



Intertidal Monitoring in the North Coast and Cascades Network

Sand Beach Monitoring 2011 Annual Report

Natural Resource Data Series NPS/NCCN/NRDS—2014/632



ON THE COVER

The sand beach at Kalaloch on the southern Olympic coast.

Photograph by: Steven Fradkin

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Abstract

Sand beach monitoring is one component of the North Coast and Cascades Network Intertidal Monitoring Protocol. This monitoring component focuses on the community structure of infaunal marine invertebrates and the physical structure of 7 sand beaches within Olympic National Park. Sand beach infauna is closely linked to its physical habitat. Sand beaches are a major habitat type in Olympic National Park, making up approximately 30% of the intertidal zone. These beaches play an important role in both nutrient cycling and food web dynamics in the nearshore ocean. This report presents data from the 2011 monitoring field season. Three shore-normal transects were sampled at each beach. Sampling included infaunal organism abundance, beach sediment composition, and beach elevation profiles. Sediments for most beaches were characterized as well sorted, fine sand beaches with shallow slopes. The exception was Toleak beach, which had moderately sorted, medium sand. These physical differences translated to infaunal community structure differences. A total of 8 taxa were found on the Olympic beaches. All beaches, except Toleak, had similar community structure with an average of 5.6 taxa. The Toleak infauna was significantly different and was substantially depauperate relative to the other beaches, with only 2.3 taxa. In particular, Toleak lacked most species of amphipods, a group that plays an important role in sand beach energy transfer, and all polychaete worms. These results, conjunction with similar results from the 2010 field season suggest that the physical and biological structure of Toleak is significantly different from the other OLYM sand beaches being monitored and is not appropriate for inclusion in this monitoring program. After the 2011 field season, Toleak will cease to be monitored.

Acknowledgments

The OLYM field crew included: B. Baccus, N. Bankston, J. Jones, A. Pfleegee, and L. Loken. John Boetsch constructed the database and provided care and feeding of it. Dr. Catharine Copass (NCCN) and Melissa Miner (University of California, Santa Cruz) provided informal peer review of the draft manuscript.

Introduction

This report presents data from the 2011 field season for the sand beach component of the North Coast and Cascades Network (NCCN) Intertidal Monitoring Protocol (Fradkin and Boetsch 2012a). The Intertidal Monitoring Protocol is part of the Inventory and Monitoring Program of the National Park Service (NPS). This program focuses on “vital signs”, which are defined as “information-rich attributes that are used to track the overall condition, or “health” of park natural resources to provide early warning of situations that require intervention” (Fancy et al. 2009). Monitoring has been implemented throughout the National Park system; for this purpose, 270 park units have been organized by ecoregion into 32 networks (Fancy et al. 2009). As one of these networks, the NCCN is composed of eight NPS units, including three parks that contain intertidal resources: Olympic National Park (OLYM), Lewis and Clark National Historical Park (LEWI), and San Juan Island National Historical Park (SAJH). Intertidal communities, particularly those in sand beach habitats, were identified as a key vital sign at numerous workshops developing the NCCN Inventory and Monitoring Program from 2000-2005 (Weber et al. 2009). This prioritization was based on a combination of perceived resource value, logistical and budgetary feasibility, and the current state of scientific methodology. Emphasis was placed on vital sign components that may provide early warning responses to the effects of global climate change and pollution. In contrast to other intertidal habitats within the NCCN, such as rocky intertidal, sand beaches supporting productive infaunal communities are found only within Olympic National Park. The mixed-coarse sediment beaches occurring at the American Camp unit of SAJH are dominated by gravel and have correspondingly low productivity and diversity. Such coarse beaches require substantially different monitoring methodologies (McLachlan 1990, McLachlan and Jaramillo 1995) and are not considered in the NCCN protocol. In LEWI, there is only a single sand beach of which only a ¼-mile long segment of the entire beach (>5 mi) is within the park boundary. As an Oregon state beach, this section of beach is considered a state highway and receives heavy automobile traffic, and thus cannot be sampled safely. As such, the sand beach monitoring component is conducted solely in Olympic National Park. Other monitoring components in the protocol include rocky intertidal community and intertidal temperature monitoring. The results from these components will be presented in separate reports.

Study Area

The coastal unit of OLYM, located on the outer Pacific coast of northwest Washington on the Olympic Peninsula (Figure 1), was incorporated into Olympic National Park in 1953. The intertidal zone was added to the park in 1986. Approximately 75% of this continuous stretch of coastline was designated wilderness by Congress in 1988 (Klinger et al. 2007). The coastal unit with its offshore islands has approximately 98 miles of diverse intertidal habitats, including cliffs, rocky platforms, boulder field, cobble beaches, gravel beaches, sand/gravel beaches, high energy fine sand beaches, and several small estuaries. If considered as a separate NPS unit, the OLYM coastal strip would be the 4th largest park (of 8) in the NCCN. The OLYM intertidal is one of the most biologically- and habitat-diverse shorelines on the west coast of North America (Blanchette et al. 2008, Schoch et al. 2006). The park shoreline can be broken up into four segments, or nearshore cells (Figure 1), that are characterized by differences in temperature and salinity (Schoch 1999). There are 28 sand beaches on the OLYM coast, occupying ~30% of the park shoreline.



Figure 1. Location of 2011 sand beach monitoring sites within the coastal strip of Olympic National Park (OLYM). Colored beach segments denote nearshore cells characterized by different temperature and salinity (Schoch 1999).

Methods

The methodology for sampling sand beaches is covered in detail in the NCCN Intertidal Monitoring Protocol (Fradkin and Boetsch 2012a) and is briefly summarized here.

