which are known to occur in the diets of juvenile Chinook and chum salmon. Several species of aquatic amphipods and harpacticoid copepods were present in low abundances in the neuston, illustrating that they are not just associated with bottom substrates but are also available as juvenile salmon prey at the water's surface.

Algae Colonization and Planted Vegetation

Aquatic algae: Kelp stipes were greater in 2009 than in 2007 at SCUBA surveyed subtidal elevations of -3.1 to -7.6 m MLLW. Overall algae percent cover was about equal between years and varied with tidal elevation. However, the overall range in 2009 was 61 to 76%, which was higher than the range of 46 to 74% in 2007. Twenty-two species of algae were observed on the created habitat bench, about equal to that observed in 2007.

Terrestrial Vegetation: All measurements of vegetative cover in 2009 increased 20% over as-built conditions or had a cover value of 50%, except the dunegrass patches, where there was an increase in cover of 12.1% and a total cover of 32.5%. However, three of the four dunegrass patches increased in overall area and all increased in shoot density. Trampling continues to be problematic, with dunegrass flourishing only where it is protected.

Physical Structure

In year 1 some minor sediment loss occurred at the pocket beach. In year 3 the beach was relatively stable, with surface sediment shifting on a seasonal basis, moving from lower (foreshore) to higher elevations (berm) on the beach during energetic winter conditions. The driftwood on the berm stabilizes the area and traps sediment. This sediment appears to move down the beach in the summer, largely due to public foot traffic and rock throwing. Although there has been no major loss of sediment at the pocket beach, the surface and sub-surface sediment have shifted and mixed together, resulting in patches where the smaller sub-surface sediment has become exposed. These exposed smaller grain sizes could be more vulnerable to movement in future storms.

Coarser sediments lower on the bench are more stable, with little or no sediment loss due to natural or human forcing. The lower tidal elevation of the bench means it is exposed only at spring low tides, and swash disturbance has less time to impact the sediment. Changes at the habitat bench have been limited to early settlement stages of initial nourishment mounds, riprap placement over the bench in year 1, and a small deepening feature towards the south end. Apart from annual landscaping activities including clean-up of trash and creosote logs placed by storms and waves, repositioning of driftwood, and maintenance of sediments associated with paths for foot traffic, the pocket beach and habitat bench have remained relatively stable and are providing the designed functions of a combination of public use and habitat for biota. Although not necessary now, the small amount of annual sediment loss from the pocket beach with no natural mechanism for replacement will eventually require renourishment.

Olympic Sculpture Park: Summary of Results

Summary comparing year 3 post-enhancement data at the habitat bench and pocket beach with armored shorelines. The comparison is made in two ways: to armored shorelines existing at OSP pre-enhancement (Pre), and to armored shorelines nearby OSP post-enhancement (Arm). When pre-enhancement datasets are not available, data is compared to year 1 data (Yr1). Data summarized by (+) positive change, (-) negative change, and (nd) no difference. See full report for specific explanations.

Fish

Summary: Positive changes for juvenile salmonid densities in 2007 and larval fish densities in 2009.

Positive for juvenile salmonid feeding, except for lower chum feeding compared to riprap in 2009.

Additional note: 91% of fish netted at the pocket beach were juvenile salmonids.
Main juvenile salmonid prey items were amphipods, crab larva, insects, and harpacticoid copepods.

	Habitat Bench		**Pocket Beach**	
	Pre	Arm	Pre	Arm
Juvenile Salmonid density*	nd	+ nd	nd	+ nd
Larval Fish density	nd	nd	+	+
Feeding in shallow water**	+	+ -	+	+ -

* (+ nd) signifies increase in 2007 and no difference in 2009

** (+) signifies increase in Chinook and chum; (+ -) signifies greater in Chinook and less in chum

Aquatic Epibenthic Invertebrates

Summary: Mostly positive, especially for overall densities, harpacticoid densities, and taxa richness.

Negative changes for epibenthic amphipod densities at the pocket beach.

Additional note: Benthic invertebrates in pocket beach substrates contain taxa unique from other habitats.

	Habitat Bench		**Pocket Beach**	
	Pre	Arm	Pre	Arm
Density (overall)	+	+	+	nd
Taxa richness	+	+	+	+
Assemblage structure*	+	+	+ -	+ -

* (+) signifies increase in harpacticoid copepods; (-) signifies decrease in amphipods

Terrestrial Insects

Summary: Mostly positive, especially for taxa richness and hemiptera densities (e.g., aphids).

Some negative changes for diptera densities (flies, e.g., chironomid midges).

Additional note: Neuston tows document presence of terrestrial insects on the surface of nearshore waters.

	Vegetation Swath		**Pocket Beach**		**Riparian**	
	Pre	Arm	Pre	Arm	Pre	Arm
Density (overall)	+	+	nd	nd	-	nd
Taxa richness	+	+	+	+	+	+
Assemblage structure*	+ -	+	+ -	+	-	+

* (+) signifies increase in hemiptera; (-) signifies decrease in diptera

Algae Colonization and Planted Vegetation

Algae Summary: Bull kelp stipes increased, algae percent cover and taxa richness stayed similar to Year 1.

Vegetation Summary: Understory and overstory vegetation increased in cover, some trampling of dunegrass

	Algae
	Yr1
Kelp density	+
Taxa richness	nd
Algae percent cover	nd

	Vegetation
	Yr1
Percent cover	+
Dunegrass density	+

Physical Structure

Summary: In year 1 there was minor sediment loss at the pocket beach, and settlement of nourishment mounds and riprap at the habitat bench. In year 3 sediment loss is apparent, but limited, and profile changes are seen on the upper foreshore in response to natural wave and tide forcing and anthropogenic use.

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Introduction

The Seattle Art Museum's Olympic Sculpture Park (OSP) opened in January 2007 at a site along 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 created in shallow nearshore waters with plantings of vegetation in the uplands and placement of coarse sediment and driftwood on the beach. These features replaced relatively unproductive armored seawall and riprap shoreline, with an overall goal of supporting higher numbers and a greater diversity of fish and invertebrates than the existing urbanized shoreline.

An average of 27% of Puget Sound's natural shoreline is armored by retaining structures, increasing to ~65% near urban centers (Simenstad et al. in press). These structures are usually composed of vertical seawalls and riprap boulder fields. Such shoreline modifications are prevalent in many aquatic systems worldwide, especially in highly developed urban areas. Recent research has started to document the detrimental effects that shoreline modifications can have on the ecotone between aquatic and terrestrial realms (Chapman 2003; Alberti et al. 2007; Toft et al. 2007; Bilkovic and Roggero 2008; Defeo et al. 2009, Bulleri and Chapman 2010). Understanding the current status of developed shorelines and potential for restoration in degraded systems is an important topic regionally (Simenstad et al. 2006, PSP 2009), nationally (NRC 2007) and worldwide (Defeo et al. 2009).

Enhancement features at OSP were incorporated because juvenile salmonids use the Seattle urban nearshore of Puget Sound for rearing and migration (Toft et al. 2007), with the nearby Green/Duwamish River being the closest source for both wild and hatchery juvenile salmon. Juvenile Chinook and chum salmon use nearshore habitats more than other species of salmon (Fresh 2006). Improved habitat for Chinook salmon is often a focus for shoreline restoration in the region, because Puget Sound Chinook are listed as threatened under the Endangered Species Act. Research in Puget Sound and elsewhere has shown that shoreline habitat types can affect nearshore fish distribution, abundance, and nursery function of estuaries (Valesini et al. 2004, Rice 2006, Toft et al. 2007, Bilkovic and Roggero 2008, Courrat et al. 2009). The nearshore is also an important source of juvenile Chinook prey items such as terrestrial insects and aquatic crustaceans (Simenstad et al. 1982, Brennan et al. 2004). Scale of armoring is an important factor to consider because sites with armoring extending into subtidal waters truncate the entire intertidal zone. When this occurs the decrease in shallow water habitat causes juvenile salmon to school directly along the armoring, as well as limits their access to terrestrial insect prey items (Toft et al. 2007). This was the case with the riprap and seawall at OSP before enhancement, so designs were based on improving fish habitat by changing the subtidal armored shorelines into lower gradient intertidal shorelines.

Nearshore restoration often emphasizes improving habitat for invertebrates that are important food for fish. Having ample invertebrate prey can increase the opportunity that juvenile salmon have to access and benefit from a site (Simenstad and Cordell 2000). Measurements of invertebrate abundance and composition additionally serve as useful metrics that may be linked to localized geomorphic processes. It has been shown that invertebrates can be negatively impacted by shoreline armoring, depending on how low in tidal elevation the armoring encroaches (Peterson et al. 2000, Chapman 2003, Cruz Motta et al. 2003, Romanuk and Levings 2003, Moschella et al. 2005, Sobocinski et al. 2010). Shoreline modifications can also add unique hard structures not naturally found, which in certain cases can attract different and sometimes non-indigenous organisms (Glasby 1998, Davis et al. 2002, Glasby et al. 2007). Benefits of restoring shorelines in urban systems include increasing invertebrate densities and diversity over heavily armored conditions. However, the science regarding this subject is still in a relatively early state, and long-term datasets are rare.

Monitoring beach structure and biota at constructed habitats can provide information on how the designs function at providing beneficial habitat. Monitoring at OSP included pre- and post-enhancement sampling, as related to construction in 2006 and opening in January 2007 (Fig. 1).

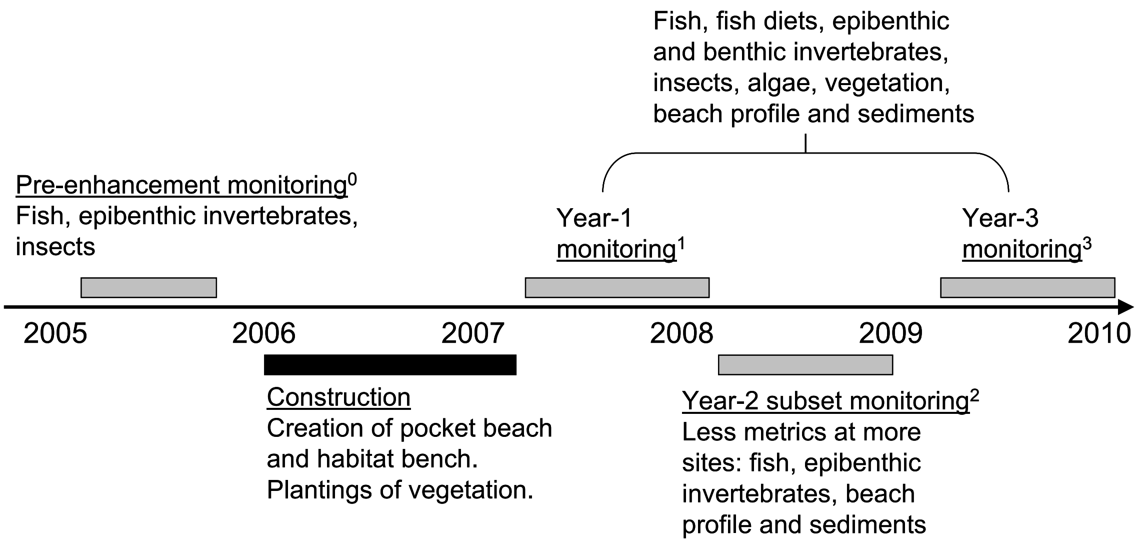

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Figure 1. Overall timeline of monitoring activities at the Olympic Sculpture Park.

Although it is not always possible to restore original conditions to extremely modified shorelines, it can still be feasible to enhance or rehabilitate shorelines within urban constraints (Simenstad et al. 2005). We use the term *restoration* to describe a general goal, and *enhancement* for actions that are intended to make progress toward that goal. Puget Sound has varying levels of natural and modified shorelines depending on the specific shoreline segment, and it is important to address how small-scale enhancements in urban areas can benefit the large-scale goal of restoration. The impact of clusters of small-scale enhancements may in aggregate be worth more than the additive features of single sites (Simenstad et al. 2005). For this reason, success at the site level can encourage similar enhancement activity in a region and lead to the development of recommendations for future enhancements.

Two main shoreline elements were enhanced during construction at OSP, a habitat bench and a pocket beach (Figs. 2 and 3). The habitat bench was created in the low intertidal along the existing north end of the Seattle seawall. The pocket beach was excavated from a stretch of riprap armoring immediately north of the existing seawall. The pocket beach consists of a pebble/cobble beach, with surrounding dunegrass and riparian vegetation. Monitoring focused on initial development of these two stretches of shoreline, sampling the following biological and physical characteristics: juvenile salmon and other fish, aquatic epibenthic and benthic invertebrate fish prey such as amphipod and harpacticoid crustaceans that live on the substrates, terrestrial insects from surrounding vegetation, development of terrestrial vegetation and aquatic algae, physical beach profiles, and sediments.

Figure 2. Photographs of the Olympic Sculpture Park (a) pre-enhancement riprap and seawall armoring, (b) post-enhancement pocket beach at high tide (habitat bench is under water) and (c) habitat bench at low tide showing kelp on the outer margin. The pocket beach replaced riprap armoring, and the habitat bench enhanced the existing seawall. Dunegrass and riparian vegetation were planted around the pocket beach, and a ‘vegetation swath’ was planted in the uplands above the habitat bench. Riprap seen in the foreground of the pocket beach in (b) and the seawall in the background of the habitat bench in (b) were sampled as reference armored sites.

Figure 3. Aerial view of the Olympic Sculpture Park site after construction, showing general sampling locations.

Artificially created or nourished beaches are becoming increasingly popular as a preferred option for shore protection in many areas worldwide. Where shoreline erosion problems have traditionally been controlled by hard structures (e.g., seawalls), created beaches that are coarse clastic (i.e., have sediments that range from sand to boulders) can provide an alternative solution to shore stabilization problems, as well as adding value to the natural system and the public who use them. Coarse clastic beaches that are nourished can presumably decrease the adverse impacts of harder forms of shoreline stabilization (e.g., increased wave energy, scour, and interruption of sediment supply to coastal systems; Williams and Thom 2001), restore or enhance natural beach processes and habitats, and create recreational and ecological opportunities where they did not exist before. However, many of the adverse impacts of armoring and scale of enhancement of nourished beaches remain untested in their specific effects on biota.

As beach enhancement and nourishment continues to become an 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). 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 to cobble; 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).

Physical beach-profile monitoring provides a 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 general approach for the physical beach-profile monitoring includes: (a) measurement of beach profile transects at the pocket beach and along the habitat bench, (b) substrate size sampling, and (c) relating the results to the natural sediment-transport processes and geomorphic setting in Puget Sound. Beach profile surveys have been conducted almost monthly throughout the three years after enhancement to document the impact of seasonal conditions and potential anthropogenic impacts to the beach profile. When combined with the biological monitoring, results from this work are intended to address the overall performance of the OSP enhanced shoreline and provide an interdisciplinary approach to evaluation of the site.

The following hypotheses are being tested by this research:

***Central hypothesis**: Nearshore enhancement at the Olympic Sculpture Park will improve habitat for biota as compared to armored shorelines.*

> ***Hypothesis 1 – Biota:** Enhancement sites along seawall and riprap provide improved habitats for juvenile Chinook salmon and other fish, as measured by fish, invertebrate, algae, and vegetation assemblages.*
>
> ***Hypothesis 2 – Physical:** The created pocket beach and habitat bench are relatively stable shoreline features along the waterfront, as measured by sediment surveys and beach profiling.*

Testing these hypotheses will allow us to determine if created shoreline enhancements along the urban waterfront provide beneficial habitat for nearshore biota, and if the physical structures remain intact with minimal beach renourishment and/or stabilization. Although it is not feasible for this urban stretch of shoreline to be restored to historic conditions, features of the park are designed to enhance a publically accessible segment of the shoreline and restore some of the original biological functions.

This report describes year 3 post-enhancement monitoring of aquatic fish, invertebrate, algae, terrestrial insects, vegetation, and physical beach properties. This work is similar to that conducted in year 1 monitoring (Toft et al. 2008) and the baseline pre-construction biological monitoring (Toft and Cordell 2006). Results from year 1 monitoring indicated that in general there had been an initial rapid development of aquatic and terrestrial biota within the newly created habitats, as evidenced by many indicators having higher values than baseline conditions or adjacent sections of seawall and riprap. Physical properties of the habitat bench and pocket beach were relatively stable, with minor sediment loss at the pocket beach. Results of the year 3 monitoring will add to previous datasets and indicate if the initial conditions are stable and/or continuing to develop after the first year. This follows the planned monitoring schedule that will also include monitoring in years 5 and 10 after construction in order to assess progression of biological and physical functions as the site develops.

Methods

Methods are briefly described below for techniques used in past monitoring and described in detail in Toft et al. (2008).

Physical Characteristics

Timeline

A timeline of field activities and of events that may have influenced 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 was delayed. An initial survey was conducted in December 2006, but subsequent construction activities limit the value of those data. Thus, we consider physical beach surveys from January through May 2007 as year 0 (baseline) and June 2007 through April 2008 as year 1 (Toft et al. 2008). We will compare these data with that collected in year 2 (June 2008- March 2009, see Toft et al. 2009) and year 3 (June 2009 – March 2010).

Beach Profile Surveys

Two across-beach transects (Fig. 4) were selected for near 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 was assumed to be immobile:

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

The central bench, a section of the habitat bench at the base of the pocket beach (Fig. 4), was monitored near monthly for elevation changes. Along this section of the bench, two transect lines were run at approximately one third and two thirds of the bench width (Fig. 4). Horizontal control was limited on the bench, so these surveys were analyzed for variability, not absolute change.

Near monthly profile surveys (Table 1) were conducted at low spring tides (coinciding with the new and full phases of the moon) to capture the complete beach profile. The elevations were determined using a laser leveler and direct rod measurements. A known point on the habitat bench (partially buried construction debris) was monitored during each survey to determine the accuracy of vertical measurements. The vertical precision was estimated to be +/- 4 cm for years 1 and 2 and was improved to +/-3 cm in year 3. 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.

In addition to near monthly profile surveys on the two established transects, more-detailed profiling was done in February and March 2010 to compare to the year 1 beach topography survey of the OSP tidal embayment/pocket beach collected in March 2008.

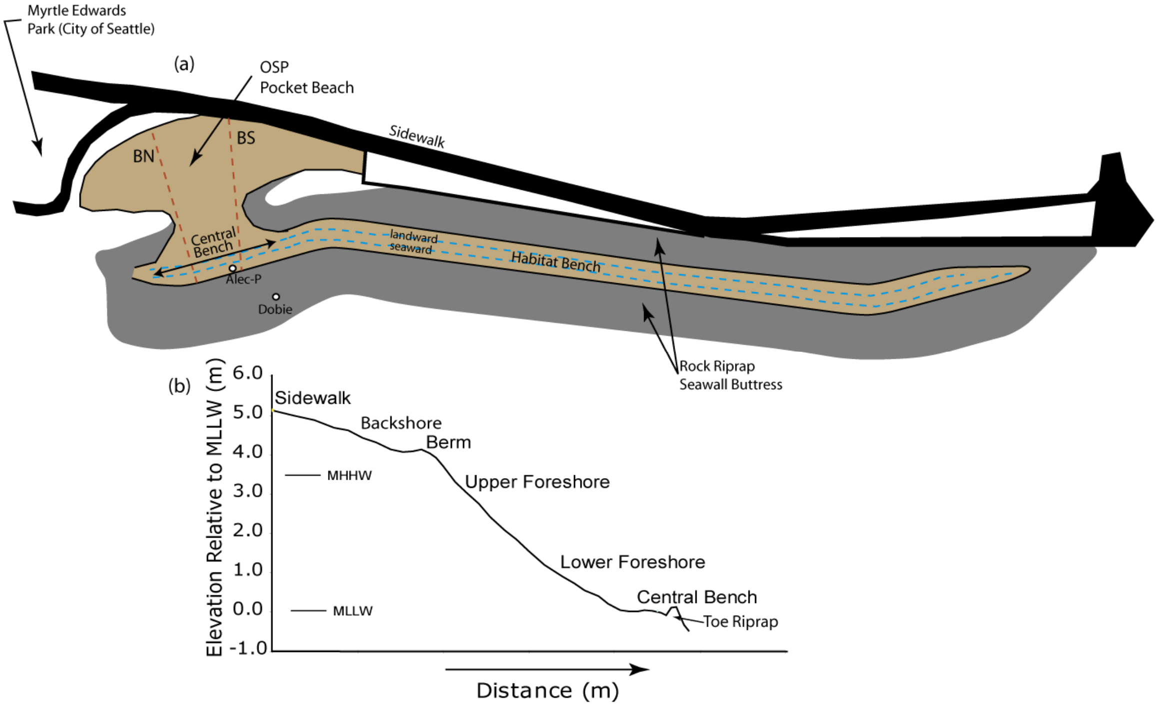


Figure 4. (a) Plan view drawing with approximate locations of the BN and BS transect lines (red) within the beach, and seaward and landward transect lines (blue) within the habitat bench. The two transect lines on the bench are spaced ~1/3 of the bench's width from each other. Where the bench is too narrow only one transect line (seaward) was used. Terminology for the across-shore beach transects is shown in (b).

Table 1. OSP pocket beach and habitat bench physical monitoring timeline for year 0 through year 3.

YR	Date	Pocket Beach Survey	Bench Survey (Full)	Bench Survey (Partial)	Sediment Sample	Other Activities
pre	September 2006					Lower beach repaired
	December 2006	X			X	Backshore construction completed
0	January 2007	X		X	X	OSP's opening weekend
	February 2007	X	X	X	X	Failed riprap repaired
	March 2007	X	X			
	April 2007	X				
	May 2007	X				
1	June 2007	X		X		
	July 2007	X		X		
	August 2007	X		X	X	
	September 2007	X		X		
	October 2007	X		X		
	November 2007	X		X		Denny Way CSO clean up
	December 2007	X		X	X	Denny Way CSO clean up
	January 2008	X		X		Denny Way CSO clean up
	February 2008	X			X	
	April 2008	X	X			
	May 2008	X				
2	June 2008	X			X	
	July 2008	X				
	August 2008	X				
	October 2008	X				
	December 2008	X				
	January 2009	X				
	February 2009	X		X		
	March 2009	X				
	April 2009	X	X			
3	June 2009	X			X	
	July 2009	X				
	September 2009	X				
	October 2009	X				
	November 2009	X		X		
	December 2009	X		X		Extreme high water levels
	February 2010	X			X	Overwash deposits
	March 2010	X		X		
	April 2010		X			

Bench Surveys

The entire (~286 m-long) habitat bench was surveyed in March 2007 for the year 0 database and again in April 2008, April 2009 and April 2010 for the years-1-3 database (Table 1). These surveys provide a basis for comparison and evaluation of change. Two transect lines were laid out along the bench (Fig. 4) along which elevations were measured using the same survey equipment as for the beach profiles. 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, except in April 2008.

Sediment Sampling

Sediment samples were obtained from the beach shoreface and berm, sampling both the surface and subsurface. 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 (<4 phi) 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 (see Toft et al. 2008). The median grain size (D_{50}) was obtained from the grain-size distribution, and sorting estimated from the width of the 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.

Water-Surface Elevation

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 were retrieved and small data gaps (e.g., <24 min) were interpolated. Observations extracted were in units of gauge height and were then converted to MLLW levels, so the tidal data could be coupled with beach survey and process data (recorded at West Point and the OSP pocket beach, respectively) to reconstruct the natural forcing mechanisms acting on OSP's beach.

Biological Characteristics

Site

An aerial map of main invertebrate and fish sampling locations is shown in Figure 5, and vegetation locations in Figure 6. Pre-enhancement 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-enhancement 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- and post-enhancement biological monitoring is outlined in Table 2.

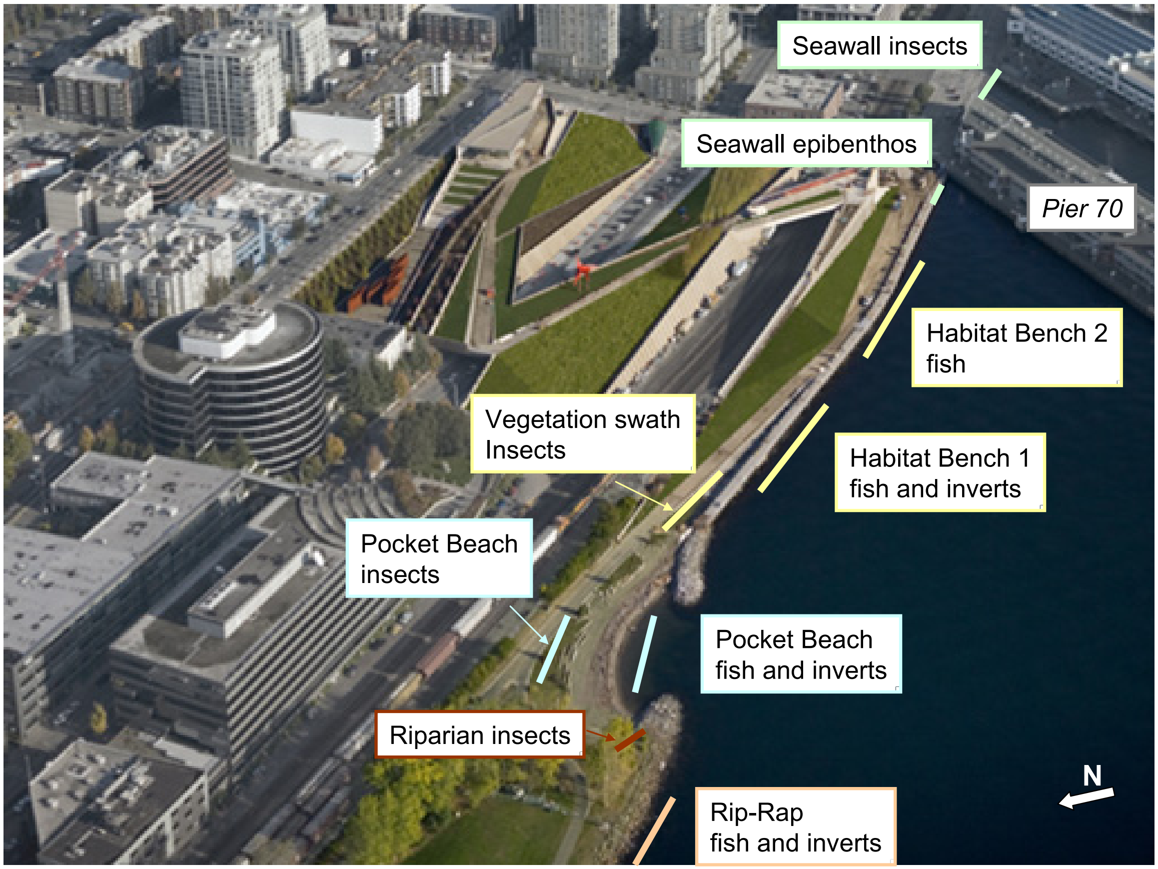


Figure 5. Aerial view of the Olympic Sculpture Park site after construction, showing main fish and invertebrate sampling locations.

Figure 6. Aerial view of the Olympic Sculpture Park site after construction, showing vegetation sampling locations.

Table 2. Timeline of biological monitoring throughout 2005 pre-enhancement and 2007 and 2009 post-enhancement samplings.

Sample	April – July 2005	Location	April – July 2007/9	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

Fish - Snorkel Surveys

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 28 April to 23 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 site was characterized 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 over all intertidal water depths at each habitat type during 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 et al. 2007, Toft et al. 2008). 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 numbers/m^2.

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 (feeding, schooling, swam away, unaffected, fleeing, hiding).
- 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.

Fish - Enclosure Nets and Diets

Enclosure Nets

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, measured for length for the first 20 fish, and released. Hatchery and wild status of Chinook and coho salmon were determined by recording hatchery-clipped adipose-fins and testing with a coded-wire tag reader (chum salmon are not marked). We refer to “hatchery” as those fish that were marked and/or tagged, and “wild” salmon as 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 can be 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 0.106 mm 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 0.0001 g.

Epibenthic Invertebrates

An epibenthic pump was used for sampling invertebrates living at the water-sediment interface at 0 to +0.3 m MLLW, twice monthly as in past monitoring (Toft et al. 2008). At each site seven replicate samples were collected at random points along the same transect that was used for snorkel surveys. The samples were fixed in 10% buffered formalin in the field, and returned to the laboratory for identification of the collected invertebrates. Samples were sieved at 0.106 mm, and taxa were identified to genus and species level for taxa known to be juvenile salmon prey items; other taxa 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. Cores were taken in the substrate at the pocket beach at two tidal elevations: approximately +3.7 m and 0 m MLLW, corresponding to high tide wrack deposits and low tide terrace, respectively. High tide wrack deposits are the accumulation of debris deposited by an ebbing tide, consisting mostly of marine algae/eelgrass and terrestrial wood/leaves, as well as some urban waste. 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 0.5 mm, 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 every other week 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 (40 x 20 cm, 0.13 mm mesh) 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. Epibenthic aquatic invertebrates were also counted in the samples, in order to measure their presence near the water surface due to natural or physical forces such as wave action.

Terrestrial Vegetation

Riparian vegetation was surveyed on 27-29 July 2009. Areas surveyed were the north and south uplands, beach dunegrass and backshore, and overlook plantings (Fig. 6). 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 between 1 (dead) and 5 (vigorous growth). Photos were taken of each riparian area from a fixed point. Cover and shoot density within each of the four dunegrass patches (numbered 1 to 4 from north to south) 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 information gathered using a measuring tape and compass.

Algae

Algae located at the habitat bench was surveyed by scuba divers on July 7 (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 m to -1.5 m MLLW, and then at -1.5, -3.0, -4.6, -6.1, and -7.6 m tidal elevations. At each elevation measurements were taken of algae percent cover by species, and number of kelp stipes (*Nereocystis luetkeana*) observed at location to visibility of 3 m.

Statistics

Data was entered in Microsoft Excel and analyzed using S-plus for univariate statistics. Density measurements were evaluated for normal distribution and homogeneity of variances, and log-transformed if necessary (this was the case for densities of epibenthic invertebrates, diptera insects in 2009, and diptera and total insects across all years). ANOVA tests (alpha = 0.05) were used to analyze densities at different habitat types for 2009 data, as well as for comparing across years pre-enhancement (2005) and post-enhancement (2007 and 2009). When results were significant, the tukey test for multiple comparisons was used to identify specific differences between all possible pairs of means (Zar 1996).

Results

Physical Characteristics

The complete set of monthly year 3 survey profiles of the beach and the year 3 habitat bench survey are shown in Figure 7. A selected profile from each of the monitoring years is shown in Figure 8 for evaluation of long-term change.

Beach Profiles within Year 3

The pocket beach profile underwent minimal change over year 3. On the north transect, BN (Fig. 7a), changes of up to 20 cm were observed in the area of the berm and driftwood accumulation (upper foreshore, elevations of +3.0 to +4.3 m MLLW), but the rest of the profile remained relatively unchanged over the year. On the south transect, BS (Fig. 7b), the profile changes were similar to those on the upper foreshore of the north transect, with a trend towards slight sediment loss over the year. In addition, there was a slight trend in accumulation lower on the foreshore (elevations of +0.6 to +1.2 m MLLW).

