TESC 332: CONSERVATION BIOLOGY IN PRACTICE
UNIVERSITY OF WASHINGTON TACOMA

Biodiversity Survey of Benthic Communities of Commencement Bay (Tacoma, WA) 2011

Final Report to be Submitted to Citizens for a Healthy Bay

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Introduction

Problem Statement

Commencement Bay and its adjoining waterways have long been known to be adversely affected by toxic chemicals (Partridge *et al.* 2010). After being placed on the Superfund National Priorities List in the 1983, Commencement Bay has been undergoing immense cleanup processes (TCP 2008). Because of the history and degree of contamination in this area, there is concern over cleanup efficacy and post-cleanup recontamination and resuspension of contaminants by disturbance (Singleton 2008). The target for the Superfund cleanup was focused on the immediate area around the sources of the contamination; therefore, it generally did not test the sediments farther removed from sources, leaving questions about the condition of the entire bay (Partridge *et al.* 2010). It is in the interest of the community surrounding Commencement Bay to learn more about how the Bay is being affected by legacy and current industry and general urban influence, including the effects of contamination on the benthic communities living within the Bay.

Monitoring of the composition of benthic communities has been shown be a useful tool to track the overall health of a marine system (Ranasinghe *et al.* 2010). Benthic organisms, in particular, are especially sensitive to the overall health of a system because they live in and around the sediment, which is generally most affected by pollution. The types of assemblages found at the bottom of large bodies of water can serve as bioindicators of ecological stresses on the community (Verlecar *et al.* 2006). In addition, the diversity and evenness of these communities has been used as an indicator of ecological “health” (Reynoldson and Metcalfe-Smith 1992).

This study was conducted by the Conservation Biology in Practice class at the University of Washington, Tacoma, to provide information on whether cleanup efforts are continuing to improve conditions and if present industry is causing disturbance in benthic communities since a 2008 sediment study conducted as part of the Urban Waters Initiative (UWI) of the Washington Department of Ecology (Ecology) (Partridge *et al.* 2010).

Site Description

Commencement Bay is a large estuary located at the southern end of Puget Sound (Fig. 1). This estuary is fed by the Puyallup River, which flows into the Bay along its eastern shore. The Bay, which was formed by retreating glaciers, has steep cliffs which drop to the shoreline. A large percentage of the shoreline has been developed, but intertidal mudflats which once made up the majority of shoreline still exist in patches. These mudflats gently slope into the Bay, forming habitat for a diversity of species.

The Bay is surrounded by the City of Tacoma on the northeast, east, and south sides with a mixed land use of residential and industrial, including one of the largest container ports in North America, the Port of Tacoma, located in the east side of the Bay (Fig. 1). Due to industrial activities over the past century, parts of Commencement Bay (approximately 12 square miles) were placed on the US EPA Superfund List in 1983. Areas in and around the Bay were found to be contaminated with toxic metals such as arsenic from the Asarco copper smelter, petroleum from boat and train yards, poly-chlorinated biphenyls from industrial plants, and wood waste from saw mills (Ecology 2007). A multi-agency cleanup effort was initiated, leading to completion of the activities of some of the project areas, including the Middle, St. Paul, and Sitcum Waterways (USEPA 2009). Most of the remediation actions in the Hylebos and Thea Foss Waterways are completed, although there is concern about recontamination issues in the Thea Foss Waterway (USEPA 2009).

Urban Waters Initiative

The UWI is a multi-agency program that has been established to assess sediment quality of bays that have experienced localized cleanups and source controls to determine if bay conditions are improving over time (Partridge *et al.* 2010). The Department of Ecology analyzed the sediment of thirty randomly selected locations throughout the Bay by using the Sediment Quality Triad Index (SQTI). The SQTI takes into account the contaminant loading and toxicity as well as the presence and type of benthic fauna in the sediment (Partridge *et al.* 2010). The result of the index gives researchers an integrated tool to assess the overall health of a particular area by taking into consideration these three important indicators of sediment health. The purpose of the 2008 UWI study was to examine the condition of Commencement Bay on a bay-wide scale and to compare the site data to that of the data that NOAA collected in 1999 from the same stations. By comparing the data it can be seen if the habitats are changing and if habitat restoration work has had a positive or negative effect on certain sites. The measured effects include the response of the benthos to these changes.

Purpose and Objectives

The purpose of this study was to analyze the benthic community within the sediment in a portion of the UWI stations. By analyzing the benthic assemblages of these stations and comparing the data to that of the UWI report, one could observe if the benthic organisms are responding to any changes in the environment. The objectives of this study were:

- Collect benthic community assemblage and biodiversity data in a variety of locations around Commencement Bay.
- Identify correlations between benthic community assemblages and other physical data from the stations, such as depth and grain size as well as legacy contamination data.
- Compare the results of this study to the results of both the PSAMP/NOAA (1999) and the UWI (2008) studies to determine if changes in ecological health can be detected.
- Create an ongoing monitoring program for UWT students to maintain while providing usable scientific information for real world applications.

Methods

Sediment samples and water column profiles were taken in Commencement Bay at five stations along two transects along both sides of Commencement Bay. Stations were of similar depth and sediment type. Sediment samples were sorted and organisms identified in order to determine the diversity of the stations.

Stations

From the 30 Commencement Bay stations sampled in the UWI report, the five station locations selected for this study were 287, 287, 292, 296, and 304 (Fig. 2 and Table 1). Station 296 is located in the Thea Foss Waterway, Stations 287 and 285 are located along the south shoreline of Commencement Bay, Station 292 is located in North East Commencement Bay, and Station 304 is located in the Hylebos Waterway. Repeated attempts to collect sediment sample at a sixth station (293), northwest of Station 292, did not result in a successful grab; therefore, this station was eliminated from the study.

Samples were taken as close as possible to the GPS coordinates of the UWI stations, although boat motion and the need to find the right bottom type for our smaller Ponar grab did not allow for exact station replication.

Sampling

Sediment samples were taken aboard the 65-foot research vessel *Indigo* (operated by Service Education and Adventure, Edmonds, WA) on February 8, 2011, between the hours of 11:30 am – 1:00 pm. It was a relatively sunny day with calm winds and waters. At the arrival of each station, depth was determined using the *Indigo's* depth sounder. A small (18cm L x 15cm W x 10cm H) Ponar Grab was then lowered from the side of the boat to about 5 meters above the seafloor and then dropped to dig the scoops into the sediment and trigger the closure mechanism. After retrieval of the grab, the quality of the sample was assessed; if the grab appeared to have been triggered incorrectly or did not contain enough material, the sample was rejected.

Once a successful grab was achieved, characteristics of the sediment were then evaluated and documented on a log sheet before sieving. The penetration of the grab was estimated using a ruler and recorded in centimeters. Temperature of overlying water was taken with a thermometer. A sample of this water was measured for salinity (ppt) using a refractometer. The sediment was then observed for color, odor, and sediment grain size was estimated by appearance and noted. The presence of debris, such as wood, shells, or plant material in the sediment was noted as well. A small representative sample of sediment (about 4 ml) was transferred to a labeled 15 ml tube for later grain size analysis. The rest of the sediment sample was then sieved through a 1 mm screen into a labeled 2 L container using seawater filtered to 500 μm. Any visible organisms were transferred to the sample jar using forceps. When all sediment had been sieved and transferred into the jar, filtered seawater was added to bring the total volume to 500 ml. At that point, 250 ml of concentrated buffered (with sodium borate) formalin was added to fix the sample (10% – 15% final concentration).

While one group was collecting the sediment sample, other students collected a number of oceanographic parameters. A Secchi depth reading was taken on the shady side of the boat. The Secchi disk was lowered first to the surface of the water and distance was recorded. This measured distance was then subtracted from final recorded depths to account for the height of the boat deck above water level. The disk continued to be lowered until it could no longer been seen and depth was noted. The disk was lowered again for a short distance and then raised until it could be seen again and depth was noted. These two depths (after deck to water surface depth was subtracted) were averaged and recorded.

A Hydrolab was also lowered from the side of the boat to take a profile of the water column which included temperature in Celsius, pH, the percentage of dissolved oxygen, and salinity at the following depths: 1 m, 2 m, 3 m, 4 m, 5 m, 7 m, 10 m, 15 m, 20 m, 25 m, and 30 m (if applicable). At each station, the depth, determined by a depth sounder, was noted before lowering the Hydrolab as it should not be lowered any further beyond 2 m above the sea floor.

