



# Puget Sound Intertidal Biotic Community Monitoring

## 2008 Monitoring Report

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*December 2009*



WASHINGTON STATE DEPARTMENT OF  
**Natural Resources**  
Peter Goldmark - Commissioner of Public Lands



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By

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# Acknowledgements

The Nearshore Habitat Program is part of the Washington State Department of Natural Resources' (DNR) Aquatic Resources Division, the steward for state-owned aquatic lands. Program funding is provided through the Aquatic Lands Enhancement Act. The Nearshore Habitat Program monitors and evaluates the status and trends of intertidal biotic communities as part of DNR's environmental stewardship activities, and to conserve and restore Puget Sound through the Puget Sound Partnership.

The following document fulfills tasks identified in the 2007-2009 Puget Sound Conservation and Recovery Plan and provides information on the status and trends of one of the provisional indicators of health in the Puget Sound Partnership's Action Agenda.

Special thanks to Betty Bookheim, Peter Duggins, Grant Schwinge, and Tessa Wyllie-Echeverria, who took part in the field work

Lisa Ferrier and Dolores Sare provided greatly appreciated assistance with preparation of eelgrass monitoring data for figures and maps.

Copies of this report may be obtained from the Nearshore Habitat Program – To get more information on the program and download reports and data, enter the search term 'nearshore habitat program' on DNR home page: <http://www.dnr.wa.gov>

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## EXECUTIVE SUMMARY

The Washington State Department of Natural Resources (DNR) is steward of 2.6 million acres of state-owned aquatic land. As part of its stewardship responsibilities, DNR monitors the condition of nearshore habitats. Monitoring results are used to guide land management decisions for the benefit of current and future citizens of Washington State.

Intertidal habitats are an important constituent of the nearshore ecosystem, and they are vulnerable to both terrestrial and aquatic stressors. One indicator of intertidal habitat health is its biotic community - the complex of the flora and fauna living in and on the beach. DNR and the University of Washington (UW) have collaboratively monitored biotic communities since 1997. Monitoring methods characterize epibiota and infauna using quadrat and core samples.

This report summarizes intertidal biotic community monitoring program findings in 2008. In 2008, we used longstanding monitoring methods to explore research questions regarding status and trends in intertidal biota in three projects within greater Puget Sound:

1. *Long Term Monitoring at Possession Point in Admiralty Inlet* - Annual long term monitoring continued at three beaches along the shoreline of southern Whidbey Island. The objective was to examine status and trends over 10 years of continuous, annual monitoring. Over the last 10 years, we have observed overall stability, and an intriguing pattern of regularly alternating levels of species richness. With respect to future monitoring, the site provides a strong baseline from which to measure potential future changes. Characteristics that make it ideal for this type of long term monitoring include relatively high diversity and highly similar replicate beaches.
2. *Collaborative Research in Possession Sound* – We sampled sites on both shores of the southern entrance of Possession Sound with five research objectives:
  - Gather intertidal biotic data in areas being studied by United States Geological Survey (USGS) for physical attributes and forage fish spawning;
  - Expand intertidal biotic community information characterizing sandy beaches;
  - Examine the feasibility of assessing bulkheading effects through comparing the highly altered eastern shoreline to the relatively unaltered western shoreline;
  - Compare infauna sampled with 1 mm and 2 mm sieves;
  - Compare infauna within and outside of eelgrass (*Zostera marina* L.) beds.

Findings include:

- We measured low levels of diversity and abundance at these relatively open (wave-exposed) sandy beaches. Low diversity is probably influenced largely by unstable sand, absence of cobbles, and highly variable salinity.

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- We observed different intertidal biotic communities along the eastern and western shores. This result could be related to natural differences in shoreline characteristics such as wave energy, slope, offshore bathymetry, and salinity. We recommend that further comparison of the two shorelines begin with considering these factors, which could overwhelm any effects of armoring.
  - The biota on sandy beaches in Possession Sound differs markedly from South Sound sand-dominated sites. This finding reinforces previous program findings, related to pebble beaches, that biotic communities in similar habitat types differ greatly among regions. Samples from multiple areas are needed in order to adequately characterize and assess Puget Sound's intertidal habitats.
  - Some areas had patchy eelgrass; effects of this species on the rest of the local biotic community are subtle, requiring much larger sample sizes to elucidate.
  - Samples for which we compared biota retained on 1 mm vs 2 mm mesh sieves show surprisingly few differences, at least for this depauperate infauna.
3. *Baseline Surveys in San Juan Embayments.* Our sampling established baseline information in three bays containing eelgrass, which is believed to be under stress in this region. We found distinct differences among the bays in abundances of epibiota, clams and other infauna. These differences probably relate to natural differences in wave exposure and sediment types. These communities can be tracked if changes in other components such as eelgrass are observed.

#### General Findings Related to Intertidal Biotic Community Monitoring

Detecting change in natural communities is a challenge because natural variation through time is often so high that it masks our ability to detect human-induced effects. One of the purposes of long-term monitoring programs such as ours is thus to establish an 'envelope' of what is normal. Monitoring needs to be conducted in such a way as to minimize sampling error, discover what parameters are most likely to detect a 'signal' of change that is greater than the background 'noise', and determine the best methods to extrapolate data gathered at a few sites to the broader ecosystem. As has been found in other marine monitoring programs, our data suggest that multivariate analyses of whole-community datasets can be a powerful tool for examining temporal change as well as spatial patterns. Species richness is also a useful metric that shows less variation than, for example, population densities of particular species. Size distribution of clam species also provides useful data about ecosystem condition and does not vary widely from year to year.

Our long-term data provide additional information on key forcing functions, factors that determine the character of biological communities on soft-sediment beaches. Tidal height has long been known as a key parameter determining intertidal community structure. In Puget Sound, the character of the substrate may be even more important in driving community characteristics than are small differences in tidal elevation. Larger-scale factors that affect substrate conditions include wave energy and nearby geomorphology, e.g. sources of sediment to the beach and topography of the nearshore zone. Nearshore and water-table salinity also affect intertidal communities but are highly variable in space and time, their roles need further investigation.





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# 1 Introduction

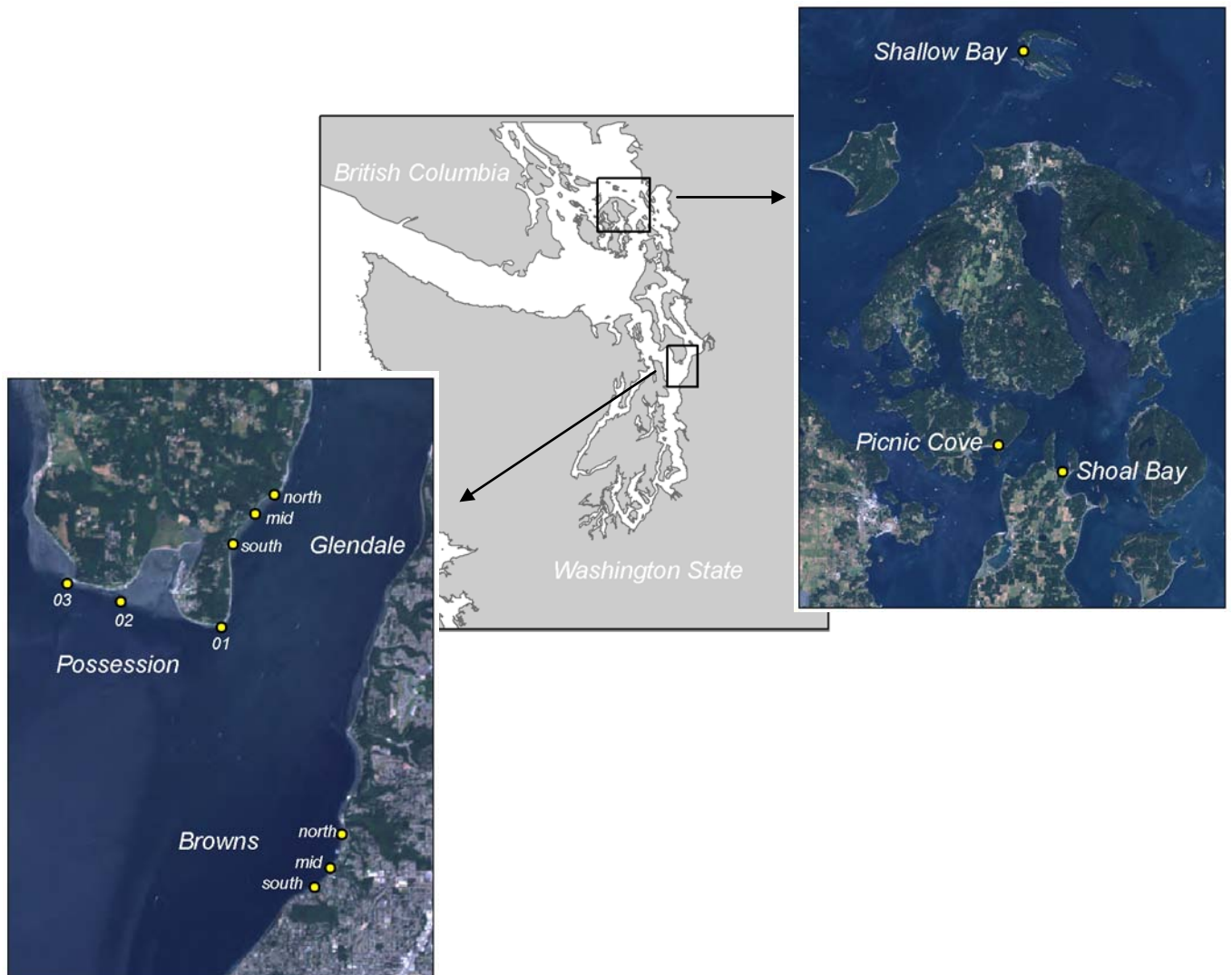
The overall goal of the Intertidal Biotic Community Monitoring Project is to assess the condition of intertidal biota in greater Puget Sound. This work supports the mandate of the the Washington State Department of Natural Resources (DNR) to ensure environmental protection of the 2.6 million acres of state-owned aquatic lands that it stewards (RCW 79.105.030). Additionally, this work supports the Puget Sound Partnership's effort to protect and restore Puget Sound through tasks that are defined in the Puget Sound Action Agenda (Puget Sound Partnership 2009), and in the monitoring plans by its predecessor, the Puget Sound Action Team (Puget Sound Action Team 2007).

Intertidal and shallow subtidal habitats are an important constituent of the nearshore ecosystem. They are highly diverse and productive, harboring extensive populations of algae and seagrasses that contribute to food webs (both nearshore and in deeper water) and provide habitat for many other organisms (e.g., Duggins et al. 1989). Invertebrates that live in intertidal habitats are important in recycling of detritus (e.g., Urban-Malinga et al. 2008) and reduction of water turbidity (e.g., Peterson and Heck 1999), as well as providing food for shorebirds, nearshore fishes, commercially important invertebrates such as crabs, and humans. Intertidal and nearshore communities also serve as useful 'indicators' of ecosystem health. Because most organisms in these habitats are relatively sessile and thus unable to move away from stressors, they are vulnerable to both natural and anthropogenic stressors from terrestrial and aquatic sources. Demonstrated examples include sensitivity to changes in rainfall (Ford et al. 2007), ocean temperatures (Schiel et al. 2006), local pollution (Hewitt et al. 2005), and larger-scale factors such as the North Atlantic Oscillation index (Labrune et al. 2007).

DNR and the University of Washington (UW) have collaborated to monitor biotic communities since 1997. The intertidal biotic community sampling design and statistical analyses have been described in peer-reviewed publications (Schoch and Dethier 1995, Dethier and Schoch 2005, Dethier and Schoch 2006) and multiple technical reports (available through DNR at [http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr\\_nrsh\\_publications.aspx](http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_publications.aspx)).

This report summarizes activities and findings in 2008. In 2008, longstanding monitoring methods were used to explore a series of research questions regarding status and trends in intertidal biotic communities in different regions within greater Puget Sound (Figure 1-1). Specific research objectives are described below for each project.

Long Term Monitoring at Possession Point in Admiralty Inlet - Annual long term monitoring continued at three beaches along the shoreline of southern Whidbey Island. The research objective was to examine patterns and trends in community composition over 10 years of continuous, annual monitoring.



**Figure 1-1. Areas sampled during The Nearshore Habitat Program’s 2008 intertidal biotic community monitoring. Yellow dots represent beaches sampled within each site. At the Possession Point, Glendale, and Browns sites, three replicate beach segments were sampled per site. At the Picnic Cove, Shoal Bay and Shallow Bay sites, one segment was sampled per site.**

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Collaborative Research in Possession Sound – We sampled two sites on the eastern and western shores of the entrance to Possession Sound (*Glendale* and *Browns Bay*) with five research objectives:

- 1) Gather intertidal biota data in areas that are being studied by United States Geological Survey (USGS) for physical attributes and forage fish spawning;
- 2) Examine the feasibility of an hypothesis by USGS to assess bulkheading effects through comparing the eastern shoreline, which has a highly altered backshore, to the relatively unaltered western shoreline;
- 3) Expand intertidal biotic community information to include sandy beaches in northern Puget Sound;
- 4) Compare infauna sampled with 1 mm and 2 mm sieves;
- 5) Compare the infaunal community within and outside of *Zostera marina* beds.

Baseline Surveys in San Juan Embayments. The research objective was to collect baseline data in embayments that contain eelgrass and may be undergoing changes in community structure and composition. Loss of eelgrass has been documented in multiple embayments in the San Juan Archipelago (Gaeckle et al. 2008 and others). Previous intertidal biotic community monitoring in Westcott Bay found that the infauna and epibiota did not appear to experience extreme shifts in community composition over a time period when eelgrass distribution decreased from 86% to 11% of the linear shoreline (Dethier and Berry 2008). We gathered data in three embayments where there is ongoing research into eelgrass condition, and which are hypothesized to represent a range of eelgrass condition: *Picnic Cove*, *Shallow Bay* and *Shoal Bay*.



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# 2 Methods

## 2.1 *Study Area and Site Selection*

Sites were selected according to the overall research objectives summarized in the *Introduction*, and specific considerations discussed below. Sites were named according to nearby geographic features. Section 2.2 provides detailed information on sampling methods employed at each site.

### 2.1.1 *Long Term Monitoring at Possession Point*

We examined long term patterns in community structure through continued sampling of three shoreline segments that make up the *Possession Point* long term monitoring site. The beaches are located at the southern tip of Whidbey Island, along the eastern edge of Admiralty Inlet, to the west of the entrance to Possession Sound (Figure 1-1). *Possession Point* was selected from our pool of long-term monitoring sites for examination of community patterns over time based on site characteristics and statistical considerations:

- Biotic communities at these beaches have relatively similar communities compared to other long term monitoring sites (Dethier 2007). This characteristic makes temporal differences relatively easy to identify in the complex community dataset.
- The beaches have relatively high diversity and taxon richness, compared to other long term monitoring sites (Dethier and Schoch 2005). High diversity and taxon richness often strengthen the ability to identify differences over time.
- The site has the longest continuous annual sampling data record. It has been sampled every year since 1999, creating an annual data record of 10 years (with the inclusion of 2008 samples).

### 2.1.2 *Collaborative Research in Possession Sound*

Three beaches were sampled at each of two sites. The *Glendale* site is located on the west side of Possession Sound (Figure 1-1), north of the *Possession Point* long term monitoring shoreline segments. The *Browns Bay* site is across the Sound and slightly south, just north of our *Edmonds* long term monitoring segments. All beaches on the east side (*Browns Bay*) had armoring (railroad grade) on the high shore; all beaches on the west side (*Glendale*) were unmodified, and this stretch of shore is characterized by largely natural eroding bluffs.

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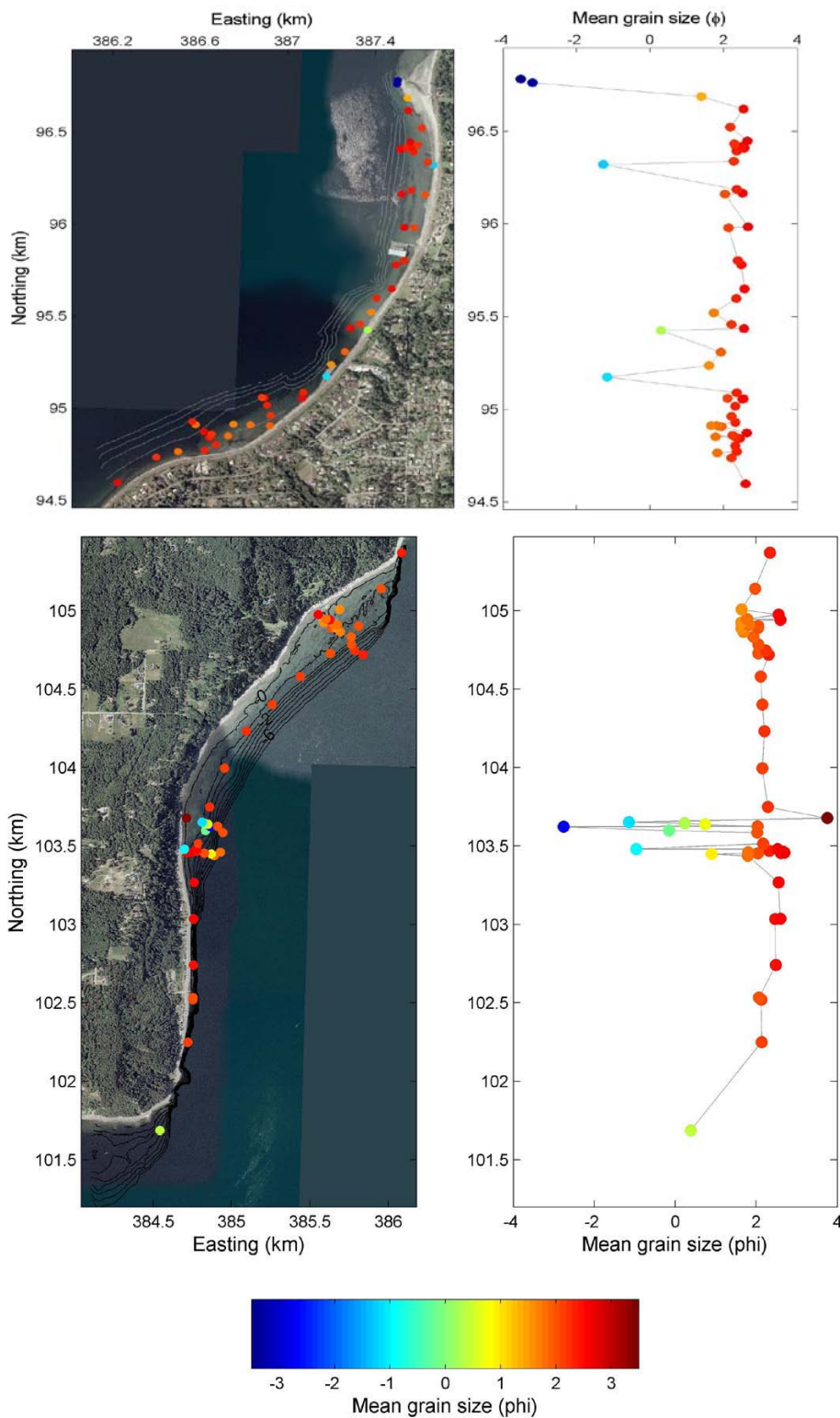
Beach segments were selected within each site to meet two requirements to the greatest extent possible:

- 1) match sampling locations used by the CHiPS program, and/or
- 2) provide reasonable replicates of each other in terms of physical characteristics, especially substrate (a physical parameter that is known to strongly control the biotic community: Dethier and Schoch 2005).

Physical data as well as subtidal eelgrass data are available from USGS (Stevens et al. 2008 and Figure 2-1). Their data suggest that both the *Browns Bay* site and the *Glendale* site were dominated by medium-fine sand in the intertidal zone. At *Browns Bay*, some cobble was observed at the northern spit and small gravel was observed near the stream mouths. *Glendale* has occasional patches of cobbles and even boulders, presumably eroded out of the bluffs above. Other data (not shown) indicate that the *Browns Bay* site has a much narrower subtidal sand shelf than *Glendale*, and much less subtidal eelgrass.

Our field evaluation of the two sites led us to conclude that the sites are less similar and less homogenous than suggested by the USGS survey data, most notably in the mid-intertidal (the USGS survey may not have extended as high into the intertidal areas). While the subtidal sediments at both sites are predominantly sand, alongshore differences are common, with areas of pebble and cobble found in portions of the intertidal zone. Our data on surface substrate size showed a greater abundance of pebble and cobble at *Browns Bay* in the mid-intertidal than at *Glendale* (see *Results* section for substrate size data). Also, the ‘beach break’, where sand transitioned to larger substrate sizes varied within and among sites. The presence at *Glendale* of the broad shelf, combined with reduced wave fetch (from the south and west) from northern Puget Sound, suggests that the intertidal substrates on this side are finer and more anaerobic.