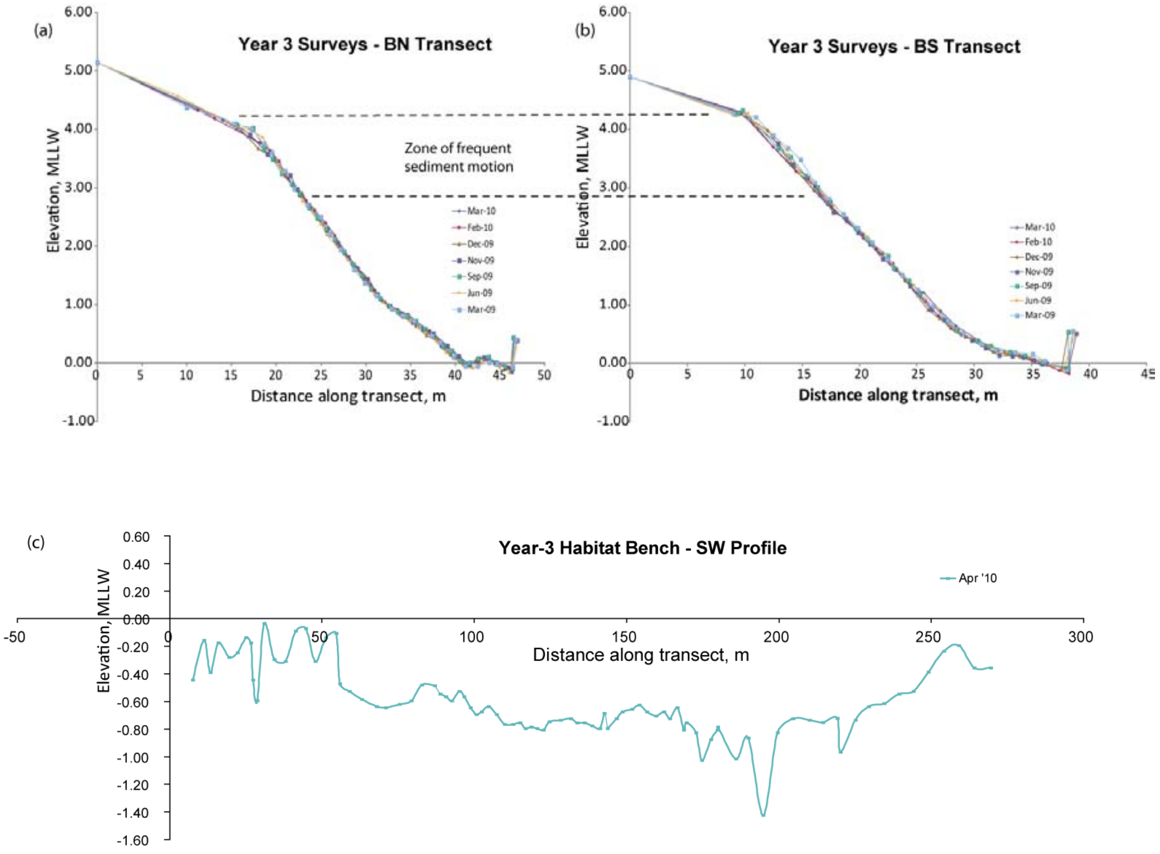


Figure 7. OSP Pocket beach and bench survey data from year 3. Transects a) BN and b) BS cross the pocket beach (see Fig. 4) and a transect c) runs along the habitat bench (seaward survey line shown). Note that the elevation scale changes between the beach and the bench profiles.

Beach Profile Changes (Year 0 – Year 3)

Comparison of surveys between years 0 and 3 show that the most significant changes in the beach profile occurred on the berm and upper foreshore (Fig. 8a and b). On the BN transect, the upper foreshore lost sediment in the first year (an approximate lowering of ~10 cm throughout), and subsequently remained relatively unchanged with the exception of shorter term variations in berm development and destruction (Fig. 8a). Small-scale variations (e.g., mounding and development of striations) were on the order of 2-3 cm, and although these variations were within the survey accuracy, they were clearly noted during surveys and were associated with grain-size variations. On the south survey line, BS (Fig. 8b), the profile changed more gradually in the first two years, increasing in elevation on the lower foreshore. In the third year, there was a decrease in elevation across the upper foreshore and building of a higher elevation berm. The overall effect was a slight reduction in elevation on the north side of the beach and a flattening of the beach slope on the south side of the beach between year 0 and year 3.

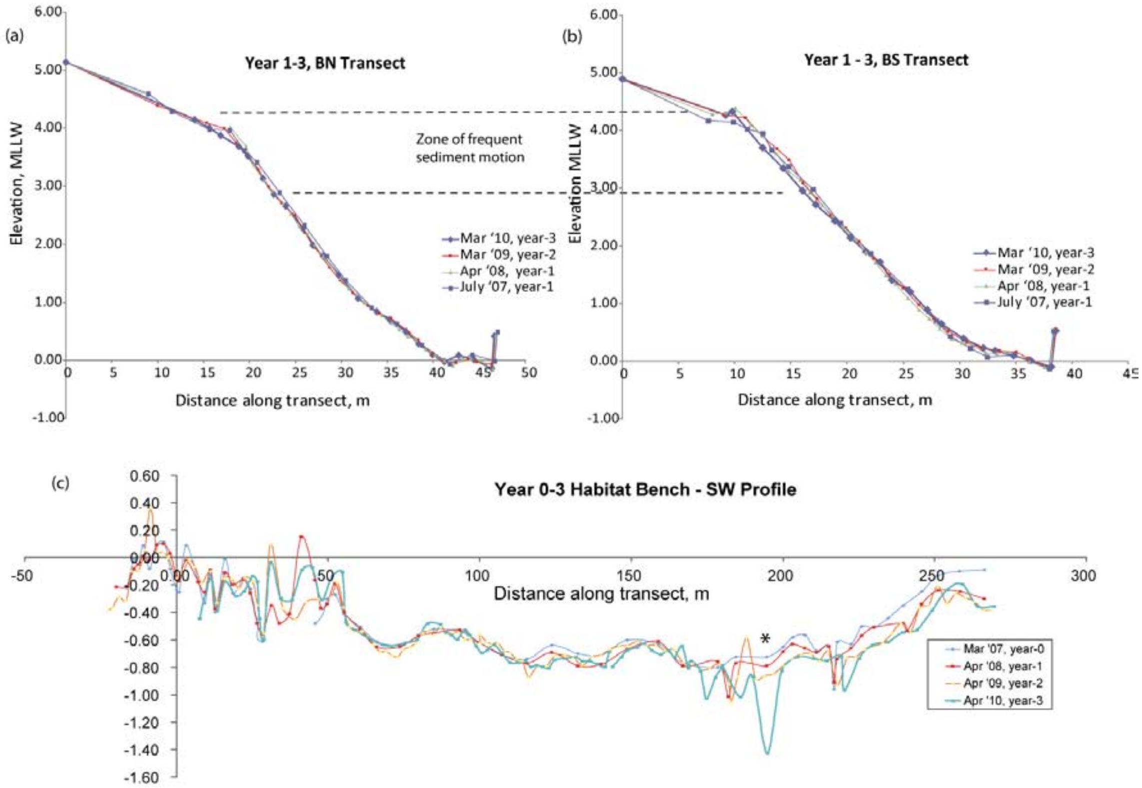


Figure 8. OSP Pocket beach and bench survey data comparison for selected surveys from year 0 to year 3. Transects a) BN and b) BS cross the pocket beach (see Fig. 4) and a transect c) runs along the habitat bench (seaward survey line shown). Note that the elevation scale changes between the beach and the bench profiles. * indicates lower holes in habitat bed material in 2010.

Bench Survey (Year 3)

The year 3 habitat bench survey was performed in April 2010. This was the first opportunity of the year to access the bench during negative (e.g., lower-low) tides and daylight hours. The tide was not particularly low and combined with significant kelp colonization accurate estimations of bench width on the south end were not possible. The habitat bench generally ranged in elevation between -0.8 and -0.2 m MLLW (Fig. 7c). There are some points (holes) on the south end of the bench that were lower where it appears that the habitat bed material was not placed level or settled following the installation. These holes extended down to -1.4 m MLLW elevation. The habitat bench at the base of the pocket beach has an elevation that averaged -0.15 m MLLW, and the rest of the bench to the south of the beach averaged -0.5 m MLLW in elevation. The width of the habitat bench (Fig. 9) as defined by the distance between the riprap slope and the riprap toe was estimated to range between ~0.9 and ~5.4 m, and averaged approximately ~3.5 m. Between transect distances of 25 to 55 m, a 30 m length of the bench was completely covered with riprap. Over-estimates in the width of the bench on the south end (Fig. 9) resulted in an overestimate of the area of habitat bench (694 m^2).

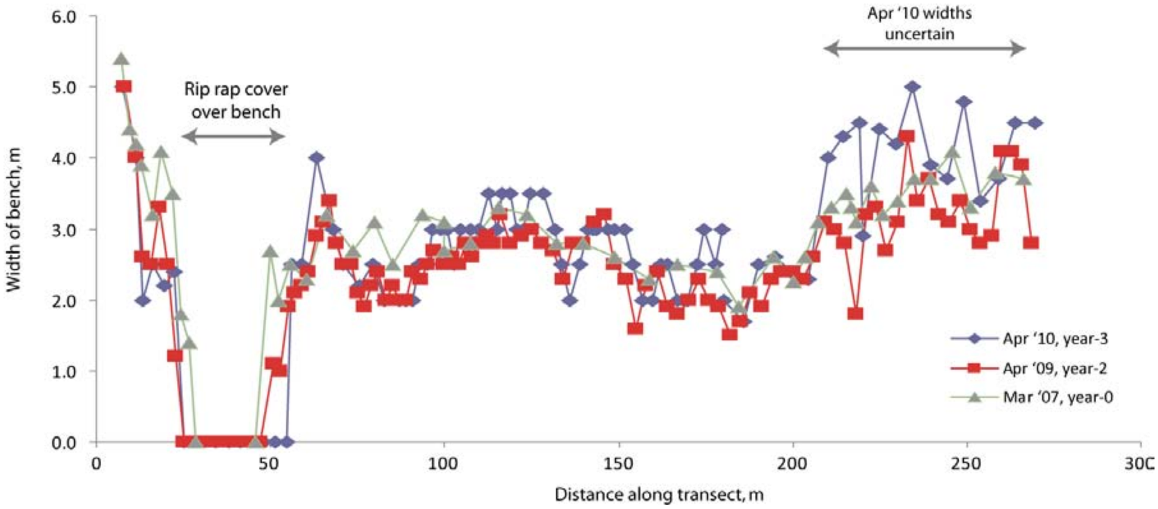


Figure 9. Width of habitat bench from year 0 to year 3. Note that in April 2010 (year 3), survey conditions for the south end of the habitat bench made width estimation difficult (towards the right of the figure). No width estimates were made in 2008.

Bench Profile Changes (Year 0 – Year 3)

Surveys conducted in years 0 to 3 are compared in Fig. 8c. Elevations in year 0 likely had a higher degree of error and the net trend between that survey and years 1-3 may not be significant. The range of elevation observations south of the pocket beach was similar for all year surveys, indicating relatively little change in the habitat bench elevation at distances of +50 m and greater along the transect (Fig. 8c) with the exception of a deeper area along the bench of <10 m length that was ~0.6 m lower in elevation than in previous surveys (see * in Fig. 8c). Over the years, the greatest observed changes occurred on the bench below the pocket beach (see below) and a section directly to the south (25 to 55 m along transect, Fig. 8) where new riprap material was placed in February 2007. The riprap covered much of the habitat bench over ~30 m of distance. Other slight differences in profiles at locations to the south of the repair area were likely due to minor differences in horizontal control on the irregular surface (i.e., whether or not the survey rod was placed on a high or low patch). The surface area of the habitat bench (south of the pocket beach) was calculated to be ~ 650 m^2.

Changes in the central bench directly below the pocket beach were monitored more frequently (Fig. 10). The initial surveys in year 0 to year 1 showed relatively steep mounds of sediment placed at the base of the beach. Over the summer of 2007 these mounds generally decreased in elevation. This can be seen in the comparison between the height of the mounds, determined by differencing the elevation between the peaks and troughs of the four major mounds over time (Table 3). In subsequent years, the mounds stabilized and no longer appear to be flattening further.

Table 3. 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.

Along Transect Location	**Date**	**Height of Mound along Survey Line (m)**
+4 m	January 2007	0.55
	March 2007	0.35
	July 2007	0.27
	January 2008	0.29
	February 2009	0.24
	December 2009	0.23
+11 m	January 2007	0.44
	March 2007	0.22
	July 2007	0.14
	January 2008	0.22
	February 2009	0.09
	December 2009	0.12

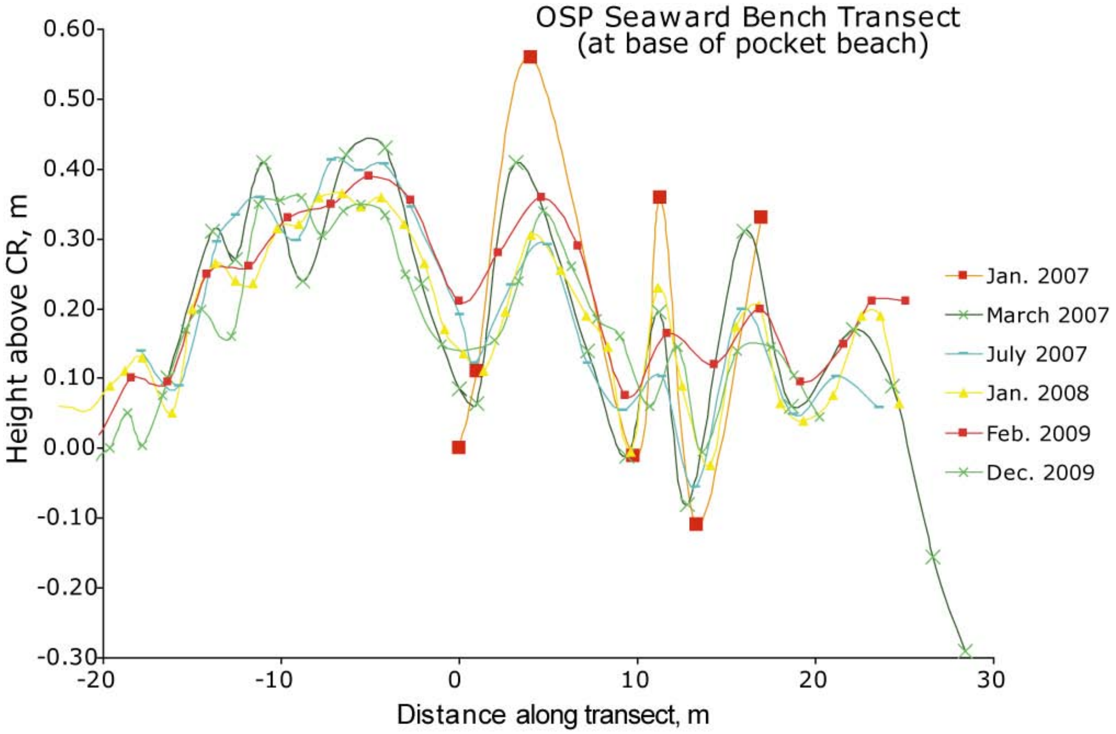


Figure 10. Detailed central bench surveys at base of pocket beach from year 0 to year 3. Mounds of gravel-sized material were placed on the habitat bench in winter of 2006. The emplaced mounds rapidly flattened between January 2007 and July 2007, likely by human use of the beach. The mounds have continued to flatten in year 2 to year 3, but are reaching a relatively stable morphology.

Sediment Grain Size

Sediment samples were obtained in winter and summer in years 0, 1 and 3. Data from the year 0 winter samples were difficult to evaluate due to continued construction and maintenance activities that occurred in winter 2006-07. Although many sediment samples were taken to characterize the beach, six cross-shore locations (three on BS and three on BN) provide consistent data for temporal comparison (Table 4). A generalized schematic of the grain-size distribution on the OSP pocket beach is shown in Figure 11. It shows a surface layer that ranged from –6.5 to –4.25 phi (D_{50} ~ 20-90 mm), and relatively well sorted sediments at profile locations across the foreshore. The surface sediment size increased at lower elevations. There was a subsurface layer in the upper foreshore that had a finer layer with median diameter of -3.75 to -2.25 phi (D_{50} ~ 5-14 mm). At elevations below approximately +2.0 m MLLW, this lower layer disappeared and the surface and subsurface sediment were equivalent in size. Specific sediment data collected in June 2009 on the upper and lower foreshore had a similar trend (Fig. 12). On the BS transect, surface sediment size ranged from 35 to 56 mm (Table 4). On the BN transect, the surface sediment data showed a thinning of the surface layer with exposure of the subsurface layer (see sample BN +22 m on the upper foreshore, Table 4 and Fig. 12). In February 2010, reorganization of the surface sediment left coarser sediment on the BN upper foreshore and a subsurface exposure on the BS upper foreshore (see sample BS +13, Table 4 and Fig. 13).

Table 4. Selected sediment grain-size results, D_{50} in mm, for years 0, 1 and 3 over the BN and BS transects. The position of the sediment sample is relative to the landward endpoint of the transect. For temporal comparison purposes, spatial groups of samples were given a sample designation.

		BN Transect			**BS Transect**		
Designation:		**BN +22m**	**BN +27m**	**BN +35m**	**BS +13m**	**BS +18m**	**BS +34m**
Approximate Elevation (MLLW):		+3.0	+2.0	+0.82	+3.7	+2.7	+0.14
Year 0	Dec. 6, 2006	33.1	38.7	---	36.6	41.9	---
	Jan. 20, 2007	15.9	---	---	12.0	29.2	---
	Feb. 15, 2007	26.6	31.5	---	11.4	32.0	---
Year 1	Aug. 10, 2007	30.5	32.1	49.8	20.2	35.5	44.9
	Dec. 11, 2007	30.6	36.4	52.4	39.2	31.3	50.8
Year 3	Jun. 10, 2009	9.1	28.8	48.8	42.8	35.3	56.5
	Feb. 5, 2010	28.2	36.7	---	11.8	42.1	---

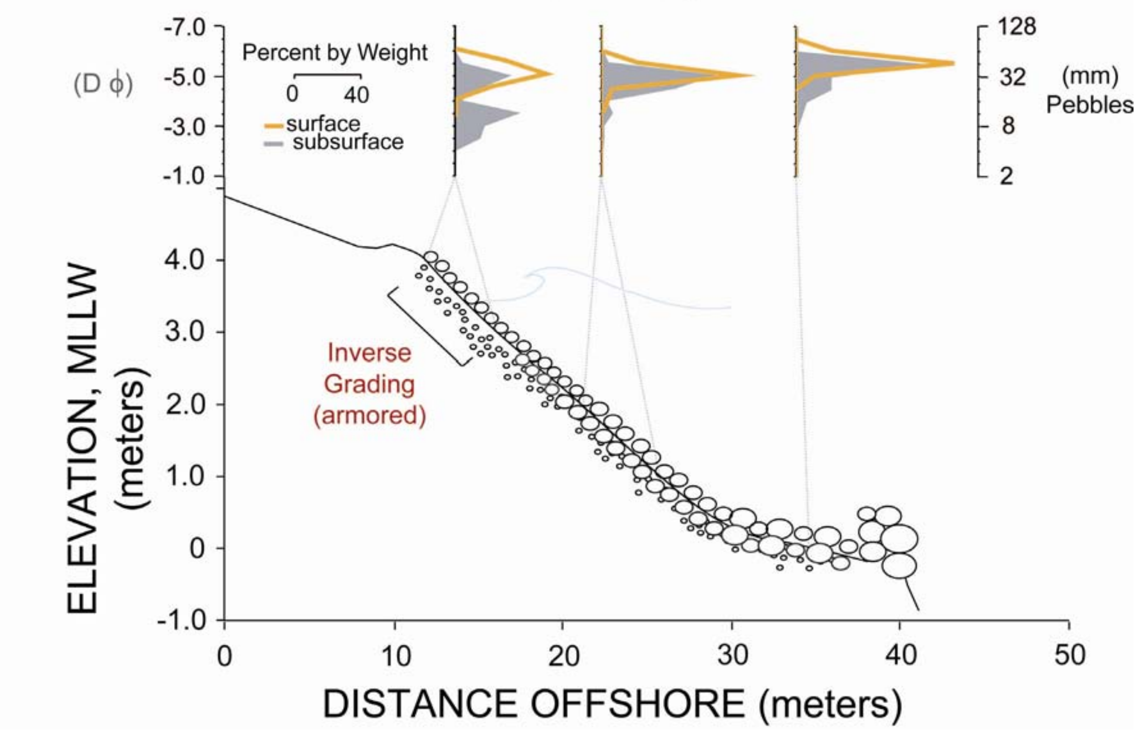


Figure 11. Schematic of sediment grain size on the OSP pocket beach. The sediment between +4.0 and +1.0 m MLLW increases in mean size down the beach reaching a maximum on the habitat bench. On the upper shoreface, the surface sediment is distinctly different than the subsurface sediment, with coarser gravel on the surface, and finer pea-sized pebbles below. Over time, the surface layer has mixed slightly with the subsurface layer.

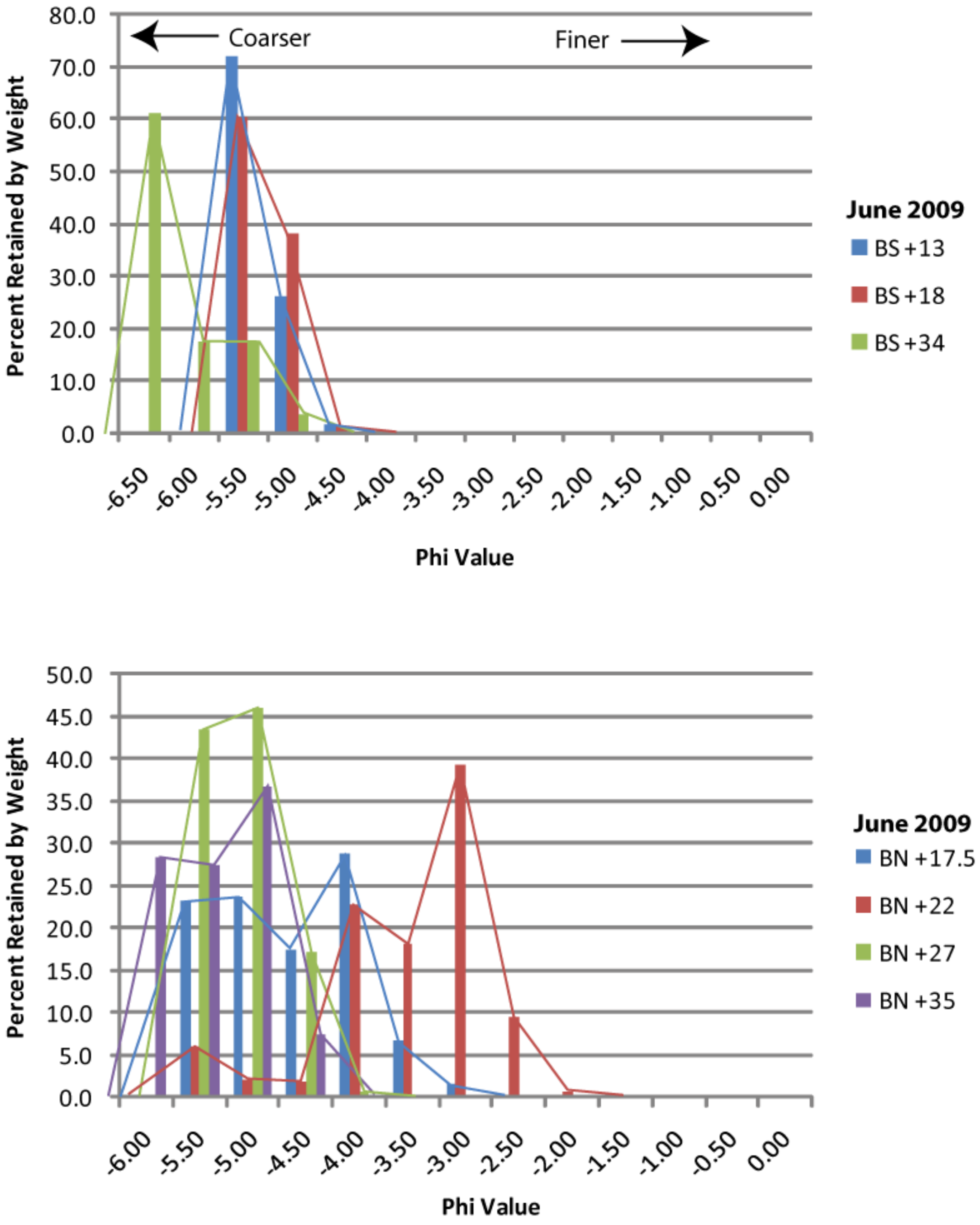
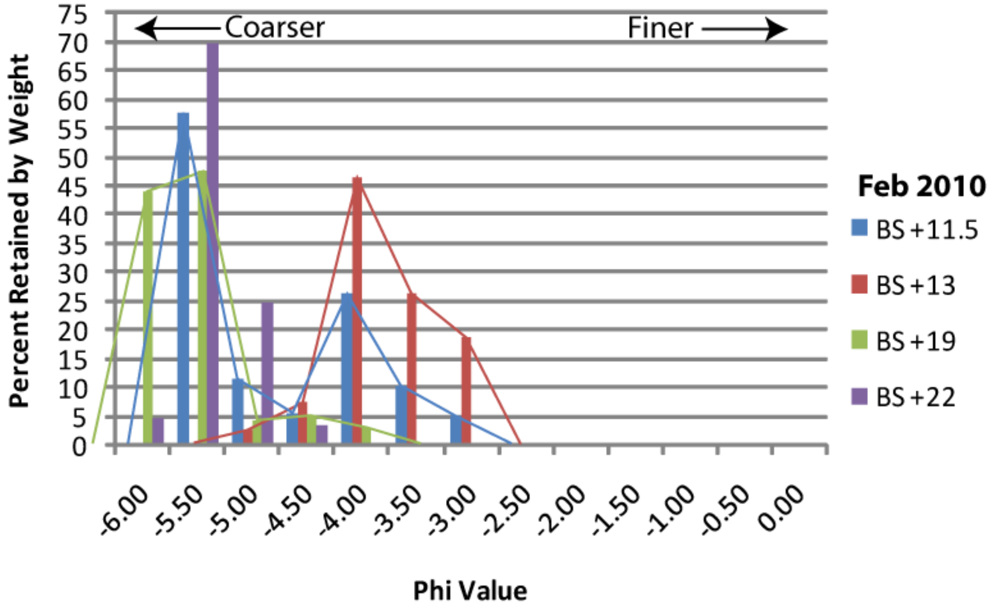


Figure 12. Surface sediment grain-size distribution across the OSP pocket beach, year 3 summer (June 2009). Sample site elevations are contained in Table 4.



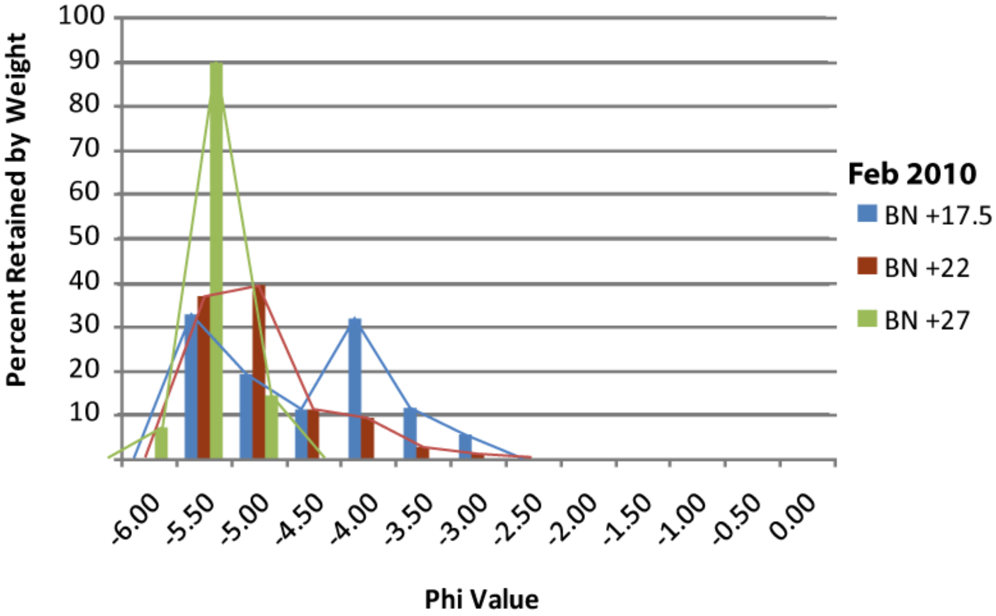


Figure 13. Surface sediment grain-size distribution across the OSP pocket beach, year 3 winter (Feb 2010). Sample-site elevations are contained in Table 4.

Grain Size Changes (Year 0 – Year 3)

Variations in grain size over years 0-3 have occurred mainly on the upper foreshore with little variation on the lower foreshore. Temporally variable striations in grain size on the upper foreshore were evident during the monthly surveys (see Toft et al. 2008), indicating active reorganization of surface sediments. Small-scale variability in the spatial distribution of sediment was observed, making absolute tracking of long-term change in the sediment composition on this small pocket beach difficult. Two sample sites on the upper foreshore (elevations of +2.1 and +2.4 m MLLW) illustrate general changes that have occurred on the beach.

On the upper to mid-foreshore of both transects, the surface sediment size distribution has become more variable since year 1, when the sediment grain size was very well sorted (Fig. 14). In year 3 (June 2009 samples) the sediment was generally less well sorted and in areas of the upper foreshore contained mixed components of the surface and subsurface sediment. Because natural processes act to move different size classes in different ways, patches of better sorted coarse and fine beach sediments can be found over the area of the pocket beach. Visual observations noted that the layer of coarser surface sediment on the upper foreshore is becoming thinner in the center of the beach with thicker coarse-grained deposits at the north and south corners as well as a small amount of loss to subtidal areas.

On the lower foreshore, the grain size appeared to coarsen between year 0 and year 1 (Toft et al. 2008), but has remained relatively stable since that time. This sediment is generally too large to move, and evidence of biological growth on the grains indicates its stability. Individual grains of upper foreshore surface sediment could be seen on the lower foreshore during profiling due to their lack of biological growth and size. These were likely brought to the lower foreshore through human intervention, e.g., throwing of rocks.

The sub-surface sediment was distinctly different from the surface sediment on the upper foreshore, but not on the lower foreshore (Fig. 11). On the upper foreshore, the sub-surface grain size is smaller ranging from -3.75 to -2.25 phi (D_{50} ~ 5-14 mm). The range of sizes observed in the subsurface increased (sediment is less well sorted) between years 1 and 3. The subsurface became 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 mixing of surface and subsurface components is evident (Fig. 15).

