# Using Sediment Profile Imaging (SPI) to Evaluate Sediment Quality at Two Cleanup Sites in Puget Sound

## Part II - Port Gamble Bay

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# Using Sediment Profile Imaging (SPI) to Evaluate Sediment Quality at Two Cleanup Sites in Puget Sound

## Part II - Port Gamble Bay

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Waterbody No. WA-15-0080 (Port Gamble Bay)

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# Table of Contents

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# List of Figures

# List of Tables

Page

# Acronyms and Abbreviations

This list contains acronyms used frequently in this document. Other acronyms are used infrequently and defined only in the text.

| | |
|---|---|
| ARI | Analytical Resources, Inc. |
| BHQI | Benthic Habitat Quality Index |
| CSL | Cleanup Screening Level |
| Ecology | Washington State Department of Ecology |
| EIM | Ecology's Environmental Information Management system |
| EPA | U.S. Environmental Protection Agency |
| GPS | Global Positioning System |
| H' | Shannon Weiner diversity metric |
| HDPE | high density polyethylene |
| IQR | interquartile range |
| J' | Pielou's evenness metric |
| MDS | multidimensional scaling |
| MEL | Ecology's Manchester Environmental Laboratory |
| OSI | Organism Sediment Index |
| ppt | parts per thousand (for salinity) |
| QA | quality assurance |
| REMOTS™ | remote ecological monitoring of the seafloor |
| RPD | redox potential discontinuity |
| RV | research vessel |
| SDI | Swartz dominance index |
| SEDQUAL | Ecology's Sediment Quality information system |
| SMS | Sediment Management Standards rule (Chapter 173-204 WAC) |
| SPI | Sediment Profile Imaging |
| SQS | Sediment Quality Standards |
| SWI | sediment water interface |
| TOC | total organic carbon |
| TVS | total volatile solids |
| WAC | Washington Administrative Code |

# Abstract

During 2006, the Washington State Department of Ecology conducted exploratory studies to determine if preliminary Sediment Profile Imaging (SPI) survey results might predict traditional sediment quality indicators and thereby reduce the need for detailed investigations at cleanup sites.

Two sites were chosen for these studies: the Lower Duwamish Waterway Superfund site (Seattle) and an area in Port Gamble Bay (Port Gamble) near an historical timber mill and associated log rafting areas. Grab samples were collected for evaluation of sediment quality at 23 of the 32 locations where SPI and other photographs were taken of surface sediments. Samples were analyzed for conventional sediment parameters and characteristics of the *in situ* benthic community. These were then compared to SPI results.

SPI survey results distinguished areas containing wood waste, combined with fine sands and silts, from sandier sediments lacking substantial amounts of wood. SPI results also provided evidence that the study site generally had an aerobic benthic habitat, and relatively complex infaunal communities.

Patterns of wood waste and related sediment conventionals were similar to patterns previously reported. Statistical evaluation of benthic results revealed several distinct communities. These did not exactly mirror groups of sampling locations that were identified by SPI or conventional results. However, SPI and conventionals could be used in combination to classify or explain much of the variability in the different communities with reasonable accuracy.

Results of this study, together with other published findings, provide good reasons to recommend that SPI be used more frequently in cleanup site investigations. SPI results can augment sediment fate and transport studies, identify areas of severe impact (anoxia, azoic sediments), map the nature and extent of wood waste, predict some sediment conventionals, and provide additional lines of evidence for the evaluation of benthic community health.

# Acknowledgements

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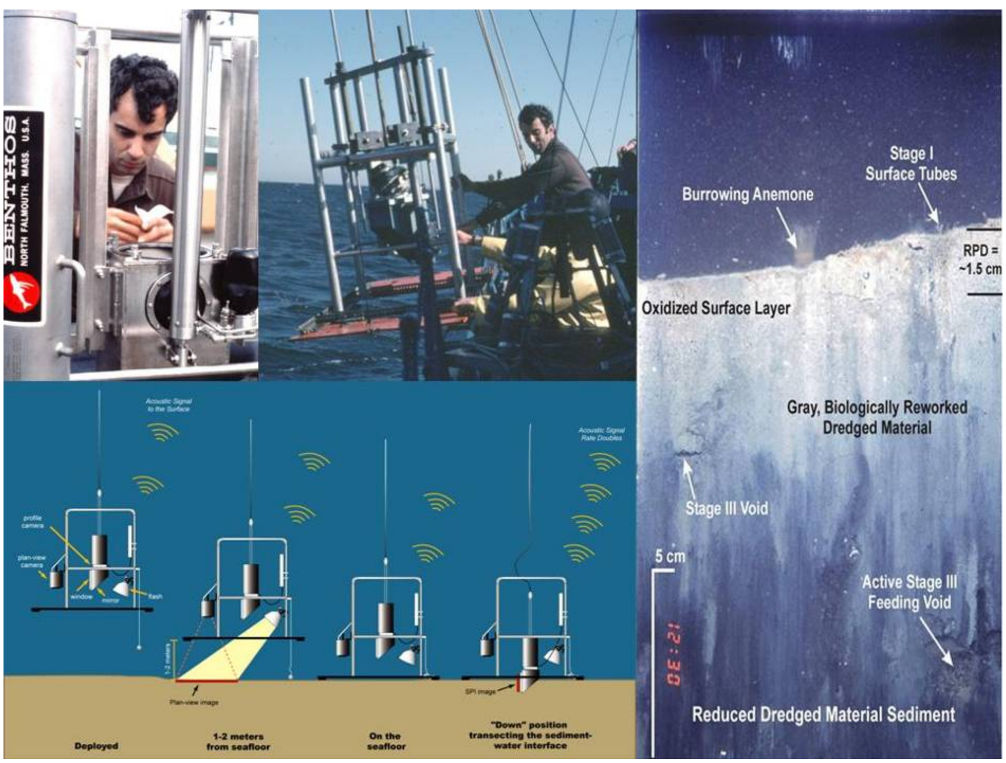
# Introduction

## Background

### Sediment Profile Imaging (SPI) and its history

Sediment Profile Imaging (SPI) technology refers to the scientific instruments, methods, and expertise associated with photographing the cross-sectional profile of the upper 15 cm of the seafloor, including the boundary between surface sediment and overlying water, and interpreting the results. After being lowered to the bottom of a waterbody, a camera housed above a sealed, wedge-shaped chamber filled with distilled water operates like an upside-down periscope and penetrates the sediment surface. After a slight delay to allow the camera prism to obtain maximum sediment penetration, a photograph is taken through a vertical window with aid of a high-intensity flash. The photograph is later analyzed for physical, chemical, and biological features using image analysis software and professional expertise. The technology, the image acquisition process, and an example SPI photograph are shown in Figure 1.




Images provided by Germano and Associates

Figure 1. Deployment of the SPI camera, image acquisition, and example photograph of the sediment water interface.

The two photographs at the top left show one of the earliest sediment profile imaging cameras being readied for deployment from a research vessel. The graphic at the bottom left depicts how the camera works. The SPI photograph at the right shows some of the interpretable features of the sediment water interface.

This technology was developed because studies being conducted in the 1970s of the fossil record in sedimentary rock were still hampered by a limited understanding of interactions between sediments and bottom-dwelling or "benthic" organisms (Rhoads and Young, 1972). To study these interactions, a sampling device was needed that preserved fine sediment structures and biological features without compromising them. This led to the development of a diver-deployed camera designed to take detailed photographs of the sediment-water interface.

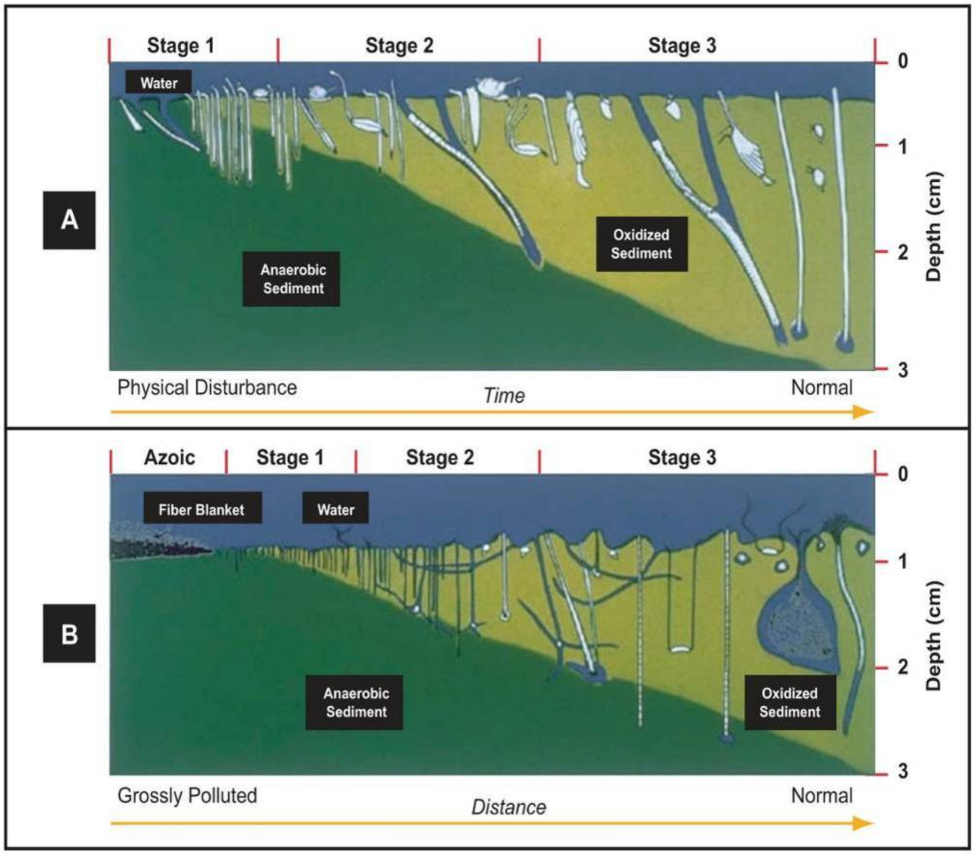
The camera was subsequently modified for deployment from the deck of an oceanographic research vessel and trademarked as REMOTS™ (Remote Ecological Monitoring Of The Seafloor). It was used successfully in early studies of how keystone organisms in Buzzards Bay and Cape Cod Bay altered sediment and community structure. The technology subsequently saw increased use as a reconnaissance tool for monitoring deposits of dredged material in Long Island Sound. This led to development of similar sediment profile imaging or "SPI" cameras.

Interpretation of SPI results over the following decade was aided by the development of models describing how succession in benthic communities is influenced by various disturbances (Rhoads and Germano, 1982, 1986). The model depicted in Figure 2 was based on extensive benthic recolonization and enrichment studies done in the eastern United States and elsewhere (McCall, 1977, Pearson and Rosenberg, 1978). It illustrates the animal-sediment relationships that are visible in sediment profile images.

These "Stage I" communities were replaced by more complex Stage II and Stage III communities comprised of infauna that mixed oxygen into progressively deeper sediments via *bioturbation*. Figure 2A shows benthic community succession after physical disturbances such as episodic dredged material disposal or propeller scour. Figure 2B shows similar succession with distance away from a source of organic enrichment.

The 1980s also saw use of SPI technology migrate into freshwater systems (Boyer and Shen, 1982), and image analysis software was developed to improve the efficiency of data analysis. SPI is now used around the world to evaluate disturbance due to biological recovery from dredged material placement (Valente, 2004), pollution discharges (Diaz, et al, 1993; Olsgard, 1999), eutrophication (Karlson, et al, 2002), and anoxia (Nilsson and Rosenberg, 2000).

Note: The preceding background was adapted in part from Rhoads (2004).




Graphic provided by Germano and Associates

Figure 2. Model of benthic infaunal community succession relative to physical or chemical disturbance.

## Regulatory applications in the Pacific Northwest

SPI technology is most commonly used to characterize general sediment structure, benthic habitat, successional stage of benthic infaunal community development, and interactions between all of these. Regulatory applications of SPI in the Pacific Northwest usually address the following three purposes.

1. Identify sites for disposal or beneficial use of dredged material, and monitor their use.
2. Identify areas of disturbance and their likely causes (e.g., physical factors or pollutant loading).
3. Assess change in benthic infaunal communities (e.g., recovery from disturbance).

Table A-1 (Appendix A) lists most of the regulatory programs and projects in the Pacific Northwest exemplifying these applications. It includes several projects that have used SPI to assess accumulations of wood waste. The table does not include projects, such as those at the Quendall/Baxter Terminals in Lake Washington (Seattle) and in the Lower Willamette River (Portland, Oregon), that used SPI to assess freshwater sediments.

# Study goals and objectives

The primary goal of the overall study was to determine the feasibility of SPI survey results to streamline and reduce overall costs of cleanup site investigations in Puget Sound.  This might be possible if relationships could be found between SPI results and accepted indicators of sediment quality.  The ideal relationships would accurately predict the degree of impairment throughout a sediment cleanup site, but a more likely scenario may be that SPI results help identify areas where the likelihood of impairment is high or low.  Subsequent sediment quality investigations could then focus on smaller areas where probability of impairment is less certain.  These investigations would be easier to design and implement, and would cost less.  Such relationships also might help monitor recovery over time.

Specific objectives of this study are to:

1. Identify relationships between SPI survey data and direct measurements of sediment quality at a wood waste cleanup site.
2. Fill in data gaps related to assessment of the site.
3. Provide data that may serve as part of an environmental *baseline* to which post-remedial action monitoring results can be compared.

The main goal and objective #1 were addressed by collecting images and samples from Port Gamble Bay that provided SPI, sediment conventionals, and benthic infaunal community results. Objective #2 was addressed by a sampling design that featured good spatial coverage and characterization of some locations where no previous samples had been collected.  Another major data gap was filled by collecting *in situ* benthic infaunal community samples at the site. Finally, results would represent the most current conditions at the study site (objective #3).

# Methods

## Study design

Figure 3 depicts how this study was planned and implemented. One design element of the study design was that two sampling events would be conducted. An SPI survey would be followed by a sediment quality survey that would focus on measuring conventional parameters and benthic infaunal community characteristics. Combining SPI and sediment sampling into a single survey was impractical because SPI surveys can obtain images from 5-10 times the number of sampling locations each day as the number of grab samples that can be collected during a sediment quality survey.

As a consequence of conducting two surveys, it was imperative that sediment samples be collected as soon as possible after the SPI survey was completed and from locations as close as possible to where SPI images were obtained. This ensured sediment samples were representative of SPI locations and results.

Another design element was to sample three separate sediment quality strata. This approach would increase the information obtainable from the limited number of samples (15) that could be collected and analyzed (US EPA, 2002). These sampling strata represented areas having *high*, *moderate*, and *low* probability of exhibiting an impaired benthic community, and were depicted in the QA Project Plan (Gries, 2006). The strata were defined using historic sediment conventionals data (Parametrix, 2004), as follows.

- The "High" stratum had substantial wood waste, >25% Total Volatile Solids (TVS), and >10% Total Organic Carbon (TOC).
- "Moderate" areas had >5% to 10% TOC
- "Low" areas had <5% TOC.

Selection of sampling locations from within these strata was coordinated with Anchor Environmental ("Anchor") who had planned a related sediment quality survey. Target sediment sampling locations were chosen from within these strata using a judgmental and design based on:

- Project goals and budget.
- Expected strata boundaries.
- A preliminary or "quick look" interpretation of SPI survey images.
- SPI sampling locations (PGSP-101 through PGSP-131).
- Locations sampled by Anchor (AS-01 through AS-14).

A total of 23 locations were chosen for collecting samples for evaluating sediment quality, Table A-2, Appendix A. The focus of the sediment quality evaluation was on conventional parameters and *in situ* benthic infaunal community characteristics. Anchor also measured sediment toxicity at 6 of the 23 locations. Contaminants in Port Gamble Bay sediments would not be measured because they were previously found in concentrations less than the Sediment Quality Standards (SQS).

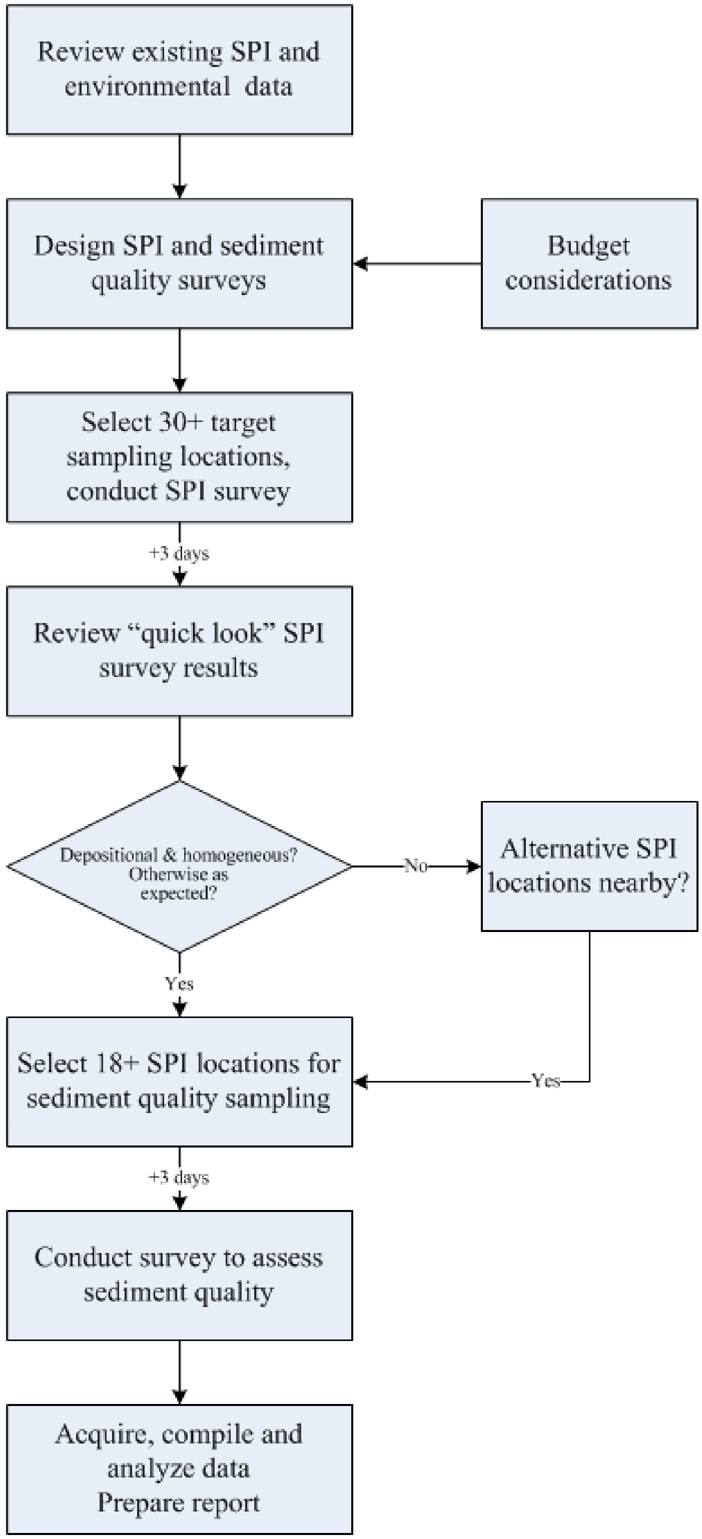



Figure 3. Planning and implementation of the 2006 SPI Feasibility Study of the Port Gamble Bay wood waste cleanup site.

## Collecting and interpreting images of surface sediment

Germano and Associates collected surface sediment plan-view and SPI images according to the sampling strategy and methods described in the Quality Assurance Project Plan (QA) (Germano and Associates, 2006), unless noted otherwise in this report.

The SPI instrument package was configured to collect three types of images of surface sediment: (1) a plan-view video during final descent, (2) a high resolution, plan-view digital still image, and (3) a high resolution SPI photograph of both surface sediment and overlying water. The instrument package was lowered three times when the RV Kittiwake reached a position acceptably near a set of target coordinates. Precise sampling coordinates and water depth were recorded for each of the three field replicates. Preliminary or "quick-look" interpretations of triplicate SPI images for each location were used to select target locations where sediment quality samples would be collected.

Germano and Associates reviewed all digital images using both image analysis software and professional expertise. Generally, 24 SPI parameters were measured, interpreted, and reported. These parameters are listed and discussed in Germano and Associates (2006, 2007). Some examples included:

- Camera penetration depth
- Boundary roughness
- Redox potential discontinuity depth (RPD)
- Grain size major mode
- % wood (by volume)
- Low dissolved oxygen and presence of methane
- Successional stage
- Number of burrows
- Number of feeding voids
- Number of tubes
- Fecal pellets
- Bedforms
- Organism Sediment Index (OSI)

Germano and Associates could not calculate or interpret certain SPI parameters for some locations where sediment quality samples were collected. In some cases, no minimum or maximum depth of feeding voids could be reported because no voids were observed. The RPD depth in some images was indistinct and reported as "indeterminate." All data that could be derived from SPI images were deemed usable and submitted to Ecology as a quality-assured, electronic data package.