Field Sampling

Seven beaches were sampled in 2011 (Figure 1). Three transects are randomly determined anew each year on each target beach. Transects were located in the field via GPS. The date, tidal elevation and time sampling started for each site in 2011 is presented in Table 1. Each vertical transect was shore-normal, starting from the most recent high tide line and extending to the water line. Sampling stations for biota were spaced every 7.5 m along the top 60 m of each transect. At each station, four sediment cores were extracted and passed through a 1 mm sieve to retain all macroscopic infaunal organisms (Figure 2). Sediment cores were 10 cm diameter, extending to a depth of 10 cm. All organisms within cores were counted and identified to the appropriate taxonomic level (see Appendix A). Sand beaches can have short sections where coarse sediments (gravel) accumulate via variation in wave action and long-shore currents. These areas represent very different, physically harsh, habitat types that support few infauna, and thus are not comparable to the surrounding sand beach areas. Where random transect locations landed on such coarse substrates (>40% gravel), a new random transect was selected.

Sediment samples were taken along the top 60 m of each transect at 15 m intervals (Figure 2). Cores were transported to the lab, where they were dried and sorted through a column of graded Tyler sieves. These size fractions were then weighed to determine sediment composition. Beach elevation profiles were also determined for the entirety of each transect. Profiles were surveyed using a laser auto-level to determine elevations from the most recent high tide line to the current water level at 7.5 m intervals.

Table 1. Date, time, and tidal height during sampling of sand beaches (north to south) in 2011.

Site	Date	Tide Height (ft)	Time Sampling Started (24 hr)
SHI	6/14/2011	-1.9	6:08
SAN	6/13/2011	-1.4	5:15
CED	7/2/2011	-1.9	8:11
SEC	6/19/2011	-1.1	9:51
TOL	6/29/2011	-1.1	6:06
RUB	8/3/2011	-0.7	9:47
KAL	7/16/2011	-1.3	8:05

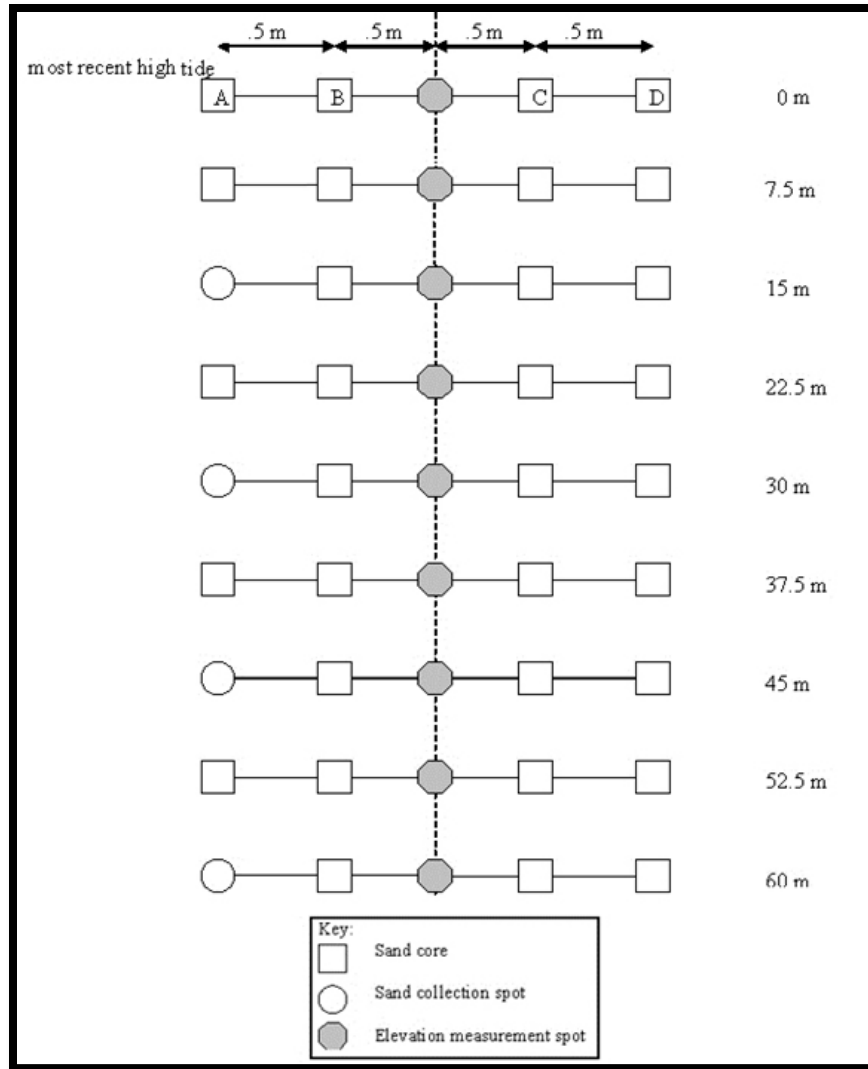


Figure 2. Schematic diagram of a sand beach monitoring transect. Each transect spans a shore-normal 2 m wide belt from the most recent high tide line to 60 m seaward. Elevations were measured at each level along the centerline (shaded symbol), and beach infauna were sampled at four stations (open symbols) at each level. Sand cores were collected for sediment size composition at four levels (open circles).

Analysis

Sediment composition and description was determined using the GRADISTAT (version 8.0) particle size analysis software (Blott and Pye 2001) following the analytic methods of Folk (1954). Beach Index (BI), an index combining slope, sand, and tidal values to characterize beach type was also computed according to McLaughlin and Brown (2006):

$$BI = \log_{10} (sand * tide/slope)$$

where *sand* is the mean particle size (Φ), *tide* is the maximum spring tidal range (m), and *slope* is the beach face slope of each transect.. Beach elevation profile data were analyzed in JMP 7.0 (SAS 2007) to determine beach face slopes.

Comparisons of sand beach infaunal community structure were made between beaches and among nearshore cells. For each transect, invertebrate count data were used to estimate the number of individuals per strip transect (IST), after Defeo and Rueda (2002):

$$IST = \frac{\sum_i q_i}{n} w$$

where q_i is the density of infauna in each core, n is the number of cores per transect and w is the width of the transect. IST data were analyzed using the multivariate methods in PRIMER-V6 (Clarke and Gorley 2006). Data were fourth root transformed to deemphasize the most abundant organisms (*sensu* Clarke and Warwick 2001). Bray-Curtis similarities were generated and represented with multidimensional scaling (MDS). Similarity percentage analyses (SIMPER) were used to identify taxa contributing the most to average similarity within beaches, and analysis of similarity (ANOSIM) was used to test the significance of differences in community structure between beaches. Taxonomic distinctness, a biodiversity analysis used to measure the relatedness of species within samples (Warwick and Clarke 1995), was conducted using the TAXTDEST procedure and a master taxa list for all beaches.