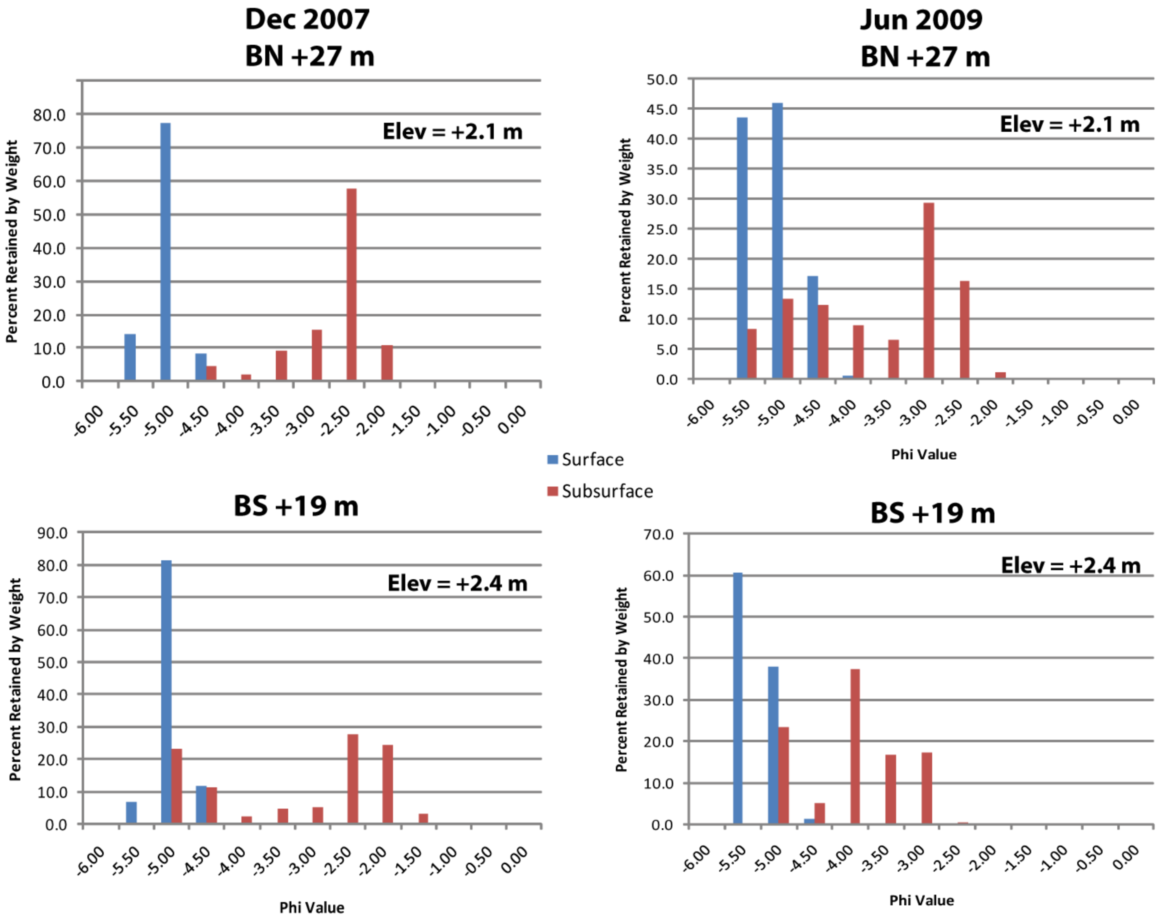


Figure 14. Changes in surface sediment grain size at elevations of +2.1-2.4 m MLLW between year 1 and year 3. The most significant difference in the grain-size distributions is the mixing of the surface sediment into the subsurface component, creating a less well-sorted subsurface distribution.

Figure 15. Image of surface and subsurface sediment taken during year 1 sampling (a) and year 3 sampling (b). The mixing of surface and subsurface components is apparent in the difference between the two photographs.

Biological Characteristics

Fish - Snorkel Surveys

Environmental Parameters

In 2009, salinity and temperature ranges varied little with water depth, averaging 24.8 ppt and 12.2 °C at the surface, and 25.9 ppt and 11.9 °C at the bottom of intertidal sampling locations. Tidal elevations during snorkel surveys differed 1.3 m between high and low tide transects, averaging +2.4 m MLLW for high tide transects and +1.1 for low tide transects. In general, water clarity was better at high tide than low tide, especially in late June and July when visibility was over 10 m at three dates during high tides (Fig. 16). Water visibility was almost always over the 2.5 m necessary to conduct snorkel surveys, except for one date in May at low tide.

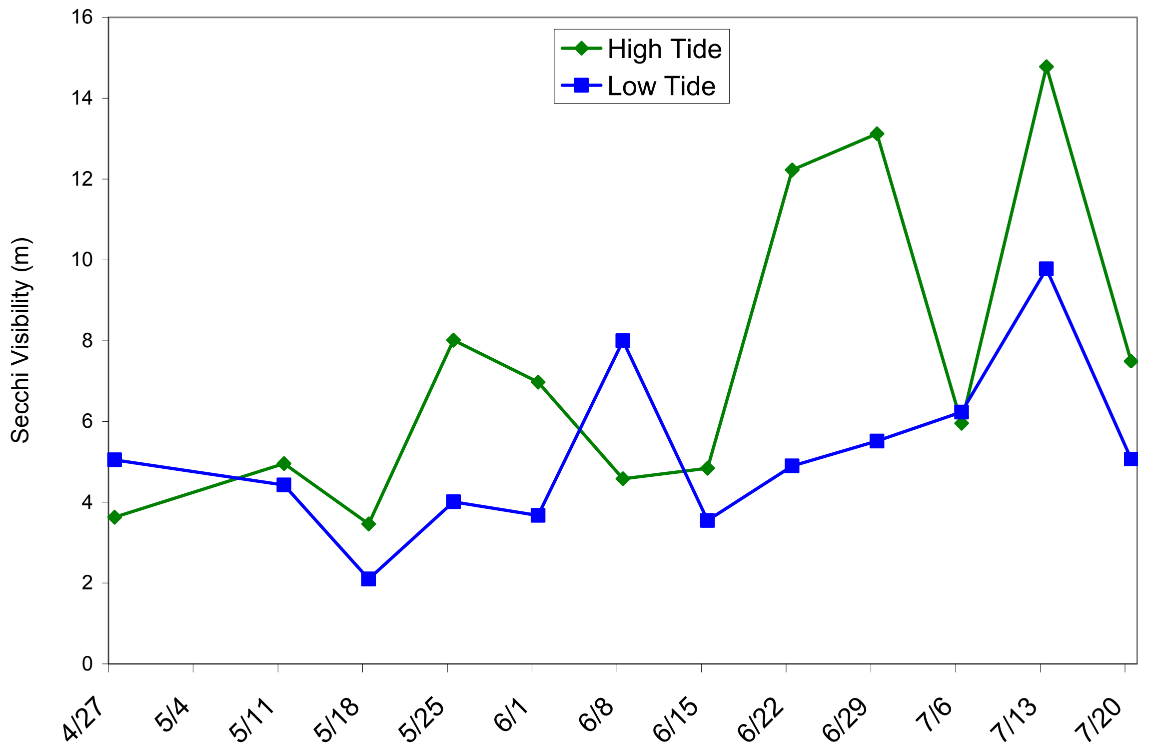


Figure 16. Average distance of underwater visibility on each 2009 snorkel survey week, at both high and low tide, based on horizontal secchi disk measurements.

Water depths during snorkel surveys varied between 1.3 and 3.9 m depending on site and tide (Table 5). 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 at high tide when the entire beach was inundated. The outer beach, habitat bench, and riprap sites all had values of 2.1-2.5 m at the shallow depth and 3.8-3.9 m at the deep depth during high tide. At low tide, shallow values ranged from 1.4-1.6 m and deep 2.6-3.4 m.

Table 5. Average water depths (m) from snorkel surveys, for high (avg +2.4 m MLLW) and low (avg +1.1 m) 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	2.4	–
Pocket Beach Shallow 3	2.5	1.6
Pocket Beach Deep	3.9	3.4
Habitat Bench Shallow	2.1	1.4
Habitat Bench Deep	3.9	3.2
Riprap Shallow	2.1	1.5
Riprap Deep	3.8	2.6

Fish – snorkel surveys

A total of 207 snorkel transects were conducted in 12 weeks of sampling. Twenty-three species of fish and crabs were counted during snorkel surveys (Table 6). 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". Over 90% of the overall numbers were of larval fish, which were a combination of all fish that were too small to identify to species level by snorkel observation. These fish formed large schools often over 1000 fish per school. Two main types of larval fish were observed: (1) post-larval forage fish, that were identified as smelt on a few occasions and had a thin linear shape, and (2) demersal-type larval fish that were more compact with large eyes, and although not identified as sculpin had that same general morphology. Of the larval fish that could be categorized, 85% were of the forage fish morphology. Abundant non-larval fish were chum salmon, shiner perch, tubesnout, and herring. Crab observations were dominated by kelp crabs and red rock crabs. There were a few observations of rare fish that did not occur in previous years: one dolly varden trout was observed at the habitat bench shallow transect, and four greenlings were observed, three at the pocket beach deep transect and one at the riprap deep transect. Potential juvenile salmonid predators were rare, and over the entire sampling included (1) eleven lingcod, which was slightly more than were seen in previous years (three each in 2005 and 2007), that were observed at the pocket beach and habitat bench shallow and deep sites, and (2) one large sculpin at the pocket beach.

Table 6. 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
Chum	*Oncorhynchus keta*	7.0	3,978
Chinook	*Oncorhynchus tshawytscha*	9.5	272
Chinook/Coho	*Oncorhynchus tshawytscha/kisutch*	10.3	19
Coho	*Oncorhynchus kisutch*	8.8	6
Juvenile Salmon, unk.	*Oncorhynchus spp.*	8.8	244
Dolly Varden	*Salvelinus malma*	25.0	1
Larval Fish	-	1.9	265,657
Herring	*Clupea harengus pallasi*	6.3	5,000
Smelt	*Osmeridae*	6.3	254
Pacific Sand Lance	*Ammodytes hexapterus*	11.3	4
Tubesnout	*Aulorhynchus flavidus*	7.7	5,054
Shiner Perch	*Cymatogaster aggregata*	8.9	11,256
Striped seaperch	*Embiotoca lateralis*	14.7	613
Pile perch	*Rhacochilus vacca*	14.4	315
Kelp Perch	*Brachyistius frenatus*	9.5	54
Three-Spined Stickleback	*Gasterosteus aculeatus*	5.0	1
Lingcod	*Ophiodon elongatus*	45.3	11
Kelp Greenling	*Hexagrammos decagrammus*	20.0	1
Greenling	Hexagrammidae	26.3	3
Sculpin	Cottidae	20.0	1
Goby	Gobiidae	6.3	3
Crescent Gunnel	*Pholis laeta*	20.0	1
Penpoint Gunnel	*Apodichthys flavidus*	12.5	1
Fish, unk.	-	8.1	5
Kelp Crab	*Pugettia* spp.	8.2	46
Red Rock crab	*Cancer productus*	13.0	76
Dungeness Crab	*Cancer magister*	11.3	2
Cheiragonid crab	*Telmessus cheiragonus*	10.0	1

Overall fish densities were dominated by larval fish, which peaked once in May and were consistently abundant from late June through July (Fig. 17). Juvenile salmonids and shiner perch were relatively abundant from May until mid-June, with tubesnout having consistent but lower numbers in late June and July. One large school of herring was observed on May 11. Striped sea perch, pile perch, and crabs were consistently observed in low abundances.

Timing of juvenile salmonids was similar to past years (Fig. 18). Juvenile chum salmon were the most abundant salmonid observed, peaking in May to early June with lower numbers by late June. Chinook and Chinook/coho categories appeared in May, and occurred consistently until the end of sampling in late July.

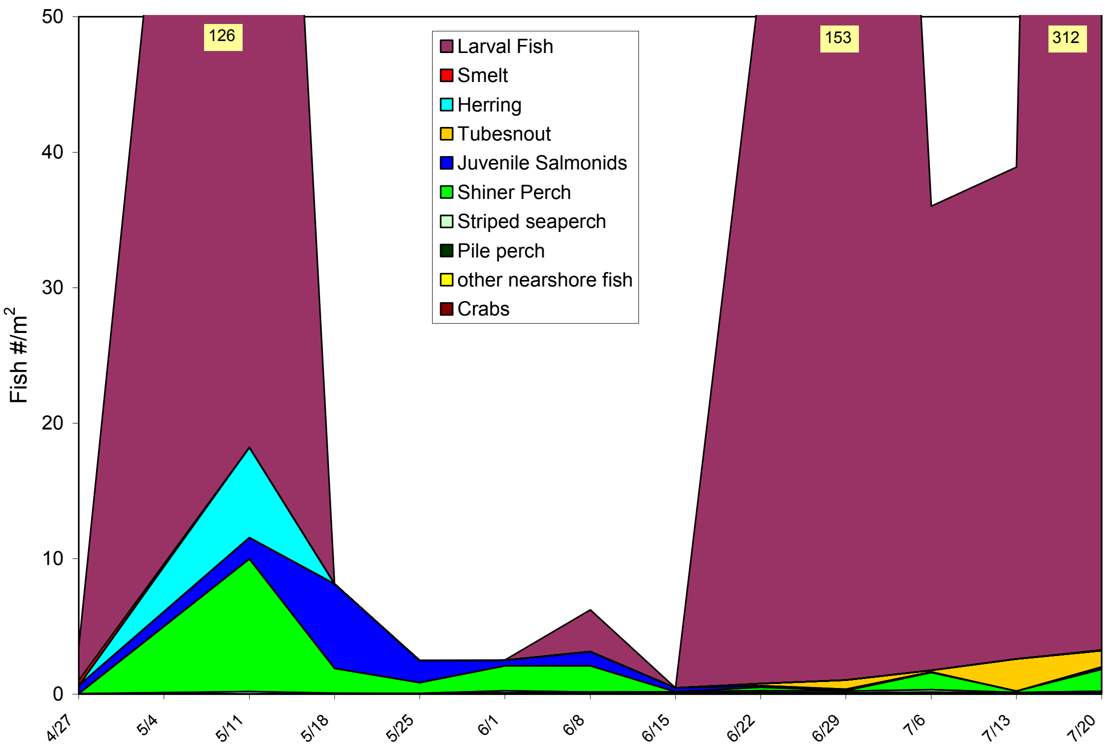


Figure 17. Total fish densities from snorkeling transects by sampling week (no sampling occurred on May 4th). In cases of extremely high densities of larval fish, scale on the y-axis is truncated and overall numbers are stated in a text box.

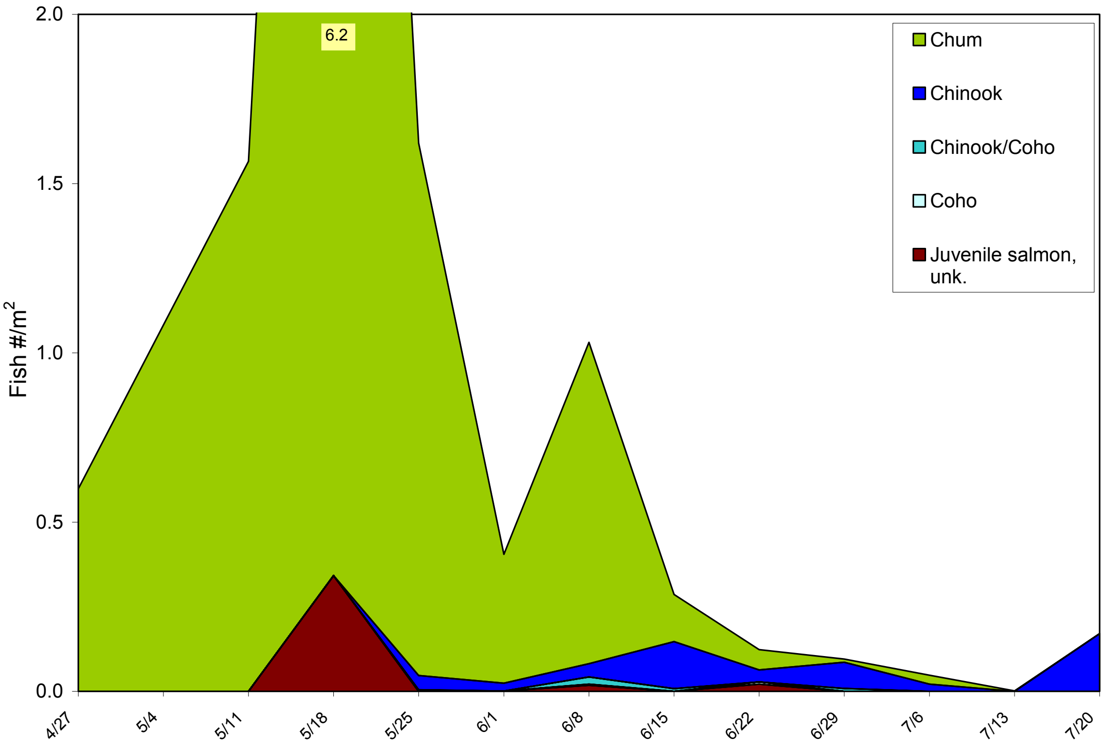


Figure 18. Juvenile salmon densities from snorkeling transects by sampling week.

The most striking difference between 2009 and past years was the increase of larval fish at the pocket beach and habitat bench (Fig. 19). Larval fish were slightly more abundant at the deep transects at these sites. There was also a small increase in tubesnout compared to past years, also mostly at the pocket beach and habitat bench. Herring were only abundant at the habitat bench deep transect, and consisted of one observed school of ~5000 fish. Smelt were also only observed at the habitat bench. Shiner perch were abundant, but less so than in past years. As in previous years, overall juvenile salmonids were most abundant at shallow transects, and their densities were also fairly consistent with those in previous years (Fig. 20). The riprap shallow transect had relatively higher abundances compared to past years, almost exclusively due to chum salmon; as previously, Chinook were most abundant at the pocket beach and habitat bench sites (Fig. 20). At the pocket beach, almost all juvenile salmonids were observed at shallow transects.

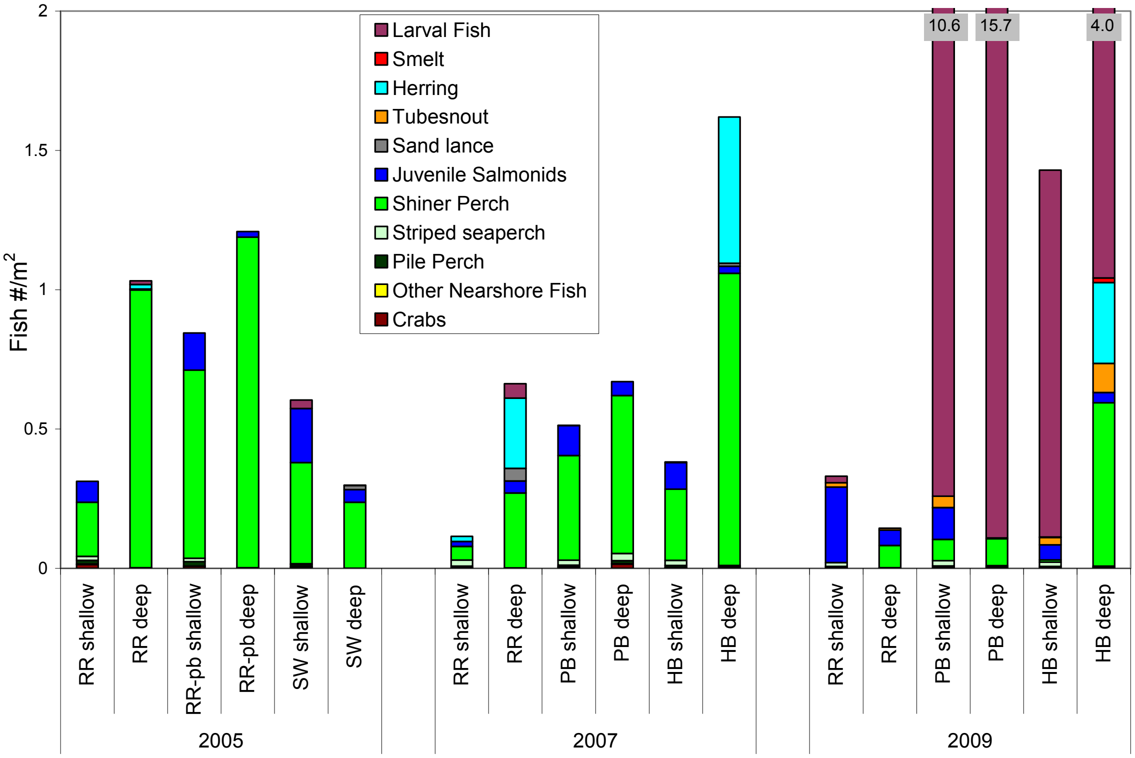


Figure 19. Average total fish densities at shallow and deep transects by habitat type and year. RR = Riprap, RR-pb = Riprap at location where pocket beach was later created, SW = Seawall at location where habitat bench was created, PB = Pocket Beach, HB = Habitat Bench.

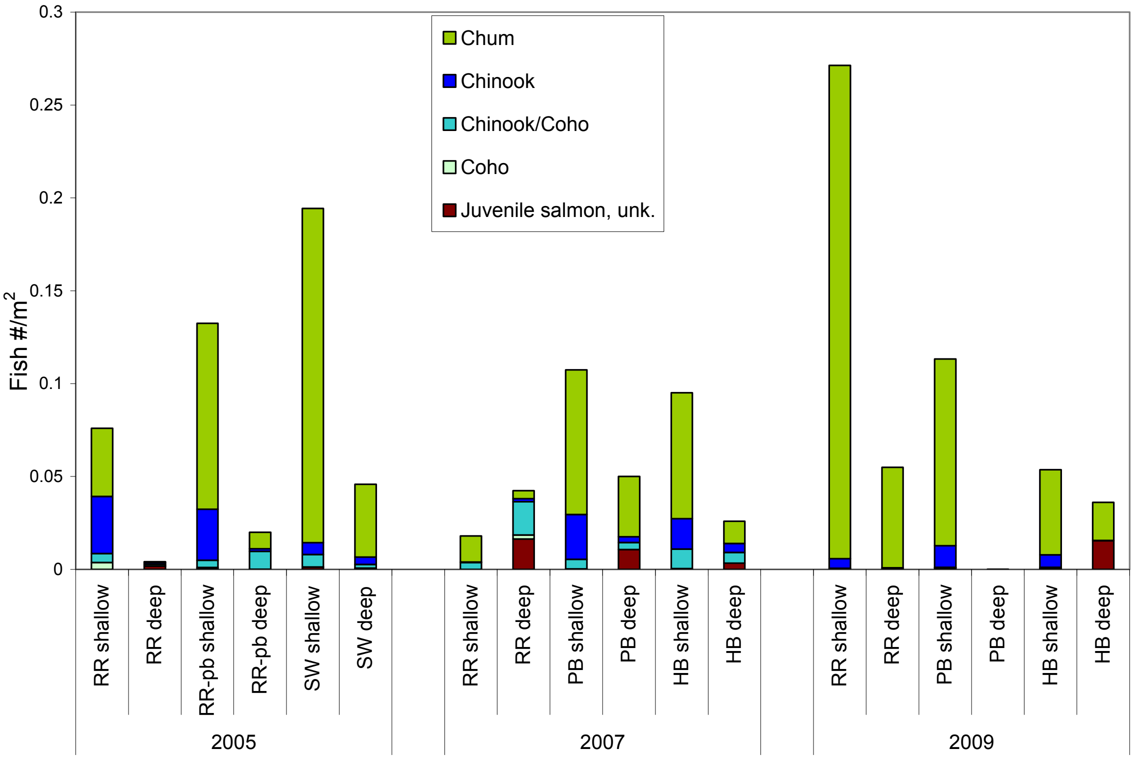


Figure 20. Average juvenile salmon densities at shallow and deep transects by habitat type and year.

ANOVA was conducted on juvenile salmonids and larval fish, two of the most abundant groups of fish that occurred in the nearshore habitats. For 2009 data, densities of larval fish were significantly greater at the pocket beach than other habitats at shallow depths (Table 7). Comparisons between years showed similar results, with significantly greater densities of larval fish in shallow depths at the pocket beach in 2009 than in past years. Larval fish densities were also significantly different among sampling periods at the deep transect at the pocket beach, but results were not strong enough to indicate specific year differences using the tukey test, although 2009 by far had the greatest densities. There were no significant differences among the sites/transects for juvenile salmonid densities in 2009, and there were also no significant results for juvenile salmonid densities at specific habitats across years.

Table 7. Results of ANOVA testing on snorkel-survey fish densities, significant results ($p < 0.05$) are in bold.

Comparison of 2009 habitats	fish	p-value	tukey test for habitat/year differences
Shallow	juvenile salmon	0.51	–
	larval fish	**0.005**	pocket beach > habitat bench & riprap
Deep	juvenile salmon	0.23	–
	larval fish	0.10	–

Comparison of years within each habitat	juvenile salmon	larval fish
Riprap shallow	0.31	0.16
Riprap deep	0.22	0.52
Pocket Beach shallow	0.92	**0.0007** (09>07,05)
Pocket Beach deep	0.18	**0.04**
Habitat Bench shallow	0.09	0.23
Habitat Bench deep	0.64	0.09

Water column position and behavior varied by species (Table 8). For juvenile salmon, main water column positions were middle and surface for Chinook and coho salmon, and surface for chum salmon; there was only one observation of an unknown juvenile salmonid in the bottom portion of the water column. Most other fishes occurred at middle to bottom depths, and some species were away from the bottom only if observed on kelp or boulders (e.g. crabs, goby, gunnel). The most common behaviors were swimming away, schooling, feeding, and unaffected. Most observations of feeding were for juvenile salmon, tubesnout, and perch species.

Table 8. Number of observations of fish and crabs for categories of water column position and behavior.

	Water column position			Behavior						
Fish Species	Bottom	Middle	Surface	Feeding	Fleeing	Hiding	Injured	Schooling	Swam Away	Unaffected
Chum		15	76	47	2			27	14	1
Chinook		32	16	29				11	8	
Chinook/Coho		9	4	4	2			2	5	
Coho		2	4	1					4	1
Juvenile salmon, unk.	1	3	2	2	2			1	1	
Dolly Varden		1		1						
Larval Fish	8	46		5				40	3	6
Herring		1		1						
Smelt	1	2	1	2				1	1	
Pacific Sand Lance		3								3
Tubesnout	17	50		21				34		12
Shiner Perch	18	85	1	26	1			29	25	23
Striped seaperch	310	34		59	3	2	1	7	139	133
Pile perch	123	46		11	7			19	77	55
Kelp Perch	2	20	2	6	1	2			3	12
Three-Spined Stickleback			1						1	
Lingcod	11				1	2			4	4
Kelp Greenling	1									1
Greenling		1							1	
Sculpin	1								1	
Goby		3							1	2
Crescent Gunnel	1									1
Penpoint Gunnel			1			1				
Kelp Crab	10	32		3		1				38
Red Rock crab	16	3		8		3				8
Dungeness Crab	1					1				
Cheiragonid crab	1									1

Percentage of juvenile salmonid numbers observed feeding was greater at shallow transects at all sites, and was also greater in 2009 than in 2005 at the shallow transects (Table 9). The habitat bench and pocket beach shallow transects had the highest observed feeding in 2009 for Chinook salmon, and in contrast to past years the riprap shallow transect had the highest observed feeding for chum. Juvenile salmonid feeding behaviors were typically characterized by fish darting to the surface to feed on neustonic prey, though there was some feeding in the middle of the water column; feeding directly on bottom substrates was rare. Water column position was fairly consistent between sites, with the exception that Chinook were almost entirely in the middle of the water column at the riprap shallow transect.

Table 9. Percentage of juvenile salmonid numbers in categories of feeding behavior at all sites and years, and water column position in 2009.

		Feeding Behavior			**Water column position**	
Fish Species	**Site**	2005	2007	2009	Middle	Surface
Chinook, and Chinook/coho	Riprap shallow	18%	53%	60%	98%	2%
	Riprap Deep	36%	41%	14%	71%	29%
	Pocket Beach Shallow	57%	59%	76%	79%	21%
	Pocket Beach Deep	2%	64%			
	Habitat Bench Shallow	67%	64%	82%	54%	46%
	Habitat Bench Deep	5%	49%	20%	80%	20%
Chum	Riprap shallow	10%	3%	81%	13%	87%
	Riprap Deep		58%	34%	37%	63%
	Pocket Beach Shallow	11%	8%	36%	5%	95%
	Pocket Beach Deep		37%			100%
	Habitat Bench Shallow	10%	55%	58%	14%	86%
	Habitat Bench Deep		69%	9%	6%	94%

Fish - Enclosure Nets and Diets

On average, the enclosure net was deployed for 3.4 hours at the pocket beach, with a maximum water depth of 2.7 m at time of net deployment. Fish composition in the net was mainly juvenile salmon, accounting for 91% of the total catch with an average count of 62 per net (Fig. 21). Chum were the most abundant species, followed by hatchery and wild Chinook, and relatively fewer coho. Average forklength and weight of salmon were: Chinook 85.9 mm and 8.1 g, coho 98.5 mm and 9.5 g, and chum 48.9 mm and 1.2 g. Most non-salmonid species were small, and were not considered to be predators on juvenile salmon except for one large lingcod.

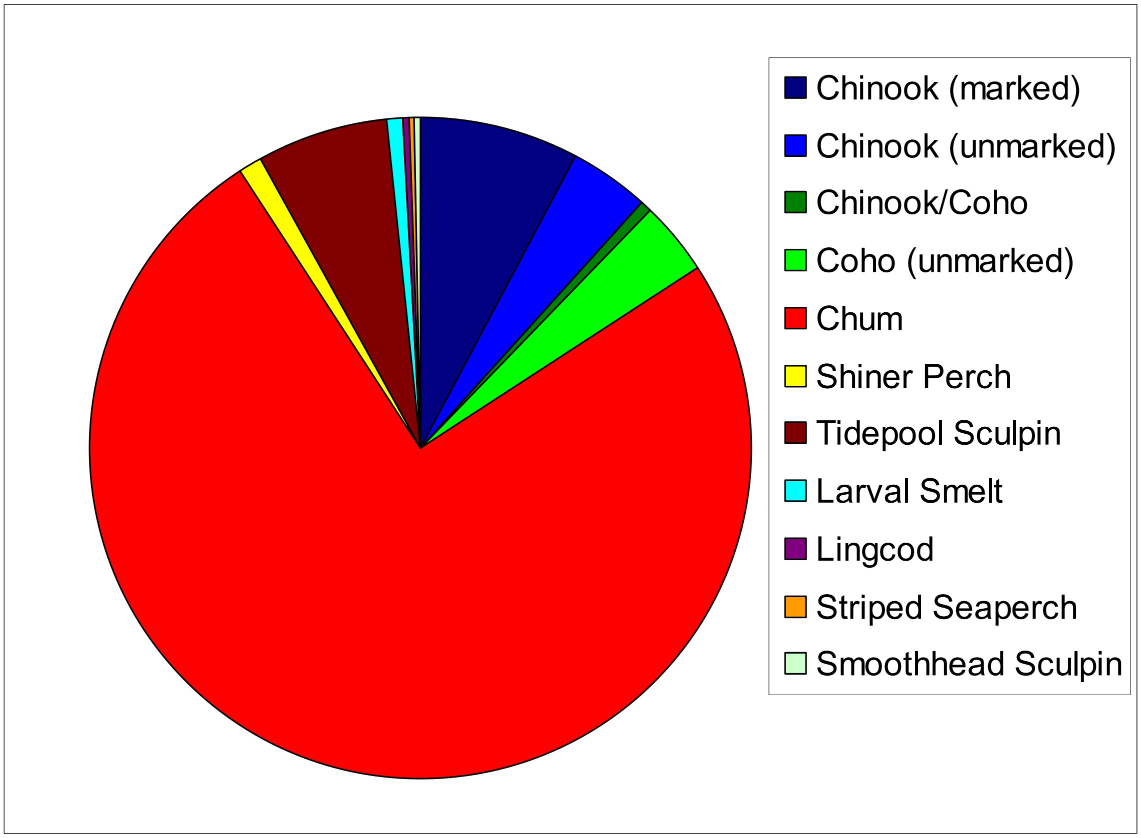


Figure 21. Numerical percent composition of fish captured by enclosure net at the Pocket Beach (n = 5; average 62 juvenile salmon).

Diet samples from 33 Chinook, 32 chum, and 6 coho salmon were analyzed from the pocket beach enclosure netting in 2009 (Fig. 22, Table 10). Chinook salmon diet biomass was dominated by decapods in May (70% of prey weight, consisting all of crab zoea, mostly in the family Cancridae), and amphipods in June and July (68% and 99%, respectively). Dominant amphipods in May were *Paramoera* sp., *Ampithoe* sp., and *Protohyale frequens*, while in June and July *Calliopius* sp. dominated amphipod prey. Diptera accounted for the majority of the remaining Chinook prey items in May and June (13% and 24%, respectively), consisting mostly of Chironomidae adults and larva. Chum salmon diets were similar to Chinook diets in proportion of decapods, amphipods, and diptera. Smaller chum captured in April fed on more diverse prey items, including 26% harpacticoid copepods. These harpacticoids were predominantly *Harpacticus* sp., *Tisbe* sp, and *Amonardia perturbata*. Chum in April and July also fed some on calanoid copepods. Coho captured in May had very similar amphipod and decapod inputs as Chinook, but had minimal diptera and instead had 10% fish in their diets.

