Assessment of the Intertidal Benthic Invertebrate Communities along the Shores of Central Strait of Juan de Fuca, Clallam County, Washington State

Prior to the Elwha Dam Removal, 2010-2012

Publication Information

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The 2012 survey was funded through the Department of Fish and Wildlife (WDFW) grant (number 11-0034) as part of an ecosystem service evaluation of the Clallam County nearshore. This report was submitted to WDFW through the Coastal Watershed Institute as one of the required deliverables.

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Table of Contents

Tables

Figures

Introduction

The surveys presented in this report were conducted with four main objectives in mind: 1) to provide monitoring data of the intertidal benthic invertebrate communities in the central Strait of Juan de Fuca, Clallam County, covering an area of approximately 20 shoreline miles (excluding Port Angeles harbor) between Freshwater Bay to the west and Dungeness Spit to the east; 2) to collect this data before the dam removal on the Elwha River and thereby provide information on the intertidal habitats and invertebrate communities before the arrival of the sediment retained behind the two dams; 3) to compare the community data from the Elwha drift cell with the community data from the Dungeness drift cell to assess the potential impact of the shoreline alterations in the Elwha drift cell had on the intertidal benthic community; and 4) to provide an opportunity for students at the Peninsula College and Huxley on the Peninsulas and local citizens to participate in the surveys to gain hands-on field and laboratory experience. An additional objective of the study was, to the extent possible, to evaluate changes in the benthic communities over the last 30 years.

The effort was initiated in 2010 when Anne Shaffer of the Coastal Watershed Institute (CWI) approached me with the idea of conducting a survey of the benthic invertebrate communities in the Elwha and Dungeness drift cells. There was no funding for the work but a lot of good will at the Peninsula College and among students and local citizens. Between the summers of 2010 and 2012 four summer surveys and two winter surveys were conducted collecting more than 300 samples at 12 locations between Freshwater Bay and Dungeness Spit. Peninsula College provided the laboratory space and some of the supplies and later on one small grant funded additional supplies and a scholarship for one student. The last summer survey, in 2012, was funded through a grant (number 11-0034) by the Washington Department of Fish and Wildlife (WDFW).

The field effort was terminated in 2012 when woody debris and sediment were being observed in the intertidal area east of the Elwha River. The three locations sampled in the summer of 2012 were all in Freshwater Bay more than 1.5 miles west of the river mouth; an area assumed to be un-impacted because of the prevailing current pushing the plume to the east. In the winter and spring of 2012/13 efforts were carried out to locate funding for taxonomical analysis of the invertebrate samples. Numerous agencies and other potential funding sources were contacted including Department of Ecology (Ecology; NRDA, Sediment Group, Spill Prevention), WDFW, US Fish and Wildlife Service (USFWS), Olympic National Park, Washington Department of Natural Resources (WDNR), National Oceanic and Atmospheric Administration (NOAA; ORR/ERD, DARRP), US Geological Survey (USGS), Environmental Protection Agency (EPA), Lower Kallam Tribe, Puget Sound Partnership, Tesoro, BP, and ConocoPhillips. In addition, two grant requests for proposal were pursued. All parties thought the monitoring data were important and supported the effort, but unfortunately no one could provide any funds for the taxonomical analysis.

This report presents the intertidal benthic invertebrate community data based on the identifications and counts done in the sorting laboratory. Clearly this dataset is not optimal, but because the data provide clear trends of the habitats and invertebrate communities between Freshwater Bay and Dungeness Spit I still think this report will serve the purposes outlined at the beginning of the introduction. The samples are currently safely stored for any future taxonomical analysis, but under the current funding environment I assume they will likely join the ranks of under-analyzed samples stored in basements and attics by biologists and scientists alike.

Acknowledgement

This study would not have been conducted without the initial request by Anne Shaffer of CWI. Anne also provided valuable contacts to the Peninsula College and Huxley on the Peninsulas. Access to laboratory space at the Peninsula College was facilitated by Brian Hauge and Jack Ganzhorn and invaluable laboratory supplies were also provided by the two faculty members. This study was conducted in conjunction with a study of the sediment dynamics along bluffed shorelines by Dave Parks from WDNR. Dave provided all the location information including coordinates, access to the beaches, and an easy way to identify the two survey transects by establishing survey monuments. Dave's work also contributed important information on the beach habitats. The study would not have been completed without the help and support of numerous students, student interns and local citizens including Kirk Lang, Max Wright, Wade Raynes, Sam Davies, Cullyn Foxlee, Rebecca Hanson, Bailey Wilkens, Joe MacDonald, Melissa Raynes, Matthew Perry, Rick Johns, Coral Wheeler and Jinx Bryant. Special thanks to Kirk Lang and Rick Johns who were always supportive and willing to work. Thanks to Kevin Ryan (USFWS) and Dungeness Wildlife Refuge volunteers for providing field support. Finally I want to express my gratitude to Eugene Ruff for volunteering his time to analyze a subset of the annelid samples, to Lucinda Tear for performing the multivariate analysis of the benthic invertebrate data, and to Ian Miller of Washington Sea Grant for providing useful information regarding sediment analysis and sediment transport in the Strait of Juan de Fuca. The study was supported by grants from Patagonia and WDFW (grant number 11-0034).

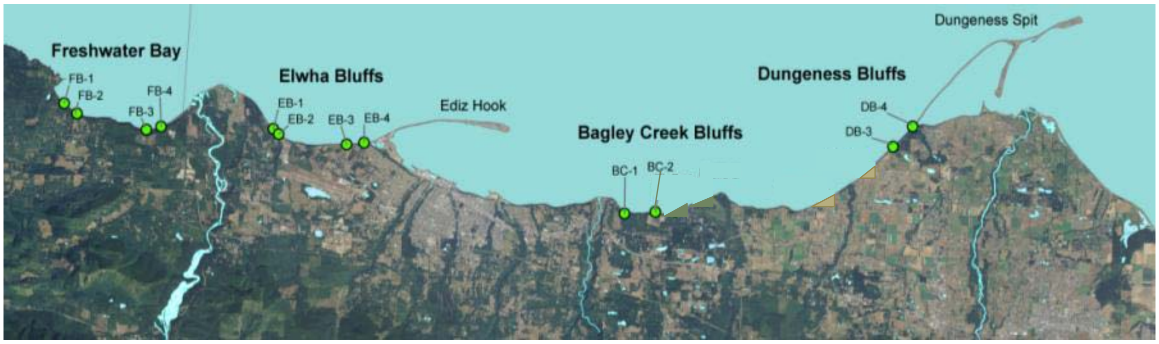
Methods

The study was designed to link the benthic communities with sediment dynamics and the nearshore physical processes along bluffed shorelines in the central Strait of Juan de Fuca. The study area covered two drift cells, the Elwha and Dungeness drift cell, easily identified by the two termini Ediz Hook and Dungeness Spit. The sediment dynamics and physical processes were studied at 16 locations with the objective to characterize the spatial differences in bluff particle size distributions and historic sediment supply from coastal bluffs to estimate changes in beach sediment storage in both Elwha and Dungeness drift cells (Parks unpublished; Parks and Andersen 2011). This study assessed the intertidal benthic invertebrate communities at 12 of the 16 locations (Figure 1). Eight of these locations were within the Elwha drift cell and the remaining four within the Dungeness drift cell.

Two historical studies of the benthic invertebrate communities have been conducted in the Dungeness nearshore. In the 1970s, the U.S. EPA sponsored the Marine Ecosystems Analysis (MESA) Program because of the threat of oil pollution from large scale oil shipment through the Strait of Juan de Fuca (Nyblad 1979). Under MESA, the benthic invertebrate communities were assessed at 10 sites throughout the strait. In 2008 Shreffler Environmental conducted a pilot field study by re-visiting two of the MESA sites to assess changes or long-term trends in the intertidal benthic community (Sheffler 2008). To enable a comparison to the historical data the same methodologies were used with the exception of sieving in the field (in the two other studies all sediment in a sample was preserved and sieved in the laboratory) (Nyblad 1979; Sheffler 2008). The two historical studies also performed an assessment of the algae communities, when present, including identification and biomass determination. Because of limited resources the current study did not perform the algae assessment. Two locations previously sampled by both studies or by MESA were revisited. The locations were west of Bagley Creek (BC-1[1]) previously sampled under the MESA program and west of Dungeness Spit (DB-4) previously sampled under both studies.

[1] The MESA location was approximately 200 m west of the current BC-1 location

Figure 1 – Survey locations along the shore of the central Strait of Juan de Fuca, Clallam County.



Map provided by David Parks, WDNR.

The study was initiated in the summer of 2010 and concluded in the summer of 2012. The original sampling design called for biannual sampling each year at a subset of the 12 locations. Because of limited resources only one complete winter survey at six locations and one partial winter survey at one location were conducted before the overall effort was reduced to summer surveys only. A total of three summer surveys were performed with one location (FB-3) sampled during one winter and all summer surveys. Table 1 summarizes the location information and the sampling effort at each location.

Table 1 – Location and sampling information

Shoreline Location	Location ID	Coordinates[1]		Elevation[2] (m)	Surveyed
		Northing	Easting		
Freshwater Bay	FB-1	429152.832	956218.808	3.22	7/10/2010 7/20/2012
	FB-2	427917.474	957875.160	3.37	3/26/2011 7/17/2011
	FB-3[3]	426030.568	967286.480	3.57	7/11/2010 3/21/2011 7/31/2011 7/31/2012
	FB-4	426348.743	968749.233	4.31	8/2/2012
Elwha Bluffs	EB-1	426110.276	983179.365	3.93	7/16/2011 3/13/2012
	EB-2	425455.090	983878.727	3.69	7/12/2010 3/25/2011
	EB-3	424216.704	992671.032	5.26	7/15/2011
	EB-4	424438.809	994905.791	4.45	7/14/2010 3/23/2011
Bagley Creek Bluffs	BC-1	416040.326	1028575.330	3.91	7/30/2011
	BC-2	415.978.488	1032484.883	4.64	7/15/2010 3/24/2011
Dungeness Bluffs	DB-3	424184.489	1063103.942	3.65	7/13/2011

Shoreline Location	Location ID	Coordinates[1]		Elevation[2] (m)	Surveyed
		Northing	Easting		
	DB-4	426671.187	1065633.448	6.31	7/13/2010 3/22/2011

[1] Coordinates in US Survey Ft. Based on (Cors96)-Epoch2002.00 Adjustment Of The Washington Coordinate System, North Zone, Datum Of 1983. Compiled using two Trimble R8 GNSS Receivers with integrated antennas.
[2] NAVD88
[3] FB-3 was moved west approximately 70 m in the winter of 2011 because of difficulties maintaining the survey monument at the first selected site.

The sampling locations were identified by survey monuments mounted during the sediment dynamics study (Parks unpublished; Parks and Andersen 2011). The Mean Tidal Level (MTL) and Mean Low Low Water (MLLW) levels were established by calculating the distance from the survey markers (Table 2).

Table 2 – Horizontal distances to MTL and MLLW

Shoreline Location	Location ID	Horizontal Distance to MTL (m)[1]	Horizontal Distance to MLLW (m)[1]
Freshwater Bay	FB-1	9.1	54.9
	FB-2	10.7	61.0
	FB-3	10.7	37.2
	FB-4	22.9	36.6
Elwha Bluffs	EB-1	13.7	27.4
	EB-2	14.3	23.8
	EB-3	19.8	38.1
	EB-4	23.5	39.0
Bagley Creek Bluffs	BC-1	13.7	45.7
	BC-2	16.8	51.8
Dungeness Bluffs	DB-3	22.9	35.1
	DB-4	28.0	39.0

[1] All horizontal distances are approximate based on vertical elevation information for station 9444090 Port Angeles, Washington for 1960-1978 Epoch.
MTL = mean tidal level
MLLW = mean low low water

Field Collection

The field work was carried out in accordance with the Quality Assurance Project Plan (QAPP) (Shaffer and Andersen 2012). At each location five benthic community samples were collected along a 50-m transect parallel to the water at the MTL and MLLW. The five sampling sites along each transect were identified based on a stratified random approach. The 50-m transect was subdivided into five subsections and the sampling site within each subsection was identified using a random number table to generate the distance from one end of the subsection.

Field collection of the benthic community samples followed the standard operation procedures (SOPs) described in Puget Sound Estuary Program (PSEP) and MESA program (PSEP 1987; Nyblad 1979). Two different substrate types, coarse sand and cobble, were present in the study area and depending on the substrate type one of the following two methods was utilized.

Coarse Sand: A 0.05 m^2 (22.5 cm x 22.5 cm) PVC frame was placed at the sampling site and the sediment was removed to a depth of 15 cm using a hand trowel (Figure 2). The sediment was placed in a bucket and sieved through a 1 mm sieve in the field. The retained material was transferred into a double-bagged Ziploc bag and preserved with 10% buffered formalin diluted with on-site saltwater.

A 0.25 m^2 (50 cm x 50 cm) PVC frame was placed at the sampling site adjacent to the smaller frame and the sediment was removed to a depth of 30 cm using a hand trowel and shovel. The sediment was placed in a large 11 mm screen and sieved in the field. Large retained invertebrates were transferred into a double-bagged Ziploc bag and preserved with 10% buffered formalin diluted with on-site saltwater.

Figure 2– Sampling in sandy and cobble substrates

Cobble: A 0.25 m^2 (50 cm x 50 cm) PVC frame was placed at the sampling site and all algae, if present, were scraped off the rocks and transferred into a double-bagged Ziploc bag (Figure 2). Next the epibenthos were collected within the frame and transferred into a double-bagged Ziploc bag. Larger easily identified benthos e.g., the purple shore crab, *Hemigrapsus nudus*, were identified and counted in the field. Three barnacle species have been reported as common in the study area (Kozloff 1983). Of these three species, *Balanus glandula, Semibalanus cariosus* and *Chthamalus dalli*, *B. glandula* was expected to be the dominant species in the study area but, because the barnacles were counted in the field and the majority were small specimens (< 5 mm), the identification was predominantly left as Balanomorpha. In cases of large abundances of small specimens the abundance was estimated. When all epibenthos within the frame had been removed or identified, the smaller 0.05 m^2 frame was placed within the larger frame and the sediment was removed to a depth of 15 cm using a hand trowel. The sediment was placed in a bucket, sieved through a 1 mm sieve in the field, and the retained material was transferred into a double-bagged Ziploc bag. All samples (algae, epibenthos, and sieved material) were preserved in 10% buffered formalin diluted with on-site saltwater.

Five invertebrate samples were collected in the wrack line using an opportunistic sampling approach by sampling the algae matt(s) present within 50 m of the survey monument (Figure 3). Each sample was collected by pressing a plastic corer (10 cm diameter) through the algae matt and into the sediment to a depth of 2 cm. The retained material was transferred into a double-bagged Ziploc bag and preserved with 10% buffered formalin diluted with on-site saltwater.