Grain Size Analysis

Back in the lab, the small reserved sample of sediment for grain analysis was processed using a grain size analyzer (LS Variable Speed Fluid Module Plus). Before adding sediment to the analyzer, water was added to the sample and it was mixed using a magnetic stirrer. Once the sample was well mixed, it was slowly pipetted into the analyzer to an obscuration level between 8% - 12%. Once analysis was complete, a graph of volume (%) vs. diameter (µm) was generated and printed. Particles greater than 62.4 µm were considered to be sand, between 3.9 and 62.5 µm were considered silt, and less than 3.9 µm were considered clay.

Benthic Invertebrate Sorting and Identification

Samples were first sorted to large taxonomic groupings by a “Station Group”, a group of students that worked together to collect and sort the sample from a single station. After 24 hours in the lab, formalin-fixed samples were triple rinsed in deionized water and transferred to 70% ethanol. The samples were then sorted under a dissecting microscope scope to separate organisms from non-living material. Organisms were divided into separate dishes for broad taxonomic categories of polychaete worms (Aciculata, with clear parapodia and setae along the body; Scolecida, with reduced parapodia and setae; and Canalipalpata, with more developed head parts related to a tube-dwelling lifestyle), bivalves, gastropods, echinoderms, arthropods, and miscellaneous. Oligochaetes were included with Scolecida (sedentary) polychaetes and divided out later. Ecology Marine Sediment Monitoring Team guidelines on which organisms can be counted were applied to focus on animals that were alive at collection and to avoid counting partial animals twice. Specifically, animals with a head were only included if the head was present. Bivalves were counted if the hinge was still attached and gastropods were counted if the operculum was still intact. Brittle stars were counted if at least half of the central disk was present.

During this sorting phase, obvious “morphospecies” were separated into a separate vial, but in most cases the samples were just sorted to the coarse taxonomic group. A running tally of each organism that was placed in a designated taxonomic group was documented using a “tick mark system” on a log sheet. Each group of organisms was transferred (after being confirmed by a second researcher) into properly labeled vials filled with a 70% ethanol mixture (or an ethanol/glycerin mix if the organisms were arthropods or annelids). A piece of color-coded tape (according to taxonomic group) was also placed over the cap of the vial. Labeled vials were then transferred to “Taxonomic Groups” via a “Chain of Custody” form that was signed by a releasing member of the Station Group and an accepting member of a “Taxonomic Group”. It should be noted that each Station Group was made up of a mix of members from the Taxonomic Groups to provide a range of expertise for each sample while doing the initial sorting.

Taxonomic Groups were responsible for further sorting the samples to family or species, if possible. Individuals were examined using a dissecting microscope and grouped into morphospecies. A list of 20 conspicuous taxa that were common or easy to identify (created in consultation with Ecology, Table 2) was preassigned to students, who each specialized in one of the species prior to sample collection. When possible, individuals belonging to these species were identified. Once identification began, it was decided that polychaetes would be identified to family rather than species. The rest of the morphospecies that were not in the conspicuous species list were assigned numbers (e.g., "Bivalve sp. 1", "Bivalve sp. 2", etc.) and were assigned to species or family when possible. Each species, morphospecies, or family was verified by a second student and then transferred into properly labeled vials filled with a 70% ethanol mixture (or an ethanol/glycerin mix). The number of species going into each vial was counted and documented on a log sheet.

It should be noted that this was the first exposure to invertebrate taxonomy for the students in this class. The identifications to coarse taxonomic groupings were very accurate, but accuracy declined with taxonomic specificity. The identification of the 20 conspicuous species was more accurate than the extra species found outside of this group. It should be noted that the Aciculata worm group did not finish their identification in time for analysis so all of these errant worms were lumped into a single category. Bivalve identifications were verified the following quarter by an independent study student.

Examples of Taxa Found at Study Site

Axinopsida serricata, commonly referred to as the lenticular axinopsid or silky axinopsid, is from the phylum Mollusca and the class Bivalvia (Turgeon 2011). *A. serricata* is a suspension feeding bivalve that grows to a length of 8 mm (Harbo 1997). It has an ovate shell with an umbo (inflated dorsal part of shell) present and a color range from white to light green. Specimens small in size tend to have valves that are transparent and those larger in size have valves that are opaque with chalky patches along the pallial line (Harbo 1997). *A. serricata* are found from Alaska to Southern California in sandy-silty habitats from the intertidal zone to 275 m (Santa Barbara Museum of Natural History 2000). They are a species that can serve as an indicator of pollution in regards to dissolved oxygen levels. In Commencement Bay, this bivalve has reddish-brown patches on its shell that are formed from an amorphous iron oxide or hydroxyl-oxide. Presence of these rust stains has the potential to provide an indication of the geochemical condition of the sediment and provide a map of cumulative organic loading and oxygen penetration of sediments around municipal outfalls (Burd *et al.* 2008).

Parvilucina tenuisculpta is a bivalve with a subcircular shell shape with low beaks. The shell surface has defined concentric striae topped by weak radial ribs. The hinge of the bivalve is slightly curved. The shell can vary from 0.3 to 13 mm in length. They often occur in dense colonies within the sediment anywhere from 1 m to as deep as 300 m below sea level (Coan *et al.* 2000). *P. tenuiscuplta* is an indicator species whose changes in abundance reflect overall changes in the normal patterns of invertebrate communities (Word *et al.* 1977). By monitoring this species, the health of a benthic community can be determined.

Euphilomedes is a genus of Crustacean in the class Ostracoda (Kozloff 1996). It can range from 1 mm – 2 mm in size, and have a circular to ovoid carapace (outer shell) that resembles that of a bivalve. The carapace has an incisor, a portion that protrudes outward, at the anterior end and opens to reveal legs and claws (Angel 2000). The females are larger than the males and the eggs are visible through the carapace towards the posterior end. It is known that some species within the genus reproduce throughout the year and reach maturity within two years of life. The diet of *Euphilomedes* is unknown at this point. Molting occurs before the species reach maturity, as post adult molting is rare (Loffler 1977).

Amphiodia is a genus of brittle stars belonging to the phylum Echinodermata. They are small, growing to a maximum of eight centimeters in length. They are mainly deposit feeders, living off the bottom of the sea floor. Brittle stars are the most mobile type of echinoderm because of their ability to flutter their long arms. They are easy to tell from sea stars because of their obvious central disk with five very distinct, long arms (Kozloff 1973). They will detach their arms when disturbed. *Amphiodia* are mostly nocturnal and some species are bioluminescent. A lower level of bioluminescence in this genus has been linked to high levels of metal contamination (Deheyn *et al.* 2000). The presence or absence of this genus of brittle star has been used as an indicator of toxic contaminants (Word *et al.* 1977).

Analysis

Once sediment samples were sorted and organisms identified, a number of biodiversity indices were calculated: total abundance, taxa richness, Shannon-Wiener Diversity Index, Pielou's Evenness Index, Swartz' Dominance Index, the relative abundance of major taxa, and Jaccard Coefficient of Community Similarity. In addition, a Collector's Curve was created to determine if the number of samples collected was sufficient to describe the biodiversity of the area sampled. Most of these calculations were consistent with those done in the UWI report (Partridge *et al.* 2010).

Total abundance and taxa richness are simple calculations to characterize the community sampled. Total abundance is the total number of individuals in the sample, regardless of taxonomy. Taxa richness is a count of the total number of species (or genera or family, etc.) in the sample. Because this value depends on the taxonomic level of the identifications (which varied among the invertebrate groups), they are only directly comparable within this study. This is true of most of the indices calculated in this study (all except total abundance and relative abundance of major taxa).

The Shannon-Wiener Index of Diversity is a way of quantifying both taxonomic richness (number of taxa) and the taxonomic evenness (the distribution of individuals among the taxa) in a single number. It is calculated as follows:

$$H' = -\sum p_i(\log p_i)$$

where p_i = the fractional abundance of the *ith* species in a sample. The higher the value, the more "diverse" the sample (i.e., higher richness and more even). This index stresses richness more than evenness.

Pielou's Evenness Index is a measure of the distribution of individuals among the different taxa. It is calculated using the following formula.

$$J' = \frac{H'}{\log S}$$

where H' is the Shannon-Wiener Index and S is total number of species or taxa. This value can be interpreted as a comparison of the actual diversity in the sample to the potential diversity if every individual belonged to a different taxon. A higher value (closer to 1) indicates that taxa are well-represented in a sample while a lower number (closer to 0) indicates that a few taxa dominate the sample.