Results and Discussion

Sediment Composition and Beach Slope

Monitored OLYM sand beaches are classified as intermediate meso-tidal beaches as defined by McLachlan and Brown (2006). With the exception of Toleak beach, these beaches were all well sorted (i.e., relatively uniform sediment composition), fine sand, moderately sloping beaches that are intermediate in their dissipation of wave energy across their face (Table 2). The sediment grain size composition was dominated by fine sand (Table 2, Figure 3). Toleak beach was moderately sorted (i.e., less uniform sediment composition) and dominated by medium sand with a sizeable component of gravelly sand (Table 2, Figure 3).

Beach face profiles illustrate the moderate slopes found on the target beaches, with the exception of Toleak which was more steeply sloped (Table 2, Figure 4). Beaches with slopes less than 10 generally indicate coarse sand and gravel beaches (McLachlan and Brown 2006).

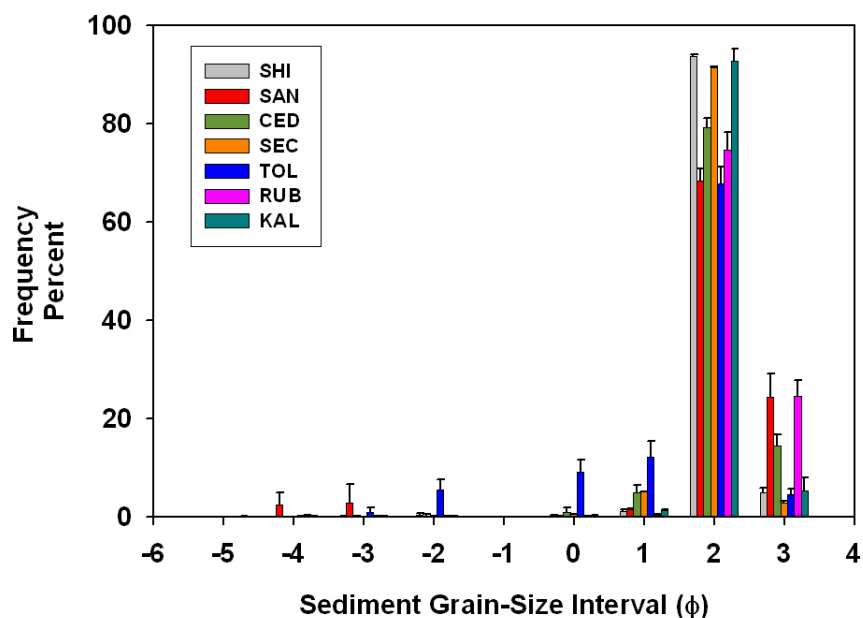


Figure 3. Beach sediment grain-size (Phi) frequency histogram for all seven Olympic study beaches (from north to south) in 2011. Histogram bars are average values (± 1 SE) for three replicate transects per beach. Small phi (Φ) values denote larger grain sizes. Sand has Φ values between -1 and 4, while gravel has values <-1 . The most abundant grain-size ($\Phi = 2$) was fine sand.

Table 2. Beach slope*, beach index, sediment grain-size composition measures, and composition type description. Values are averages of three replicate transects per beach. Beach slope* is the reciprocal of the beach face slope. Beach index combines slope, mean sand particle size, and maximum spring tidal range (4.12 m) into a single beach characterization measure ranging from 0 to 4. 0 represents beaches with coarse sand, small tides and small waves, while 4 represents fine sand, large tides, and big waves. Olympic National Park study beaches are intermediate meso-tidal beaches (McLachlan and Brown 2006).

Beach	Beach slope*	Beach index (log Φ m)	Mean grain size	Mean Φ	Sediment type	Mean sorting value	Sorting type	Mean skewness	Skewness type	Mean kurtosis	Kurtosis type
SHI	17.0	2.34	229.9	2.1	Fine sand	0.09	Very well	0.03	Symmetrical	0.95	Mesokurtic
SAN	19.3	2.39	230.5	2.1	Fine sand	0.16	Very well	-0.11	Coarse	2.42	Very leptokurtic
CED	21.5	2.43	240.5	2.1	Fine sand	0.26	Very well	0.04	Symmetrical	3.20	Extremely leptokurtic
SEC	14.2	2.25	239.7	2.1	Fine sand	0.17	Very well	-0.23	Coarse	1.80	Very leptokurtic
TOL	6.0	1.83	318.2	1.7	Med. sand	0.56	Moderately sorted	-0.63	Very coarse	1.88	Very leptokurtic
RUB	18.2	2.37	229.1	2.1	Fine sand	0.13	Very well	0.16	Fine	1.84	Very leptokurtic
KAL	16.8	2.34	229.8	2.1	Fine sand	0.07	Very well	0.00	Symmetrical	0.74	Platykurtic