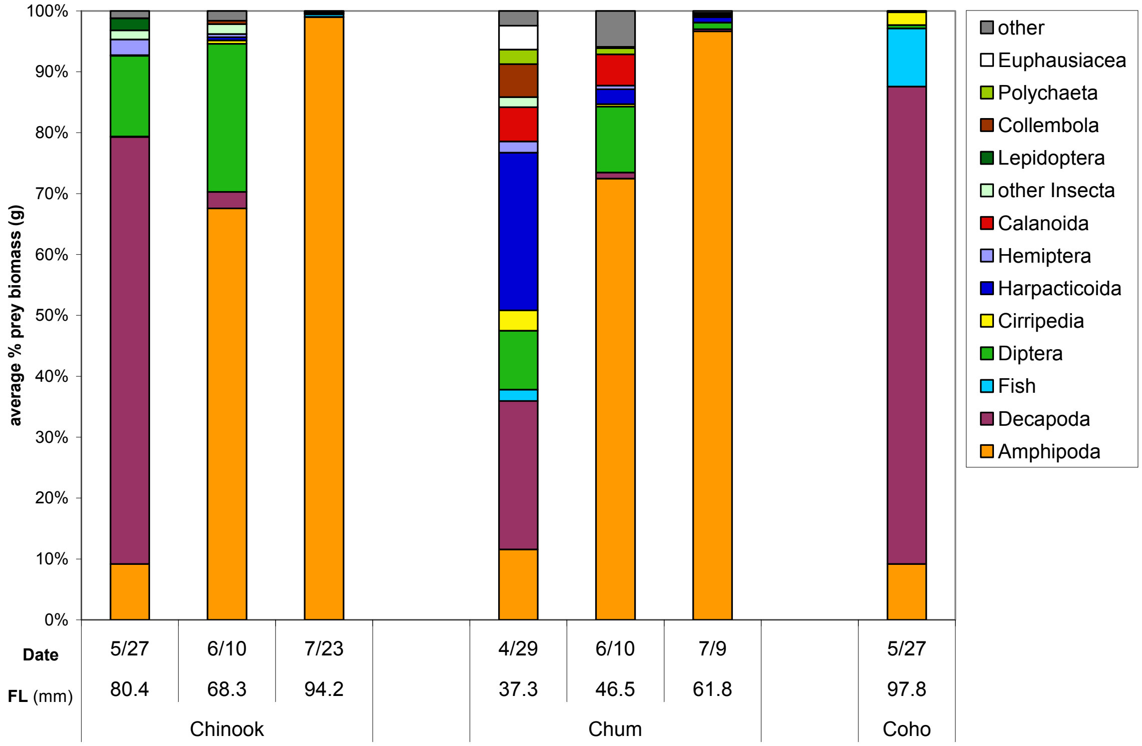


Figure 22. Average percent weight composition of juvenile salmon prey in 2009, by date and average forklength (mm) of Chinook, chum and coho.

Table 10. Species listing of fish diet contents, in descending gravimetric importance within each category.

Taxa Grouping	Taxa
Amphipoda (*scuds*)	*Calliopius* sp., *Ampithoe* sp., *Hyperia medusarum*, *Themisto pacifica*, *Desdimellita* sp., Hyperiidea, *Protohyale frequens*, *Paramoera* sp., *Foxiphalus similis*, *Aoroides columbiae*, Phoxocephalidae, *Paramoera mohri*, *Allorchestes* sp., *Paracalliopiella pratti*, *Aoroides* sp., Calliopiidae, *Paramoera bousfieldi*, *Americorophium salmonis*, *Ichyrocerus anguipes*, *Caprella laeviuscula*
Calanoida and Cyclopoida (*copepods*)	*Calanus* sp., *Epilabidocera longipedata*, *Calanus pacificus*, *Corycaeus* sp., Calanoida nauplii, *Corycaeus anglicus*, *Paracalanus* sp., *Pseudocalanus* sp., *Centropages abdominalis*, Oncaea sp., Aetidius divergens, Cyclopoida
Cirripedia (*barnacles*)	Cirripedia, Cirripedia exuvia, Cirripedia nauplii, Cirripedia Cyprid
Cladocera (*water fleas*)	*Evadne* sp., *Podon* sp
Collembola (*springtails*)	Isotomidae, Onychiuridae
Cumacea	*Nippoleucon hinumensis*, *Cumella vulgaris*
Decapoda (*crabs/shrimp*)	Cancridae zoea, Brachyura zoea, *Hemigrapsus* zoea, *Hemigrapsus* sp., *Neotrypaea californiensis* zoea, Paguridae megalopa, Xanthidae megalopa, Paguridae zoea, Anomura megalopa, Pinnotheridae zoea, Anomura zoea, Decapoda zoea, *Neotrypaea californiensis*, Grapsidae zoea

Diptera (*true flies*)	Chironomidae, Chironomidae larva, Dryomyzidae, Diptera larva, Tipulidae, Chironomidae pupa, Sciaridae, Cecidomyiidae, Chloropidae, Ceratopogonidae, Phoridae, Psychodidae
Harpacticoida (*copepods*)	*Harpacticus uniremis*, *Tisbe* sp., *Harpacticus septentrionalis*, *Diosaccus spinatus*, *Harpacticus* sp. unk., *Amonardia perturbata*, *Harpacticus* sp. A, *Dactylopusia crassipes*, *Zaus* sp., *Harpacticus compressus*, *Harpacticus uniremis* group, *Amphiascopsis cinctus*, *Dactylopusia vulgaris*, *Harpacticus obscurus* group, *Dactylopusia glacialis*, *Heterolaophonte longisetigera*, *Paradactylopodia* sp., *Parathalestris californica*, *Scutellidium* sp., Ectinosomatidae
Hemiptera (*true bugs*)	Aphididae, Cicadellidae, Aphidoidea
Hymenoptera (*wasps*)	Ichneumonidae, Braconidae
General Taxa Groupings	Fish (fish, fish larva), Lepidoptera, Euphausiacea, Polychaeta, Araneae, Ostracoda, Psocoptera, Coleoptera larva, Ectoprocta, Neuroptera (Coniopterygidae), Acari, Isopoda (Epicaridea), Mysidacea (*Neomysis mercedis*), Oligochaeta

Epibenthic Invertebrates

Taxa richness in epibenthic samples was much higher in 2009 than 2005 at all of the sites (Fig. 23). The largest differences were at the pocket beach and habitat bench sites, both of which were greater than at the adjacent riprap and seawall sites. Taxa richness at the habitat bench continued to increase from 2007 to 2009, while taxa richness at the pocket beach decreased slightly.

As in previous years, 2009 epibenthic invertebrate taxa composition was dominated by two orders of crustaceans: harpacticoid copepods and amphipods (Fig. 24). Harpacticoids were particularly abundant at the pocket beach and habitat bench sites, and amphipods were most abundant at the riprap and habitat bench sites. Cirripedia (barnacles), consisting mostly of larval naupliar stages, were relatively numerous at the seawall. At the enhanced sites, composition of amphipods changed after site construction. In 2005 over 93% of amphipod composition at the armored sites (including locations that were to become the pocket beach and habitat bench) consisted of one species, *Paracalliopiella pratti* (Fig. 25). In 2007 and 2009, *P. pratti* continued to be abundant at the enhanced sites ranging from 29% to 77%, but amphipod diversity was greater due to contributions from other taxa such as *Calliopius* sp., *Desdimelita* sp., *Protohyale* sp., and *Pontogeneia rostrata*. In 2009 the armored sites continued to be dominated by *P. pratti* (95% at riprap, 87% at seawall). Harpacticoid copepods had very low densities in 2005 before the habitat enhancements (Fig. 26). After the pocket beach and habitat bench were constructed, harpacticoid densities were much higher than at the corresponding riprap and seawall sites (see below). Among the main harpacticoid taxa present were the juvenile salmon prey taxa *Tisbe* sp. and *Harpacticus* spp., and overall there was a diverse mix of taxa (Fig. 26). Overall listings of 2009 epibenthic invertebrates and taxa groups are in Table 11.

ANOVA conducted on 2009 overall densities of epibenthic invertebrates indicated that densities at the habitat bench were significantly higher than at other habitat types (Table 12). ANOVA was also conducted for amphipods and harpacticoid copepod densities, the two most abundant orders containing epibenthic juvenile salmonid prey. Results showed that harpacticoid densities were significantly higher at the habitat bench and pocket beach compared to the seawall and riprap sites. Amphipods were significantly more numerous at the habitat bench and riprap sites than the seawall and pocket beach.

ANOVA on each habitat type across all three years indicated that densities of all invertebrates, harpacticoids, and amphipods were significantly higher at all habitat types in the two post-enhancement sampling years compared to 2005, with the exception of amphipods at the riprap and pocket beach sites (Table 12). In general, densities of most invertebrate categories at both the pocket beach and habitat bench were lower in 2009 than 2007, and in some cases these differences were significant. However, 2009 densities for most categories were still greater than those from 2005 (pre-enhancement) samples, and the difference was significant for overall invertebrates and harpacticoids at both sites, as well as amphipods at the habitat bench.

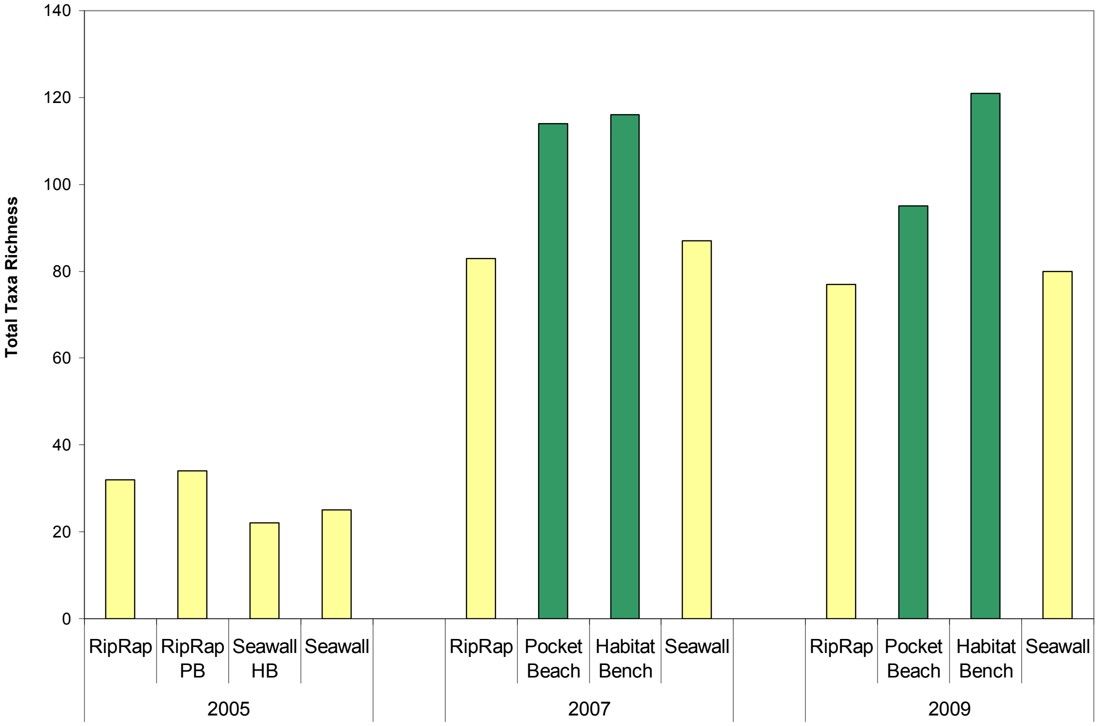


Figure 23. Overall taxa richness (# of taxa) of epibenthic invertebrates by year and site. Enhanced habitats are colored in green.

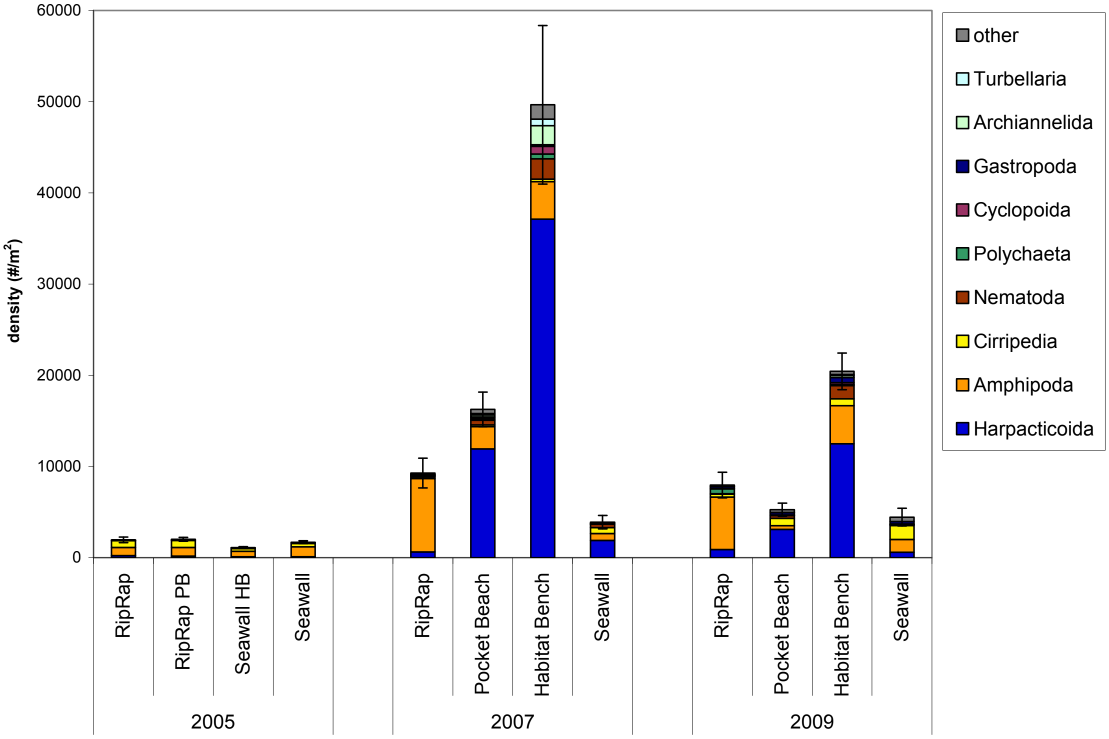


Figure 24. Average densities and general taxa composition of epibenthic invertebrates by habitat and year.

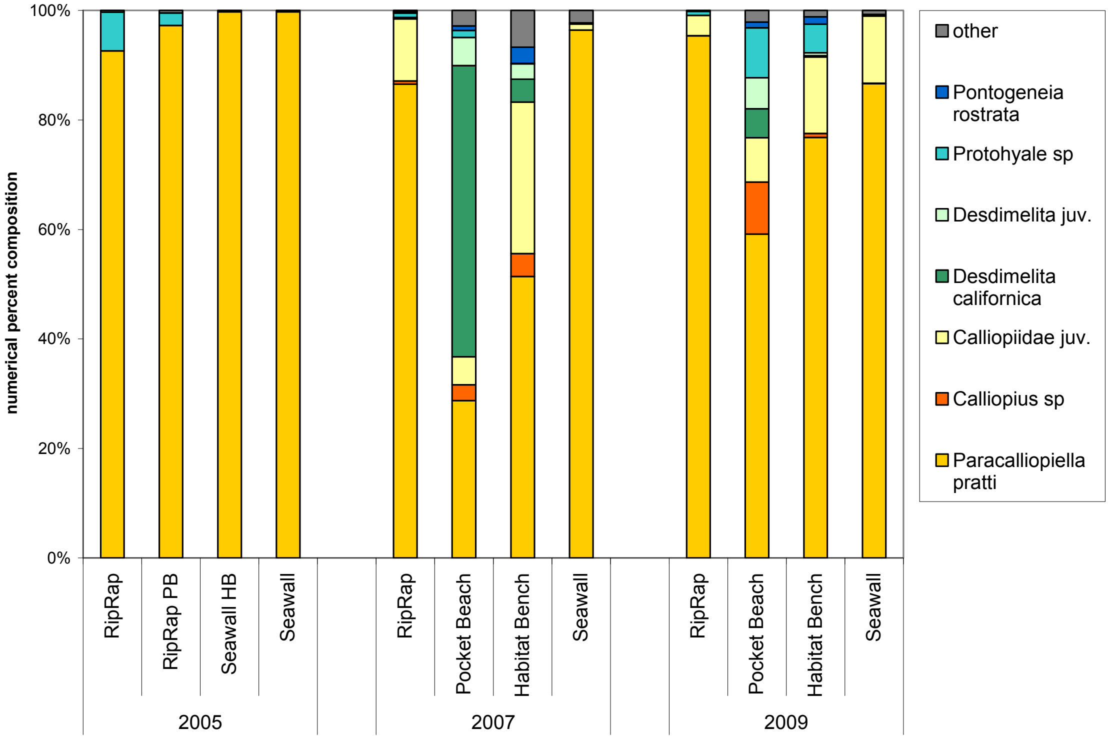


Figure 25. Average numerical percent composition of epibenthic amphipods by habitat and year.

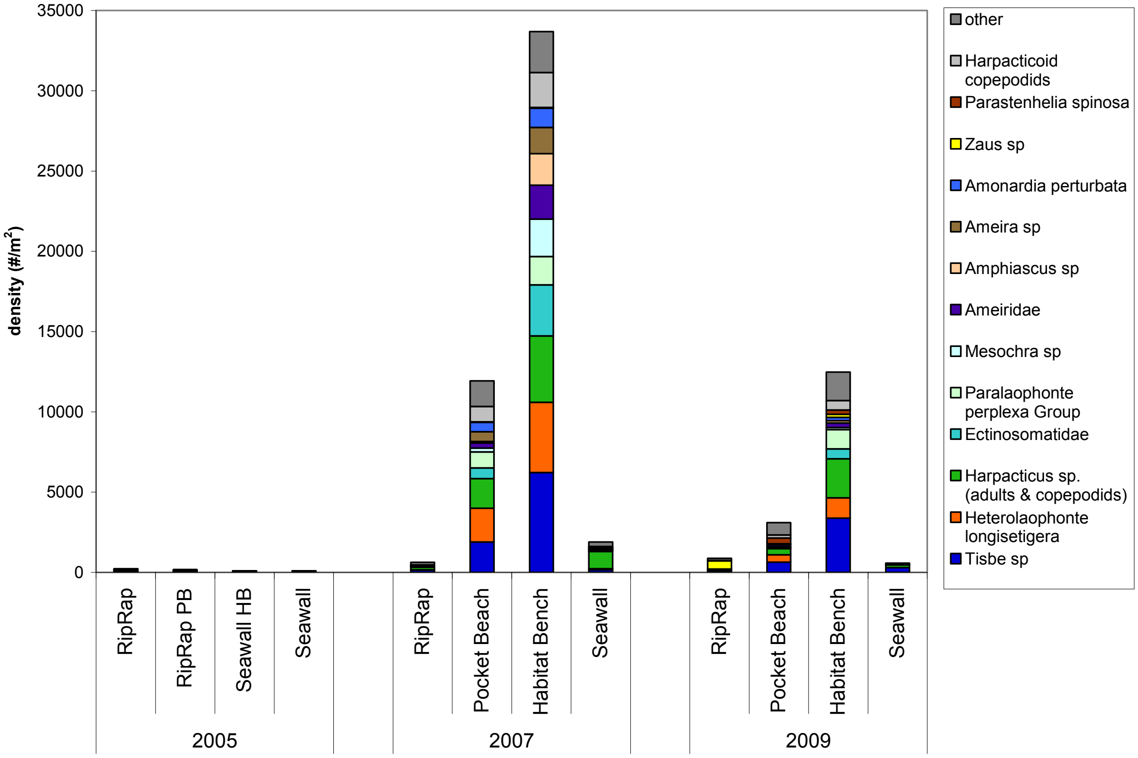


Figure 26. Average densities and general taxa composition of epibenthic harpacticoids by habitat and year.

Table 11. List of sampled epibenthic invertebrates and taxa groups, taxa are listed in descending numerical abundance within each grouping.

Taxa Grouping	Taxa
Amphipoda (*scuds*)	*Paracalliopiella pratti*, Calliopiidae Juvenile, *Protohyale* Juvenile, *Protohyale frequens*, *Calliopius* sp., *Pontogeneia rostrata*, *Desdimelita* Juvenile, *Desdimelita californica*, *Ampithoe* sp., *Ichyrocercus anguipes*, *Ischyrocerus* sp., *Parathemisto pacifica*, *Aoroides columbiana*, *Protohyale* sp., *Caprella laeviuscula*, Hyperiidea Juvenile, *Themisto pacifica*, *Caprella* sp., *Oligochinus lighti*, *Caprella mutica*, *Caprella hennerlyi*, *Photis brevipes*, Anisogammaridae, *Aoroides exilis*, *Aoroides* sp., *Desdimelita desdichada*
Harpacticoida (*copepods*)	*Tisbe* sp., *Heterolaophonte longisetigera*, *Harpacticus uniremis* group, *Paralaophonte perplexa* group, *Harpacticus uniremis*, *Zaus* sp., Ectinosomatidae, *Parastenhelia spinosa*, *Rhynchothalestris helgolandica*, Unidentified Harpacticoid Copepodid, Ameiridae, *Diarthrodes* sp., *Diosaccus spinatus*, *Harpacticus* Copepodid, Laophontidae Copepodid, *Harpacticus obscurus* group, *Heterolaophonte* sp., *Amonardia perturbata*, *Amphiascopsis cinctus*, *Mesochra* sp., *Paralaophonte* sp., *Amphiascoides* sp., *Amphiascus* sp., *Dactylopusia vulgaris*, *Paradactylopodia* sp., *Amonardia normani*, Harpacticoida Nauplii, *Scutellidium* sp., *Dactylopusia glacialis*, *Dactylopusia crassipes*, *Echinolaophonte* sp., Peltidiidae, *Laophonte elongata*, *Danielssenia typica*, *Parathalestris californica*, *Dactylopusia* Copepodid, Tegastidae, *Normanella* sp., *Laophonte cornuta*, *Dactylopusia* sp., *Harpacticus* sp. A, Unidentified Harpacticoida, *Parathalestris* sp., *Laophontodes* sp., Laophontidae, *Thalestris* sp., *Pseudonychocamptus* sp., *Amphiascoides* sp. A, *Microsetella* sp., Clausidiidae Copepodid, *Stenhelia* sp.
Polychaeta (*worms*)	Spionidae Juvenile, Polychaeta Juvenile, Syllidae, Spionidae, Polynoidae, Phyllodocidae, *Armandia brevis*, *Platynereis bicaniculata*, *Paleanotus bellis*, Opheliidae, *Prionospio lighti*, Sabellidae, *Eulalia quadrioculata*, Pholoidae
Isopoda (*pillbugs)*	Epicaridea, Sphaeromatidae Juvenile, *Idotea wosneseskii*, *Dynamenella sheareri*, *Idotea* sp., *Gnorimosphaeroma insulare*, *Pseudosphaeroma* sp.
Decapoda (*crabs/shrimp*)	Caridea, Paguridae Megalopa, Hippolytidae, Xanthidae Zoea, Majidae Zoea, Pagarus Megalopa, Grapsidae Zoea
Diptera (*true flies*)	Chironomidae Larva, Chironomidae Adult, Chironomidae Pupa, Diptera Larva, Diptera Adult, Nematocera Larva, Ceratopogonidae Pupa, Diptera Pupa
Calanoida (*copepods)*	Calanoida, Calanoida Nauplii, *Stephos* sp.
Cirripedia (*barnacles*)	Cirripedia Nauplii, Cirripedia Cyprid, Cirripedia
Cumacea	*Cumella vulgaris*, *Nippoleucon hinumensis*
Gastropoda (*snails/sea slugs/limpets*)	*Littorina scutulata* egg case, Gastropoda Juvenile, Gastropoda, *Lottia* sp., *Lottia digitalis*, Sacoglossa, *Alvania compacta*
General Taxa Groupings	Nematoda, Cyclopoida, Archiannelida (*Nerilla* sp.), Turbellaria, Acari, Ostracoda (Ostracoda, *Euphilomedes producta*), Bivalvia (Bivalvia, Mytilidae), Oligochaeta, Cladocera, Poecilostomatoida (*Oncaea* sp.). Crustacea Nauplii, Hydrozoa, Larvacea, Nemertea, Euphausiacea, Chaetognatha, Coleoptera (Staphylinidae, larva), Collembola (Hypogastruridae), Hemiptera (Aphididae)

Table 12. Results of ANOVA testing on epibenthic invertebrate densities, significant results are in bold.

Comparison of 2009 habitats	p-value	tukey-test for habitat/year differences
Overall densities	**9.2E-15**	habitat bench **>** pocket beach, riprap, seawall
Harpacticoida	**1.0E-15**	habitat bench **>** pocket beach **>** riprap, seawall
Amphipoda	**5.4E-13**	habitat bench, riprap **>** seawall **>** pocket beach

Comparison of years within each habitat	Overall densities	Harpacticoida	Amphipoda
Riprap	**3.8E-8** (09,07>05)	**0.033** (07>05)	**9.4E-6** (07>05,09)
Pocket Beach	**1.0E-12** (07>09>05)	**1.0E-12** (07>09>05)	**5.9E-10** (07>05>09)
Habitat Bench	**1.0E-12** (07>09>05)	**1.0E-12** (09,07>05)	**1.0E-12** (09,07>05)
Seawall	**0.00069** (09,07>05)	**4.8E-11** (09,07>05)	**3.2E-6** (09>07,05)

Benthic Invertebrates

Total taxa richness was higher in 2009 than in 2007 at both of the sampled elevations (Fig. 27). The 0 m MLLW tidal elevation benthic samples in 2009 were dominated by nematode worms, Chironomidae larva (non-biting midges) and the amphipod *Desdimelita californica* (Fig. 28). The +3.7 m elevation was dominated by juveniles of semi-terrestrial talitrid amphipods, along with collembola (springtails in the families Onychiuridae and Isotomidae), and gastropoda (snails/slugs). There were some notable differences in taxa between years: in 2009 the aquatic amphipod *Paramoera mohri* did not occur, while the talitrid amphipod *Paciforchestia klawei* did, and gastropods, nematodes, and collembola were much more abundant in 2009. Complete taxa listings for 2009 are in Table 13.

Overall benthic invertebrate densities at the 0 m elevation were not significantly different based on ANOVA (Table 14). Two important groups that contain juvenile salmonid prey taxa, amphipods and Chironomidae larva, were also tested and amphipods had significantly higher abundances in 2007 while Chironomidae larvae had significantly higher abundances in 2009. There was no significant difference at the +3.7 m elevation in overall densities, or in densities of talitrid amphipods, which are important inhabitants of beach-wrack.

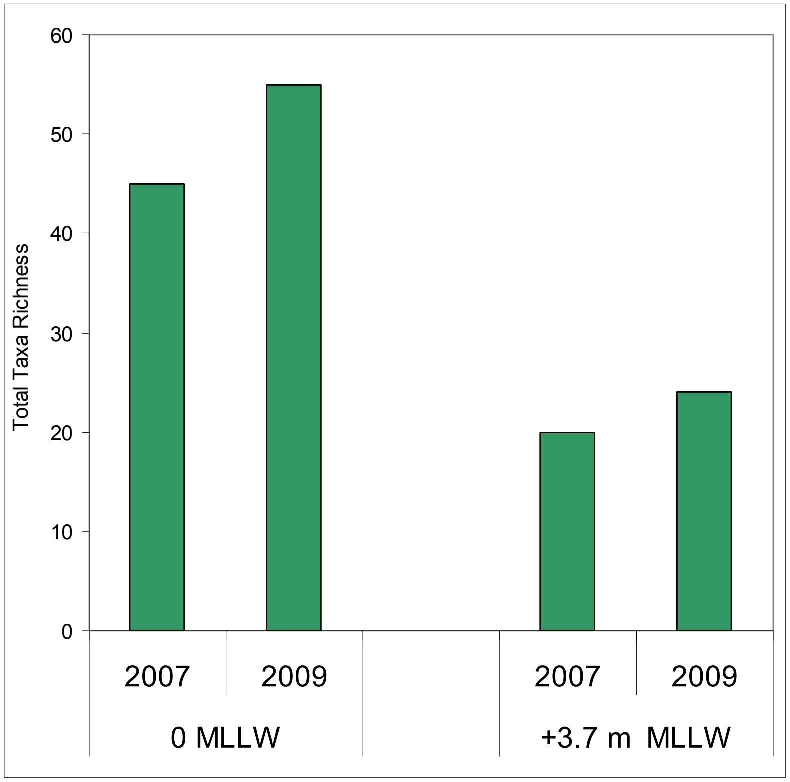


Figure 27. Overall taxa richness (# of taxa) of benthic invertebrates by year and tidal elevation.

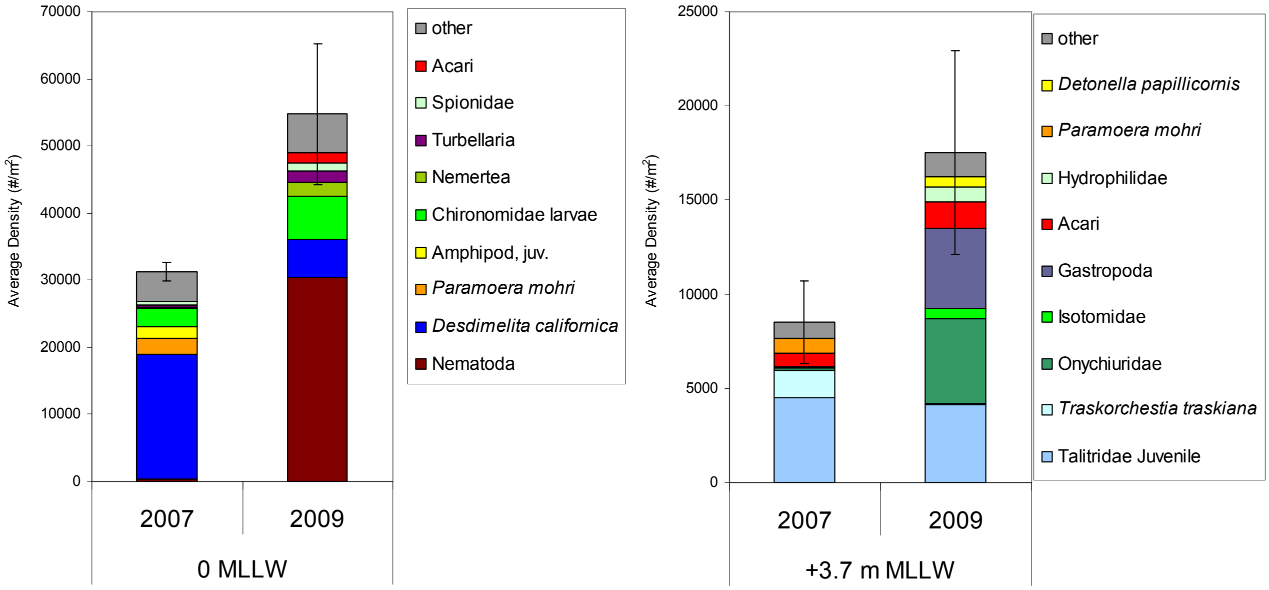


Figure 28. Average densities and taxa composition of benthic invertebrates at the pocket beach by year and tidal elevation (scales differ between graphs).

Table 13. List of sampled benthic invertebrates and taxa groups, taxa are listed in descending numerical abundance within each grouping.