Swartz' Dominance Index is an indicator of whether a small number of taxa dominate the sample. It is the minimum number of taxa accounting for 75% of the total invertebrate abundance in a sample (Partridge *et. al* 2010). It was calculated by sorting the total abundance from each sample by largest to smallest on an Excel spreadsheet. Starting with the most abundant organism, the percentage of individuals represented by that organism was determined. For each taxon thereafter, the cumulative percentage of individuals represented by that organism, and all of the more abundant organisms, was calculated. The first taxon for which the cumulative percentage was greater than 75% was the last organism included. The total number of taxa included in the calculation was determined. This number of species was the value used for the Swartz' Dominance Index.

In the UWI report, multivariate statistics were used to classify invertebrate assemblages. Due to the smaller sample size in this study, we used a simpler approach to describe the similarity among the communities found at our five stations: relative abundance of taxonomic groups and Jaccard Coefficient of Community Similarity. The relative abundance of major taxonomic groups is the percentage of individuals belonging to each of the major groups we defined: annelids, gastropods, bivalves, arthropods, echinoderms, and miscellaneous taxa, all remaining organisms (nemerteans and foramifera). Since this calculation focused on number of individuals rather than the number of taxa, and was independent of the size of the sample, the lack of taxonomic resolution should not affect direct comparison of these values with UWI results.

Jaccard Coefficient of Community Similarity *(CC_J)* can be used to calculate the similarity in the community composition between two stations. It is calculated by determining:

$$CC_J = \frac{c}{S}$$

where *c* is the number of species common to both communities and *S* is the total number of species present in the two communities. When this value is 0, there are no species in common between the two communities (they are completely different). When the value is 1, all species are found in both communities (they are exactly the same). We used this index to compare all possible pairs of stations for a total of 10 comparisons.

The collector's curve is a way to measure if sufficient samples have been taken to adequately represent the diversity of the sampled stations. This curve represents the chances of randomly selecting a new species at a new station after all the species at a previous station has been accounted for. It is calculated by adding up the species from one station and then adding to that number any new species from the second station and so on. When the curve levels off, the community has likely been well sampled. Since the order of the samples can affect the shape of the curve, the five stations were shuffled at random 10 times to create an average curve.

All students calculated and interpreted the simplest measures: total abundance, taxa richness, and the relative abundance of major taxa. Each student was then assigned an additional measure to analyze, one of the following: Shannon-Wiener Diversity Index, Pielou's Evenness Index, Swartz' Dominance Index, Jaccard Coefficient of Community Similarity, and the collector's curve. The results were then synthesized in this compiled version.

Results

Water Column Profiles
The water column for all stations was profiled for temperature and salinity (Fig. 3). Salinity measurements for Station 287 were made incorrectly. As a result, the information from Station 287 was not included in the salinity profiles.

Temperature was colder in the first 2 m of the water column, with warmer, more consistent temperatures below 3 m. Generally during this time of year, the water column has a more mixed temperature profile as seen at Station 304, located in the mouth of Hylebos Creek. The slight temperature stratification was more than likely caused by a recent cold rain event that occurred prior to sampling, which deposited colder fresh water on the surface.

Similarly, water was fresher in the first 2 m of the water column at all stations, with a consistent salinity of approximately 30 psu below 3 m. Low salinity is expected at the water column surface after high rain fall.

Grain Size Analysis
Distribution (by percent) of the three particle size classes (sand, silt, and clay) are depicted for all stations in Figure 4. Stations 304 and 296 were approximately 20% clay, 70% silt, and 10% sand. These stations were classified as “Silt + clay” (Partridge *et al.* 2010). Stations 287 and 292 were approximately 15% clay, 55% silt, and 30% sand. These stations were classified as “mixed”. Station 285 was approximately 5% clay, 10% silt, and 85% sand. This station was classified as “Sand”, and was quite different from the other four.

Grain size has an influence on what benthic species are present. Sandier substrates tend to support more suspension feeders, which favor the faster currents, and increased food availability, found with larger grain sizes. Smaller grain sizes also have a tendency to clog their filters. Deposit feeders tend to be found in muddier substrates, which have higher organic matter and tend to be calmer areas (Pinet 2009). In addition, silt and clay have greater surface area relative to volume, leaving more room for pollutants to bond (Partridge *et al.* 2010). Some species are less tolerant to pollution than others and might not be found in muddy polluted areas.

Total Abundance
Total abundance is the sum of all the organisms found at a station (Fig. 5). In order from most abundant to least abundant the stations were as follows: Station 287 (349 organisms), Station 304 (251), Station 296 (190), Station 292 (157), and Station 285 (90). It is notable that Stations 287 and 285, which were fairly close together and at similar depths, had the least and the most total individuals. Station 285 was dominated by sand, while Station 287 was more mixed. It is possible that grain size influenced the total number of individuals.

Penetration depth of the Ponar grab may be a significant factor in the total number of specimens collected at each station (Table 1). Since we did not standardize our values relative to the volume sampled, the total number of individuals could be due to sampling differences rather than actual differences among the stations. However, measured penetration depth at Station 285 was in the middle of the stations, and was therefore unlikely to be very different from the others. Station 287, where most samples were found, did have the highest measured penetration depth. It is likely that our results reflect a combination of sampling factors (penetration depth and student sorting ability) and actual differences in total abundance at the stations.

Differences in total abundance of organisms should be considered when interpreting the diversity data that follows, as a larger sample of the same community would likely contain more diversity just due to the increase in volume.

Taxa Richness

Taxa richness is the total number of taxa found in a sample and is used to describe the basic diversity of an area (Fig. 6). Taxa richness from highest to lowest was Station 296 (25 taxa), 287 and 292 (20), 304 (16) and 285 (12). The low richness at Station 285 could be related to the low number of individuals, but the low richness at Station 304 does not have a clear sampling explanation.

Shannon-Wiener Index

The Shannon-Weiner Index combines taxa richness and evenness in a single index. Values at the stations ranged from 0.70 to 1.01 (Fig. 7). The highest station was 296 (Thea Foss Waterway) while the lowest were 285 and 304. This result was similar to what was found for species richness, although Station 304 scored lower on a relative scale, due to the low evenness as well as low richness at this station.

Pielou's Evenness Index

Pielou's Evenness Index, which quantifies the distribution of individuals among the taxa, was calculated for each station (Fig. 8). The overall evenness of the stations was intermediate and fairly similar, although 304 was lower than the others (0.58). The most even station was 296 (0.72).

Swartz' Dominance Index

The Swartz' Dominance Index, the number of species that account for 75% of the individuals in a community, is a measure of whether the community is dominated by a few common species (Fig. 9). Station 285 was tied for the lowest value (3). The three taxa that dominated this station were "ostracod sp. 1", *Parvilucina tenuisculpta* (bivalve), and all Aciculata (errant worms). Station 304 was also dominated by three taxa: Cirratulidae (tube-dwelling worms), all Aciculata (errant worms), and *Axinopsida serricata* (bivalve). Station 287 was intermediate with 4 dominant species: *Axinopsida serricata* (bivalve), all Aciculata (errant worms), *Macoma* spp. (bivalves), and Pectinariidae (tube-dwelling worms). Stations 287 and 296 were dominated by five taxa each. The five taxa at Station 287 were: *Axinopsida serricata* (bivalve), *Parvilucina tenuisculpta* (bivalve), all Aciculata (errant worms), *Macoma* spp. (bivalves), and "ostracod sp. 1". Station 296 was dominated by: all Aciculata (errant worms), Cirratulidae (tube-dwelling worms), *Axinopsida serricata* (bivalve), nemerteans, and "gastropod sp. 1".

Relative Abundance of Major Taxonomic Groups

Most of the diversity indices used in this study treat all taxa the same regardless of how they are related. The relative abundance of major taxa (Fig. 10) describes the composition of the invertebrate community as a whole. All individuals of a major taxonomic group are summed, regardless of whether they are individual species or families. The groupings were bivalves, gastropods, annelids, echinoderms, arthropods, and miscellaneous taxa (foraminifera and nemerteans) (Fig. 10).

In this study, bivalves and annelids were the most common taxa found. Gastropods, echinoderms, and at most stations, arthropods were minor parts of the community. Nemerteans were rarely encountered, except at Station 296 where they were more common but still not dominant. One benthic foraminiferan was found. Stations 285 and 287 were dominated by bivalves with a low number of polychaetes. These two stations contained a notably larger number of arthropods (mostly ostracods). In contrast, Stations 296 and 304 were dominated by annelids, with a small number of bivalves. Station 292 was intermediate, with a large number of both bivalves and annelids.