Figure 3– Typical wrack lines during the five surveys

Laboratory Process

In the laboratory the invertebrate samples were sorted into the following four major taxonomic groups: Annelida, Arthopoda, Mollusca, and miscellaneous taxa which included all other phyla. During the sorting process the numbers of organisms were enumerated using the easily identifiable invertebrate groups listed in Table 3. The laboratory processing of the benthic invertebrate samples followed the QAPP (Shaffer and Andersen 2012) and the SOPs by PSEP and Ecology (PSEP 1987; Ecology 2007).

One of the study objectives was to give students hands-on experience which meant that the students were trained "on the job" in the laboratory sorting process of the invertebrate samples. A thorough QA/QC process was used to ensure all the organisms were picked out of the samples (100% re-sort of most student sorted samples), but the counts of the organisms and the sorting categories were not verified for each sample (this verification process would occur in the identification process done by taxonomists). The students sorted 20% of the invertebrate samples collected during the five surveys. The majority of these samples were collected during the winter 2011 and summer 2012 surveys constituting 31% and 64%, respectively, of the samples collected in these two surveys. Of the remaining three surveys the students sorted less than 10% of the samples in a given survey (for further information on the quality of the sorting process see the Annelid Taxonomy subsection).

Table 3 - Invertebrate groups used for enumeration

Invertebrate Groups	
Annelida	**Mollusca**
Polychaeta (polychaetes)	Polyplacophora (chitons)
Oligochaeta (oligochaetes)	Gastropoda (snails)
Arthropoda	Patellogastropoda (limpets)
Copepoda (copepods)	Bivalvia (bivalves)
Harpacticoida (harpacticoids)	**Misc. Taxa**[1]
Ostracoda (seed shrimps)	Cnidaria (cnidarians)
Balanomorpha (barnacles)	Actiniaria (sea anemones)
Pycnogonida (sea spiders)	Nematoda (round worms)
Arachnida (mites)	Platyhelminthes (flatworms)
Isopoda ("pill bug")	Nemertea (ribbon worms)
Amphipoda (scuds)	Sipuncula (peanut worms)
Decapoda (crabs & shrimps)	Echinodermata (echinoderms)
Other crustaceans	Ophiuroidea (brittle stars)
Insecta (insect larvae)	Asteroidea (starfish)
	Ascidiacea (ascidians or sea squirts)

[1] all other taxonomical groups

Sediment Analysis

The sediment dynamic study determined the grain sizes of the surface sediment at the 12 locations using photographic methods in combination with standard sieve analysis of bulk sediment samples to verify a subset of photographic grain-size measurements (Parks unpublished; Parks and Andersen 2011). To assess the grain sizes of the deeper sediment in which the benthic invertebrates lived, a grain size analysis was conducted at the locations surveyed in the summers of 2011 and 2012. Two of the sampling sites at each of the MTL and MLLW transects were randomly selected and a sediment sample was collected to a depth of 15 cm. The sediment samples were analyzed in the laboratory in accordance with ASTM (2006) and the grain size distributions and statistics were determined using the GRADISTAT computer program (Blott and Pye 2001).

At locations with cobbled substrate only the sediment between the cobbles was collected. The sediment layer lodged between the cobbles ranged from a thin cover to more than 15 cm deep (the sampling depth of invertebrate samples). To derive an estimate of the infauna sediment habitat, the volume occupied by cobble was estimated as a percentage of the total volume during collection of the five 0.05 m^2 infauna samples. The collection of these data points was initiated in the winter of 2011.

Statistical Analysis

A non-metric multidimensional scaling (NMS) analysis was conducted on the summer survey data to evaluate the relative distribution of the taxonomical groups within the MTL and MLLW. NMS is an ordination method that is well suited for non-normal data or data that are on arbitrary or discontinuous scales (McCune et al 2002). The NMS was performed in PCOrd Version 5 using an automated routine which identifies the optimum number of gradients (axes) found in the data and calculates the correlation between the axes and the input variables. The fit of the final model is measured by an indicator called "stress". The taxa data were relativized by the maximum count for the taxon before performing the NMS analysis[2].

An Indicator Species Analysis was conducted on the summer MTL and MLLW data in PCOrd to determine if any taxonomical groups were more frequently and abundantly associated with the three geomorphic habitat types. In PCOrd, indicator values were calculated according to Dufrene and Legendre (1997). A Monte Carlo randomization test was used to determine significance of the final indicator values. The Monte Carlo P values were calculated as the proportion of randomized trials with indicator value equal to or exceeding the observed indicator value.

In addition, a t-test was conducted on a limited part of the summer survey dataset using IQ Macro 2013 for Excel to evaluate if there was a significant difference between total abundances in the Elwha and Dungeness drift cells.

Results

The results of the study are presented in this section by first describing the intertidal habitats and substrate types at the 12 locations. The following two subsections summarize the MTL and MLLW invertebrate community data which comprise the majority of the data collected during this study. The last three subsections present preliminary data on the invertebrate community in the wrack line, a qualitative description of the algae communities at the sampling locations, and identification of annelids in a subset of samples performed by an expert polychaete taxonomist.

[2] It should be noted that replicates with no organisms are excluded from the analysis.

Intertidal Habitats

The intertidal habitats were all associated with bluffs and primarily along open exposed shorelines with the exception of Freshwater Bay. The bay offered some protection from the predominant westerly wave and wind actions especially in the most western corner of the bay. This was the only area within the study area, where the intertidal habitats included a fine-sandy beach. Intertidal low-tide terraces with cobbled substrate existed in both drift cells and were often associated with headlands. Approximately 2 miles of the bluffed shoreline in the Elwha drift cell were armored whereas all the bluffed shoreline in the Dungeness drift cell was unarmored. Table 4 summarizes the geomorphic habitat types at the 12 sampling locations and Figures 4 and 5 show the habitat types at MLLW in the Elwha and Dungeness drift cells.

Table 4 – Habitat types at the sampling locations

Habitat Type	Elwha Drift Cell Locations	Dungeness Drift Cell Locations
Embayment, fine-sandy beach	FB-1	-
Embayment, cobble low-tide terrace	FB-2, FB-3	-
Embayment, sandy-gravel beach	FB-4	-
Open beach, cobble low-tide terrace	EB-1, EB-2[1]	BC-1, BC-2
Open beach, sandy-gravel		DB-3, DB-4
Armored open beach, sandy-gravel	EB-3, EB-4	-

[1] This location is at the edge of an intertidal low-tide terrace. In the summer 2010 the MLLW was on the terrace, but in the winter 2011 the MLLW was covered with rocks and gravel.

Figure 4– MLLW habitat types in Elwha drift cell

Fine-sandy beach

Freshwater Bay low-tide terrace

Open beach low-tide terrace

Armored sandy-gravel beach

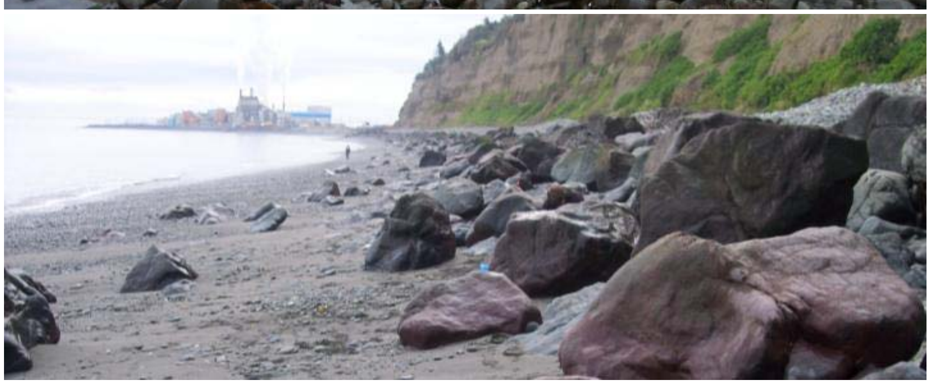


Figure 5– MLLW habitat types in Dungeness drift cell

Sandy-gravel beach

Low-tide terrace

Sediment Analysis

All sediment samples collected at the MTL and MLLW were classified as medium sand to very fine gravel using the GRADISTAT program (Blott and Pye 2001) except for the westernmost location in Freshwater Bay (FB-1) at the MLLW which was classified as very fine sand (Table 5).

Table 5 – Grain sizes and sediment descriptions at the sampling locations

Location	Year	Tidal Elevation	Mean Grain Size (mm) (n=2)	Standard Deviation (n=2)	Sediment Description
FB-1	2012	MTL	1.035	0.006	Polymodal, poorly sorted, very coarse sand
		MLLW	0.525	0.572	Bimodal, moderately to moderately well sorted, very fine sand
FB-2	2011	MTL	256.8	1.3	Bi- or trimodal, moderately to poorly sorted, medium sand
		MLLW	393.3	9.3	Tri- or polymodal, very poorly sorted, medium sand
FB-3	2011	MTL	1784.4	411.9	Tri- to polymodal, moderately well to poorly sorted, very coarse sand to very fine gravel
		MLLW	1445.3	233.8	Polymodal, poorly to very poorly sorted, very coarse sand
FB-3	2012	MTL	1640.0	3.6	Polymodal, poorly sorted, very coarse sand
		MLLW	2481.6	1219.1	Uni- or polymodal, poorly sorted, very coarse sand to very fine gravel
EB-1	2011	MTL	803.9	200.3	Polymodal, poorly sorted, coarse sand
		MLLW	921.5	591.2	Polymodal, poorly to very poorly sorted, coarse to very coarse sand
EB-3	2011	MTL	904.2	21.3	Polymodal, poorly sorted, coarse sand
		MLLW	952.7	396.8	Polymodal, very poorly sorted, coarse to very coarse sand
BC-1	2011	MTL	1102.8	229.7	Polymodal, poorly to very poorly sorted,

Location	Year	Tidal Elevation	Mean Grain Size (mm) (n=2)	Standard Deviation (n=2)	Sediment Description
					coarse to very coarse sand
		MLLW	1280.0	304.3	Polymodal, very poorly sorted, very coarse sand
DB-3	2011	MTL	1320.8	38.1	Polymodal, poorly to very poorly sorted, very coarse sand
		MLLW	773.0	365.2	Polymodal, poorly to very poorly sorted, coarse to very coarse sand

MTL = mean tidal level
MLLW = mean low low water

The majority of the samples were identified as very poorly or poorly sorted sediment with only a few samples collected at the three westernmost locations in Freshwater Bay indentified as moderately or moderately well sorted sediment. Only one sample was found to be unimodal (2012 FB-3 MLLW); all the other samples were either bimodal, trimodal, or polymodal. Because the sediments were classified as multimodal further analysis of the data is not included in this report. Graphs of the grain size distributions are included in Appendix A.

Table 6 summarizes the percent volume occupied by cobble in the infauna samples (0.05 m^2 to a depth of 15 cm) collected in one winter and two summer surveys. These numbers are estimations only but they provide rough measurements of the sediment habitat available for the infauna e.g., in winter 2011 at location FB-2 97 percent of the substrate at the MTL was sediment, whereas at the MLLW only 16 percent was sand and gravel. Seasonal data collected at two locations (FB-2 and FB-3) indicate relatively large changes in the availability of sediment for the infauna. No cobble was observed at the locations not associated with intertidal low-tide terraces (FB-4, EB-3, EB-4, DB-3, and DB-4). However, at the two locations with armored bluffs (EB-3 and EB-4) a relatively large percentage of the volume was occupied by boulders.

Table 6 – Estimated percent volume occupied by cobble in 0.05 m^2

		MTL		MLLW	
Location	Season, Year	Mean Percent Cobble (n=5)	Standard Deviation (n=5)	Mean Percent Cobble (n=5)	Standard Deviation (n=5)
FB-1	S, 2012	13	4	2	4
FB-2	W, 2011	3	4	84	7
	S, 2011	51	28	36	29
FB-3	W, 2011	66[1]	31	53[1]	21
	S, 2011	8	18	31	16
	S, 2012	54	18	8	18
FB-4	S, 2012	0	0	0	0
EB-1	S, 2011	4	5	53	29
EB-2	W, 2011	10	4	7	10
EB-3	S, 2011	44[2]	31	54[2]	20
EB-4	W, 2011	66[2]	17	30[2]	14
BC-1	S, 2011	51	30	20	15
BC-2	W, 2011	59	35	65	35
DB-3	S, 2011	0	0	0	0
DB-4	W, 2011	0	0	0	0

[1] number of samples = 4
[2] estimate of armored boulders
MTL: mean tidal level
MLLW: mean low low water
S: summer
W: winter

Benthic Invertebrate Communities

The benthic invertebrate communities at 12 locations between Freshwater Bay and Dungeness Spit were assessed during three summer and two winter surveys. The 2012 winter survey was very small; only one location was surveyed and because of inadequate low-tide only the MTL transect could be surveyed. The benthic communities at one location in Freshwater Bay, FB-3, were assessed during the three summer and one winter survey. Because of difficulties maintaining the survey monument at the first selected site, the FB-3 location was moved west approximately 70 m in winter of 2011.

The following subsections present the results of the MTL and MLLW benthic invertebrate community assessments. The invertebrate community data is based on the collection effort using the 0.05 m^2 frame and the 1 mm sieve. Very few organisms were collected using the method targeting larger organisms (0.25 m^2 and 11 mm screen); No organisms were collected at the MTL and only five polychaetes were collected at the MLLW at FB-1 during two summer surveys.

In the figures provided in the two subsections the taxonomical group, decapods, includes predominantly the purple shore crab, *Hemigrapsus nudus*. More detailed data on the decapods species are provided in Appendix A. As previously stated in the method section barnacles are grouped under Balanomorpha but the majority of this taxonomical group is assumed to be *Balanus glandula*. Summary tables of abundances are included in Appendix A. Tables A1 and A2 present the mean abundances and standard deviations for each MTL location in the Elwha drift cell during the summer and winter surveys, respectively. Table A3 presents similar data for the surveys conducted in the Dungeness drift cell. Table A4 and A5 present the mean abundances and standard deviations for each MLLW location during the summer surveys in the Elwha and Dungeness drift cell, respectively, and Table A6 presents the similar data for the winter surveys.