+ 3.7 m MLLW

Taxa Grouping	Taxa
Amphipoda (*beachhoppers*)	Talitridae juvenile, *Paciforchestia klawei*, *Traskorchestia traskiana*
Collembola (*springtails*)	Onychiuridae, Isotomidae
Isopoda (*woodlice*)	*Detonella papillicornis*, Oniscidea
Coleoptera (*beetles*)	Hydrophilidae, Staphylinidae
Diptera (*true flies*)	Chironomidae adult, Sphaeroceridae, Chironomidae larvae, Diptera pupae, Ephydridae
General Taxa Groupings	Gastropoda, Acari, Nemertea, Nematoda, Oligochaeta, Bivalvia (*Mytilus* sp.), Tanaidacea (*Leptochelia dubia*), Ostracoda, Hymenoptera (Formicidae)

0 m MLLW

Taxa Grouping	Taxa
Diptera (*true flies*)	Chironomidae larvae, Chironomidae adult, Chironomidae pupae, Diptera pupae
Amphipoda (*scuds*)	*Desdimelita californica*, *Protohyale* sp., *Ampithoe lacertosa*, *Paracalliopiella pratti*, Corophiidae, *Aoroides* sp., *Americorophium* sp., *Calliopius* sp.
Polychaeta (*worms*)	Spionidae, Syllidae, Phyllodocidae, Sabellidae, Polychaete, *Armandia brevis*, Nereidae Juvenile, *Paleonotus bellis*, Syllinae, *Prionospio lighti*, Polynoidae, Terebellidae, Pholoidae, *Micropodarke dubia*, Serpulidae, *Nereis procera*, Chrysopetalidae, *Mediomastus californiensis*
Gastropoda (*snails/sea slugs/limpets*)	*Lottia* sp., Gastropoda, Opistobranch, Nudibranch
Bivalvia (*mussels/clams/oysters*)	*Mytilus* sp., Bivalve Juvenile, *Pododesmus* sp.
Isopoda (*pill bugs*)	*Idotea* sp., *Uromunna ubiquita*, Epicaridea
Decapoda (*crabs*)	Paguridae Megalopa, *Hemigrapsus oregonensis*, Paguridae Adult
Echinodermata (*sea cucumbers/sea urchins*)	Holothuroidea, Echindoderm Juvenile, Echinoidea Juvenile
General Taxa Groupings	Nematoda, Nemertea, Turbellaria, Acari, Oligochaeta, Ostracoda, Araneae, Fish (gunnel), Tanaidacea

Table 14. Results of ANOVA on benthic invertebrate densities between 2007 and 2009 at the pocket beach, significant results are in bold.

Tidal Elevation	Overall densities	Amphipoda	Chironomidae larva
0 m MLLW	0.097	**0.00003** (07>09)	**0.027** (09>07)
	Overall densities	Talitridae	
+ 3.7 m MLLW	0.23	0.66	

Terrestrial Insects

Taxa richness in fall-out traps from all enhanced vegetation areas increased in 2007 and 2009 data as compared to the 2005 pre-enhancement levels (Fig. 29). At the armored habitat types, taxa richness was similar across the sampling years and lower than in the enhanced areas. The vegetation swath had the highest taxa richness in 2009, and the vegetation swath and the pocket beach increased the most compared to 2007.

In 2009, the vegetation swath had much higher densities than in previous years and habitats, although most of the percent composition consisted of collembolans (springtails) and acari (mites), which were rare in juvenile salmon diets (Fig. 30). Of the insects, compositions were similar to previous years, with dipterans (true flies) being most abundant followed by lower numbers of other orders such as hemiptera (true bugs), psocoptera (booklice/barklice), and hymenoptera (wasps/bees/ants). Diptera consisted mostly of Chironomidae (71%; non-biting midges), and hemipterans were dominated by Aphididae (61%; aphids). Overall listings of 2009 fall-out trap invertebrates and taxa groups are in Table 15.

ANOVA on 2009 data indicated that total invertebrate densities were significantly higher at the vegetation swath as compared to other habitats (Table 16). For two important orders of juvenile salmon prey taxa, diptera and hemiptera, ANOVA showed no difference in dipteran log-transformed densities in 2009. Hemiptera densities were significantly higher at all enhanced areas (riparian, pocket beach sites, vegetation swath) than at the armored riprap and seawall sites.

Similar ANOVA tests were used on 2005, 2007, and 2009 data separated for each habitat type (Table 16). Overall densities increased only at the vegetation swath compared to its pre-enhanced seawall condition, whereas overall densities were greater in 2005 at the riparian and seawall habitats. Hemiptera densities increased at the pocket beach and vegetation swath, compared to the pre-enhanced riprap and seawall habitats, respectively. There were some clear interannual differences, as diptera densities were very high in 2005 and have not reached those levels since then.

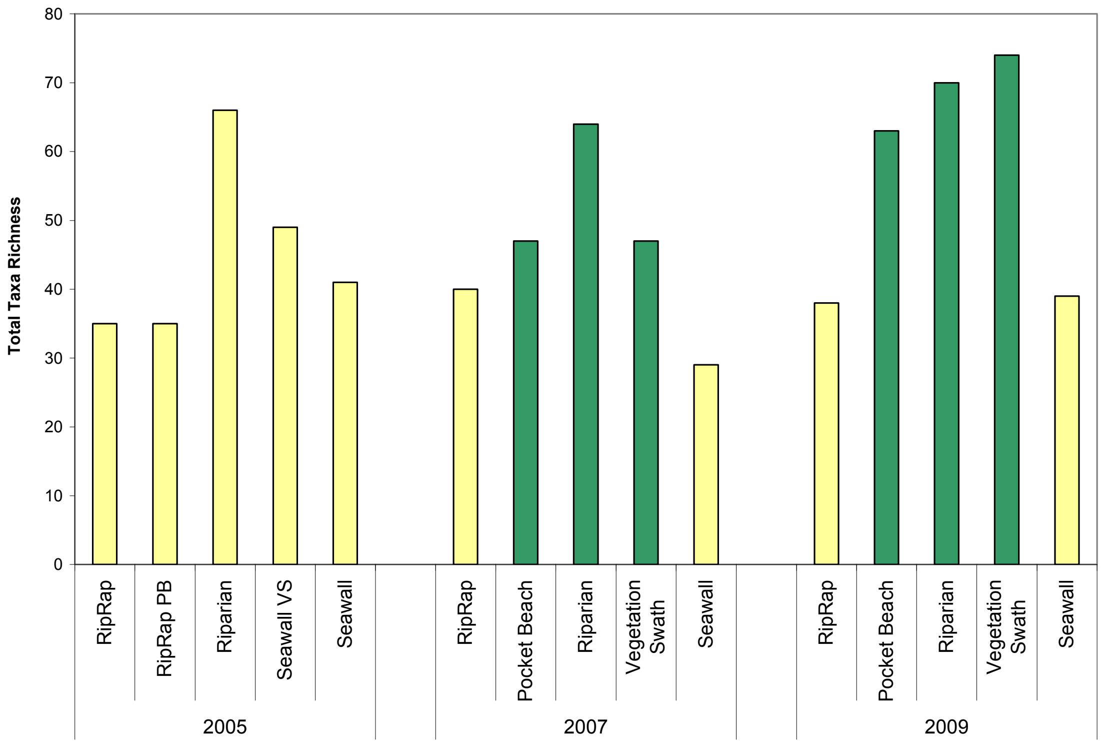


Figure 29. Overall taxa richness (# of taxa) of insects by year and site. Enhanced vegetation areas are colored in green.

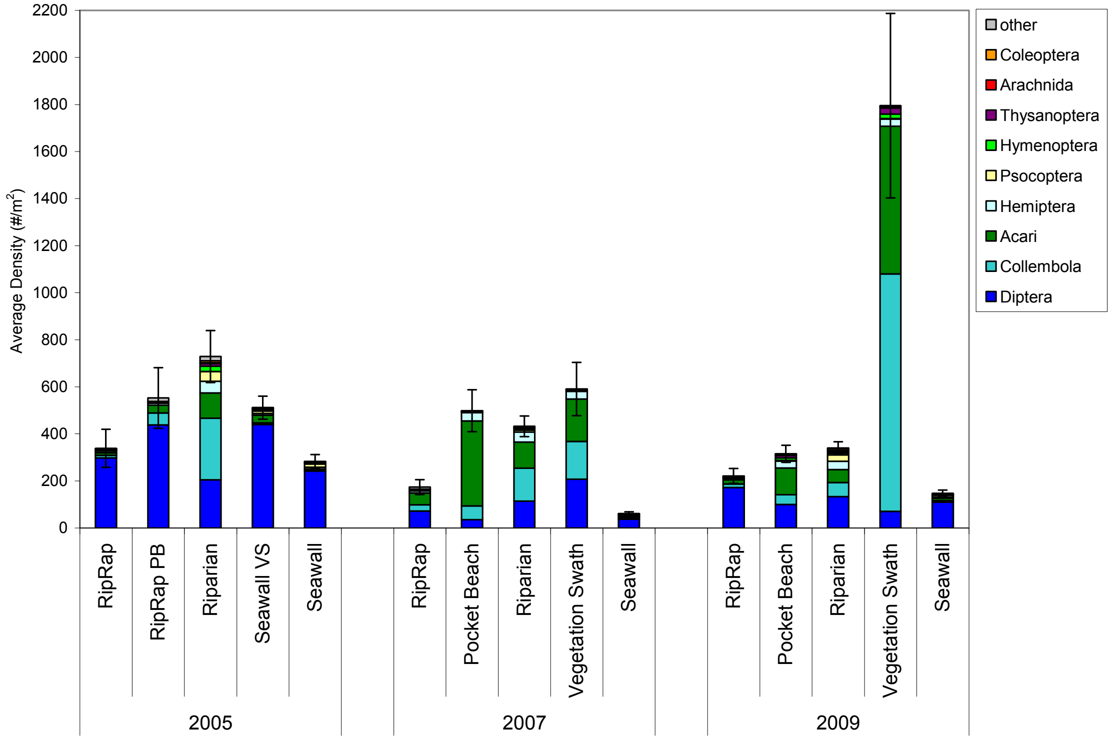


Figure 30. Average densities and general taxa composition of insects by habitat and year.

Table 15. List of sampled fall-out trap invertebrates and taxa groups, taxa are listed in descending numerical abundance within each grouping.

Taxa Grouping	Taxa
Diptera *(true flies)*	Chironomidae, Cecidomyiidae, Sciaridae, Dryomyzidae, Muscidae, Dolichopodidae, Phoridae, Sphaeroceridae, Chloropidae, Tipulidae, Psychodidae, Calliphoridae, Cecidomyiidae larva, Anthomyiidae, Empididae, Ceratopogonidae, Ephydridae, Mycetophilidae, Syrphidae, Aulacigasteridae, Heleomyzidae, Diptera larva, Culicidae, Sarcophagidae, Agromyzidae, Rhinophoridae, Clusiidae, Lauxaniidae, Tachinidae, Carnidae, Canacidae, Scatopsidae, Syrphidae larva, Scathophagidae, Anisopodidae
Hemiptera *(true bugs)*	Aphididae, Sternorrhyncha immature, Cicadellidae immature, Psyllidae immature, Cicadellidae, Coccoidea, Psyllidae, Heteroptera immature, Cercopidae, Auchenorrhyncha immature, Miridae, Aleyrodidae, Pyrrhocoridae, Homoptera immature, Miridae immature, Aphidoidea, Reduviidae
Hymenoptera *(wasps/bees/ants)*	Ceraphronidae, Mymaridae, Ichneumonidae, Diapriidae, Encyrtidae, Sphecidae, Braconidae, Formicidae, Megaspilidae, Perilampidae, Pteromalidae, Scelionidae, Torymidae, Eulophidae, Andrenidae, Aphelinidae, Cynipidae, Symphyta larva, Proctotrupoidea, Megachilidae, Tenthredinidae, Proctotrupidae, Hymenoptera, Chalcidoidea, Vespidae, Platygasteridae, Hymenoptera larva
Coleoptera *(beetles)*	Coccinellidae, Coleoptera larva, Coccinellidae larva, Staphylinidae, Throscidae, Carabidae, Latridiidae, Elateridae, Melyridae, Nitidulidae, Curculionidae
Neuroptera *(lacewings)*	Hemerobiidae larva, Coniopterygidae, Hemerobiidae, Neuroptera immature
Thysanoptera *(thrips)*	Thripidae, Thysanoptera immature, Phlaeothripidae
Collembola *(springtails)*	Entomobryidae, Sminthuridae, Hypogastruridae, Isotomidae
Amphipoda *(beachhoppers)*	Talitridae, *Traskorchestia* sp.
General Taxa Groupings	Acari, Psocoptera (adults and immature), Araneae, Lepidoptera (adults and larva), Opiliones, Trichoptera, Gastropoda (slug), Dermaptera (Forficulidae), Isopoda (*Ligia pallasii*)

Table 16. Results of ANOVA testing on fall-out trap insect densities, significant results are in bold.

Comparison of 2009 habitats	p-value	tukey-test for habitat/year differences
Overall densities	**4.9E-11**	vegetation swath **>** all other sites
Diptera	0.08	
Hemiptera	**0.0000002**	riparian, pocket beach, vegetation swath **>** riprap & seawall

Comparison of years within each habitat	Overall densities	Diptera	Hemiptera
Riprap	0.53	0.08	0.67
Pocket Beach	0.89	**4.5E-12** (05>09>07)	**0.002** (09,07>05)
Riparian	**0.0006** (05>07,09)	**0.002** (05>07,09)	0.50
Vegetation Swath	**3.1E-5** (09>05,07)	**2.7E-14** (05>07>09)	**0.001** (09,07>05)
Seawall	**1.2E-11** (05>09 >07)	**1.2E-12** (05>09>07)	0.35

Neuston

Neuston tows were replicated less than the other sampling methods (three 10 m tows per habitat/date), and were characterized by high variability. Although terrestrial invertebrate densities in the neuston were highest at the riprap in 2009, the results were not significant for total densities (one-way ANOVA on habitat type, $p > 0.05$; Fig. 31). The large number of Diptera at the riprap in 2009 was due to one large catch of 313 flies in the family Sciaridae (dark-winged fungus gnats), which are a rare occurrence in juvenile salmonid diets, unlike the more common Chironomidae. In terms of percent composition, neuston tows in 2009 had higher contributions of diptera compared to 2007 neuston tows and 2009 fallout trap samples (Fig. 32). Fallout traps also had much higher contributions by collembola and acari, which are usually associated with vegetation.

The neuston tows also contained non-terrestrial invertebrates, such as aquatic amphipods and harpacticoids that are more typically sampled in epibenthic habitats. These were patchily distributed in low abundances (average harpacticoids < 7/m^2, amphipods <3/m^2), but represent an available prey resource near the water's surface where juvenile salmonids were usually observed to be feeding during snorkel surveys. Taxa composition of amphipods in the neustonic layer did not directly reflect that of epibenthic pump samples (proportionally more *Calliopius* sp. and Hyperiidea and fewer *Paracalliopiella pratti*), showing that some of the amphipod species are more mobile than others and/or do not always associate with bottom substrates (Fig. 33). The copepod *Harpacticus* sp. accounted for 21.5% of the harpacticoids in the neuston; this genus is an abundant epibenthic copepod and is an important prey item for juvenile chum salmon.

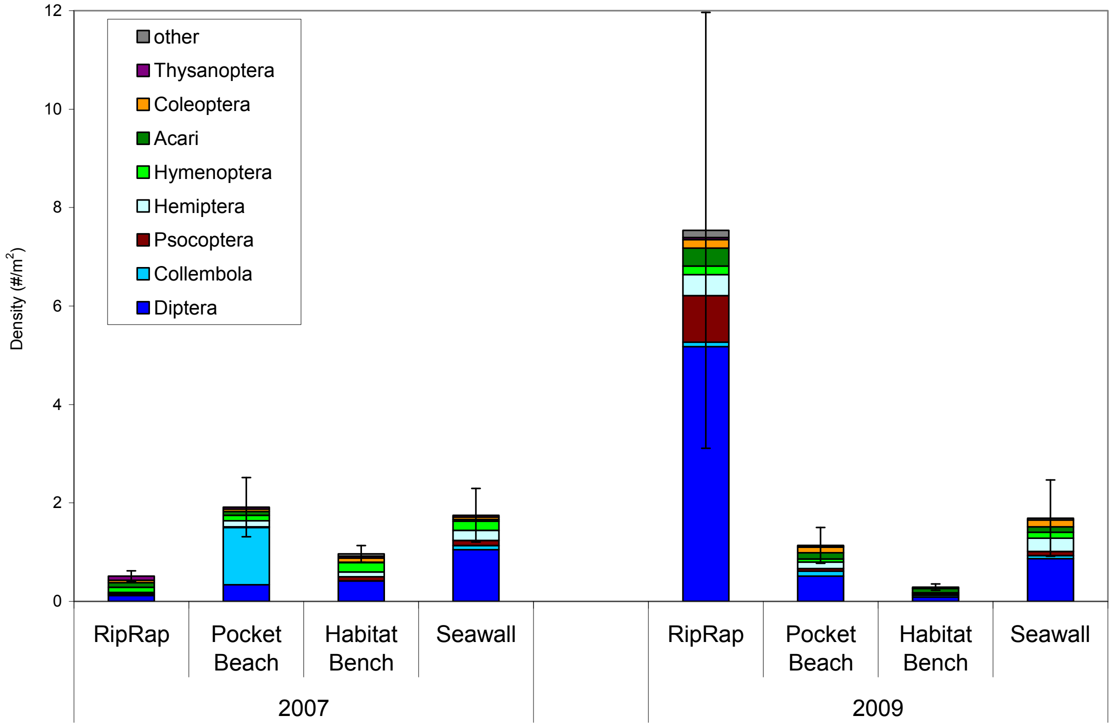


Figure 31. Average overall densities and taxa composition of neuston by habitat type in 2007 and 2009. The large number of diptera at riprap in 2009 was due to one large catch of 313 Sciaridae (dark-winged fungus gnats); these numbers were not significant.

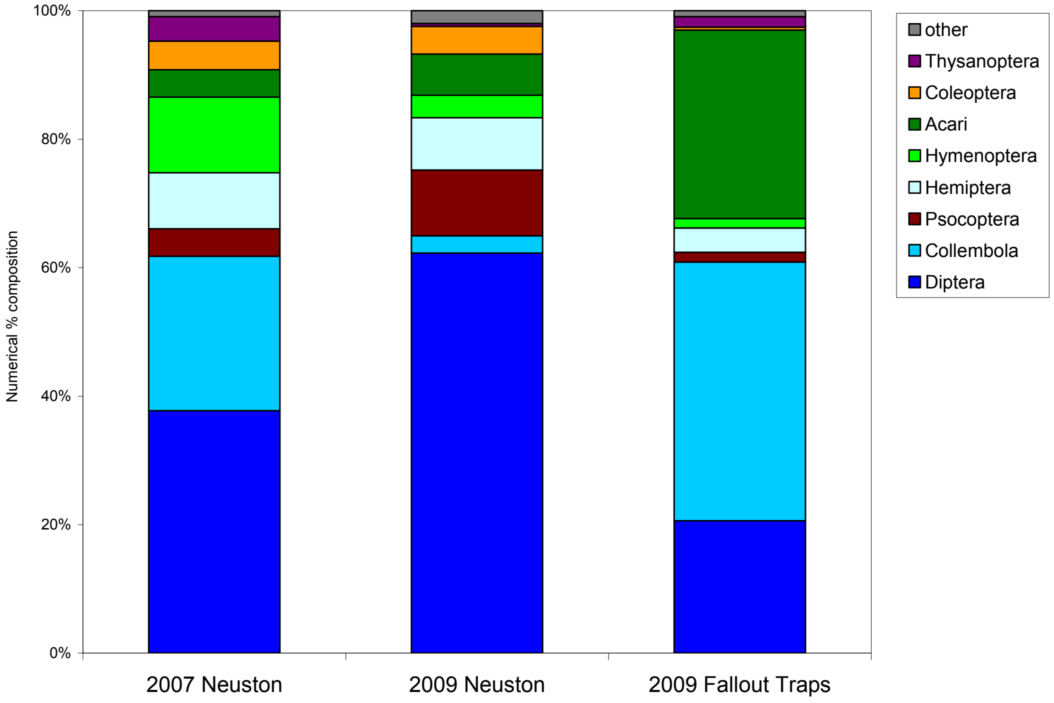


Figure 32. Numerical percent composition of invertebrates from neuston tows in 2007 and 2009, and fallout traps in 2009.

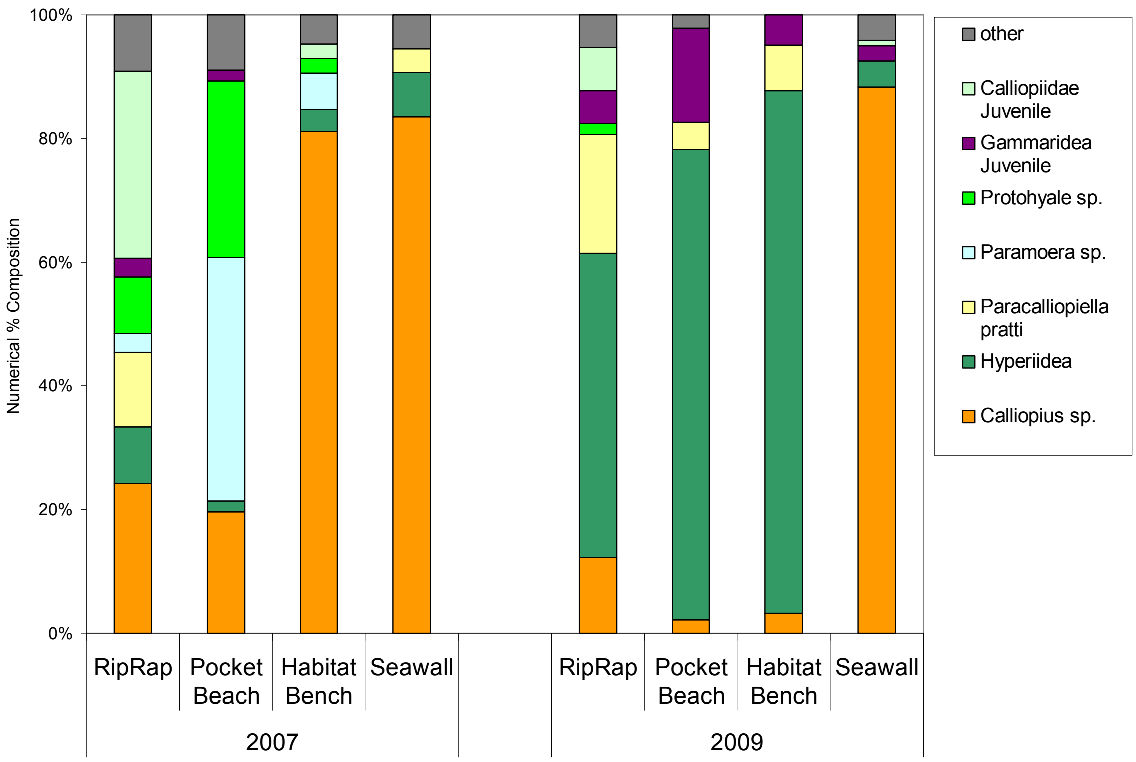


Figure 33. Numerical percent composition of amphipods from neuston tows in 2007 and 2009.

Terrestrial Vegetation

A species list for each riparian area is provided in Table 17. There were new plantings of pacific wax myrtle (*Myrica californica*) and sweet gale (*Myrica gale*) in the South Uplands in 2009. Other changes in the species composition were mainly due to colonization by volunteer, mostly weedy, species. The percent cover of both over and understory vegetation exceeded the as-built condition in all areas (Fig. 34 and 35; Table 18). The north and south uplands understory greatly increased in cover due largely to growth of grasses and weedy species in the south uplands and dense growth of soft rush (*Juncus effusus*) in the north uplands (Fig. 36 and 37). The slight decrease in dunegrass cover from year 1 conditions is probably due to damage by pedestrians. Three of the four dunegrass patches increased in area while the fourth experienced a slight decrease (Table 19). Patch 3 experienced a large increase, more than tripling in size by spreading into the backshore area (Fig. 38). Patch 2 had the smallest increase in percent cover and was the only patch to shrink in size. The dunegrass patches all increased in shoot density compared to the as-built conditions (Table 19).

The average canopy diameter for each tree species increased compared to the as-built condition with two exceptions. In the North Uplands two of the three Garry oak (*Quercus garryana*) continued to decrease in diameter and in the South Uplands one large Sitka spruce (*Picea sitchensis*) was removed and two small new specimens planted.

Health ratings were assigned separately to the overstory and understory plants (Table 20). All areas were in relatively good health with few changes from conditions in July 2007. The health rating was slightly lower in the beach backshore where the salal (*Gautheria shallon*) was brown. The beach strawberries in the backshore appeared healthy but were not spreading as vigorously as in 2007. The overall health rating for the south uplands was lower than in 2007 due to the unhealthy appearance of the garry oaks in that area.

Table 17. List of all plant species present in each of the five riparian areas in Year 1 and Year 3.

	Year 1 (July 2007)		Year 3 (July 2009)	
North Uplands	CAOB	*Carex obnupta*	Asteraceae	Asteraceae
	DECA	*Descampsia caespitosa*	Besp	*Betula* sp.
	FEID	*Festuca idahoensis*	CAOB	*Carex obnupta*
	FRCH	*Fragaria chiloensis*	CIsp.	*Cirsium* sp.
	GASH	*Gaultheria shallon*	COST	*Cornus stolonifera*
	OECE	*Oemleria cerasiformis*	DACA	*Daucus carota*
	PICO	*Pinus contorta*	EQAR	*Equisetum arvense*
	PISI	*Picea sitchensis*	FRCH	*Fragaria chiloensis*
	QUGA	*Quercus garryana*	GASH	*Gaultheria shallon*
	ROsp	*Rosa* sp.	HYPE	*Hypericum perforatum*
	SAsp	*Salix* sp.	JUEF	*Juncus effusus*
	SPDO	*Spirea douglasii*	LUsp	*Lupinus* sp.
	SYAL	*Symphoriocarpus albus*	MAAQ	*Mahonia aquifolia*
	Juncaceae	Juncaceae	Poaceae	Poaceae
	Cyperaceae	Cyperaceae	RAsp	*Ranunculus* sp.
	VAOV	*Vaccinium ovatum*	ROPS	*Robinia pseudoacacia*
	VIED	*Viburnum edule*	ROsp	*Rosa* sp.
			SAsp	*Salix* sp.
			SCAC	*Scirpus acutus*
			SCMI	*Scirpus microcarpus*
			SPDO	*Spirea douglasii*
			SYAL	*Symphoriocarpus albus*
			TRsp	*Trifolium* sp.
			TYAN	*Typha angustifolia*
			VAOV	*Vaccinium ovatum*
			VIED	*Viburnum edule*
South Uplands	ARCO	*Arctostaphylus columbiana*	ALRU	*Alnus rubra*
	DECA	*Descampsia caespitosa*	ARCO	*Arctostaphylus columbiana*
	ELGL	*Elymus glaucus*	Asteraceae	Asteraceae
	FEID	*Festuca idahoensis*	COST	*Cornus stolonifera*
	FRCH	*Fragaria chiloensis*	DACA	*Daucus carota*
	GAEL	*Garrya elliptica*	EPsp	*Epilobium* sp.
	MAAQ	*Mahonia aquifolium*	GAEL	*Garrya elliptica*
	MANE	*Mahonia nervosa*	HYPE	*Hypericum perforatum*

	PISI	*Picea sitchensis*	JUEF	*Juncus effusus*
	QUGA	*Quercus garryana*	LUSP	*Lupinus* sp.
	THPL	*Thuja plicata*	MYCA	*Myrica californica*
	Poaceae	Poaceae	MYGA	*Myrica gale*
	Juncaceae	Juncaceae	Papaveraceae	Papaveraceae
	VAOV	*Vaccinium ovatum*	PHCA	*Physocarpus* sp. 'diablo'
			PLSP	*Plantago* sp.
			Poaceae	Poaceae
			QUGA	*Quercus garryana*
			RULA	*Rubus laciniatus*
			SASP	*Salix* sp.
			THPL	*Thuja plicata*
			TRsp	*Trifolium* sp.
Overlook	ALRU	*Alnus rubra*	ANMA	*Anaphalis margaritaceae*
	FRCH	*Fragaria chiloensis*	GASH	*Gaultheria shallon*
	FRVI	*Fragaria virginiana*	HODI	*Holodiscus discolor*
	GASH	*Gaultheria shallon*	JUEF	*Juncus effusus*
	HODI	*Holodiscus discolor*	LEMO	*Lyemus mollis*
	LEMO	*Lyemus mollis*	MAAQ	*Mahonia aquifolium*
	MAAQ	*Mahonia aquifolium*	PICO	*Pinus contorta*
	PICO	*Pinus contorta*	PISI	*Picea sitchensis*
	PISI	*Picea sitchensis*	Poaceae	Poaceae
	ROsp	*Rosa* sp.	POTR	*Populus trichocarpa*
	SAsp	*Salix* sp.	ROsp	*Rosa* sp.
	SYAL	*Symphoriocarpus albus*	SAsp	*Salix* sp.
	THPL	*Thuja plicata*	SCMI	*Scirpus microcarpus*
			SYAL	*Symphoriocarpus albus*
			THPL	*Thuja plicata*
			TRsp	*Trifolium* sp.
Backshore	ALRU	*Alnus rubra*	ALRU	*Alnus rubra*
	FRCH	*Fragaria chiloensis*	ANMA	*Anaphalis margaritaceae*
	FRVI	*Fragaria virginiana*	Asteraceae	Asteraceae
	GASH	*Gaultheria shallon*	EPsp	*Epilobium* sp.
	HODI	*Holodiscus discolor*	FRCH	*Fragaria chiloensis*
	LEMO	*Lyemus mollis*	GASH	*Gaultheria shallon*
	MAAQ	*Mahonia aquifolium*	HODI	*Holodiscus discolor*
	PICO	*Pinus contorta*	JUEF	*Juncus effusus*
	ROsp	*Rosa* sp.	LEMO	*Lyemus mollis*
	SYAL	*Symphoriocarpus albus*	MAAQ	*Mahonia aquifolium*
			PICO	*Pinus contorta*
			ROsp	*Rosa* sp.
			RUDI	*Rubus discolor*
			SYAL	*Symphoriocarpus albus*
			TRsp	*Trifolium* sp.
Dunegrass	FRCH	*Fragaria chiloensis*	FRVI	*Fragaria virginiana*
	FRVI	*Fragaria virginiana*	GRIN	*Grindelia integrifolia*
	GRIN	*Grindelia integrifolia*	LEMO	*Lyemus mollis*
	LEMO	*Lyemus mollis*		

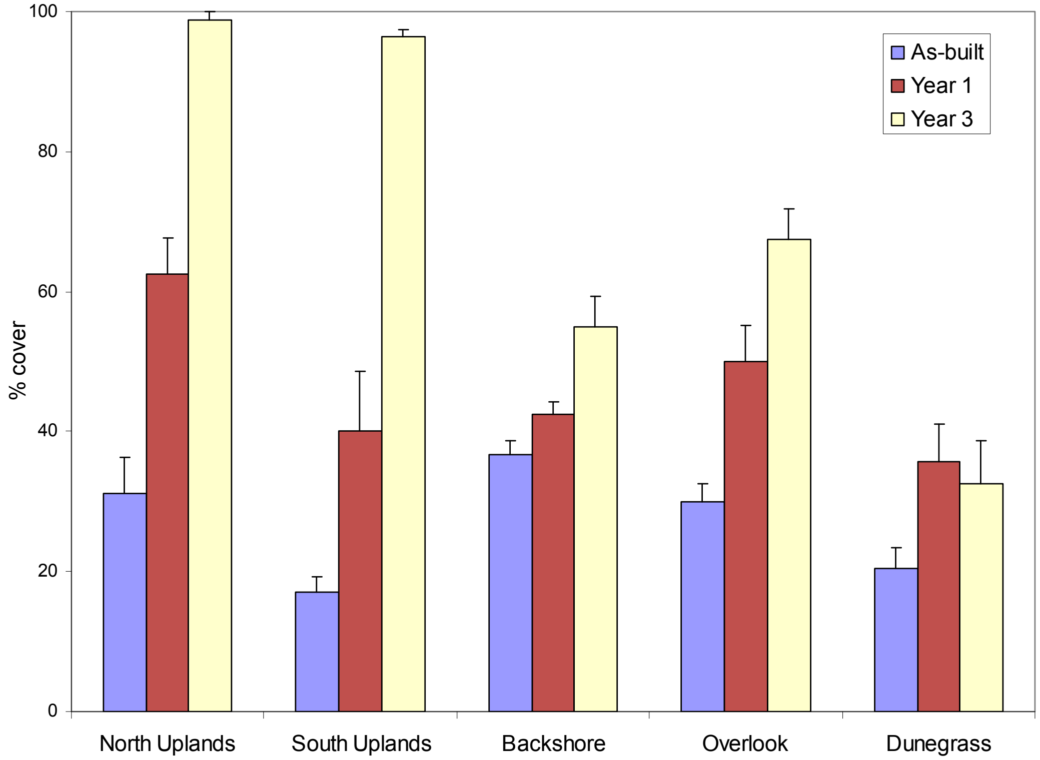


Figure 34. Average percent cover of understory vegetation at shoreline habitats.