Biotic community data from *Glendale* and *Browns Bay* were compared. In order to broaden the understanding of the sites within the context of Puget Sound, the sites were compared with samples from 3 beaches in Carr Inlet (sampled in 1999) that were similar in terms of having mostly sandy substrate, and in not being dominated by sand dollars. Sand dollars dominate some sandy sites and, when present, have a major effect on the rest of the community.



**Figure 2-1. USGS Surface sediment grain size from Browns Bay (above) and Glendale (below). On beaches, medium sand (Phi 2) to fine sand (Phi 3) sand was generally observed . In areas, larger grain sizes were observed, including medium-coarse sand to cobble (Phi -3).**

<http://pubs.usgs.gov/sir/2008/5009/sir2008-5009.pdf>

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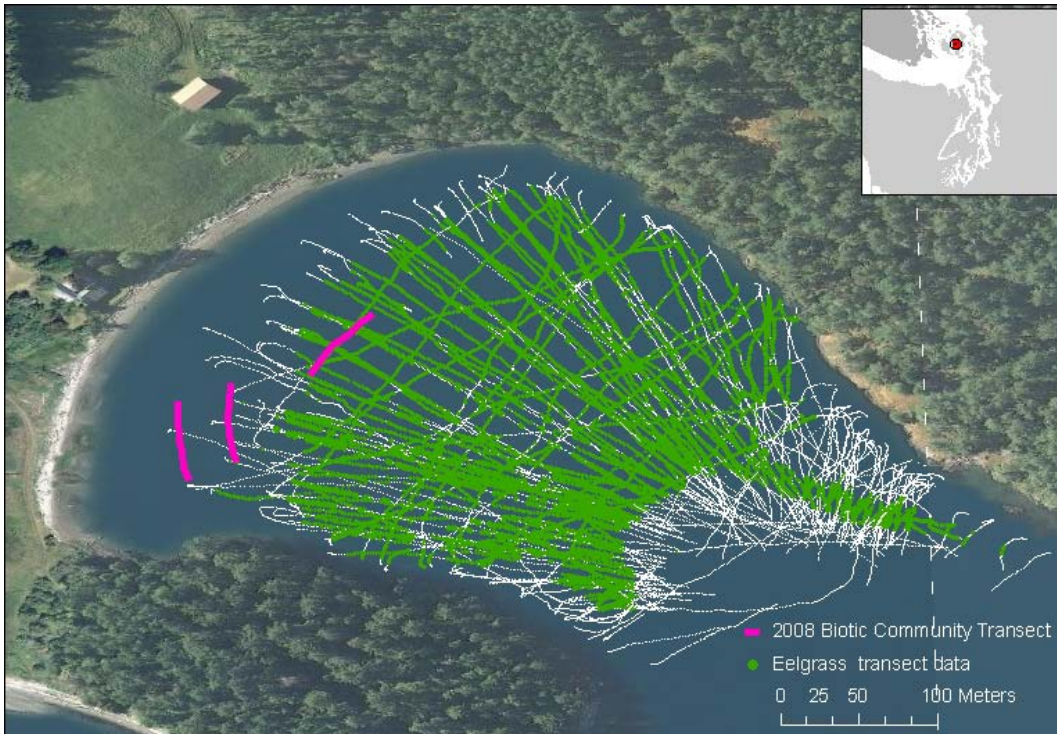
### 2.1.3 San Juan Embayments with Eelgrass

After extensive sampling in Summer 2007 in one bay in the San Juan Islands where eelgrass had largely disappeared (Westcott Bay: see Dethier and Berry 2008), we sampled in 3 additional eelgrass-dominated bays in San Juan Islands in 2008. We selected bays based on expert assessment that represent a range in eelgrass condition (S. Wyllie-Echeverria, personal communication), including a declining site (*Picnic Cove*), a site of minor concern (*Shoal Bay*), and an apparently stable site (*Shallow Bay*). As previously discussed, our sampling objective was to gather baseline transect data on the abundance of clams, smaller infauna, and eelgrass in the event of further changes to these ecosystems.

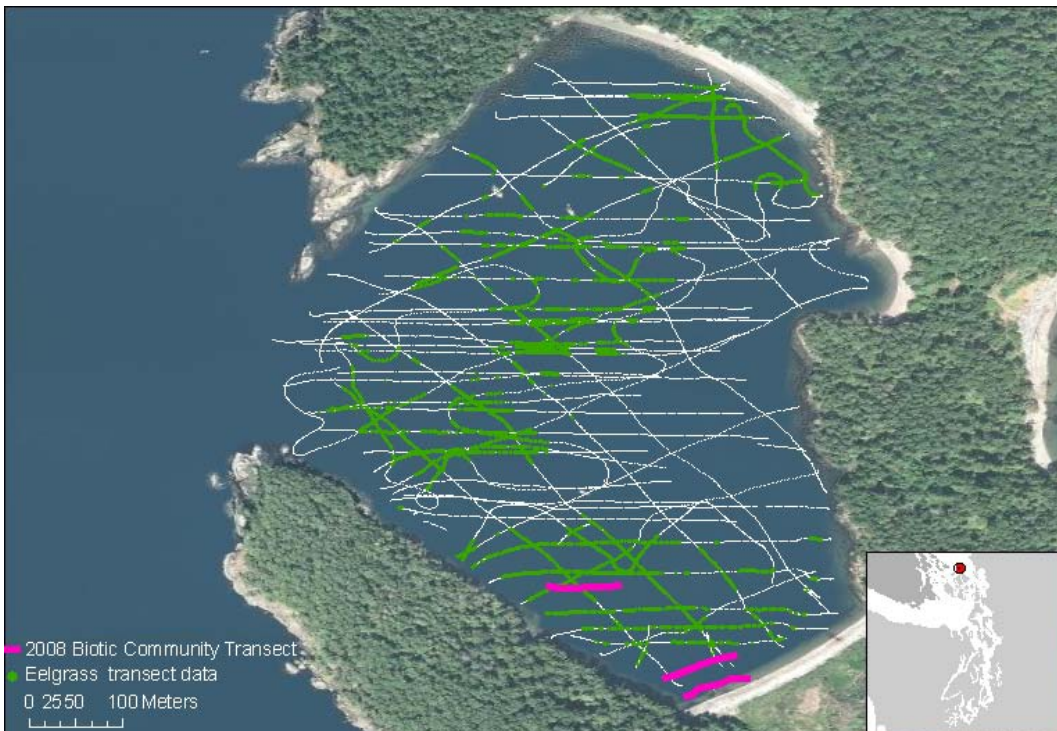
Monitoring data from DNR's Submerged Vegetation Monitoring Program (Gaeckle et al. 2009 and Ferrier et al. in preparation) and other sources provide information on the status, location and abundance of eelgrass:

- *Picnic Cove* has been sampled annually by the SVMP since 2000 (Figure 2-2 and Appendix A). Eelgrass area in the bay shows a significant declining trend between 2000 and 2008. Losses in area were accompanied by deepening in the mean minimum eelgrass depth. Additionally, research by Wyllie-Echeverria has documented substantial losses along intertidal transects (Wyllie-Echeverria personal communication).
- *Shallow Bay* was sampled by the SVMP in 2003, 2007 and 2008 (Figure 2-3 and Appendix A). Overall area and mean minimum depth have not changed significantly during this period.
- *Shoal Bay* was sampled in by the SVMP in 2003, 2004 and 2008 (Figure 2-4 and Appendix A). Overall area and mean minimum depth have not changed significantly during this period.

Biotic community sampling transects were placed as close as possible to existing eelgrass beds, in areas with geomorphic characteristics that were as broadly representative of the site as possible. At all three sites, the lowest elevation (-2 ft) transect was located in an area where eelgrass has occurred throughout the DNR SVMP eelgrass monitoring record (Figures 2-2, 2-3, 2-4). At *Picnic Cove* and *Shallow Bay*, eelgrass is currently extremely sparse or absent at the two higher sampling elevations, 0 ft and +2.8 ft (Appendix A). Therefore, transects were placed adjacent to the beds. At *Shoal Bay*, where eelgrass has been observed growing at higher elevations during all DNR sampling events, 0 ft and +2.8 ft transects were located within the naturally occurring eelgrass bed.



**Figure 2-2. Map of *Picnic Cove* showing the locations of three intertidal biotic community sampling transects (at +2.8 ft, 0 ft and – 2 ft, MLLW), and eelgrass presence and absence (shown in green and white, respectively) along transects sampled by DNR’s SVMP annually between 2000 and 2008.**



**Figure 2-3. Map of *Shallow Bay* showing the locations of three intertidal biotic community sampling transects (at +2.8 ft, 0 ft and – 2 ft, MLLW), and eelgrass presence and absence (shown in green and white, respectively) along transects sampled by DNR’s SVMP in 2003, 2007, and 2008.**





**Figure 2-4. Map Shoal Bay showing the locations of three intertidal biotic community sampling transects (at +2.8 ft, 0 ft and – 2 ft, MLLW), and eelgrass presence and absence (shown in green and white, respectively) along transects sampled by DNR’s SVMP in 2003, 2004, and 2008.**

## 2.2 Sampling Methods

The intertidal biotic community sampling design and statistical analyses have been described in previous peer-reviewed publications (Schoch and Dethier 1995, Dethier and Schoch 2005, Dethier and Schoch 2006) and technical reports (available through DNR at [http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr\\_nrsh\\_publications.aspx](http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_publications.aspx)). General methods are summarized here, followed by detailed methods for each site sampled in 2008 (Table 2-1).

We used a nested sampling design to quantitatively assess patterns in benthic nearshore populations and communities at spatial scales ranging from meters to tens of kilometers within the Puget Sound region. At the smallest scale, we selected and sampled shore segments that were physically similar in terms of substrate size, slope angle, and field cues of wave energy such as exposure to long wave fetch, and local presence of fine sediments. Generally three segments within a distance of 3 kilometers provided spatial replicates for a site. The exception to this rule occurred at *Picnic Cove*, *Shallow Bay*, and *Shoal Bay*. Only one beach segment within each bay was sampled in order to visit multiple bays within limited field time and to sample at lower tidal heights, at elevations close to eelgrass beds.

Biological sampling was conducted during spring tides in late June and early July. A surveying level and stadia rod were used to locate the appropriate transect elevation relative to the predicted tide at the time of the measurement. This approach has been

compared to the actual tide within this region, locations were typically within  $\pm 0.15$  m of the target elevation (Dethier and Schoch 2005).

Site Name	# of Shore Segments (Segment Names, if applicable)	Elevations Sampled for Epibiota/Infauna (MLLW ft.)	Elevations Sampled for Clams (MLLW ft.)	Sieve Size for Epibiota/Infauna Samples	Date Sampled
<i>Browns Bay</i>	3 (North, Mid, South)	+2.8 0	+1.5 0	1 mm, 2 mm	17 and 18 June
<i>Glendale</i>	3 (North, Mid, South)	+2.8 0	+1.5 0	1 mm, 2 mm	18 and 19 June
<i>Possession Point</i>	3 (po1, po2, po3)	0	none	2 mm	1 July
<i>Picnic Cove</i>	1	0 -2	+1.5 0	2 mm	3 July
<i>Shallow Bay</i>	1	0 -2	+1.5 0	2 mm	4 July
<i>Shoal Bay</i>	1	0 -2	+1.5 0	2 mm	2 July

**Table 2-1. Summary of Locations and Tidal Elevations Sampled in 2008.**

Biotic community samples consisted of mean species abundances for epibiota and infauna from 10 randomly spaced sample units along a 50 m horizontal transect. Each sample unit consisted of a 0.25 m<sup>2</sup> quadrat to quantify abundance of surface macroflora and fauna, plus a 10 cm diameter x 15 cm deep core for macroinfauna. Percent cover was estimated for all sessile taxa in the quadrats, and all motile epifauna (organisms > ca. 3 mm) were counted. Fresh core samples were washed through 2 mm mesh sieves, thereby excluding meiofauna, juveniles of some worms, and adults of smaller crustaceans such as cumaceans and harpacticoids. At some sites (*Browns*, *Glendale*), all samples were washed through stacked 2 and 1 mm sieves in order to assess what organisms are ‘lost’ using the larger mesh. At all other sites, time constraints kept us from testing sieve sizes. Thus samples collected at *Possession Point*, *Picnic Cove*, *Shoal Bay*, and *Shallow Bay* were washed through 2 mm sieves only.

We collected additional core samples at two beaches where eelgrass was present, to test for differences in infauna found among eelgrass vs. at the same level but with no eelgrass. We collected 5 extra cores at *Browns Bay North*, where most of the transect did not have eelgrass but where cores with eelgrass nearby could be sampled. At *Glendale South*, most of the samples along 0 ft (MLLW) transect had eelgrass, so we collected 5 additional cores adjacent to the transect, in areas without eelgrass. In the +2.8 ft (MLW) zone, about half of the randomly selected cores had eelgrass, so additional cores were not collected.

The finest taxonomic resolution used in field sampling and laboratory identification was species level, although some difficult taxa were only identifiable to genus or higher levels

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(e.g. *Pagurus* spp., Phylum Nemertea). Taxonomic references were Kozloff (1996) for invertebrates and Gabrielson et al. (2000) for macroalgae.

Separate sampling was conducted at most sites to estimate adult clam populations; these larger and longer-lived organisms can constitute better ‘integrators’ of long-term conditions than most of the other, shorter-lived infauna (e.g. worms). Additional 0.1 m<sup>3</sup> (0.3 m per side and 0.3 m deep) box core samples were collected and sieved using 1 cm mesh to characterize adult clam abundance and size distribution. These larger core samples are targeted to adequately sample large clams, but they are prohibitively large for sampling smaller infauna. The only site where these samples were not collected was *Possession Point*, where the primary objective was long term monitoring, and larger clam samples have not been part of our Sound-wide long term monitoring dataset.

At each site, one or more tidal elevations were selected for sampling (Table 2-1) based on the research question, target species, availability of historical data for comparison, and the tidal sampling window. Specific rationale for selecting certain tidal elevations for sampling was:

- 0’ (MLLW) - the most frequently sampled elevation for both epibiota/infauna and adult clams. This is the lowest elevation that can be fully sampled at a number of nearby locations during spring tide sampling windows. MLLW is preferred over higher tidal elevations (which provide longer sampling windows) because more organisms are generally collected at this elevation than higher on the shore. At MLLW, organisms are submerged ca. 90% of the time.
- +1.5’ – clam samples were additionally collected at this elevation because surveys in the San Juans found clam abundances to be high at this level, and comparative data exist.
- +2.8’ – represents the mean low water (MLW) datum in areas within Puget Sound including southern Possession Sound and Edmonds. This tidal level is selected to represent the mid-intertidal community, which tends to be less diverse and abundant than at MLLW. This level was sampled at Possession Sound sites because comparison of communities higher on the shore is important for evaluating the indirect effects of anthropogenic shoreline alteration, which commonly occurs in the upper intertidal and backshore. Data can be compared to nearby sites in Central Puget Sound, which were sampled in order to monitor construction impacts associated with King County’s Brightwater sewage treatment plant. This level was also sampled in the San Juan embayments to be consistent with the Puget Sound sites and also close to the mid-shore zone used in previous studies in Westcott Bay, where transects were sampled at +3’.
- -2.0’ - the lowest intertidal level that can be readily sampled using our sampling techniques. Relatively few sites can be sampled because the sampling windows are severely restricted by tides. Sampled in the San Juan embayments because it is closely linked – at least spatially – to shallow subtidal communities such as eelgrass.

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### 2.3 *Data Analysis*

The multivariate analysis methods of Clarke and Warwick (1994) and PRIMER software (Clarke and Gorley 2001) were used to detect patterns in the spatial and temporal distributions of communities. The data matrix of taxon abundances was square-root transformed to reduce the contribution of highly abundant species in relation to less abundant ones in the calculation of similarity measures. We used the ordination technique of non-metric multidimensional scaling (MDS) to group communities based on the Bray-Curtis similarity metric. Graphic plots of ordination results for the two axes explaining the greatest proportion of the variance were examined for obvious sample groupings. Analysis of similarity (ANOSIM) tested the significance of hypothesized differences among sample groups. Similarity percentage (SIMPER) analyses identified the variables (species) that contributed the most to different groupings seen in the MDS plots. For one dataset (the longterm *Possession Point* data), we also calculated a “control chart” for the multivariate data, using software (“Control chart.exe”) written by Dr. M. Anderson of Massey University, available at: <http://www.stat.auckland.ac.nz/~mja/Programs.htm> These charts are designed for ecological monitoring programs as a way of assessing whether a given measurement (e.g. date) is ‘unusual’ relative to what is expected based on observations up to that time. It assumes that natural systems are stochastic and their variation can be modeled (Anderson and Thompson 2004).

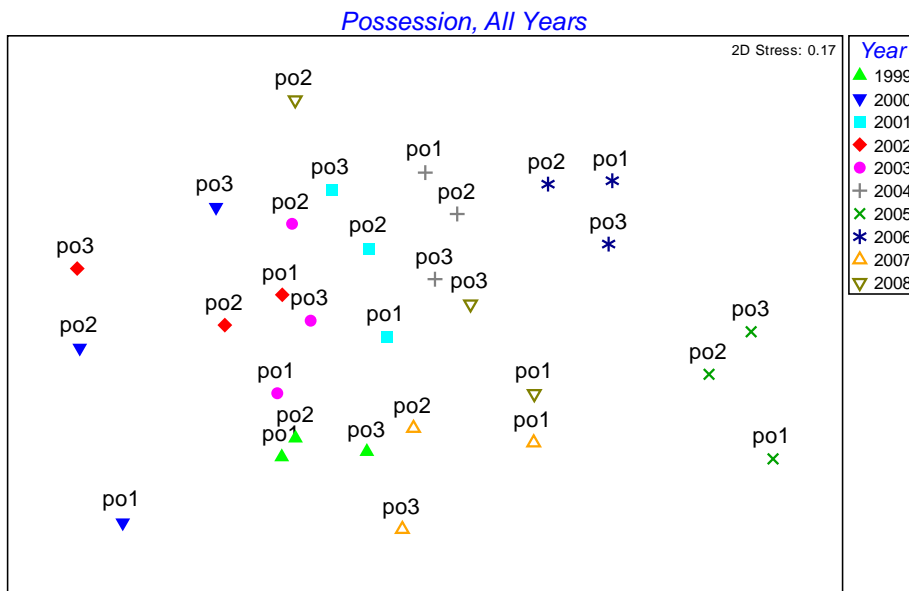
Monitoring data collected at other sites were incorporated for comparison with 2008 results when appropriate, including:

- Long term monitoring site data in South and Central Puget Sound;
- Data from a focused study in Westcott Bay, to further explore biotic community structure in San Juan embayments with historical or current eelgrass populations (Dethier and Berry 2008).
- Data from an ongoing 5-year project to evaluate intertidal construction impacts associated with King County’s Brightwater sewage treatment plant.

# 3 Results

## 3.1 Long term Monitoring at Possession Point Beaches

Appendix B lists all species found in 2008. Figure 3-1 shows an MDS analysis of the community-level data from all 3 *Possession Point* beaches over all 10 years. There is a clear pattern of the 3 beaches being similar to each other each year (i.e., the points for each year cluster together), with a high Global R = 0.802 (ANOSIM test,  $p = 0.001$ ).<sup>1</sup> In contrast, for each beach (e.g. “po1”) the years cluster poorly, i.e. there is a moderate amount of variation within a beach among years (low Global R 0.176,  $p = 0.003$ ).