MTL Communities

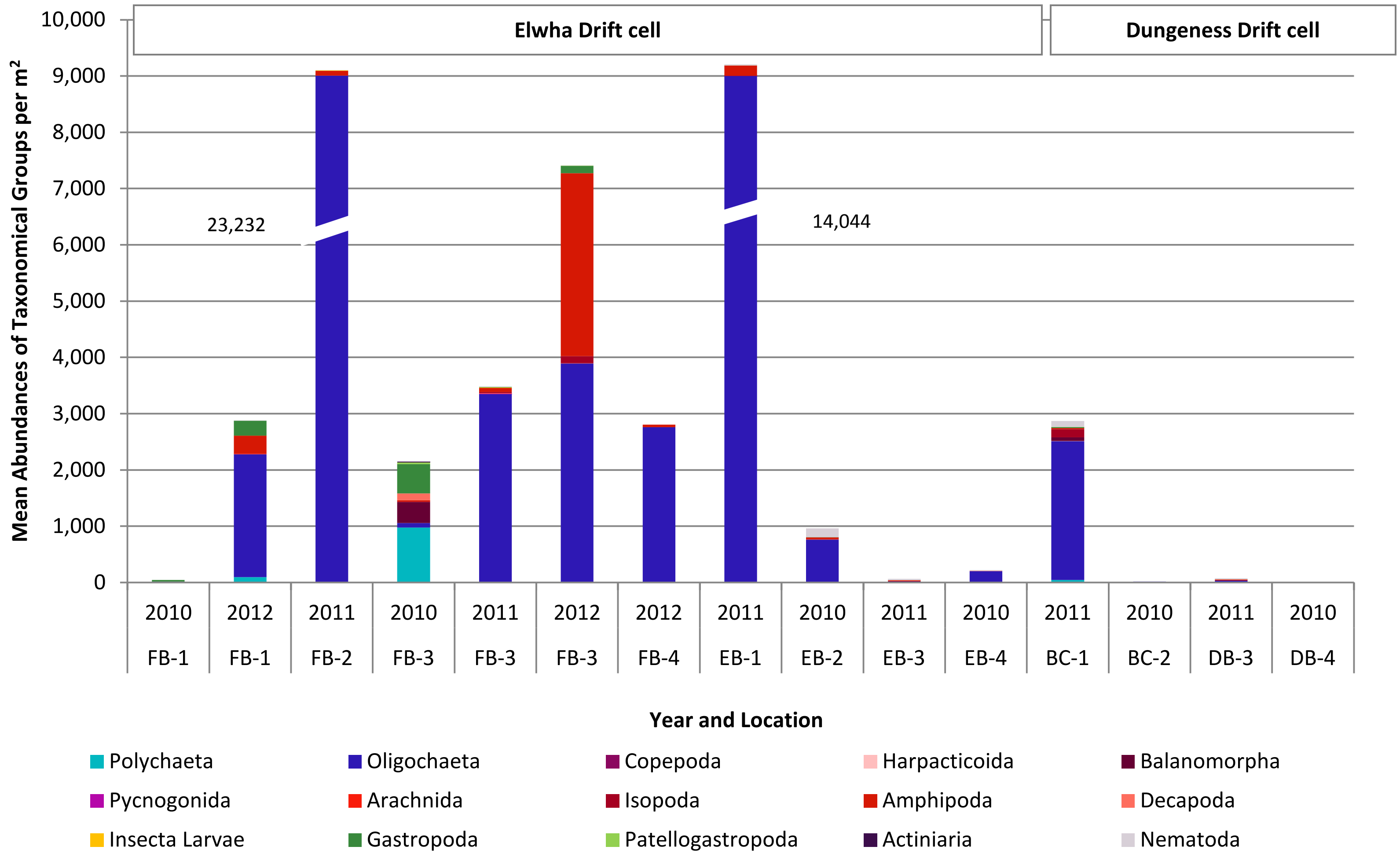
The MTL benthic invertebrate communities during the summer surveys were dominated by oligochaetes at all locations except FB-3 in 2010 (Figure 6). That year at this location the community was dominated by polychaetes, barnacles, and gastropods and quite different from the following two years. This difference may be attributed to seasonal differences or because the location was moved approximately 70 m to the west. The composition of dominant taxonomical groups was similar in the 2011 and 2012 summer surveys except amphipods were much more abundant in 2012.

Other common groups at all MTL locations included amphipods, gastropods and to a lesser extent isopods. The highest diversity with 12 taxonomical groups was observed at BC-1 in the Dungeness drift cell. FB-3 also had relatively high diversity with 10 or 11 taxonomical groups in 2010 and 2011, respectively. All other locations had six or less taxonomical groups. FB-1 was the only fine-sandy beach location and the invertebrate community at the MTL consisted of oligochaetes and gastropods in low abundances.

The highest abundances of invertebrates during the summer surveys were observed in the Elwha drift cell especially at FB-2 and EB-1 with more than 23,000 and 14,000 organisms per m^2, respectively, of which 99.6% and 98.5% were oligochaetes. Higher abundances were generally associated with the MTL transects associated with intertidal low-tide terraces. The only exception was the benthic community at BC-2 which was similar to the communities at the open gravel-sandy beaches (EB-3, EB-4, DB-3, and DB-4).

Winter surveys of the benthic invertebrate communities were only conducted at six locations (Figure 7). Of these locations five were associated with low-tide terraces and only one location with a gravel-sandy beach (DB-4). The abundances of invertebrates were much lower in the winter surveys with a maximum of less than 3,300 organisms observed at FB-3. The communities were no longer dominated by oligochaetes but, depending on the location, by polychaetes, gastropods, amphipods, isopods and barnacles.

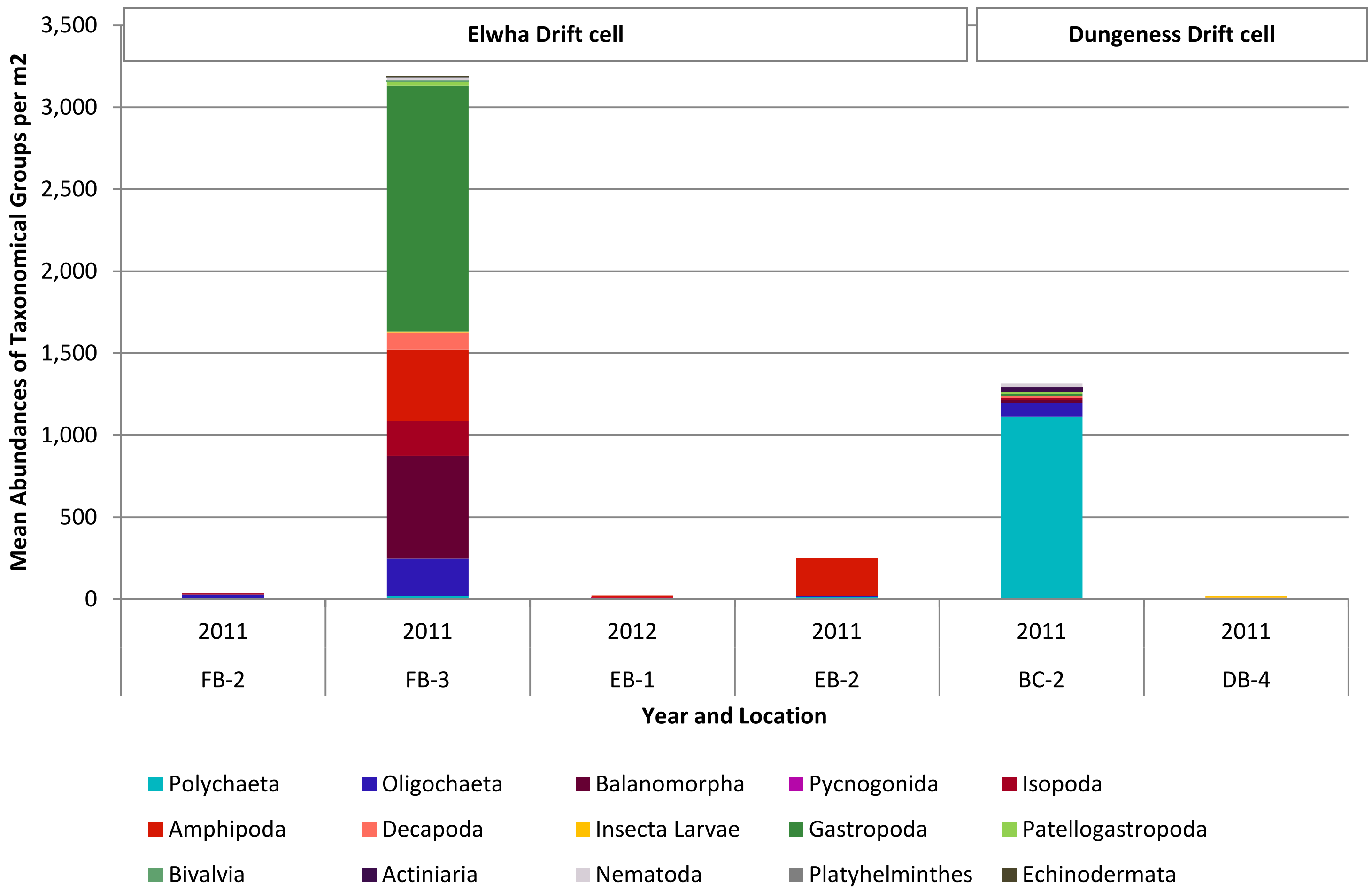
Figure 6 - Mean abundances per m^2 of invertebrate groups at MTL in the summer surveys



Freshwater Bay: FB-1 fine-sandy beach; FB-2 and FB-3 cobble intertidal low-tide terrace; FB-4 sandy-gavel beach

Open Beach: EB-1, EB-2, BC-1 and BC-2 cobble intertidal low-tide terrace; EB-3, EB-4, DB-3 and DB-4 sandy-gravel beach

Figure 7 - Mean abundances per m^2 of invertebrate groups at MTL in the winter surveys



Freshwater Bay: FB-2 and FB-3 cobble intertidal low-tide terrace

Open Beach: EB-1, EB-2 and BC-2 cobble intertidal low-tide terrace; DB-4 sandy-gravel beach

MLLW Communities

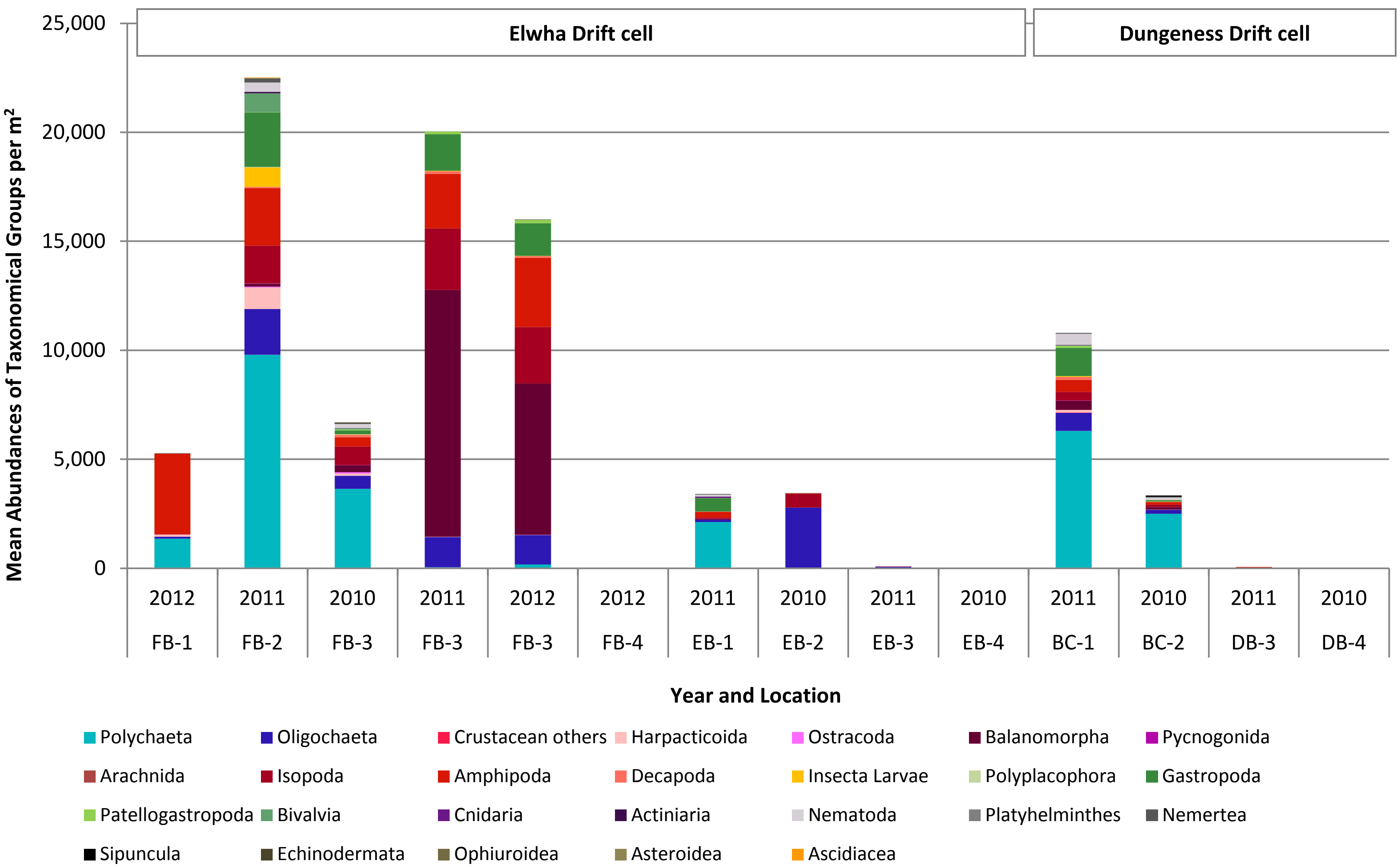
In the summer surveys the more diverse benthic invertebrate communities with higher abundances at the MLLW were all associated with intertidal low-tide terraces (Figure 8). The highest diversity was observed at FB-2 with 28 taxonomical groups. All the other locations associated with intertidal low-tide terraces, except EB-2, had relatively high diversity ranging from 15 to 23 taxonomical groups. EB-2 was located at the very edge of an intertidal low-tide terrace and was more exposed to sediment transport which may have caused the lower diversity of seven taxonomical groups and a community composition more similar to the MTL communities. Common taxonomical groups at the low-tide terrace locations included polychaetes, amphipods, isopods, gastropods and barnacles. The invertebrate communities associated with the gravel-sandy beaches had very low diversity with either one or three taxonomical groups (polychaetes, oligochaetes, amphipods or isopods). The community at FB-1, the only fine-sandy beach location, included eight taxonomical groups and was dominated by polychaetes and amphipods.

The highest abundance was observed at FB-2 with almost 22,500 organisms per m^2. Relatively high abundances were also observed at FB-3 in 2011 and 2012 with about 20,000 and 16,000 organisms per m^2. The abundances at the other locations associated with intertidal low-tide terraces ranged between 3,300 and 11,000 organisms per m^2. The invertebrate communities on the gravel-sandy beaches had very low abundances of less than 100 organisms per m^2 and the community at FB-1 had an abundance of almost 5,300 organisms per m^2.