Jaccard Coefficient of Similarity

The Jaccard Coefficient of Similarity is used to measure how similar communities are. Each pair of stations was compared (Table 3). If the stations we examined, two pairs were most similar: 287/296 and 296/304. Stations 296 and 304 are both located in waterways, so it is not as surprising that they are fairly similar. It is notable that 287 (outside of the Thea Foss Waterway) and 296 (inside Thea Foss Waterway) are relatively close geographically and were found to be most similar. However, Stations 285 and 287, which are close together and along the same shore of the Bay, were not as similar. In fact, 285 was the least similar to all of the stations examined. This could be due to the fact that Station 285 had a much different grain size distribution compared to the other stations.

Collector's Curve

A collector's curve reveals the incremental benefit of adding another sample to accurately describe the taxa in a community. When the curve approaches an asymptote, the number of samples is sufficient. After five samples, the curve was beginning to level out, but was not yet level (Fig. 11).

The shape of the curve could be extended to predict the actual taxa richness expected in the site independent of sample size (Sanders 1968). This would be useful to compare the taxa richness calculated in this study to the UWI. However, due to differences in the taxonomic specificity of the data, the richness is not comparable regardless of sampling effort.

Discussion

Comparisons of Stations and Affected Benthos

The sampling stations were chosen to represent two transects through Commencement Bay, starting from two waterways that are known to be negatively affected by human activities, The Thea Foss (Station 296) and the Hylebos Waterway (Station 304) (Figure 2). This perception was supported by data from the UWI report that indicated that State Sediment Quality Standards (SQS) were exceeded and the benthos were graded as “affected” at these two sites (Partridge *et al.* 2010). Station 296 exceeded the SQS in a number of organic pollutants, while Station 304 exceeded the SQS for hexachlorobenzene. Stations 287 and 285 were located at increasing distance from the Thea Foss and Stations 292 and 293 were similarly positioned from Station 304. We therefore expected to find the lowest richness and evenness at Stations 296 and 304, with increasing numbers with increasing distance.

Although stations were selected to be as similar as possible for maximum comparability, there were unavoidable differences among the sites that could affect their communities regardless of human activity. Stations 296 and 304 were shallower than the others (Table 1), and were composed of smaller grain sizes (Figure 4). However, the communities described by the UWI at all stations were considered similar to each other when compared to deeper sites (Partridge *et al.* 2010).

Our results were quite different than our prediction. Station 296 was one of the highest scoring samples in terms of both richness and evenness (Figs. 6-9). This was unlikely to be a sampling artifact since the measured penetration depth was lowest for this site (Table 1) and the total abundance was not particularly high (Fig. 5). These results indicate that the quality of the sediment for benthic communities is improving in the Thea Foss.

This is in contrast to the Hylebos Waterway (Station 304). Although Stations 296 and 304 were similar in terms of composition (Fig. 10 and Table 3), Station 304 ranked as one of the lowest in terms of richness and evenness (Figs. 6-9), despite the high total abundance (Fig. 5) and penetration depth (Table 1) at this station. In our study, this station scored as more affected than the others, especially in terms of the evenness of the community.

We expected Stations 285 and 287 to be quite similar, due to their close proximity and similar depth. They were both dominated by bivalves (Fig. 10), but were not very similar in terms of the specific taxa found (Table 3). Station 287 was one of the highest in terms of richness and evenness (Figs. 6-9), especially in terms of evenness. The nearby Station 285, however, was one of the lower scoring, especially in terms of taxa richness. There are a few possible explanations for this difference. This station had the lowest total abundance (Fig. 5), possibly reflecting a smaller sample or a difference in sorting among the groups. There were more than three times the number of individuals found at Station 287 than at 285. In addition, Station 285 was the only sample dominated by sand (Fig. 4), and grain size is known to be a major driver of community composition in the benthos. Lastly, data from the UWI study indicated that two stations near 285 (286 and 282) both exceeded the SQS and the Cleanup Screening Levels in 2008 (Partridge *et al.* 2010). Station 286 was particularly high in mercury and Station 282 was notably high in bis(2-ethylhexyl)phthalate. It is possible that our results are reflecting negative effects of human activity, such as the sewage treatment plant at Mason Creek or the activities of ASARCO near this site. We noted that Stations 287 and 296 were more similar than Stations 285 and 287, possibly reflecting “healthier” conditions in the Thea Foss (Table 3).

We would like to further explore the pattern in composition we found among the Stations. The two waterways were dominated by polychaetes, while the more "open" stations contained more bivalves. This could be reflective of physical differences (notably grain size) or it could be an indication of different habitat health. Our sandiest site, Station 285, was the only one with a large number of ostracods present.

Comparison with past studies (2008 and 1999)

The methods used in this study were similar to those used by the UWI (Partridge *et al*. 2010), although there were unavoidable differences that affected the comparability of our results. Ecology used a larger Van Veen grab, while we used a smaller Ponar grab. In addition, Ecology employs professional taxonomists to identify their organisms, while this class project was completed by undergraduate students with little prior experience. However, there are enough similarities between the studies (locations, sieve size, basic approach) that a comparison can be made as long as results are considered relative to the study year. Therefore, an analysis using rank scores within a year was conducted (Figs. 12-16).

When comparing the ranks of the Stations in this study to results from 199 and 2008, a few patterns emerge. It appears that Station 296 has been steadily improving in richness and evenness (Figs. 13-16), while Station 304, which was beginning to improve, has declined in diversity (Fig. 14), probably due to a decrease in evenness (Figs. 15 and 16) rather than richness, which has remained low (Fig. 13). Station 285 ranked relatively high in diversity (Fig. 14), both in terms of richness (Fig. 13) and evenness (Figs. 15 and 16), scored much lower in this study. It should be noted that Station 285 was also found to be dominated by sand in 2008, so the effect of grain size on results should be similar among the different years. It is possible that this site is declining in health, although it is also likely that this is due to sampling artifacts. This station should be re-examined in future years.

Recommendations for Future Classes

There are a number of changes that would improve this study in the future. During the quarter, our polychaete group switched their focus from the species level to the family level, to improve our accuracy. Next year, polychaetes should be studied at the family level only. Samples should be standardized by volume, so the sieved sediment should be retained, dried, and measured. According to the Collector's Curve in this study, two or three additional samples would help to capture more of the diversity in Commencement Bay.

There are a number of logistical improvements that could be made in future classes. It would be helpful complete the sampling trip earlier in the quarter as this would allow additional time to identify the organisms in the lab. The sooner identification is complete the sooner analysis of the data can begin. The students of this study were fortunate to have a taxonomist help to identify some of the benthic fauna, which was invaluable. It would be beneficial for future classes if a longer visit with a taxonomist could be arranged.

An interesting focus for a future class study would be the species *Axinopsida serricata* which form rust encrustations on their shells when they inhabit sediment near municipal outfalls that has cumulative organic loading and oxygen penetration (Burd *et al.* 2008). A study using this species could potentially be used to create a map of affected areas within Commencement Bay.

Conclusion

This class project was intended to repeat a component of the study conducted in 2008 as part of the Urban Waters Initiative, to determine if changes in diversity of benthic communities in Commencement Bay had changed since the last study. Our results indicate that the health of the Thea Foss Waterway (Station 296) is improving and the Hylebos Waterway (Station 304) is declining. One site along the southern shoreline of the bay (Station 285) might be in decline, although additional study should be focused at this site to determine if this is a sampling artifact.

The educational benefit of this study was harder to quantify but was quite high. Twenty two students with limited taxonomic experience learned how to sample and identify the benthos in their local area. A number of these students are continuing their participation through independent studies and interships at Ecology. We will continue to study the health of Commencement Bay through this course, to monitor the success and challenges of the cleanup of our shared marine resources.

Table 1. Characterizations of five Commencement Bay stations sampled in this study.

Station ID	Location	Latitude	Longitude	Depth (m)	Ponar Penetration Depth (cm)
285	S. Shoreline Commencement Bay	47’16.727	-122’27.688	-27	4
287	S. Shoreline Commencement Bay	47’16.122	-122’26.747	-23	6
292	N.E. Commencement Bay	47’17.509	-122’25.144	-15	3
296	Thea Foss Waterway	47’15.515	-122’26.205	-10.2	2
304	Hylebos Waterway	47’16.759	-122’24.007	-10	5

Table 2. List of conspicuous taxa in Commencement Bay that were targeted for this study. Each student was assigned a taxon to study as the class “expert”.