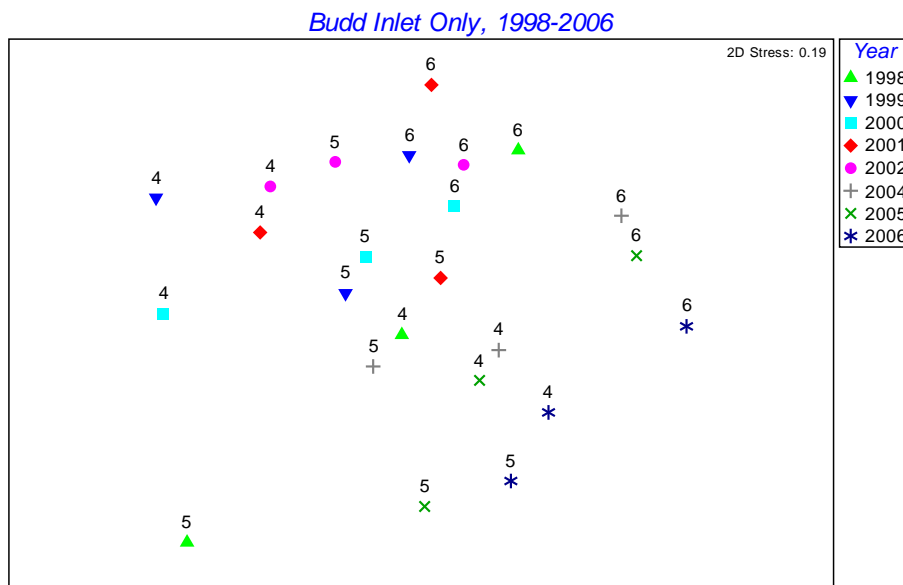
**Figure 3-1. MDS analysis of community-level data from 1999-2008 at three shore segments at the *Possession* long term intertidal monitoring site. All samples were collected at 0' (MLLW) except in 2005, when the samples were collected approximately one foot lower.**

<sup>1</sup> R values, which usually fall between 0 and 1, are a measure of the degree of discrimination between (user-defined) groups. If similarities among groups are approximately equal to similarities within groups, R will be close to 0; visually, this would occur when it is impossible to draw non-overlapping circles around groups in an MDS plot. R = 1 occurs when *all* samples within a group are more similar to each other than all samples from different groups, i.e. the groups are totally distinct on a plot. This comparative measure is more meaningful than the p value from the ANOSIM test which may indicate “significance”, even with very small R values, when sample sizes are large; even when groupings are weak (with little ecological relevance), if there are many samples within a group, there are likely to be some dissimilarities among groups, causing R to be significantly different from zero.

The similarity (clustering of points) of beaches within each year allows us to distinguish the clear year-to-year variation (separation of points). For example, it is readily visible that 2005 was a very ‘different’ year in terms of the biota found at all 3 beaches (points to the lower right); in this year we sampled too low on the shore due to methodological errors, thus encountering a different community.

If the biota at one beach changes in a given year in a way that moves it away from the other two beaches, this change is reflected in the multivariate plots. For example, in 2008 beach po2 shows a relatively greater degree of separation from the other replicate beaches (po1 and po3). This distance is attributed to relative high numbers of some organisms (amphipods, sphaeromids, and juvenile *Cancer* crabs) and relatively lower numbers of other organisms (*Spio filicornis*, and no *Armandia* worms) relative to the other replicate beaches.

In contrast, Figure 3-2 shows similar long-term monitoring data from three beaches sampled in previous years in Budd Inlet (from Dethier 2007). This MDS plot shows that the three beaches group together poorly by year ( $R = 0.420$  vs.  $0.802$  for *Possession Point*). The different dates for a given beach group together to some extent, e.g. all the Beach 6 points are in the upper right ( $R = 0.292$  vs.  $0.176$  for *Possession Point*). This means that for Budd Inlet, it would be harder to detect a temporal change in biota; the ‘expected’ biotic composition is less well defined than at *Possession Point*.



**Figure 3-2. MDS analysis of community-level data from 1999-2006 at three shore segments at the Budd Inlet monitoring site. All samples were collected at 0’ (MLLW). From Dethier (2007).**

Another way to analyze the long-term dataset for *Possession Point* beaches is the use of “control charts” to detect changes in the biota that are outside the normal temporal variation. While the three sites used in this analysis were not enough to set confidence limits on the temporal variation expected at a larger pool of such sites, we were able to

calculate a measure of year to year variation. Figure 3-3 plots, for each *Possession Point* beach, the deviation from the multivariate centroid for that beach, which is the ‘target’ or expected assemblage as calculated from the first year’s (1999) data. The figure illustrates year to year variation in the assemblage that is consistent among beaches, as seen in the MDS plot above, and clearly illustrates how different the 2005 assemblages were from all other years. This method can be used in the future to seek either single-beach or whole-site changes in biota.

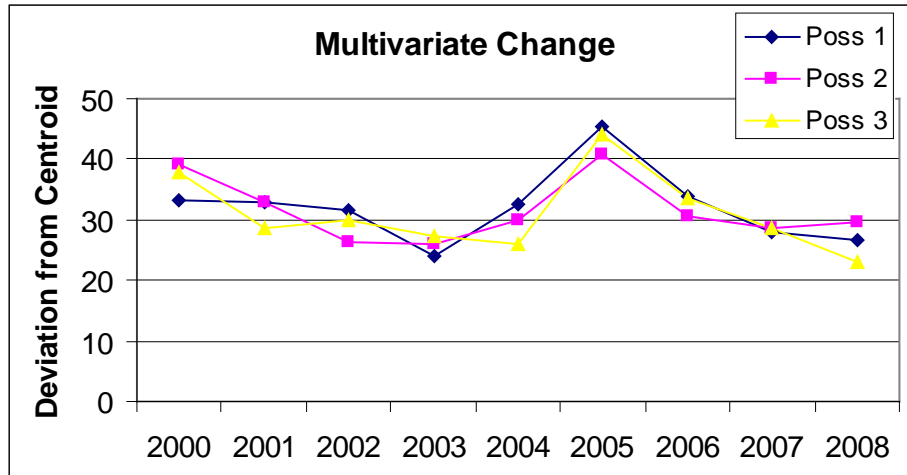


Figure 3-3. A “control chart” of distances from a centroid ‘baseline’ value for the multivariate assemblage at each *Possession Point* beach over time. All distances are defined as positive square roots of a formula based on squared inter-point dissimilarities.

The pattern noted in our 2007 report (Dethier 2007) of regular interannual variation in species diversity at *Possession Point* beaches continues to be seen in the 2008 data; years alternate in their levels of species richness (Figure 3-4a) and Shannon diversity (Figure 3-4b), which incorporates evenness of individuals among species. Interestingly, except for the *Poss 1* beach, the lower-shore 2005 assemblages were not substantially more species-rich, as we might have expected given the general pattern of higher richness lower on the shore.

Exploration of the differences in species composition between even (low diversity) and odd (high diversity) years shows many small differences, although none that are very striking or consistent. Even years tend to have more gammarid amphipods, live barnacles, sphaeromid isopods, *Onchidoris*, and *Acrosiphonia*. Odd years have more *Lacuna*, flatworms, limpets, and *Mediomastus*. The database analyzed for the MDS plots and the diversity analyses do not include dead barnacles; when these are analyzed, their abundances are irregular but do show a general pattern of being more abundant in odd years (Figure 3-5). Note that 2005 is the year we sampled too low on the shore; there might have been more dead barnacles had we been at the right level. The unusually large pulse of dead barnacles at all 3 beaches in 2003 followed a large pulse of live barnacles seen in 2002. The overall average percent cover for odd years is  $9.5 \pm 9.8\%$  s.d., while in even years it is  $2.5 \pm 1.7\%$ . Even when 2003 is excluded from the odd-year data, the mean value ( $6.7 \pm 5.3$ ) is higher than in even years.

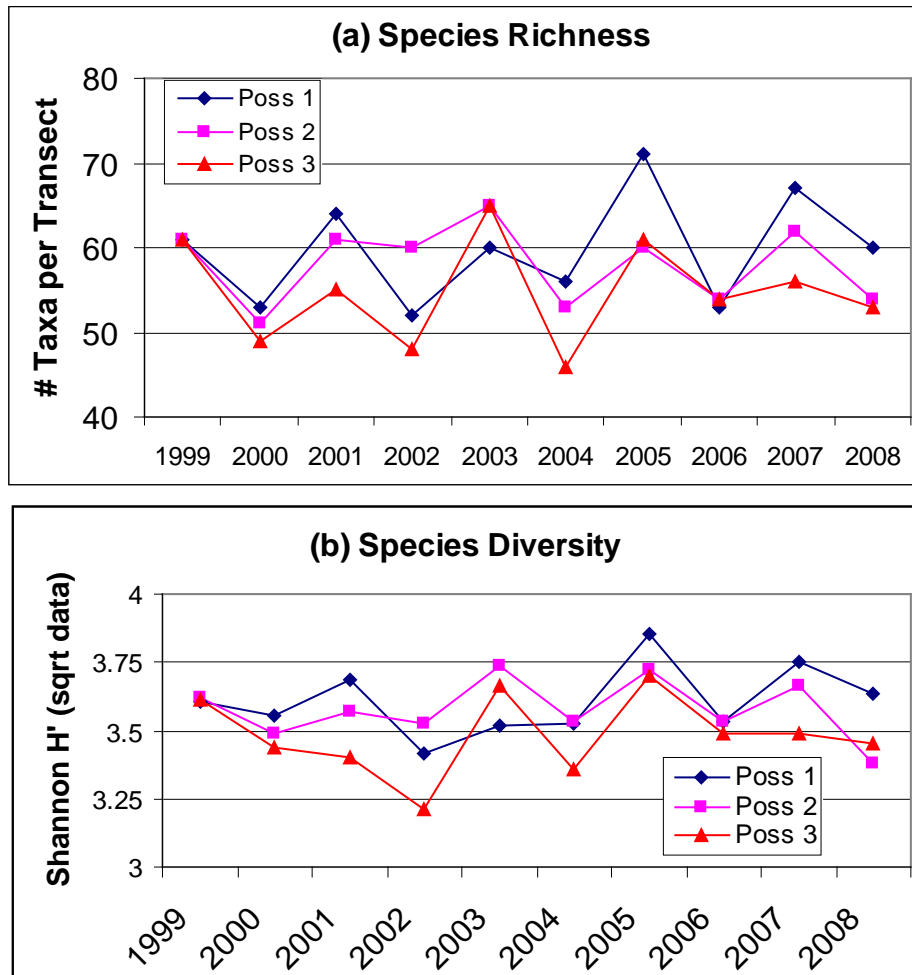
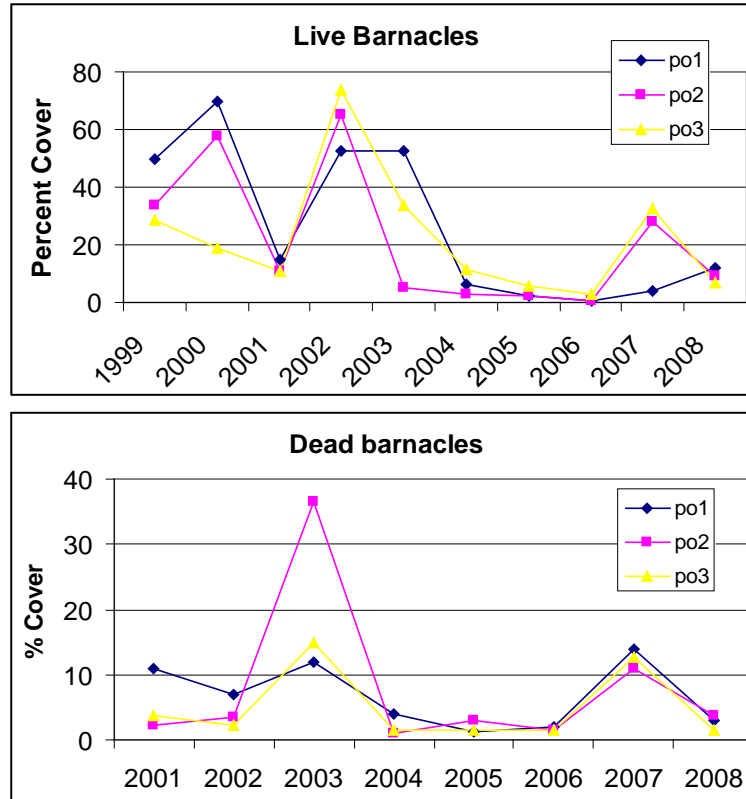


Figure 3-4. Species richness (a) and species diversity (b) between 1999 and 2008 at three shoreline segments at the *Possession Point* long term intertidal monitoring site.





**Figure 3-5.** Percent cover of barnacles between 1999 and 2008 at three shoreline segments at the *Possession Point* long term intertidal monitoring site. Data on dead barnacles were not collected until 2001.

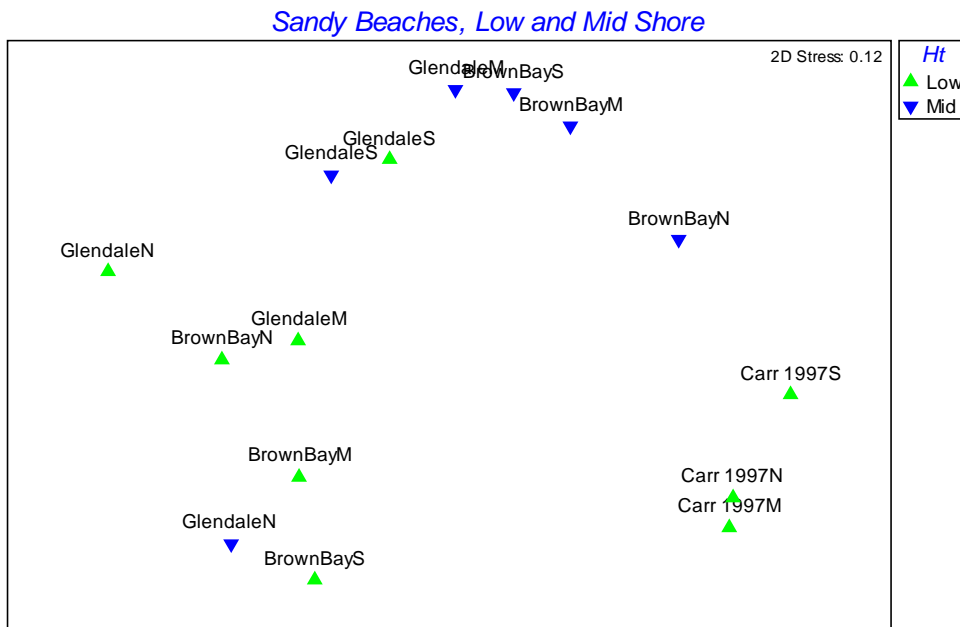
The driver of a regular alteration of abundance of dead barnacles is unknown; there is no apparent relationship (from scattergrams) between dead barnacles and cover of either cobble or sand. There are logical connections, however, between dead barnacles and the species seen primarily in odd vs. even years. When there are many dead barnacles (odd years) there are more species that are scavengers and detritivores in the sediment (flatworms and *Mediomastus*), and more that might take advantage of the bare cobble space not occupied by barnacles (*Lacuna* and limpets). When there are few dead barnacles, there are more live barnacles and organisms that consume them (*Onchidoris*), hide among them (amphipods, isopods), or attach to them (*Acrosiphonia*).

### 3.2 Comparison of Browns Bay and Glendale

#### 3.2.1 Biota

Appendix C lists all species found at *Browns Bay* and *Glendale* beaches in 2008. Figure 3-6 compares the biotic communities at the *Browns Bay* and *Glendale* beaches, and also includes previous monitoring data collected at sand beaches in Carr Inlet. Each point represents the biota per transect, i.e. averaged over the 10 samples per transect. For the Low zone (MLLW) samples, the biota at the Carr Inlet beaches is very different (Global R value is high, 0.835) from that at the more northern sites; the average dissimilarities

among these sites, from SIMPER analyses, are 98%). These Carr beaches have some *Dendraster* (although not the very high numbers seen elsewhere), as well as *Spiochaetopterus* tubes, the capitellid *Notomastus lineatus*, and the anemone *Edwardsia* – none of which were seen at either *Browns Bay* or *Glendale*. *Browns Bay* and *Glendale*, despite their relative proximity, are also rather dissimilar (average dissimilarity 81%), although much less than comparisons with Carr. The Global R value comparing *Browns Bay* and *Glendale* was a low 0.259, indicating poor ‘separation’ between these sites (but sample sizes are too low to run statistics). *Browns Bay* has more *Lacuna* and *Scoloplos* polychaetes, whereas *Glendale* beaches have more *Zostera*, *Tellina* and *Macoma* clams, ulvoids, gammarids, and various polychaetes.



**Figure 3-6. The two-dimensional solution for non-metric multidimensional scaling ordination (final stress = 0.12) for sandy beaches at *Browns Bay* and *Glendale* in 2008 and sites in Carr Inlet in 1997. Data points from 2008 are labeled with site and segment code. Data from Carr Inlet are included for comparison (labeled by site, year, and segment.) Low shore points represent 0' (MLLW) samples, and Mid samples were collected at +2.8'.**

Figure 3-7 compares species richness at these three sets of sandy beaches. *Glendale* beaches were usually richer than those at Brown; all are much less rich than the nearby cobble beaches at *Possession Point*, which have 50-70 taxa per transect. In most habitats, richness declines from the low to mid shore, but this was not consistently the case at these sandy beaches; at *Glendale M* and *Browns Bay S*, richness was clearly higher in the mid zone than the low zone.

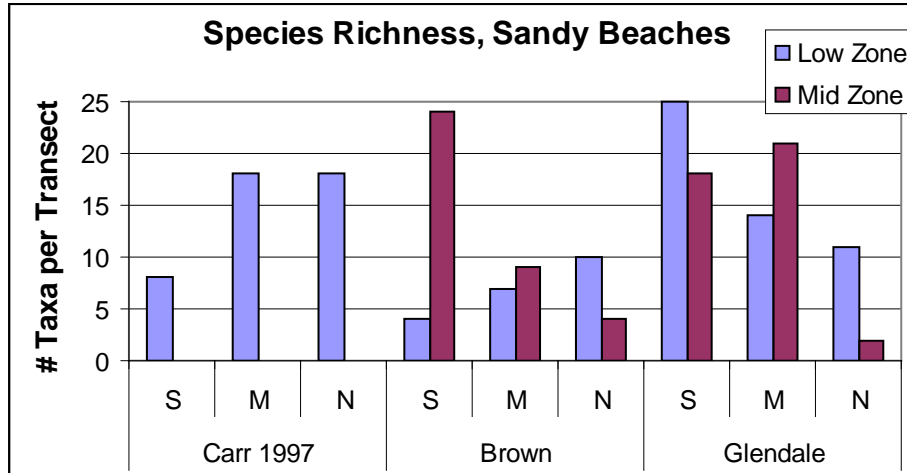


Figure 3-7. Species richness at *Browns Bay* (2008), *Glendale* (2008) and Carr beaches (2007). Low shore points represent 0' (MLLW) samples, and Mid samples were collected at +2.8'.

While the Carr Inlet sites were pure sand, some of the *Browns Bay* and *Glendale* Beaches had mixes of other substrate types (Figure 3-8). All low-zone transects were in clean sand, sometimes with eelgrass, although *Glendale S* had muddier/softer sand than the other beaches. Mid-zones varied highly, however (Figure 3-8); sometimes they were pure sand (*Glendale S* and *Glendale N*), sometimes they had a small amount of cobble (*Glendale M* and *Browns Bay S*). The two other *Browns Bay* beaches (*M* and *N*) had relatively steep mid-shore areas, with substrate dominated by unstable pebble-gravel (larger than our sand category but smaller than cobble). Half of the samples from the *Browns Bay N* mid-zone transect had no organisms on the surface or in the cores.