The MLLW benthic invertebrate community at FB-3 was surveyed three consecutive years. Similar to the MTL community the community in 2010 was quite different from the following two years. In 2010 polychaetes were the dominant group whereas in 2011 and 2012 the community was dominated by barnacles, amphipods, isopods, gastropods, and oligochaetes. This difference may be attributed to seasonal differences or because the location was moved approximately 70 m to the west.

Winter surveys of the benthic invertebrate communities were only conducted at six locations (Figure 9). Of these locations four were associated with intertidal low-tide terraces and two locations with a gravel-sandy beach (EB-4 and DB-4). Overall the abundances of invertebrates at the low-tide terrace locations were much lower in the winter surveys than in the summer surveys, except for the community at BC-2 where the winter abundance was approximately 1,500 organisms per m^2 higher than the summer abundance. The abundances at the intertidal low-tide terrace locations ranged between approximately 600 and 10,200 organisms per m^2.

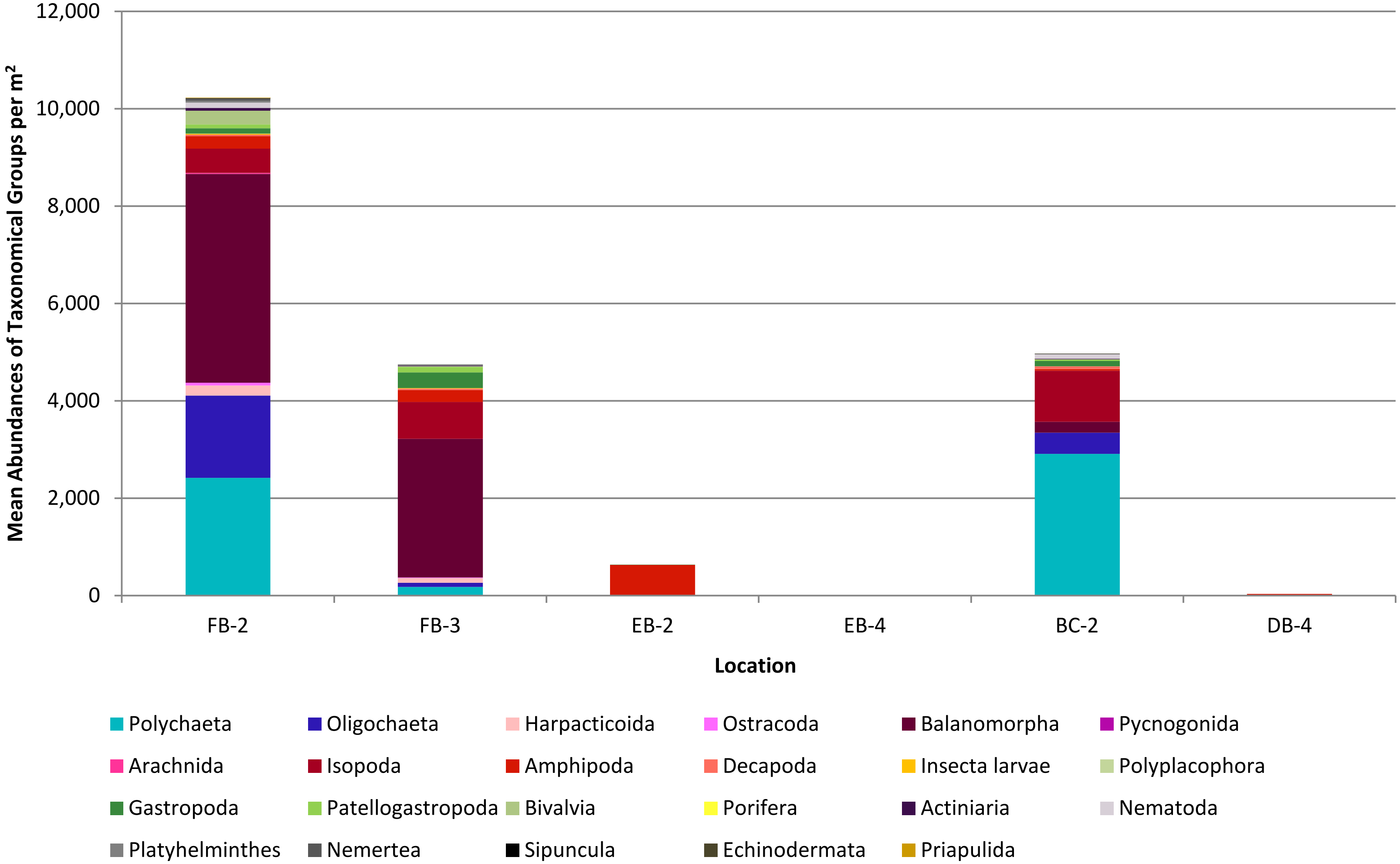
Figure 8 - Mean abundances per m^2 of invertebrate groups at MLLW in the summer surveys



Freshwater Bay: FB-1 fine-sandy beach; FB-2 and FB-3 cobble low-tide terrace; FB-4 sandy-gavel beach

Open Beach: EB-1, EB-2, BC-1 and BC-2 cobble low-tide terrace; EB-3, EB-4, DB-3 and DB-4 sandy-gravel beach

Figure 9 - Mean abundances per m^2 of invertebrate groups at MLLW in the 2011 winter survey



Freshwater Bay: FB-2 and FB-3 cobble low-tide terrace

Open Beach: EB-2 and BC-2 cobble low-tide terrace; EB-4 and DB-4 sandy-gravel beach

The low abundance of 600 organisms per m^2 was observed at EB-2 which as stated above was at the edge of the low-tide terrace and in the winter of 2011 became covered by gravel and rocks (Figure 10). The abundances at the two gravel-sandy beaches were less than 50 organisms per m^2.

At three of the locations associated with intertidal low-tide terraces (FB-2, FB-3, and BC-2) the diversity remained relatively high in the winter survey with between 17 and 25 taxonomical groups. Common groups included polychaetes, amphipods, isopods, barnacles, and limpets (patellogastropods). The other three locations (EB-2, EB-4, and DB-4) had low diversity with one or two taxonomical groups present (amphipods, nematodes, platyhelmithes, or gastropods).

Figure 10 – Substrates at EB-2 during the summer 2010 and winter 2011 surveys

Sampling at the MLLW transect in the July 2010 summer survey.

March 2011 winter survey. The MLLW transect was at the surf line about 1 m below the flags (poor tide of -0.2 ft)

Wrack Line Communities

The study was not intended to provide a complete assessment of the wrack line communities at the 12 locations which would have required a different sampling design including sampling in the late summer and into late fall when the wrack line is most extensive and a better way to quantify the amount of algae mats on a given beach. Instead, sampling of the wrack line was included to give a more complete assessment of the standing stock of invertebrates along the beaches at a time when the benthic invertebrate communities at the MTL and MLLW were expected to be either the most or least prolific and diverse (i.e., summer and winter survey).

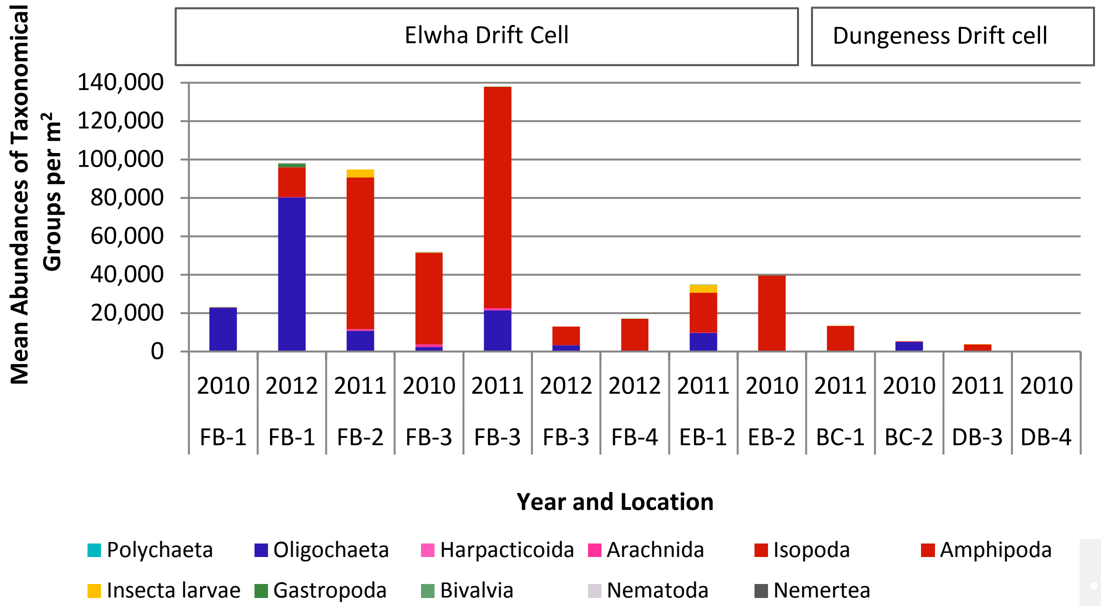
The wrack line present at the 12 locations during the summer surveys was never an extensive continuous band along the shore but consisted of patches of algae or a thin layer of primarily green algae. A wrack line was not present at any of the locations in the late winter surveys and at two locations, EB-3 and EB-4, in the summer surveys. The relatively high energy along the Elwha and Dungeness shorelines and the timing of the surveys are likely reasons for the limited presence of a wrack line at the 12 locations.

The invertebrate communities were dominated by oligochaetes and amphipods (Figure 11). The abundances ranged from no organisms in the wrack line samples at DB-4 to a mean abundance of almost 140,000 organisms at FB-3 in 2011. The highest abundances were seen at FB-1, FB-2, and FB-3 in Freshwater Bay.

The current data shows that the communities in the wrack line can contribute a significant portion of the standing stock of invertebrates along the Elwha and Dungeness shorelines even at times of the year when the wrack line is limited. For example, during the summer survey 2011 at FB-3 in the Elwha drift cell almost 140,000 organisms were present per m^2 in the wrack line compared to 3,500 organisms per m^2 at the MTL and 20,000 organisms per m^2 at the MLLW. However, because of the patchy distribution of algae mats in the wrack line and the limitations in the sampling design, the current dataset does not provide sufficient information to draw any more quantitative conclusions.

Table A7 and A8 present the mean abundances and standard deviations of invertebrates collected in the wrack line during the summer surveys in the Elwha and Dungeness drift cell, respectively.

Figure 11 - Mean abundances per m^2 of invertebrate groups in the wrack line during the summer surveys



Freshwater Bay: FB-1 fine-sandy beach; FB-2 and FB-3 cobble intertidal low-tide terrace; FB-4 sandy-gavel beach. Open Beach: EB-1, EB-2, BC-1 and BC-2 cobble intertidal low-tide terrace; EB-3, EB-4, DB-3 and DB-4 sandy-gravel beach

Algae Communities

A comprehensive assessment of the algae communities at the intertidal low-tide terrace locations was not conducted during the surveys because of limited resources. However, based on the sampling method, which was initiated by scraping all the algae off the hard substrate and placing them separately in a container, qualitative data was collected on the presence of algae. Notes were taking in the laboratory on the categories of algae (green, brown and red) and easily recognizable algae were identified to genus.

Table 7 presents the MLLW algae community information collected at the six intertidal low-tide terrace locations in the summer and winter surveys. The most diverse and abundant community was observed at FB-2 in Freshwater Bay. This was the only location at which algae were present both in the summer and winter surveys. At FB-3 algae were present sporadically and not at all five sampling sites along the transect in a given survey. The summer algae communities at EB-1 and BC-1 were dominated by species of *Ulvae* and *Porphyra* and at BC-2 the community was dominated by *Ulvae* sp.

Table 7 – Qualitative description of algae communities

Location	Season, Year	Presence	Description
FB-2	W, 2011	Present	Community primarily included *Fucus* sp. and red algae with a few *Ulvae* sp.
	S, 2011	Very Abundant	Diverse community with green, brown and red algae including *Ulvae* sp., *Fucus* sp., *Acrosiphonia* sp., and *Porphyra* sp.
FB-3	S, 2010	Sporadic	Algae only present at 2 of the 5 MLLW sampling sites. Dominated by *Ulvae* sp. and *Acrosiphonia* sp.
	S, 2011	Sporadic	Algae only present at 1 out of the 5 MLLW sampling sites. Mostly red algae.
	S, 2012	None	-
EB-1	S, 2011		Community dominated by *Ulvae* sp. and *Porphyra* sp.
EB-2	S, 2010	None	-
	W, 2011	None	-
BC-1	S, 2011	Abundant	Community dominated by *Ulvae* sp. and *Porphyra* sp.
BC-2	S, 2010	Abundant	Community dominated by *Ulvae* sp.

S: summer
W: winter

Annelid Taxonomy

During the efforts to locate funding for the taxonomical analysis of the invertebrate samples a team of taxonomists was identified which included Eugene Ruff as the annelid taxonomist. When funding was not secured, Eugene Ruff kindly volunteered to identify the annelids in a subset of the samples to provide preliminary data of the annelids present in the survey area.

The subset consisted of samples collected during one winter and two summer surveys predominately from the MLLW at four locations and two locations in the Elwha and Dungeness drift cell, respectively (Table 8). The epifauna and algae samples were collected from a 0.25 m^2 area whereas the infauna samples were collected from a 0.05 m^2 area. Only the data for FB-1 represent the complete data for one sampling site along a transect; the other ten data sets represent one of up to three sample types (algae, epifauna, and infauna) collected at a given sampling site at an intertidal low-tide terraces location.

Common species included the spionids *Rhynchospio glutaea* and *Boccardia proboscidae*. The family Glyceridae was represented by *Hemipodia simplex* and another family, Onuphidae, by several juvenile specimens and *Mooreonuphis stigmatis*. Three other species identified in the samples *Exogone lourei, Mediomastus californiensis* and *Platynereis bicanaliculata* are common in moderate to high energy shallow areas and *Thelepus crispus* are often associated with intertidal boulders (Dethier 1990).