Species Name	Phylum	Coarse Taxonomic Group
Alvania compacta	Mollusca	Gastropoda
Amphiodia spp	Echinodermata	Ophiuroidea
Aphelochaeta spp	Annelida	Canalipalpata
Axinopsida serricata	Mollusca	Bivalvia
***Capitella capitata* Cmplx**	Annelida	Scolecida
Cossura pygodactylata	Annelida	Scolecida
Euphilomedes spp	Arthropoda	Ostracoda
Glycera nana	Annelida	Aciculata
Levinsenia gracilis	Annelida	Scolecida
Lumbrineris californiensis	Annelida	Aciculata
Macoma spp	Mollusca	Bivalvia
Mediomastus spp	Annelida	Scolecida
Parvilucina tenuisculpta	Mollusca	Bivalvia
Pinnotheridae	Arthropoda	Decapoda
Prionospio spp	Annelida	Canalipalpata
Rochefortia tumida	Mollusca	Bivalvia
Scoletoma luti	Annelida	Aciculata
Terebellides californica	Annelida	Canalipalpata
Turbonilla sp	Mollusca	Gastropoda

Table 3. Jaccard Coefficient of Community Similarity showing comparisons of pairs of five stations sampled in Commencement Bay, 2011. The closer this value is to 1, the more similar the communities are.

	287	**292**	**296**	**304**
285	0.28	0.19	0.23	0.27
287		0.33	**0.41**	0.38
292			0.25	0.29
296				**0.41**
304				

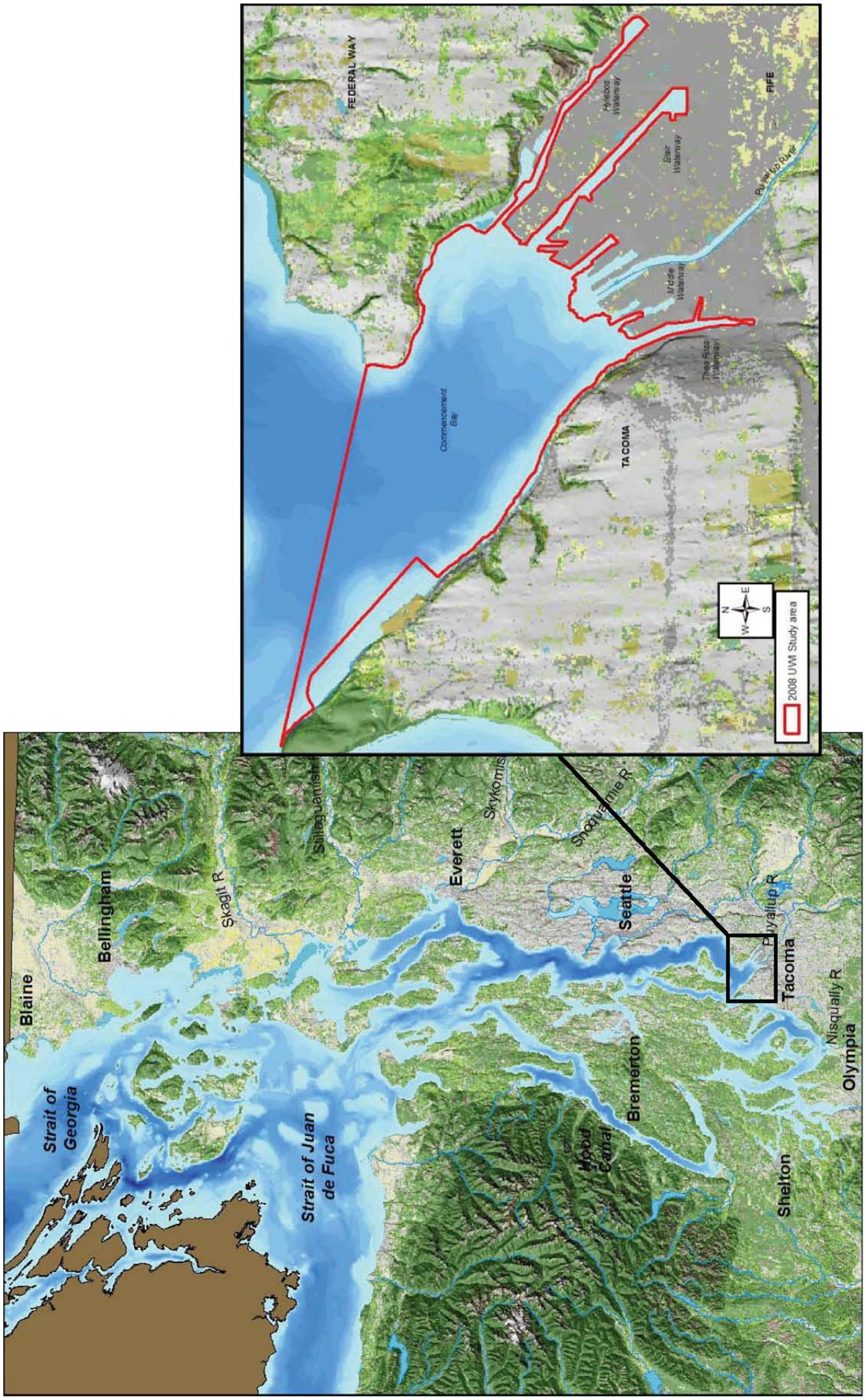

Figure 1. Map of Commencement Bay (Tacoma, WA) and environs (Partridge *et al.* 2010).

Figure 2. Map of stations sampled in Commencement Bay, Washington. Base map provided by Google. No sample was taken from Station 293.

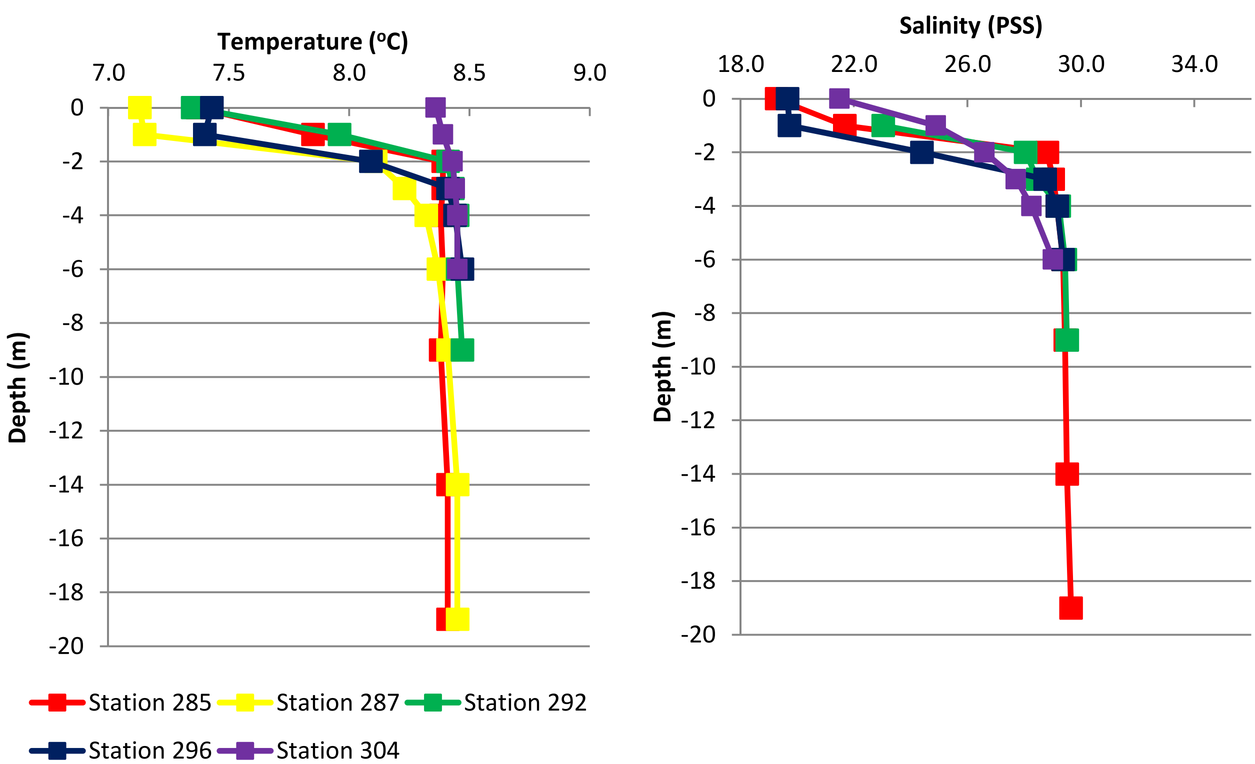

Figure 3. Temperature (left) and salinity (right) profiles of five stations in Commencement Bay, Febrauary 2011. Note that no salinity information is shown for Station 287 due to sampling error.