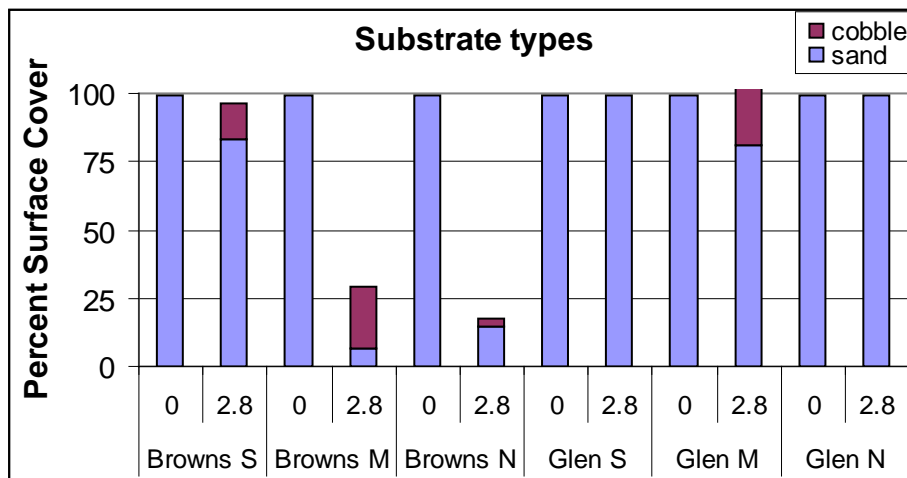
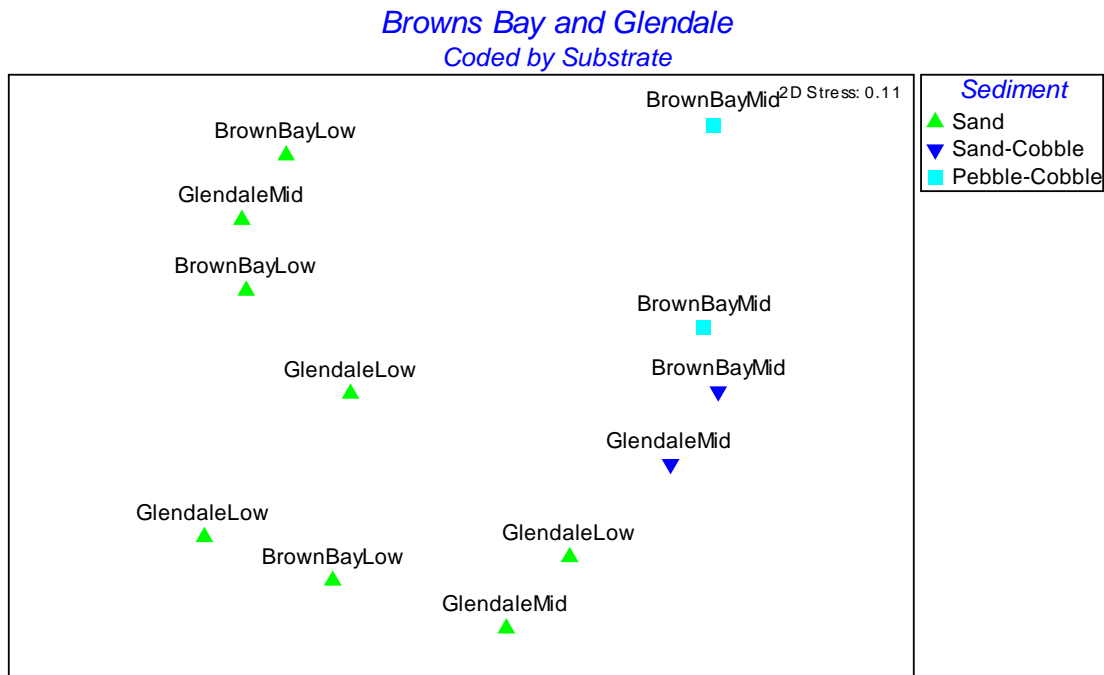


Figure 3-8. Surface sediments at each of the *Browns Bay* and *Glendale* transects (mean values across the 10 quadrats per transect).

Figure 3-9 shows an MDS plot of the same data as in Figure 3.6 but with the Carr Inlet data omitted. The biota on these transects do not cluster by site (first part of label:

ANOSIM for Site gave an insignificant R value of .019) and only weakly by tidal height (second part of label: R = .294, p = .05). The only grouping by beach is that the two lower-right “Sand” *Glendale* transects are both from *Glendale M*. However, the biota at these 12 transects cluster clearly by substrate type, with R = .493 (p = .002) for this factor. Pairwise comparisons showed that Sand was different from the other two substrate types. The sand-cobble and pebble-cobble did not appear different in pairwise analyses, but with only 2 samples per group, there was no power to detect a difference there. Another pattern is that only two of these transects were noted as “steep” versus “flat”, and these were the two pebble-cobble points: the mid-shore transects at *Browns Bay N* (uppermost point) and *Browns Bay M* (lower pebble-cobble point).



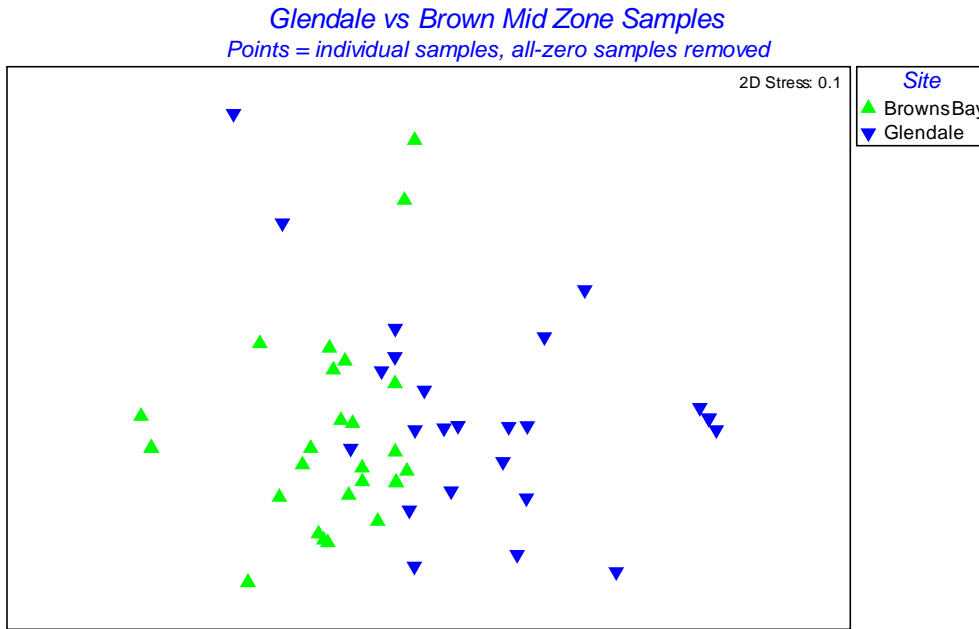
**Figure 3-9. MDS analysis of all *Browns Bay* and *Glendale* transects, with points labeled by site and tidal height, and color-coded by substrate type.**

In addition to biotic community observations, we observed large salinity differences between the eastern and western shores of the embayment. During our June sampling, we measured nearshore surface salinities ranging from 26 - 28 psu at *Browns Bay*, compared to 16 – 19 psu at *Glendale*. The low open-water salinities near *Glendale* are a striking signal of the freshwater plume from the rivers to the north.

The salinity signal was less distinct in the beach porewater measurements, which is affected by many other factors. Variation within and among beaches was high. At *Browns Bay*, our low-shore (MLLW) porewater samples ranged from 24 - 27 psu , while our mid-shore (+2.8 ft) measurements were substantially more fresh, 11 – 15 psu. In comparison, *Glendale* measurements were highly variable at both intertidal heights (12-24 along the low shore and 12-20 along the mid shore). USGS salinity sampling

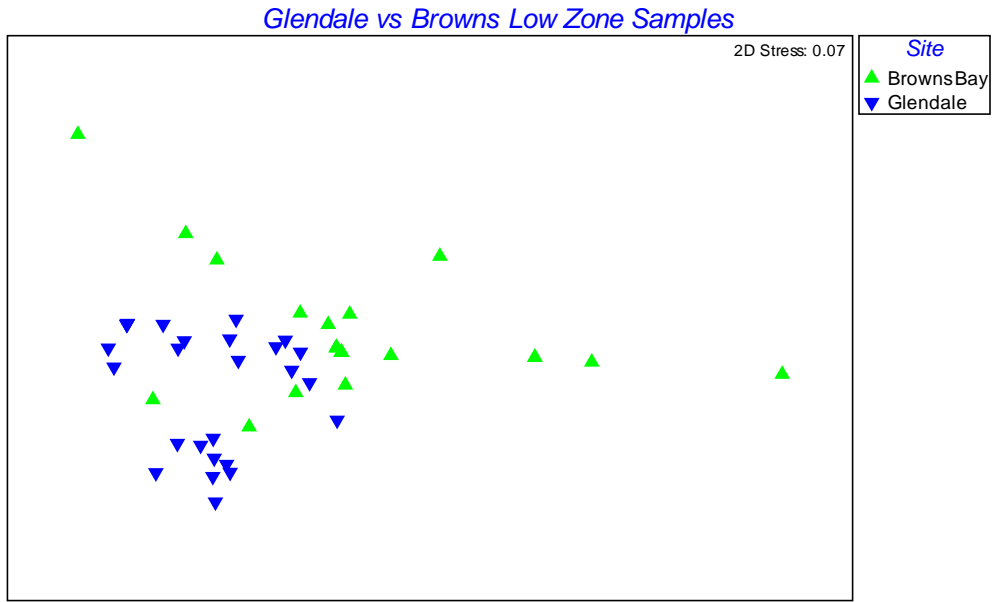
(*Browns Bay* side only) found substantial surface-water discharge from culverts onto the beach, and brackish groundwater being forced to the surface in seeps, often at the slope/grain-size break on the shore (Rick Dinicola, personal communication). Thus organisms at both sites must contend with substantial variation in salinity.

Figures 3-10 and 3-11 show MDS plots of the *Glendale* and *Browns Bay* biota separated by tidal height, and with each point representing a sample rather than mean values for a transect. In the mid zone, we removed for analysis 4 samples with no organisms (all from *Glendale*). The sites are somewhat different in this zone, although there is overlap; the Global R value is low (0.207).



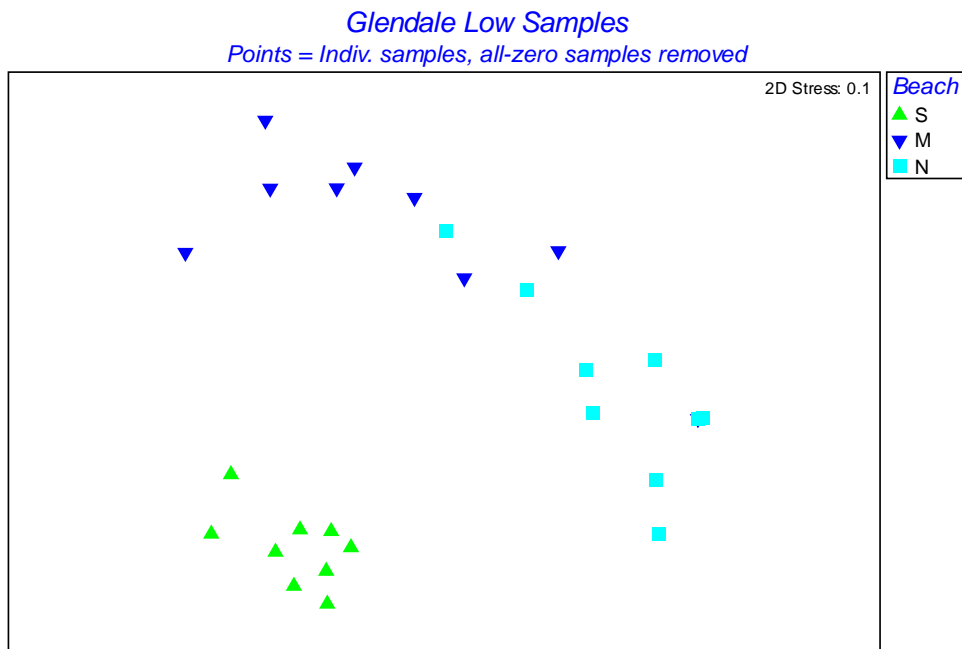
**Figure 3-10.** MDS analysis of mid-zone samples at *Glendale* and *Browns Bay*. Each point is a single sample.

For analysis of the low zone samples, we had to remove many all-zero samples (7 at *Browns Bay* and 2 at *Glendale*). *Glendale* samples were relatively similar to each other whereas *Browns Bay* samples were quite variable; the separation among sites is again moderately clear ( $R = 0.263$ ,  $p = 0.001$ ).



**Figure 3-11.** MDS analysis of low-zone samples at *Glendale* and *Browns Bay*. Each point is a single sample.

Figures 3-12 and 3-13 illustrate the low zone samples from each site by itself, and with the points (samples) coded by beach to illustrate beach-to-beach differences. For *Glendale*, the beaches are clearly different in their biotic communities ( $R = 0.738$ ,  $p = 0.001$ ); in particular, the South beach is different from Mid and North.



**Figure 3-12.** MDS analysis of low-zone samples at *Glendale* only. Each point is a single sample.

At *Browns Bay*, however, communities in the low zone were not significantly different among beaches ( $R = 0.042$ ); the biota differ among samples but in all cases are low-diversity, which makes it almost impossible to find patterns in these multivariate analyses.

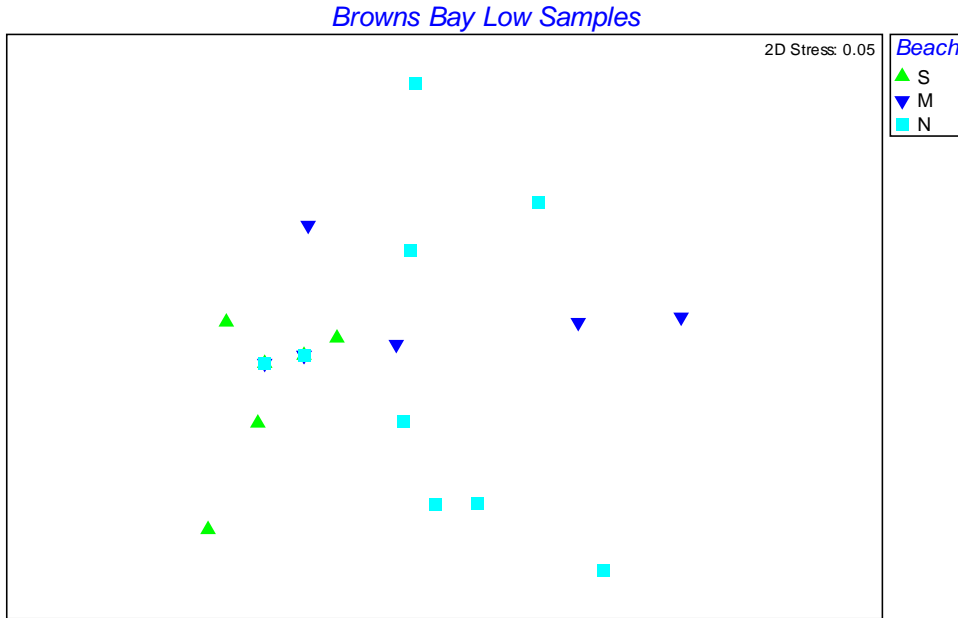
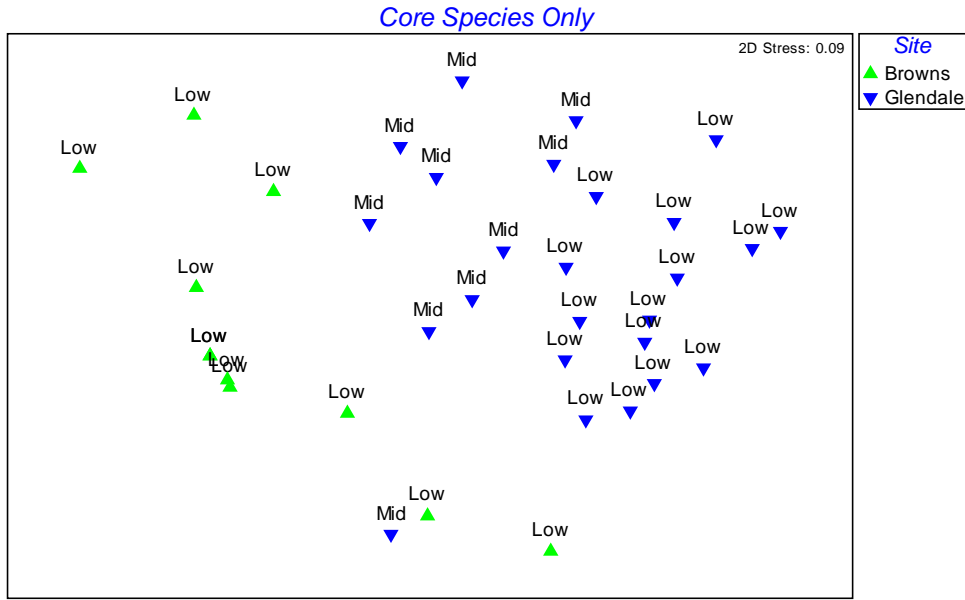


Figure 3-13. MDS analysis of low-zone samples at *Browns Bay* only. Each point is a single sample.

### 3.1.1 Eelgrass Infauna

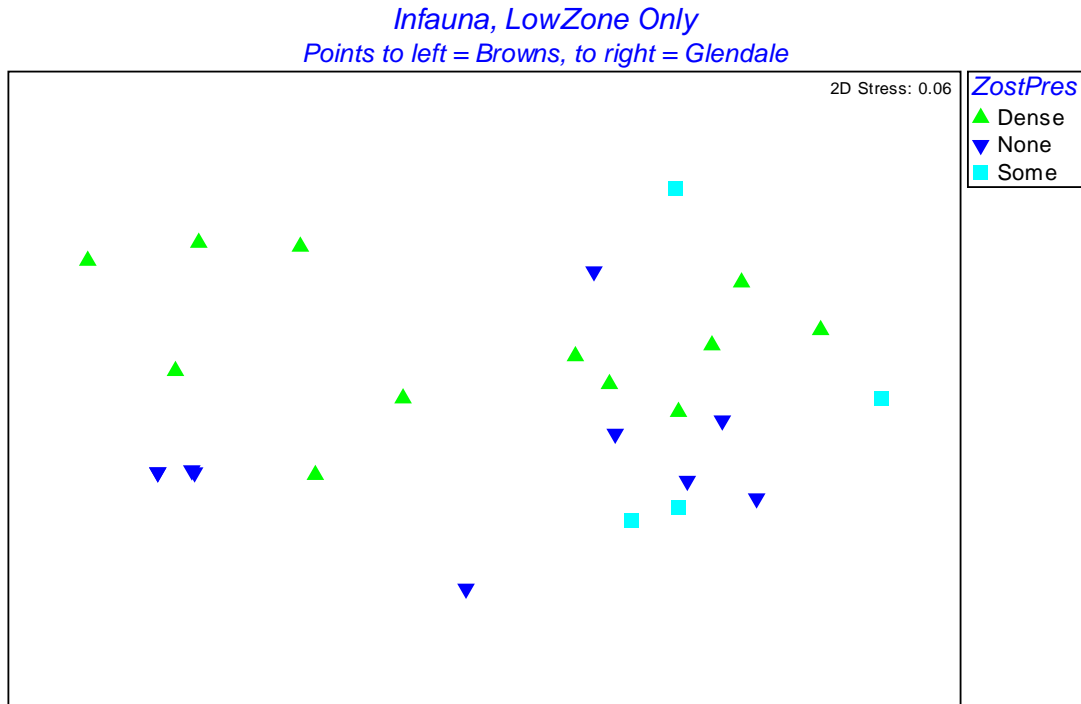
We compared the biota found in cores (i.e., not including quadrat data) at the beaches and tidal levels where eelgrass was found (*Glendale S* and *Browns Bay N* only). Figure 3-14 compares the infaunal communities at these beaches and treatments, with each point representing infauna in an individual core rather than an average value per transect. When all cores are plotted, regardless of eelgrass presence, the biota at *Browns Bay* clearly was different from that at *Glendale* (as seen in Figure 3-14), and the *Glendale* mid-zone biota (blue points in center) were different than the low-zone (blue points to the right).



**Figure 3-14.** The two-dimensional solution for non-metric multidimensional scaling ordination (final stress = 0.09) of infaunal communities at Browns Bay and Glendale in 2008. Low-zone points represent individual 0' (MLLW) samples, and mid-zone samples were collected at +2.8' (MLLW). Four cores from Browns Bay which contained no infauna were omitted to allow patterns among the other samples to be seen.

When the low-zone data are analyzed without the mid and the points are coded for amount of *Zostera* (Dense = >50% cover, Some = 1-50%), there were no differences in community structure relating to *Zostera* abundance (Figure 3-15). An ANOSIM analysis found no grouping by *Zostera* abundance ( $R = 0.033$ , not significant). Any differences among cores would be hard to quantify because of the very low abundances of all infauna in all samples, and the small numbers of cores. SIMPER analyses showed that dense-eelgrass cores tended to have tube-building oweniid polychaetes and *Transenella* clams, while cores without eelgrass had more *Tellina* clams.