Summarized findings were submitted to Ecology as draft and final reports (Germano and Associates, 2007).

## Positioning for sediment sampling

Ecology chose 18 primary and several alternate target locations for sediment quality sampling after the "quick look" review of SPI results occurred on August 25, 2006. Five additional "AS" locations--those where Anchor planned to collect samples and measure sediment conventionals and toxicity--were chosen for characterization of the *in situ* benthic community only. The final target sampling coordinates, chosen in the field, were based on the central-most latitude and longitude values from the set of triplicate SPI sample coordinates. Target latitude and longitude for sediment sampling locations were often obtained from different SPI replicates.

Sediment sampling from Ecology's vessel RV Skookum began on August 28, 2006, six days after the SPI survey was completed. Target coordinates for sediment sampling were located using a differentially corrected, 12-channel GPS receiver (Leica MX420) mounted on the stern corner of the vessel, combined with a U.S. Coast Guard, land-based beacon differential receiver. The GPS unit received satellite signals, and the Coast Guard receiver acquired corrections to those signals.

The pilot of the RV Skookum recorded northing and easting coordinates at the moment the van Veen grab sampler closed, when each sediment sample was collected. Washington State Plane Coordinates, North (NAD 83) were converted into degrees and decimal minutes. The vessel heading (compass bearing) was also recorded so that coordinates could be corrected for the known offset between GPS receiver and winch cable.

The water depth at the sampling location was also recorded and later corrected relative to Mean Lower Low Water using the predicted tidal elevation for Port Gamble Bay for the same date and time (National Oceanic and Atmospheric Administration and BioMarine Enterprises). Corrected water depth was compared to the similarly-corrected water depth of the equivalent SPI sampling location as a means of verifying the accuracy of vessel positioning.

Additional details on vessel positioning are provided in the QA Project Plan (Gries, 2006).

## Collecting sediment samples

Details of methods used to collect, handle and store surface sediment samples are described in the QA Project Plan (Gries, 2006). Some of the sampling procedures and sample handling methods are summarized below.

Sediment was collected from locations as close as possible to each set of target sampling coordinates. A double van Veen grab sampler (0.1 $m^2$ each side) was used to collect 0-10 cm surface sediment from each grab. This depth interval was presumed to contain most of the macrobenthic infaunal organisms and reflect their associated activities.

Criteria for accepting sediment grab samples included:

- Sampler penetration of at least 11 cm.
- Sediment not extruded out the top of the sampler (no overpenetration).
- Minimal loss of overlying water (sampler closed completely).
- Relatively flat or undisturbed surface after removal of overlying water.

The principal investigator accepted grab samples slightly less than 10 cm in depth from locations AS-09, AS-14, PGSP-108, and PGSP-121.

The field crew recorded field notes for each acceptable grab. Information recorded included date, time, geographic coordinates, water depth, overlying salinity, van Veen penetration depth, presence of wood waste, sediment color and texture, presence of any sheen or odor, as well as biological structures. At almost all sampling locations, a single lowering of the van Veen was sufficient to collect an adequate volume of sediment for analysis of conventional parameters (approximately 2 liters) and characterization of the *in situ* benthic community.

A subsample of surface sediment for bulk sulfide analysis was collected first. The planned subsampling method was to take a small core of 0-10 cm surface sediment from one side of the van Veen using a 60 mL syringe. This was not successful for early samples containing appreciable wood waste, so a stainless steel spoon was used instead to collect 0-5 cm surface sediment. This material was placed in a 2-ounce glass sample jar, covered with a zinc acetate preservative solution, and capped with zero headspace.

The remaining sediment not in contact with the walls of the van Veen was homogenized using a stainless steel spoon or paint stirrer. Subsamples were then placed into appropriate containers for analysis of total solids, grain size distribution, total volatile solids, total organic carbon, and bulk ammonia. All sediment samples to be analyzed for these conventional parameters were labeled, handled, and stored as described in the QA Project Plan.

Surface sediment in the second side of the double van Veen sampler was used for benthic community assessment. This material was transferred into a plastic tub and then onto a 1.0 mm mesh wire screen. Smaller particles and organisms were gently washed through using strained site water, while macrobenthic organisms and larger debris were carefully collected on the screen and placed in one-gallon zip-lock bags. The samples were preserved with a solution of buffered formalin and placed in sealed secondary containers, such as 5-gallon HDPE buckets, in the field.

All sampling devices and homogenizing equipment were decontaminated prior to sampling and between grabs at individual sampling locations according to established guidelines. Decontamination between sampling locations consisted only of scrubbing the sampler with a coarse bristled brush and rinsing it thoroughly with site water. This was a minor deviation from the QA Project Plan that required a phosphate-free detergent wash, a second rinse with site water again, and final rinses with acetone and distilled water if visible contamination was observed. However, no visible contamination was noted, and only sediment not in contact with van Veen walls was collected.

Waste management, shipping, and chain-of-custody procedures described in the QA Project Plan were followed without exception.

# Measuring sediment quality

## Sediment conventionals

Ecology's Manchester Environmental Laboratory (MEL) measured total solids, total volatile solids (TVS), and total organic carbon (TOC) in 18 sediment samples and one field duplicate. Analytical Resources Inc. measured total solids, grain size (before and after combustion at 550$^{o}$ C), ammonia, and sulfide in the same 18 samples and one field duplicate. The methods used for each analysis are described in the QA Project Plan (Gries, 2006), and were consistent with Puget Sound Estuary Protocols and Guidelines (EPA, 1986 and updates). All conventional parameters in samples collected by Anchor from AS-01, AS-03, AS-05, AS-13, and AS-14 were measured by Analytical Resources, Inc. (ARI).

## Benthic community assessment

Ecology collected and preserved surface sediment samples for analysis of the *in situ* benthic communities found at the 18 locations mentioned above, plus five "AS" locations. All samples were later removed from secondary containers, rescreened using a 0.5 mm mesh sieve, and placed in a solution of 70% ethanol, with Rose Bengal added to aid organism identification.

Procedures for sorting benthic community samples and identifying and counting infaunal organisms followed the QA Project Plan. Samples were next transferred to OIKOS and the taxonomic specialist tasked with sorting the samples. Sorting consisted of placing small amounts of each sample into a Petri dish and examining them with a compound dissecting microscope. Organisms were separated from debris using fine forceps and placed into containers labeled according to major taxonomic group (Annelida, Arthropoda, Mollusca, Echinodermata, and Miscellaneous Taxa). Each Petri dish of material was "picked" twice, and the process was repeated until the entire sample was sorted. All organisms were then preserved in 70% ethanol.

For each sample, taxonomic specialists identified all organisms to the lowest practical taxonomic level practical (usually species) and totaled the number belonging to each taxon. Table B-2, Appendix B, shows that one-fourth of each sorted sample was counted a second time and never differed from the first count by more than 10%. Quality assurance checks on taxonomic identifications resulted in no substantial changes to the taxa identified or number of individuals counted.

Total abundance of individual organisms, total number of taxa (taxa richness), abundance and richness of each major taxonomic group, Swartz' Dominance Index (SDI), Shannon-Weiner diversity index (H'), and Pielou's Evenness metric (J') were calculated for each sample. This was done using established formulae and corresponding algorithms developed by Ecology's Marine Sediment Monitoring Program (Ecology, 1998).

SDI was calculated as the minimum number of taxa that could account for 75% of the total number of organisms identified in a sample (75% of total abundance). The Shannon-Weiner diversity index H' was calculated as:

$$H' = -\sum_{i=1}^{s} p_i \log p_i$$

where $p_i$ is the proportion of the assemblage that belongs to the ith taxa (number of individuals in taxonomic group "i" / total number of individuals), and s is the total number of taxa identified.

Pielou's Evenness J' was calculated as the proportion of the maximum possible diversity for the entire data set:

$$J' = H'/\log s$$

There were two deviations from the QA Project Plan associated with collecting, preserving, and processing benthic samples, prior to transferring them to the taxonomic expert for sorting and analysis.

- The first two batches of benthic community samples were preserved with 20%-30% formalin (instead of the 10%).
- An average of 20 days (34 days maximum) was needed to rescreen the preserved samples and transfer them into an ethanol solution (instead of all samples within three weeks).

Exposure of benthic samples to either too strong a formalin preservative or too long a time undoubtedly had adverse effects on some organisms and their identification. This is a particular concern for the mollusks, whose shells begin to dissolve in the presence of the acidic formalin solution. However, it appeared that the combination of buffer in the formalin solution and wood waste in the samples minimized the impact. This was evident from reports of sorting efficiency and the observed condition of the benthic community samples.

## Data quality and usability

Results of the QA review are summarized below and in Table B-1. Virtually all data collected were found to be usable for the stated goals and objectives of this project.

The SPI expert performed a quality assurance review of SPI data and determined that they all met or exceeded requirements of the SPI QA Project Plan (Germano and Associates, 2007). Certain SPI parameters could not be determined or calculated for some samples or replicates, but this had little effect on analyses.

Sediment quality samples were collected to represent SPI locations and results:

- The sediment survey followed the SPI survey by less than one week.
- Vessel positioning relative to final SPI coordinates was excellent, especially considering all locations showed evidence of surface sediment homogeneity.
- Sampling locations were chosen based on "quick look" SPI results showing homogeneous surface sediment.
- Sampling procedures generally followed those described in the QA Project Plan.

Analytical results for sediment conventionals passed an initial quality review performed by various laboratory personnel. The principal investigator conducted a separate review according to the QA Project Plan (Gries, 2006), Ecology guidance (2004, 2005), and with assistance from Ecology's QA officer.

All total solids and TVS results were acceptable without qualification. Field duplicate results for all conventional parameters were very similar except for sulfide and the associated preserved solids. These results were also accepted without qualification because wood waste samples are likely to be heterogeneous even if they appear homogeneous on a macroscopic scale. Field duplicate results were averaged when used to characterize sediment quality. Only the results from the replicate from which a benthic community sample was collected were used for analyses of relationships between sediment and benthic community characteristics.

Laboratory replicate results for all conventionals except for TOC were within control limits. Two lab replicates for sample AS-09 differed by 28% and 40% from the original sample; therefore, MEL qualified the TOC result for this sample as an estimated value. When considered as triplicates, the mean TOC was 23.7%, the coefficient of variation was 0.33, and the standard error was 4.5%. All TOC results for samples analyzed in this batch were considered estimated values.

Anchor's sampling coordinates and the analytical methods used by ARI to measure total solids, TVS, and TOC in "AS" samples differed only slightly from those in Ecology's study and therefore were used for exploratory analyses.

Information provided by taxonomic specialists about sorting benthic community samples, Table B-2, Appendix B, identifying the various taxa, and counting organisms indicated that all quality assurance requirements were met. Formalin solutions used to preserve the first two batches of benthic samples were too strong, and the samples were exposed to the solutions for longer than the recommended time. However, these factors did not appear to have a substantial effect on the taxonomist's ability to identify organisms to the desired species level, Table B-3, Appendix B.

The quality assurance review results described and summarized above had minimal impact on data usability, statistical analyses, or the findings presented here.

# Managing and analyzing data

## Data entry and management

Analytical results for sediment conventionals were provided by MEL and ARI electronically and as printed reports. The data were also manipulated for analysis using SEDQUAL 5.1, statistical and GIS software. The primary taxonomic specialist provided benthic community data in an electronic format that was readily modified to meet analytical needs. All of the electronic data submittals were modified, as needed, for entry into Ecology's EIM system. The principal investigator evaluated the accuracy of importing or transferring analytical results into spreadsheets and databases. This was done by randomly selecting 25% of the sediment samples (6) and performing a check for 100% accuracy for all data types.

## Data analysis

Different approaches and statistical methods were used to examine the relationships between categories of data, as well as results for individual parameters (Figure 4). Statistical analyses were performed using Systat 11 (Systat Software, Inc). TerraStat Consulting Group used S-PLUS 2000, Professional Release 3, to independently conduct certain statistical analyses.

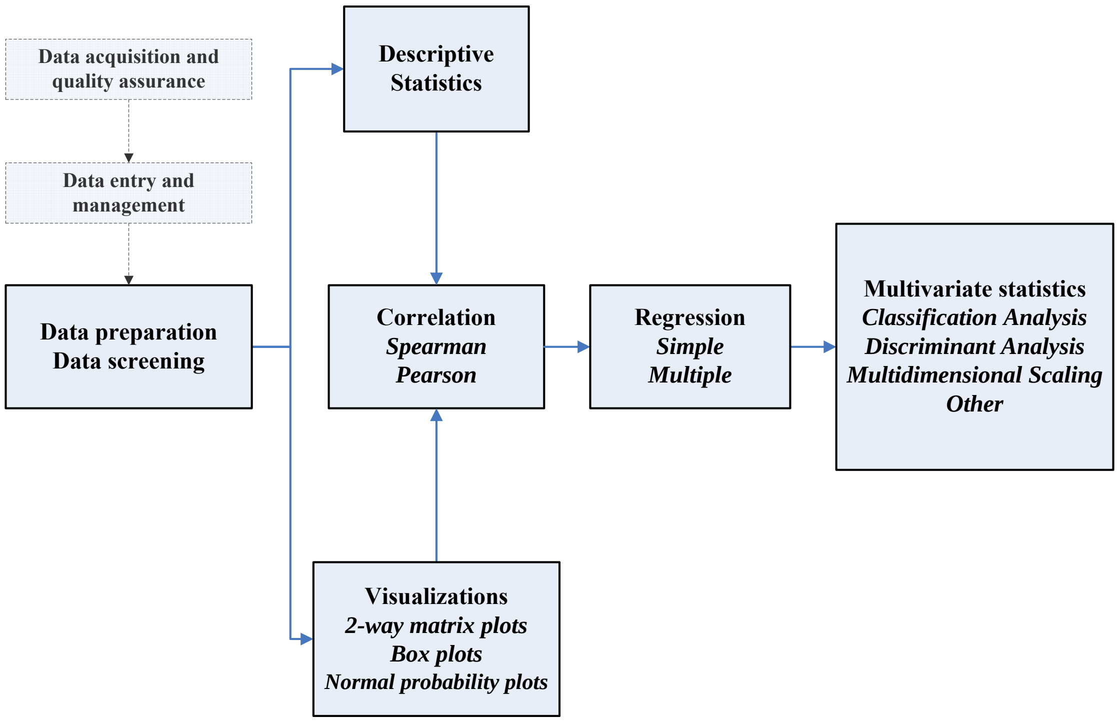



Figure 4. General scheme for preparing, screening, and analyzing SPI, sediment conventionals, and benthic community data collected for the Port Gamble Bay study site.

The principal investigator carefully reviewed the Port Gamble Bay data set before conducting extensive statistical analyses (Figure 4). Potential outlier values were identified by examining:

- Descriptive statistics (Appendix C).
- Two-way matrix plots, Figures D-1, Appendix D.
- Box-and-whisker plots, Figure D-2, Appendix D.
- Maximum normal residuals (Snedecor and Cochran, 1989).

Table D-1, Appendix D, summarizes potential outliers, those removed from analysis, and reasons for their removal.

Data distributions were examined using normal probability and other types of plots (Figures D-3 and D-4, Appendix D), as well as statistical tests for normality such as Shapiro-Wilk. Results are summarized in Table D-2, Appendix D. Variables of all types were identified that had only a limited range of values and therefore less likely to be analytically useful. Missing values and their likely analytical implications were also identified.

After screening the results, the range of values for each parameter was determined and median values were used to describe *typical* sampling locations. A description of spatial distributions, north-to-south gradients, and other obvious patterns was then prepared. These were useful for comparisons to past results, for understanding and interpreting overall results, and for planning statistical analyses.

Spearman rank correlation analysis was used to assess potential linear or nonlinear relationships between two variables. Significant correlation coefficients (rho), Table D-3, Appendix D, were one basis for reducing the list of variables used in the subsequent analyses. Regression analysis was used to probe for relationships between individual SPI parameters (independent variables), individual benthic community metrics, and sediment conventional parameters (dependent variables). Data were transformed when necessary to achieve a linear relationship, usually by means of a square root, fourth root or $\log_{10}$ transform. The lack of simple relationships between SPI and benthic community data led to the multivariate phase of analysis.

Multivariate statistical methods focused on cluster analysis and multidimensional scaling with benthic infauna results to identify related groups of sampling locations that could be considered unique benthic communities. SPI and sediment quality results were then used in discriminant analysis to identify the factors that could explain the differences between the communities. Classification trees were also explored as a means of predicting the sampling locations belonging to each benthic community identified.

Mean values for distinct groups of sampling locations were compared using box-and-whisker plots, a two-sample Student's t-test or the non-parametric Mann-Whitney test, depending on distribution of residuals.

Results for conventional sediment parameters were compared to 2003 results to confirm predicted sampling strata. These comparisons took the form of contingency tables that could be evaluated using the Chi square or Kendall's coefficient of concordance.

# Results

## SPI and sediment quality surveys

Germano and Associates conducted the SPI survey of this study site on August 22, 2006 (Germano and Associates, 2006). Weather and sea state were favorable for sampling and did not adversely affect vessel positioning or image collection. Underwater video equipment generally provided better images, especially with respect to the degree of homogeneity of surface sediments, than did the high resolution plan-view digital camera. The clarity of the latter type of images was often poor because of residual turbidity from the instrument contacting the bottom.

Images of the sediment water interface were collected at 32 sampling locations according to the procedures described in the SPI QA Project Plan (Germano and Associates, 2006). Five locations were near pier structures north of the former mill site peninsula, and 28 locations were south of the peninsula. All target and actual coordinates for locations where replicate SPI images were obtained are presented in the final SPI report (Germano and Associates, 2007). The SPI camera failed to penetrate the surface sediment at location PGSP-131 due to unusually hard substrate.

On August 25, 2006, the SPI expert reviewed preliminary image interpretations with Ecology's principal investigator and discussed sampling locations that would be most suitable for Ecology's sediment survey. Locations showing evidence of erosive processes or surface heterogeneity were generally excluded from consideration for sediment sampling. An example of "quick look" results is shown in Table 1, and complete results are shown in Germano and Associates (2007).

Ecology's sediment quality survey of Port Gamble Bay was conducted during August 28-30, 2006. Target coordinates and the actual sediment sampling locations, selected with prior evidence of homogeneous surface sediments, are shown in Figure 5 and listed in Table A-2, Appendix A. The differences between target and actual sampling coordinates were calculated using an internet calculator (www.nhc.noaa.gov/gccalc.shtml) and averaged 1.1 meters (3.6 feet). This met positioning goals but did not account for a known offset between the digital GPS receiver on the RV Skookum vessel and the point where the winch cable enters the water. The offset was cause for some residual uncertainty about how representative sediment samples were of SPI locations.

Water depth was recorded for each sampling location at the moment a grab sample was collected. Depth was corrected for the predicted tides at Port Gamble and compared with the tide-corrected water depth calculated by the SPI survey navigator (Eaton, 2006). The average difference between the two corrected depths was less than 0.8 meters (2.5 feet). This depth difference could have been real for samples collected from sloping areas. However, the magnitude of the average difference was more likely from comparing calibrated cable depths from one vessel to uncalibrated cable depths or depth finder readings from the other vessel.

Table 1. Sample of "quick look" SPI survey results (italics added for emphasis).

Sampling location PGSP-123 appeared to accumulate sediment ("depositional") and be relatively homogeneous. PGSP-124 showed evidence of erosion or "washing" and greater heterogeneity. Sediment samples were collected at PGSP-123 and not at PGSP-124.

| Quick look results → / Sampling location ↓ | Rep | Substrate | Successional stage | Sediment Stability | Observations |
|---|---|---|---|---|---|
| PGSP-123 | A | Very fine sandy silt | 1 on 3 | *Static* | *Net depositional, poorly sorted*. SWI algae, voids, polychaetes. *Good candidate for Low.* |
| PGSP-123 | B | Very fine sandy silt | 1 on 3 | *Deposi-tional* | Similar to A. Some dragdown. |
| PGSP-123 | C | Very fine sandy silt | 1 on 3 | Slight washing | Deep oxidized burrows. *Base substrate very similar* though reps show some different features. *Good candidate for Low*. |
| PGSP-124 | A | Slightly silty, fine-medium sand | 1→2 | *Washing* | *Dynamic*. Firm sand. Algae at SWI, broken tube fragments. |
| PGSP-124 | B | Slightly silty, fine-medium sand | 2→3 | *Slight washing* | Firm. Similar to A. Large sea pen at right. SWI with biogenic mounds and some small wood fragments. |
| PGSP-124 | C | Slightly silty, fine-medium sand | 2 | *Washing* | Similar to A. *Sorting increases towards SWI. Broken tubes at SWI. Dynamic.* |

Successional stage - see Figure 2 for explanation.
SWI = sediment water interface.