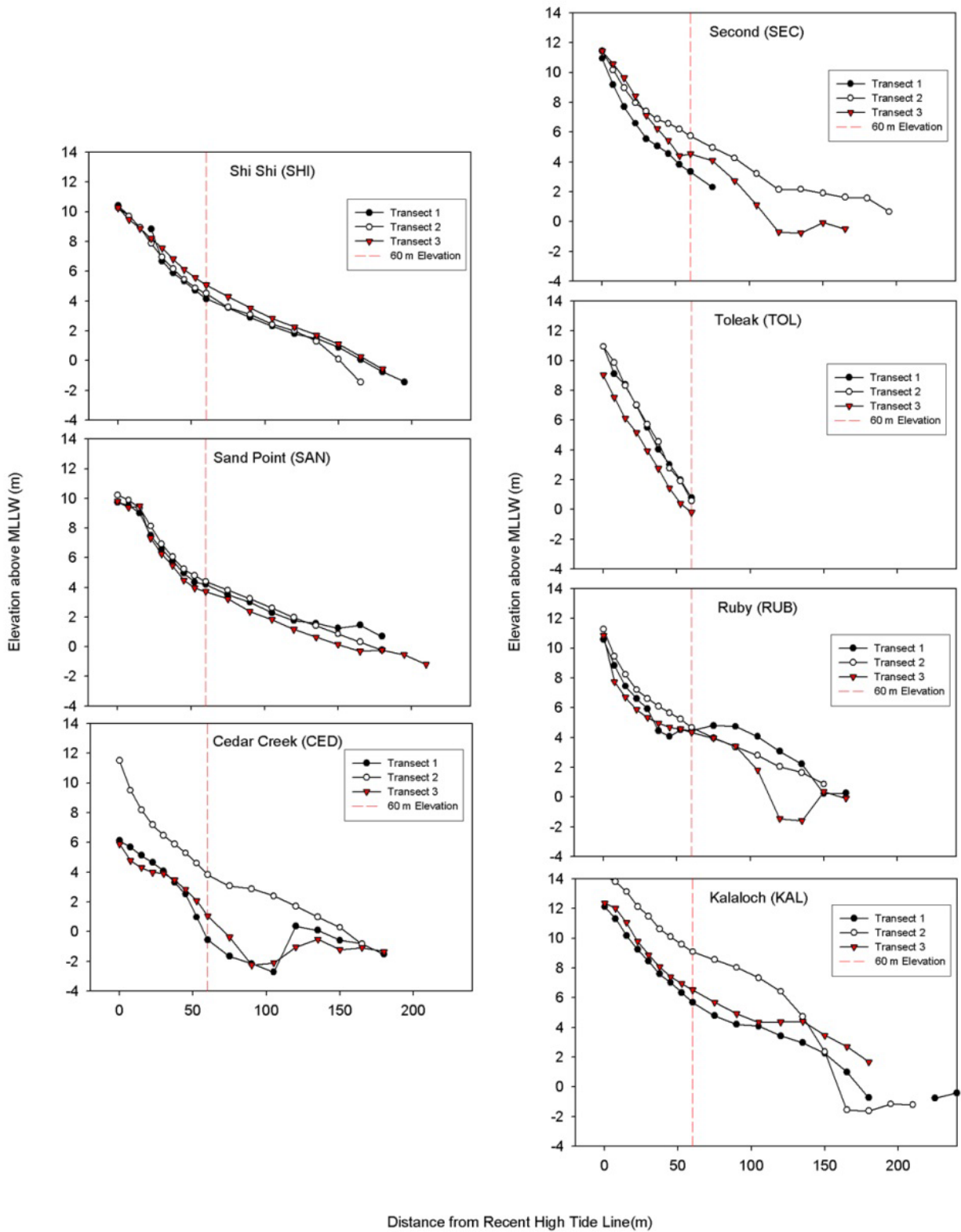


Figure 4. Beach face profiles of triplicate shore normal transects at each sand beach monitoring site in Olympic National Park in 2011. Transects start from most recent high tide line and extend to water level at time of sampling. Red vertical dotted lines denote the lowest extent of benthic infaunal sampling (60 m).

Infaunal Community Structure

The infaunal community composition of replicate beach transects was similar, as illustrated by the clustering of triplicate points in the MDS analysis (Figure 5). Significant community structure differences between nearshore cell beaches were detected by one way analysis of similarities (ANOSIM $R=0.402$, $p=0.001$) between the nearshore cell containing Toleak beach (cell 3) and the three other nearshore cells (cells 1, 2 and 4; $R=0.574$, $p=0.024$, $R=0.459$, $p=0.006$ and $R=0.717$, $p=0.002$ respectively Figure 5). However, once Toleak was removed from the analysis, no differences in community structure between any of the four nearshore cells existed ($R=0.035$, $p=0.265$; Figure 6). This result is consistent with the similarity of sediment composition and slopes across beaches, implying that the relatively coarse grained, steeply sloped physical structure of Toleak beach favors a different infaunal community structure. This result is also consistent with similar monitoring data from 2010 (Fradkin and Boetsch 2012b).

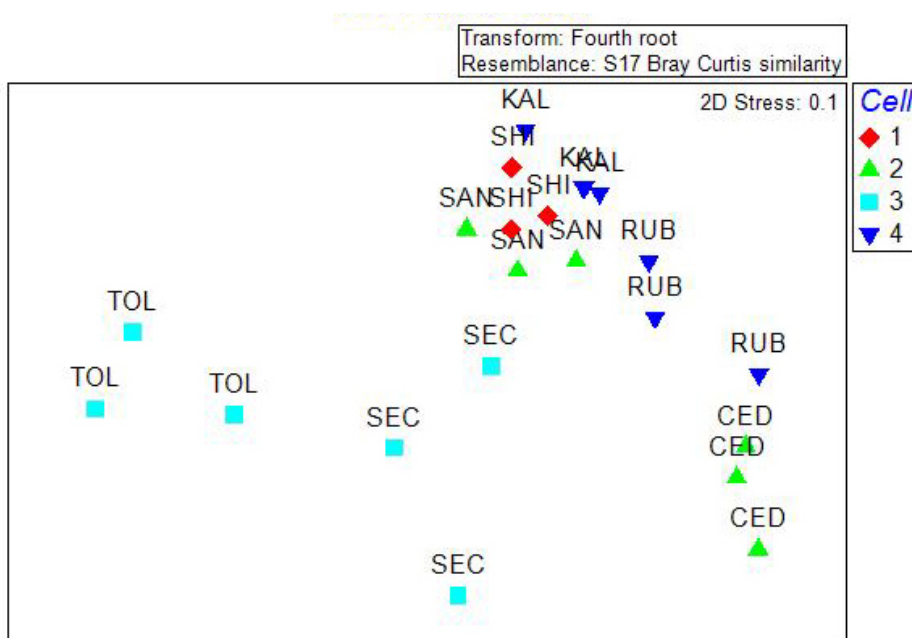


Figure 5. Sand beach infaunal assemblages from all 2011 Olympic study beaches. MDS plot for fourth root transformed taxa counts from nine taxa from three replicate transects within each of seven beaches. Symbols represent nearshore cells and labels represent beach codes..