Table 8 – Annelids per m^2 indentified in a subset of samples collected in one winter and two summer surveys

Location	FB-1	FB-2	FB-2	FB-3	FB-3	EB-1	EB-1	BC-1	BC-1	BC-2	BC-2
Season and Year	S 2012	W 2011	W 2011	S 2010	S 2010	S 2011	S 2011	S 2011	S 2011	W 2011	W 2011
Tidal Elevation	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MTW
Sample Type	Infauna	Epifauna	Infauna	Algae	Infauna	Epifauna	Infauna	Infauna	Epifauna	Infauna	Infauna
Polychaeta											
Aphelochaeta sp.	0	0	0	0	260	0	0	0	0	0	0
Arenicolidae	0	0	40	0	220	0	0	100	0	260	60
Armandia brevis	0	0	0	0	20	0	0	0	0	0	0
Axiothella rubrocincta	0	0	0	0	20	0	0	0	0	0	0
Boccardia proboscidea	0	16	0	0	20	0	0	160	8	60	420
Capitella teleta	20	0	0	0	100	0	0	20	0	40	20
Capitella sp.	0	0	0	0	0	0	100	0	0	0	0
Eteone californica	0	0	0	0	0	0	0	20	8	80	0
Exogone lourei	0	40	360	4	100	24	240	80	0	20	100
Glycera americana	20	0	0	0	0	0	0	0	0	0	0
Glycinde picta	20	0	0	0	0	0	0	0	0	0	0
Halosydna brevisetosa	0	16	0	0	0	0	0	0	0	0	0
Hemipodia simplex	0	0	0	0	140	0	780	140	0	180	20
Lumbrineridae	0	4	0	0	0	0	0	0	0	40	0
Mediomastus californiensis	0	0	80	0	80	0	0	60	0	0	0
Mooreonuphis stigmatis	0	4	0	0	360	0	0	20	12	900	740
Neanthes brandti	0	0	0	0	0	0	0	0	0	40	0
Nephtys sp.	20	0	0	0	0	0	0	0	0	0	0
Nereididae	0	0	0	0	0	0	0	0	4	0	20
Nereis sp.	0	0	0	16	0	40	0	0	16	0	0
Nereis vexillosa	0	0	0	0	0	0	0	40	8	0	0
Notomastus tenuis	20	0	0	0	40	0	0	100	0	0	0
Onuphidae	0	4	20	8	180	0	0	20	16	460	20

Location	FB-1	FB-2	FB-2	FB-3	FB-3	EB-1	EB-1	BC-1	BC-1	BC-2	BC-2
Season and Year	S 2012	W 2011	W 2011	S 2010	S 2010	S 2011	S 2011	S 2011	S 2011	W 2011	W 2011
Tidal Elevation	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MLLW	MTW
Sample Type	Infauna	Epifauna	Infauna	Algae	Infauna	Epifauna	Infauna	Infauna	Epifauna	Infauna	Infauna
Ophelia limacina	0	0	0	0	0	0	20	0	0	0	0
Ophiodromus pugettensis	0	0	20	0	0	0	0	0	0	0	0
Owenia johnsoni	20	0	0	0	0	0	0	0	0	0	0
Paraonella platybranchia	560	0	0	0	0	0	0	0	0	0	0
Pholoe glabra	0	0	0	0	0	0	40	0	4	0	0
Phyllodoce maculata	0	0	0	0	0	0	0	0	0	80	0
Platynereis bicanaliculata	0	0	0	72	0	0	0	0	12	0	0
Podarkeopsis glabrus	20	0	0	0	0	0	0	0	0	0	0
Protodorvillea gracilis	0	0	0	0	0	0	0	20	0	20	280
Rhynchospio glutaea	440	28	260	36	700	192	180	1080	60	580	100
Schizobranchia insignis	0	4	0	0	0	0	0	0	0	0	0
Scoletoma sp.	0	0	0	0	0	0	0	0	0	20	0
Scoloplos armiger	20	0	0	0	0	0	0	0	0	0	0
Sphaerosyllis sp.	0	0	0	4	20	0	0	0	0	0	0
Spiophanes norrisi	20	0	20	0	0	0	0	0	0	0	0
Syllides sp.	0	8	0	0	0	0	0	0	0	0	0
Thelepus crispus	0	68	60	0	0	0	0	0	0	0	0
Typosyllis caeca	0	0	0	0	0	0	0	20	0	0	0
Typosyllis pigmentata	0	12	0	0	0	0	200	20	4	80	40
Typosyllis sp.	0	0	0	12	40	0	0	0	0	0	0
Oligochaeta	20	0	0	0	160	0	60	320	4	20	40

MLLW = mean low-low water

S: summer

W: winter

The annelid taxonomy data also provides an idea of the quality of the data based on the laboratory sorting process. Of the 852 organisms identified by Eugene Ruff only five were incorrectly placed in the annelid subsample indicating an error rate of less than 1% in identification of the taxonomical groups provided in Table 3. The enumeration was, as expected, less accurate. Annelids are by far the hardest to count for laboratory technicians with limited training because of the difficulties identifying an annelid head from the tail and the tendency to count fragments. Based on this limited subset of annelids identified by a taxonomist, 80% of the samples have an average enumeration error rate of less than 10% whereas the 20% sorted by the students may have an average error rate of about 37%. The data with the higher error rates were primarily collected during the winter 2011 and summer 2012 surveys and constitute 31% and 64%, respectively, of the samples collected in these two surveys. Of the remaining three surveys the students sorted less than 10% of the samples in a given survey.

Discussion

The intertidal habitats in the study area between Freshwater Bay and Dungeness Spit are strongly influenced by current, wave and wind actions. The sediment dynamics study have documented large sediment transport, both depositional and erosional, at the 12 locations ranging from 0.3 m to more than 1.5 m at the MTL and from 0.2 m to more than 1 m at the MLLW within one year (Parks unpublished; Parks and Andersen 2011). Other studies have found high longshore sediment rates along the central Strait of Juan de Fuca caused by exposed to large fetch distances, oblique wave approach angles, and large wave amplitudes from Pacific Ocean swells (Wallace, 1988; Galster, 1989; Finlayson, 2006; Warrick et al., 2009). The large sediment transport strongly impacts the benthic invertebrate communities in the study area and prevents the establishment of a long-term community at the open exposed beaches by either burying or sweeping away the invertebrates. Only areas with alleviating features such as cobble and boulders or protection behind a headland provided a more stable habitat and supported a more long-term benthic invertebrate community.

The invertebrate communities in the Elwha and Dungeness drift cells were clearly defined by the three primary geomorphic habitat types: exposed sandy-gravel beach, intertidal low-tide terrace, and protected sandy beach based on the total abundances. At the sandy-gravel beaches and at both tidal elevations the diversity of the communities was limited to a maximum of three taxonomical groups, which were predominantly oligochaetes and amphipods. The abundances were low ranging at both tidal elevations between 4 and 220 organisms per m^2 except at FB-4 with 2,800 organisms per m^2 at the MTL of which 98 percent were oligochaetes.

At the intertidal low-tide terrace locations the invertebrate communities were more diverse and had higher abundances. The communities at this geomorphic habitat type were influenced by tidal elevation and the exposure to the predominantly westerly wind and wave actions. At the MTL higher abundances were present in Freshwater Bay and at the locations most protected by a headland along the open shoreline (EB-1 and BC-1). During the summer surveys the communities at all MTL locations except FB-3 were dominated by oligochaetes which, with a density of up to 23,200 organisms per m^2, constituted between 50 and 99.6 percent of the overall abundances. At FB-3 in 2012 amphipods was another dominant taxonomical group encompassing 44 percent of the total abundance and a more diverse community were present in 2010, when FB-3 was located approximately 70 m to the east. This community included ten taxonomical groups and was dominated by polychaetes, barnacles and gastropods. The diversity at the other MTL locations associated with an intertidal low-tide terrace ranged from 2 to 11 taxonomical groups.

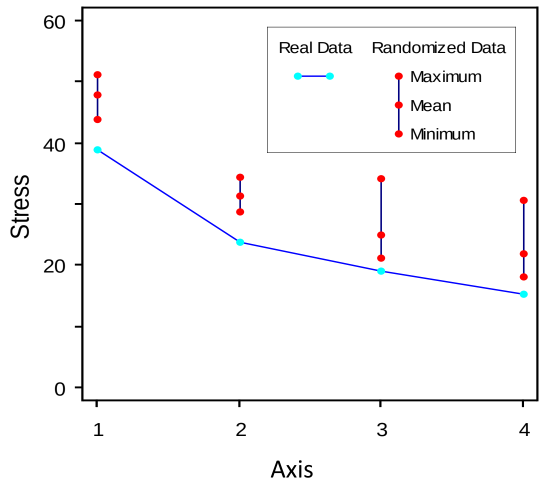
During the winter surveys oligochaetes no longer dominated the communities at the MTL. Oligochaetes frequently occur in ephemeral and disturbed habitats and they typically undergo a pronounced yearly cycle, with low abundance during winter, reaching maximum population densities in the summer, after which the populations collapse and occur at low densities until the following spring (Nilsson et al 2000).

At the MLLW the invertebrate communities associated with the intertidal low-tide terraces were, with one exception, diverse. The diversity during the surveys ranged between 15 and 28 taxonomical groups with highest diversity seen at the more protected intertidal low-tide terrace location (FB-2) in Freshwater Bay. The community at EB-2 was the exception with three and seven taxonomical groups in the winter and summer surveys, respectively. The abundance at all locations ranged between 3,300 - 22,500 organisms per m^2 in the summer surveys and 600 – 10,200 organisms per m^2 in the winter survey. The lower abundances in both the summer and winter surveys were seen at EB-2. As previously stated EB-2 was located at the very eastern edge of an intertidal low-tide terrace and was more exposed to the longshore sediment transport which may have caused a community more similar to the MTL communities with lower diversity and abundance.

The invertebrate community associated with the fine-sandy beach, the last geomorphic habitat type in the study area, was quite different from the other communities. Only two taxonomical groups were present at the MTL with less than 50 organisms per m^2 and the MLLW community with eight taxonomical groups was dominated by polychaetes and amphipods which comprised 98 percent of the approximately 5,300 organisms per m^2.

The NMS model for the MTL summer data found some structure in the data as indicated by the stress being lower than the levels for randomized data (Figure 12). The model explained approximately 40 percent of the variance. None of the correlations between the taxa and the two axes (1 and 2) capturing most of the variability were high (Table 9). Nine taxa were associated with axis 1 of which the correlation with gastropods was the highest (0.60). Three taxa were associated with axis 2 two of which (harpacticoides and isopods) were also included in the taxa groups describing axis 1. All correlations were positive which mean that increasing values along the axes are associated with increasing values of each of the correlated taxa.

Figure 12 – NMS fit for MTL summer data



NMS: non-metric multidimensional scaling
MTL = mean tidal level

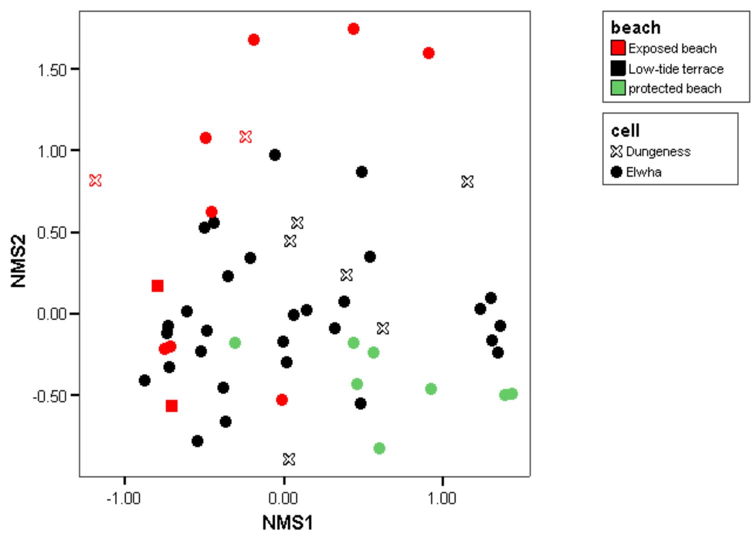
Table 9 – Correlations between taxa and NMS axis 1 and 2 for MTL summer data

Taxon	Kendall's tau r	Taxon	Kendall's tau r
Axis 1			
Actiniaria	0.26	Hemigrapus nudus	0.32
Balanormorpha	0.40	Isopoda	0.27
Decapoda	0.33	Patellogastropoda	0.37
Gastropoda	0.60	Polychaeta	0.42
Harpacticoida	0.21		
Axis 2			
Nematoda	0.45	Isopoda	0.30
Harpacticoida	0.29		

NMS: non-metric multidimensional scaling
MTL = mean tidal level

Figure 13 presents the distribution of replicates collected at the MTL elevation along the two NMS axes. The replicates are identified by beach type (exposed sandy-gravel beach, low-tide terrace, and protected sandy beach) and drift cells. As indicated by the large degree of overlap in the distributions of the different beach types the model found no clear separation between the relative distributions of taxonomical groups at the three beach types. The model may have detected a weak gradient from exposed to protected beaches (upper left hand corner to lower right hand corner), but only 40 percent of the data variability is captured in the model and all the correlations are relatively low. The graph also indicates that the NMS found no difference between the relative distributions of taxonomical groups at the MTL in the two drift cells.

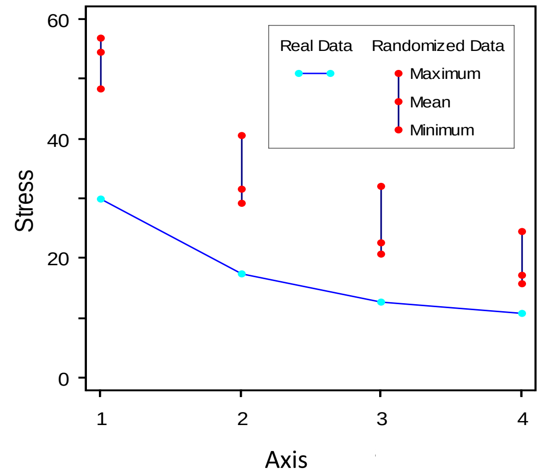
Figure 13 – NMS scores for the MTL summer data based on beach type and drift cell



Note: Red square depicts overlapping replicates from Dungeness and Elwha drift cell
NMS: non-metric multidimensional scaling
MTL = mean tidal level

The stress for the MLLW summer data indicates that the model found a slightly better structure in the data explaining approximately 57 percent of the variance (Figure 14). None of the correlations between the taxa and the two axes (1 and 2) capturing most of the variability were high; the highest correlations was 0.58 between polychaetes and axis 2 (Table 10).