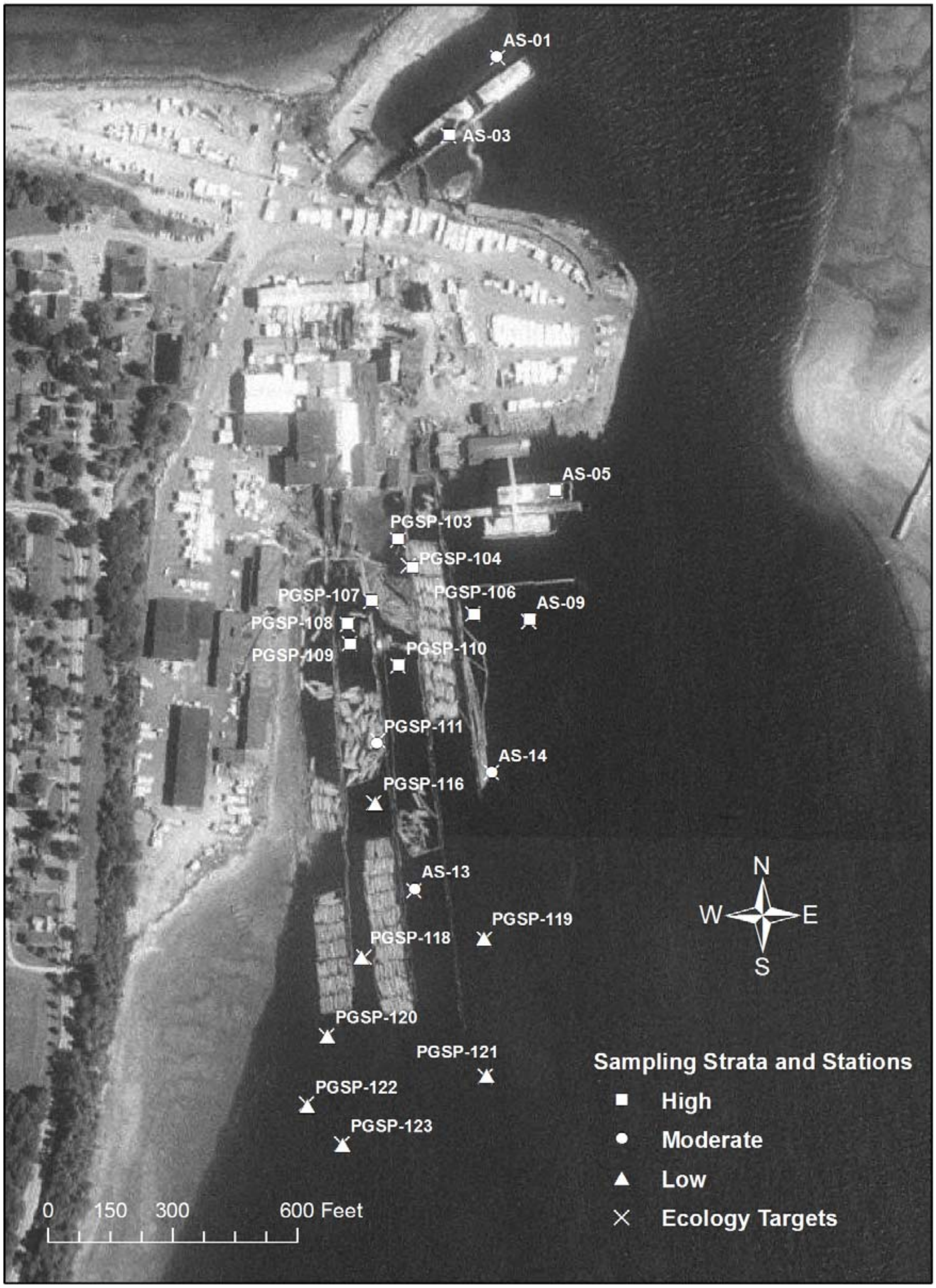



Figure 5. Aerial view of the Port Gamble Bay study site showing target and actual sediment quality sampling locations, with preliminary sampling strata indicated.

## SPI results

Ecology collected and analyzed sediment samples from 23 of the SPI locations that appeared depositional and superficially homogeneous, Table A-2, Appendix A. Some of the parameters from this subset of SPI results--ones easily summarized from triplicate images and exhibiting a good range of values--are presented in Table 2. More complete SPI results are presented in Table C-1, Appendix C.

Table 2. Summary of selected SPI parameters for sampling locations in Port Gamble Bay.

| | Penetration depth (cm) | Boundary roughness (cm) | RPD depth (cm) | % wood (by vol) | Voids max. depth (cm) | Number of small tubes | Number of burrows | VTB | OSI | BHQI |
|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 6.7 | 0.5 | 1.5 | 0 | 5.5 | 0 | 0 | 3 | 6.5 | 7 |
| Maximum | 17.1 | 3.0 | 4.5 | 56.7 | 15.1 | 5.3 | 14.3 | 19 | 10.7 | 12.7 |
| Range | 10.4 | 2.5 | 2.9 | 56.7 | 9.5 | 5.3 | 14.3 | 16 | 4.2 | 5.7 |
| Median | 13.5 | 1.8 | 2.95 | 4.3 | 10.1 | 2 | 4.7 | 8 | 9 | 9.7 |
| Mean | 12.7 | 1.8 | 3.0 | 10.4 | 10.2 | 2.0 | 4.9 | 8.4 | 9.0 | 9.7 |
| Number of samples | 23 | 23 | 23 | 23 | 16 | 23 | 23 | 23 | 23 | 23 |

Boundary roughness = maximum minus minimum penetration depth for each replicate image
VTB = total number of voids, small tubes, and burrows per replicate
OSI = Organism Sediment Index (See Germano and Associates, 2006)
BHQI = Benthic habitat quality index (Nilsson and Rosenberg, 1997)

Using median values, the *typical* SPI sampling location was one where the camera prism penetrated more than 13 cm into the surface sediment, the boundary roughness (maximum minus minimum penetration) was just under 2 cm, and the Redox Potential Discontinuity (RPD) depth was 3 cm. The typical location also had 4% wood (average >10%), and the deepest feeding void occurred 10 cm below the surface. Two small tubes and five burrows were usually present. There were a total of eight voids, small tubes, and burrows. The Benthic Habitat Quality Index and Organism Sediment Index values were both 9-10. An OSI value <7 generally indicates some form of disturbance has occurred.

The range in values for most of the other SPI parameters reported by Germano and Associates (2007) was limited and less analytically useful (Table C-1, Appendix C).

SPI images showed that the sampling locations that were closer to wood waste sources contained fine to medium wood integrated with fine sand and silt. Larger pieces of wood were sometimes noted on the surface. Images of locations removed from wood waste sources showed sandier sediments with minimal or no wood, and sometimes macroalgae, shell debris, or both.

Observations about the spatial distributions of SPI results included:

- RPD and burrow counts appeared to increase from north to south.
- Locations north of the peninsula had greater than average % wood waste.
- The 11 sampling locations closest to sources of wood waste exhibited statistically greater prism penetration depth, boundary roughness, and % wood, but statistically fewer burrows.
- Locations along the eastern perimeter often had shallower penetration depths and lower than average boundary roughness and % wood.
- Locations in the southern portion of the study site had a deeper average RPD depth, shallower minimum and maximum void depths (where data were available), no or minimal % wood, and a higher number of burrows.
- With few exceptions, the average RPD depth, number of burrows, OSI, and BHQI were greatest at locations in the south and along the perimeter of the main wood waste area.

Germano and Associates (2007) ranked the 23 locations sampled by Ecology for sediment quality in order of "likelihood of alteration to benthic habitat quality" based on SPI results alone. These are shown in Figure 6. Eleven locations were reported as being disturbed due to organic loading or wood waste (AS-01 through AS-05, PGSP-103 through PGSP118). The 6 locations identified as showing signs of physical disturbance (AS-09, PGSP-106, PGSP-119, PGSP-121, PGSP-122, PGSP-129) included some that might otherwise be considered potential reference locations. The remaining 6 locations that showed no substantial disturbance (AS-13, AS-14, PGSP-110, PGSP-120, PGSP-123, and PGSP-130) included one that had similar % wood as those identified as disturbed (PGSP-110).

Overall, the SPI experts concluded that the benthic infaunal communities found at the Port Gamble Bay study site "were fully recolonized and the ecosystem and had fully recovered (high apparent RPD values and widespread occurrence of Stage 3 assemblages)."

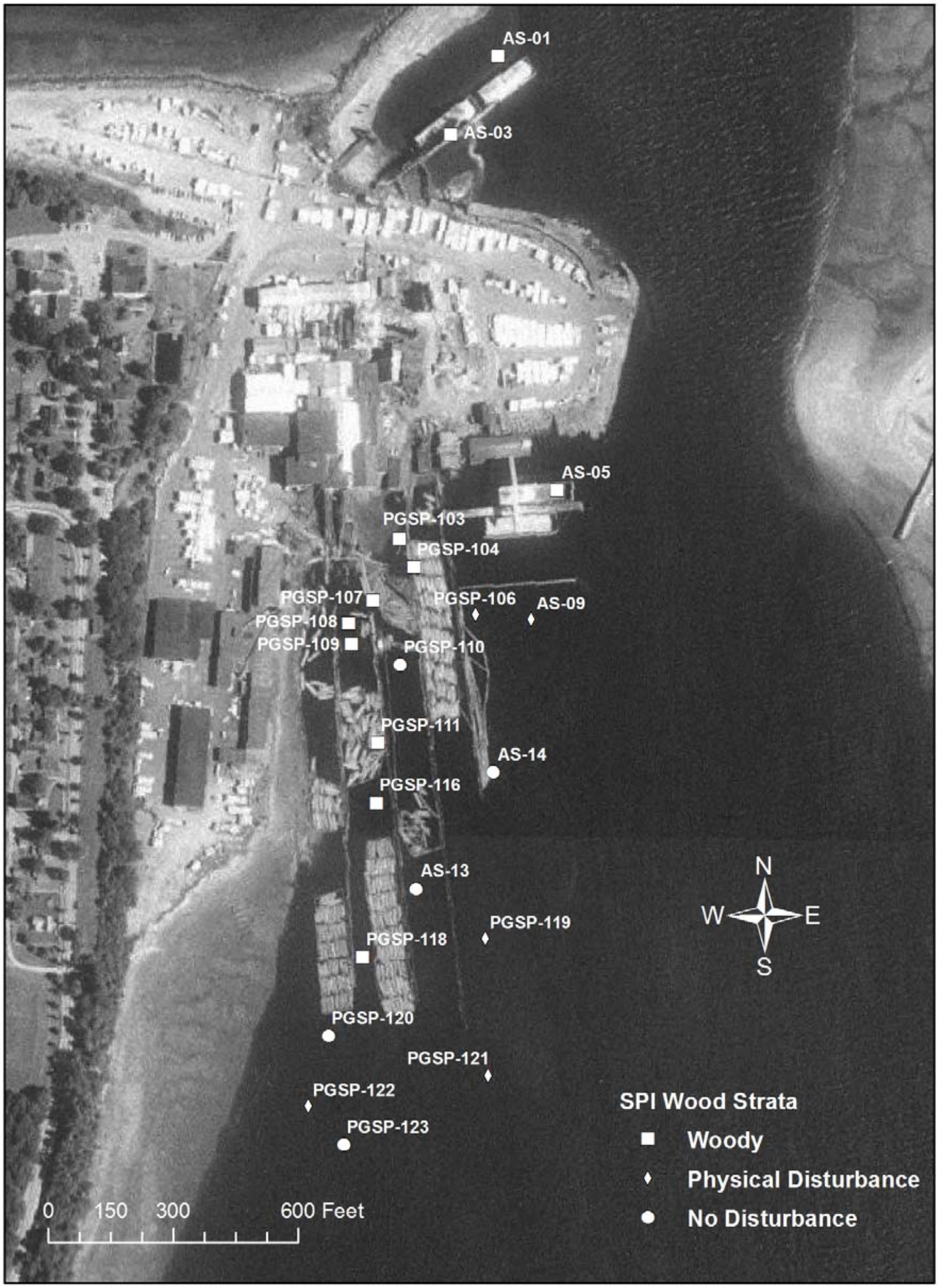



Figure 6. Aerial view of the Port Gamble Bay study site showing sampling locations grouped by category of disturbance from final SPI report (Germano and Associates, 2007).

## Results for sediment conventionals

Table 3 summarizes the nine conventional parameters measured in the 23 sediment samples collected by Ecology and Anchor Environmental. Using median values again, the *typical* sample from this study contained approximately 60% total solids, 64% sand, 20% fines, 8% total volatile solids (mean of 13%), 2.7% total organic carbon (mean of >6%), 11 ppm ammonia (as N) and more than 200 pm sulfides. Analogous median values for non-wood waste areas of Puget Sound were similar for total solids and ammonia but different for grain size (40% sand, 56% fines), TVS (4.6%, mean of 6%), TOC (1.6%, mean of 2.1%), and sulfides (more than 80 ppm). Except for TVS, these results are not particularly unusual for Puget Sound.

Table 3. Summary of selected sediment conventionals measured at the Port Gamble Bay study site. Complete data can be found in Appendix C.

| | Total Solids (% wet) | Sand (% dry) | Silt (% dry) | Clay (% dry) | Fines (% dry) | Total Volatile Solids (% dry) | Total Organic Carbon (% dry) | Ammonia (mg/Kg dry) | Sulfide (mg/Kg dry) |
|---|---|---|---|---|---|---|---|---|---|
| Minimum | 26.4 | 39 | 3.1 | 3.6 | 6.7 | 1.9 | 0.7 | 2.8 | 0.05 |
| Median | 59.2 | 63.7 | 11.8 | 8.2 | 20.3 | 8.15 | 2.7 | 8.8 | 67.1 |
| Mean | 51.9 | 68.3 | 16.9 | 9.8 | 26.7 | 13.0 | 6.6 | 11.8 | 206 |
| Maximum | 74.8 | 93.3 | 33.6 | 18.2 | 51.6 | 33 | 23.7 | 33.7 | 951 |
| Range | 48.4 | 54.3 | 30.5 | 14.6 | 44.9 | 31.1 | 23.0 | 30.9 | 951 |
| Number of samples | 23 | 23 | 23 | 23 | 23 | 22 | 23 | 23 | 23 |

The distribution pattern of TVS and TOC was consistent with 2003 results (Parametrix, 2004). Sampling locations having highest TVS and TOC were nearest the sources of wood waste, while sandier sediments were more common east and south of the wood waste accumulations.

Preliminary assignment of sampling locations to the various strata was generally accurate (Table 4). This classification table lists the sampling locations as assigned to preliminary strata in the "Expected" column. Stratum assignments based on 2006 results are listed in the "Observed" columns. Accuracy of assigning sampling locations to the three different strata proved to be nearly 90% for the *low* stratum (8/9), 60% for the *high* stratum (6/10), and 60% overall (14/23). Accuracy was poorest for *moderate* sampling locations, reflecting areas most likely to represent conditions transitional between high and low wood waste. This analysis appeared to indicate either that sediment characteristics had changed since 2003 or that the thresholds defining the different strata were not optimal.

Table 4. Classification or contingency table showing preliminary and final assignment of 23 sampling locations to *high*, *moderate* and *low* strata for Port Gamble Bay, 2006.

| Expected | Observed | | |
|---|---|---|---|
| | *High* | *Moderate* | *Low* |
| *High* (10)<br>AS-03, AS-05, AS-09<br>PGSP-103, PGSP-104,<br>PGSP-106 -- PGSP-110 | (6)<br>PGSP-103, PGSP-104,<br>PGSP-107 - PGSP-109[a]<br>PGSP-110[b] | (1)<br>AS-05 | (3)<br>AS-03, AS-09,<br>PGSP-106 |
| *Moderate* (4)<br>AS-01, AS-13, AS-14,<br>PGSP-111 | (1)<br>PGSP-111[a] | | (3)<br>AS-01, AS-13,<br>AS-14 |
| *Low* (9)<br>PGSP-116 – PGSP-130 | | (1)<br>PGSP-116 | (8)<br>PGSP-118 –<br>PGSP-130 |

a = TOC>10% but $TVS_{2006}$ <25%
b = $TVS_{2006}$ > 25% but TOC <10%

Cumulative frequency distributions for the various sediment conventional parameters (not shown) revealed two distinct groups of sampling locations had been sampled, more so than the expected three. Group A was comprised of the locations immediately south of the peninsula and closest to sources of wood waste (AS-05, PGSP-103 and PGSP-104, PGSP-107 through PGSP-111, PGSP-116, and PGSP-118). These 10 locations generally contained total solids <40%, sand <65%, silt >15%, clay >10%, fines >25%, total volatile solids >15%, and total organic carbon >4%.

Group B was comprised of locations along the outer perimeter of the site and in the most southern locations (AS-13 and AS-14, PGSP-106, PGSP-119 through PGSG-130). These 10 locations generally had total solids >60%, sand >80%, silt <15%, % clay <10%, fines <25%, total volatile solids <10%, and total organic carbon <4%. No obvious ammonia or sulfide concentration divided these samples into the same two groups, but Group A samples did have the highest sulfide concentrations. Sampling locations AS-01, AS-03, and AS-09 belonged to Group A or Group B, depending on the conventional parameter.

Figure 7 shows sampling locations in Groups A and B. The box-and-whisker plots in Figure 8 show the conventionals parameters were significantly different between the two groups:

- Median values for Group A were 33% total solids, 50% sand, 44% fines, 24% TVS, 12.7% TOC, and 420 mg/Kg sulfides.
- Median values for Group B were 69% total solids, 85% sand, 15% fines, 2.6% TVS, 1% TOC, and 27 mg/Kg sulfides.
- $95^{th}$ percentile confidence intervals for the median values (see footnote to Figure 8) did not overlap, indicating statistically significant differences in location ($\alpha \approx 5\%$).

Finally, as mentioned in methods, grain size analysis for 18 samples and one field duplicate was done both before and after combustion at 550$^{o}$ C. The "double analysis" was used to distinguish "apparent" grain size distribution (including wood waste particles of all sizes) from "actual" sediment grain size distribution. Differences between these two measurements of grain size were intended to help characterize the habitat (e.g., amounts of wood waste) and interpret benthic community data.

The seven samples having the greatest increase in % sand after combustion (PGSP-107 through PGSP-111, PGSP-116, and PGSP-118) were also listed by the SPI expert as disturbed due to organic loading (wood waste) and members of Group A. Prior combustion did not have as great an impact on grain size distribution for PGSP-103 and PGSP-104 despite their close-in location. This may be due to removal of most of the larger wood waste from surface sediments when these locations were dredged in 2003.