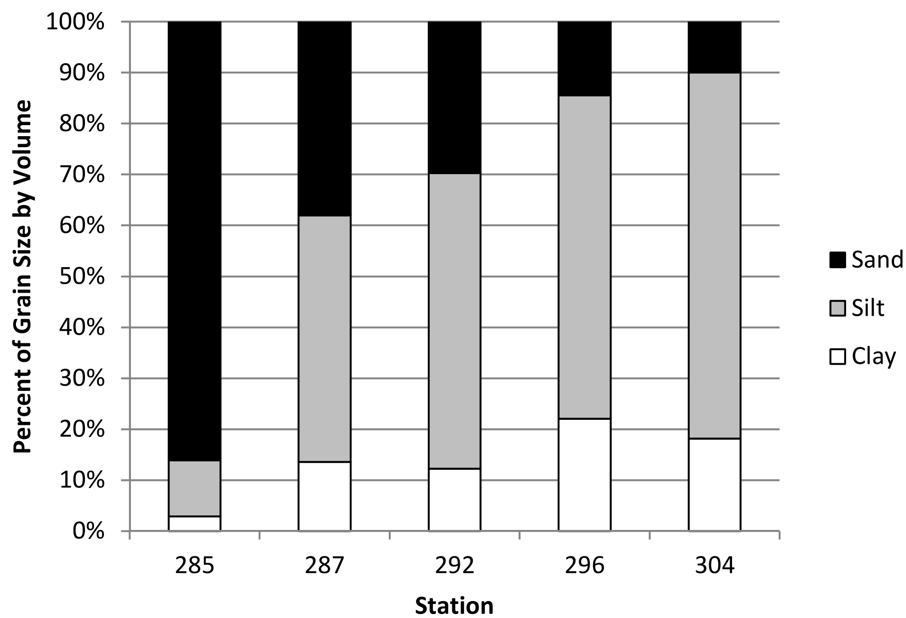

Figure 4. Grain size classes of five stations sampled in Commencement Bay, February 2011.

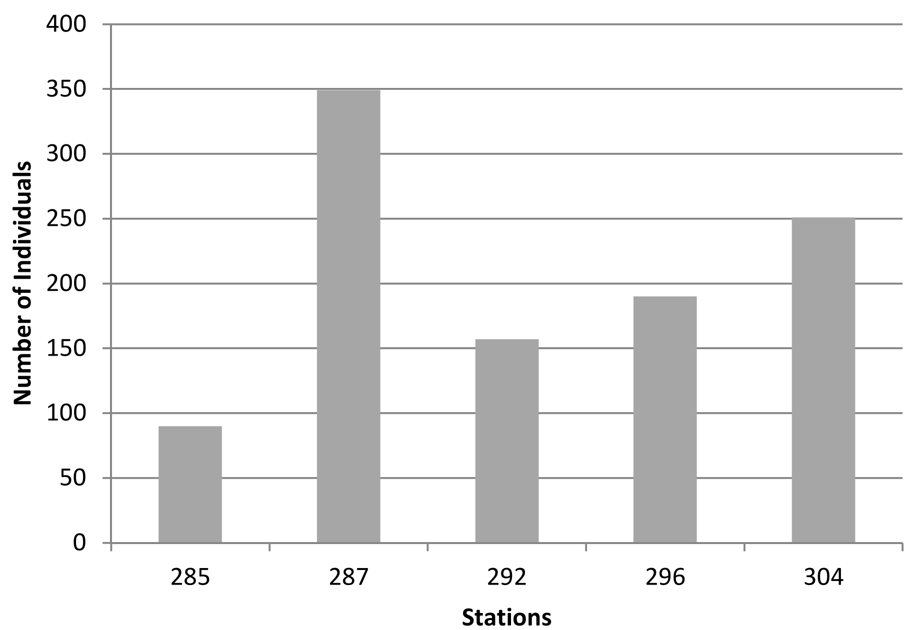

Figure 5. Total abundance of benthic invertebrates found at five stations sampled in Commencement Bay, February 2011, regardless of taxonomic group.

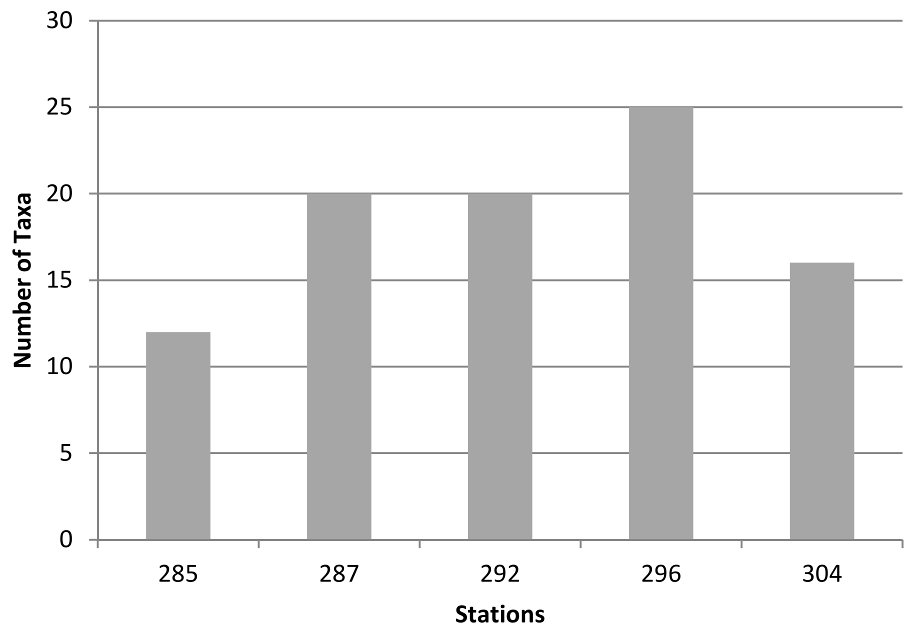

Figure 6. Taxa richness at five stations sampled in Commencement Bay, February 2011. A “taxon” was the finest level of identification for a given organism type (species, morphospecies, class, etc.)

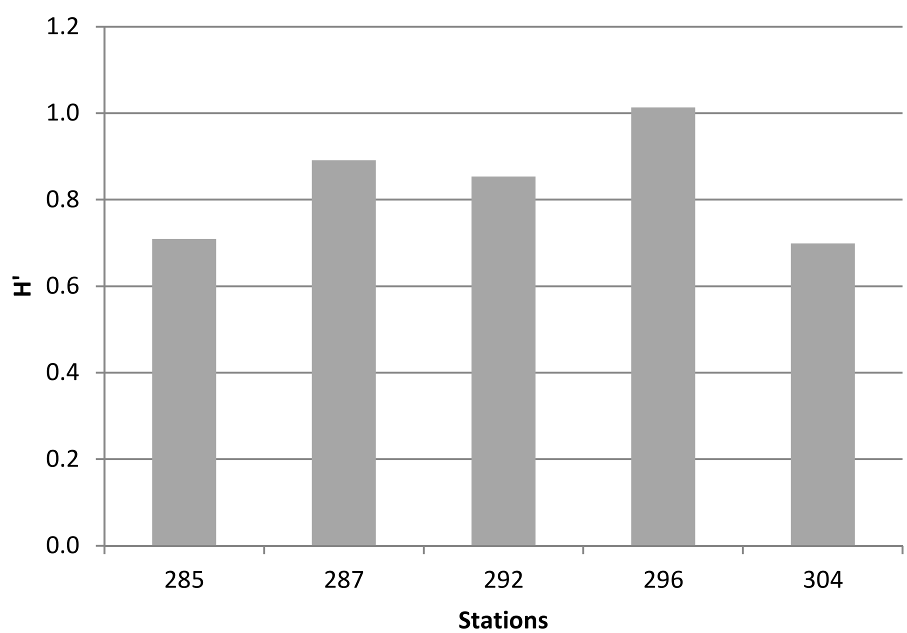

Figure 7. Shannon-Wiener Index, which considers both richness and evenness, at five stations sampled in Commencement Bay, February 2011. A “taxon” was the finest level of identification for a given organism type (species, morphospecies, class, etc.)