Figure 14 – NMS fit for MLLW summer data



NMS: non-metric multidimensional scaling
MLLW = mean low low water

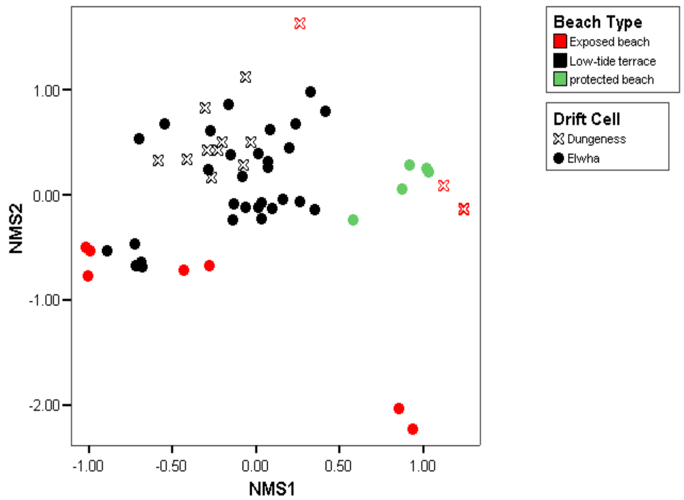
Table 10 – Correlations between taxa and NMS axis 1 and 2 for MLLW summer data

Taxon	Kendall's tau r	Taxon	Kendall's tau r
Axis 1			
Amphipoda	0.35	Oligochaeta	-0.26
Axis 2			
Actiniaria	0.48	Nemertea	0.35
Bivalvia	0.36	Ostracoda	0.28
Chironomidae	0.32	Platyhelminthes	0.34
Cnidaria	0.34	Polychaeta	0.58
Decapoda	0.31	Polyplacophora	0.28
Gastropoda	0.29	Pycnogonida	0.30
Nematoda	0.39	Sipuncula	0.31

NMS: non-metric multidimensional scaling
MLLW = mean low low water

Figure 15 presents the distribution of replicates collected at the MLLW elevation along the two NMS axes. Similar to the MTL graph the replicates are identified by beach type and drift cells. The largest cluster of data points is created by the majority of the replicates collected at the low-tide terraces in both the Dungeness and Elwha drift cell indicating similar relative distribution of taxonomical groups. Similar to the total abundance analysis the replicates from EB-2, the location at the edge of a low-tide terrace, cluster closer together with the exposed beach replicates from the Elwha drift cell. The replicates collected at the protected beach create a separate loosely fitted cluster at the upper range of the NMS axis 1 supporting the finding that that protected beach habitat supports a different benthic community compared to the other habitats in the study area.

Figure 15 – NMS scores for the MLLW summer survey data based on beach type and drift cell



NMS: non-metric multidimensional scaling
MLLW = mean low low water

The replicates from the exposed sandy-gravel beaches are scattered on either side of the main cluster. The replicates from the Elwha drift cell are at the lower triangle of the graph whereas the replicates from the Dungeness drift cell are in the upper triangle indicating a difference in the relative distribution of taxonomical groups at the exposed beaches from the two drift cells. The difference is driven by the Dungeness communities consisting of amphipods and polychaetes and the Elwha communities consisting mostly of oligochaetes and a few amphipods. That the model indicates a difference between the benthic communities at the exposed beaches is interesting and one of the first explanations that comes to mind is the difference in armoring (Elwha drift cell being armored and Dungeness not). However, it should be kept in mind that the model only explains 57 percent of the variability in the data and replicates without organisms, constituting 35 percent of the exposed beach data, are excluded from the analysis. Some light may be shed on this finding if the taxonomical analysis were carried out on the invertebrate samples, but as always with low frequency data more benthic invertebrate samples and/or bigger samples should be collected to enable a statistical detection of a potential difference in the relative distribution of taxonomical groups along the exposed beaches in the two drift cells.

The Indicator Species Analysis identified two and five taxa in the MTL data as significantly more frequent and abundant along the protected sandy beach and low-tide terraces, respectively. Similarly, one and twelve taxa were identified in the MLLW data as significantly more frequent and abundant within the same two habitat types (Table 11).

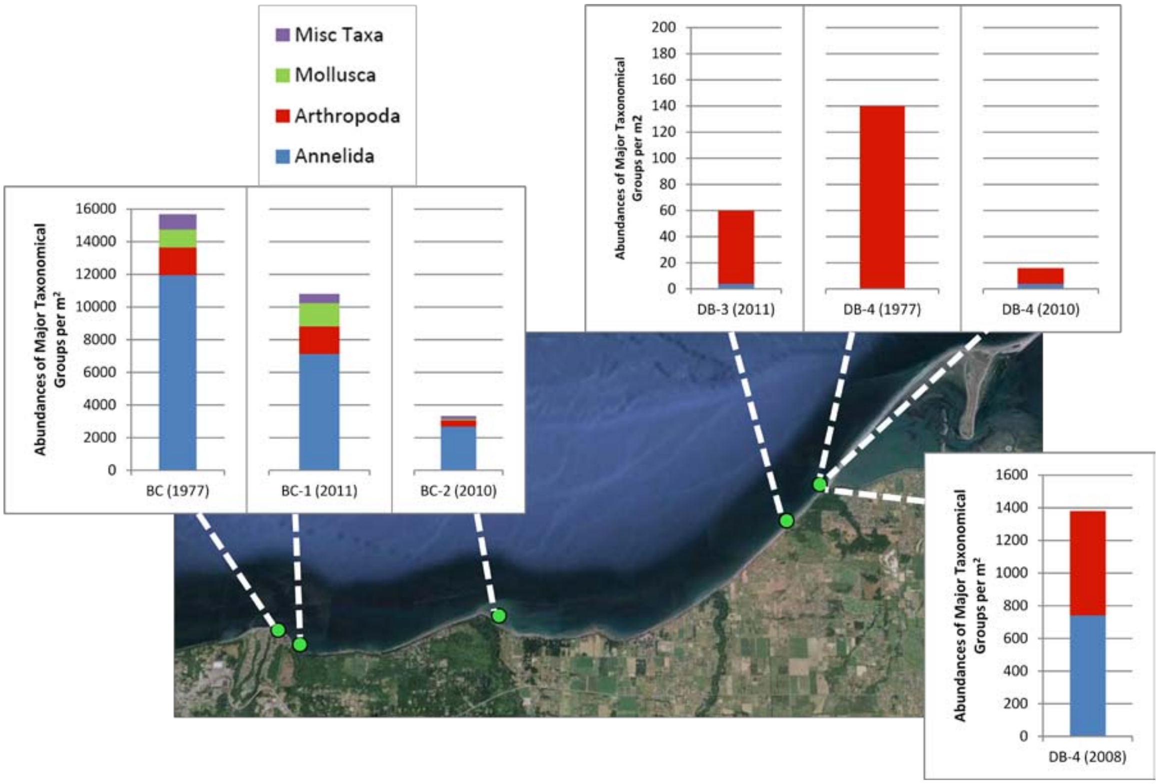
Table 11 – Taxonomical groups significantly more frequent and abundant in two geomorphic habitat types.

Taxon	p value	Taxon	p value
MTL Protected Beach		**MLLW Low-Tide Terrace**	
Arachnida	0.017	Balanomorpha	0.001
Gastropoda	0.0012	Chironomidae	0.0138
MLLW Protected Beach		Decapoda	0.0004
Amphipoda	0.0002	Gastropoda	0.0002
MTL Low-Tide Terrace		Hemigrapsus nudus	0.0268
Balanomorpha	0.0176	Isopoda	0.0002
Isopoda	0.0062	Nematoda	0.0072
Oligochaeta	0.002	Nemertea	0.0402
Patellogastropoda	0.0248	Oligochaeta	0.0002
MLLW Low-Tide Terrace		Patellogastropoda	0.0002
Actiniaria	0.0112	Polychaeta	0.0078

MLLW = mean low-low water
MTL = mean tidal level

The two previous surveys conducted in the Dungeness drift cell support the findings in this study. The 1977 MESA study evaluated the benthic invertebrate community at two locations in the current study area (Nyblad 1979). One location was associated with the intertidal low-tide terrace just west of BC-1 and the other location was the current DB-4 location. The latter location was also surveyed in 2008 (Sheffler 2008) (Figure 16). The benthic community data for this comparison were all collected at the MLLW. Because the Sheffler study (2008) reported the invertebrates at the phylum level the data from the two other studies were regrouped into these categories. The communities at the three locations associated with the intertidal low-tide terrace surveyed in 1977 and 2010-2011 had higher abundances of invertebrates representing all four taxonomical groups whereas the communities associated with the exposed sandy-gravel beaches generally had much lower abundances and were dominated by arthropods. The benthic community observed in the 2008 survey at DB-4 was slightly different with higher abundances of both arthropods and oligochaetes.

Figure 16 – MLLW invertebrate community data collected in the Dungeness drift cell 1977, 2008, and 2010-11.



MLLW = mean low-low water

One of the objectives of this study was to compare the benthic invertebrate community data from the Elwha drift cell with the community data from the Dungeness drift cell to assess potential impacts the shoreline alterations in the Elwha drift cell may have on the intertidal benthic community. Based on the geomorphic habitat types, the multivariate analysis and the current level of taxonomical analysis, no difference was apparent in the data sets from the Elwha and Dungeness drift cells. The multivariate analysis indicated a potential difference between the relative distribution of taxonomical groups along the exposed beaches in Elwha and Dungeness drift cells but, as stated above, the data in this report does not provide a solid foundation for such a conclusion and a t-test found no significant difference ($p=0.86$) between the total invertebrate abundances at the exposed beaches in the two drift cells.

The primary driver for this study was to provide information on the intertidal habitats and invertebrate communities before the arrival of the sediment retained behind the two dams on the Elwha River. Large sediment volumes and changes have already been reported from the mouth of the Elwha River (Stevens et al., unpublished data) and, because of the predominantly easterly longshore sediment transport, the benthic invertebrate communities at EB-1 and EB-2 may be the first communities surveyed in this study to undergo major changes. However only future studies of the benthic invertebrate communities will document the changes after the major pulses of sediment have reach the nearshore.

The information collected during this study may provide useful information in assessing potential effects of an oil spill on the intertidal benthic invertebrate communities between Freshwater Bay and Dungeness Spit including the Strait of Juan de Fuca Environmental Sensitivity Index which characterize the marine and coastal environments and wildlife by their sensitivity to spilled oil (NOAA 2013). By extrapolating the benthic community data generated at the 12 locations to similar geomorphic habitat types between Freshwater Bay and Dungeness Spit, preventative efforts protecting the intertidal benthic invertebrate habitats should focus on the western end of Freshwater Bay and all areas associated with intertidal low-tide terraces. Figure 17 outlines the areas of these habitat types and estimates of the shoreline distances of each geomorphic habitat type are presented in Table 12. A more precise and detailed map could easily be made using GIS and the information gathered during this study. The shoreline around the Elwha River estuary and Port Angeles harbor are not included because these areas were not sampled during this study. USGS initiated a survey of the benthic community at the mouth of the Elwha river in 2012 (Clark, unpublished data) and large amounts of sediment is currently being delivered to the nearshore near the mouth of the river changing the substrate from cobbles and coarse gravel to sand and silt (Stevens et al., unpublished data). Port Angeles harbor has been identified as a priority clean-up site under the Puget Sound Initiative and several environmental studies are currently being done in the harbor (Ecology 2013).

Figure 17 – Intertidal habitats between Freshwater Bay and Dungeness Spit with higher benthic invertebrate abundances and diversities.

White dashed line indicates overall study area
Red lines indicate intertidal habitats with higher benthic invertebrate abundances and diversity
Green circles indicate areas not included in this study

Table 12 - Shoreline distances of MTL and MLLW beaches based on substrate types within Elwha and Dungeness drift cells[1]

Tidal Elevation/Beach Type	Elwha Drift cell Distance (m)	Dungeness Drift cell Distance (m)
MTL		
Sandy-gravel	11,700	13,000
MLLW		
Fine-sandy beach	900[2]	-
Freshwater Bay low-tide terrace	3,500	-
Sandy-gravel	5,300[3]	8,800
Low-tide terrace	2,000[4]	4,200[5]
Total MLLW distance	11,700	13,000

[1] This information was derived from field GPS measurements, GIS calculations and Google Earth (2013).
[2] Measured from Freshwater Bay boat ramp
[3] Includes the beach in the eastern part of Freshwater Bay and the beach from Dry Creek to Ediz Hook
[4] Includes intertidal low-tide terrace east of Elwha River deltaic headland
[5] The shoreline distances of three smaller intertidal low-tide terraces near Green Point not included in this study were estimated based on a visual survey performed from the bluffs in January, 2013
MLLW = mean low-low water
MTL = mean tidal level

Conclusions

This study provides a baseline of the benthic invertebrate communities along approximately 20 shoreline miles in the central Strait of Juan de Fuca, Clallam County, between Freshwater Bay and Dungeness Spit. The surveys were conducted in 2010-2012 before the sediment retained behind the two dams on the Elwha River reached the intertidal nearshore.

The intertidal habitats in the study area are strongly influenced by current, wave and wind actions and the large fetch distances in the Strait of Juan de Fuca combined with oblique wave approach angles and large wave amplitudes cause a large sediment transport primarily to the east. The large sediment transport strongly impacts the benthic invertebrate communities in the study area and prevents the establishment of a long-term community at the open exposed beaches by either burying or sweeping away the invertebrates. Only areas with alleviating features such as cobble and boulders or protection behind a headland provided a more stable habitat and supported a more long-term benthic invertebrate community.

The invertebrate communities were clearly defined by the three primary geomorphic habitat types: exposed sandy-gravel beach, intertidal low-tide terrace, and protected sandy beach based on the total abundances. At the sandy-gravel beaches and at both tidal elevations the communities had low diversity and abundances. At the intertidal low-tide terraces the communities were influenced by the tidal elevation and exposure to the predominantly westerly wind and wave actions. At the MTL the diversity and abundances were relative high with higher abundances present in Freshwater Bay and at locations along the open shoreline most protected by a headland. At the MLLW the invertebrate communities were diverse and abundant. The benthic community at one intertidal low-tide terrace location did not follow this pattern but was more similar to the sandy-gravel beach communities with lower diversity and abundance. This location was at the very eastern edge of the low-tide terrace and more exposed to the longshore sediment transport. The invertebrate communities at the fine-sandy beach were quite different from the communities at the other two geomorphic habitats especially at the MLLW. The multivariate analysis of the MTL summer data found no clear separation between the relative distributions of taxonomical groups at the three geomorphic habitat types. The analysis of the MLLW summer data indicated similar benthic invertebrate communities at the low-tide terraces in the Dungeness and Elwha drift cell and a unique community associated with the protected sandy beach.

A comparison between the community data from the Elwha drift and the Dungeness drift cell found no obvious differences that could be linked to the shoreline alterations in the Elwha drift cell. The multivariate analysis indicated a potential difference between the benthic communities along the exposed sandy-gravel beaches in the two drift cells. However, because the model only explained 57 percent of the variability in the data and replicates without organisms (constituting 35 percent of the exposed beach data) were excluded from the analysis, this data does not provide a solid foundation for such a conclusion. In addition, a t-test found no significant difference between the total invertebrate abundances at the exposed beaches in the two drift cells.

Two historical surveys support the findings in the current study; that intertidal low-tide terraces sustain an abundant and diverse benthic invertebrate community, whereas the communities along the exposed sandy-gravel beaches have low diversity and abundances and often dominated by organisms able to survive in ephemeral and disturbed habitats.