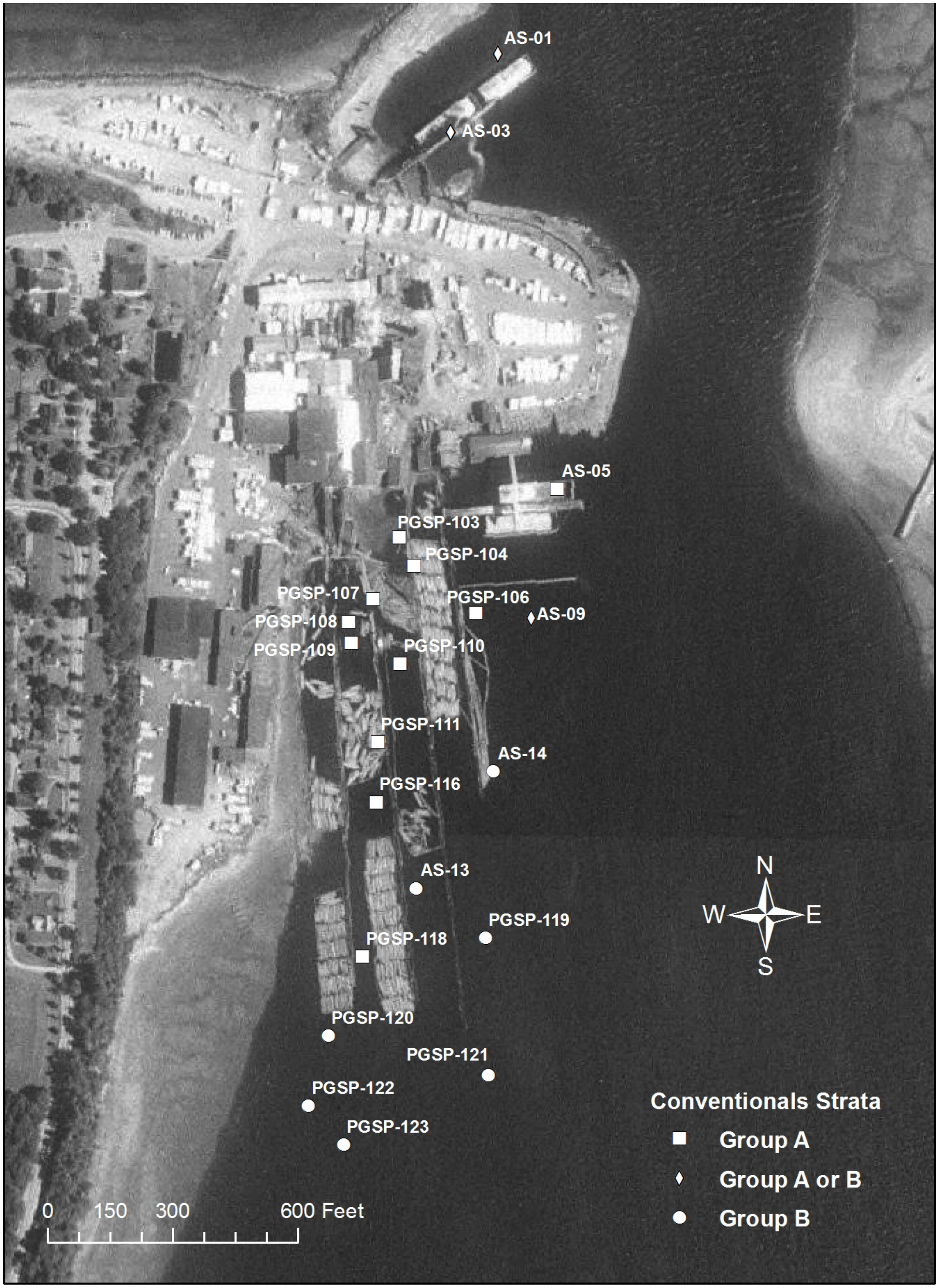



Figure 7. Aerial view of the Port Gamble Bay study site showing sampling locations grouped by results for sediment conventionals.

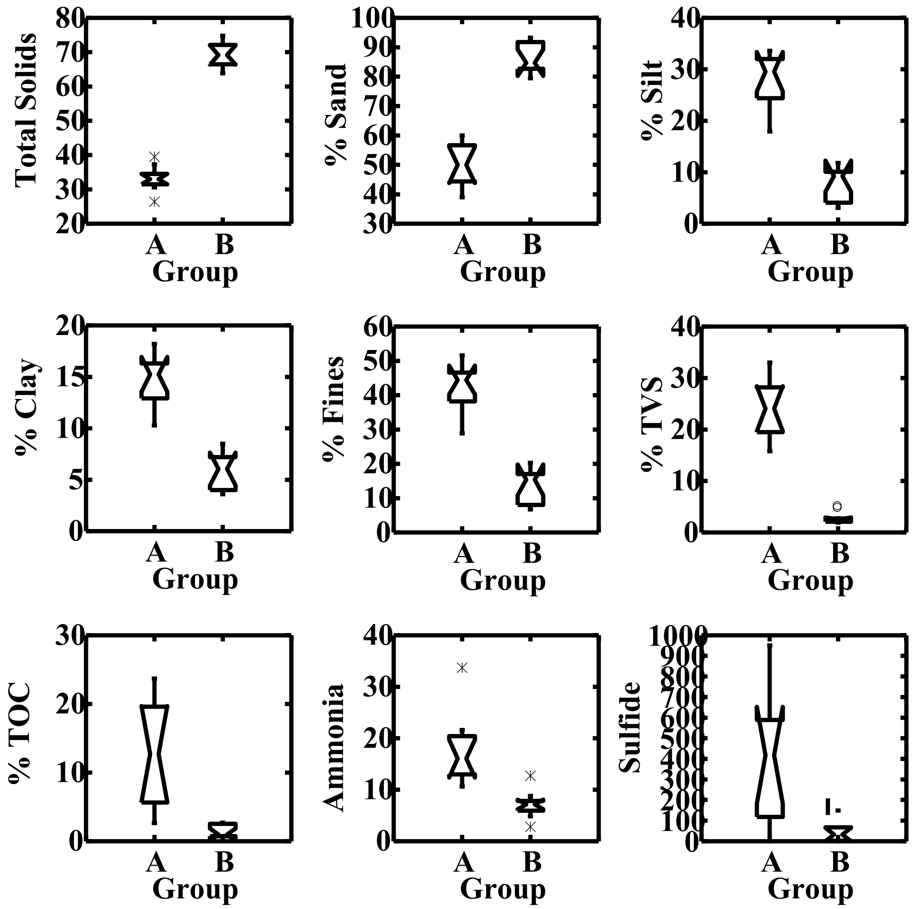



Figure 8. Box-and-whisker plots for nine sediment conventional parameters measured in sampling Groups A and B.

Units are % wet weight for total solids, and % dry weight for remaining parameters except ammonia and sulfide (mg/Kg dry weight).

The median is shown as the constricted waist in the vertical box. The difference between top and bottom of the box is the interquartile range. The 95% confidence interval of the median is where the box first reaches its maximum width. Whiskers end at values equal to the 25$^{th}$ percentile value minus 1.5 times the IQR and the 75$^{th}$ percentile value plus 1.5 times the interquartile range.

## Benthic community results

The main goal of the Sediment Management Standards (SMS) rule is protection of human health and the environment, with most of its provisions aimed at evaluating sediment quality to protect marine ecosystems at the level of benthic communities. Sediment criteria in the rule define significant adverse effects in communities (reduced abundance of major taxa) and surrogate indicators that predict those effects (sediment chemistry and toxicity).

Contaminant concentrations were known to be low at this study site, and measuring sediment toxicity in sediment containing wood waste has often proven to be difficult. Consequently, evaluation of sediment quality focused on characterizing *in situ* benthic communities and the conventional sediment parameters that influence them. Analysis of benthic communities involved the following.

- Sorting, identifying, counting, and reporting the organisms in the 23 samples collected.
- Reviewing results for general community composition and distribution patterns.
- Interpreting results according to the SMS rule (to the extent possible).
- Applying statistical methods to identify natural groupings of organisms that constituted communities.
- Using statistical methods to identify factors explaining the observed variability or influencing any communities that could be identified.

OIKOS and a team of taxonomic specialists were responsible for the first part of this analysis. They reported a total of 35,124 individual organisms belonging to 328 separate taxa. Detailed taxonomic results and a summary of 14 benthic community metrics for each sampling location are provided in Appendix C. The major taxonomic groups, in order of abundance, were: Annelida, Crustacea, Mollusca, Echinodermata, and Miscellaneous Taxa (Figure 9). The latter two groups comprised only 1% of the total. Their presence, abundance, and taxonomic identities were mainly useful for interpreting results for a few of the individual samples.

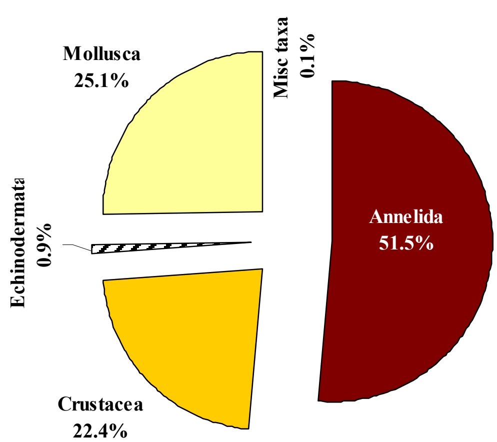



Figure 9. Summary of benthic community composition at 23 Port Gamble Bay sampling locations.

Just four annelid taxa comprised more than 29% of all the organisms counted at this study site. Of the taxa most often identified as being one of the top ten most abundant at individual sampling locations, 7 were annelids. Table C-4, Appendix C.

Twenty-five taxa accounted for three-fourths of the total abundance at all locations Table C-5, Appendix C. Most of these common taxa were cautiously assigned descriptors related to their apparent tolerance of disturbance, hypoxia, or pollution. Assignments were based on peer-reviewed publications, the professional opinions of Ecology's Marine Sediment Monitoring Program staff, and regional benthic experts (Musgrove and Word, 2006). However, there was no obvious pattern in the distribution of more-than-slightly tolerant taxa as a fraction of total abundance at sampling locations.

Table 5 provides summary descriptive statistics for benthic community metrics at 23 sampling locations. Using the median values, the *typical* benthic community grab sample (0.1 $m^2$) contains more than 1450 individuals belonging to 85 separate taxa. There are 726 annelids representing 39 taxa, 178 crustaceans from 22 taxa, 188 mollusks from 18 taxa, and 18 individuals from other taxonomic groups. The typical Swartz' Dominance Index value (SDI) indicates that individuals from an average of 13 taxa made up 75% of each sample's total abundance. Average values for Shannon Wiener diversity (H') and Pielou's evenness (J') are 1.36 and 0.71, respectively.

Table 5. Summary of selected benthic community metrics for 23 Port Gamble Bay sediment samples. Median values are highlighted.

| | Total abundance | Total richness | Annelid abundance | Annelid richness | Crustacea abundance | Crustacea richness | Mollusca abundance | Mollusca richness | Miscellaneous Taxa abundance | Echinodermata abundance | SDI | H | J |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 370 | 47 | 215 | 20 | 62 | 8 | 36 | 9 | 0 | 0 | 2 | 0.72 | 0.38 |
| Maximum | 3416 | 130 | 2092 | 52 | 1336 | 39 | 1006 | 32 | 60 | 71 | 20 | 1.57 | 0.80 |
| Range | 3046 | 83 | 1877 | 32 | 1274 | 31 | 970 | 23 | 60 | 71 | 18 | 0.85 | 0.42 |
| Median | 1454 | 85 | 726 | 39 | 178 | 22 | 188 | 18 | 12 | 6 | 13 | 1.36 | 0.71 |
| Mean | 1527 | 85 | 779 | 38 | 339 | 22 | 379 | 18 | 16 | 14 | 13 | 1.34 | 0.70 |

With respect to spatial distribution, Figure 10 indicates no obvious north-south trend in benthic abundance (upper plot) or richness (lower plot). However, sampling locations with the greatest total abundance were either north of the peninsula (AS-01, AS-03), along the perimeter of the site (AS-05 and AS-09), or in the extreme south (PGSP-130). There was no clear spatial pattern of annelid abundance at the site. Four of the five locations with greatest Crustacea abundance were close to sources of wood waste. Mollusks tended to be most abundant at perimeter locations and least abundant at sampling locations nearest the sources of wood waste or in the extreme south. The lowest number of organisms in miscellaneous taxa, including Echinodermata, was usually found at the sampling locations nearest sources of wood waste.

Taxa richness was greatest at perimeter locations (AS-01, PGSP-106, AS-09, and AS-13) or more southerly locations (PGSP-116, PGSP-118, PGSP-119, and PGSP-121). Least rich locations were almost all from the heart of the site (PGSP-107 through PGSP-111). Annelid richness was consistently greatest in samples collected outside of the area containing the greatest wood waste. There was no discernable pattern in Crustacea richness, but Mollusca richness tended to be lowest at locations near wood waste sources.

Except for PGSP-104, SDI values were highest at locations north of the peninsula (AS-01), along the outer margins of the site (AS-09), or in the south (PGSP-116 through PGSP-123). Most of the sampling locations having the lowest SDI and H' values were close to the sources of wood waste. There was no obvious pattern associated with evenness values.

There appeared to be only one significant difference in the benthic communities found at the three groups of sampling locations identified by the SPI experts (see SPI results). Figure 11 shows that the mean abundance of Crustacea found at sampling locations disturbed by organic loading (wood waste) was significantly greater than Crustacea abundance at undisturbed locations ($p < 0.05$). Other apparent differences were not statistically significant.

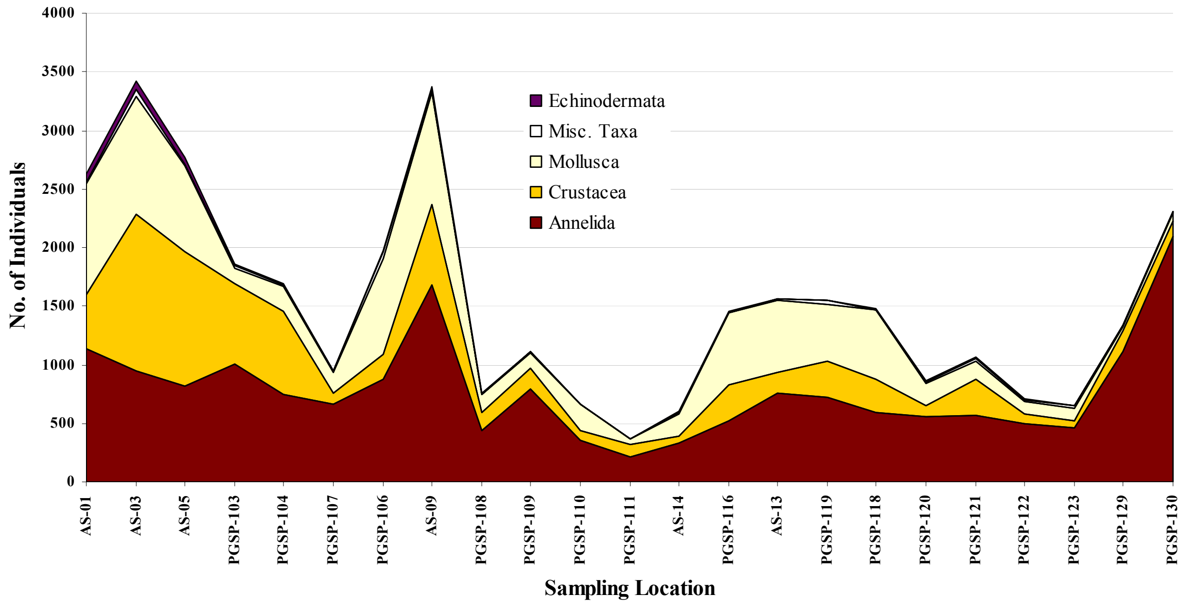
The benthic infaunal communities found at Group A and Group B locations (see Results for sediment conventionals) showed a few significant differences. The box-and-whisker plots shown in Figure 12 indicate that total richness, annelid richness, and SDI were significantly reduced at Group A locations--those having high concentrations of TVS and TOC. These groups of locations did not appear to be significantly different for other benthic community indicators (total and major group abundance or richness, SDI, H', and J').

There were four sampling locations identified where *in situ* benthic community results appeared anomalous (AS-01, AS-03, PGSP-129, PGSP-130). Benthic results for these locations were excluded from some statistical analyses for the following reasons. Locations AS-01 and AS-03 had potential outlier values for abundance of crustaceans, echinoderms, or miscellaneous taxa, as well as crustacean taxa richness (Table D-1, Appendix D). Benthic communities at these two locations appeared similar in some respects to those found at AS-05 and PGSP-106, perhaps due to their proximity to various types of structures. However, AS-01 and AS-03 were both outside the bay proper. As such, the benthic communities at these locations likely experienced more dynamic and different environmental influences than those located within the more protected inner bay.

Benthic results for PGSP-129 and PGSP-130 had anomalously low values for SDI, H' and J'. For example, fully 75% of all individuals counted at these locations belonged to just two or three taxa. No other location had an SDI value less than eight.

Finally, the benthic community results were interpreted according to the SMS rule, despite having only collected a single grab per sampling location instead of the recommended 3-5 replicate grabs per sampling location (Ecology, 2003; EPA, 1986).

SMS guidance defines unacceptable benthic community effects in terms of reduced abundance of major taxa (Crustacea, Mollusca, and Polychaeta), relative to an appropriate reference sample. Choosing a reference sample, however, was problematic. The two sampling locations most removed from the main sources of wood waste (PGSP-129 and PGSP-130) were selected as potential benthic community reference samples. But they were clearly anomalous with respect to several benthic metrics (Table C-3, Appendix C, and Table D-1, Appendix D). The abundances of major taxa for locations PGSP-120 and PGSP-123 were instead pooled for this purpose. These locations were (1) among the sampling locations most distant from sources of wood waste, (2) not identified by the SPI expert as showing evidence of disturbance, and (3) did not have potential outlier benthic community results. When these two locations were used as a pooled reference, the difference between the average abundance of major taxa in the pooled reference and that of other locations identified 6 locations impaired at the SQS level (PGSP-103, PGSP-108, PGSP-109, PGSP-110, PGSP-129, and PGSP-130) and three more locations impaired at the CSL level (AS-14, PGSP-111, and PGSP-122).



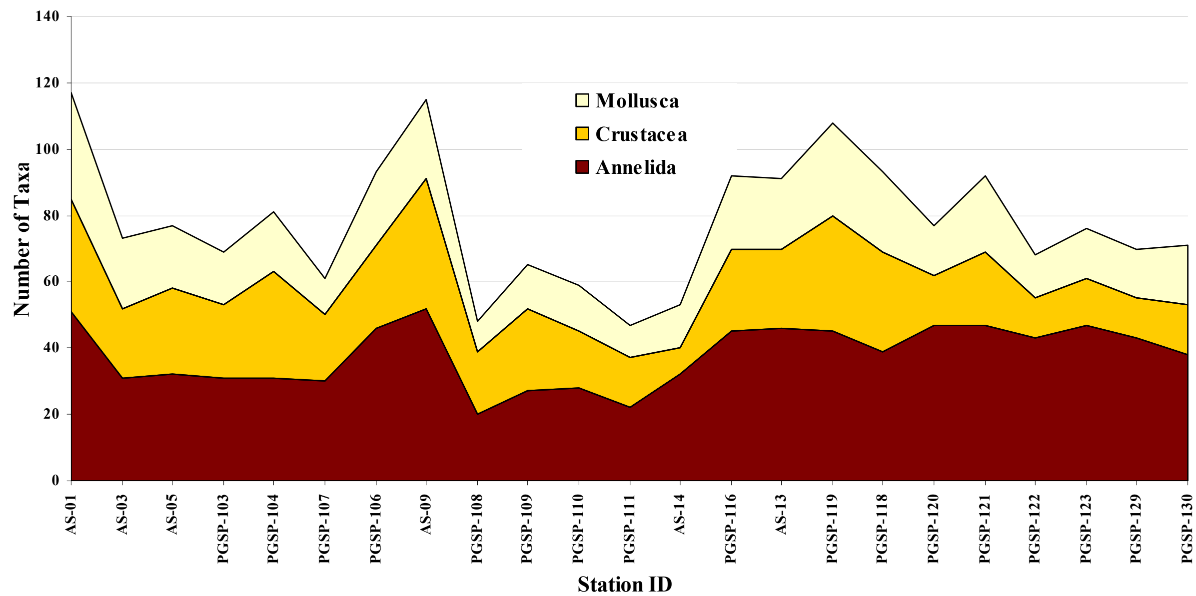
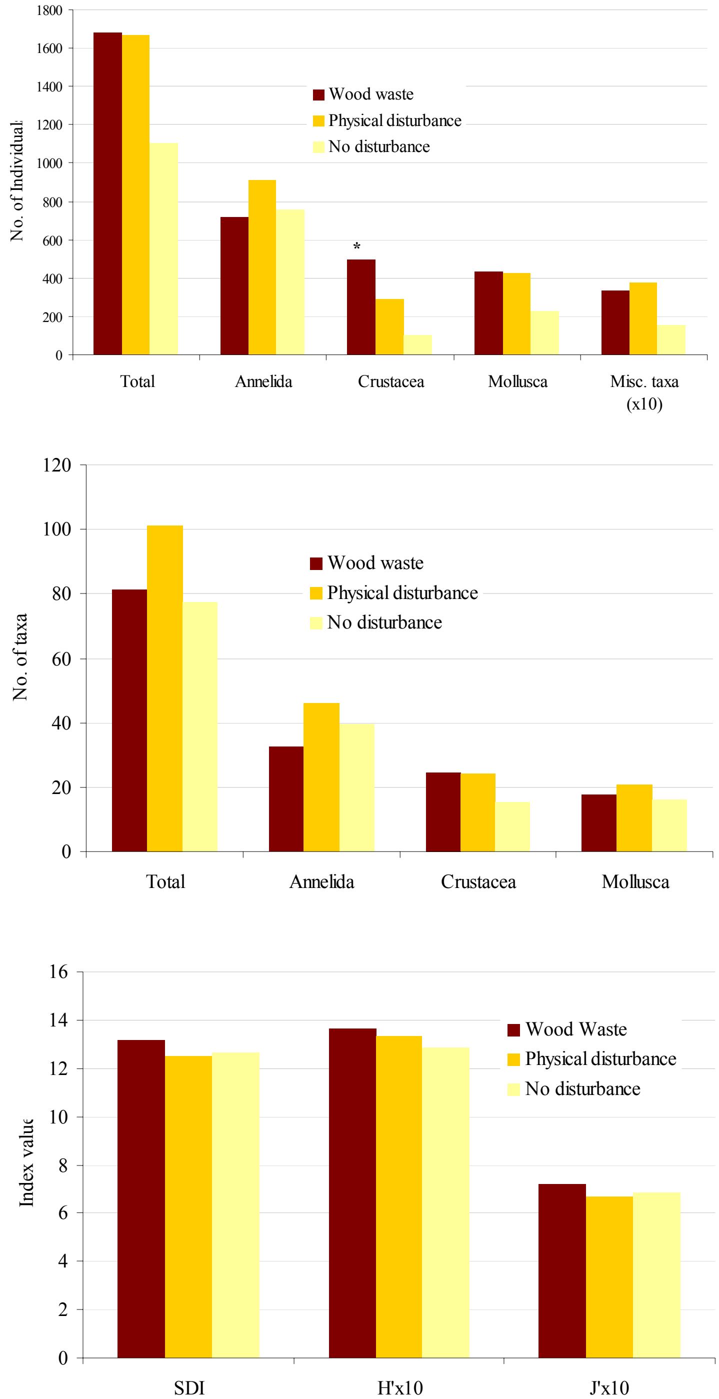




Figure 10. Benthic community abundances (upper) and taxa richness (lower) for 23 sampling locations within the Port Gamble Bay study site. The two left-most locations shown are outside the bay proper. The remaining locations are shown arranged roughly from north (left) to south (right), although not along a single transect.