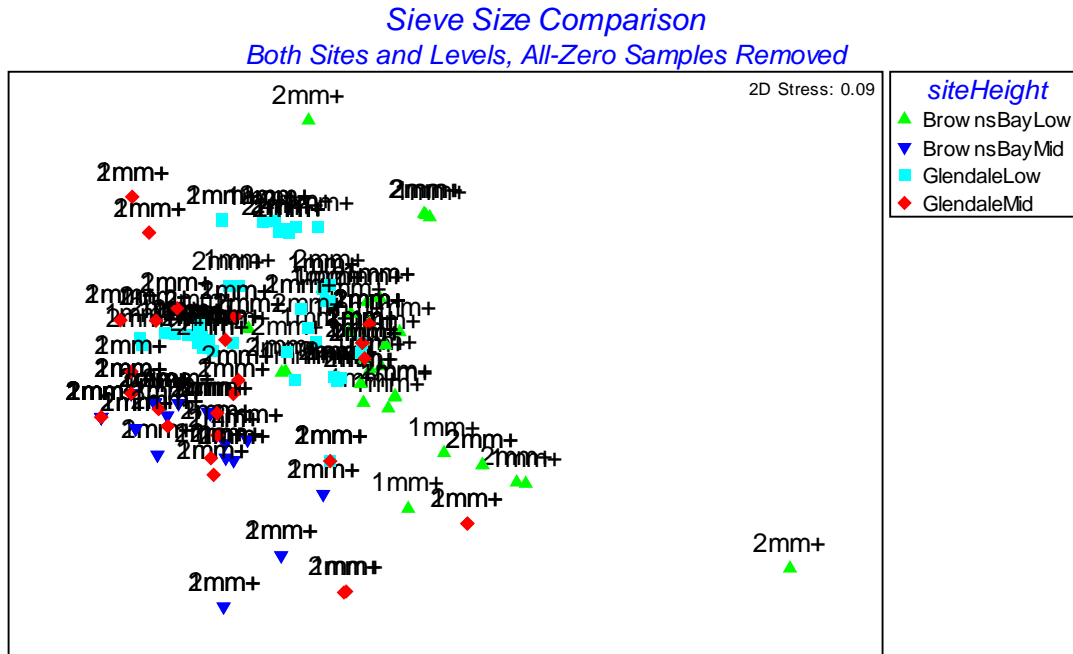
**Figure 3-15. MDS analysis of infaunal community data at Browns Bay and Glendale in areas with eelgrass present and absent. All samples are from MLLW elevation. Points are coded to reflect percent cover of eelgrass in the area of the core sample.**

### 3.1.2 Comparison of Sieve Mesh Sizes

All analyses comparing organisms retained on 2 mm vs 1 mm sieves showed no substantive differences. Out of 23 infaunal species in these samples, all but 5 species retained on the 1 mm sieves were found at least once on the 2 mm sieves. Of those 5 species (4 amphipods and 1 tiny clam), all were rare, found only once among the 120 samples. For several species, densities were somewhat higher in the 1 mm samples. This was true for the tiny clams *Nutricola lordi* and *Tellina modesta*, and for the very small polychaete *Scoloplos acmeceps*; for each, the overall mean counts were about 50% higher on the 1 mm sieves than the 2 mm sieves. The tiny polychaete *Paraonella platybranchia* was seen for the first time in some of these samples; 2 (total) individuals were found on the 2 mm sieves, while a total of 5 were found on the 1 mm sieves. All of these taxa are larger than 2 mm in some dimension (length), and thus are likely to occasionally be retained on the larger sieve mesh.

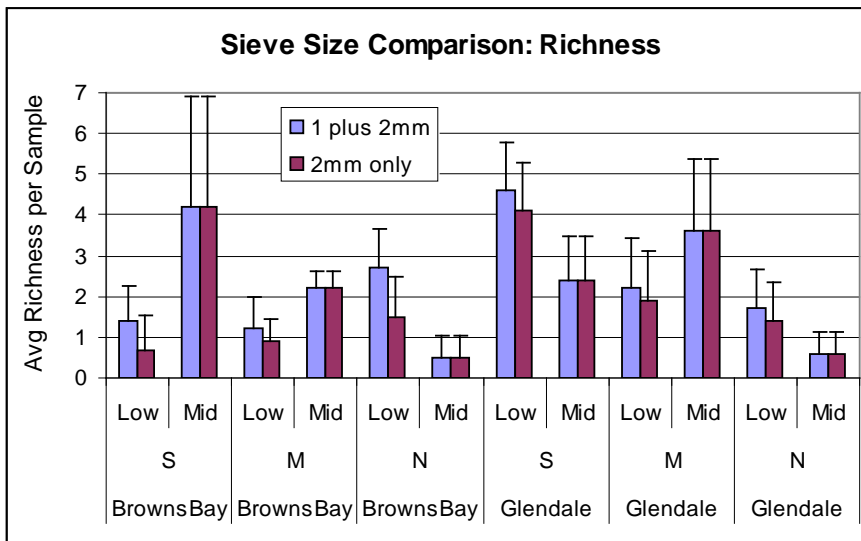
Figure 3-16 shows an MDS analysis of the biota found in each of the samples that was sieved through two mesh sizes; it shows that there are some differences in biota among sites and heights (colors), as discussed above, but there is no pattern in the 1 mm vs. 2 mm points. In many cases, these points lie right on top of each other, indicating zero difference within that sample for infauna retained on the two meshes. This plot omits the 17 samples (out of 120) for which no biota were found in the quadrats or in either

sieve. ANOSIM tests on these data, both with and without including the all-zero samples, showed no effect of mesh size ( $R = 0$ ).



**Figure 3-16.** MDS- analysis of 2008 infaunal community data collected using 1 mm and 2 mm mesh sieves. Points are individual samples, not average values. Labels with an overlapping 2 and 1 indicate that the samples with the different mesh sizes were identical.

Species richness was identical at most sites and tidal heights when the two mesh sizes are compared (Fig. 3-17).



**Figure 3-17.** Comparison of species richness on 1 mm and 2 mm mesh sieves. Error bars are one s.d. around the mean value.

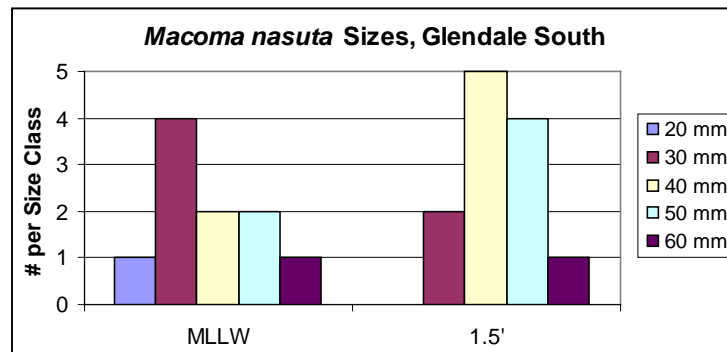
### 3.1.3 Clam Data

Five of the six beaches sampled were characterized by very low clam abundance and diversity, both at MLLW and higher levels. Out of the 24 box cores at *Browns Bay*, a total of only 4 clams were found (Table 3-1). The *Glendale* box cores had more clams overall, a total of 27, with most (24) of these found at *Glendale S* (Table 3-1). The beach at *Glendale S* appeared to be the most wave-protected, and was the only one of the three *Glendale* beaches to have a significant *Zostera* population at our sampled levels. It appears that the other sandy beaches on both sides of the Sound may have had too high wave energy (with associated unstable substrates) to support significant clam populations. Relative to the other *Glendale* beaches, *Glendale S* receives some protection from southerly wave fetch by Protection Point (Figure 1-1).

Site Name	Segment Names	0 ft (MLLW)	+1.5 ft (MLLW)
<i>Browns Bay</i>	North	None	None
	Mid	<i>Lucinoma aequizonatum</i> (1)	<i>Clinocardium</i> (1)
	South	None	<i>Macoma secta</i> (2)
<i>Glendale</i>	North	<i>Macoma nasuta</i> (1)	None
	Mid	<i>M. secta</i> (1)	<i>M. nasuta</i> (1)
	South	<i>Clinocardium</i> (2) <i>M. nasuta</i> (10)	<i>M. nasuta</i> (12)

**Table 3-1. Species and number of adult clams found in 2008 at *Glendale* and *Browns Bay* sites.**

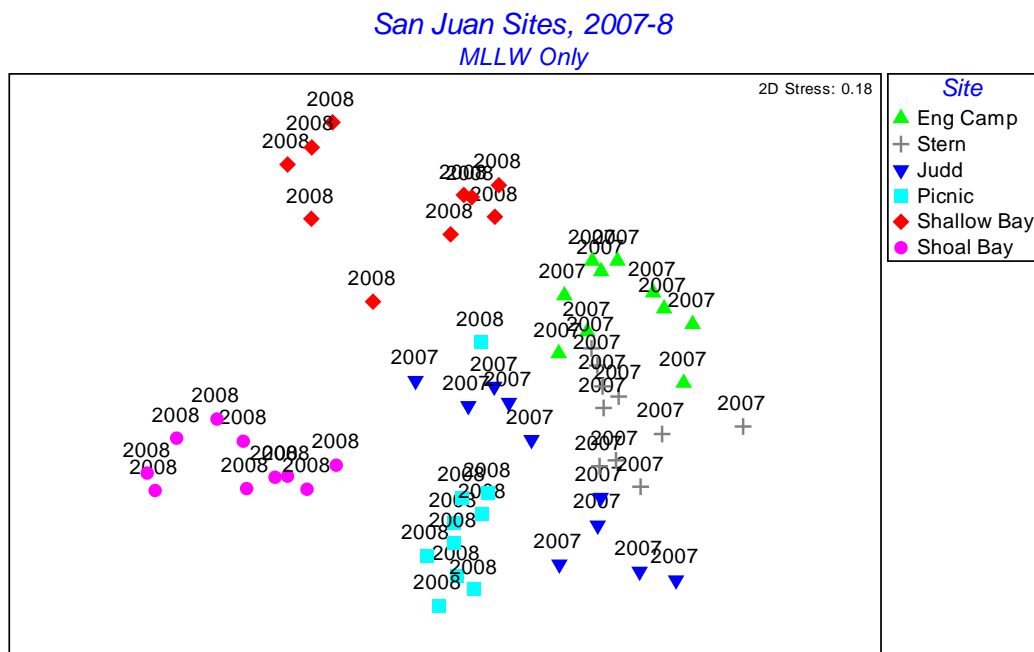
Figure 3-18 shows sizes of *Macoma nasuta* found at the only transect where there were enough individuals to analyze. This range of sizes is quite similar to those found in the San Juan Bays, with few individuals below 30 mm or above 60 mm.



**Figure 3-18. Number of *Macoma nasuta* clams per size class at two intertidal elevations at *Glendale South*.**

### 3.2 Baseline Information from Embayments in the San Juans with Eelgrass

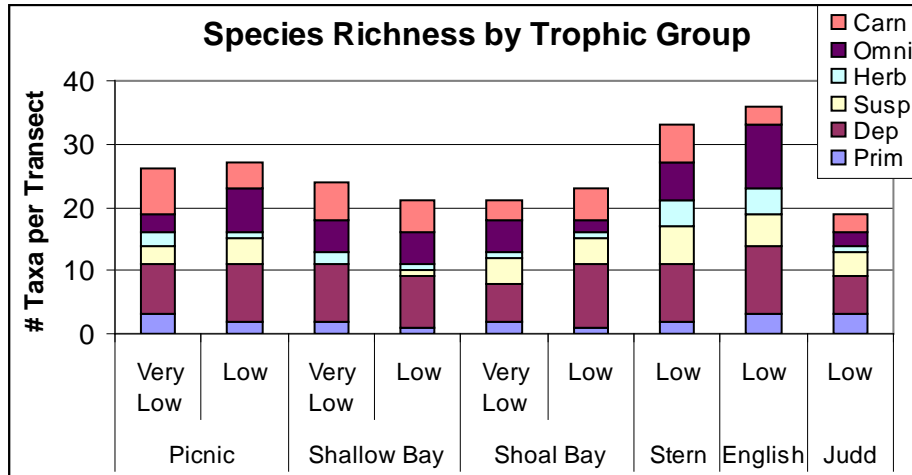
The biotic communities found in the three San Juan embayments in 2008 differed both from each other and from sites sampled in Westcott Bay in 2007. Figure 3-19 shows an MDS plot representing community composition at MLLW both for the 2007 Westcott Bay sites and the three bays sampled in 2008. Samples from each site cluster cleanly with each other and separately from the other sites, indicating considerable differences in communities among all sites. ANOSIM analysis for Sites indicates very strong separation:  $R = 0.924$ ,  $p = 0.001$ . Pairwise analyses are all also significant; the most similar sites are Judd and Stern, and English Camp and Stern (as seen in Figure 3-19). Each site has a rather characteristic set of species (Appendix D). The communities also differ among years (ANOSIM  $R = 0.448$ ,  $p = 0.001$ ), with the 2007 Westcott Bay sites clearly dissimilar from the three 2008 sites. This separation could be due to differences either among years or areas; the bays differ in wave exposure, sediment grain sizes, amount of eelgrass, and other parameters, and our sampling method differed in sieve size (1 mm mesh in Westcott Bay in 2007, 2 mm at all 2008 sites). However, since many tiny species (e.g., certain spionids) were retained on the 2 mm sieves used in 2008, and our comparison of 1 vs 2 mm sieved samples showed few differences (see section 3.1.2), it is unlikely that this factor is responsible for significant among-year differences.



**Figure 3-19. MDS plot representing community composition at MLLW both for the 2007 Westcott Bay sites (Eng Camp, Stern, Judd) and the three bays sampled in 2008. Each point represents one sample (surface quadrat plus core), i.e. the data are not averaged along the transect (since this would reduce each beach to one point).**

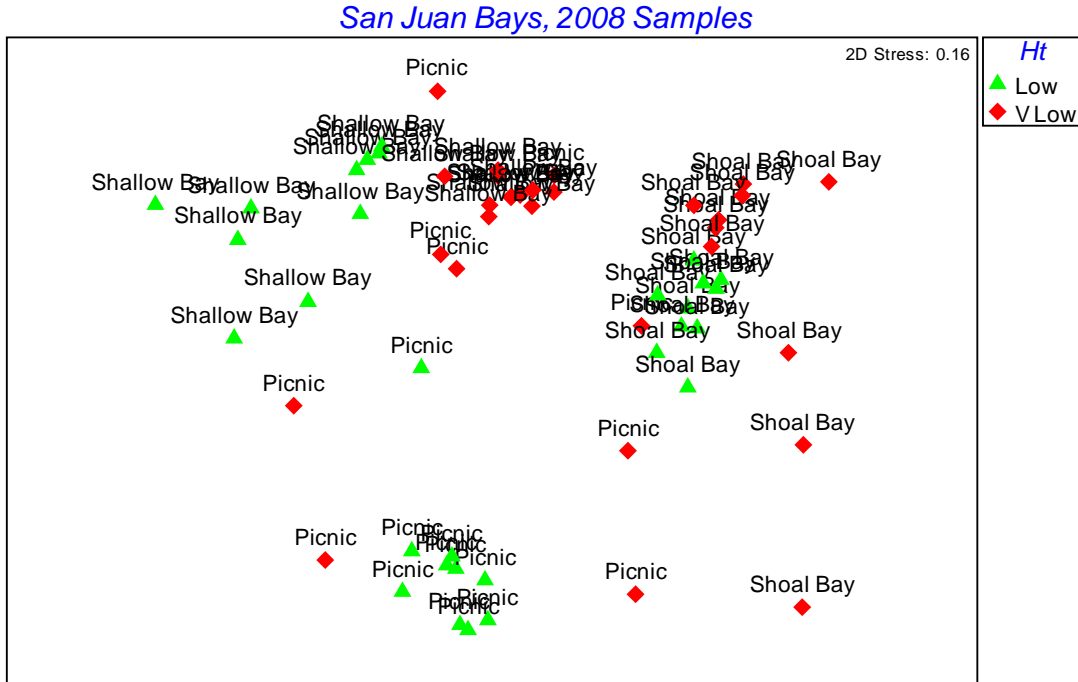
Figure 3-20 compares species richness by trophic groups at these 6 sites for the Low (MLLW) and Very Low (-2') elevations (where sampled). These two elevations have very similar overall species richness at the 3 bays where both were sampled. The three

small embayments (Picnic, Shallow, and Shoal) have similar richness, whereas richness overall was higher at two of the Westcott Bay sites sampled in 2007; these two sites both had some cobble in the Low zone, which led to both higher species diversity and higher clam abundance (see below). The lower-richness Judd site, however, was more similar to the small embayments in terms of being rather uniform muddy sand. As expected for soft-sediment habitats, all sites had few primary producers, and the richness was dominated by deposit feeders, consisting of both tellinid clams and various polychaetes.



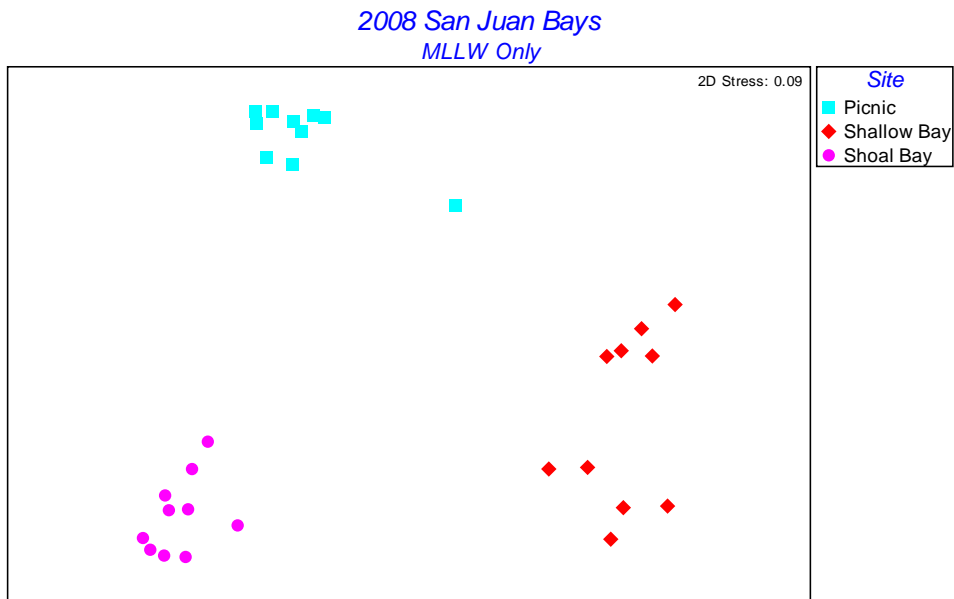
**Figure 3-20. Species richness in San Juan Embayments and three Westcott Bay sites at Low (MLLW) and Very Low (-2) tidal elevations.**

Figure 3-21 illustrates the biotic data for just the 3 bays sampled in 2008. As with the richness measure, this plot suggests that communities are quite similar at the two lower levels sampled, i.e. there is only weak separation among the Low and Very Low points for each site ( $R = .184$ ). There is much clearer separation among sites ( $R = 0.611$ ), with *Shallow Bay* points at the upper left and *Shoal Bay* points at the upper right; the *Picnic Cove* points are more broadly spread, indicating high sample-to-sample variability in biotic communities there. The average among-samples similarity at *Picnic Cove* was only 30%, versus 48 and 52% at *Shoal Bay* and *Shallow*, respectively. *Picnic Cove*, but not the other two bays, had ghost shrimp mounds at both MLLW and -2'; the presence of these bioturbators may have affected the rest of the biota, even though the shrimp themselves were not found in the core samples.



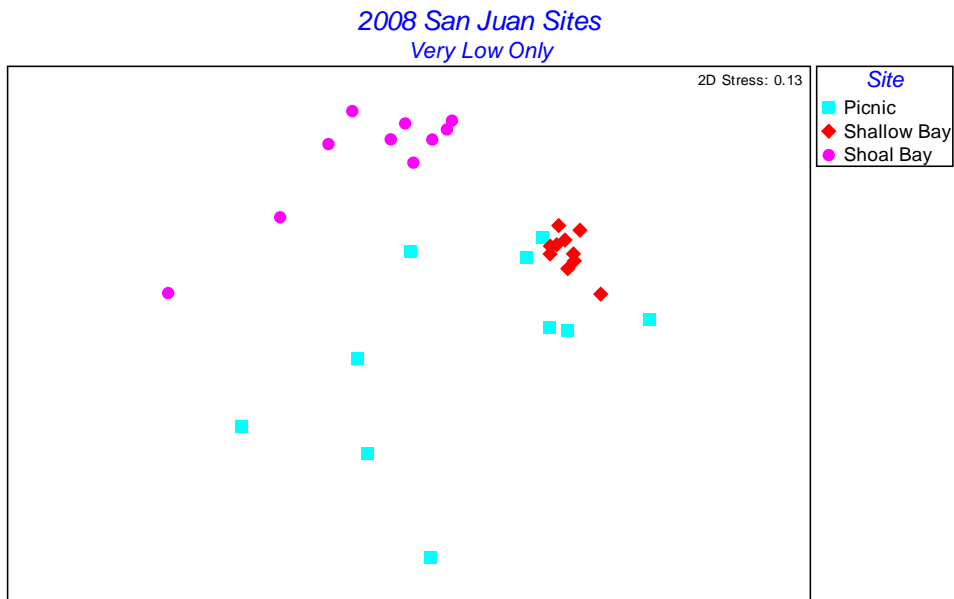
**Figure 3-21. MDS plot representing the community composition at Low and Very Low Tidal Heights in Three Embayments in 2008. Each point is one sample.**

Figure 3-22 shows the community data for the 2008 MLLW transects only. At this level, there are clear differences among bays and high consistency among samples in the communities found at each; ANOSIM for Sites R = 0.987,  $p = 0.001$ . There is very little overlap in characteristic species among these bays; dissimilarities between pairs of bays range from 87 to 95%. *Picnic Cove* is characterized at this level by a lack of vegetation except surface diatoms, and an abundance of various polychaetes (the capitellids *Mediomastus* and *Notomastus*, the predator *Glycinde*), tanaids, and juvenile *Macoma*; *Shallow Bay* had more ulvoids, a different capitellid (*Capitella*) and many spionids (*Malacoceros*), and *Shoal Bay* was dominated by *Zostera* at this level, with associated *Lacuna* snails and with *Notomastus* in the sediment.