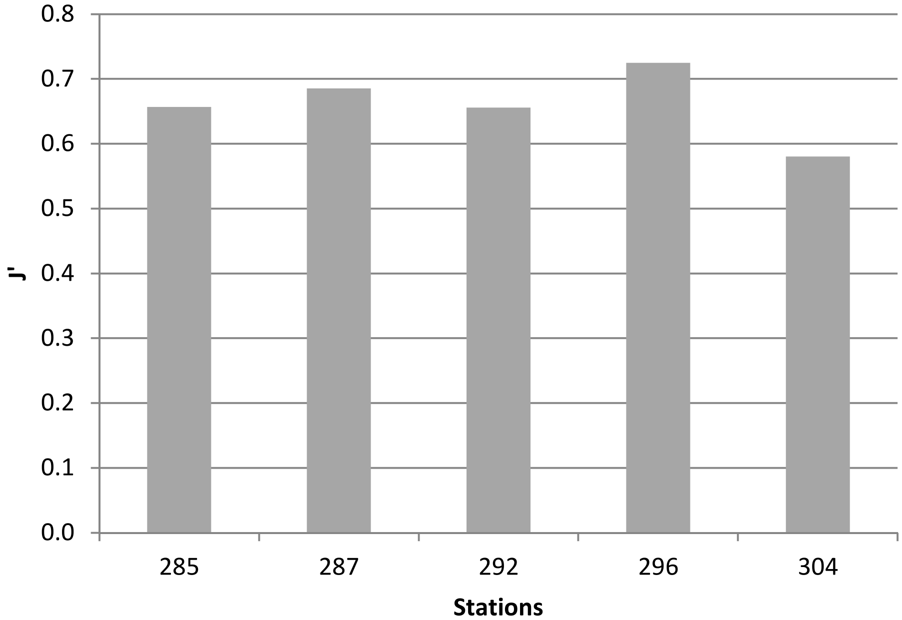

Figure 8. Pielou's Evenness Index, a measure of the distribution of individuals among the taxa, at five stations sampled in Commencement Bay, February 2011. A "taxon" was the finest level of identification for a given organism type (species, morphospecies, class, etc.)

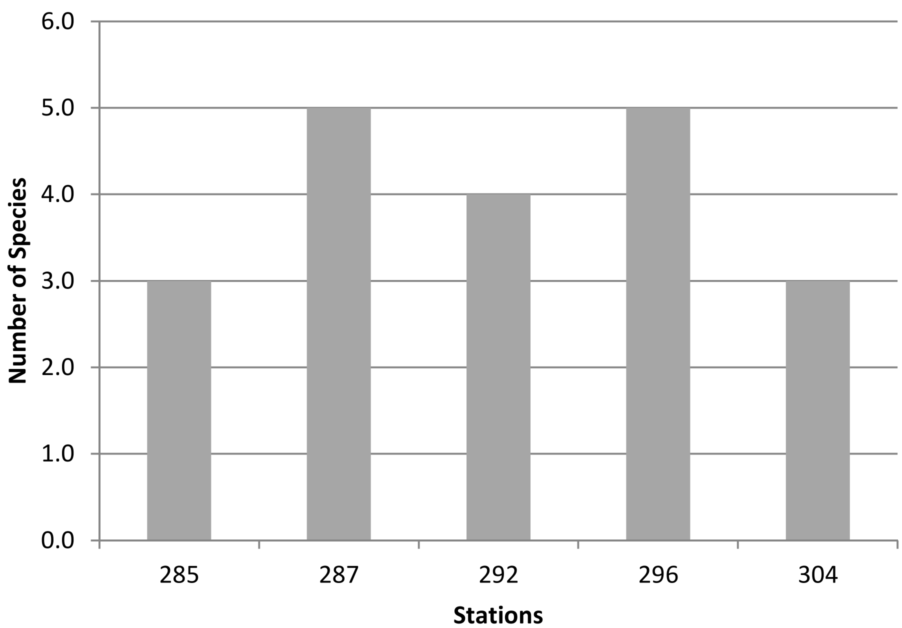

Figure 9. Swartz' Dominance Index, the number of taxa that makes up more than 75% of individuals in a community, is a measure of whether a small number of taxa dominates that community. Measured at five stations sampled in Commencement Bay, February 2011. A "taxon" was the finest level of identification for a given organism type (species, morphospecies, class, etc.)

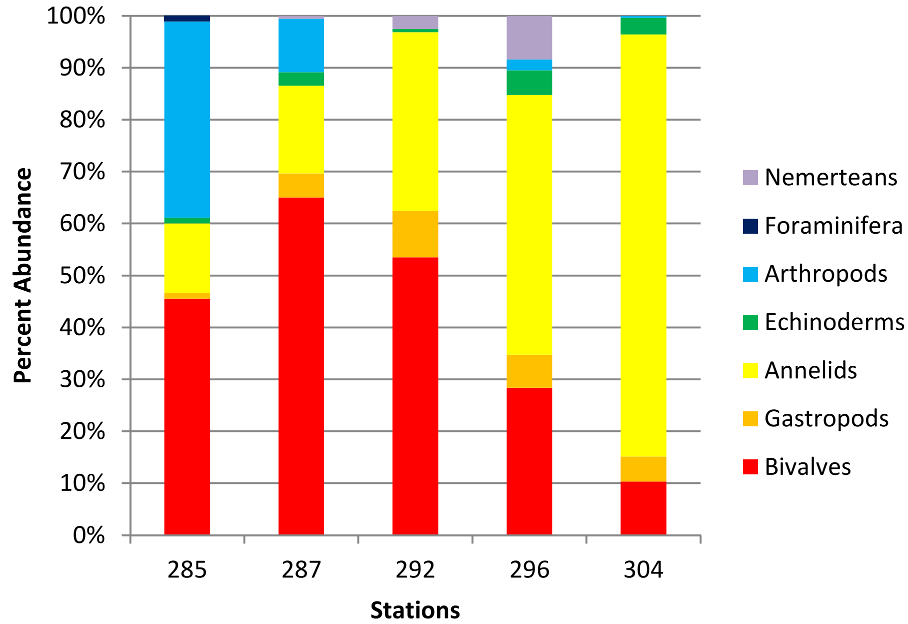

Figure 10. Relative abundance of major taxa found at five stations sampled in Commencement Bay, February 2011.

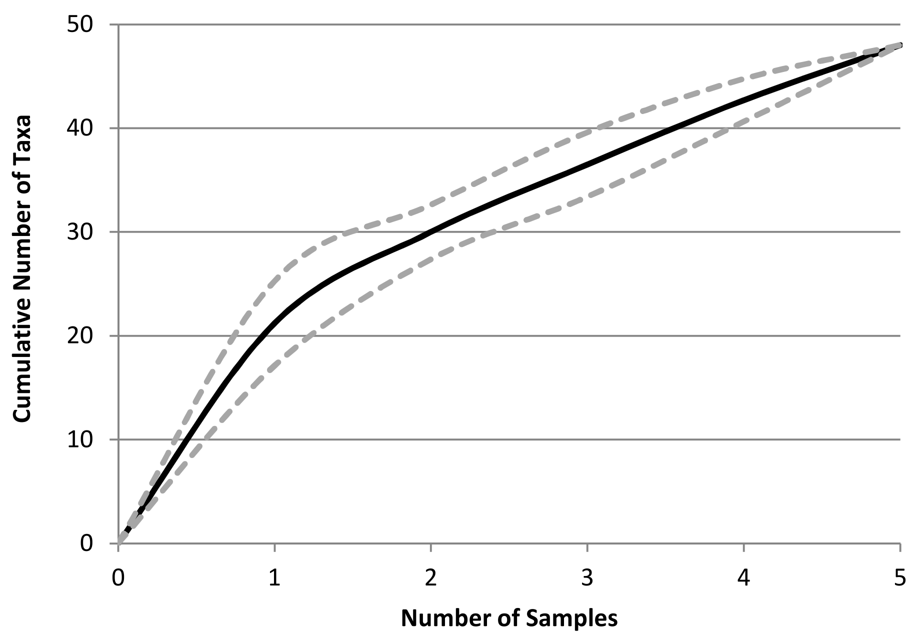

Figure 11. Average collector's curve for five stations in Commencement Bay sampled in February 2011. Shows the number of new taxa found by adding more samples. When a collector's curve levels off, then enough sampling has occurred to describe the diversity at the site. Since the curve differs depending on the order of the samples, the order of the stations was varied randomly and an average curve generated. Dotted lines are $\pm$1 SD.