Figures 11. Benthic community metrics for three groups of SPI sampling locations in Port Gamble Bay.

Figure 11a (top) abundance, Figure 11b (middle) richness, and Figure 11c (bottom) dominance (SDI), diversity (H') and evenness (J'). * indicates significantly different from undisturbed locations ($p < 0.05$)

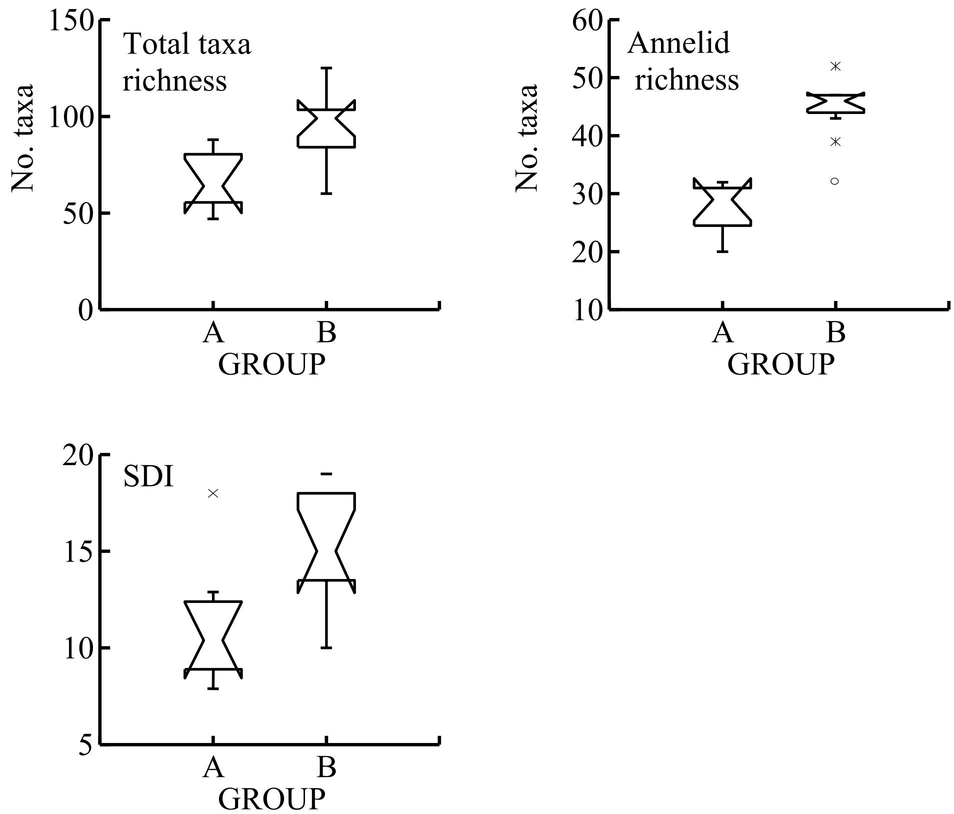



Figure 12. Box plots showing total taxa richness, annelid richness, and Swartz Dominance Index (SDI) data for 19 Port Gamble Bay sampling locations.

Groups A and B were chosen based on breakpoints in cumulative frequency distribution plots of the sediment conventionals data (habitat) without considering results of benthic community data analyses. SDI is the number of taxa comprising 75% of total abundance.

# Data analysis

## Data preparation and screening

Potential outlier values in the overall data set were identified using descriptive statistics shown in Tables C-1 to C-3 (Appendix C), two-way matrix plots, box-and-whisker plots, and Dixon's outlier identification formulae (Snedecor and Cochran, 1989). Examples of the latter are provided in Figures D-1 and D-2, Appendix D. Potential outliers are summarized in Table D-1, Appendix D. Benthic community results for four sampling locations (AS-01, AS-03, PGSP-129, and PGSP-130) were excluded from most analyses that explored relationships between SPI and benthic results. This was done because they (1) were geographically removed from the main study site and subject to different environmental influences, or (2) had multiple metrics statistically identified as outliers. All other potential outliers were included in analysis.

Data distributions were assessed using a variety of graphical methods, including normal probability plots (see Figures D-3 and D-4, Appendix D), as well as statistical tests for normality. Data distributions are summarized in Table D-2, Appendix D. Most SPI and benthic variables exhibited normal distributions. However, results for most sediment conventionals needed to be transformed prior to any analysis that assumed a normal data distribution.

Variables having only a limited range of values were also identified. Continuous variables with limited range included: boundary roughness, RPD depths, minimum and maximum grain size, number of voids per replicate, number of mudclasts, number of large tubes, few burrows per replicate, number of oxic voids, and % gravel. Categorical variables with limited range included: boundary roughness type, SPI grain size results, presence or absence variables (methane bubbles, low dissolved oxygen, bacterial mats, bedforms, fecal pellets, infauna), infaunal successional stage and successional stage ranks, mudclast number and state, dynamics, and physical disturbance. These variables were assumed to have limited analytical utility and were seldom used despite their importance for understanding the structure and function of the sediment and benthic community at a specific sampling location.

Variables with a substantial number of missing values, and their likely importance, were identified prior to statistical analysis. For example, minimum and maximum depths of feeding voids (six missing values) were often not used because the sample size and utility of other data would have been reduced.

## Correlation analysis

After removing variables lacking range and outlier values, a matrix of Spearman rank correlation rho values was calculated for different combinations of SPI, conventional, and benthic variables Table D-3, Appendix D. This was done according to Zar (1984), and did not assume that (1) data distributions were uniform or normal, or (2) relationships were linear or positive. Significant Spearman rho values were most frequently found for paired variables within a single data type.

Most significant relationships were between parameters of the same type, but there were some between parameters of different types. This was particularly true for SPI metrics and sediment conventionals. For example, penetration depth, boundary roughness, RPD depths, % wood, and number of burrows were significantly correlated with almost all conventional parameters. OSI was significantly correlated with most conventionals, but BHQI was not. Percent wood and maximum void depth were also significantly correlated with sulfide.

Of particular importance to this study were significant correlations between SPI (or sediment conventionals) results and benthic infaunal community indicators. However, this was seldom the case. Some notable exceptions included:

- Annelid richness and miscellaneous taxa abundance were correlated with many SPI metrics and all conventionals parameters.
- Miscellaneous taxa abundance (echinoderms included) was correlated with most conventionals but few SPI metrics.

These findings are summarized in Table 6.

Table 6. SPI metrics, sediment conventional parameters, and benthic community metrics with the greatest number of significant Spearman rank correlations ($p<0.05$).

| | SPI (y) | Conventionals (y) | Benthic (y) |
|---|---|---|---|
| SPI<br>(x) | OSI<br>BHQI<br>RPD depths<br>% Wood<br>Boundary roughness<br>VTB | Fines (silt + clay)<br>TOC<br>TS<br>Sand<br>TVS | Annelid richness<br>Misc. taxa abundance<br>SDI |
| Conventionals<br>(x) | % Wood<br>Boundary roughness<br>Penetration depth<br>Number of burrows<br>OSI<br>RPD | All | Annelid richness<br>Misc. taxa abundance<br>Miscellaneous + Echinodermata abundance<br>Total richness |
| Benthic<br>(x) | Boundary roughness<br>Wood<br>Number of burrows<br>OSI<br>RPD max depth<br>V+T+B | Fines<br>Silt<br>TOC<br>Sand<br>TVS | Total richness<br>Mollusca richness<br>Echinodermata abundance<br>Annelid abundance<br>Total abundance<br>Miscellaneous + Echinodermata abundance |

## Regression analysis

Relationships of potential use to regulators were explored using ordinary least squares linear regression analysis, guided by Spearman rank correlations as described below. Results of this analysis identified some relationships between SPI parameters and results for sediment conventionals at this site that might be useful to regulators. These include:

- $Log_{10}$ % Wood = 5.5 - 2.9*$Log_{10}$% TS ($r^2$ = 0.76), predicts % wood from total solids
- $Log_{10}$ % Wood = -0.33 + 1.07*$Log_{10}$% TVS ($r^2$ = 0.81), predicts % wood from % TVS
- $Log_{10}$ % Wood = -0.24 + 1.27*$Log_{10}$% TOC ($r^2$ = 0.88), predicts % wood from % TOC
- $Log_{10}$ % TVS = 0.425 + 0.77*$Log_{10}$% Wood ($r^2$ = 0.81), predicts % TVS from % wood
- $Log_{10}$ % TOC = 0.25 + 0.70$Log_{10}$*% Wood ($r^2$ = 0.88), predicts % TOC from % wood

Other than these, there were few strong linear correlations between two parameters of different types. All relationships between the transformed results for sediment conventionals and total abundance were weak ($r < 0.39$). This was also true for the one between OSI and total taxa richness ($r = 0.36$).

Spearman rank correlation analysis suggested that multiple independent variables might improve prediction of important dependent variables. Examples included:

- % fines, % TVS, and % TOC might be used to predict total taxa richness.
- The number of burrows, OSI values, % fines, and % TOC might be used to predict SDI.
- Combinations of SPI parameters and sediment conventionals might be used to predict annelid richness or miscellaneous taxa abundance.

For this reason, multiple "step-wise" and "best subsets" regression analyses were conducted to answer the question: "Can linear combinations of relatively few SPI parameters or sediment conventionals be used to predict key indicators of benthic community health?"

The results summarized in Table 7 were encouraging because much of the variability exhibited by certain benthic community indicators could be explained by using multiple SPI parameters and sediment conventionals as independent predictors (adjusted multiple $r^2 \geq 0.75$). Unfortunately, the relationships found to have the best adjusted multiple $r^2$ values involving the most important benthic indices also usually involved numerous predictor variables. Those involving 2-4 independent predictors had adjusted multiple $r^2$ values in the 0.4-0.6 range. Adjusted $r^2$ values for regressions involving SDI and H' (not shown) were less than 0.4-0.5.

Table 7. Summary of exploratory multiple regression results involving SPI parameters and sediment conventionals (independent predictors) and benthic community metrics (dependent variables).

| Independent Variables | Dependent Variables | Adjusted multiple $r^2$ | No. of Independent Variables |
|---|---|---|---|
| Stepwise Multiple Regression | | | |
| SPI parameters | $Log_{10}$ Total Abundance | <.40 | 4 |
| | Total Richness | 0.50 | 4 |
| | Annelid Richness | 0.60 | 3 |
| Conventionals | $Log_{10}$ Total Abundance | <.40 | 4 |
| | Total Richness | 0.57 | 6 |
| | Annelid Richness | 0.78 | 5 |
| SPI + Conventionals | $Log_{10}$ Total Abundance | 0.41 | 4 |
| | Total Richness | 0.70 | 6 |
| | Annelid Richness | 0.79 | 5 |
| Best Subset Multiple Regression | | | |
| SPI parameters | $Log_{10}$ Total Abundance | 0.51 | 6 |
| | Total Richness | 0.48 | 4 |
| | Annelid Richness | 0.74 | 3 |
| Conventionals | $Log_{10}$ Total Abundance. | 0.63 | 5 |
| | Total Richness | 0.67 | 3 |
| | Annelid Richness | 0.79 | 3 |
| SPI + Conventionals | $Log_{10}$ Total Abundance | 0.59 | 4 |
| | Total Richness | 0.61 | 4 |
| | Annelid Richness | 0.81 | 3 |

## Multivariate statistical analysis

This study initially considered multivariate statistical methods for analyzing its SPI and sediment quality sample results because:

- Multivariate methods can relate multiple variables (e.g., SPI results and sediment conventional parameters with multiple benthic community metrics).
- Multivariate methods are often cited in published investigations as effectively reducing the number of measured environmental factors that explain the variability observed in biological systems.
- Multivariate statistical methods have been used to study estuarine and marine benthic communities elsewhere (Jackson, 1993; Reynoldson et al, 1997; McRae et al, 1998; Engle and Summers, 1999).
- Studies of freshwater benthic communities, forest and grassland ecosystems, and microbial communities, at least somewhat analogous to this one, have also used multivariate methods.

It became apparent that multivariate methods were key to this study because:

- SPI results did not appear to accurately predict sediment quality as defined by the numeric criteria for biological acceptable effects (toxicity or benthic results).
- Univariate methods showed limited promise for describing benthic community health.
  - There appeared to be few strong correlations between SPI parameters and indicators of benthic community health.
  - It appeared that too many SPI parameters and sediment conventionals were needed as predictor variables for useful multiple regressions.

Therefore, multivariate methods were used to address the following two key questions:

1. How many distinct benthic communities are present at the Port Gamble Bay study site?
2. If different benthic communities can be identified, what are the combined variables that are most useful for distinguishing or predicting them?

Two main methods were used to address the first question: cluster analysis and multi-dimensional scaling (MDS).

Numerous hierarchical, agglomerative cluster analyses were conducted, based on results for either 23 or 19 sampling locations. They usually used either benthic community indicators, such as abundance and richness of major taxa, or detailed results for a “trimmed” list of taxa (those that comprised 90% of the total abundance in the entire data set, Table C-6, Appendix C).

The agglomerative clustering method used results for a single sample as a starting point. The sample having the most similar set of benthic results was then identified using any of several measures of distance or similarity. The next closest case was linked to the first two cases using one of many linking algorithms.

The cluster analyses presented in this report used normalized Euclidian distance and complete linkages to group sampling locations. Euclidian distance is the shortest (orthogonal) distance between points and was calculated by SYSTAT software (SYSTAT, 2004). If the range of absolute values for various metrics or parameters were substantially different, then results fit to a common scale.

Figure 13 shows the results of a cluster analysis that was based on benthic community results for 23 sampling locations. This particular result used total abundance and richness, abundance and richness of three major taxa, as well as SDI and diversity. The figure shows that the benthic community results can be grouped into at least three distinct clusters or communities. The nine sampling locations on the left side of the figure (dashed lines) are among the sandier ones located either on the perimeter or in the southern portion of the site. Most of the 12 sampling locations in the second and largest cluster (solid lines) are associated with wood waste in the inner bay. The two locations on the far right (dotted lines) are the southern sampling locations found to be anomalous (PGSP-129 and PGSP-130).

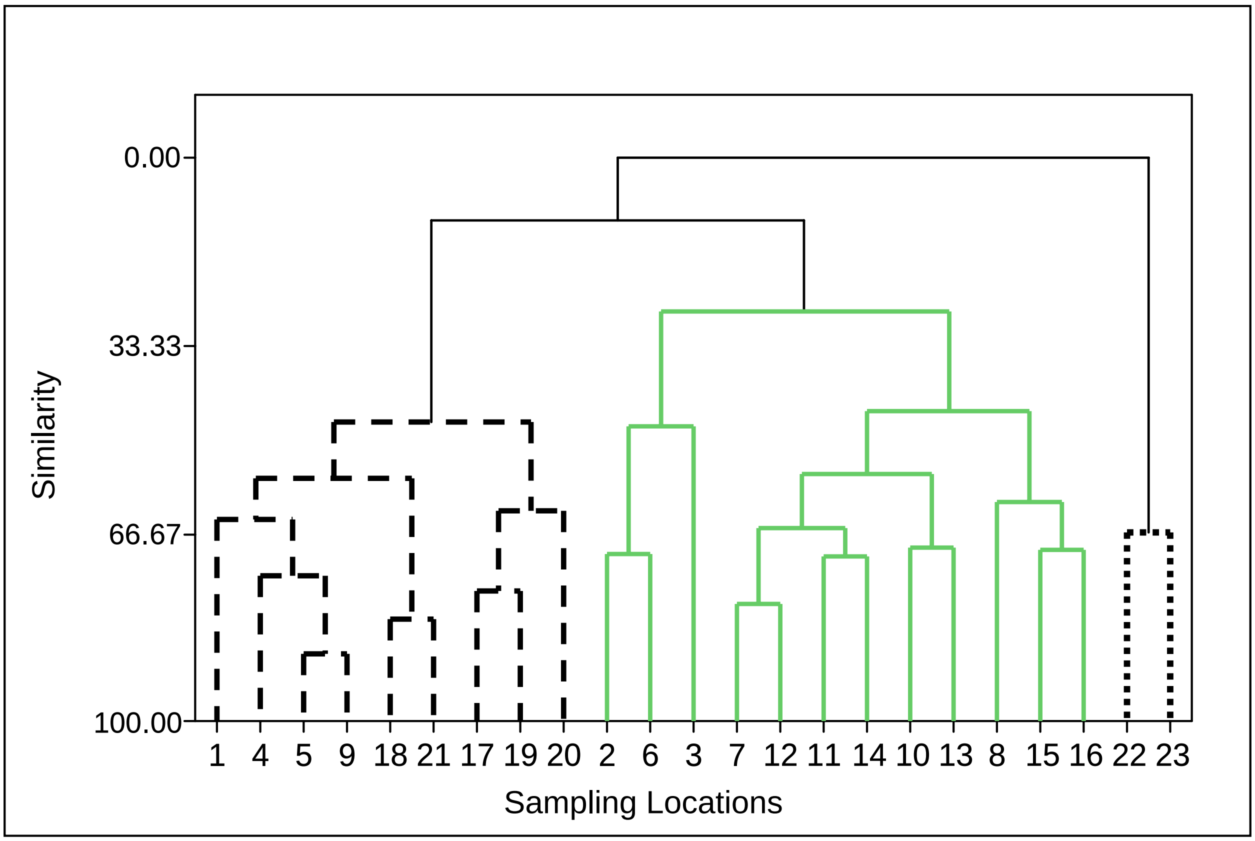



Figure 13. Benthic communities in Port Gamble Bay identified as clusters, using ten benthic metrics for 23 sampling locations. Note: sampling locations in this figure can be linked to those in the text using Table A-2, Appendix A.

Results of other cluster analyses based on benthic indicator variables or trimmed benthic abundances were generally similar. Results based on SPI parameters alone, conventionals alone, SPI and conventionals, or all types of results could differ more substantially (results not shown). This suggested at least two things:

- Clusters of sampling locations, assumed to represent distinct benthic communities, were influenced by more environmental factors than were measured for this study.
- Future cluster analyses may require more standardization of the statistical method, e.g., distance or similarity measure and linkage algorithm.

MDS provides a means of displaying information for a data set as points in space. The distance between points reflects complex empirical relationships. As such, MDS can be a powerful tool to help visualize similarities between different cases (samples) based on multiple variables in two (or more) dimensions. It is used extensively to help understand relationships between benthic (or other) communities, habitats, and environmental stressors.

Figure 14 illustrates the power of MDS. At least two distinct benthic community groups were identified by the similarities among the trimmed benthic abundance results for 23 sampling locations listed in Table C-6, Appendix C. Group 1 included locations nearest sources of wood waste and a few along the perimeter of the site (AS-01, AS-03, AS-05, AS-09, PGSP-103, PGSP-104, PGSP, 107, PGSP-108, PGSP-109, PGSP-110, PGSP-111, and PGSP-118). Group 2 included some perimeter and all of the southern, higher % sand locations. PGSP-106, one of the locations identified by the SPI expert as physically disturbed, did not appear to belong to either group. The proportion of total variance explained by this analysis and 2-dimensional configuration was 65%. A similar MDS analysis split the second group so there were three benthic community groups that accounted for 86% of the total variance (result not shown).