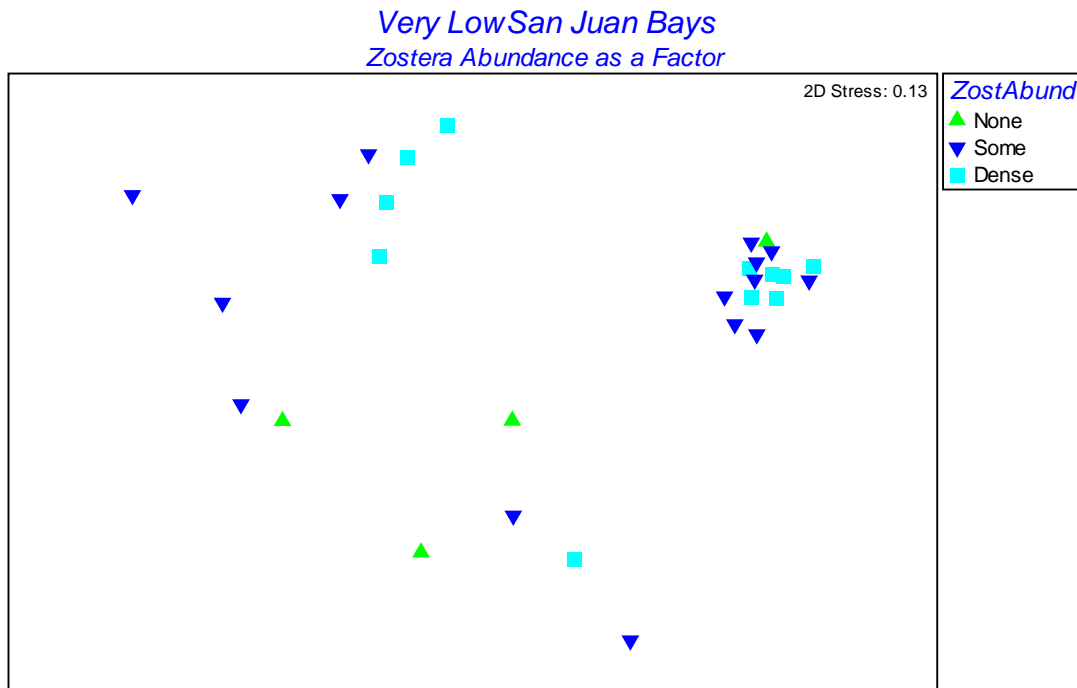
**Figure 3-22. MDS plot representing community composition at MLLW Tidal Elevation. Each point is one sample.**

The within-beach consistency seen at MLLW is much less clear for the Very Low (-2') samples (Fig. 3-23); except at *Shallow Bay*, samples within a beach were much more variable, perhaps because some but not all of the very low samples contained *Zostera*, which could affect all of the flora and fauna. The ANOSIM for Sites at this level has an R value of 0.504, much less than for the Low zone.



**Figure 3-23. MDS plot representing community composition at Very Low Tidal Elevation.**

This variability holds even when *Zostera* itself is omitted from the community analyses and samples are coded by *Zostera* abundance (Fig. 3-24), showing that there are other biotic differences among samples. In this analysis, sites are still significantly different (not illustrated:  $R = 0.679$ ,  $p = 0.001$ ), with *Shoal Bay* and *Shallow Bay* particularly different ( $R = 0.996$ ). *Picnic Cove* was characterized by ulvoids, *Lacuna*, stichaeid fishes, and diatoms. *Shallow Bay* had ulvoids, the polychaete *Capitella*, and gammarid amphipods. *Shoal Bay* had the red alga *Gracilaria*, *Lacuna*, and sabellid and orbinid polychaetes. No pattern emerges relative to eelgrass dominance; an ANOSIM test using *Zostera* abundance categories (none, some, dense) showed no significant difference among samples grouped in this way (Fig. 3-24;  $R = 0$ ). Individual samples lacking eelgrass often lack species commonly associated with eelgrass, such as *Lacuna*, but others do not show such a pattern. A more important factor affecting community structure at *Picnic Cove* may have been a general physical gradient along the beach; the west end of the transect appeared to be more wave-exposed and coarser and the samples there tended to clump together (not illustrated), while samples towards the east end of the transect became progressively finer-grained and more *Zostera*-dominated. Thus while *Zostera* likely has an impact on the biota around it, its presence does not override the site-to-site differences that probably relate to sediment issues (see below).

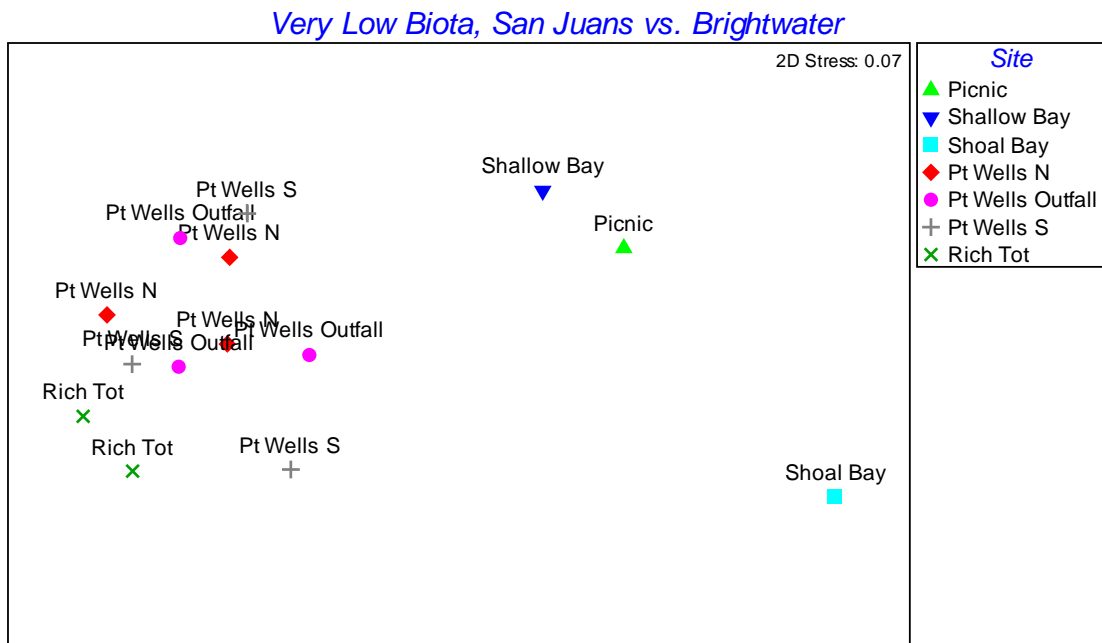


**Figure 3-24.** MDS plot of biota in the 2008 San Juan Bays; *Zostera* abundance was removed as a variable but categories of its abundance (none, some, dense) were used as a factor in the analysis. Each point is a single sample.

Because samples have been taken in the Very Low zone (-2') only in these San Juan Bays and as part of the Brightwater sampling effort in north-central Puget Sound, we compared the biota in this zone among these sites in another multivariate analysis.



Figure 3-25 shows that the communities in these regions are very different (ANOSIM  $R = 0.402$ ,  $p = 0.001$ ), even though superficially both were in muddy sand with patches of *Zostera*. Perhaps most importantly, none of the Very Low transects in the San Juans had any cobble, while the Brightwater sites averaged about 25% cover cobble in this zone. Associated with the cobble is higher species richness (34-59 species per transect, vs. 21-26 in the San Juans), comprising a variety of types of organisms. The Brightwater sites were characterized in large part by species that live on cobble, including ulvoids, *Lacuna*, algal crusts, barnacles, and *Porphyra*, as well as by some infauna including *Notomastus* polychaetes. The San Juan bays had more *Zostera* and, like the Brightwater sites, had ulvoids (although not attached to cobble) but otherwise were characterized by *Capitella*, *Gracilaria*, and stichaeids. All the San Juan embayments are quieter-water habitats than the Brightwater sites. In addition, given the differences we have seen in biota from spatially separated regions, these large differences are not surprising.



**Figure 3-25. MDS plot comparing community composition at 3 San Juan Bays and 4 sites being monitored for construction impacts associated with Brightwater (Pt Wells Outfall is the impact site, the other Pt. Wells and Richmond sites are controls). Points represent mean values per transect.**

Clams sampled in box cores at the three San Juan bays in 2008 were more abundant (Table 3-2) and diverse than clams in the sandy *Glendale* and *Browns Bay* sites, although much less so than clams in Westcott Bay. Most samples in the San Juan Bays had 1-2 species of clams in them (Fig. 3-26), with *Picnic Cove* being the most diverse.

Segment Names	0 ft (MLLW)	+1.5 ft (MLLW)
Picnic Cove	<u>Soft sandy mud</u>	<u>Sandy mud</u>
	<i>Macoma inquinata</i> (7)	<i>Macoma inquinata</i> (5)
	<i>Macoma nasuta</i> (21)	<i>Macoma nasuta</i> (12)
	<i>Protothaca staminea</i> (1)	<i>Clinocardium</i> (2)
	<i>Clinocardium</i> (1)	<i>Mya arenaria</i> (3)
	<i>Saxidomus</i> (2)	
	<i>Mya arenaria</i> (4)	
Shallow Bay	<u>Sandy mud</u>	<u>Sandy mud</u>
	<i>Macoma inquinata</i> (5)	<i>Macoma inquinata</i> (6)
	<i>Macoma nasuta</i> (32)	<i>Macoma nasuta</i> (15)
		<i>Saxidomus</i> (1)
Shoal Bay	<u>Muddy sand</u>	<u>Pebbles, sand, mud</u>
	<i>Macoma inquinata</i> (1)	<i>Macoma inquinata</i> (4)
	<i>Macoma nasuta</i> (16)	<i>Macoma nasuta</i> (3)
	<i>Macoma secta</i> (3)	<i>Clinocardium</i> (1)
		<i>Protothaca</i> (2)
	<i>Saxidomus</i> (3)	

Table 3-2. Species and number of adult clams found in 2008 at Picnic Cove, Shallow Bay, and Shoal Bay.

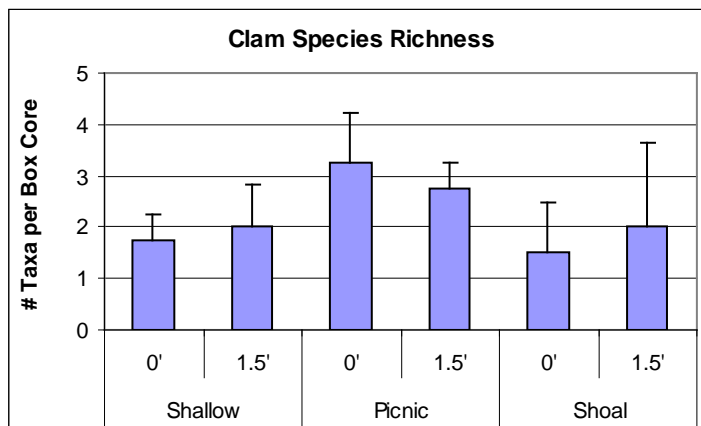


Figure 3-26. Clam Species Richness at three San Juan Embayments. Bars are mean number of species per box core and one s.d.

*Macoma nasuta* was the most abundant species in all of the bays, as was expected for these muddy sites, although some *M. inquinata* were also present (Table 3-2, Fig. 3-27). For comparison, densities of *M. nasuta* at the Judd site (with muddier sediment) in Westcott Bay were 12-30 per box core, and *M. inquinata* at the Stern site were ca. 1-3.

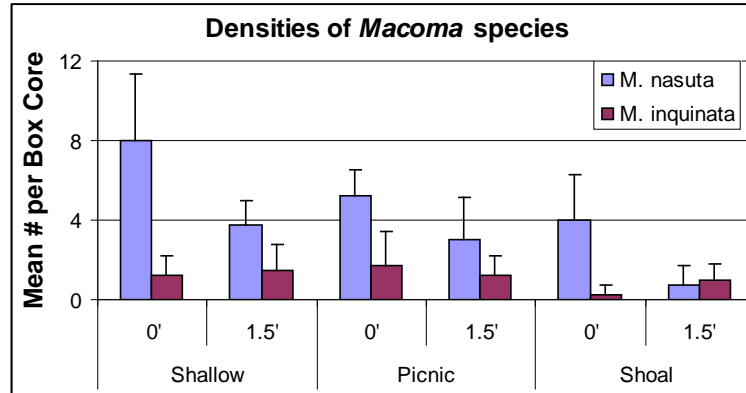


Figure 3-27. Densities of *Macoma* clams at three San Juan Embayments. Bars are mean number of species per box core and one s.d.

Substrate observations noted differences among the 3 San Juan embayments and among tidal heights (Table 3-2). *Shallow Bay* (Sucia Island) and *Picnic Cove* (Shaw Island) had sandy mud at both sampled tidal heights, with the lower zones generally being softer (muddier). *Shoal Bay* (Lopez Island) had the coarsest sediment, especially at +1.5' where it was a mix of pebbles, sand, and mud. This coarser substrate is poor for *Macoma nasuta*, the most common clam in the sandy mud at other sites, but there were also surprisingly few *M. inquinata* at *Shoal Bay*. However, more *Saxidomus* and *Protothaca* were found at this location than elsewhere; these species often are associated with such coarser sediments.

Only two clam species were found often enough to examine size class data. A range of sizes of *M. nasuta* was found at all sites, although *Picnic Cove* seemed to be lacking larger individuals (Figure 3-28), and none of the 2008 sites had as many large clams as the 2007 Westcott Bay sites. The few *M. inquinata* found were also mostly small compared to Westcott Bay, where larger clams were common (Figure 3-29). However, too few clams were found at the 2008 sites to allow statistical analyses.

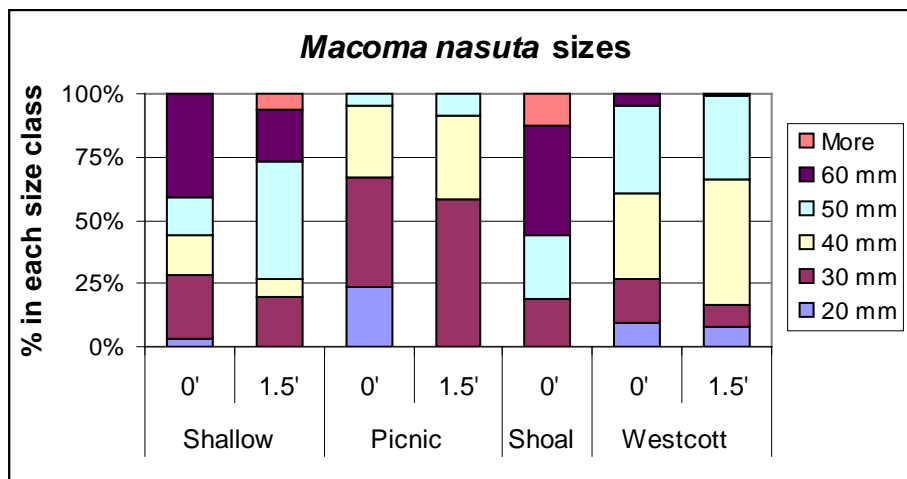
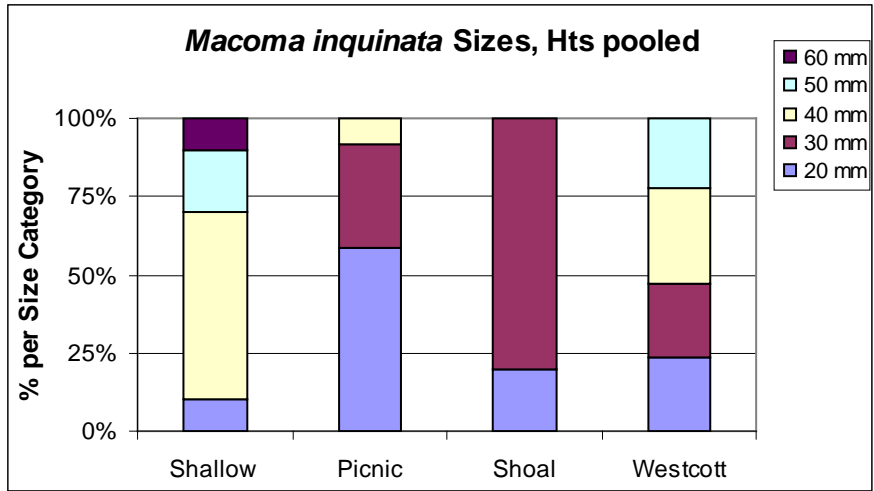


Figure 3-28. Percentages of *Macoma nasuta* clams in each size class from each of the 2008 San Juan embayments and from the 2007 Westcott Bay samples (all Westcott sites pooled).



**Figure 3-29. Percentages of *Macoma inquinata* clams in each size class from each of the 2008 San Juan embayments and from the 2007 Westcott Bay samples (all Westcott sites pooled).**

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# 4 Discussion and Conclusions

## **4.1 Long term monitoring at Possession Point**

The long-term (10 year) data for three beaches at *Possession Point* suggest that these community-level analyses are sensitive to change, for example a slight alteration in the zone of sampling in one year that showed up as a clear ‘outlier’ in the analyses. This power to detect change at the *Possession Point* sites occurs because: 1) the beaches tend to ‘track’ each other through time – probably enabling us to detect if one beach deviated in a given year because of some local impact (although this has not yet occurred); 2) changes in the communities occur each year, generally in relative abundances of the organisms, but are relatively minor (as is true at most of our monitored sites); and 3) these beaches are very species-rich, meaning that minor year-to-year changes in a few species will not show up as an ‘impact’, as they would for a species-poor beach.

## **4.2 Comparison of Browns Bay and Glendale Beaches**

Although one of our initial objectives for the comparison of sites on the opposite sides of Possession Sound was to compare nearby beaches with and without shoreline armoring, the data and our field observations suggest that the biotic differences between *Glendale* and *Browns Bay* beaches, at least in the mid and low intertidal zones, are likely to be a function of wave energy and substrate type rather than a direct effect of armoring. At both sites the subtidal and lower intertidal zone sediments are dominated by medium-fine sand. Other data (Stevens et al. 2008) indicate that the *Browns Bay* site has a much narrower subtidal sand shelf than *Glendale*, and much less subtidal eelgrass. The presence at *Glendale* of the broad shelf, combined with reduced wave fetch (from the south and west) from northern Puget Sound, means that the intertidal substrates on this side are finer and more anaerobic; this was especially true at *Glendale S*, which receives the most protection from southerly fetch. *Glendale* also has occasional patches of cobbles and even boulders, presumably eroded out of the bluffs above. Perhaps most importantly, all the sampled beaches at *Glendale* had relatively gentle slopes, whereas two of the *Browns Bay* beaches had a distinct low-slope low-tide terrace but then a slope break and much steeper upper-shore conditions. These steeper beaches are characterized by unstable pebble and cobble sediments, which are biologically very different from the flatter sandy beaches. *Browns Bay S* had a less steep mid-shore,

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perhaps affected by sediment from the small stream mouth nearby. We cannot distinguish the causes of these slope-substrate differences between the two sides of Possession Sound; they could be affected by on-site armoring, by up-drift sediment supply, by wave energy affected by fetch, or by wave energy affected by the shallow nearshore bathymetry.