As stated in the introduction and throughout the report the findings are based on identifications and counts of the intertidal benthic invertebrates done in the sorting laboratory. The benthic community data and thereby the conclusions drawn from the data would be greatly improved if taxonomical analysis was conducted on the invertebrate samples. However, despite the limitations of the current dataset, clear trends could be drawn between the intertidal habitats and invertebrate communities in the nearshore between Freshwater Bay and Dungeness Spit.

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Appendix A

Figures A1 and A2 present the grain size distributions at the MTL and MLLW measured at 8 of the 12 survey locations.

Figure A1 – Grain-size distributions at MTL locations

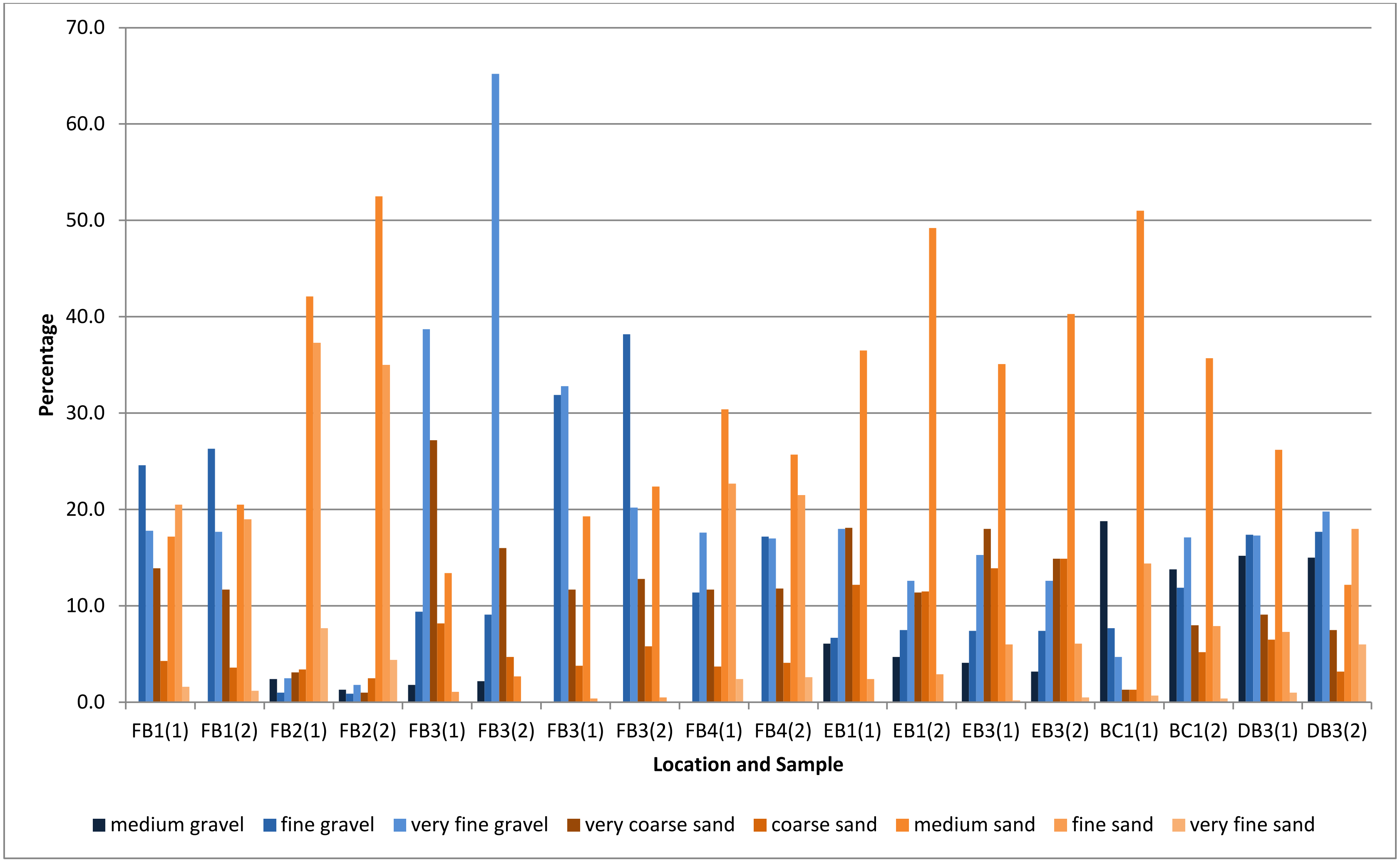
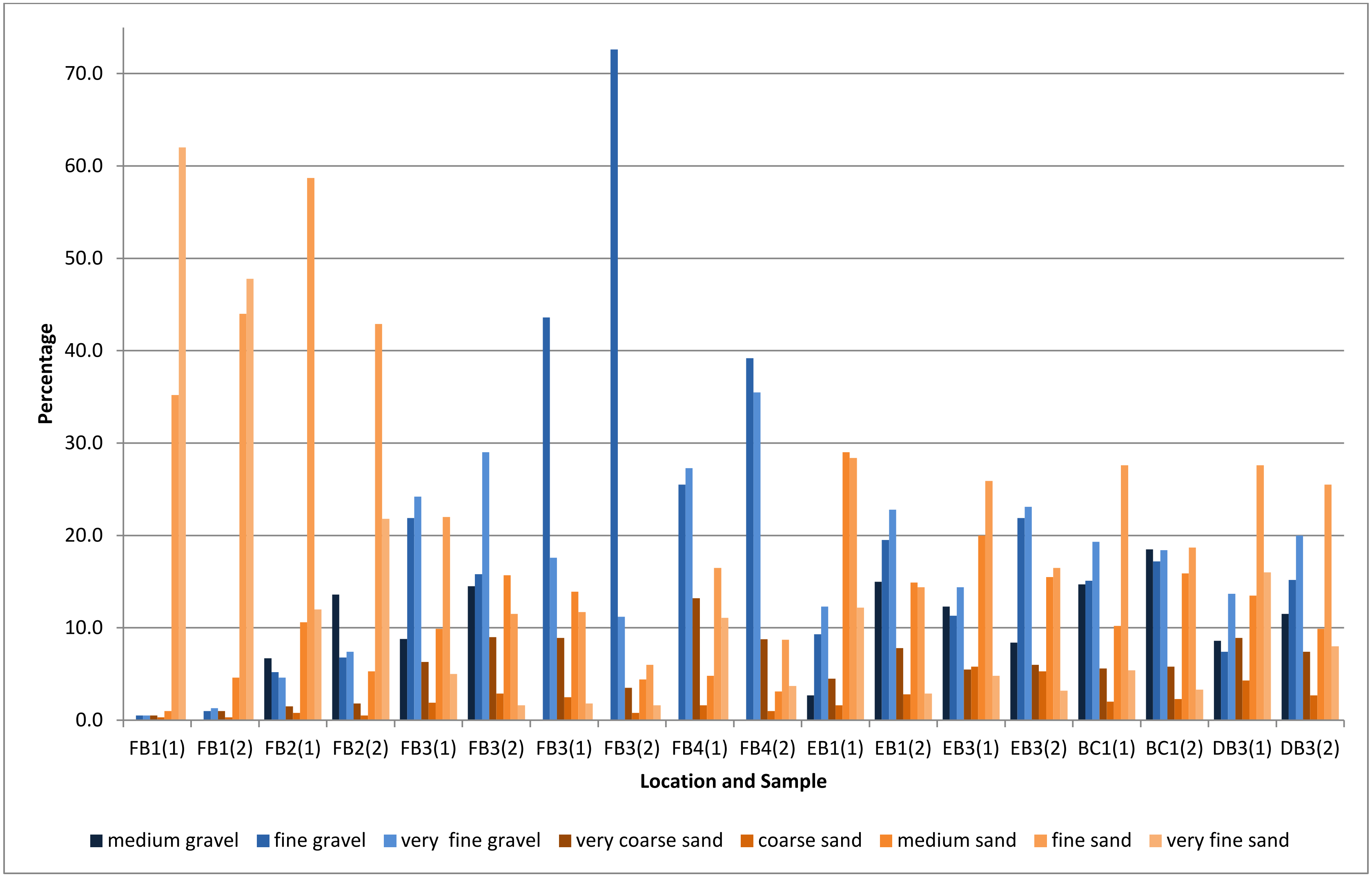


Figure A2 – Grain-size distributions at MLLW locations



Tables A1 and A2 summarize the mean abundances and standard deviations of the invertebrate groups present at the MTL locations sampled in the summer and winter surveys in the Elwha drift cell. Surveys were conducted twice at FB1 (summer 2010 and summer 2012) and four times at FB3 (summer 2010, winter 2011, summer 2011, and summer 2012).

Table A1 - Mean abundances and standard deviations per m^2 of invertebrate groups at MTL present during summer surveys in the Elwha drift cell

Location	FB-1		FB-1		FB-2		FB-3		FB-3		FB-3		FB-4		EB-1		EB-2		EB-3		EB-4	
Year	**2010**		**2012**		**2011**		**2010**		**2011**		**2012**		**2012**		**2011**		**2010**		**2011**		**2010**	
Taxonomical Group	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Annelida																						
Polychaeta	0	0	96	89	8	18	979	895	8	18	0	0	0	0	0	0	0	0	4	9	0	0
Oligochaeta	16	9	2,184	1,957	23232	23895	80	86	3,336	4,557	3,893	2,800	2,760	872	14044	7,096	764	439	16	9	200	199
Crustacea																						
Copepoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	9	0	0	0	0	0	0
Harpacticoida	0	0	0	0	0	0	0	0	4	9	0	0	0	0	0	0	0	0	0	0	8	11
Balanomorpha[1]	0	0	0	0	0	0	371	176	4	9	0	0	0	0	0	0	0	0	0	0	0	0
Pycnogonida	0	0	0	0	0	0	0	0	4	9	0	0	0	0	0	0	0	0	0	0	0	0
Arachnida	0	0	12	11	4	9	0	0	8	11	4	9	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	4	9	0	0	8	11	20	14	125	170	0	0	4	9	4	9	0	0	0	0
Amphipoda	0	0	312	410	80	63	26	33	72	54	3,253	3,491	44	64	176	338	36	41	20	14	4	9
Decapoda	0	0	0	0	0	0	34	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemigrapus nudus	0	0	0	0	0	0	85	29	0	0	1	2	0	0	0	0	0	0	0	0	0	0
Insecta																						
Chironomidae	0	0	4	9	8	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Insecta larvae	0	0	0	0	0	0	0	0	8	18	0	0	0	0	4	9	0	0	0	0	0	0
Mollusca																						
Gastropoda	28	11	264	320	0	0	521	202	12	18	128	106	0	0	0	0	4	9	0	0	0	0
Patellogastropoda	0	0	0	0	0	0	30	23	0	0	6	10	0	0	0	0	0	0	0	0	0	0
Misc. Taxa[2]																						
Actiniaria	0	0	0	0	0	0	11	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nematoda	0	0	4	9	4	9	0	0	4	9	1	2	0	0	20	28	156	274	24	43	8	11
Total No. Organisms	**44**	**17**	**2,880**	**2,178**	**23336**	**23983**	**2,145**	**888**	**3,480**	**4,565**	**7,410**	**6,057**	**2,804**	**884**	**14252**	**6,905**	**964**	**622**	**64**	**33**	**220**	**187**

[1] averages are based on abundance estimates in the field; three species, *Balanus glandula, Semibalanus cariosus* and *Chthamalus dalli*, may be present in the area but *B. glandula* is expected to be the dominant species

[2] all other taxonomical groups

Stdev = standard deviation

Table A2 - Mean abundances and standard deviations per m^2 of invertebrate groups at MTL present during winter surveys in the Elwha drift cell

Location	**FB-2**		**FB-3**		**EB-1**		**EB-2**	
Year	**2011**		**2011**		**2012**		**2011**	
Taxonomical Group	**Mean**	**StDev**	**Mean**[3]	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Annelida								
Polychaeta	0	0	20	23	0	0	16	17
Oligochaeta	28	11	227	209	4	9	4	9
Crustacea								
Balanomorpha[1]	0	0	629	386	0	0	0	0
Pycnogonida	0	0	0	0	4	9	0	0
Isopoda	8	11	209	94	0	0	0	0
Amphipoda	0	0	436	432	16	17	228	236
Decapoda	0	0	85	68	0	0	0	0
Hemigrapus nudus	0	0	21	13	0	0	0	0
Insecta								
Chironomidae	0	0	6	12	0	0	0	0
Insecta larvae	0	0	0	0	0	0	0	0
Mollusca								
Gastropoda	0	0	1,497	460	0	0	0	0
Patellogastropoda	0	0	26	20	0	0	0	0
Bivalvia	0	0	7	11	0	0	0	0
Misc. Taxa[2]								
Actiniaria	0	0	0	0	0	0	0	0
Nematoda	0	0	17	23	0	0	0	0
Platyhelminthes	0	0	7	11	0	0	0	0
Echinodermata	0	0	5	10	0	0	0	0
Total No. Organisms	**36**	**17**	**3,192**	**1,143**	**24**	**22**	**248**	**233**

[1] averages are based on abundance estimates in the field; three species, *Balanus glandula, Semibalanus cariosus* and *Chthamalus dalli*, may be present in the area but *B. glandula* is expected to be the dominant species

[2] all other taxonomical groups

[3] mean and standard deviation based on 4 samples

Stdev = standard deviation

Table A3 summarizes the mean abundances and standard deviations of the invertebrate groups present at the MTL locations sampled in the summer and winter surveys in the Dungeness drift cell.

Table A3- Mean abundances and standard deviations per m^2 of invertebrate groups at MTL present during summer and winter surveys in the Dungeness drift cell

Location	**BC-1**		**BC-2**		**BC-2**		**DB-4**		**DB-4**	
Season, Year	**Summer, 2011**		**Summer, 2010**		**Summer, 2010**		**Summer, 2010**		**Winter, 2011**	
Taxonomical Group	**Mean**	**Mean**	**Mean**	**StDev**	**Mean**	**Mean**	**Mean**	**StDev**	**Mean**	**StDev**
Annelida										
Polychaeta	44	0	0	0	1,114	1,114	0	0	0	0
Oligochaeta	2,465	36	36	30	81	81	0	0	0	0
Crustacea										
Copepoda	0	0	0	0	0	0	0	0	0	0
Harpacticoida	4	0	0	0	0	0	0	0	0	0
Balanomorpha[1]	74	0	0	0	20	20	0	0	0	0
Pycnogonida	0	0	0	0	0	0	0	0	0	0
Arachnida	0	0	0	0	0	0	0	0	0	0
Isopoda	144	0	0	0	14	14	0	0	0	0
Amphipoda	22	20	20	35	0	0	4	9	8	11
Decapoda	0	0	0	0	4	4	0	0	0	0
Hemigrapus nudus	1	0	0	0	4	4	0	0	0	0
Insecta										
Chironomidae	0	0	0	0	0	0	0	0	0	0
Insecta larvae	0	0	0	0	0	0	0	0	12	27
Mollusca										
Gastropoda	17	0	0	0	16	16	0	0	0	0
Patellogastropoda	5	0	0	0	14	14	0	0	0	0
Misc. Taxa[2]										
Actiniaria	0	0	0	0	26	26	0	0	0	0
Nematoda	105	20	20	45	23	23	0	0	0	0
Total No. Organisms	**2,879**	**76**	**76**	**61**	**1,316**	**1,316**	**4**	**9**	**20**	**24**

[1] averages are based on abundance estimates in the field; three species, *Balanus glandula, Semibalanus cariosus* and *Chthamalus dalli*, may be present in the area but *B. glandula* is expected to be the dominant species

[2] all other taxonomical groups

Stdev = standard deviation

Tables A4 and A5 summarize the mean abundances and standard deviations of the invertebrate groups present at the MLLW locations sampled in the summer surveys in the Elwha and Dungeness drift cell, respectively. Surveys were conducted three times at FB-3 (summers 2010, 2011, and 2012).