MDS analyses were also conducted after excluding results for sampling locations AS-01, AS-03, PGSP-129 and PGSP-130. One result is shown in Figure 15. This analysis was based on similarities among the richness of the major taxonomic groups found at 19 sampling locations and explained 99% of the total variance. Here, Group 1 consisted of wood waste locations (AS-05, PGSP-103, PGSP-104, PGSP-107, PGSP-108, PGSP-109, PGSP-110, and PGSP-111). Group 2 included locations along the perimeter of the site (AS-09, AS-13, PGSP-106, PGSP-116, PGSP-118, PGSP-119, and PGSP-121). Finally, Group 3 featured southern, high % sand locations (AS-14, PGSP-120, PGSP-122, and PGSP-123). These groups of sampling locations, representing different benthic infaunal communities, are shown in Figure 16.

Finally, limited independent MDS analysis was conducted, in part to confirm Ecology's preliminary and general MDS results. Figure 17 shows a non-metric MDS plot that identified three benthic community groups based on Bray-Curtis distances involving eight benthic metrics for 19 sampling locations. In this figure, Group 1 was comprised of perimeter sampling locations, Group 2 of sandy southern locations, and Group 3 of wood waste locations. Figure 18 also identifies three benthic community groups using Bray-Curtis distances between the trimmed benthic taxa results for the same 19 locations. These three groups roughly describe the same three types of sampling locations.

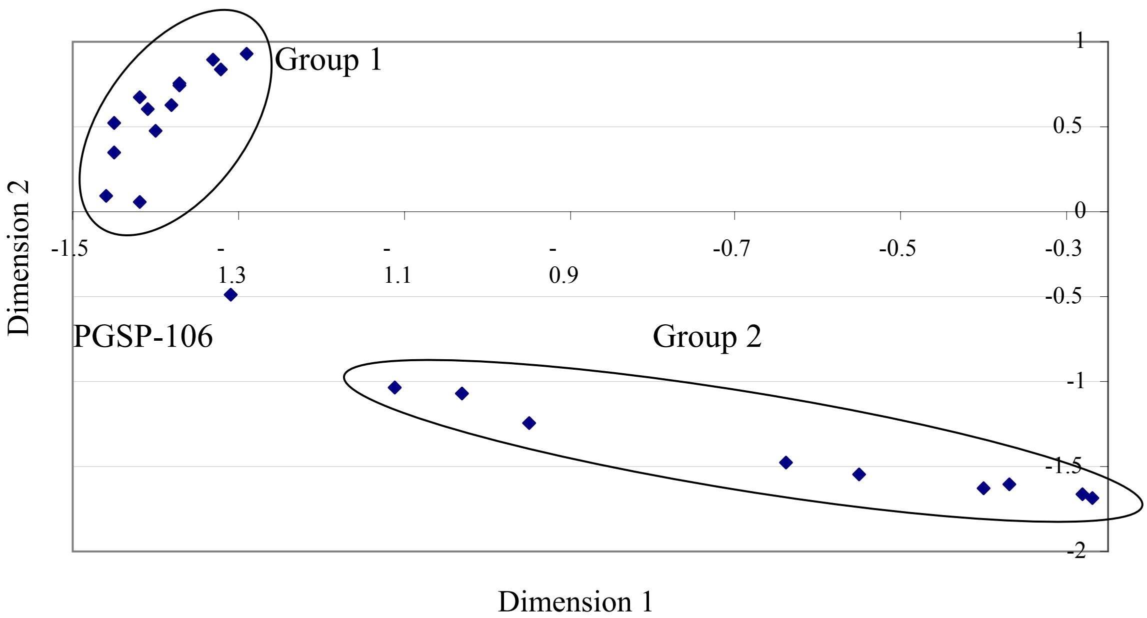



Figure 14. MDS using trimmed benthic abundance data for 23 sampling locations in Port Gamble Bay.

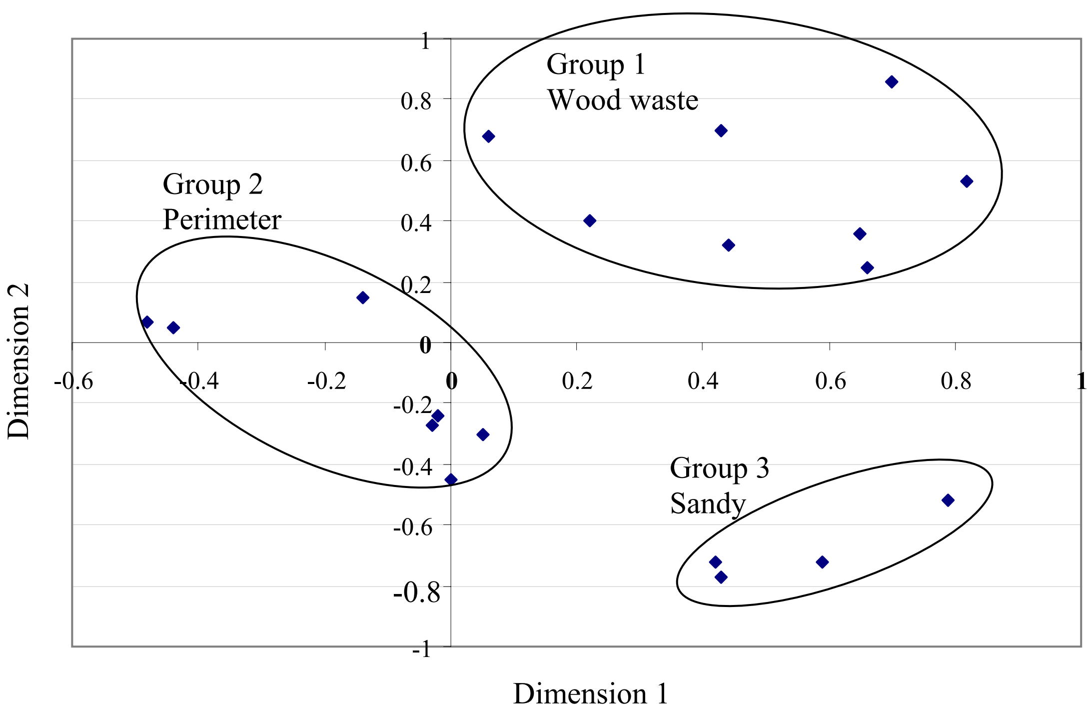



Figure 15. MDS plot based on taxa richness of Annelida, Crustacea, and Mollusca for 19 sampling locations in Port Gamble Bay.

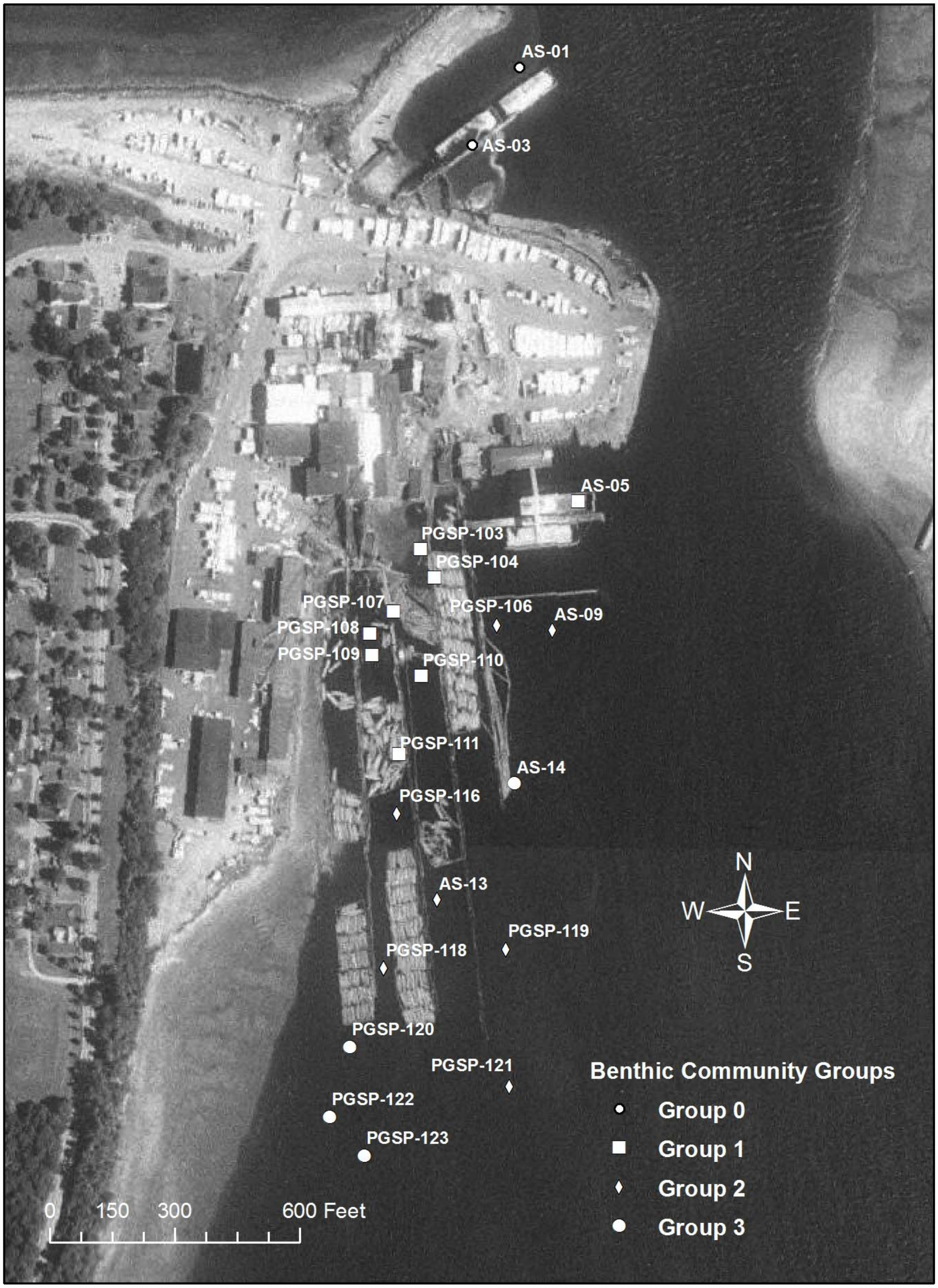



Figure 16. Map of benthic communities identified by MDS analysis using taxa richness of Annelida, Crustacea, and Mollusca for 19 sampling locations in Port Gamble Bay (Figure 15).

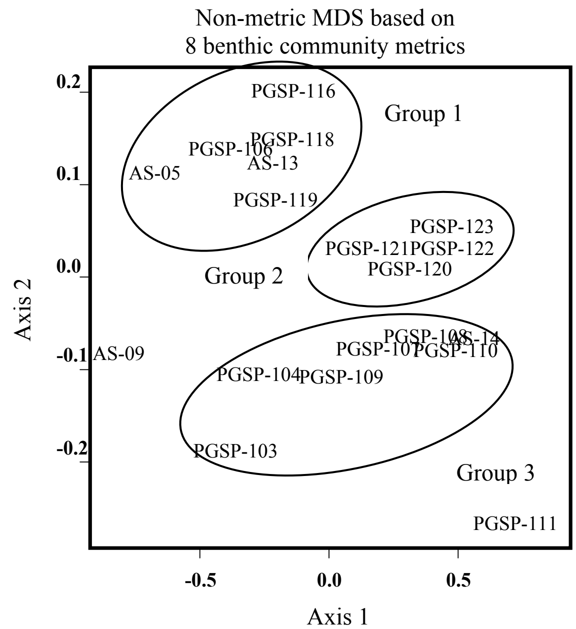



Figure 17. Nonmetric MDS plot based on eight benthic metrics. Confirmatory analysis provided by (TerraStat Consulting Group).

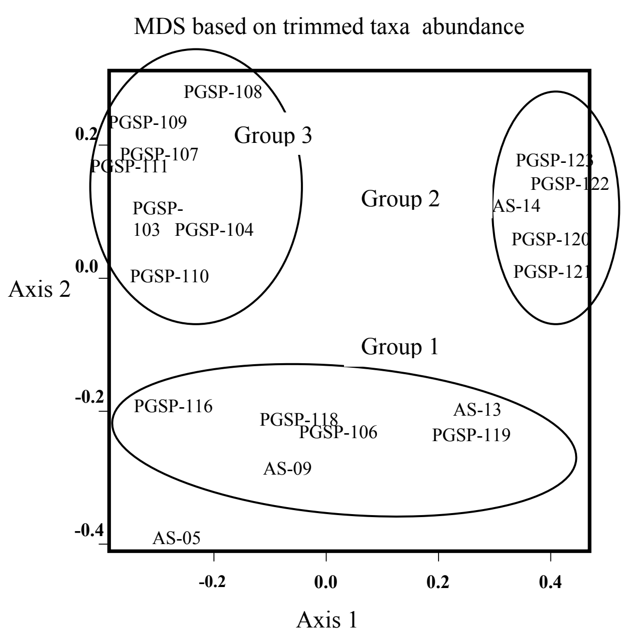



Figure 18. Classical MDS plot showing three benthic community groups based on trimmed benthic taxa results (TerraStat Consulting Group).

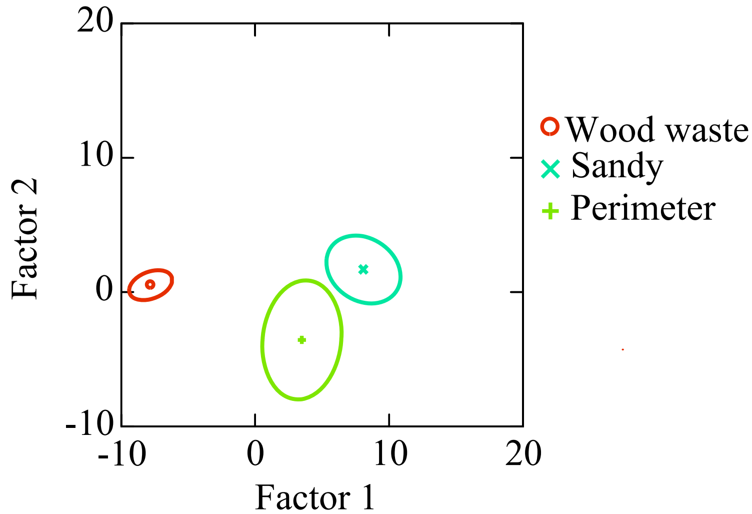
Discriminant analysis, classification trees, and examination of the most important factors in each MDS axis were used to address the second question: "If different benthic communities can be identified, what are the combined variables that are most useful for distinguishing or predicting them?"

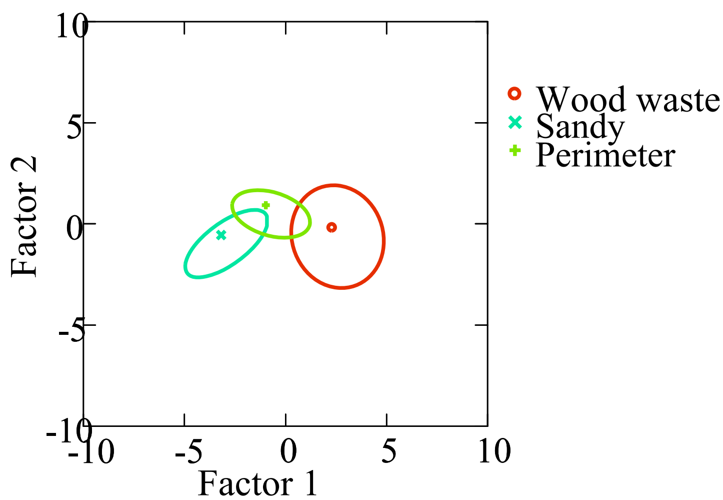
Discriminant analysis can help identify linear combinations of variables or factors that are major sources of variance explaining known data groupings.

A number of discriminant analyses were conducted using:

- Benthic communities identified by the cluster analysis or MDS analysis results (known groupings).
- SPI and sediment conventionals parameters (independent predictor variables), as indicated by results of Spearman rank correlations and other analysis.

Example results are shown in plots of canonical means that show confidence envelopes containing all, or nearly all, sampling locations for each group. The upper plot in Figure 19 indicates that the variability between benthic communities at the Port Gamble Bay study site, identified in this case by the MDS results shown in Figure 15, can be explained by the habitat or environmental stressors represented by SPI and conventionals data. The two factors, comprised of SPI and conventional results, discriminated between or correctly classified sampling locations with an accuracy of 82%. A second discriminant analysis, shown in the lower plot of Figure 19, based on different SPI and conventionals data, shows that the factors clearly distinguished the wood waste benthic community from the one found in sandy sampling locations.




Figures 19. Canonical means plots showing that factors comprised of multiple SPI and conventionals can discriminate between groups previously identified using benthic community results.

Classification or regression trees can be used to classify cases or sample results into previously defined groups. Such groups are defined in terms of a single continuous variable assumed to be normally distributed, such as total taxa richness, or a categorical variable, such as stratum.

The plot of such a tree shows branches that should be balanced at each node (so that the branch is level). The variable and value defining the split at each node is indicated. The end of each branch may show descriptive statistics, a box plot, a dot plot, or a histogram.

Figure 20 is an example of a regression tree that shows that the Port Gamble Bay sampling locations can be classified according to a single important benthic metric--total taxa richness--by means of various sediment conventionals (silt, TVS, and clay content). The six sampling locations that were relatively silty (>28.8% silt) also had the lowest average total richness (66 taxa). Of the remaining 16 locations, the 5 that had a relative high % TVS (> 2.7%) also had average total taxa richness (83 taxa). Of the remaining 11 locations, those with % clay < 6.4% had the highest total richness (124 taxa). Thus the greatest number of taxa were recorded for the sampling locations having the lowest % silt, % clay, and % TVS.

Similar results (not shown) can be obtained using only the SPI parameters such as boundary roughness and % wood, or SPI and conventionals in concert (boundary roughness and % TVS). Sampling locations grouped according to their benthic community dominance (SDI value) can also be classified using SPI results alone (OSI and sum of voids, small tubes, and burrows), conventionals, or a combination of SPI and conventional results (% fines and mean RPD depth).

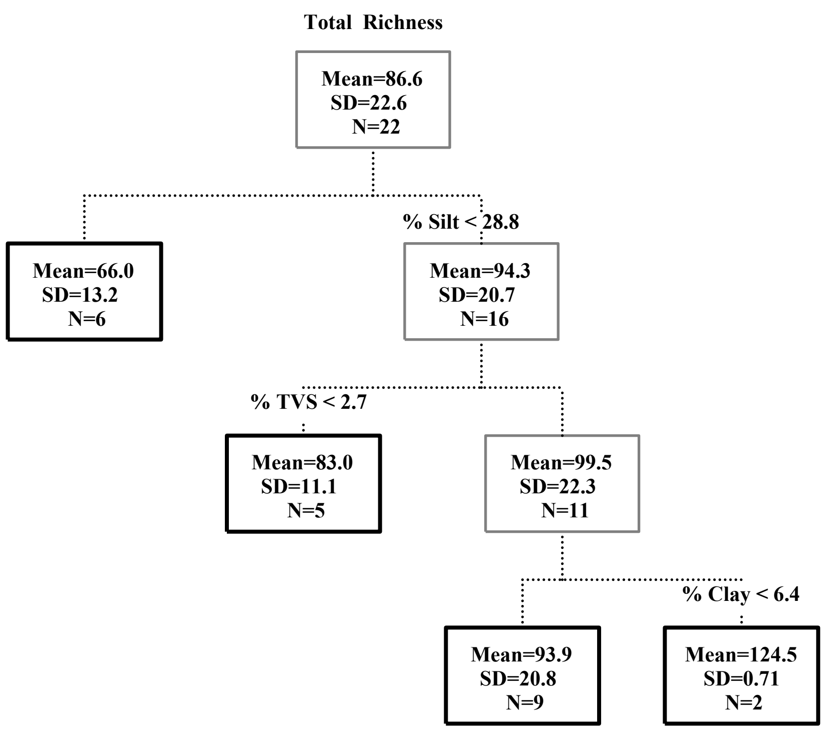



Figure 20. Regression tree using conventionals to classify sampling locations according to total taxa richness.

Perhaps more important to the goal of this study, trees can successfully use SPI and conventional results to classify a categorical result such as groups of sampling locations identified by cluster analysis or MDS. Figure 21, for example, shows that sampling locations belonging to the benthic community groups identified in Figure 18 can be classified using only the mean RPD depth and % TOC. In Figure 18, Group 2 is comprised of sandy reference locations having a mean RPD > 3.46 cm (also Group 2 below). The perimeter locations shown in the upper portion of the MDS plot have a shallower mean RPD *and* % TOC < 6.07 (Group 1 below). Inner bay wood waste locations in Figure 18 have a shallow RPD and the highest % TOC (Group 3 below).