#### **4.3 Baseline Sampling in San Juan Embayments with Eelgrass**

The biota in the sampled San Juan embayments differed significantly from each other, perhaps related to differences in wave exposure and its effect on sediment type. The presence of eelgrass may be another “forcing function” for the rest of the local biotic community, but our data have not yet demonstrated this. Eelgrass populations were present at some of the *Glendale* and *Browns Bay* beaches, and at all of the San Juan embayments, in substrates ranging from fairly clean sand to soft mud. Our limited data comparing communities found in samples with eelgrass versus adjacent samples lacking eelgrass did not find clear differences, with the obvious exception of species that live on the eelgrass itself, such as caprellid amphipods, *Lacuna* snails, etc. It is likely that eelgrass presence affects both the richness and types of other organisms; studies in other systems have shown that eelgrass can strongly affect infaunal communities (e.g., Herkul and Kotta 2009) as well as key species like juvenile fishes that hide among the blades. Organisms living on transects with eelgrass are very different in the San Juan embayments than at *Glendale* or our Brightwater sites, although we have not systematically studied how eelgrass-associated low-shore communities vary throughout Puget Sound. Thus we cannot yet generalize about the role of eelgrass in determining the character of low-shore communities, and thus cannot make predictions about how the loss of eelgrass, of concern for these San Juan embayments, might affect the rest of the system.

#### **4.4 Monitoring Biotic Variability on Puget Sound Beaches**

Ecologists have long been aware that while it is possible to quantify and understand patterns of variation through space in natural systems, variation through time tends to be highly stochastic. While the goal of many monitoring programs is to detect anthropogenic changes, natural variation can be so high that it inhibits detection of human-induced effects (Eckert 2009). Anderson and Thompson (2004) note: “At any particular place through time (say, from year to year), we would expect to see natural variation caused by the dynamic interplay of many simultaneous ecological mechanisms, such as recruitment, competition, predation, natural variation in birth and death rates, habitat or environmental variation.” Thus before human-induced variation can be detected, natural variation needs to be quantified to establish an “envelope” of what is normal. This is a challenge both because this envelope may be genuinely large, and because perceived variability is the sum of real ecological change and the variation caused by our sampling error. Monitoring natural communities in a way that reduces sampling error, allows us to detect change, and

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allows us to draw conclusions about the breadth and causes of that change is a large challenge.

Our ongoing monitoring of the biota at beaches in Puget Sound attempts to deal with these issues by characterizing a wide variety of sites, quantifying parameters at the community, population and environmental levels, building up a database over many years, and analyzing the data in a variety of ways. We are at a point to draw some conclusions about types of sampling and analyses that are most useful, and what issues need further attention.

#### 4.4.1 *Types of Data and Analyses*

Multivariate analyses, because they examine the entire biotic community at each site, can be a powerful tool for examining temporal change. Past years' reports (e.g., Dethier 2007) and Dethier and Schoch (2005) have shown how effectively MDS analyses can illustrate *spatial* differences among the biota at beaches at various scales throughout the Sound. In those reports and in this one we also see how they can define and characterize *temporal* variability.

The multivariate data used in MDS analyses can also be used to calculate 'control charts', which are specifically designed for ecological monitoring programs as a way of assessing whether a given measurement (e.g. date) is 'unusual' relative to what is expected based on prior observations. It assumes that natural systems are stochastic and their variation can be modeled (Anderson and Thompson 2004) based on either several years' worth of 'baseline' data or on data from a pre-impact analysis. Once temporal variation has been modeled for a variety of sites, a bootstrapping procedure allows the calculation of confidence limits for what is 'normal' variation, and then data from a post-impact date or from a long-term database can be examined for deviations from normal. For example, all sites from central Puget Sound (which might be expected to show similar patterns and degrees of temporal variation) could be used to calculate such confidence limits, and then sampling periods when particular sites exceeded these limits could be found and examined further.

Species richness is a higher-order metric that has some of the advantages of multivariate analyses in terms of taking into account entire communities, and of varying less through time than population-level parameters such as counts of a particular species (e.g., see barnacle data in Figure 3-5). Species richness is also easier to communicate and understand than multivariate analyses. Our data show that it can undergo interesting patterns through time, such as the regularly-varying richness at *Possession Point* beaches every other year; these may be indicative of significant community-level processes (e.g., a key role of barnacle recruitment) that can then be investigated further. Our data also suggest that species richness is very sensitive to substrate type, stability, and elevation, as indicated by a) the overall low richness of sand beaches relative to those with cobble; b) the extremely low richness of pebble-sand substrates such as the mid-shore beaches at *Browns Bay*;

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and c) the variation in richness at different zones on the shore, including the unusually high species richness at *Possession Point* in 2005 when we sampled anomalously low on the shore.

Population parameters (density, biomass, percent cover) are notoriously variable in space and time (reviewed by Osenberg et al. 1994, Eckert 2008); while we gather density or percent cover data for all the species at our sampled beaches, analyses of these have not generally proved useful (Dethier et al. 2003). Some studies suggest, however, that individual attributes such as growth rates or reproductive output as well as higher-level metrics such as species richness may be less variable and thus have a greater power to detect change (Murray et al. 2006). Unfortunately, they also tend to be much more labor-intensive to sample. The only individual-level parameter we have monitored is size distribution of common clam species at some of our sites. Static patterns, i.e. data from one year, do not provide much information except for the abundance of very small individuals (an indicator of recruitment strength) or very large individuals (indicating good long-term habitat). We have few multi-year size distribution data for clams, but where they exist (e.g. Dethier and Berry 2008), they are good indicators of population (and therefore habitat) stability. Thus size distributions within and among sites, if sample sizes are large enough, could be useful parameters for detecting significant site-level or system-level change.

For all of these data types and analyses, our monitoring program would be strengthened (in terms of our ability to detect change or communities that are ‘outside the envelope’) if we were able to do additional sampling of years or sites that we knew were ‘not normal’. Because almost all of our beach sampling has been done at sites considered to be representative of types and levels of impacts that are common on Puget Sound’s shoreline, we lack data on what either ‘pristine’ or ‘highly impacted’ communities look like. This will vary, of course, with type of impact (e.g. hydrocarbon pollution, effects of seawalls, disturbance by clam digging) – and finding beaches that are clearly impacted by one factor but do not vary in other forcing factors (see below) is a challenge.

#### 4.4.2 *Forcing Functions in Shoreline Biotic Communities*

Our findings from 2008 sampling, in combination with those from past years, suggest that a limited number of parameters play key roles in determining the biotic communities found on “normal” Puget Sound shorelines.

The first factor is tidal height (elevation relative to datum). While most of our sampling has been at MLLW, it is clear that communities are very different above and below this level; the role of tidal elevation in determining community structure was one of the earliest described marine ecological patterns. The pattern for most habitat types is for species richness (and often biomass, although we have not studied this) to decline from extreme low water up the shore. This is clearly the case on cobble-sand beaches, such as *Possession Point*; this pattern has been



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quantified, for instance, in surveys for the Brightwater project (unpubl. data). The pattern is less clear in sand habitats such as those studied this year at *Glendale* and *Browns Bay*, and in mud habitats such as in the San Juan embayments. In these habitats our data suggest that community changes with elevation are complicated by substrate change, for instance when higher levels have more cobble on the beach surface, as was seen at some *Glendale* beaches.

The role of cobble overlying sand illustrates the profound structuring role of substrate characteristics, which overrides most other factors in determining community structure of Puget Sound beaches. This factor was described in our first SCALE study (Schoch and Dethier 1997) in Carr Inlet, and consistently seen since. In Puget Sound, the presence or absence of cobble, and to what extent it ‘armors’ or stabilizes the beach substrate, is critical. The contrast between pure-sand beaches, such as the low zone at *Glendale*, and cobble-sand beaches, such as the spatially close *Possession Point*, is dramatic, with *Possession Point* having 50-70 species per transect and *Glendale* 10-25 at the same tidal elevation. Although the role of armoring cobble has not been experimentally demonstrated, its importance can be seen at various scales. Our data comparing *Glendale* and *Browns Bay* beaches suggest that cobble affects local assemblages, including increasing the abundance of clams. In the San Juan Islands, comparisons of sites with varying amounts of surface cobble (high at Stern and English Camp, low at Judd and at the other San Juan embayments) all suggest that more-mixed substrate has richer biota. Clean sand is a rather depauperate habitat type; at *Glendale* and *Browns Bay* there were many samples with no organisms, and even the large box cores often contained no clams. Mechanisms behind this pattern probably include the physical instability of un-armored sand; it is difficult for many species (except rapidly-burrowing ones) to inhabit substrate that becomes very mobile in stormy conditions. In addition, aquaculturists found decades ago that adding gravel or cobble to the surface of beaches increased the survival of clams, which may relate either to stability or to the increased difficulty that predators have digging beneath cobbles. Mud or muddy sand may be less depauperate than clean sand; *Glendale South*, which was the muddiest of the sand beaches studied in this region, had the greatest abundance of clams and other species, and the muddy San Juan embayments generally had more species per transect than the clean-sand beaches elsewhere. We have data from only a few sites on a common higher-shore substrate type, steep pebble-sand beaches (seen at some *Browns Bay* beaches, as well as at Brightwater and many other Puget Sound sites), but they appear to be even more depauperate than clean sand.

Determinants of local substrate type, i.e. a higher-level forcing function, are much harder to elucidate. Factors include local wave energy, which for example has clear effects on the presence of mud, but wave energy reaching the shore is impacted not only by fetch and beach orientation but by nearshore bathymetry. In addition, the available substrates on which waves act are affected by geological legacy, factors that affect sediment supply updrift, and direct human alteration of the beach including nourishment with imported sediment. While our comparison of *Glendale* and *Browns Bay* beaches sought to investigate effects of armoring on the shore

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(none at *Glendale*, extensive at Browns), and that armoring may have been related to the substrate and slope differences of the beaches, those differences could also have been caused by variation in some of the other factors mentioned above.

A final physical forcing function that may be important in affecting Puget Sound biota, including at some of the sites studied this year, is salinity. At high tide, organisms living on shorelines encounter variation in salinity of the overlying water column; this is highly variable at the *Glendale* and *Browns Bay* sites, due to the influence of the large rivers draining from the north. At low tide, organisms (especially infauna) are surrounded by beach porewater, which is affected by the characteristics of the marine water table and by terrestrial groundwater running over the surface or percolating down through the beach sediment. While the salinity of water encountered by *Glendale* and *Browns Bay* biota clearly varied, we cannot dissociate the importance of this factor from other factors that varied among these sites, including substrate type.



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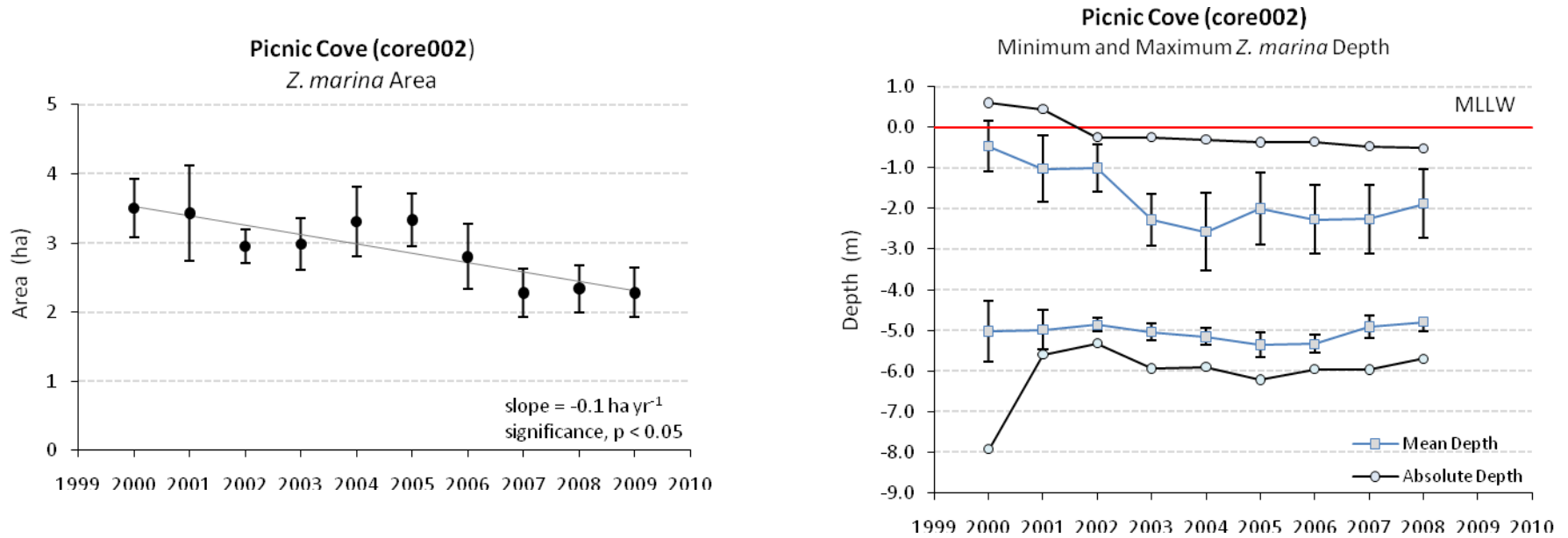
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# APPENDICES

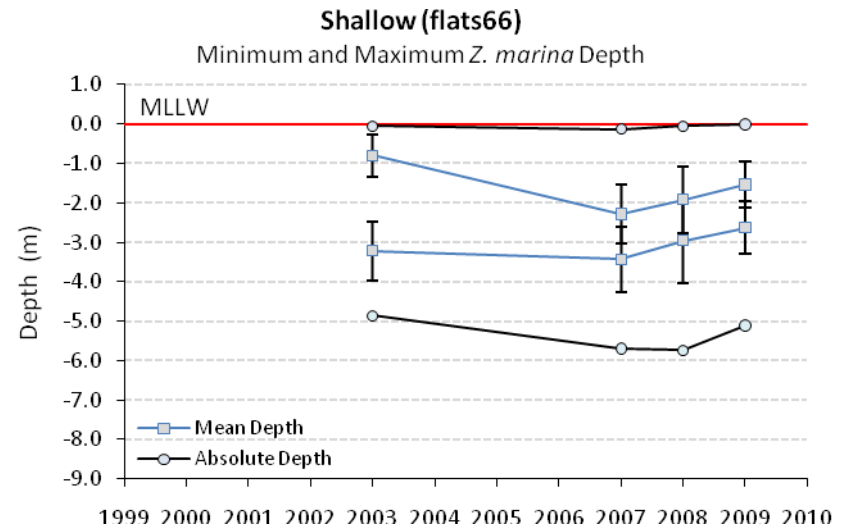
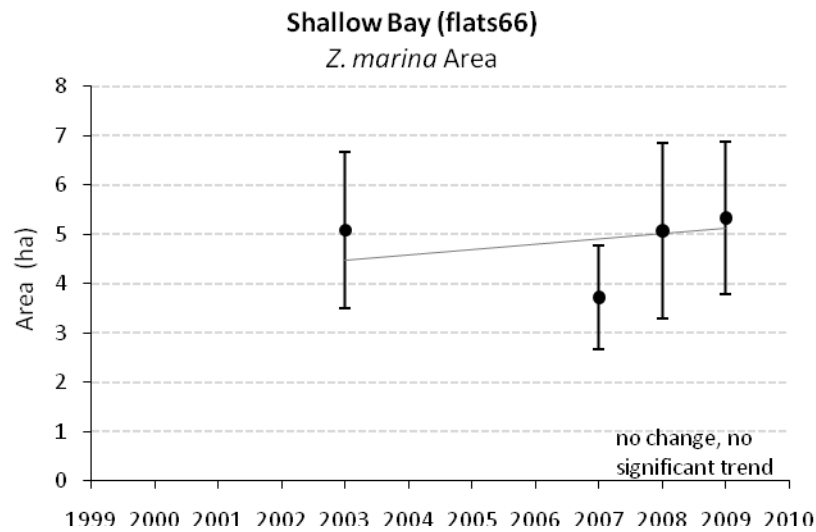
**Appendix A. Eelgrass (*Z. marina*) Abundance and Distribution Information from the DNR Submerged Vegetation Project.**

*Picnic Cove* (core 002): a) Eelgrass area, with 95% confidence intervals and trend information based on regression analysis; b) Minimum and maximum eelgrass depth measured at random transects, including the absolute values and mean values with 95% confidence intervals.



**Appendix A (continued). Eelgrass (*Z. marina*) Abundance and Distribution Information from the DNR Submerged Vegetation Project.**

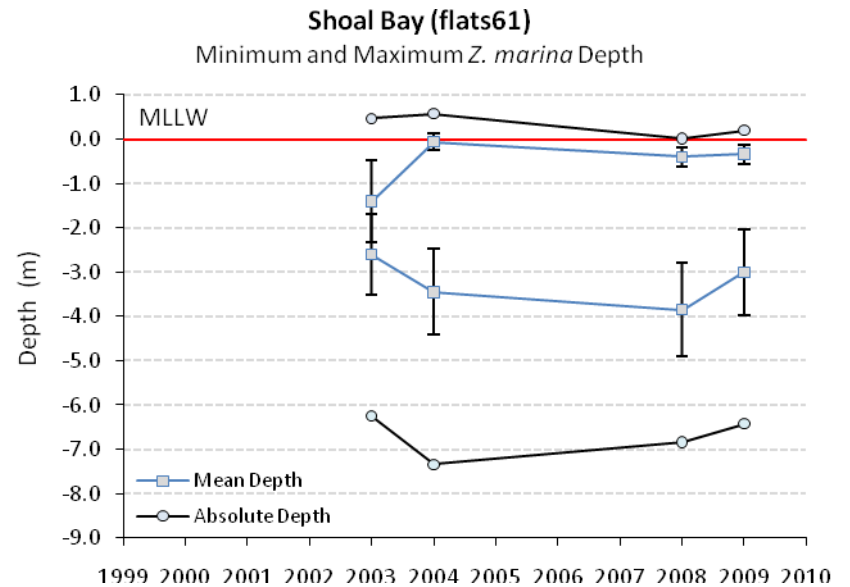
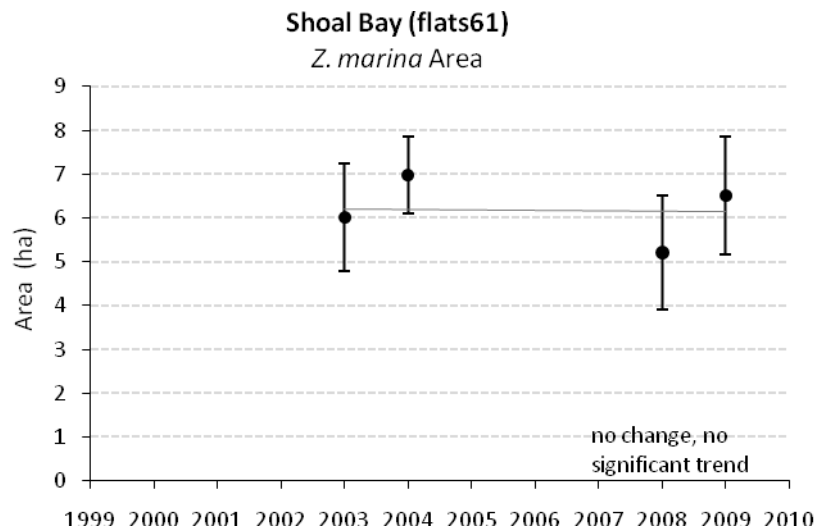
*Shallow Bay* (flats 66): a) Eelgrass area, with 95% confidence intervals and trend information based on regression analysis; b) Minimum and maximum eelgrass depth measured at random transects, including the absolute values and mean values with 95% confidence intervals.





**Appendix A (continued). Eelgrass (*Z. marina*) Abundance and Distribution Information from the DNR Submerged Vegetation Project.**

*Shoal Bay* (Flats 61): a) Eelgrass area, with 95% confidence intervals and trend information based on regression analysis; b) Minimum and maximum eelgrass depth measured at random transects, including the absolute values and mean values with 95% confidence intervals.



## Appendix B. Organisms found at *Possession Point* Beaches.

Organisms and their average abundances (counts for mobile organisms, percent cover for sessile organisms) in 0.25 m<sup>2</sup> quadrats and 10 cm x 15 cm deep cores. 10 random samples collected along a 50 meter transect.