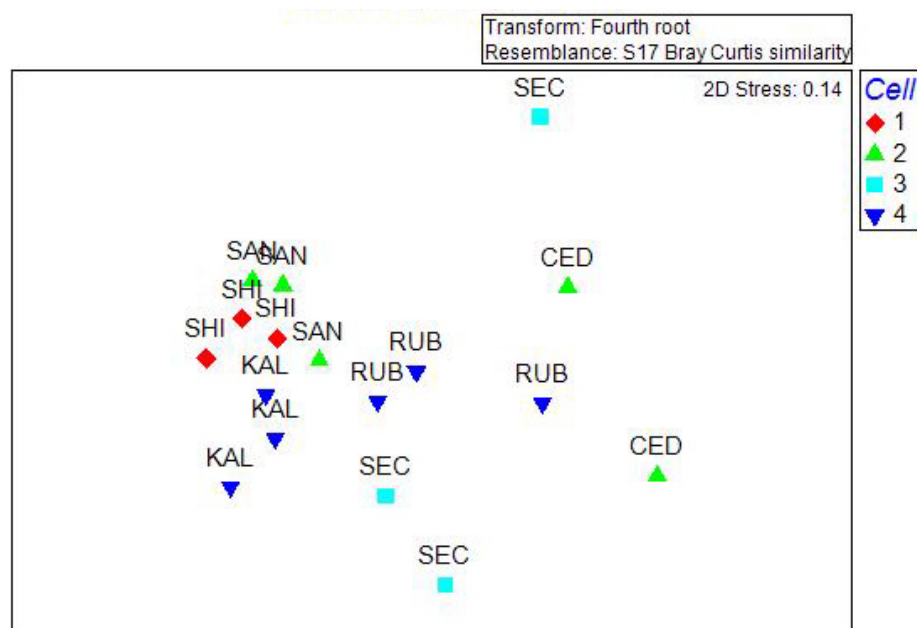


Figure 6. Sand beach infaunal assemblages from all 2011 OLYM study beaches except Toleak beach. MDS plot for square root transformed taxa counts from nine taxa from three replicate transects within each of six beaches.

A SIMPER analysis examining similarities in community structure shows Olympic sand beaches in 2011 were structured around *Eohaustorius* amphipods, in addition to *Excirolana* isopods and the bloodworm *Euzonus mucronatus* (Table 3). The mean IST of *Eohaustorius* spp., *Probosciotus loquax*, *Euzonus mucronatus*, and *Excirolana* spp. are illustrated in Figure 7. A SIMPER analysis of dissimilarities shows that Toleak differed from the other beaches largely due to the absence of *Eohaustorius* (Table 4). The average dissimilarity of all beaches from each other, without Toleak, was 41.8 ± 11.7 , while the average dissimilarity of all beaches from Toleak was 82.5 ± 7.9 . Haustoriid amphipods are known to be dominant taxa on North American fine sandy beaches (McLachlan and Brown 2006) and their absence at Toleak is consistent with the coarser grain size and steeper slopes found there.

Table 3. Infaunal taxonomic contribution to similarity of community structure at seven OLYM study beaches as determined by SIMPER analysis. Taxa shown are those contributing up to a cut-off of ~80% cumulative percent contribution. Beaches are arranged latitudinally from north to south.

Beach	Species	Average Abundance	Average Similarity	Similarity SD ratio	Percent Contribution	Cumulative Percent
SHI	<i>Eohaustorius spp.</i>	2.01	24.28	19.81	29.01	29.01
	<i>Probosciniotus loquax</i>	1.45	16.92	9.53	20.22	49.23
	<i>Excirolana spp.</i>	1.17	13.66	20.48	16.32	65.55
	<i>Euzonus mucronatus</i>	1.21	13.62	12.15	16.27	81.82
SAN	<i>Eohaustorius spp.</i>	1.79	24.99	13.32	29.16	29.16
	<i>Excirolana spp.</i>	1.19	16.67	9.88	19.45	48.62
	<i>Euzonus mucronatus</i>	1.15	15.57	18.31	18.17	66.79
	<i>Megalorchestia spp.</i>	1.06	14.58	14.09	17.02	83.8
CED	<i>Eohaustorius spp.</i>	1.31	38.79	17.39	51.17	51.17
	<i>Phoxocephalidae</i>	0.68	19.67	7.57	25.95	77.12
	<i>Euzonus mucronatus</i>	0.89	12.07	0.58	15.93	93.05
SEC	<i>Eohaustorius spp.</i>	1.12	27.13	5.97	50.14	50.14
	<i>Excirolana spp.</i>	0.7	16.97	4.08	31.36	81.5
TOL	<i>Excirolana spp.</i>	0.74	38.93	17.97	50	50
	<i>Megalorchestia spp.</i>	0.7	38.93	17.97	50	100
RUB	<i>Eohaustorius spp.</i>	1.89	28.37	24.67	35.42	35.42
	<i>Phoxocephalidae</i>	0.75	12.94	6.79	16.16	51.57
	<i>Polychaete spp.</i>	0.73	12.52	5.63	15.64	67.21
	<i>Euzonus mucronatus</i>	0.59	9.82	4.92	12.26	79.47
KAL	<i>Eohaustorius spp.</i>	3.05	33.65	18.29	39.59	39.59
	<i>Probosciniotus loquax</i>	1.6	15.48	3.6	18.21	57.8
	<i>Polychaete spp.</i>	0.94	9.55	22.12	11.24	69.04
	<i>Excirolana spp.</i>	0.87	9.37	10.81	11.03	80.07

Table 4. Pairwise comparisons of infaunal taxonomic contribution to differences (dissimilarity) in community structure between all Olympic study beaches and Toileak beach (TOL) as determined by Similarity Percentage Analysis (SIMPER). Taxa shown are those contributing up to a cut-off of ~80% cumulative percent contribution. The average dissimilarity of all beaches (except TOL) from each other is 41.76 ± 11.73 .