The tree in Figure 21 correctly classified 16 of the 18 sampling locations associated with the three clusters, for an 89% accuracy rate. The accuracy of other trees was usually in the range of 70%-90%.

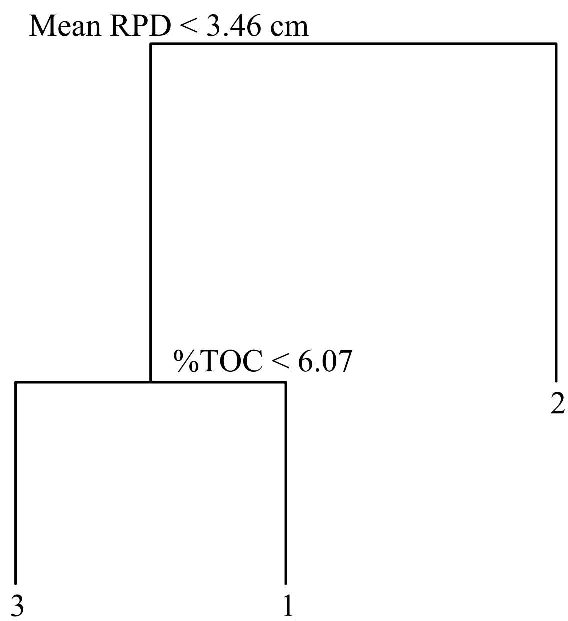



Figure 21. Tree using SPI and conventional parameters to classify sampling locations into the benthic community groups identified in Figure 18.

## Project costs

SPI results cost approximately $675 for each of 33 SPI sampling locations. This estimate includes all costs associated with project planning, vessel lease, field work, image and data analysis, report preparation, and staff time.

Total cost per sampling location to obtain sediment quality results was more difficult to estimate. Sediment conventionals and benthic infaunal community results cost $220 for each of 18 locations and $445 for each of 23 locations. The staff's time for all planning, contracting, field sampling, data quality assurance, data entry and management, statistical analysis, and reporting represented approximately 0.5 full-time equivalents. Costs would also have increased substantially had the recommended number of benthic infaunal community field replicates been collected and analyzed.

When these differences are considered, a project having a similar purpose and scale, and including analysis of three benthic community field replicates at each location, would cost approximately five times the comparable SPI survey.

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# Conclusions

The major goal of this study was to determine the feasibility of SPI survey results to streamline and reduce costs associated with investigations of contaminated sediment cleanup sites. Based on study results from this wood waste cleanup site, and increased understanding of SPI capabilities relative to such investigations, the overarching conclusion is that:

*An SPI survey yields information potentially very useful to cleanup project managers*.

Reasons for this become more apparent from conclusions linked to the three study objectives.

## 1. Relationships between SPI and sediment quality results

The ability of SPI parameters to predict the regulatory indicators of benthic community health (chemical and biological SQS, CSL) at this study site is unclear but promising:

- Benthic community data collected for this study could not be interpreted according to regulations because of the limited number of field replicates and uncertain suitability of reference sample(s). Not surprisingly, SPI did not appear to predict abundance-based benthic community effects even when an adequate number of field replicates, appropriate reference samples, and significant differences were assumed. Only 5 of the 11 sampling locations identified using SPI as being disturbed by organic loading or wood waste could possibly be interpreted as exceeding the benthic community SQS.
- The number and range of sediment toxicity results were too limited to warrant a close examination of relationships to SPI parameters.
- There were relatively few significant correlations and regressions between SPI parameters and biological effects results.
- SPI parameters such as % wood were shown to predict % TVS and % TOC, parameters that regulators might use to set boundaries for subsequent investigations or remedial actions.
- SPI parameters appeared able to classify the sampling locations shown by multivariate methods as belonging to specific benthic communities. If regulators determined that one of those communities was unacceptably affected by wood waste, then an SPI survey would potentially be a cost-effective way to identify areas of impairment.
- Seven of the 9 locations within Port Gamble Bay identified by SPI to be disturbed due to organic loading (Figure 6) also belonged to the benthic community group most closely associated with sources of wood waste (Figures 15-16, Group 1).

Relatively few significant Spearman rank correlations between SPI and benthic community metrics were identified. Only boundary roughness, % wood, and number of burrows were significantly correlated with more than one of the 14 benthic community metrics that were tabulated. The only benthic metrics significantly correlated with more than one of the SPI parameters were annelid richness and miscellaneous taxa abundance. The most promising results were multiple linear regressions that use at least 3 SPI parameters to predict annelid richness, which is not related to the existing SQS or CSL.

This study found that the % wood waste, estimated from SPI, explained 80% - 90% of the variability in TVS and TOC concentrations. It also found that SPI parameters used in classification trees could assign sampling locations to specific benthic communities with reasonable accuracy (63% - 93%). These findings do not fit into the standard regulatory decision-making paradigm, but both might be used in a "latest scientific knowledge" approach for evaluating sediment quality (Section 130 of Ecology, 1995).

The latest scientific knowledge policy in the SMS rule might provide the means to justify using:

- SPI surveys to map distribution of wood waste at new sites. There is a growing list of wood waste sites where SPI has been used for just this purpose (see Table A-1).
- Published literature and regional reports to identify sediment TVS or TOC thresholds for Puget Sound above which there would be a high probability of negative consequences for benthic communities.
- SPI results to estimate and map TVS or TOC relative to thresholds and thereby identify investigation boundaries, remedial action objectives, or cleanup levels at wood waste sites.
- Benthic community results other than the reduction in abundance of three major taxa to define significant effects.
- Multivariate statistical methods to identify different benthic infaunal communities and SPI results to distinguish them.

Latest scientific knowledge might also recognize that sediment quality evaluations and decisions always involve "multiple lines of evidence" and that SPI constitutes a meaningful, separate line of evidence for evaluating sediment quality and benthic community health. SPI has a well-published record of providing information on:

- Sediment structure (sediment grain size mode and layering).
- Sediment stability (visual evidence of physical disturbance).
- Benthic habitats (sediment grain size mode, estimated % wood waste, and thickness of sediments most likely to be oxic).
- Apparent functional complexity of benthic infaunal communities (successional stage).
- Biological modification of the sediment column functions (type, depth, and degree of bioturbation).

Collectively, these results help identify areas of disturbance due to organic loading and how well benthic communities and functions have recovered. For this reason, SPI survey results are routinely used to make regulatory decisions about sediment quality in dredging and various monitoring programs.

Finally, the pattern of disturbance due to organic loading or wood waste at this site, as indicated by SPI results (Figure 6), was similar to the map of substrate or habitat type indicated by conventional sediment parameters (Figure 7), as well as the map of the distinct benthic infaunal communities identified multivariate statistical results (Figure 15). SPI wood waste locations south of the peninsula nearly coincided with wood waste benthic community sampling locations. SPI failed to identify one of the benthic sampling locations associated with wood waste (PGSP-110) and included two locations apparently having different communities (PGSP-116 and PGSP-118).

## 2. Do SPI results fill data gaps?

Results from this study supplement existing information in several ways.

- SPI results provide additional information about benthic habitats (grain size major mode, surface roughness, and apparent depth of oxic zone) and biological functions (surface colonization, depth, and type of bioturbation) as some locations not previously sampled.
- SPI results can predict TVS and TOC for locations having only SPI results.
- Measured conventional sediment parameters update similar ones from 2003 and provide grain size, TVS, TOC, ammonia, and sulfide data for some new locations.
- Benthic infaunal community results from the 23 locations sampled for this study are the first of their kind collected within the study area and, therefore, constitute a substantial addition to benthic community results for 3 mid-bay locations collected as part of the Marine Sediment Monitoring Program (Aasen, 2006).

## 3. Can SPI results help define "baseline" conditions?

This study presents SPI, sediment conventionals, and benthic community results that represent recent conditions outside of the area dredged in early 2007. As such, future monitoring results could be compared to these 'baseline' conditions, especially if no more cleanup actions are taken.

## Other conclusions

Conducting separate SPI and sediment quality surveys, as close as possible in time and space, appears to be an effective approach for investigating relationships between the two types of results.

SPI results indicate that there is no obvious impairment of benthic habitats and functions in the bay. The evidence for this includes:

- There is little indication that sediments have been impaired by low dissolved oxygen. This is probably due to relatively strong circulation in the bay, evident from SPI photographs and other images of surface sediments at various locations.
- Stage III organisms (see Figure 2) are present and bioturbate the sediment to a reasonable depth at almost all depositional locations, (e.g., ones that accumulate sediment).

Measuring sediment conventionals and their spatial distribution within the Port Gamble Bay study site distinguishes areas with substantially different substrates and benthic habitats. Wood waste areas at this study site have higher % fines, TVS, and TOC values and can readily be distinguished from areas having high % sand and low wood waste, TVS, and TOC. The areas identified by sediment conventionals as having different substrates and habitats are generally consistent with those identified by SPI results.

Taxa richness and diversity within the bay was generally lowest in areas of wood waste and greatest along the margins or perimeter of the site. Sampling locations along the eastern margin of the site had lower % fines, TVS, and TOC than expected. This may be due to their proximity to the entrance channel and higher current velocities maintaining fine sediment and wood in protected area behind the peninsula. Sandy sampling locations further south had some of the lowest taxa abundances. Benthic communities at PGSP-129 and -130 were statistically anomalous (very low SDI, H', J) and unexpectedly appeared to be impaired. Communities outside the bay (locations AS-01, AS-03) had high miscellaneous taxa abundances.

Multivariate statistical methods are key to understanding relationships between environmental or habitat variables, represented by SPI and conventionals data, and biological variables such as benthic community richness, dominance, or diversity.

# Recommendations

The major recommendations from this study are:

1. Additional confirmatory analysis and peer review should be conducted.
2. Similar studies of other wood waste sites should be conducted.
3. SPI surveys should be included in more cleanup site investigations.
4. The latest scientific knowledge should be used to evaluate sediment quality, including:

- Establish effects thresholds for organic loading (TVS or TOC) at wood waste sites.
- Interpret benthic infaunal community results using other benthic metrics and multivariate statistical methods.

## 1. Conduct more confirmatory analysis and peer review.

An independent statistician conducted confirmatory statistical analysis using this data set. Results were generally consistent with Ecology's, but the effort was very limited. Additional independent analysis might:

- Confirm individual results.
- Identify analytical errors.
- Apply more optimal or entirely new statistical methods (detrended correspondence analysis, multivariate regression, path analysis).
- Result in new findings.
- Identify "standard operating procedures" for multivariate statistical methods.

An independent expert on benthic infaunal communities in Puget Sound should also review findings of this study. This review would likely lead to a better understanding of:

1. The detailed ecology of the benthic communities that were identified.
2. The extent to which organic loading, as measured by SPI and sediment conventionals, explains the distribution of communities and important individual taxa.
3. How the observed benthic communities might differ in the absence of organic enrichment.

## 2. Conduct similar studies of other wood waste sites.

Characteristics of wood waste sites can differ substantially, depending mainly on the age, historic uses of the site, and hydrodynamics of the specific area (Germano and Browning, 2004). Thus, relationships between SPI results and sediment quality indicators at one wood waste site may not apply at a different wood waste site. Relationships that are more predictive of sediment quality indicators than those found by this study (more generally applicable to a variety of sites, or both) will require results from different types of wood waste cleanup sites.

Future studies should involve sediment quality triad sampling and analysis according to the SMS and should use SPI as a fourth line of evidence. A posteriori analysis might reveal whether or not SPI results could eliminate the need to collect any other line of evidence or provide other valuable information (physical or water quality disturbances). In particular, future studies might use more standardized multivariate statistical approaches to identify wood waste-associated benthic communities and compare their distribution to that derived from SPI results for areas of organic loading.

## 3. Include SPI surveys in more cleanup investigations.

The potential benefits of conducting a preliminary SPI survey at wood waste and other cleanup sites are that SPI would:

- Augment studies of the "fate and transport" of sediment.
- Fill data gaps for "nature and extent" investigations.
- Predict concentrations of some conventional parameters (without collecting and analyzing samples) that could help define site boundaries and remedial action objectives.
- Identify areas most, and perhaps least, likely to exhibit impaired benthic communities.
- Provide additional lines of evidence that could help in weight-of-evidence decision-making at a cleanup site. For example, a high likelihood of anoxia and poorly developed benthic communities, as indicated by SPI results, could spur action when other evidence is not clear. Conversely, SPI evidence of physical disturbance could reduce the need to focus on areas where the benthos appears to be poorly developed.
- Provide a basis for cost-effective, long-term monitoring of cleanup sites after remedial actions have occurred.

## 4. Use latest scientific knowledge to evaluate sediment quality.

SPI parameters did not appear to predict regulatory indicators of sediment quality at this study site. However, regulators should use the latest scientific knowledge policy contained in the SMS rule to their advantage. They could consider setting benthic community effects thresholds for % wood waste, TVS, or (most likely) TOC at wood waste sites. This process might be somewhat analogous to setting tissue threshold reference values for bioaccumulative chemicals based on tissue concentrations reported in the published scientific literature to be associated with organism or population-level harm and might involve:

- Determining the range and typical concentrations for TVS and TOC (what is normal) for appropriate Puget Sound and other West Coast sediments not associated with accumulations of wood waste.

- Compiling results from published and gray literature on the concentrations of TVS or TOC believed to have had substantial negative effects on *in situ* benthic communities at individual sites.

An effects threshold for TOC, for example, could be used to establish boundaries for subsequent investigations or remedial actions at new wood waste sites.

Regulators should also consider using the latest scientific knowledge to make interpretations of benthic community results more technically and legally defensible. The existing SMS definition of unacceptable benthic community effects, based only on abundances of major taxa, does not acknowledge that:

- There may be superior measures for evaluating benthic community health at some sites.
- Areas of organic enrichment or other disturbance that often show high abundance and likely to pass the SQS and CSL, also show evidence of poor diversity, taxa richness, and surface sediments processing.

This recommendation is generally supported by regional experts and at least two Ecology publications (Ecology, 1996, 1999).

## Other recommendations and "lessons learned"

A design feature of this study was sequencing the SPI and sediment surveys to collect what should be truly synoptic data. Accurate vessel positioning was one of several ways Ecology minimized uncertainties about how representative sediment samples were of SPI sampling locations. The following measures would reduce such uncertainties further:

- The offset between the vessel's GPS receiver and end of the boom that lowers sampling devices should be eliminated or minimized.
- Either the same vessel should be used for both surveys or the meter wheels on both vessels should be recently-calibrated (so tide-corrected depths for both surveys better match).
- Field crews should be certain to record water depth from both the meter wheel and the vessel's depth finder.

An SPI survey that includes collecting some *ground truth* data (% fines, TOC) should be used as a cost-effective way to assess the distribution of certain sediment conventionals at a cleanup site. This would be especially true for a site that is new (lacks such data), large, or highly variable.

Characterizing benthic communities at a cleanup site, because of spatial variability, should involve more than a single replicate grab sample. This recommendation is consistent with current regional guidance (EPA, 1987), but does have substantial costs associated with it. Therefore, Ecology should explore the advantages and disadvantages of collecting benthic community data using reduced sample volume (smaller surface area or shallower depth) or identifying benthic infaunal organisms at a higher taxonomic level (Ferraro and Cole, 2004).

Samples collected from locations PGSP-129 and PGSP-130 for this study had anomalously low and inexplicable SDI and diversity values. This should be investigated further.

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# Appendices

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# Appendix A - Background and Vessel Positioning

Table A-1. Applications of SPI technology to regulatory programs and marine sediment sites in the Pacific Northwest.

| Program/project name | Application/purpose | References |
|---|---|---|
| PSDDA and DMMP, WA<br>Regional dredging program | Identify and monitor open-water dredged material disposal sites. | Cooper Consultants, 1986<br>PSDDA, 1988<br>PSDDA/ DMMP, 1990-2006 |
| Eagle Harbor (Seattle), WA<br>Sediment cleanup site | Map areas capped with clean dredged material or sand. | USACE, 1994<br>SAIC, 1996 and 1998<br>Striplin Environmental Associates, 2000 |
| *Hylebos Waterway (Tacoma), WA*<br>*Sediment cleanup site with wood waste component* | Determine likely causes of impaired benthic communities.<br>Map areas of wood waste. | Striplin Environmental Associates, et al, 1996. |
| Denny Way CSO (Seattle), WA<br>Sediment cleanup/restoration cap | Map sediment cap and recovery of benthic community. | Striplin Environmental, 2001 |
| *Port Angeles Harbor, WA*<br>*Sediment cleanup site* | Survey nature and extent of wood waste in harbor, areas of high oxygen demand, apparent health of benthic communities. | SAIC, 1999 |
| Coos Bay, OR<br>Navigation dredging program | Identify and monitor open-water dredged material disposal sites. | Striplin Environmental Associates, 2000 |
| Puget Sound Naval Shipyard (Bremerton), WA<br>Cleanup and navigation site | Map distribution of recent dredged material and sand near confined aquatic disposal site | Germano and Associates, 2002 |
| *Port Gamble Bay, WA*<br>*Sediment cleanup site* | Map distribution of wood waste.<br>Characterize sediment and benthic communities. | Parametrix, 2004<br>Anchor Environmental, 2006 |
| *West Hylebos log storage facility Tacoma, WA* | Survey nature and extent of wood waste at the site | Gerrmano and Associates, 2004 |
| Mouth of Columbia River, OR<br>Regional dredging program | Identify open-water dredged material disposal sites.<br>Characterize beneficial use site. | SAIC and Weston Solutions, 2006 |
| *Alaska Pulp Corp., (Sitka) AK* | Fate and effects of wood waste. | Foster Wheeler, 1998 |
| *Thorne Bay and Ward Cove, AK*<br>*Ketchikan Pulp Co.*<br>*Sediment cleanup and 303(d) sites* | Survey sediments, benthic habitats, and benthic communities. | Germano and Browning, 2006 |
| *Woodard Bay (Olympia), WA*<br>*Habitat restoration site* | Map distribution of wood waste | Germano and Associates, 2005 |

Wood waste sites are shown in *italics*.

Table A-2. Coordinates for 23 sampling locations in Port Gamble Bay (NAD 1983) and types of samples collected.