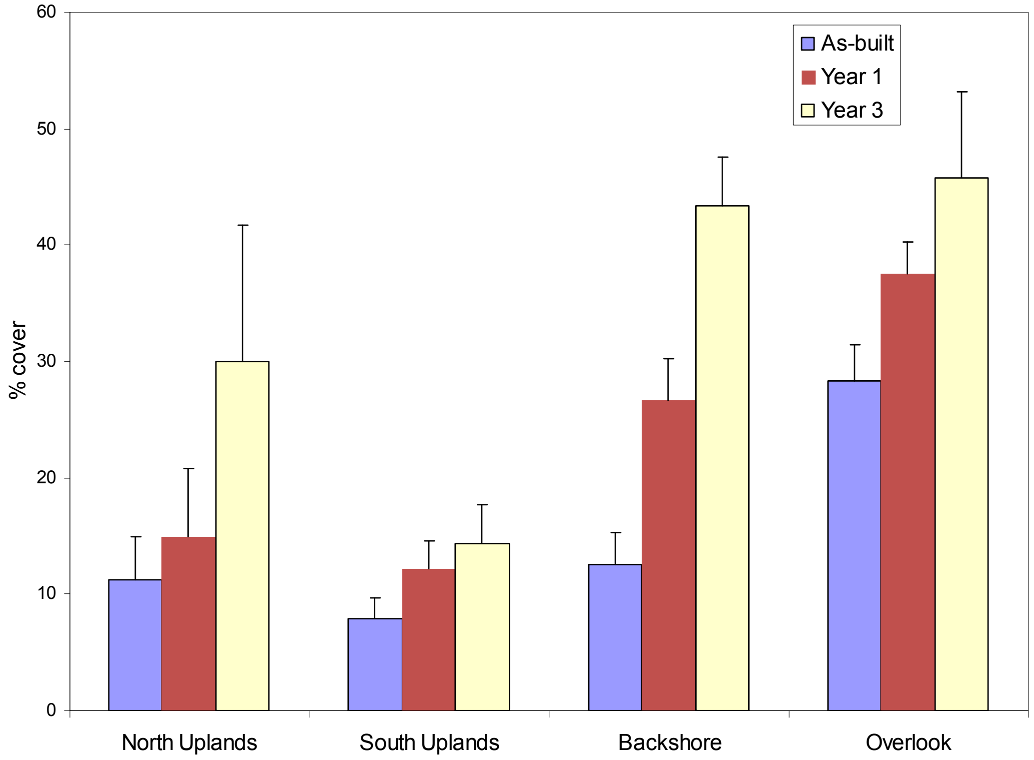


Figure 35. Average percent cover of overstory vegetation at shoreline habitats.

Table 18. A summary of the changes in % cover at all riparian areas as-built (May 2007) to year 3 (July 2009).

		% Cover in Year 3	Average increase % cover
Overstory	North Uplands	30.0	+18.8
	South Uplands	14.3	6.4
	Backshore	43.3	30.8
	Overlook	45.8	17.5
Understory	North Uplands	98.8	67.5
	South Uplands	96.4	79.3
	Backshore	55.0	18.3
	Overlook	67.5	37.5
	Dunegrass	32.6	12.1

Figure 36. A section of Northern Uplands, looking south in July 2007.

Figure 37. The same section as above, looking south in July 2009. Note dense growth of soft rush (*Juncus effusus*).

Table 19. Summary of changes between as-built and year 3 conditions for dunegrass.

	Percent Cover		Patch Area (m^2)		# Shoots/m^2	
	Year 3	Average Change	Year 3	Average Change	Year 3	Average Change
Patch 1	29.2	+8.0	62.0	+21.3	52.0	+28.0
Patch 2	33.0	5.4	92.2	-5.4	57.6	19.2
Patch 3	32.0	16.6	61.4	43.9	56.0	25.6
Patch 4	36.0	18.4	22.2	0.4	65.6	34.4

Figure 38. Spread of dunegrass into beach backshore area.

Table 20. A summary of the overall health ratings for each riparian area (1-5, with 1 being all dead and 5 being vigorous growth).

		As-built	Year 1	Year 3
Overstory	North Uplands	3.8	4.3	3.8
	South Uplands	4.5	4.3	3.9
	Backshore	3.3	3.7	4.7
	Overlook	3.3	3.8	4.2
Understory	North Uplands	3.5	4.0	5.0
	South Uplands	3.7	4.1	4.9
	Backshore	4.0	4.0	3.2
	Overlook	4.0	4.0	4.2
	Dunegrass	3.3	4.3	3.3

Algae

Beds of bull kelp (*Nereocystis luetkeana*) occurred between -1.5 and -7.6 m, with the greatest numbers of stipes at 3.0 and -4.6 m MLLW (Fig. 39). A two-way ANOVA of Year x Elevation on number of kelp stipes showed significant differences with both factors and interactions ($p < 0.001$). One-way ANOVAs on year separated for each elevation showed significantly greater numbers in 2009 than 2007 at elevations of -3 to -7.6 m ($p < 0.05$). A one-way ANOVA and post-hoc tukey test on elevation in 2009 also showed that the -3.0 and -4.6 m elevations had higher numbers than the other elevations.

Twenty-two species of algae were observed between tidal elevations 0 to -7.6 m MLLW, one less than was observed in 2007 (Table 21). This slight fluctuation was due to observation of rare species; algae observed in 2007 but not 2009 were Stalked Kelp (*Pterygophora californica*; 4 total), and Small Delesseria (*Delesseria decipiens*; two transects at 1%). *Fucus* spp. on the habitat bench was observed in 2009 but not 2007, this algae is an intertidal species and did occur in higher elevations above the SCUBA transects in 2007. Eight species occurred on the habitat bench in 2009 up from four in 2007, with the remainder occurring in shallow subtidal waters off the edge of the habitat bench between -5 to -7.6 m MLLW.

Algae percent cover was about equal between years and variable dependent on the tidal elevation: almost identical at the habitat bench and -1.5 m MLLW, lower in 2009 at -3.0 and -4.6 m, and higher in 2009 at -6.1 and -7.6 m (Fig. 40). However, the overall range was 61 to 76%, higher than the range of 46 to 74% observed in 2007. There were some assemblage changes between years. In 2009, there was less *Saccharina latissima*, *Desmarestia ligulata*, and *Ulva fenestrata*, and more *Chondracanthus exasperatus* and *Agarum fimbriatum*, with also *Fucus* spp. at the habitat bench. Green algae were abundant in shallower depths to -1.5 m, brown and red algae were dominant in deeper water. Black rockfish were observed at -6.1 to -7.6 m MLLW, a fish species that was not seen in our surface water snorkel surveys.

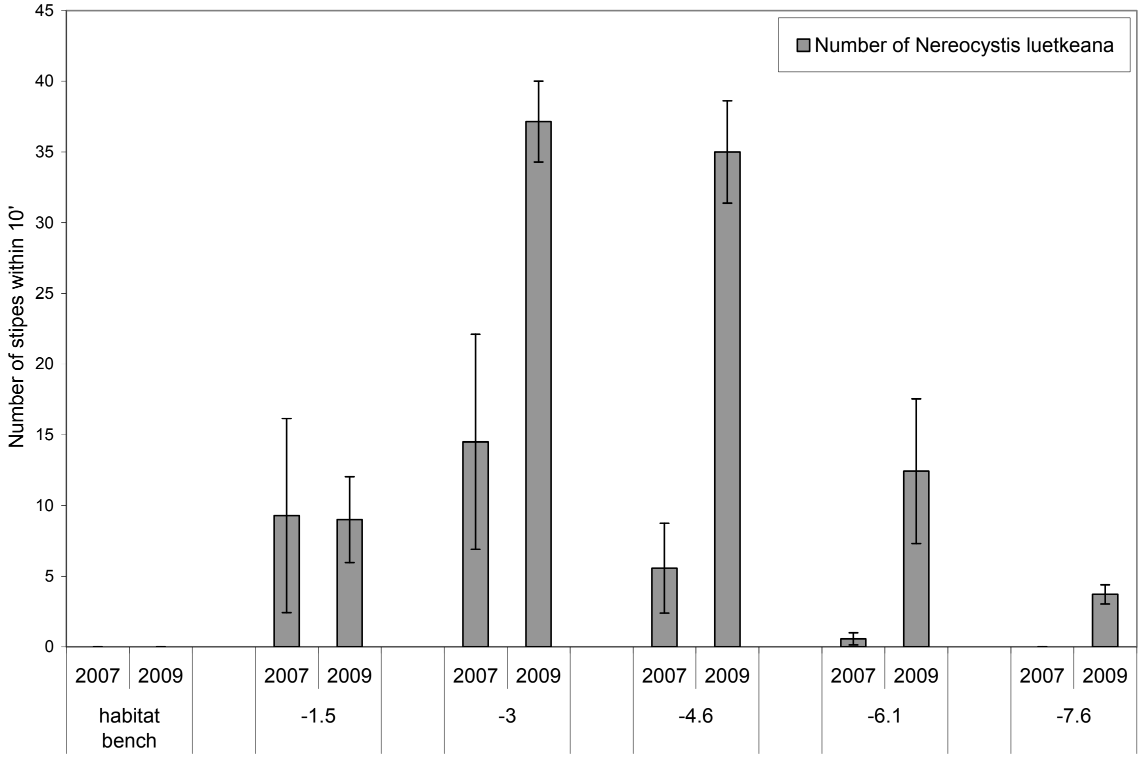


Figure 39. Number of *Nereocystis luetkeana* kelp stipes observed within 3 m, by tidal elevation (m below MLLW) in 2007 and 2009. Statistical tests showed that kelp stipes in 2009 were most abundant at -3.0 and -4.6 m, and all elevations between -3.0 and -7.6 had more kelp stipes than in 2007.

Table 21. Species list of algae and presence at each tidal elevation (m below MLLW) in 2007 and 2009, with average number of stipes observed within 3 m for Bull and Stalked Kelp.

Algae Type	**Species**	**habitat bench (0 to -1.5)**		**-1.5**		**-3**		**-4.6**		**-6.1**		**-7.6**	
		2007	2009	2007	2009	2007	2009	2007	2009	2007	2009	2007	2009
Brown	Bull Kelp (*Nereocystis luetkeana)*			9.3	9.0	14.5	37.1	5.6	35.0	0.6	12.4		3.7
	Stalked Kelp *(Pterygophora californica)*					0.2				0.3		0.3	
	Sugar Kelp *(Saccharina latissima)*			X	X	X	X	X	X	X	X	X	X
	Seive kelp *(Agarum fimbriatum)*					X	X				X		X
	Flat Desmarestia *(Desmarestia ligulata)*			X		X	X	X		X		X	
	Rockweed *(Fucus* sp.)		X										
	Seersucker kelp *(Costaria costata)*				X	X	X		X		X		X
	Stringy Desmarestia (*Desmarestia viridis*)					X	X		X				X
	Wireweed *(Sargassum muticum)*			X	X								
Green	Sea Lettuce *(Ulva fenestrata)*	X	X	X	X	X	X	X		X			
	Green Ribbon *(Enteromorpha intestinalis)*	X	X		X								
Red	Branching Palmaria (*Palmaria callophylloides)*				X	X	X	X	X	X	X	X	X
	Turkish Towel *(Chondracanthus exasperatus)*		X	X	X		X	X	X	X	X		X
	Hidden Rib Red (*Cryptopleura ruprechtiana*)			X	X	X	X	X	X	X	X	X	
	Splendid iridescent seaweed *(Mazzaella splendens)*		X	X	X		X	X	X		X		X
	Purple laver *(Porphyra perforata)*	X	X		X								
	Fine Branching Reds (*Ceramium pacificum*)			X			X		X		X	X	X
	Sea Comb *(Plocamium cartilagineum)*			X	X	X	X	X	X	X	X	X	X
	Fuzzy Reds (*Polysiphonia* sp.)		X	X	X	X	X			X	X		X
	Red Ogo *(Gracilaria pacifica)*				X	X	X	X	X	X	X	X	X
	Flat Palmaria (*Palmaria mollis*)				X	X	X	X		X	X		X
	Turkish Washcloth *(Mastocarpus papillatus)*	X	X		X								
	Red Islet Silk *(Sparlingia pertusa)*						X	X					
	Small Delesseria (*Delesseria decipiens*)			X		X							

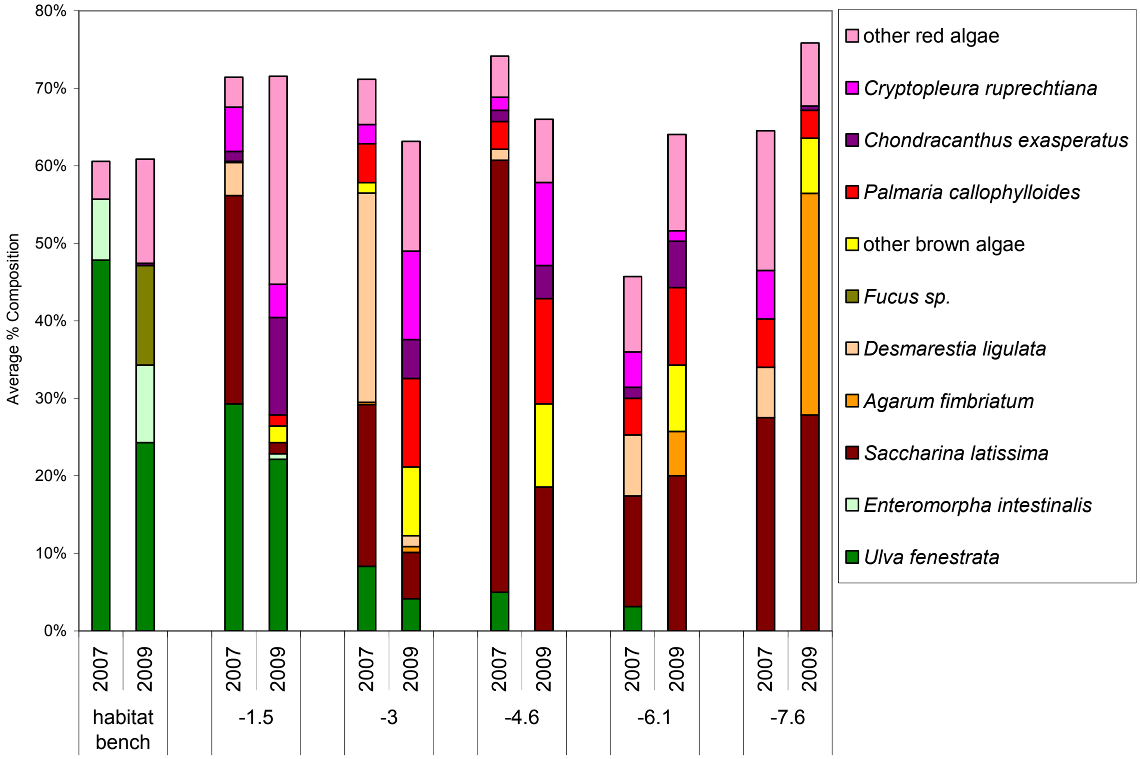


Figure 40. Average percent algae cover by tidal elevation (m below MLLW) in 2007 and 2009, showing species with percentage > 10%. Algae types are grouped together: green algae are coded green, brown algae are brown/orange/yellow, and red algae are red/purple/pink.

Discussion and Conclusions

Table 22 summarizes the main results from monitoring the OSP created sites before and after enhancement, as compared to armored shorelines. Overall, even though there is significant public use of the park and the enhanced sections were constrained by urban features, the beach structure is relatively stable and there has been a rapid and fairly stable development of aquatic and terrestrial biota within the first three years.

For each type of data collected, we first discuss the results in the context of pre- and post-enhancement findings. We then more generally compare the results to similar datasets from the surrounding Puget Sound area, in an attempt to place the OSP results in context to other beaches and further evaluate the meaning of our findings after the first few years of enhancement. Because these comparative datasets often used different methods for collection and processing of samples, we summarize them with the goal of making qualitative comparisons of major trends among the datasets. Following the discussion specific to each component, we present an overall conclusion and conceptual model summarizing the major findings.

Table 22. Summary comparing year 3 post-enhancement data at the habitat bench and pocket beach with armored shorelines. The comparison is made in two ways: to armored shorelines existing at OSP pre-enhancement (Pre), and to armored shorelines nearby OSP post-enhancement (Arm). When pre-enhancement datasets are not available, data is compared to year 1 data (Yr1). Data summarized by (+) positive change, (-) negative change, and (nd) no difference. See full report for specific explanations.

Fish

Summary: Positive changes for juvenile salmonid densities in 2007 and larval fish densities in 2009.

Positive for juvenile salmonid feeding, except for lower chum feeding compared to riprap in 2009.

Additional note: 91% of fish netted at the pocket beach were juvenile salmonids.
Main juvenile salmonid prey items were amphipods, crab larva, insects, and harpacticoid copepods.

	Habitat Bench		**Pocket Beach**	
	Pre	Arm	Pre	Arm
Juvenile Salmonid density*	nd	+ nd	nd	+ nd
Larval Fish density	nd	nd	+	+
Feeding in shallow water**	+	+ -	+	+ -

* (+ nd) signifies increase in 2007 and no difference in 2009

** (+) signifies increase in Chinook and chum; (+ -) signifies greater in Chinook and less in chum

Aquatic Epibenthic Invertebrates

Summary: Mostly positive, especially for overall densities, harpacticoid densities, and taxa richness.

Negative changes for epibenthic amphipod densities at the pocket beach.

Additional note: Benthic invertebrates in pocket beach substrates contain taxa unique from other habitats.

	Habitat Bench		**Pocket Beach**	
	Pre	Arm	Pre	Arm
Density (overall)	+	+	+	nd
Taxa richness	+	+	+	+
Assemblage structure*	+	+	+ -	+ -

* (+) signifies increase in harpacticoid copepods; (-) signifies decrease in amphipods

Terrestrial Insects

Summary: Mostly positive, especially for taxa richness and hemiptera densities (e.g., aphids).

Some negative changes for diptera densities (flies, e.g., chironomid midges).

Additional note: Neuston tows document presence of terrestrial insects on the surface of nearshore waters.

	Vegetation Swath		**Pocket Beach**		**Riparian**	
	Pre	Arm	Pre	Arm	Pre	Arm
Density (overall)	+	+	nd	nd	-	nd
Taxa richness	+	+	+	+	+	+
Assemblage structure*	+ -	+	+ -	+	-	+

* (+) signifies increase in hemiptera; (-) signifies decrease in diptera

Algae Colonization and Planted Vegetation

Algae Summary: Bull kelp stipes increased, algae percent cover and taxa richness stayed similar to Year 1.

Vegetation Summary: Understory and overstory vegetation increased in cover, some trampling of dunegrass

	Algae
	Yr1
Kelp density	+
Taxa richness	nd
Algae percent cover	nd

	Vegetation
	Yr1
Percent cover	+
Dunegrass density	+

Physical Structure

Summary: In year 1 there was minor sediment loss at the pocket beach, and settlement of nourishment mounds and riprap at the habitat bench. In year 3 sediment loss is apparent, but limited, and profile changes are seen on the upper foreshore in response to natural wave and tide forcing and anthropogenic use.

Physical Characteristics

Analysis of Beach and Bench Profile Change

Analysis of the change in area on transects BS and BN was accomplished by calculating the cross-sectional area of sediment between the beach profile and the -2 m MLLW elevation line. The change in area between surveys gives an indication of the volume change of sediment on the beach. Overall, between year 0 and year 1 surveys, the amount of sediment on the beach at the two transects declined (Fig. 41). Survey datum errors probably contribute significantly to the vertical rate of change between any two surveys, but the trend over the 3.5 years of data collection is robust. In both beach transects, sediment appears to have been lost over the monitoring time period. The data trend suggests that the beach lost sediment from these transects in 2007-2008 (year 1 and 2) and has stabilized or is losing sediment at a lower rate in 2009-2010 (year 3). Between monthly surveys, sediment shifts on the beach caused monthly variations in cross-sectional area at the measured transects. A linear fit to the full three-year data set suggests that the beach may still be losing sediment, but inspection of the trend suggests that the beach may have reached a relatively stable condition, with sediment shifting from north to south, with only a small amount of net loss.

Seasonally on the OSP beach, sediment moves from the lower and middle foreshore into the berm under energetic winter conditions (Fig. 42). This sediment appears to move back down the beach in the summer, largely due to anthropogenic influences. This is in contrast to classical sandy beach profiles where a berm-type profile is seen in the summer and a flatter, more dissipative beach is seen in energetic winter conditions. Additionally, peak high tides and storm surge conditions occurred simultaneously in year 3 leading to overwash of beach sediments onto the backshore (Fig. 43). These deposits, although not a large volume of the beach sediment, likely will not return to the foreshore of the beach under natural forcing.

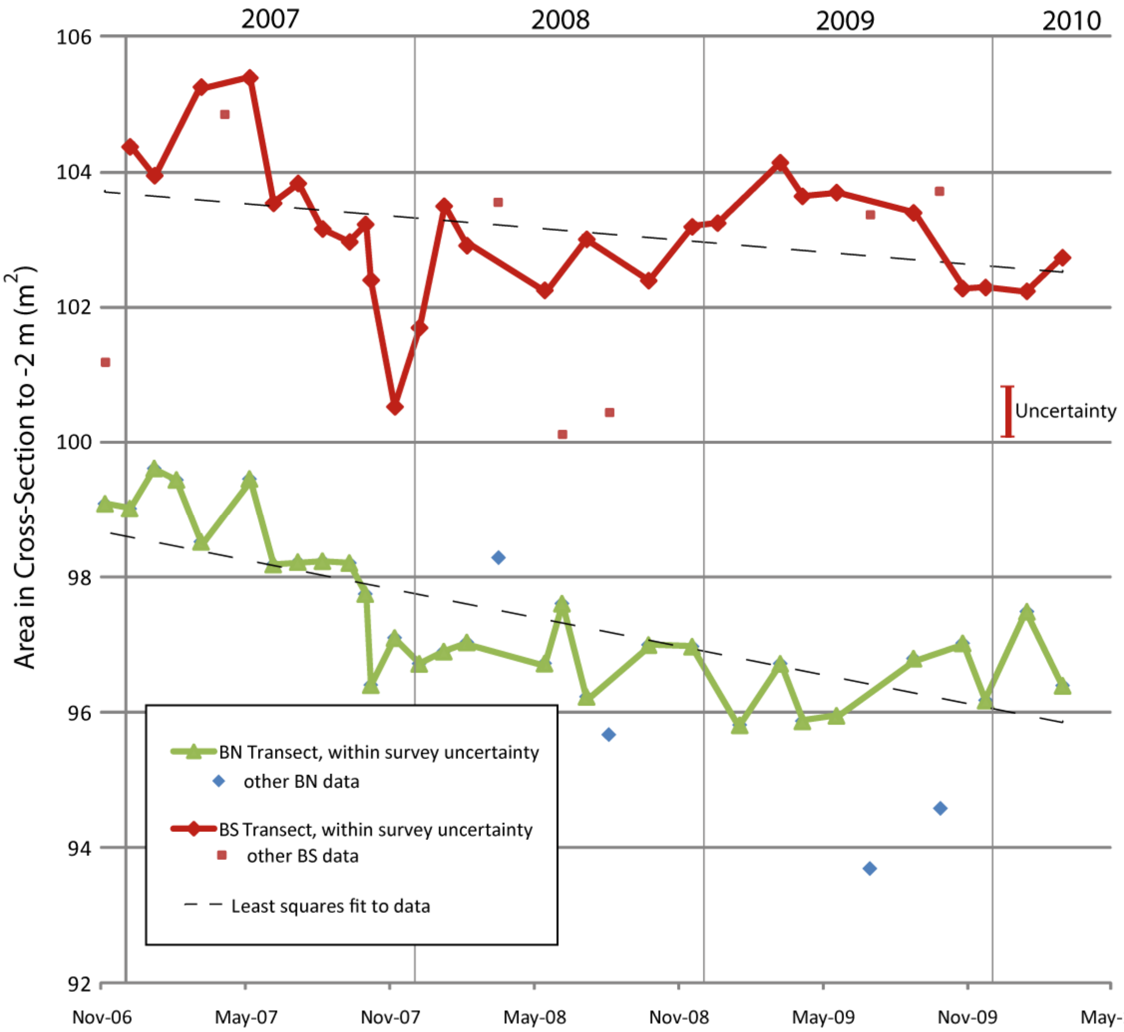


Figure 41. Cross-sectional area within the beach profiles for BS (green) and BN (red) transects relative to -2 m MLLW elevation. The data trend suggests that the beach lost sediment from these transects in 2007-2008 and has stabilized in 2009-2010. Sediment moves on the beach between surveys and there may still be net loss (see later half of BS transect), but there seems to be only a small amount of net change.

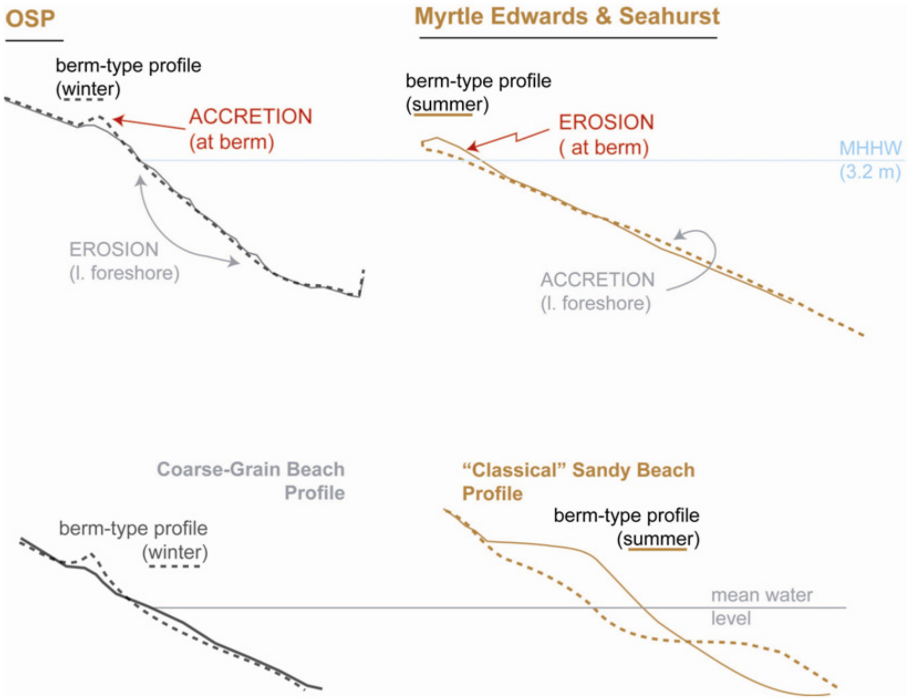


Figure 42. Schematic of beach cross-sectional area change. Beaches that are coarse-grained respond to seasonal variation in wave energy differently than beaches that are more composed of sand sizes.

Figure 43. Overwash deposit photographed January 24, 2010 resulting from extreme spring tides and storm surge in Puget Sound.

Comparative Datasets

Toft et al. 2009 measured beach profiles and slopes on nine restored beaches around Puget Sound using identical methods to those used in this study. The beach morphologies were compared among the sites (Fig. 44) and groupings made of beaches that appeared to have similar physical form and function. All beaches were relatively stable through time, although a slight seasonal variation between surveys was observed at OSP south, Myrtle Edwards and Seahurst middle and south. Berm elevations reached +4.42 m (relative to MLLW) and in general varied between the multiple surveys at each site where a berm could form. The beaches backed by riprap or a seawall had less sediment cover at higher intertidal elevations due to truncation of the upper profiles. The differences in observed beach slope and berm heights led to a differing general beach morphology and differing beach width between MHHW and MLLW.

Finlayson (2006) studied Puget Sound beaches that were largely natural, and developed a classification scheme for different beach profiles. Compared to the beaches from Finlayson (2006) as shown in Figure 45, the OSP pocket beach has a slope that is steeper (~0.20) than the natural coarse-grained beaches (generally observed slopes of 0.06 to 0.15). Another study of coarse-grained beaches in an open ocean environment (Jennings and Shulmeister 2002) recorded beach slopes of up to 0.24.

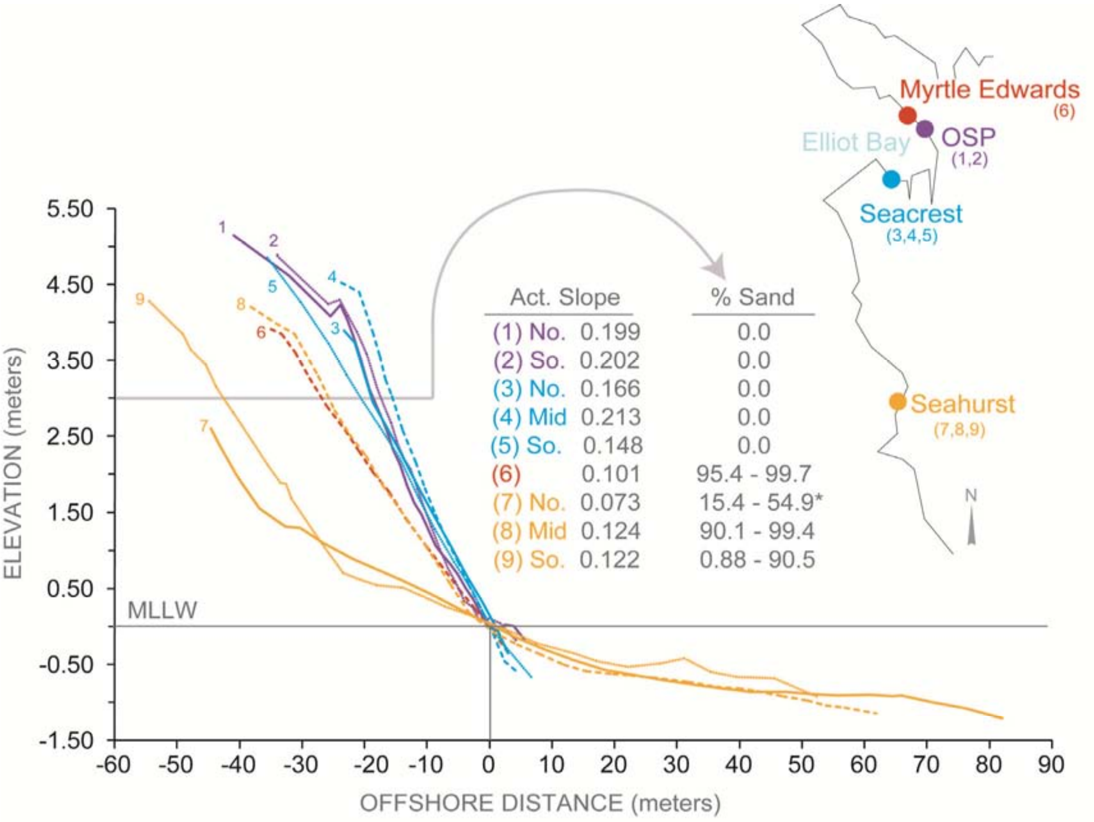


Figure 44. Beach profiles, slopes and percent sand at +3 m MLLW from comparative study sites around Puget Sound (data collected summer 2008, Toft et al. 2009). No. = North, So. = South, Mid = Middle of the transect.