<u>Name</u>	<u>Trophic</u>	<u>Poss 1</u>	<u>Poss 2</u>	<u>Poss 3</u>
Acrosiphonia spp.	Prim	7.6	17.5	14
Allorchestes angusta	Scav	0	1	0.1
Amphissa columbiana	Carn	0	0.1	0
Amphiodia spp	Scav	0	0.1	0
Anisogammarus pugettensis	Scav	0	0.3	0
Anthopleura spp.	Carn	1.8	0	0.1
Armandia brevis	Dep	0.3	0	0.6
Axiothella rubrocincta	Dep	0.1	0	0
Live barnacles (Class Cirripedia)	Prim	12.1	9.2	7
Capitella capitata	Dep	0.2	0.1	0
Cancer sp. Juvenile	Carn	0	1.3	0.3
Cancer sp.	Carn	0	0	0.1
Chrysopetalum occidentale	Carn	0.1	0	0
Cirratulus multioculatus	Dep	0	0	0.4
Cirratulus cingulatus/robustus	Dep	0	15.4	0.3
Fleshy crust	Prim	4.5	7	4.8
Diatoms, chain-forming	Prim	3.2	0.4	0.4
Dorvillea longicornis	Carn	0	0.2	0.1
Exosphaeroma inornata	Scav	0.2	1.9	0.3
Flatworm (unident.)	Carn	0.1	0.1	0
Fucus gardneri	Prim	4.1	0	0
Gammarid amphipods	Scav	0.5	215.5	3
Gelidium spp.	Prim	0.3	0.5	0.3
Glycera americana	Carn	0	0.5	0
Glycinde picta	Carn	0.3	0	0.1
Harmothoe imbricata	Carn	0.3	0	0.1
Hemipodus borealis	Carn	0	0	0.5
Hesperonoe complanata	Carn	0.1	0	0
Hermisenda crassicornis	Carn	0	0	0.8
Hemigrapsus oregonensis	Scav	0	1.1	0.1
Hyale frequens	Scav	0.1	3.5	0.1
Idotea sp.	Herb	0.1	0	0
Lacuna spp.	Herb	18	32.5	36
Lottid limpets	Herb	4	4.3	3.4
Lumbrineris zonata	Omni	0.9	3.8	0.4
Macoma inquinata	Dep	2.2	1.4	0.1
Mastocarpus sp.	Prim	6.2	2.9	4.7
Mazzaella splendens	Prim	1	0.1	0.1
Mediomastus californiensis	Dep	2.6	2.3	2.9
Metridium sp.	Susp	0.8	0.1	0.3
Macoma inquinata juveniles	Dep	0.7	0.3	0
Mopalia lignosa	Herb	1.3	0.3	0.4

Continued on next page

<b>Name</b>	<b>Trophic</b>	<b>Poss 1</b>	<b>Poss 2</b>	<b>Poss 3</b>
Mopalia muscosa	Herb	0.1	0.1	0
Mytilus trossulus	Susp	0	1	0
Mysella tumida	Susp	0.1	0	0
Naineris dendritica	Dep	0	0	0.3
Nemertean (unident.)	Carn	0.1	0.8	0.3
Neorhodomela oregona	Prim	0.1	0	0
Nereis procera	Omni	0.3	0	0
Notomastus tenuis	Dep	0	0.6	0.1
Nucella lamellosa	Carn	3	0.4	1.4
Odonthalia floccosa	Prim	0.6	0	0
Odostomia sp. (unident.)	Carn	0.1	0.6	0
Onchidoris bilamellata	Carn	0.6	0	2.2
Owenia fusiformis	Dep	2.7	0.2	2.3
Pagurus spp.	Scav	1.7	0.3	6.2
Petalonia fascia	Prim	0.4	0	0
Phoronopsis harmeri	Susp	0.4	0.3	8.6
Pholoe minuta	Dep	0.4	0.5	0
Pinnixia faba	Comm	0	0.1	0
Pisaster ochraceus	Carn	0.2	0.3	0.1
Pinnixia schmitti/occidentalis	Comm	0.1	0.2	0
Polynoid (unident., in quadrat)	Carn	1.8	1.3	0.1
Podarke pugettensis	Omni	0	0	0.2
Porphyra sp.	Prim	0	2	1.8
Polysiphonia sp. (unident.)	Prim	14	1	0.6
Prionitis sp. (unident.)	Prim	0.1	0.1	0.2
Protothaca staminea juv.	Susp	0.7	0.2	0.1
Protothaca staminea	Susp	0.1	0	0
Rhamphidonta retifera	Susp	0.1	0	0
Sarcodiotheca sp. (unid.)	Prim	1.3	0.8	0.9
Saxidomus giganteus	Susp	1.2	0.5	0.2
Scytosiphon simplicissimus	Prim	0.1	0	0.1
Spio filicornis	Dep/Susp	0	0	0.1
Sphaeromid isopods	Scav	0	6	0.9
Stronglyocentrotus droebachiensis	Herb	0.1	0	0
Stichaeidae (gunnels and pricklebacks)	Omni	0.3	0.1	0.1
Tellina modesta	Dep	0.1	0	0
Tresus capax	Susp	1.5	1	0.5
Tresus capax juveniles	Susp	0.1	0.3	0
Ulvoids (unident.)	Prim	91	57.5	79.5

## Appendix C. Organisms found at *Browns Bay* and *Glendale Beaches*

Organisms and their average abundances (counts for mobile organisms, percent cover for sessile organisms) in 0.25 m<sup>2</sup> quadrats and 10 cm x 15 cm deep cores. 10 random samples collected along a 50 meter transect.

<u>Name</u>	<u>Trophic</u>	<b>Browns Bay</b>						<b>Glendale</b>					
		<u>South</u> <u>0'</u>	<u>South</u> <u>+2.8'</u>	<u>Middle</u> <u>0'</u>	<u>Middle</u> <u>+2.8'</u>	<u>North</u> <u>0'</u>	<u>North</u> <u>+2.8'</u>	<u>South</u> <u>0'</u>	<u>South</u> <u>+2.8'</u>	<u>Middle</u> <u>0'</u>	<u>Middle</u> <u>+2.8'</u>	<u>North</u> <u>0'</u>	<u>North</u> <u>+2.8'</u>
Acrosiphonia spp.	Prim	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Allorchestes angusta	Scav	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Americorophium salmonis	Scav	0.0	0.1	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
Anthopleura spp.	Carn	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Live barnacles (Class Cirripedia)	susp	0.0	6.6	0.0	1.4	0.1	0.0	0.7	0.0	0.1	8.3	0.0	0.0
Capitella capitata	Dep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Clinocardium nuttallii juveniles	Susp	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Clinocardium nuttallii	Susp	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Fleshy crust	Prim	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Dendraster juv. in core	Susp	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Diatoms, chain-forming	Prim	0.0	0.1	0.0	0.0	1.8	0.0	0.0	5.0	0.0	0.0	0.0	0.0
Evasterias troschellii	Carn	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Exosphaeroma inornata	Scav	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gammarid amphipods	Scav	0.0	0.8	0.0	4.0	0.5	0.0	0.2	0.0	0.8	0.2	0.3	0.0
Glycinde picta	Carn	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.2	0.6	0.0
Hemipodus borealis	Carn	0.0	1.5	0.0	0.1	0.0	0.5	0.1	0.0	0.0	0.1	0.0	0.0
Hemigrapsus oregonensis	Scav	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Idotea sp.	Herb	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Lacuna spp.	Herb	0.0	0.0	0.0	0.0	5.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0
Leitoscoloplos pugettensis	Dep	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3	0.0
Littorina scutulata	Herb	0.0	10.2	0.0	2.3	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0
Lottid limpets	Herb	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0
Lucina tenuisculpta	Susp	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Macoma balthica	Dep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.1	0.1	0.0	0.0
Macoma nasuta	Dep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Macoma nasuta juv.	Dep	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Mastocarpus sp.	Prim	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mediomastus californiensis	Dep	0.0	0.3	0.0	0.0	0.0	0.0	1.1	0.1	0.5	0.2	0.0	0.0

Table continued on next page.

Name	Trophic	Browns Bay						Glendale					
		South		Middle		North		South		Middle		North	
		0'	+2.8'	0'	+2.8'	0'	+2.8'	0'	+2.8'	0'	+2.8'	0'	+2.8'
Macoma inquinata juveniles	Dep	0.0	0.0	0.1	0.0	0.5	0.0	1.7	0.3	0.1	0.0	0.2	0.0
Monocorophium spp.	Scav	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Mya arenaria juveniles	Susp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0
Mytilus trossulus	Susp	0.0	0.5	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.8	0.0	0.0
Mysella tumida	Susp	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Nereis brandti	Omni	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Nephtys caeca	Carn	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0
Nephtys caecoides	Carn	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Nemertean (unident.)	Carn	0.0	0.0	0.3	0.0	0.2	0.0	0.1	0.2	0.1	0.0	0.0	0.0
Nereis procera	Omni	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Nereis vexillosa	Omni	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Notomastus tenuis	Dep	0.0	0.9	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Nuttallia obscurata juvenile	Susp	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
Nucella lamellosa	Carn	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Nuculana minata	dep	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuttallia obscurata	Susp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Owenia fusiformis	Dep	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.1	0.0	0.1	0.0
Paraonella platybranchia	Herb	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phoronopsis harmeri	Susp	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.1	0.0	0.0
Porphyra sp.	Prim	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Protothaca staminea juv.	Susp	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Pseudopolydora kempii japonica	Dep/Susp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Saxidomus giganteus juv.	Susp	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Scoloplos acmeceps	Dep	0.7	0.0	1.1	0.0	1.0	0.0	0.0	0.2	1.3	0.2	0.3	1.1
Scolecopsis squamata	Dep/Susp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Sphaeromid isopods	Scav	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spiochaetopterus tube	Susp	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tellina modesta	Dep	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.4	0.1	1.8	0.0
Tellina nuculoides	Dep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Tresus capax	Susp	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Transennella tantilla	Susp	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ulvoids (unident.)	Prim	0.0	13.2	0.1	7.6	0.0	0.9	13.9	2.7	0.0	27.0	0.0	0.0
Venerupis philippinarum	Susp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Zostera japonica	Prim	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	0.0	0.0	0.5	0.0
Zostera marina	Prim	0.0	0.0	0.0	0.0	7.8	0.0	62.8	11.5	0.0	0.0	0.0	0.0

## Appendix D. Organisms found at Beaches in San Juan Embayments.

Organisms found in the Very Low zone (-2') and their average abundances (counts for mobile organisms, percent cover for sessile organisms) in 0.25 m<sup>2</sup> quadrats and 10 cm x 15 cm deep cores. 10 random samples collected along a 50 meter transect.

<u>Name</u>	<u>Picnic</u>	<u>Shallow</u>	<u>Shoal</u>	<u>Trophic Group</u>
Cancer sp.	0.1	0.1	0	Carn
Cancer sp. Juvenile	0.5	0.1	0.1	Carn
Cottidae (sculpins)	0.2	0.3	0	Carn
Glycinde picta	0.2	0.3	0	Carn
Melanochlamys diomedea	0	0.3	0	Carn
Nemertean (unident.)	0.1	0.1	0.1	Carn
Nephtys caeca	0.2	0	0	Carn
Nephtys caecoides	0.3	0	0.1	Carn
# species carnivores	7	6	3	Carn
Arenicolid juvenile	0	0.1	0	Dep
Armandia brevis	0	0.3	0	Dep
Capitella capitata	1.5	7.7	0	Dep
Diastylopsis dawsoni	0	0.4	0.4	Dep
Leitoscoloplos pugettensis	0.3	0	0.3	Dep
Macoma nasuta	0.4	0.4	0	Dep
Macoma nasuta juv.	0.2	0.1	0.2	Dep
Mediomastus californiensis	0.5	0	0.2	Dep
Notomastus tenuis	0.1	0.3	0.2	Dep
Owenia fusiformis	0	0	0.2	Dep
Tellina modesta	0.1	0.1	0	Dep
Malacoceros glutaeus	0.1	0.9	0	Dep/Susp
# species deposit feeders	8	9	6	Dep
Haminoea vesicular	0.3	0	0	Herb
Lacuna spp.	3.1	2	1	Herb
Lottid limpets	0	0.1	0	Herb
# species herbivores	2	2	1	Herb
Amphiodia spp	0	0	0.1	Omni
Aoroides ?columbiae	0	0.1	0	Omni
Gammarid amphipods	0	5.7	0.1	Omni
Leptochelia dubia	0.1	0	0	Omni
Nereis procera	0	0	0.1	Omni
Pagurus spp.	0	0.1	0	Omni
Platynereis bicanaliculata	0	0.1	0	Omni
Stichaeidae (gunnels and pricklebacks)	1.2	0.1	0.2	Omni
Pinnixia schmitti/occidentalis	0.1	0	0.2	Comm
# species omnivore/commensals	3	5	5	Omni
Diatoms, chain-forming	4	0	0	Prim
Gracilaria pacifica	0	0	2.6	Prim
Ulvoids (unident.)	46.9	92.4	0	Prim
Zostera marina	11.5	39.5	33.5	Prim
# species primary producers	3	2	2	Prim

Table continued on next page

## Appendix D (continued). Organisms found at Beaches in San Juan Embayments.

Organisms found in the Very Low zone (-2') and their average abundances (counts for mobile organisms, percent cover for sessile organisms) in 0.25 m<sup>2</sup> quadrats and 10 cm x 15 cm deep cores. 10 random samples collected along a 50 meter transect.

<u>Name</u>	<u>Picnic</u>	<u>Shallow</u>	<u>Shoal</u>	<u>Trophic Group</u>
Clinocardium nuttallii	0.2	0	0	Susp
Nebalia pugettensis	0.4	0	0	Susp
Phoronopsis harmeri	0	0	0.1	Susp
Rhamphidonta retifera	0.1	0	0	Susp
Sabellid (unident.)	0	0	0.6	Susp
Spiochaetopterus tube	0	0	0.1	Susp
Tresus capax	0	0	0.2	Susp
# species suspension feeders	3	0	4	Susp

## Appendix D (continued). Organisms found at Beaches in San Juan Embayments.

Organisms found in the Low zone (MLLW) and their average abundances (counts for mobile organisms, percent cover for sessile organisms) in 0.25 m<sup>2</sup> quadrats and 10 cm x 15 cm deep cores. 10 random samples collected along a 50 meter transect..

<u>Name</u>	<u>Eng</u> <u>Camp</u>	<u>Judd</u>	<u>Picnic</u>	<u>Shallow</u> <u>Bay</u>	<u>Shoal</u> <u>Bay</u>	<u>Stern</u>	<u>Trophic</u> <u>Group</u>
Cancer sp. Juvenile	0	0	0.2	0.1	0.1	0	Carn
Cottidae (sculpins)	0	0	0	0.1	0	0	Carn
Dorvillea annulata	10.4	0	0	0	0	9.1	Carn
Eteone tuberculata	0	0	0	0.1	0	0	Carn
Eulalia spp.	0	0	0	0	0	0.1	Carn
Glycera americana	0	0	0.1	0	0	0	Carn
Glycinde picta	0.6	1.6	0.7	0	0.1	2.7	Carn
Haliplanella lineata	0	0	0	0	0	0.2	Carn
Harmothoe imbricata	0.1	0	0	0	0	0	Carn
Melanochlamys diomedea	0	0.2	0	0	0	0.2	Carn
Nemertean (unident.)	0	0.1	0.5	0.2	0.3	0.2	Carn
Nephtys caeca	0	0	0	0.1	0.1	0	Carn
Nephtys caecoides	0	0	0	0	0.4	0	Carn
# species carnivores	3	3	4	5	5	6	Carn
Aphelochaeta multifilis	0.2	0	0	0	0	0.5	Dep
Arenicolid juvenile	0	0	0	0.4	0	0	Dep
Armandia brevis	0	0	0	0.3	0	0	Dep
Capitella capitata	0.1	0.7	0	16.4	0	0.3	Dep
Cirratulus multioculatus	0	0	0	0	0.1	0	Dep
Diastylopsis dawsoni	0	0	0	0	0.3	0	Dep
Leitoscoloplos pugettensis	0	0	0.1	0	0.5	0	Dep
Macoma inquinata	0.4	0	0	0	0	0.2	Dep
Macoma inquinata juveniles	0.2	0	0.7	0	0	0.1	Dep
Macoma nasuta	0.1	1.1	0.2	0.2	0	0.5	Dep
Macoma nasuta juv.	0.5	2.5	0.6	0.3	0.4	2.1	Dep
Macoma secta	0	0.2	0	0	0	0	Dep
Mediomastus californiensis	0.7	2	6.9	0.4	1.9	5.8	Dep
Notomastus tenuis	0.1	0	1.6	0.1	4.5	0.1	Dep
Owenia fusiformis	0	0	0.2	0	0.4	0	Dep
Pectinaria granulata	0.1	0	0	0	0	0	Dep
Scoloplos acmeceps	0	0	0	0	0.2	0	Dep
Tellina modesta	0	0.1	0.2	0	0.2	0	Dep
Thelepus crispus	0.5	0	0	0	0	0.4	Dep
Tubifex spp.	0.1	0	0	0	0	0	Dep
Malacoceros glutaesus	0	0	0.2	9.9	0	0	Dep/Susp
Spio filicornis	0	0	0	0	0.1	0	Dep/Susp
# species deposit feeders	11	6	9	8	10	9	Dep/Susp
Bittium eschrichtii	1	0	0	0	0	0.1	Herb
Haminoea vesicula	0.1	0.1	0.1	0	0	0.3	Herb
Lacuna spp.	0	0	0	0.6	14.1	0	Herb
Lirularia succincta	0.1	0	0	0	0	2.3	Herb

Table continued on next page.



## Appendix D (continued). Organisms found at Beaches in San Juan Embayments.

Organisms found in the Low zone (MLLW) and their average abundances (counts for mobile organisms, percent cover for sessile organisms) in 0.25 m<sup>2</sup> quadrats and 10 cm x 15 cm deep cores. 10 random samples collected along a 50 meter transect.

<u>Name</u>	<u>Eng Camp</u>	<u>Judd</u>	<u>Picnic</u>	<u>Shallow</u>	<u>Shoal</u>	<u>Stern</u>	<u>Trophic Group</u>
Littorina scutulata	0	0	0	0	0	1	Herb
Lottid limpets	0.8	0	0	0	0	0	Herb
# species herbivores	4	1	1	1	1	4	Herb
Amphipholis squamata	0	0	0	0	0	0.1	Omni
Anisogammarus pugettensis	0	0	0	0.1	0	0	Omni
Eogammarus confervicolus	0.2	0	0	0	0	0	Omni
Eogammarus oclairi	0	0	0.1	0	0	0	Omni
Gammarid amphipods	2	0	0	0.2	0.1	0	Omni
Hemigrapsus oregonensis	0.1	0	0.1	0.1	0	0	Omni
Hesionid sp. (unident.)	5.7	0.5	0	0	0	7.9	Omni
Hyale frequens	0	0	0	0.1	0	0	Omni
Leptochelia dubia	0	0	1	0	0	0	Omni
Lumbrineris zonata	1.2	0	0	0	0	0.5	Omni
Megalorchestia pugettensis	0	0	0.3	0	0	0	Omni
Monocorophium spp.	0.1	0	0	0	0	0	Omni
Nereis brandti	0	0	0	0	0	0.2	Omni
Nereis procera	0	0	0.3	0	0.3	0	Omni
Pagurus spp.	0.2	0	0.2	0.3	0	0	Omni
Platynereis bicanaliculata	0.1	0	0	0	0	0	Omni
Podarke pugettensis	0.2	0	0	0	0	1.7	Omni
Podarkeopsis glabrus	0	0.5	0	0	0	0	Omni
Stichaeidae (gunnels and pricklebacks)	0.1	0	0	0	0	0	Omni
Cryptomya californica	0	0	0.2	0	0	0	Comm
Pinnotherid sp. (unident.)	0	0	0	0	0	0.2	Comm
# species omnivore/commensals	10	2	7	5	2	6	Omni
Diatoms, chain-forming	4.6	0.8	74	0	0	0	Prim
Polysiphonia sp. (unident.)	0.1	0.1	0	0	0	0.7	Prim
Ulvoids (unident.)	45.9	1.3	11.4	45.5	0	5.5	Prim
Zostera marina	0	0	0	0	66.4	0	Prim
# species primary producers	3	3	2	1	1	2	Prim
Clinocardium nuttallii	0.3	0.4	0.2	0	0	0.2	Susp
Live barnacles (Class Cirripedia)	0.4	0	0	0	0.7	0.1	Susp
Mysella tumida	0.1	0	0.3	0	0	0	Susp
Phoronopsis harmeri	0	0	0	0	0.2	0	Susp
Protothaca staminea	0.7	0.1	0	0	0	1.2	Susp
Protothaca staminea juv.	0	0	0.1	0	0	0.3	Susp
Sabellid (unident.)	0	0	0	0	0.5	0	Susp
Transennella tantilla	0	0.7	0.3	0	0	1.4	Susp
Tresus capax	0	0.3	0	0.1	0.1	0.2	Susp
Venerupis philippinarum	0.1	0	0	0	0	0	Susp
# species suspension feeders	5	4	4	1	4	6	Susp