Table A4 - Mean abundances and standard deviations per m^2 of invertebrate groups at MLLW present during summer surveys in the Elwha drift cell

Location	**FB-1**		**FB-2**		**FB-3**		**FB-3**		**FB-3**		**FB-4**		**EB-1**		**EB-2**		**EB-3**		**EB-4**	
Year	**2010**		**2011**		**2010**		**2011**		**2012**		**2012**		**2011**		**2010**		**2011**		**2010**	
Taxonomical Group	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Annelida																				
Polychaeta	1,356	507	9,797	5,185	3,647	4,240	55	21	183	72	0	0	2,122	773	10	15	0	0	0	0
Oligochaeta	88	165	2,101	574	591	708	1,383	688	1,343	1217	16	17	98	48	2,771	931	80	85	4	9
Crustacea																				
Crustacean others	0	0	0	0	0	0	0	0	0	0	8	11	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Harpacticoida	100	47	983	575	109	228	14	20	6	9	0	0	2	4	0	0	0	0	0	0
Ostracoda	4	9	39	48	63	137	0	0	1	2	0	0	0	0	0	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Balanomorpha[1]	0	0	128	194	321	211	11,317	7,773	6,946	2,806	0	0	43	31	12	27	0	0	0	0
Semibalanus cariosus	0	0	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pycnogonida	0	0	17	18	2	4	0	0	0	0	0	0	3	5	0	0	0	0	0	0
Arachnida	0	0	8	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	8	11	1,724	1,984	852	838	2,822	2,360	2,586	1,346	8	11	62	36	622	493	0	0	0	0
Amphipoda	3,700	453	2,630	1,430	429	408	2,504	869	3,176	1169	0	0	266	189	30	23	12	18	0	0
Decapoda	0	0	71	42	99	45	49	20	44	25	0	0	5	11	0	0	0	0	0	0
Hemigrapus nudus	0	0	2	4	7	5	65	42	38	18	0	0	0	0	0	0	0	0	0	0
Insecta																				
Chironomidae	0	0	878	805	14	18	26	37	6	13	0	0	5	4	0	0	0	0	0	0
Insecta larvae	0	0	12	25	2	4	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Mollusca																				
Polyplacophora	0	0	18	13	8	9	0	0	0	0	0	0	2	2	0	0	0	0	0	0
Gastropoda	0	0	2,504	1,017	182	246	1,678	435	1,508	706	0	0	602	128	0	0	0	0	0	0
Patellogastropoda	0	0	13	5	38	20	128	33	145	76	0	0	6	5	0	0	0	0	0	0
Bivalvia	12	18	866	461	46	45	1	2	1	2	0	0	6	2	0	0	0	0	0	0
Misc. Taxa																				
Cnidaria	0	0	2	2	0	0	0	0	0	0	0	0	71	35	0	0	0	0	0	0

Location	FB-1		FB-2		FB-3		FB-3		FB-3		FB-4		EB-1		EB-2		EB-3		EB-4	
Year	**2010**		**2011**		**2010**		**2011**		**2012**		**2012**		**2011**		**2010**		**2011**		**2010**	
Taxonomical Group	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Actiniaria	0	0	59	49	22	16	0	0	1	2	0	0	1	2	0	0	0	0	0	0
Nematoda	0	0	433	72	194	270	8	11	0	0	0	0	80	71	1	2	0	0	0	0
Platyhelminthes	0	0	4	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertea	4	9	161	37	29	35	0	0	8	18	0	0	14	18	2	5	0	0	0	0
Sipuncula	0	0	20	28	5	9	0	0	0	0	0	0	4	9	0	0	0	0	0	0
Echinodermata	0	0	0	0	20	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophiuroidea	0	0	13	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asteroidea	0	0	7	10	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chordata																				
Ascidiacea	0	0	8	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total No. Organisms	**5,272**	**896**	**22,498**	**6,514**	**6,681**	**6,265**	**20,051**	**10,523**	**15,991**	**1714**	**32**	**18**	**3,391**	**913**	**3,449**	**1,363**	**92**	**100**	**4**	**9**

[1] averages are based on abundance estimates in the field; three species, *Balanus glandula, Semibalanus cariosus* and *Chthamalus dalli*, may be present in the area but *B. glandula* is expected to be the dominant species

[2] all other taxonomical groups

StDev = standard deviation

Table A5 - Mean abundances and standard deviations per m^2 of invertebrate groups at MLLW present during the summer surveys in the Dungeness drift cell

Location	BC-1		BC-2		DB-3		DB-4	
Year	**2011**		**2010**		**2011**		**2010**	
Taxonomical Group	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Annelida								
Polychaeta	6,305	2,648	2,503	1,700	4	9	4	9
Oligochaeta	826	643	179	139	0	0	0	0
Crustacea								
Crustacean others	8	18	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0
Harpacticoida	126	80	6	9	0	0	0	0
Ostracoda	6	6	6	12	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0
Balanomorpha[1]	372	167	109	148	0	0	0	0
Semibalanus cariosus	40	89	0	0	0	0	0	0
Pycnogonida	12	20	0	0	0	0	0	0

Location	BC-1		BC-2		DB-3		DB-4	
Year	2011		2010		2011		2010	
Taxonomical Group	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Arachnida	0	0	0	0	0	0	0	0
Isopoda	397	319	112	138	0	0	0	0
Amphipoda	554	418	114	99	56	62	12	18
Decapoda	127	83	14	16	0	0	0	0
Hemigrapus nudus	1	2	1	2	0	0	0	0
Insecta								
Chironomidae	46	30	13	8	0	0	0	0
Insecta larvae	0	0	0	0	0	0	0	0
Mollusca								
Polyplacophora	0	0	0	0	0	0	0	0
Gastropoda	1,290	538	70	45	0	0	0	0
Patellogastropoda	91	29	7	4	0	0	0	0
Bivalvia	33	37	0	0	0	0	0	0
Misc. Taxa								
Cnidaria	3	5	0	0	0	0	0	0
Actiniaria	20	13	7	3	0	0	0	0
Nematoda	496	435	100	213	0	0	0	0
Platyhelminthes	25	40	18	20	0	0	0	0
Nemertea	9	10	20	28	0	0	0	0
Sipuncula	4	9	56	84	0	0	0	0
Echinodermata	0	0	0	0	0	0	0	0
Ophiuroidea	0	0	0	0	0	0	0	0
Asteroidea	0	0	0	0	0	0	0	0
Chordata								
Ascidiacea	0	0	0	0	0	0	0	0
Total No. Organisms	**10,790**	**3,400**	**3,334**	**2,148**	**60**	**71**	**16**	**17**

[1] averages are based on abundance estimates in the field; three species, *Balanus glandula, Semibalanus cariosus* and *Chthamalus dalli*, may be present in the area but *B. glandula* is expected to be the dominant species

[2] all other taxonomical groups

StDev = standard deviation

Table A6 summarizes the mean abundances and standard deviations of the invertebrate groups present at the MLLW locations sampled in the winter survey in the Elwha and Dungeness drift cells.

Table A613 - Mean abundances and standard deviations per m^2 of invertebrate groups at MLLW present during the 2011 winter survey in Elwha and Dungeness drift cells

Location	FB-2		FB-3		EB-2		EB-4		BC-2		DB-4	
Taxonomical Group	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Annelida												
Polychaeta	2,419	1,698	177	225	4	9	0	0	2,910	2,279	0	0
Oligochaeta	1,687	2,401	85	164	0	0	0	0	433	417	0	0
Crustacea												
Harpacticoida	207	261	96	192	0	0	0	0	0	0	0	0
Ostracoda	56	79	14	15	0	0	0	0	0	0	0	0
Balanomorpha[1]	4,241	3,719	2,846	2,615	0	0	0	0	224	191	0	0
Semibalanus cariosus	46	66	0	0	0	0	0	0	0	0	0	0
Pycnogonida	6	8	0	0	0	0	0	0	0	0	0	0
Arachnida	13	19	0	0	0	0	0	0	0	0	0	0
Isopoda	500	620	758	673	0	0	0	0	1,050	710	0	0
Amphipoda	258	325	247	85	624	766	0	0	38	27	32	72
Decapoda	21	22	24	19	0	0	0	0	50	21	0	0
Hemigrapus nudus	10	19	1	2	0	0	0	0	4	5	0	0
Insecta	0	0	1	2	0	0	0	0	0	0	0	0
Chironomidae	14	11	12	8	0	0	0	0	0	0	0	0
Mollusca												
Polyplacophora	9	8	2	5	0	0	0	0	2	4	0	0
Gastropoda	107	77	321	185	4	9	0	0	110	50	0	0
Patellogastropoda	78	74	115	72	0	0	0	0	25	18	0	0
Bivalvia	285	178	11	10	0	0	0	0	6	13	0	0
Misc. Taxa												
Porifera	0	0	0	0	0	0	0	0	1	2	0	0
Actiniaria	57	23	9	12	0	0	0	0	10	2	0	0
Nematoda	107	120	1	2	0	0	4	9	92	103	0	0

Location	FB-2		FB-3		EB-2		EB-4		BC-2		DB-4	
Taxonomical Group	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Platyhelminthes	33	27	22	25	0	0	4	9	0	0	0	0
Nemertea	54	73	5	9	0	0	0	0	8	11	0	0
Sipuncula	4	9	0	0	0	0	0	0	1	2	0	0
Echinodermata	5	9	0	0	0	0	0	0	6	9	0	0
Priapulida	2	5	0	0	0	0	0	0	0	0	0	0
Total No. Organisms	**10,220**	**7,086**	**4,746**	**2,764**	**632**	**759**	**8**	**11**	**4,968**	**2,979**	**32**	**72**

[1] averages are based on abundance estimates in the field; three species, *Balanus glandula, Semibalanus cariosus* and *Chthamalus dalli*, may be present in the area but *B. glandula* is expected to be the dominant species

[2] all other taxonomical groups
StDev = standard deviation

Tables A7 and A8 summarize the mean abundances and standard deviations of the invertebrate groups present in the wrack line sampled in the summer surveys in the Elwha and Dungeness drift cells, respectively. Surveys were conducted three times at FB-3 (summers 2010, 2011, and 2012).

Table A7 - Mean abundances and standard deviations per m^2 of invertebrate groups in the wrack line present during summer surveys in the Elwha drift cell

Location	FB-1		FB-1		FB-2		FB-3		FB-3		FB-3		FB-4		EB-1		EB-2	
Year	**2010**		**2012**		**2011**		**2010**		**2011**		**2012**		**2012**		**2011**		**2010**	
Taxonomical Group	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Annelida																		
Polychaeta	0	0	0	0	25	56	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	22,775	26,267	80,275	76,819	10,850	15,242	2,375	2,325	21,475	41,349	3,300	4,888	450	563	9,725	12,259	0	0
Crustacea																		
Harpacticoida	0	0	25	56	0	0	0	0	0	0	0	0	0	0	0	0	150	335
Arachnida	0	0	100	163	850	797	1,500	713	1175	577	50	68	100	56	100	137	75	112
Isopoda	0	0	25	56	0	0	25	56	0	0	0	0	0	0	0	0	0	0
Amphipoda	250	250	15,525	7,161	78,950	30,488	47,500	35,243	115,050	72,245	9,725	8,358	16,400	17,025	20,875	11,285	39,475	37,636
Insecta	0	0	0	0	0	0	0	0	0	0	0	0	25	56	0	0	0	0
Insecta larvae	0	0	0	0	4,150	8,793	225	311	25	56	0	0	0	0	3,900	4,677	25	56
Chironomidae	0	0	0	0	25	56	0	0	25	56	0	0	0	0	0	0	0	0
Mollusca																		
Gastropoda	200	168	1,925	1,473	0	0	0	0	25	56	0	0	25	56	25	56	0	0
Bivalvia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	68
Misc. Taxa[1]																		
Nematoda	0	0	25	56	0	0	100	224	0	0	0	0	0	0	0	0	0	0

Location	FB-1		FB-1		FB-2		FB-3		FB-3		FB-3		FB-4		EB-1		EB-2	
Year	**2010**		**2012**		**2011**		**2010**		**2011**		**2012**		**2012**		**2011**		**2010**	
Taxonomical Group	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Nemertea	0	0	25	56	0	0	50	112	0	0	0	0	0	0	0	0	0	0
Total No. Organisms	23,225	26,451	97,925	79,837	94,850	28,082	51,775	35,173	137,775	83,291	13,075	11,879	17,000	17,379	34,625	18,873	39,775	37,537

[1] all other taxonomical groups

StDev = standard deviation

Table A8 - Mean abundances and standard deviations per m^2 of invertebrate groups in the wrack line present during summer surveys in the Dungeness drift cell

Location	**BC-1**		**CB-2**		**DB-3**		**DB-4**	
Year	**2011**		**2010**		**2011**		**2010**	
Taxonomical Group	**Mean**	**StDev**	**Mean**	**Mean**	**Mean**	**StDev**	**Mean**	**StDev**
Annelida								
Polychaeta	0	0	0	0	50	112	0	0
Oligochaeta	50	112	9,900	9,435	0	0	0	0
Crustacea							0	0
Harpacticoida	0	0	0	0	0	0	0	0
Arachnida	100	137	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0
Amphipoda	26,500	22,840	800	891	7,200	3,801	0	0
Insecta	0	0	0	0	0	0	0	0
Insecta larvae	150	224	0	0	100	137	0	0
Chironomidae	0	0	0	0	0	0	0	0
Mollusca							0	0
Gastropoda	0	0	0	0	0	0	0	0
Bivalvia	0	0	0	0	0	0	0	0
Misc. Taxa[1]							0	0
Nematoda	0	0	0	0	0	0	0	0
Nemertea	0	0	0	0	0	0	0	0
Total No. Organisms	26,800	23,046	10,700	9,883	7,350	3,736	0	0

[1] all other taxonomical groups

StDev = standard deviation