Profile Vulnerability

Different regions on the OSP pocket beach cross-sectional profiles are more or less vulnerable to sediment transport on the beach surface and therefore show 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 a few meters in the horizontal direction. Consistent with other studies (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.

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 ("striping", see Appendix of Toft et al. 2008) and the mixing of sediment from the surface and subsurface layers (Fig. 15). This is the zone where tidal elevations in Puget Sound occur most frequently and therefore is the zone that experiences processes associated with swash, such as active wave breaking and runup.

On the lower foreshore and central bench, the sediment grain size is significantly coarser, and swash processes less frequent (see Toft et al. 2008). Therefore, the profiles were more stable in this region with deposition being the dominant process. 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 initial nourishment mounds that existed there in the previous winter (Fig. 10; Table 3). Summer tides provide lower water surface elevations during 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, either as a function of natural or anthropogenic forcing. The tidal elevation reaches these lower levels only at spring low tides, and therefore swash processes have less time for impact. Even though, it appears that the bench sediment does move across the bench and the initial relatively flat surface has become more tilted. The riprap toe acts to limit loss of sediment from the bench. There does appear to be an area of erosion or settling at the south end of the bench that will need to be monitored for further loss (located at transect distance 190 m in Fig. 7). The early failure of the riprap buttress on the bench near the pocket beach does not seem to be progressing further, although some smaller unstable riprap was noted during the survey in that area.

Sediment Grain Size Changes

Consistent with observations made in year 1, most of the observed grain-size changes in year 3 occurred on the berm and upper foreshore, which are the regions most vulnerable to sediment transport. In general, the surface sediment became well sorted over year 1 following construction activities that acted to mix the subsurface and surface sediments. In subsequent years, the surface sediment thickness has become 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 and mixing between the surface and subsurface sediment is apparent in the grain-size analysis (e.g., sample BN +22 in Fig. 13). Although this has not been associated with major loss of sediment from the beach, the exposed finer sediment could be vulnerable to storms in the coming years and should be monitored. Local disturbances (e.g., water-logged debris) can also create zones where the subsurface sediment is exposed.

Comparative Datasets
Grain size evaluation in Toft et al. 2009 on nine nourished beaches around Puget Sound showed a range in sediment size and sorting. The beaches fall into two categories. In the first category, beaches were composed of coarse sediment that maintained a range of slopes (e.g., all Seacrest beaches, Seahurst-north, and 32nd St). These beaches were relatively stable at slopes up to 0.22 and showed little response to natural processes (Fig. 45). The OSP pocket beach transects fall within this group. The second group contained beaches that were composed of smaller grain sizes as indicated by higher percentages of sand (e.g., Myrtle Edwards and Seahurst-south and middle). These beaches were more responsive to natural processes and their slopes were controlled by the sediment grain size and wave conditions for the area.

Sediment grain size on the OSP pocket beach falls at the edge of the range of observations of more natural beaches around Puget Sound (Finlayson 2006). The beaches in Finlayson (2006) were generally less coarse in median size than the OSP pocket beach. The sediment is much better sorted at the OSP pocket beach, lacking the range in sediment sizes seen on natural beaches. The open ocean coarse-grained beaches studied in Jennings and Shulmeister (2002) had similar median sediment grain sizes as seen in Finlayson as well as some coarser grain sizes, encompassing the range of sizes at OSP.

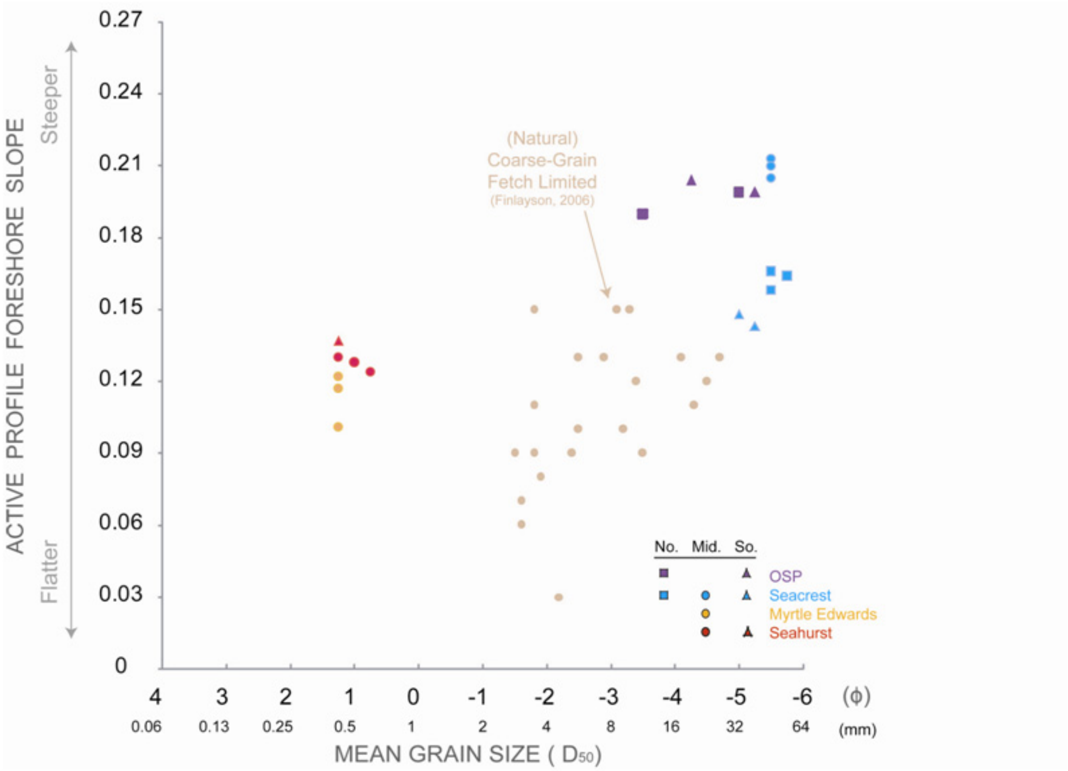


Figure 45. Median grain size of beach sediment (D_{50}) at an elevation of ~+3 m MLLW as a function of active beach profile slope for regionally comparable enhanced beaches as well as natural beaches in Puget Sound. Multiple points for a specific beach reflect different sampling periods.

Natural Forcing

Tidal and Wind Observations

Tides and their impacts on the OSP pocket beach morphology were addressed in Toft et al. 2008. Briefly, tides in Puget Sound are mixed semidiurnal, which produces two nearly equal high water levels and two unequal low water levels each day. The average diurnal tidal range between MLLW and MHHW is 3.46 m (http://tidesandcurrents.noaa.gov/). Over time, the cumulative interaction between the tidal components produces an upward skew in the distribution of water level observations, also with extreme low tides occurring during the day in summer and at night in winter. This impacts the duration of time that different beach elevations are subject to wind and wave-driven processes as well as anthropogenic processes.

The wind intensity and direction in Puget Sound also have seasonal cycles. During the winter (October-March), winds are generally stronger and dominate from the south, and during the summer (April-September) winds are generally weaker and from the north/northeast directions. 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 low energy. At the OSP beach the waves are controlled by the beach's orientation and the physiographic constraints of Elliot Bay. They dominantly come from the southeast to southwest directions. Because of the smaller fetch lengths, wave heights are generally low (e.g., range from 0 to 0.4 m).

Wave-Driven Forcing of Sediment Transport

Annual weather conditions for year 1 were analyzed in Toft et al. 2008. The wind conditions during year 3 were considered typical in their seasonal pattern, although somewhat weaker than those experienced in year 1 (Fig. 46). Therefore, we conclude that changes in the beach profile noted during year 3 are attributable to both waves and anthropogenic forcing, as was found in year 1 studies.

The combination of tidal elevation and energetic wave conditions determine the zones on the beach most impacted by natural sediment transport on the beach. The peak vulnerability to transport conditions is during periods of extreme high tidal elevation combined with storm conditions. These conditions early in the winter can result in major reorganization of the beach sediments, similar to or greater than those seen in the profile area changes in November 2009 when sediment was moved into the berm (see Toft et al. 2008) and alongshore from the south to north side of the beach (Fig. 41). Under summer conditions, the sediment moves out of the peaked berm and in 2009 shifted from the north to the south. In this fetch-limited environment, seasonal trends are muted by extreme events and heavy anthropogenic use of the beach.

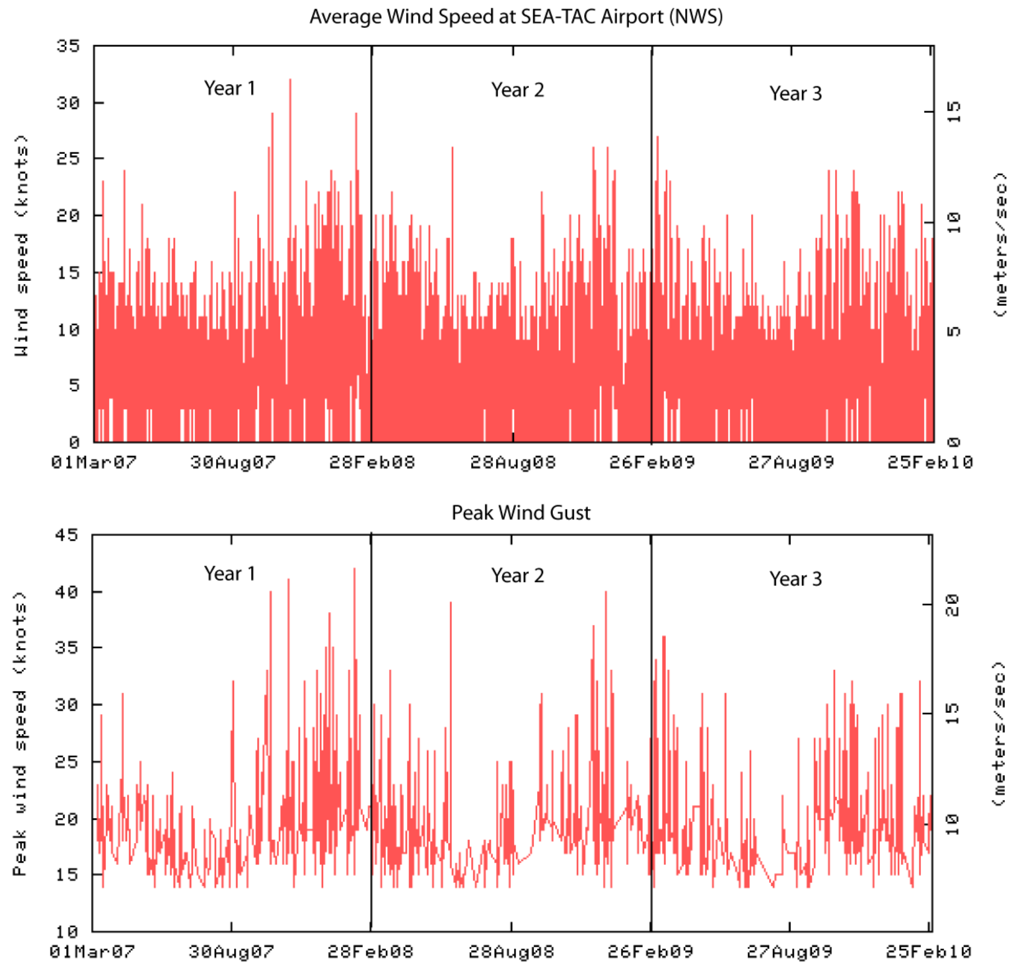


Figure 46. Average wind speed and peak wind gust data from SEATAC Airport for the three years of monitoring. Note that seasonal patterns are consistent between the years, but peak wind speeds occurred in year 1 and year 2.

Anthropogenic Forcing of Sediment Transport

Beach profile changes at OSP during the summer indicate that there may be forcing mechanisms not associated with winds and waves that are important to the movement of sediment on the beach. During summer, the wind and wave climate in Puget Sound is lower in energy, reducing the potential for sediment transport of coarse grains. The ability of pure gravel beaches to effectively dissipate lower magnitudes of wave energy suggests that at OSP, the beach should remain relatively stable during the summer. However, beach profile measurements showed a slight lowering of the beach slope and berm elevations.

OSP was constructed to provide the public with access to Puget Sound in an otherwise heavily armored shoreline. As visually observed during fieldwork in the summer when extreme low tides occurred during daylight hours, the public actively use the beach.

With fewer storms to counteract the pulses of human use on the beach during the summer, it is likely that increased foot traffic causes the observed decreases in berm elevation and flattening of beach slope. Similar anecdotal scenarios were hypothesized during monitoring efforts at Marine Park in Puget Sound (pers. comm. Shipman, WA Dept. Ecology) where following the winter season, well-defined berms were observed on the beach and their forms were muted once the park opened during the summer season. It is likely that humans are drivers of change on urban beaches and anthropogenic use is important for understanding beach processes in urban public parks.

Regional and Global Comparative Datasets

For comparison, the sediment size and profile slope relationship of the OSP pocket beach is plotted with data from other sand and coarse-grained beaches from Puget Sound and worldwide (Fig. 47). Data for sandy beaches was obtained from Komar (1998), Bascomb (1953), Weigel (1964) and Jackson et al. (2002). Data for coarse-grained beaches was obtained from Jennings and Schulmeister (2002) and Finlayson (2006). The Finlayson (2006) data set is a comprehensive survey of beaches around Puget Sound. Data for other nourished beaches in central Puget Sound was obtained from Toft et al. (2008).

There is a clear separation between the data for sandy beaches in both open ocean and fetch-limited environments and coarse-grained beaches. The data from sandy beaches provides a fairly clear relationship between sediment size and beach slope, and the slope of that relationship changes with wave energy (Bascomb 1953, Wiegel 1964). The relationship for coarse-grained beaches is not as straight-forward and seems to be less a function of wave energy. The poor correlation between grain size and beach morphology suggests that for coarse-grained beaches antecedent morphology of source area characteristics and the subsequent beach material play a complex role in defining the morphology of the beaches (McLean and Kirk 1969, Finlayson 2006). Most Puget Sound beaches are relatively coarse-grained with some exceptions, generally near river or stream sources of sediment.

The size/slope relationship for the OSP pocket beach falls slightly outside the envelope of data from natural beaches in Puget Sound (Finlayson 2006). The OSP beach is generally steeper and slightly coarser than natural Puget Sound beaches. In comparison to a global range of coarse-grained beaches both open ocean and fetch limited, OSP falls within the envelope, but groups with only a few other steep beaches.

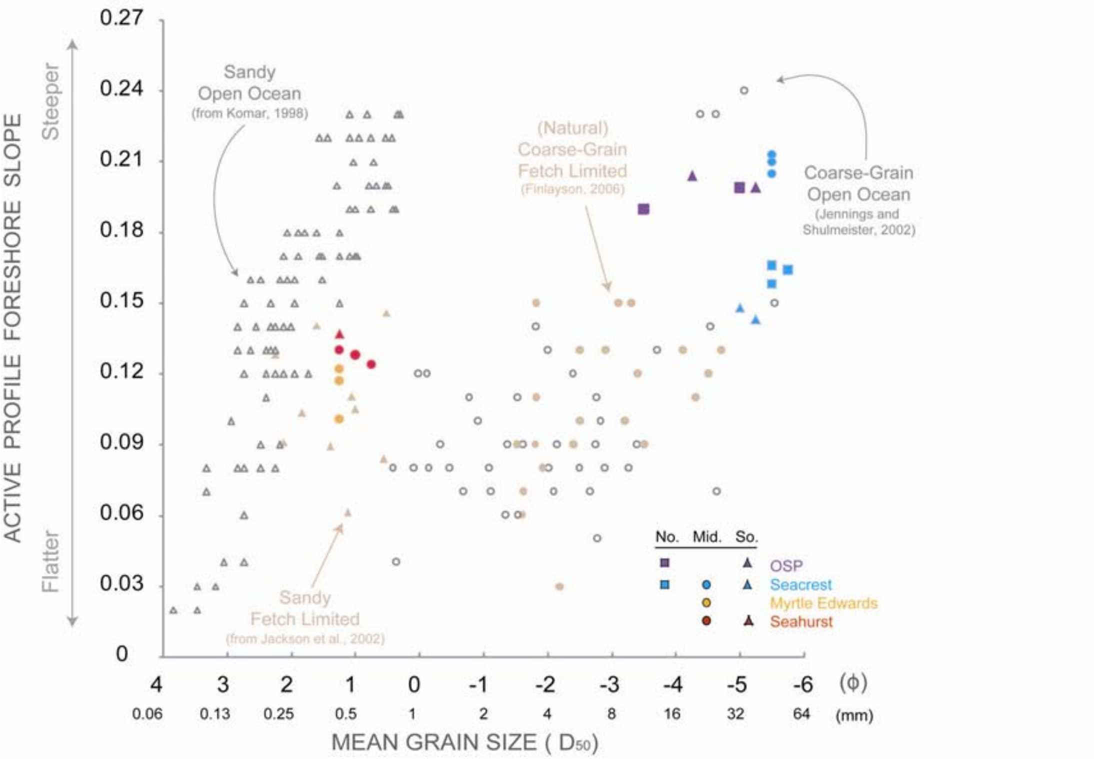


Figure 47. Median grain size of beach sediment at an elevation of ~+3 m MLLW as a function of active beach profile slope for nourished and natural beaches from studies in Puget Sound and coastlines around the world. Multiple points for a specific beach reflect different sampling periods.

Biological Characteristics

Fish – Snorkel Surveys

Results of pre-enhancement monitoring in 2005 indicated that benefits resulting from created habitat at 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 confirmed this, because juvenile salmon were significantly more abundant in shallow waters at the habitat bench and pocket beach than adjacent riprap (Toft et al. 2008). In 2009, juvenile salmonids were again most abundant at shallow transects, but densities were fairly consistent among sites and with that of past years. Observed feeding by juvenile salmonids was highest in shallow waters at all sites and was greater than in past years at these shallow depths, suggesting an improved amount of available prey. Behavior measurements are rare in assessing restoration success, and have mostly been applied to studies of birds (Lindell 2008). Increased feeding behavior especially in juvenile Chinook at the enhanced shorelines represents a potential for improvement in fitness, although we can not say specifically in all cases what those fish were feeding on.

The main difference in fish assemblages compared to 2007 and 2005 monitoring was the high numbers of larval fish observed at the pocket beach and habitat bench in 2009.

This was also the case found in 2008 as part of a separate year 2 study (Toft et al. 2009). In 2009, larval fish were significantly greater in shallow waters at the pocket beach, as compared to other sites and past years. These small larval fish were most often observed in large schools in the middle of the water column, and were typically fairly localized and not swimming away. There were two types of observed morphologies, post-larval forage fish and demersal fish, indicating a diversity of larval types. It is possible the larval fish hatched at the site, or they may have been attracted to the pocket beach as a refuge habitat because it is the first shallow water located north of downtown Seattle at the end of the seawall. This suggests that providing refuge for larval fish is an added benefit of creating shallow water beach types in a highly modified urban setting, where the majority of the shoreline has a truncated steep intertidal zone. Smelt, herring, and tubesnout were also most abundant at the habitat bench and pocket beach, and it is possible that there is a link between these nearshore spawners and the observed larval fish. Even though the sediment sizes at the pocket beach are too coarse to be ideal for spawning of surf smelt and Pacific sand lance, nearshore habitats are known to be used as nursery grounds by larval forage fish (Penttila 2007).

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 at the created habitats, which throughout the entire sampling consisted of eleven lingcod and one large sculpin.

Although difficult to observe via snorkel surveys, several species of fish have been observed in low numbers that were not documented before enhancement in 2005: one wolf eel and two clingfish were observed in 2007, and one dolly varden trout and four greenlings were observed in 2009. 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 continue to occur or if they were chance occurrences. Although not measured before enhancement, juvenile gunnels were observed underneath cobble at the pocket beach during the process of taking benthic cores, and these fish may have benefited from shelter created by cobbles placed at the site.

Comparative Datasets

Sampling in 2008 compared fish densities at OSP to other beaches in Elliott Bay and central Puget Sound (Toft et al. 2009). That study was conducted on a pink salmon outmigration year, with the result that the majority of juvenile salmonid observations were of pink and chum salmon. Proportions of juvenile salmonids observed with snorkel surveys at OSP were intermediate between those at adjacent beaches, and proportions of larval fish were highest at the OSP habitat bench and pocket beach. Percent of juvenile salmonid feeding observations was high at the habitat bench and intermediate at the pocket beach (range 35-68%, slightly lower than 2009); both of these values were lower than the 89% that was observed at Seahurst Park, an unarmored, wide, low-gradient beach. Therefore, data collected in 2009 is similar to that described in the 2008 synoptic study, differing mainly in higher densities of larval fish and observed feeding in 2009.

Analysis of fish densities from a range of armored and unarmored sites within the City of Seattle boundaries in 2003 found fish species similar to those observed in 2009 at OSP, with the exception that more forage fish occurred in 2003 and more larval fish occurred in 2009, although this is probably due to lifestage of fish (Toft et al. 2007). In the 2003 dataset, which used snorkel surveys only directly along shore (i.e. adjacent to shore, either 1.5 m water-depth or 3 m from shore) in a non-pink salmon outmigration year, larger schools of juvenile salmonids were found grouped along shore at sites where armoring extended into shallow subtidal waters, truncating the intertidal zone and eliminating the shallow water gradient for fish to spread out on. Similarly, at the OSP shallow transects sampled in 2009, average juvenile salmonid school sizes were higher (58) at the riprap sites, and lower (15) at both the pocket beach and habitat bench sites.

Other fish sampling efforts in the vicinity of Elliott Bay have typically used beach seines, which offer a good general assessment of fish presence in the area (Brennan et al. 2004, Nelson et al. 2004). Seasonal patterns of juvenile salmonid use at OSP are similar to those found in these studies, with peak chum numbers occurring in April/May, and Chinook abundant throughout June/July. Juvenile salmonids also use the nearshore in lower numbers in other months, and our sampling at OSP does not monitor for Chinook fry migrants which would be outmigrating earlier in the season in February/March (Nelson et al. 2004). Mesh sizes of beach seines are too big to efficiently sample very small larval fish, and snorkel surveys focus more on pelagic fish than demersal fish; apart from these differences, general fish communities measured by the two methods are similar.

Summary of OSP context to comparative datasets from the surrounding area:
Juvenile salmonid outmigration timing, distribution, and proportional abundance in the overall fish community was similar to that found in other datasets. The high numbers of larval fish observed at the pocket beach and habitat bench are a notable feature, and have not been documented in such consistently high numbers in other nearshore sampling in the vicinity of Elliott Bay. Observed feeding rates of juvenile salmonids appear to be near the maximum of that observed at a more natural unarmored beach.

Fish - Enclosure Nets and Diets

The pocket beach has created a new shallow water habitat that replaced the previously armored shoreline. Because juvenile salmon were the main species netted 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 were rare at the site. For example, shiner perch, which overlap somewhat in diet composition with juvenile salmon (they feed mostly on small crustaceans and algae; Bane and Robinson 1970) were rare in pocket beach net samples.

Since juvenile salmon were held at the beach for an average of 3.4 hours per enclosure net, we assumed that undigested prey items mostly represented taxa fed on at the pocket beach. Main prey items within each taxa grouping were often similar to those from invertebrate samples at the site. For example some of the main prey amphipods like *Calliopius* sp. and *Desdimellita* sp. were more common in epibenthic and benthic samples at the pocket beach. However, the amphipod *Paracalliopiella pratti* that was most abundant at armored shorelines was not common in the diets. There were also some prey items that occurred in lower abundances in our benthic and epibenthic invertebrate samples, such as other amphipods that may be more pelagic or associated with algae (e.g., *Themisto pacifica, Hyperia medusarum*) and calanoid copepods which are planktonic in the water column. These prey may have been consumed in habitats that were not sampled for invertebrates or before the fish were enclosed at the pocket beach. More fish sampling would have to occur along the downtown seawall to know if prey resources abundant there (e.g., *Paracalliopiella pratti*) are preyed upon when there are less available options, as well as invertebrate sampling in other nearshore habitats (e.g., pelagic, different algae types) to complete the full spectrum of all available prey resources.

Comparative Datasets

Juvenile salmon netted at the pocket beach consumed a diversity of prey. For Chinook salmon, diets consisted mostly of amphipods, crab zoea, and insects. This finding is similar to diet results from beach seining efforts in 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 at OSP overlapped somewhat with Chinook salmon diets, but fed more on smaller prey such as harpacticoid and calanoid copepods. Juvenile chum are known to prey on harpacticoid copepods, (Kaczynski et al. 1973, Sibert et al. 1977, Sibert 1979, Simenstad et al. 1980, Landingham 1982, Cordell 1986, Webb 1991a), so it is promising to see an increase in harpacticoid feeding in 2009 compared to 2007 (Toft et al. 2008). 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.

Analysis of juvenile Chinook diets from enclosure nets deployed at a range of armored and unarmored sites within the City of Seattle boundaries also showed an overall mix of prey from benthic/epibenthic, terrestrial riparian, and planktonic/neritic sources (Toft et al. 2007). Similar to the OSP results, Chinook from that study also had higher amounts of terrestrial prey (insects) in their diets compared to chum and coho. When diet results were separated into armored and unarmored sites, Toft et al. (2007) found that gravimetric composition of terrestrial prey ranged from 8 to 9% at armored supratidal or intertidal locations, and was 63% at unarmored shorelines. Diet data from OSP had a range of 21 to 28% terrestrial prey in May and June, with almost no terrestrial input in July. Therefore, in the spring and early summer terrestrial input of prey is between that of the previously measured values at armored and unarmored sites in the vicinity, decreasing to lesser values by mid-summer.

Diets of juvenile Chinook salmon collected with beach seines in Elliott Bay had a low terrestrial component along Alki (7%) and a fairly high terrestrial component at the mouth of the Duwamish River (56%) (unpublished data from fish catches reported in Nelson et al. 2004). The OSP values again fell in the middle of this range in May and June. It is possible that there is some riverine input of terrestrial/emergent marsh prey coming from the Duwamish that is localized to where it enters Elliott Bay, as fish at Alki that were more distant from Duwamish sources fed more on epibenthic/benthic polychaete worms and amphipods.

When Chinook move into offshore waters, they switch to feeding more on water-column sources dominated by crab larvae and fish (Duffy et al. 2010). Epibenthic/benthic and terrestrial riparian sources of prey are more associated with nearshore shallow-water habitats, as has been found with our OSP sampling.

Summary of OSP context to comparative datasets from the surrounding area:
Juvenile Chinook, chum, and coho salmon at OSP fed on a mix of epibenthic/benthic, water column, and terrestrial riparian prey sources similar to what has been found elsewhere in nearshore waters of Puget Sound. Juvenile Chinook at OSP fed on insects in an intermediate amount compared to diets previously analyzed from neighboring armored and unarmored shorelines, suggesting an improvement in terrestrial prey input compared to pre-enhanced armored conditions, but perhaps not to the level of a more natural unarmored beach.

Epibenthic Invertebrates

Enhanced 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, and taxa occurred that were previously rare or not present at armored seawall and riprap sites. In particular the habitat bench had the highest densities of total epibenthic invertebrates and taxa richness. Both the habitat bench and pocket beach had higher numbers of harpacticoid copepods than the armored sites, which is a category that contains major prey items for juvenile chum salmon. Total invertebrate densities at the enhanced sites were higher than 2005 baseline levels, except for amphipods at the pocket beach. The habitat bench and the riprap site had higher densities of amphipods than the seawall and pocket beach, and several of the amphipod species observed were also important prey for juvenile Chinook salmon. The dominant amphipod at armored sites both before and after habitat enhancement was *Paracalliopiella pratti*, a species known to be associated with algae and organic debris (Bousfield and Hendrycks 1997), but again was not common in juvenile Chinook diets. This species may be utilizing algae being produced at lower intertidal levels of the established armored shorelines. The greater diversity of both amphipods and harpacticoids at the habitat bench and pocket beach suggests that even small scale enhancement projects can increase biological function along the highly developed Seattle shoreline.

Comparative Datasets
In 2008 sampling was conducted that allowed comparisons between epibenthic invertebrates at the OSP sites to other beaches in Elliott Bay and central Puget Sound (Toft et al. 2009). This study also found that assemblages were composed mainly of harpacticoids and amphipods. Across all sites the main harpacticoid taxa were *Harpacticus* spp., *Tisbe* sp., and Ectinosomatidae, and the main amphipod taxa were *Paracalliopiella pratti*, *Calliopius* sp., and *Pontogeneia rostrata*. The OSP habitat bench and pocket beach had levels of taxa richness and harpacticoid densities that were similar to more natural low-gradient beaches of various sediment types. As in the results presented here, the 2008 study also found that amphipods dominated riprap sites, and were associated with the OSP habitat bench more than they were with the pocket beach. These findings are all similar to the patterns found in the pre- and post-enhancement datasets at OSP, and illustrate that the OSP enhanced sites experienced increased diversity and numbers of non-amphipod invertebrates.

Thom et al. (1984) sampled 31 habitats across 18 intertidal beaches (ranging in tidal elevation from -0.9 to +1.4 m MLLW) in central Puget Sound with low replication, and also sampled quarterly at Seahurst Park at low intertidal cobble and sand habitats. Samples were sieved at 0.253 mm. Harpacticoids dominated assemblage compositions, particularly *Tisbe* sp., *Harpacticus* sp., Ectinosomatidae, *Zaus* sp., *Huntemannia jadensis*, *Amonardia perturbata*, and *Diosaccus spinatus*, many of these taxa were also common in OSP samples. Amphipods in the Thom et al. study were lower in abundance, with *Photis* sp. being the most numerous at 1.23% of total abundances. Calliopiidae amphipods were not abundant, with *Paracalliopiella pratti* accounting for only 0.27% of total abundances. Peak abundances in spring and summer were ~37,500/m^2 one year and 56,250/m^2 the next, slightly higher than that found at OSP habitats.

Simenstad et al. (1988) studied epibenthic invertebrates on a natural tidal flat in the Padilla Bay National Estuarine Research Reserve. Conducted in May 1986, eelgrass habitats were sampled at tidal elevations and with methods similar to those at OSP (but coarser 0.250 mm sieve size), and were found to be composed primarily of harpacticoids at densities similar to those at OSP (range 1,271 - 13,083/m^2). Amphipods were not very abundant in the Padilla Bay eelgrass habitats. Taxa richness was lower (range 27-53) than that at OSP, but this may be due to lower sample sizes and coarser sieve size.

Haas et al. (2002) sampled epibenthic invertebrates around three ferry terminals in Puget Sound (Bainbridge, Clinton, Southworth) during March-May of 2000 at similar tidal elevations as those sampled at OSP, using a slightly coarser 0.246 mm sieve size. As with other studies, harpacticoids were the most abundant taxa. Results were somewhat variable across the three sites, but in general strata sampled away (100 m) from ferry terminals had slightly higher densities and lower taxa richness than the OSP sites, whereas strata near or under ferry terminals had lower densities and taxa richness than those found at OSP.