Beach	Average Dissimilarity from TOL	Taxa	Comparative Beach Average Abundance	TOL Beach Average Abundance	Average Dissimilarity	Dissimilarity SD ratio	Percent Contribution	Cumulative Percent
CED	92.58	<i>Eohaustorius spp.</i>	1.31	0.19	23.69	3.07	25.59	25.59
		<i>Euzonus mucronatus</i>	0.89	0	17.12	1.32	18.49	44.08
		<i>Excirolana spp.</i>	0	0.74	15.57	4.7	16.82	60.9
		<i>Megalorchestia spp.</i>	0	0.7	14.58	6.54	15.75	76.66
KAL	69.82	<i>Eohaustorius spp.</i>	3.05	0.19	27.8	6.83	39.81	39.81
		<i>Probosciniotus loquax</i>	1.6	0	15.72	3.58	22.52	62.33
		<i>Polychaete spp.</i>	0.94	0	9.07	8.38	12.98	75.31
		<i>Euzonus mucronatus</i>	0.66	0	6.06	1.09	8.68	84
RUB	85.51	<i>Eohaustorius spp.</i>	1.89	0.19	23.86	3.7	27.91	27.91
		<i>Phoxocephalidae</i>	0.75	0	10.73	5.18	12.55	40.45
		<i>Polychaete spp.</i>	0.73	0	10.67	4.07	12.48	52.94
		<i>Megalorchestia spp.</i>	0	0.7	9.96	6.07	11.65	64.58
		<i>Nephtys spp.</i>	0.61	0	8.85	4.25	10.35	74.94
		<i>Euzonus mucronatus</i>	0.59	0	8.46	4.54	9.89	84.83
SAN	85.3	<i>Eohaustorius spp.</i>	1.79	0.19	19.08	4.34	31	31
		<i>Euzonus mucronatus</i>	1.15	0	13.62	7.16	22.13	53.13
		<i>Probosciniotus loquax</i>	0.82	0	9.78	5.59	15.9	69.03
		<i>Excirolana spp.</i>	1.19	0.74	5.41	2.44	8.8	77.83
		<i>Nephtys spp.</i>	0.38	0	4.35	1.32	7.07	84.9
SEC	76.94	<i>Eohaustorius spp.</i>	1.12	0.19	19.55	2.06	37.45	37.45
		<i>Megalorchestia spp.</i>	0.38	0.7	8.37	0.97	16.04	53.49
		<i>Phoxocephalidae</i>	0.44	0	8.2	1.32	15.72	69.21
		<i>Excirolana spp.</i>	0.7	0.74	4.76	1.45	9.12	78.34
		<i>Euzonus mucronatus</i>	0.16	0	4.7	0.66	9.01	87.34

Table 4. Pairwise comparisons of infaunal taxonomic contribution to differences (dissimilarity) in community structure between all Olympic study beaches and Toileak beach (TOL) as determined by Similarity Percentage Analysis (SIMPER). Taxa shown are those contributing up to a cut-off of ~80% cumulative percent contribution. The average dissimilarity of all beaches (except TOL) from each other is 41.76 ± 11.73 (continued).

Beach	Average Dissimilarity from TOL	Taxa	Comparative Beach Average Abundance	TOL Beach Average Abundance	Average Dissimilarity	Dissimilarity SD ratio	Percent Contribution	Cumulative Percent
SHI	84.62	<i>Eohaustorius spp.</i>	2.01	0.19	19.9	4.6	30.81	30.81
		<i>Probosciniotus loquax</i>	1.45	0	15.99	4.54	24.76	55.58
		<i>Euzonus mucronatus</i>	1.21	0	13.18	5.66	20.4	75.98
		<i>Excirolana spp.</i>	1.17	0.74	4.59	1.76	7.11	83.09