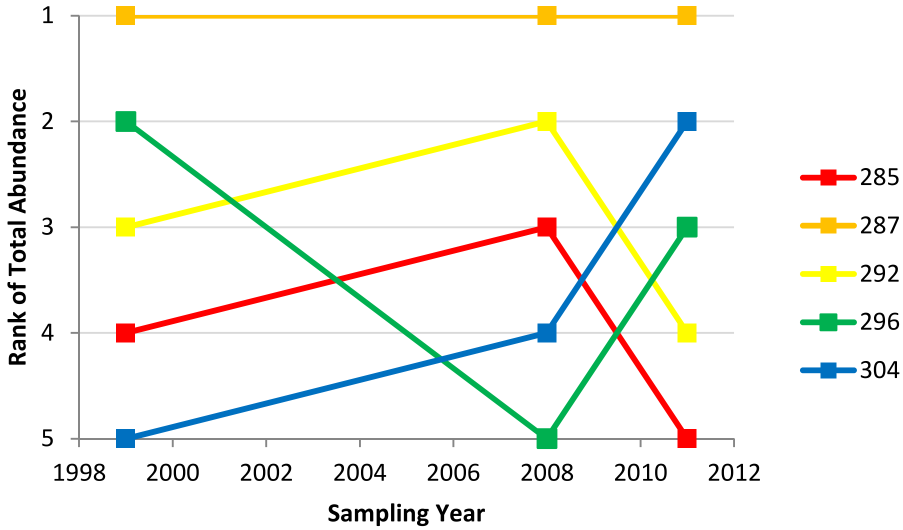

Figure 12. Rank scores of total abundance for stations in Commencement Bay in studies conducted in 1999 (NOAA), 2008 (UWI) and 2011 (this study). Earlier data from Partridge *et al.* 2010.

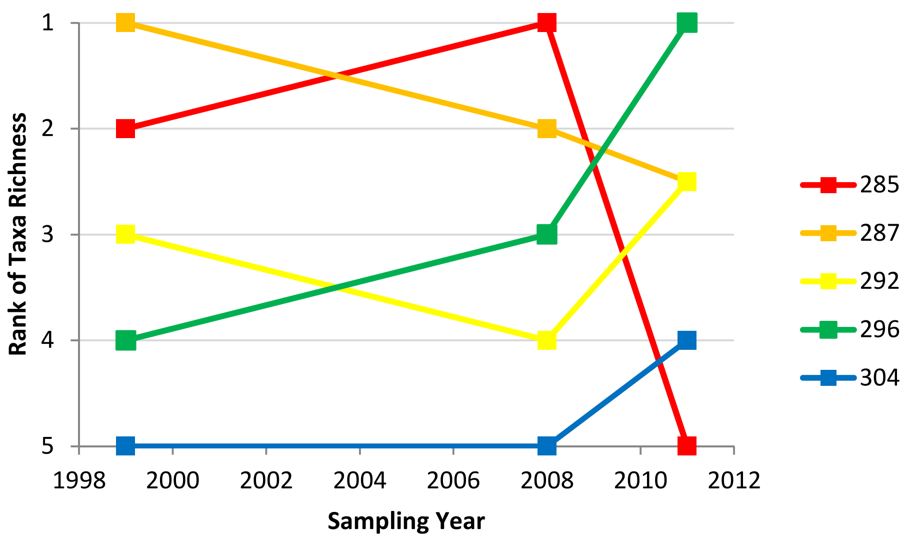

Figure 13. Rank scores of taxa richness for stations in Commencement Bay in studies conducted in 1999 (NOAA), 2008 (UWI) and 2011 (this study). Earlier data from Partridge *et al.* 2010.

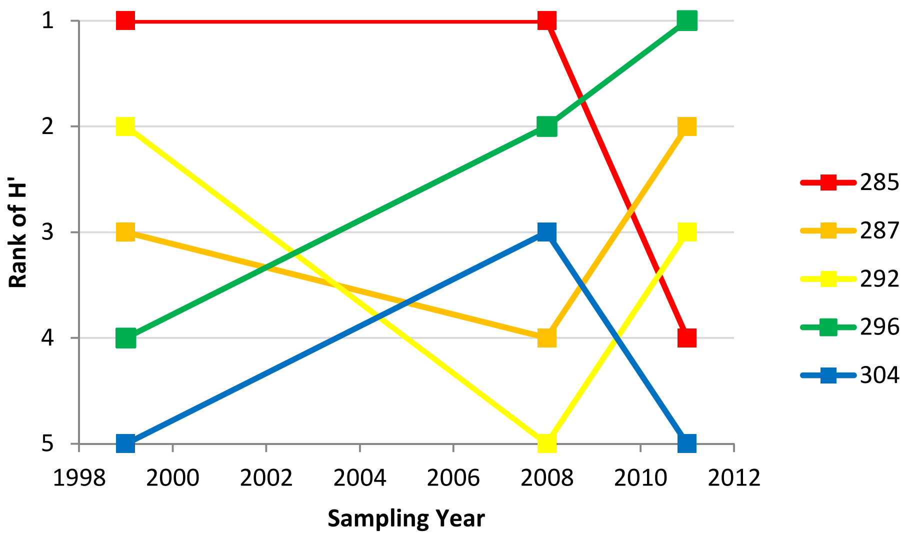

Figure 14. Rank scores of Shannon-Wiener Diversity Index for stations in Commencement Bay in studies conducted in 1999 (NOAA), 2008 (UWI) and 2011 (this study). Earlier data from Partridge *et al.* 2010.

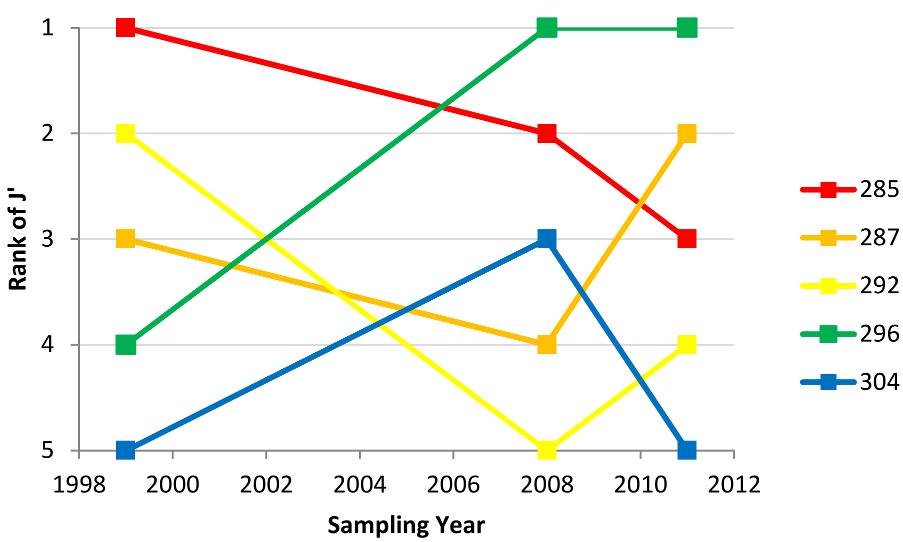

Figure 15. Rank scores of Pielou's Evennes Index for stations in Commencement Bay in studies conducted in 1999 (NOAA), 2008 (UWI) and 2011 (this study). Earlier data from Partridge *et al.* 2010.

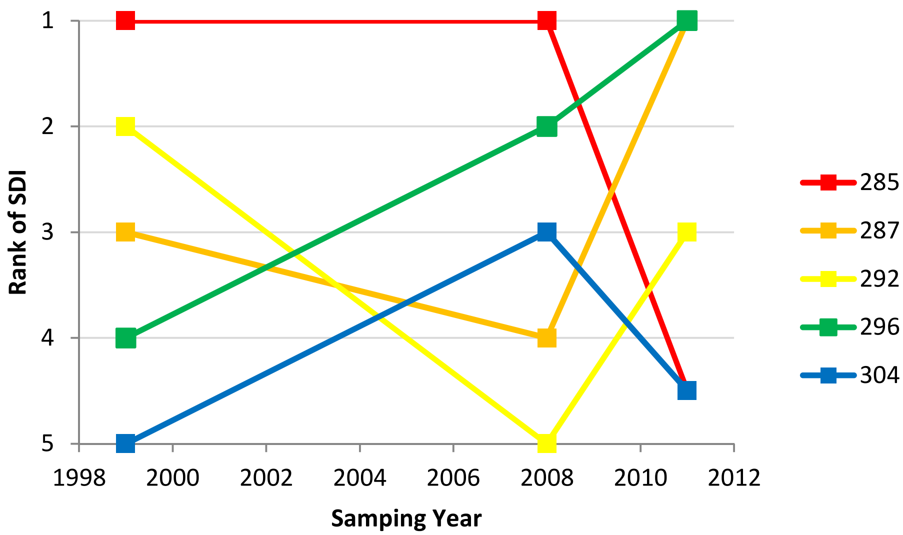

Figure 16. Rank scores of Swartz' Dominance Index for stations in Commencement Bay in studies conducted in 1999 (NOAA), 2008 (UWI) and 2011 (this study). Earlier data from Partridge *et al.* 2010.

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