Simenstad et al. (1991) sampled two gravel-enhanced aquaculture sites and adjacent tidal flats in Hood Canal and south Puget Sound. Their sampling design was comparable to that at OSP, occurring at a similar tidal elevation five times March to May, using a coarser 0.253 mm sieve size. Their samples had a high percent composition of harpacticoids and a low percent composition of amphipods at all of the sites. Taxa richness was lower than that found at the OSP enhanced habitats. At the Hood Canal site, abundances of the amphipod *Paracalliopiella pratti* increased at gravel addition plots during three of the five sampling periods, perhaps further indicating this species' association with disturbances or coarsening of beach habitats.

Simenstad et al. (1993) summarized epibenthic sampling from various studies in Commencement Bay, WA. Methods varied, and included different intertidal and subtidal elevations, with pump samples ranging from 0.016 to 0.1 m^2, and sieve sizes of 0.15 to 0.5mm. The range in overall densities was comparable to that at OSP, with most densities being below 20,000 m^2 and few occurrences over 100,000 m^2. Similar to OSP results, the harpacticoid species *Harpacticus* spp., *Tisbe* sp., and *Zaus* sp. were common and abundant, and harpacticoids in general were the most abundant taxa. The amphipod *Paracalliopiella pratti* occurred in all of the collections, but other amphipods such as *Corophium* spp. and *Eogammarus confervicolus* were typically the most abundant amphipod species, which may be indicative of different physical conditions such as finer substrates than the coarse-grained beach at OSP. The cumacean *Cumella vulgaris* was also fairly abundant, which was present but rare at OSP.

Summary of OSP context to comparative datasets from the surrounding area:
The OSP enhanced habitats support high taxa richness and similar abundances compared to epibenthic invertebrate samples from other habitat types in Puget Sound, although many other studies used a slightly coarser sieve size (0.25 vs 0.106 mm). This is a promising sign, as harpacticoid densities have been shown not to be limited by juvenile salmonid predation in more natural tidal flats with eelgrass (Webb 1991b). Furthermore, associations of epibenthic invertebrates with the enhanced structures is similar to the association found with natural structural complexity, as epibenthic invertebrate densities have been found to be higher in oyster and eelgrass plots than mudflats in Willapa Bay (Hosack et al. 2006).

Benthic Invertebrates

As documented in 2007, 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 m and talitrid beach-hoppers at +3.7 m MLLW – are different from the amphipods that were sampled in 2005, when the more epibenthic *Paracalliopiella pratti* dominated the riprap at the 0 m elevation and there was no high intertidal beach wrack zone for talitrids to inhabit. Other studies have also shown that talitrid amphipods in the supralittoral are impacted by armoring and may be a good predictor of beach health (Dugan et al. 2008, Sobocinski et al. 2010).

There were some significant differences among post-enhancement years at the 0 m elevation in densities of two important categories that contain juvenile salmonid prey taxa, with amphipods being more abundant in 2007 and Chironomidae larvae more abundant in 2009. Chironomidae larvae were found in benthic core samples and Chironomidae adults were common in insect fall-out traps, further demonstrating the importance and potential linkages of having both aquatic and upland habitats at the site. Polychaete worms were taxa rich but not particularly abundant in the benthic substrate, and included taxa not documented in epibenthic sampling.

Comparative Datasets

Similar benthic cores were taken at a restored and reference beach in Seahurst Park (City of Burien) at +3.7 m MLLW elevation three years after restoration (Toft 2009). The main taxa were talitrid amphipods, oligochaetes, and nematodes. In comparison, OSP had relatively more gastropods and collembola and fewer oligochaetes and nematodes than Seahurst. Taxa richness at OSP (24) was between that of the Seahurst reference (23) and restored beach (29). Both sites had talitrids of the species *Traskorchestia traskiana*, while *Traskorchestia georgiana* and *Megalorchestia pugettensis* were found only at Seahurst and *Paciforchestia klawei* at OSP. Overall average densities at OSP were slightly lower (137/core) than at the Seahurst restored (173) and reference beach (259).

Sobocinski et al. (2010) took benthic cores at four pairs of armored and reference natural beaches in central Puget Sound, one pair of which was also at Seahurst Park, from March to June 2001. Tidal elevations at the reference beaches were similar to the +3.7 m MLLW samples taken at OSP, but armored elevations were lower at around +2.4 m. Average taxa richness at OSP (11.2) was higher than the average at reference beaches (8.6). Trends in percent composition between OSP and the reference beaches were similar for talitrids, but again oligochaetes and nematodes were more abundant at the reference beaches, and gastropods and collembola more abundant at OSP.

Dethier and Schoch (2005) studied the benthos of central and southern Puget Sound in May and June 1999, using the same core size as that used at OSP and at the 0 m MLLW tidal elevation. The samples were sieved at a coarser mesh size (2 mm as opposed to 0.5 mm). This excluded many of the smaller crustaceans, so exact comparisons between the two datasets are difficult to make. However, taxa richness was never greater than 30 for these samples, lower than the 55 at OSP. In a more extensive technical report from the same study (Dethier and Schoch 2000), results were qualitatively compared to historical studies focused on sewage treatment plants in central Puget Sound from the 1970s to 1990s (Armstrong 1977, Staude 1979, Thom et al. 1994). Recognizing the inherent differences due to sampling methods between studies, they found substantial similarity among datasets when similar locations, tidal elevation, and substrate type were compared. These historical studies plus two others are examined below.

Thom et al. (1984) sampled 31 habitats across 18 intertidal beaches in central Puget Sound with low replication, ranging in tidal elevation from -0.3 to +0.4 m MLLW, and also sampled quarterly at Seahurst Park at low intertidal cobble and sand habitats. Samples were sieved at 1 mm. Abundances and taxa richness were lower than OSP across all sampling, but again this could be due to the greater sieve size and lower replication. Taxa assemblages were dominated by polychaetes and nematodes. In comparison, OSP also had high numbers of nematodes, but fewer polychaetes and more chironomid larva and amphipods. These assemblage differences could be due to the coarser sediments found at OSP, and greater input of mud and sand at the other sites that would favor polychaete assemblages.

Armstrong (1977) sampled five beaches in central Puget Sound, quarterly from October 1974 to April 1976, in sand, gravel, cobble and boulder habitats. Tidal elevations included 0 m MLLW, as well as +0.91 and +1.82 m. Four benthic cores were taken at all sampling events (31.2 cm^2, 15 cm deep, 1 mm sieve size). Nematodes were abundant at all five sites (>100/m^2) in mixed sediments and sand, similar to that found at OSP. Abundant amphipods (>100/m^2) were *Corophium acherusicum*, *Paramoera* sp., *Photis brevipes*, and *Allorchestes angustus*. The most abundant amphipod at OSP, *Desdimelita californica*, was not found in Armstrong's study, although *Melita dentata* was found and could possibly be the same due to differences in taxonomic resolution. Staude (1979) sampled the intertidal near a sewage treatment plant at West Point in central Puget Sound in 1971, 1973, and 1975, in conjunction with Armstrong's 1977 study. Samples were sieved at 6mm, so useful comparisons can not be made with that of the smaller 0.5 mm sieve used at OSP.

Thompson (1995) studied the effects on benthic invertebrates of adding gravel and gravel/oyster shell to a natural mudflat in south Puget Sound, as part of research testing ways to improve Manila clam production. Benthic invertebrates were sampled at +0.3 and +0.6 m MLLW, with core size the same as that used at OSP (10x15 cm) but sieved at 1 mm. He found more gammarid amphipods and nemertean worms and fewer polychaete worms in plots with enhanced substrates. Similarly, the OSP samples also had more amphipods and nemerteans than polychaetes.

Simenstad et al. (1988) studied benthic invertebrates on a natural tidal flat in the Padilla Bay National Estuarine Research Reserve. Conducted in May 1986, cores (28 cm^2, 10 cm depth, 0.25 mm sieve) were taken in eelgrass habitats at similar tidal elevations to those sampled at OSP. Excluding harpacticoids that were retained by the smaller sieve size, the main taxa were nematodes and polychaetes. Nematodes were also abundant at OSP, but OSP had more amphipods and chironomid larva and less polychaetes.

Summary of OSP context to comparative datasets from the surrounding area:

The +3.7 m MLLW elevation at the OSP pocket beach generally had values of benthic invertebrate taxa richness similar or higher to that of other beaches in Puget Sound, with similar assemblages of talitrid amphipods, but more gastropods and collembola and fewer oligochaetes and nematodes. At the 0 m MLLW elevation values of taxa richness and abundance at OSP were similar or higher, with similar assemblages of nematodes, but more chironomid larva and amphipods and fewer polychaete worms. One other study also found more amphipods and fewer polychaetes in tidal flats with added gravel. These assemblage differences could be due to the coarser sediments found at OSP, as opposed to studies that sampled at habitats with more mud and sand.

Terrestrial Insects

All of the enhanced vegetation areas (pocket beach, riparian, and vegetation swath) had greater taxa richness and hemiptera densities than the adjacent modified shorelines (seawall and riprap). The vegetation swath also had greater overall insect densities. This suggests that production of certain insects that are associated with vegetation has increased as a result of plantings of shoreline vegetation and other site enhancements. These include some insects that are known to be juvenile salmonid prey items such as hemipterans (Brennan et al. 2004), whereas other prey taxa, such as dipterans, have not increased since enhancement.

Interannual differences were evident in the insect trap results, especially for dipterans, which were less abundant at most habitats compared to 2005 levels. This can make pre- and post-enhancement evaluations difficult for insect samples. Post-enhancement increases were most notable at the pocket beach and vegetation swath as compared to the pre-enhancement riprap and seawall, as both taxa richness and hemiptera densities increased. The newly planted riparian habitat was similar in percent composition and slightly higher in taxa richness but lower in densities compared to the established riparian habitat measured in 2005, suggesting that the new riparian habitat has experienced good initial colonization by a diversity of taxa but still has not achieved the insect densities typical of a more mature riparian habitat. The pre-enhanced riparian habitat was an established vegetated area, so comparing the new riparian habitat differed from that of the other enhanced habitats that previously had armored (riprap, seawall, pavement) conditions with little biological function.

Comparative Datasets

Sobocinski et al. (2010), sampled insects at four paired reference and armored beaches in Puget Sound using methods almost identical to ours. Replication was only slightly less in that study, using 5 traps as compared to 7 at OSP, with fallout traps deployed for 20 hours compared to 24 at OSP. Taxa richness was somewhat higher at the OSP enhanced sites (range 63-74 vs 22-61). Diptera and collembola were the two most abundant taxa at Sobocinksi's sites, which is similar to OSP. The main difference was higher abundances of Talitridae amphipods at Sobocinski's natural reference sites, and higher abundances of acari (mites) at OSP. Talitridae amphipods occupy the high-tide line of beaches in the wrack, and their large numbers in the fallout trap samples at the natural reference beaches may be due to the combination of wrack-deposition and directly overhanging shoreline vegetation, a feature that is absent at the OSP habitats until plantings of vegetation mature. Overall densities were similar in the two studies, and the most abundant Family of diptera, Chironomidae, was also the same.

Armbrust et al. (2009) sampled insects at Seahurst Park (Burien, WA), using identical methods as ours at a restored and reference beach in Puget Sound. The site was one of Sobocinski's sites mentioned above, with the same reference beach, and adjacent armoring removed and restored to a beach in 2005. Although replication through time was less (sampling events of 2 compared to 7 at OSP), data can be qualitatively compared. Taxa richness was somewhat higher at the OSP enhanced sites (range 63-74, as opposed to 64 at Seahurst reference). The main difference was the presence of large numbers of Talitridae amphipods at the Seahurst reference beach, probably for reasons similar to those mentioned above. For other taxa, diptera and collembola were the two most common taxa at the Seahurst sites, similar to the OSP habitats. Densities of diptera and hemiptera (important juvenile salmonid prey items), and acari, were somewhat higher at OSP. The sites differed in the most abundant families of diptera, which were Chironomidae at OSP, and Empididae and Phoridae at Seahurst.

Toft et al. (2005) sampled insects in Shilshole Bay at an overwater structure and reference riparian habitat, using methods almost identical to ours. Replication through time was only slightly less in that study, sampling 6 events as compared to 7 at OSP, with fallout traps deployed for 72 hours compared to 24 at OSP. Taxa richness was 70 at the riparian habitat, similar to that at the OSP enhanced sites (range 63-74). Taxa were similar to that of the OSP riparian habitat, mainly composed of collembola, acari, hemiptera, and diptera. When adjusted for the longer time that the Shilshole Bay fallout traps were deployed (3 days vs 1 day), overall densities were similar to that at OSP. Diptera in the family Chironomidae were more abundant at OSP; Cecidomyiidae were the most abundant dipteran at Shilshole, followed by Chironomidae.

Fallout traps have been deployed at several wetland restoration sites in the Duwamish River (Cordell et al. 2008ab), using methods almost identical to ours with fallout traps deployed for 72 hours compared to 24 at OSP, for 3-4 sampling events. These sites are not directly comparable to OSP, as they are not on shorelines of Puget Sound but a few miles up the river estuary in restored wetland vegetation habitats. However, in general the main taxa were similar to that at OSP (diptera, collembolan, acari, hemiptera), and taxa richness was slightly lower (range 44-64).

Research in Howe Sound, British Columbia found that both aquatic and terrestrial arthropods were more abundant when there was supralittoral vegetation (Romanuk and Levings 2003). This study used methods similar to ours, deploying fallout traps for 24 hours four dates. Overall densities were similar, and taxa richness was lower than at OSP (which could be due to level of taxonomy used in sample processing). Collembola, Talitridae amphipods, and Chironomidae were the most abundant taxa. This was similar to findings at OSP except for the Talitridae that are associated with beach-wrack and overhanging vegetation, as noted above.

Summary of OSP context to comparative datasets from the surrounding area:
The OSP enhanced habitats support high numbers of insect densities and taxa richness, with overall similar compositions. Beachhopper amphipods in the family Talitridae are the one taxa that are less at OSP, due to the combination of high-tide beach wrack and overhanging vegetation at more natural beaches.

Neuston

Data from neuston samples taken at the water's surface differed little among the enhanced and armored shorelines. Potential salmon prey in the neuston were evenly distributed along sections of shoreline at OSP. Diptera were the most common insect in the neuston, which are juvenile salmonid prey items, especially chironomid flies.

Many of the taxa captured in insect fallout trap samples were also available to juvenile salmon as neustonic prey. These consisted mainly of diptera, psocoptera, and hemiptera, all of which are known to occur in the diets of juvenile chum and Chinook salmon, with less input of acari and collembola. The extent to which the invertebrates captured in the neuston net were actually produced at OSP sites is unknown, because drift insects could have originated from outside the area. However, the types of insects found in salmon diets and neuston samples were also found at OSP 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 et al. 2010), and continued development of the vegetation communities along the shoreline will probably increase the input of these riparian insects.

Several species of aquatic amphipods and harpacticoid copepods were present in low abundances in the neuston, illustrating that they are not exclusively associated on the epibenthos of bottom substrates, and are available to juvenile salmonid near the water's surface. It remains to be determined if the amphipods and harpacticoids were in the neustonic layer due to mobile behaviors, were there more passively in association with clumps of algae on the water's surface, or were washed there by tidal/wave physical forces. They represent an available prey resource near the water's surface where we typically observed juvenile salmonids feeding during snorkel surveys. Taxa composition of amphipods and harpacticoids in the neuston were representative of some of the main taxa seen in juvenile salmonid diets, of which not all were common in epibenthic samples.

Comparative Datasets
Juvenile salmonid prey items in the neustonic layer of Puget Sound waters have not been well-studied, and results when available have been expressed in percent numerical compositions. Simenstad et al. (2003) analyzed neuston tows from Shilshole Bay and found insects to occur in low percentages, with the neuston being dominated by

zooplankton from the nearby Lake Washington Ship Canal and Locks. Shreffler (1992) took neuston samples higher up in a Puget Sound watershed at the Puyallup River estuary in a restored wetland, and found chironomids to be the most abundant insect. This is similar to our OSP samples, in which chironomids were the second most abundant insect taxon (21% overall numerical composition) next to sciarids (26%).

Elsewhere in areas close to Puget Sound, the availability of terrestrial prey in Lake Washington was low based on neuston samples, which contained very few terrestrial organisms (0.0–0.9 organisms/m^2; Koehler 2002). This is lower than the OSP neuston samples, which had an overall average of 2.0/m^2, ranging 0.3 – 7.5/m^2. Brodeur (1989) studied neuston off the coasts of Washington and Oregon, and found that hyperiid amphipods were common in the neuston, as was also the case in our OSP neuston samples.

Terrestrial Vegetation

Performance standards for year 3 vegetative cover require either 20% increase over as-built conditions or a cover value of 50%, whichever is larger (OSP monitoring plan). For overstory and understory vegetation combined, this standard was met in all areas. However, the dunegrass patches did not meet this standard, with an increase in percent cover of 12.1% and a total cover of 32.6% within measured quadrats. Three of the four dunegrass patches increased in overall area. This is informative, as 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 reflect growth and vigor that might be missed by measurements of percent cover alone. Trampling continues to be a problem with dunegrass flourishing only where it is protected, although average shoot density increased in all patches. While patch 1 grew in size its center had sparse growth and signs of heavy foot traffic. Patch 2 is confined to a narrow strip along placed driftwood logs which are heavily used as seating by visitors. Without further protection, dunegrass will likely be present only close to and mostly behind the logs in this patch. Patch 4 is the least impacted by park visitors and also has the highest shoot density and percent cover values.

Comparative datasets

The native vegetation of Western Washington is divided into several plant community zones. The Olympic Sculpture Park lies within the Puget Sound Area Zone where the tree cover is typified by Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*) and a variety of shrubs and herbaceous plants dominate the understory (Brennan 2007). The species present in the riparian areas of OSP are similar to those found in natural marine riparian areas of Puget Sound (Brennan 2007, Romanuk and Levings 2006). Overhanging vegetation is present along only 17.6% of modern Puget Sound shorelines yet serves an important ecological function providing shade that benefits spawning forage fish (Brennan 2007) and refuge and feeding opportunities for juvenile salmon (Levings and Jamieson 2001). Information regarding canopy cover values in undisturbed marine riparian areas of Puget Sound is lacking. At a relatively undisturbed shoreline site on Vancouver Island, B.C., the overstory canopy cover was 89% (Romanuk and Levings 2003). It can be surmised that a mature riparian area would approach 100% overstory cover together with a complex understory, so in that regard there is still room for the overstory to increase in coverage at OSP, as would be expected after only three years of growth. At OSP there is a balance with vegetative cover and aesthetic landscape maintenance, so it is unlikely that the maximum potential of riparian habitat will be achieved.

American dune grass (*Leymus mollis*) planted at the pocket beach is a common native species on the sandy upper reaches of beaches in Puget Sound, although data on coverage and density of shoots is lacking. Dune grass is generally found in areas of shifting sand where it has a stabilizing effect (Levings and Jamieson 2001). On natural beaches it may be the dominant (> 50% cover) species (Cowles and Hayward 2008). Spreading through rhizomes it can cover a large area, but in coastal dunes tends to lose vigor where it is not subject to frequent burial by sand (Pickart 2008).

Algae

The created habitat bench has been colonized with a diverse, dense growth of kelps and other algae, with twenty-two species of green, red, and brown algae documented in 2009. The performance standard of an increase in algae was met for number of kelp stipes, which was greater than that in 2007 at the subtidal elevations of -3.0 to -7.6 m MLLW. However, average algae percent cover did not show an overall increase, and was about equal between years and variable depending on the tidal elevation. The overall range was 61 to 76%, which is relatively high and greater than in 2007, so it is possible that algae quickly recruits to a high coverage and might not be expected to increase every year.

Comparative Datasets

At OSP, the bull kelp *Nereocystis luetkeana* was found at the range of depths reported by Mumford (2007) and Maxell and Miller (1996) as typical in Puget Sound. Due to the paucity of information on abundance and trends of kelp in Puget Sound it is not possible to compare our data to an overall trend for either the floating or non-floating kelps (Mumford 2007). For available datasets, Thom (1978) counted kelp densities ranging between 0.9 - 3.8 m^2 at Lincoln Park and West Point in May-August, and Maxell and Miller (1996) counted kelp densities ~1 m^2 at the Tacoma Narrows in July. Although survey methods were not identical, kelp densities at -10 and -4.6 m MLLW at OSP ranged approximately between 0.6 – 1.6 m^2 in 2007 and 3.8 – 4.0 m^2 in 2009, which is within the range of the other surveys.

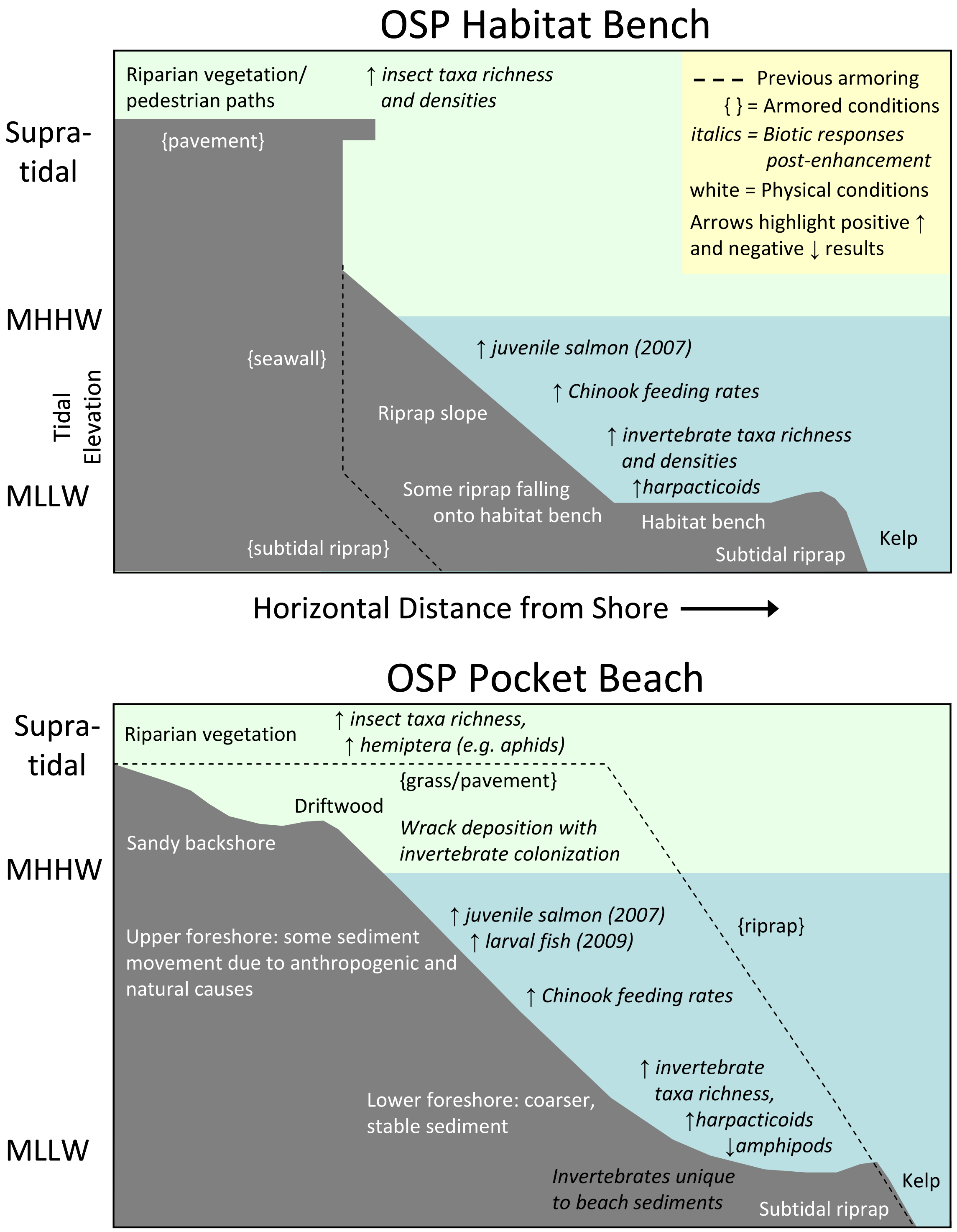
Of the 23 algal species found at OSP, 16 were found by Thom (1978) in his survey of five Puget Sound beaches and 11 were cited by Dethier (1990) as common or diagnostic species at several central Puget Sound locations. Sixteen of the OSP species are also mentioned by Kozloff (1983) in his description of rocky beaches of Puget Sound. The single OSP species not mentioned by Thom or Dethier (*Delesseria decipiens*) is listed by Kozloff in his description of algal communities "around floating docks and pilings."

Of the species found at OSP at the highest elevation (0 to -1.5 m MLLW) around 25% were species of green algae, 12.5% were brown and 62.5% were red. In his survey of intertidal algal communities, Thom (1978) reported similar numbers of an average of 32.5% species of green algae, 18.4% brown and 49.1% red at five beaches in central Puget Sound (Carkeek Park, Richmond Beach, Alki, West Point, Lincoln Park). Thom (1978) also surveyed two of these beaches (West Point and Lincoln Park) at subtidal elevations and found an average of 24.1% species of green algae, 19.9% brown and 53.4% red. At OSP the percentages between -1.5 and -7.6 m MLLW were also quite similar at 8.7% species of green algae, 21.7% brown and 56.5% red. Thus, the number of species at all of these sites was very similar in overall presence of green, brown, and red algae. There are many possible reasons for differences in algal community composition including salinity, wave energy, substrate differences, seasonal variation (photoperiod) and water clarity (Neushul 1976, Thom 1978).

The overall range of 61-76% total algae coverage at OSP is similar to other measurements; quadrats from the low intertidal sites (0 m MLLW) in Thom (1978) had an overall average maximum percent algae coverage of ~80% over a two-year time span (in October), with a maximum of ~70% in July (during the same season as our surveys).

Overall Conclusions

A conceptual model summarizing the major findings is presented in Figure 48. Overall, the enhanced beach structures at OSP are fairly stable and many of the invertebrate and fish indicators have improved values compared to both current and baseline armored conditions. There are some biological indicators that have not yet developed to their presumed full potential, such as diptera insects in terrestrial vegetation, which may depend on more developed growth of the vegetation. If diptera production and availability does increase in the future as compared to the prey resources abundant on armored shorelines, these insects may then in turn be incorporated more into the diets of juvenile salmon. Continuing to assess the physical stability of the pocket beach and habitat bench will provide important information on if or when renourishment of sediment or maintenance of other features is needed, which will benefit the long-term resilience of the site and inform management on how viable these options are in future designs of enhanced shorelines.



Mean Higher High Water (MHHW): approximate high-tide line
Mean Lower Low Water (MLLW): approximate low-tide elevation

Figure 48. Conceptual model of the Olympic Sculpture Park monitoring results.

The Puget Sound Partnership (PSP) and the Puget Sound Nearshore Ecosystem Restoration Partnership (PSNERP) both list shoreline armoring as a major threat to the health of Puget Sound (Simenstad et al. 2006, PSP 2009). PSP and PSNERP were created to help guide the restoration of Puget Sound, and bulkhead removal is one of the foci of restoration actions of these groups. Enhancing armored shorelines in order to approach restored conditions is relatively new to both design and science, and several take-home lessons from the OSP monitoring could help guide future efforts:

(1) Juvenile salmon use enhanced features that mimic shallow-water habitat along armored shorelines.
(2) Invertebrates that are prey for juvenile salmon and other fish colonize sloping intertidal habitat that is incorporated into vertical armored shorelines.
(3) Terrestrial insects in some cases can be linked to patches of shoreline vegetation.
(4) Connectivity between aquatic and terrestrial zones can be maximized by providing a continuous link without any armoring.
(5) Enhanced shorelines in urban settings have constraints on sediment supply and physical stability, and may require maintenance.

Management of armored shorelines will increasingly be an issue due to the conflicting forces of sea level rise and shoreline development, termed “coastal squeeze” (NRC 2007, Defeo et al. 2009). More information about the effects of coastal squeeze is available for sandy beaches than it is for mixed sediment beaches characteristic of Puget Sound (Nordstrom 2000, Defeo et al. 2009), and rigorous studies are needed in Puget Sound to fully understand these processes. Along a developed shoreline, the ecosystem goods and services provided by a mosaic of engineered and natural conditions may be more resilient under current processes than an unobtainable historic goal (Jackson and Hobbs 2009). Novel ecosystems that have formed under altered conditions require creative management solutions for restoration goals, and collaborations between managers and scientists are necessary to understand the usefulness and application of shoreline enhancements (Seastedt et al. 2008).

The Olympic Sculpture Park has shown improvements in the first three years after enhancements, and long-term benefits will presumably continue to be apparent as the site becomes more stable in ecological and physical structure, depending on site-specific processes (Simenstad and Thom 1996, Dethier and Schoch 2005). We recommend continuing monitoring on the planned timeline at 5 and 10 years post-enhancement. This timeline will reflect early changes in development and stabilization of biological and physical processes in the first five years with more frequent monitoring, and then begin to assess long-term trends in year 10. Maintaining the sampling design and methodologies used in this study will increase the likelihood of detecting changes associated with the enhanced habitats, within the range of natural variation. In addition to the attributes measured in the planned monitoring, the following additional sampling should be considered in future efforts if the opportunities arise:

1) Monitoring of any new enhancements along the urban waterfront that would benefit by placing them in context to the OSP sites. For example, as the city develops designs and implementation of a new seawall, any enhancements incorporated could be monitored using OSP as a reference enhanced site. Using similar sampling methodologies would make it easier for comparative datasets to be more quantitatively analyzed along with the OSP data. As illustrated in our 'comparative dataset' section for each component, it is difficult to analyze different datasets together when there is not overlap in the methods.
2) Continued low-level monitoring of certain events during years of no planned monitoring. Although the next sampling periods in years 5 and 10 will supply vital information on the long-term evolution of the structural and ecosystem development of the enhanced shoreline sites, understanding why those changes occur would benefit from having a more continual monitoring of key factors on the beach. For example, occasional monitoring of seasonal beach profiles and terrestrial vegetation that might change on an annual basis as a function of storms, drought, and human interference, will help us to understand the factors that drive long-term change. Part of this service could be generated by record keeping by SAM of physical activities and beach cleaning efforts during time periods that monitoring is not occurring, for later reference.
3) Sampling of fish along the urban seawall/pier matrix in downtown Seattle south of OSP. This could focus not only on fish composition, but obtaining diet samples of juvenile salmon for comparison to the OSP enhanced sites. We are not aware of any diet sampling from this area, and it would provide information on whether juvenile feed on invertebrates abundant along the seawall (e.g., the amphipod *Paracalliopiella pratti*), and whether prey items along this urban stretch are different from those in more natural areas. Due to the vertical profile of most of the armoring, methods for sampling fish would most likely require setting nets and processing fish from a boat.
4) Conducting experiments at OSP and along the urban waterfront that would test for more specified functions of the enhanced shorelines. For example, cage experiments could measure growth and survival rates of invertebrates under different conditions at the habitat bench versus vertical portions of the seawall. Other techniques such as sampling of stable isotope signatures in biota could measure sources of terrestrial versus aquatic food sources along different stretches of shoreline.
5) Sampling of invertebrates and fish that are associated with beds of kelp growing in deeper water on the habitat bench and elsewhere along the urban waterfront. This would document specific sources of invertebrates that are associated with kelp habitat, as potential prey items for nearshore fish. SCUBA surveys have documented black rockfish in subtidal kelp along the habitat bench. Further surveying would describe more extensively any species that benefit from subtidal portions of enhancements that are not seen in shallow intertidal waters.

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