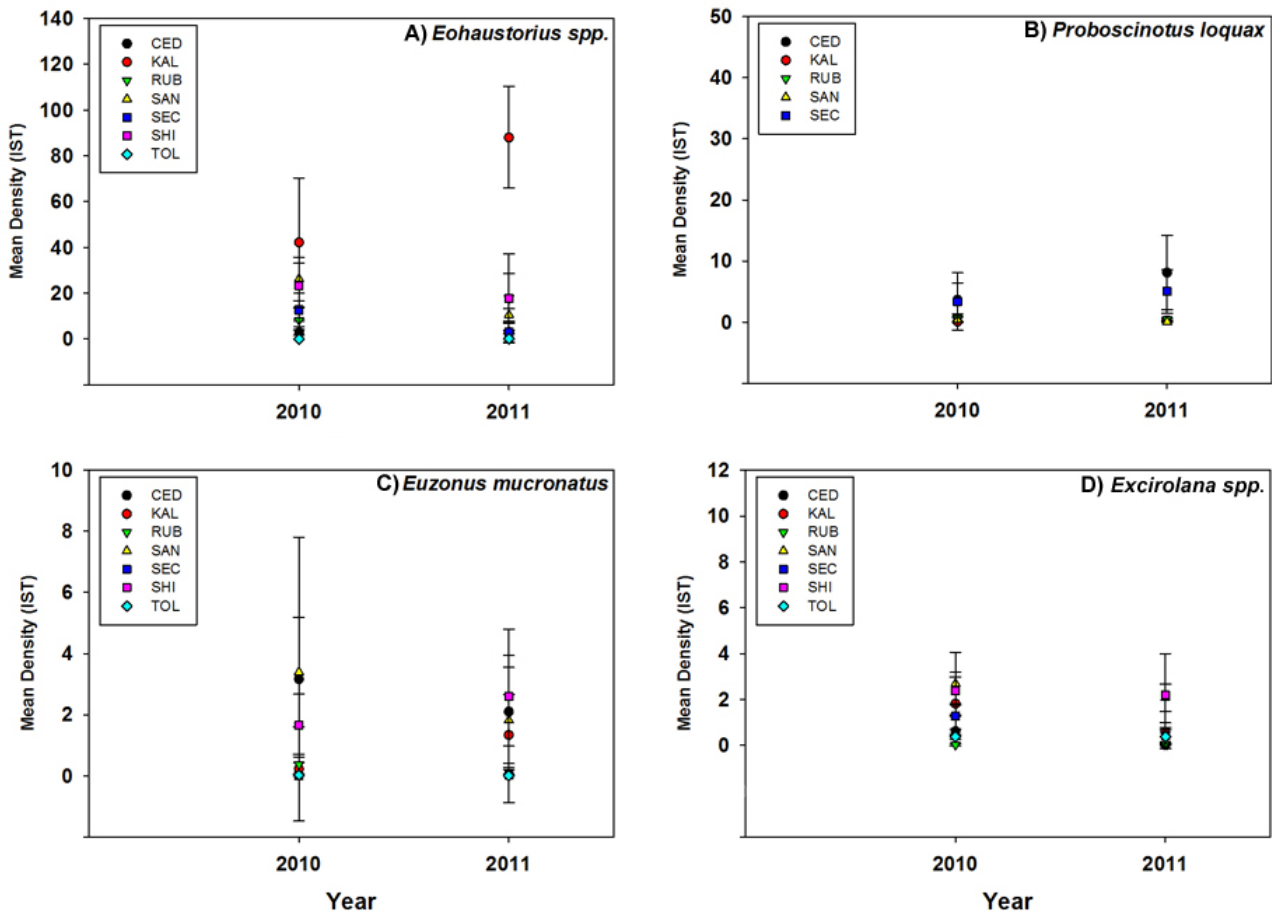


Figure 7. Mean abundances (± 1 SD) of the four dominant sand beach infaunal taxa present on Olympic sandy beaches from 2010-2011. A) The amphipod *Eohaustorius* spp., B) the amphipod *Probosciniotus loquax*, C) the polychaete *Euzonus mucronatus*, D) the isopod *Excirolana* spp.

Taxonomic Distinctness

Average taxonomic distinctness is the average taxonomic distance apart (phylogenetically) of all species pairs within a species list (Clarke and Gorley 2006). Taxonomic distinctness measures the taxonomic breadth of a sample. Figure 8 displays a funnel plot with simulated 95% probability limits for average taxonomic distinctness based on 999 taxa sub-lists drawn randomly from a master list of 9 taxa. Toleak beach had many fewer taxa (mean of 2.3) than other beaches (group average of 5.6; Appendix A). Second Beach (SEC) had an individual transect with significantly narrower taxonomic breadths (i.e. low average taxonomic distinctness as determined by points falling outside of the 95% probability limit), illustrating the utility of replicate transects.

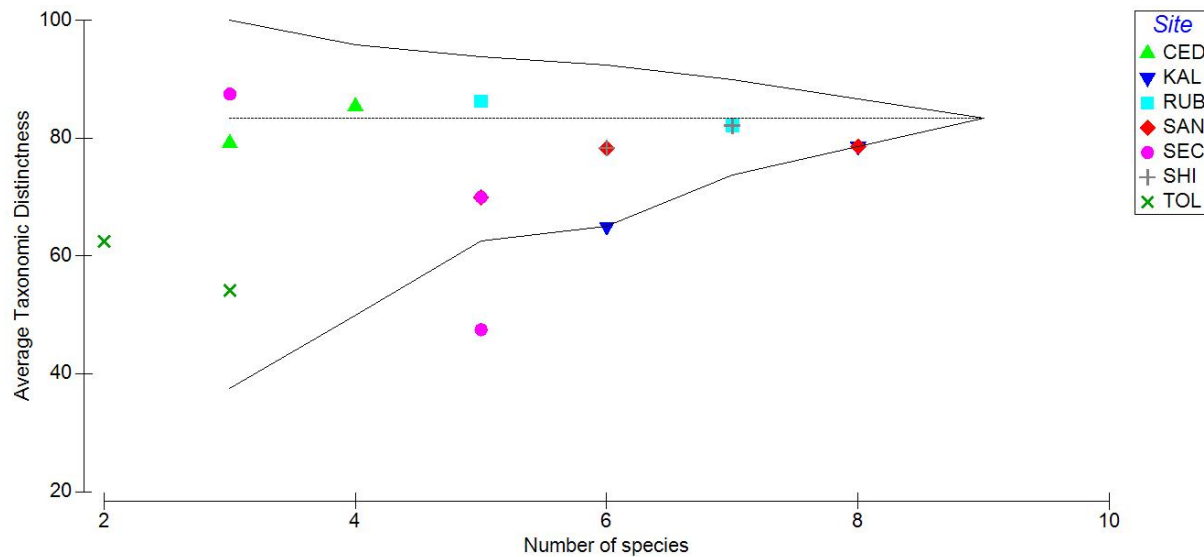


Figure 8. Funnel plot of average taxonomic distinctness ($\Delta+$) versus number of species in taxonomic sub-list for 2011 sand beach infaunal assemblages in each transect at each beach. Thick lines indicate 95% probability limits for simulated $\Delta+$ values. The dotted line denotes $\Delta+$ for the entire taxa list. Symbols denote actual $\Delta+$ values for the beach/transect combinations. Not all symbols are visible due to overlap of symbols

Conclusions

The target sand beaches sampled as part of the NCCN Intertidal Monitoring Protocol span the latitudinal gradient of the 65-mile Olympic National Park shoreline. The 2011 sampling reported here suggests that, with exception of Toleak beach, the physical and biological structure of these beaches is very similar to each other. Toleak beach was found to be structurally and faunally different from the other monitoring beaches. These results are consistent with the results from the 2010 sampling season (Fradkin and Boetsch 2012b), suggesting that Toleak is a consistently different beach through time. These seven sand beaches were selected to represent replicate beaches dispersed across the 65 mile latitudinal gradient of the Olympic coastline. While superficially appearing similar to the casual observer on the beach, Toleak is truly not a replicate similar to the other six beaches. As such, Toleak beach will be dropped from the NCCN monitoring program after the 2011 sampling season. The removal of Toleak from the sampling design will modestly reduce the number of sentinel beaches to six, but will not affect the ability to detect temporal trends on a beach. The remaining monitoring beaches still represent a powerful latitudinal array of sites in which changes associated with climate change and oil spills along the Olympic coast can be detected.

Literature Cited

- Blanchette, C. A., C. M. Miner, P. T. Raimondi, D. Lohse, K. E. K. Heady, and B. R. Broitman. 2008. Biogeographical patterns of rocky intertidal communities along the Pacific coast of North America. *Journal of Biogeography* 35:1593-1607.
- Blott, S. J., and K. Pye. 2001. GRADISTAT: A grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms* 26:1237-1248.
- Clarke, K. R., and R. N. Gorley. 2006. PRIMER v6: User manual/tutorial. PRIMER-E, Plymouth, UK.
- Clarke, K. R., and R. M. Warwick. 2001. Change in marine communities: An approach to statistical analysis and interpretation. 2nd edition. PRIMER-E, Plymouth, UK.
- Defeo, O., and M. Rueda. 2002. Spatial structure, sampling design and abundance estimates in sandy beach macroinfauna: Some warnings and new perspectives. *Marine Biology* 140:1215-1225.
- Fancy, S. G., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in US national parks. *Environmental Monitoring and Assessment* 151:161-174.
- Folk, R. L. 1954. The distinction between grain size and mineral composition in sedimentary-rock nomenclature. *Journal of Geology* 62:344-359.
- Fradkin, S. C., and J. R. Boetsch. 2012a. Intertidal monitoring protocol for the North Coast and Cascades Network. Natural Resource Report NPS/NCCN/NRR-2012/512. National Park Service, Fort Collins, Colorado.
- Fradkin, S. C., and J. R. Boetsch. 2012b. Intertidal monitoring in the North Coast and Cascades Network: Sand beach monitoring 2010 annual report. Natural Resource Report NPS/NCCN/NRTR—2012/592. National Park Service, Fort Collins, Colorado.
- Klinger, T., R. M. Gregg, K. Herrmann, K. Hoffman, J. Kershner, J. Coyle, and D. Fluharty. 2007. Assessment of coastal water resources and watershed conditions at Olympic National Park, Washington. Natural Resource Technical Report NPS/NRPC/WRD/NRTR-2007/068. National Park Service, Fort Collins, Colorado.
- McLachlan, A. 1990. Dissipative beaches and macrofauna communities on exposed intertidal sands. *Journal of Coastal Research* 6:57-71.
- McLachlan, A., and A. C. Brown. 2006. The ecology of sandy shores, 2nd edition. Academic Press, Burlington, Massachusetts.
- McLachlan, A., and E. Jaramillo. 1995. Zonation on sandy beaches. *Oceanography and Marine Biology: An annual review*. 33:305-335.
- SAS. 2007. JMP 7 statistics and users guide. SAS Institute Inc. Cary, North Carolina.

- Schoch, G. C. 1999. Untangling the complexity of nearshore ecosystems: Examining issues of scaling and variability in benthic communities. Dissertation. Oregon State University, Corvallis, Oregon.
- Schoch, G. C., B. A. Menge, G. Allison, M. Kavanaugh, S. A. Thompson, and S. A. Wood. 2006. Fifteen degrees of separation: Latitudinal gradients of rocky intertidal biota along the California Current. *Limnology and Oceanography* 51:2564-2585.
- Warwick, R. M., and K. R. Clarke. 1995. New 'biodiversity' measures reveal a decrease in taxonomic distinctness with increasing stress. *Marine Ecology Progress Series* 129:301-305.
- Weber, S., A. Woodward, and J. Freilich. 2009. North Coast and Cascades Network vital signs monitoring report (2005). Natural Resource Report NPS/NCCN/NRR—2009/098. National Park Service, Fort Collins, Colorado.
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Appendix A: Sand Beach Infauna IST abundances.

Table A.1. Number of individuals per strip transect (IST) at each replicate transect on the seven study beaches in Olympic National Park.

Row Labels	SHI			SAN			CED			SEC			TOL			RUB			KAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Arthropoda																					
Crustacea																					
Amphipoda																					
<i>Eohaustorius</i>	10.50	12.33	30.33	7.50	11.00	13.06	3.07	3.88	2.06	8.17	0.50	0.50	0.00	0.00	0.11	7.94	40.00	4.81	70.33	112.94	80.78
<i>spp.</i>																					
<i>Megalorchestia</i>	0.72	0.28	1.72	0.89	1.72	1.22	0.00	0.00	0.00	0.17	0.06	0.00	0.12	0.36	0.28	0.00	0.00	0.00	0.17	0.56	0.17
<i>spp.</i>																					
0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.21	0.13	0.32	0.22	0.17	0.00	0.00	0.00	0.00	0.19	0.39	0.38	0.22	0.06	0.06
Phoxocephalidae																					
<i>Probosciniotus</i>	2.11	9.06	3.89	0.50	0.61	0.28	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.25	0.67	0.00	8.61	1.78	13.94
<i>loquax</i>																					
Isopoda																					
<i>Excirolana</i>	1.06	1.22	4.28	2.72	1.94	1.56	0.00	0.00	0.00	0.06	1.06	0.11	0.12	0.71	0.28	0.06	0.11	0.00	0.56	0.39	0.78
<i>spp.</i>																					
Annelida																					
Polychaeta																					
<i>Euzonus</i>	5.06	0.83	1.89	2.78	1.22	1.44	2.86	3.44	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.19	0.06	0.13	0.11	3.89	0.00
<i>mucronatus</i>																					
<i>Nephtys spp.</i>	0.11	0.06	0.00	0.11	0.00	0.11	0.07	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.06	0.13	0.06	0.06	0.00
0.17	0.00	0.11	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.31	0.17	0.44	1.50	0.72	0.39
Polychaete																					
<i>spp.</i>																					
Number of taxa	7	6	6	6	5	8	4	3	3	5	5	3	2	2	3	7	7	5	8	8	6
Mean taxa abundance	2.8	4.0	7.0	2.4	3.3	2.3	1.6	2.5	0.8	1.7	0.4	0.2	0.1	0.5	0.2	1.3	5.9	1.2	10.2	15.1	16.0