Most SPI sampling locations were identified with the prefix "PGSP" followed by a number, e.g., PGSP-103. Some proposed sampling locations were moved slightly to coincide with ones sampled independently by Anchor Environmental Consultants. Those locations were identified as "AS" followed by a number, e.g., AS-01.

| Sampling location ID | Analysis Sampling Location Number | Target latitude (from SPI) | Target longitude (from SPI) | Sediment quality survey latitude | Sediment quality survey longitude | Distance to target (m) | SPI and other photographs | Conventionals | Toxicity | Benthic community characteristics |
|---|---|---|---|---|---|---|---|---|---|---|
| AS-01 | 1 | 47.857325 | 122.580078 | 47.857327 | 122.580090 | 0.9 | G&A | Anchor | Anchor | Ecology |
| AS-03 | 2 | 47.856800 | 122.580535 | 47.856805 | 122.580533 | 0.6 | G&A | Anchor | Anchor | Ecology |
| AS-05 | 3 | 47.854475 | 122.579398 | 47.854472 | 122.579402 | 0.5 | G&A | Anchor Ecology | Anchor | Ecology |
| AS-09 | 4 | 47.853608 | 122.579622 | 47.853618 | 122.579620 | 1.1 | G&A | Anchor | Anchor | Ecology |
| AS-13 | 5 | 47.851810 | 122.580680 | 47.851820 | 122.580677 | 1.1 | G&A | Anchor | Anchor | Ecology |
| AS-14 | 6 | 47.852602 | 122.579950 | 47.852602 | 122.579950 | 0.0 | G&A | Anchor | Anchor | Ecology |
| PGSP-103 | 7 | 47.854122 | 122.580928 | 47.854128 | 122.580930 | 0.8 | G&A | Ecology | | Ecology |
| PGSP-104 | 8 | 47.853957 | 122.580818 | 47.853943 | 122.580782 | 3.1 | G&A | Ecology | | Ecology |
| PGSP-106 | 9 | 47.853645 | 122.580175 | 47.853640 | 122.580162 | 1.1 | G&A | Ecology | | Ecology |
| PGSP-107 | 10 | 47.853710 | 122.581180 | 47.853715 | 122.581173 | 0.7 | G&A | Ecology | | Ecology |
| PGSP-108 | 11 | 47.853555 | 122.581405 | 47.853563 | 122.581400 | 1.0 | G&A | Ecology | | Ecology |
| PGSP-109 | 12 | 47.853427 | 122.581375 | 47.853422 | 122.581373 | 0.6 | G&A | Ecology | | Ecology |
| PGSP-110 | 13 | 47.853292 | 122.580897 | 47.853295 | 122.580887 | 0.8 | G&A | Ecology | | Ecology |
| PGSP-111 | 14 | 47.852792 | 122.581072 | 47.852775 | 122.581088 | 2.2 | G&A | Ecology | | Ecology |
| PGSP-116 | 15 | 47.852382 | 122.581100 | 47.852380 | 122.581087 | 1.0 | G&A | Ecology | | Ecology |
| PGSP-118 | 16 | 47.851360 | 122.581152 | 47.851360 | 122.581178 | 2.0 | G&A | Ecology | | Ecology |
| PGSP-119 | 17 | 47.851503 | 122.579980 | 47.851505 | 122.579987 | 0.5 | G&A | Ecology | | Ecology |
| PGSP-120 | 18 | 47.850833 | 122.581497 | 47.850833 | 122.581492 | 0.4 | G&A | Ecology | | Ecology |

| Sampling location ID | Analysis Sampling Location Number | Target latitude (from SPI) | Target longitude (from SPI) | Sediment quality survey latitude | Sediment quality survey longitude | Distance to target (m) | SPI and other photographs | Conventionals | Toxicity | Benthic community characteristics |
|---|---|---|---|---|---|---|---|---|---|---|
| PGSP-121 | 19 | 47.850595 | 122.579937 | 47.850600 | 122.579918 | 1.5 | G&A | Ecology | | Ecology |
| PGSP-122 | 20 | 47.850383 | 122.581678 | 47.850368 | 122.581670 | 1.8 | G&A | Ecology | | Ecology |
| PGSP-123 | 21 | 47.850125 | 122.581325 | 47.850118 | 122.581318 | 0.9 | G&A | Ecology | | Ecology |
| PGSP-129 | 22 | 47.846967 | 122.580595 | 47.846973 | 122.580598 | 0.8 | G&A | Ecology | | Ecology |
| PGSP-130 | 23 | 47.844165 | 122.579952 | 47.844180 | 122.579953 | 1.7 | G&A | Ecology | | Ecology |

G&A = Germano and Associates, LLC

# Appendix B - Quality Assurance Review

Table B-1. Summary of quality assurance review findings.

| Procedure/ Parameter | | Methods | Holding/ Handling | Calibrations | Blanks | RLs | RPD/ RSD | LCS | Spike Recovery | Accuracy | Decision |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Positioning | | Per QAPP | | | | | | | | ±3.6 ft of target (average) | Acceptable, Representative |
| Sampling | | Per QAPP | Per QAPP | | | | | | | | Acceptable |
| Conventionals | Total Solids | Per QAPP | Per QAPP | Acceptable | 100% | 0.1% | RPD <2% | | | | Acceptable |
| | Grain size | Per QAPP | Per QAPP | Acceptable | <1% | 1% | RSD <35% | | | | Acceptable |
| | TVS | Per QAPP | Per QAPP | Acceptable | Not detected | 0.1% | RPD <10% RSD <35% | | | | Acceptable |
| | TOC | Per QAPP | Per QAPP | Acceptable | Not detected | 0.1% | RPD >20% RSD 33% | 88% | | | One batch qualified as estimates |
| | Ammonia (mg/Kg) | Per QAPP | Per QAPP | Acceptable | <0.1 | 0.1 | RSD <35% | 80-120% | 75-125% | | Acceptable |
| | Sulfide (mg/Kg) | Per QAPP | Per QAPP | Acceptable | <0.1 | 0.1 | RSD <35% | 65-135% | 65-135% | | Acceptable |
| Benthic Community | | Minor deviations | Minor deviations | Incorrect formalin concentration (see text). Held too long between sampling and rescreening (see text) | | | | | | | Acceptable |

Table B-2. Quality assurance summary for sorting benthic macroinvertebrates into major taxonomic groups prior to community analysis. Sort efficiency equals [1- (QA x 4)/Total]*100.

| Taxa/Sort Data: Station ID ↓ | Annelida | Mollusca | Crustacea | Misc | Total | QA | Sort Efficiency | QA Status |
|---|---|---|---|---|---|---|---|---|
| AS01 | 1997 | 933 | 528 | 79 | 3537 | 36 | 95% | PASS |
| AS03 | 952 | 1050 | 1100 | 110 | 3212 | 6 | 99% | PASS |
| AS05 | 886 | 729 | 1288 | 60 | 2963 | 24 | 96% | PASS |
| AS09 | 2969 | 1041 | 649 | 28 | 4687 | 18 | 99% | PASS |
| AS13 | 1389 | 521 | 167 | 13 | 2090 | 26 | 95% | PASS |
| AS14 | 537 | 182 | 61 | 15 | 795 | 7 | 96% | PASS |
| PGSP103 | 1244 | 127 | 721 | 31 | 2123 | 18 | 95% | PASS |
| PGSP104 | 617 | 325 | 625 | 17 | 1584 | 4 | 99% | PASS |
| PGSP106 | 981 | 786 | 223 | 46 | 2036 | 13 | 97% | PASS |
| PGSP107 | 664 | 184 | 91 | 2 | 941 | 2 | 99% | PASS |
| PGSP108 | 783 | 161 | 155 | 4 | 1103 | 11 | 95% | PASS |
| PGSP109 | 786 | 150 | 178 | 51 | 1165 | 20 | 92% | PASS |
| PGSP110 | 475 | 222 | 92 | 1 | 790 | 5 | 97% | PASS |
| PGSP111 | 266 | 64 | 113 | 0 | 443 | 10 | 91% | PASS |
| PGSP116 | 635 | 596 | 335 | 17 | 1583 | 5 | 99% | PASS |
| PGSP118 | 879 | 586 | 273 | 15 | 1753 | 8 | 98% | PASS |
| PGSP119 | 1234 | 494 | 313 | 32 | 2073 | 2 | 99% | PASS |
| PGSP120 | 1032 | 185 | 95 | 24 | 1336 | 2 | 99% | PASS |
| PGSP121 | 973 | 159 | 274 | 27 | 1433 | 9 | 97% | PASS |
| PGSP122 | 877 | 105 | 85 | 19 | 1086 | 5 | 98% | PASS |
| PGSP123 | 927 | 98 | 60 | 38 | 1123 | 4 | 98% | PASS |
| PGSP129 | 1728 | 36 | 158 | 12 | 1934 | 4 | 99% | PASS |
| PGSP130 | 3503 | 73 | 129 | 19 | 3724 | 4 | 99% | PASS |

Table B-3. Analysis of condition of benthic community samples to assess potential negative effects from excessive exposures to formalin preservative.

| Taxonomic Group | Percent Total Abundance | Percent Annelida with only juveniles, damage noted, or poor condition | Maximum percent damaged individuals | Percent taxa noted in poor condition | Total taxa | Percent taxa identified > genus | Percent taxa identified > species |
|---|---|---|---|---|---|---|---|
| Annelida | 51.5 | 5.4 | 0.8 | 9.4 | 138 | 41 | 43 |
| Crustacea | 22.4 | 5.3 | 4.6 | 11 | 100 | 8.9 | 19 |
| Mollusca | 25.1 | 13.9 | 9.4 | 35 | 62 | 1.8 | 11.8 |

# Appendix C - SPI and Sediment Quality Survey Results

Table C-1. Summary and descriptive statistics for selected SPI results from Port Gamble Bay. Results listed represent the mean of three replicates.

| Sampling Location = Station ID | Preliminary stratum | Penetration depth (cm) | Boundary roughness (cm) | RPD mean depth (cm) | RPD max. depth (cm) | Wood (% vol) | Voids total number | Voids max. depth (cm) | Small tubes total number | Burrows total number | VTB = No. of voids+tubes+ burrows | Organism-Sediment Index (OSI) | Benthic Habitat Quality Index (BHQI) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AS-01 | M | 12.00 | 1.49 | 2.28 | 3.61 | 13.33 | 4.00 | 10.04 | 7.00 | 13.00 | 24 | 8.67 | 10.00 |
| AS-03 | H | 11.62 | 1.83 | 2.29 | 4.08 | 26.67 | 1.00 | 5.54 | 8.00 | 9.00 | 18 | 7.33 | 8.33 |
| AS-05 | H | 13.07 | 3.04 | 1.52 | 2.34 | 7.33 | 2.00 | 10.20 | 3.00 | 7.00 | 12 | 6.50 | 8.50 |
| AS-09 | H | 14.41 | 0.88 | 3.21 | 4.41 | 5.33 | 4.00 | 10.54 | 14.00 | 17.00 | 35 | 10.00 | 10.67 |
| AS-13 | M | 14.18 | 1.37 | 2.55 | 4.20 | 1.00 | 6.00 | 9.64 | 11.00 | 23.00 | 40 | 8.67 | 11.67 |
| AS-14 | M | 7.50 | 2.01 | 2.13 | 3.81 | 1.00 | 0.00 | -- | 3.00 | 19.00 | 22 | 6.50 | 8.00 |
| PGSP-103 | H | 15.02 | 2.05 | 2.95 | 4.03 | 56.67 | 0.00 | -- | 3.00 | 13.00 | 16 | 8.33 | 7.33 |
| PGSP-104 | H | 12.56 | 3.01 | 2.49 | 4.03 | 35.00 | 5.00 | 8.06 | 6.00 | 17.00 | 28 | 8.67 | 9.33 |
| PGSP-106 | H | 13.49 | 1.19 | 2.60 | 4.27 | 4.00 | 5.00 | 10.86 | 9.00 | 18.00 | 32 | 9.00 | 11.33 |
| PGSP-107 | H | 17.09 | 2.09 | 3.33 | 4.67 | 30.00 | 6.00 | 15.08 | 5.00 | 8.00 | 19 | 9.33 | 11.67 |
| PGSP-108 | H | 13.88 | 2.48 | 2.48 | 3.50 | 16.67 | 2.00 | 13.87 | 16.00 | 7.00 | 25 | 9.00 | 8.67 |
| PGSP-109 | H | 12.56 | 1.65 | 2.08 | 2.91 | 20.00 | 4.00 | 9.13 | 0.00 | 5.00 | 9 | 8.33 | 7.00 |
| PGSP-110 | H | 15.23 | 1.79 | 3.02 | 4.57 | 4.33 | 6.00 | 11.94 | 5.00 | 13.00 | 24 | 9.67 | 11.00 |
| PGSP-111 | M | 15.91 | 2.71 | 2.53 | 4.26 | 9.00 | 2.00 | 13.57 | 0.00 | 7.00 | 9 | 8.00 | 7.33 |
| PGSP-116 | L | 16.98 | 1.69 | 1.90 | 4.35 | 3.67 | 5.00 | 13.72 | 3.00 | 12.00 | 20 | 7.50 | 9.00 |
| PGSP-118 | L | 16.64 | 2.30 | 3.01 | 4.60 | 5.00 | 0.00 | -- | 2.00 | 16.00 | 18 | 9.67 | 8.33 |
| PGSP-119 | L | 7.90 | 0.84 | 4.46 | 5.34 | 0.67 | 0.00 | -- | 7.00 | 10.00 | 17 | 10.33 | 10.00 |
| PGSP-120 | L | 13.48 | 1.31 | 3.71 | 4.76 | 0.00 | 6.00 | 6.71 | 8.00 | 20.00 | 34 | 10.33 | 12.67 |
| PGSP-121 | L | 6.68 | 0.54 | 4.31 | 5.22 | 0.00 | 0.00 | -- | 7.00 | 17.00 | 24 | 10.00 | 8.67 |
| PGSP-122 | L | 7.46 | 2.07 | 4.20 | 5.09 | 0.00 | 0.00 | -- | 9.00 | 20.00 | 29 | 10.00 | 9.67 |
| PGSP-123 | L | 13.71 | 1.80 | 3.59 | 5.25 | 0.00 | 3.00 | 6.65 | 1.00 | 34.00 | 38 | 10.33 | 10.67 |
| PGSP-129 | L | 7.84 | 1.39 | 4.23 | 5.50 | 0.00 | 0.00 | -- | 6.00 | 21.00 | 27 | 10.33 | 11.00 |
| PGSP-130 | L | 12.90 | 1.50 | 4.05 | 5.67 | 0.00 | 6.00 | 7.33 | 8.00 | 43.00 | 57 | 10.67 | 12.67 |

| Sampling Location = Station ID | Preliminary stratum | Penetration depth (cm) | Boundary roughness (cm) | RPD mean depth (cm) | RPD max. depth (cm) | Wood (% vol) | Voids total number | Voids max. depth (cm) | Small tubes total number | Burrows total number | VTB = No. of voids+tubes+ burrows | Organism-Sediment Index (OSI) | Benthic Habitat Quality Index (BHQI) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | | 23 | 23 | 23 | 23 | 23 | 23 | 16 | 23 | 23 | 23 | 23 | 23 |
| Minimum | | 6.7 | 0.5 | 1.5 | 2.3 | 0.0 | 0.0 | 5.5 | 0.0 | 5.0 | 9.0 | 6.5 | 7.0 |
| 25th %ile | | 11.8 | 1.4 | 2.4 | 4.0 | 0.3 | 0.0 | 7.9 | 3.0 | 9.5 | 18.0 | 8.3 | 8.4 |
| Median | | 13.5 | 1.8 | 3.0 | 4.3 | 4.3 | 3.0 | 10.1 | 6.0 | 16.0 | 24.0 | 9.0 | 9.7 |
| Mean | | 12.7 | 1.8 | 3.0 | 4.4 | 10.4 | 2.9 | 10.2 | 6.1 | 16.0 | 25.1 | 9.0 | 9.7 |
| StdDev | | 3.2 | 0.7 | 0.9 | 0.8 | 14.5 | 2.4 | 2.9 | 4.1 | 8.9 | 11.0 | 1.2 | 1.7 |
| 75th %ile | | 14.7 | 2.1 | 3.6 | 4.9 | 15.0 | 5.0 | 12.3 | 8.0 | 19.5 | 30.5 | 10.0 | 11.0 |
| Maximum | | 17.1 | 3.0 | 4.5 | 5.7 | 56.7 | 6.0 | 15.1 | 16.0 | 43.0 | 57.0 | 10.7 | 12.7 |
| Interquartile range (IQR) | | 2.9 | 0.7 | 1.3 | 0.9 | 14.7 | 5.0 | 4.5 | 5.0 | 10.0 | 12.5 | 1.7 | 2.6 |
| 25th %ile - 1.5*IQR | | 7.5 | 0.3 | 0.5 | 2.7 | -21.7 | -7.5 | 1.2 | -4.5 | -5.5 | -0.8 | 5.8 | 4.5 |
| 75th %ile - 1.5*IQR | | 19.1 | 3.1 | 5.5 | 6.3 | 37.0 | 12.5 | 19.1 | 15.5 | 34.5 | 49.3 | 12.5 | 14.9 |
| Mean - 2.5*StdDev | | 4.7 | 0.2 | 0.9 | 2.3 | -25.9 | -3.2 | 2.9 | -4.2 | -6.1 | -2.5 | 5.9 | 5.5 |
| Mean + 2.5*StdDev | | 20.7 | 3.4 | 5.1 | 6.4 | 46.7 | 9.0 | 17.4 | 16.4 | 38.2 | 52.6 | 12.1 | 13.9 |

Table C-2. Summary and descriptive statistics for sediment conventional results from Port Gamble Bay. Italicized results were provided by Anchor Environmental Consultants. Results listed represent the mean of three replicates.

| Sampling Location = Station ID | Preliminary stratum | Total Solids (% wet wt.) | Gravel (% dry wt.) | Sand (% dry wt.) | Sand (% dry wt. after 550°C) | Silt (% dry wt.) | Clay (% dry wt.) | Fines (% dry wt.) | Fines (% dry wt. after 550 °C) | TVS (% dry wt.) | TOC (% dry wt.) | Ammonia (mg/Kg dry wt.) | Sulfide (mg/Kg dry wt.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *AS-01* | M | ***50.7*** | ***12.4*** | ***63.7*** | -- | ***15.7*** | ***8.2*** | ***23.9*** | -- | ***8.7*** | ***4.6*** | ***8.8*** | ***0.27*** |
| *AS-03* | H | ***59.2*** | ***22.5*** | ***62.7*** | -- | ***8.1*** | ***6.6*** | ***14.7*** | -- | ***7.6*** | ***2.8*** | ***8.5*** | ***5.1*** |
| *AS-05* | H | ***33.8*** | ***5.5*** | ***44.4*** | -- | ***32.0*** | ***18.2*** | ***50.1*** | -- | ***18.0*** | ***5.5*** | ***13.4*** | ***0.16*** |
| AS-09 | H | 59.6 | 0.25 | 85.5 | 89.6 | 8.1 | 6.1 | 14.2 | 10.4 | 6.9 | 2.60 | 8.64 | 26.9 |
| *AS-13* | M | ***63.9*** | ***0.7*** | ***81.7*** | -- | ***10.1*** | ***7.5*** | ***17.6*** | -- | ***5.0*** | ***2.7*** | ***2.8*** | ***0.05*** |
| *AS-14* | M | ***71.9*** | ***0.1*** | ***93.3*** | -- | ***3.1*** | ***3.6*** | ***6.7*** | -- | -- | ***2.6*** | ***7.8*** | ***0.05*** |
| PGSP-103 | H | 26.4 | 0.9 | 60 | 54.4 | 28.8 | 10.3 | 39.1 | 45.6 | 33 | 23.7 | 15 | 118 |
| PGSP-104 | H | 30.6 | 4.1 | 57.7 | 62.2 | 24.4 | 13.8 | 38.2 | 36.0 | 28.3 | 17.1 | 17.9 | 192 |
| PGSP-106 | H | 64.0 | 0.2 | 82.9 | 88.9 | 9.8 | 7.2 | 17.0 | 11.3 | 4.7 | 2.5 | 5.9 | 148 |
| PGSP-107 | H | 32.2 | 3.4 | 50.6 | 60.7 | 30.9 | 15.3 | 46.2 | 38.8 | 28.2 | 22.3 | 13 | 900 |
| PGSP-108 | H | 34.3 | 21.9 | 49.4 | 63 | 17.9 | 11 | 28.9 | 36.1 | 26.3 | 13.6 | 17.1 | 553 |
| PGSP-109 | H | 31.5 | 3 | 51.9 | 63.7 | 32.2 | 12.9 | 45.1 | 36.3 | 22.4 | 19.6 | 21.6 | 80 |
| PGSP-110 | H | 32.2 | 12.5 | 40.8 | 63.3 | 30.3 | 16.3 | 46.6 | 33.9 | 25.7 | 6.53 | 20.4 | 951 |
| PGSP-111 | H | 34.5 | 9.4 | 39.0 | 58.2 | 33.6 | 18 | 51.6 | 41.1 | 19.7 | 11.8 | 33.7 | 386 |
| PGSP-116 | M | 37.3 | 10 | 46.1 | 60.8 | 28 | 15.8 | 43.8 | 37.3 | 19.5 | 5.61 | 12.7 | 589 |
| PGSP-118 | M | 39.5 | 6.6 | 56.7 | 72.7 | 21.7 | 15.2 | 36.9 | 25.6 | 15.8 | 2.64 | 10.6 | 449 |
| PGSP-119 | L | 72.3 | 0.1 | 91.8 | 93.9 | 4.1 | 3.9 | 8.0 | 5.9 | 2.7 | 0.97 | 6.45 | 2.24 |
| PGSP-120 | L | 68.6 | < 0.10 | 84.6 | 90.4 | 9.8 | 5.7 | 15.5 | 9.6 | 2.5 | 1.18 | 4.82 | 22 |
| PGSP-121 | L | 74.8 | 0.1 | 92.7 | 95 | 3.2 | 4.0 | 7.2 | 5.0 | 2.1 | 0.69 | 8.77 | 42.3 |
| PGSP-122 | L | 69.6 | < 0.10 | 84.9 | 90.2 | 8.7 | 6.5 | 15.2 | 9.7 | 2.1 | 0.74 | 6.79 | 67.1 |
| PGSP-123 | L | 68.8 | 0.2 | 82.7 | 89.3 | 10.6 | 6.4 | 17.0 | 10.4 | 2.7 | 0.95 | 7.78 | 21.1 |
| PGSP-129 | L | 72.1 | < 0.10 | 89.3 | 91.3 | 5.9 | 4.9 | 10.8 | 8.5 | 1.9 | 0.69 | 7.48 | 48.6 |
| PGSP-130 | L | 66.5 | 0.1 | 79.5 | 90 | 11.8 | 8.5 | 20.3 | 9.9 | 2.6 | 0.93 | 12.7 | 148 |

| Sampling Location = Station ID | Preliminary stratum | Total Solids (% wet wt.) | Gravel (% dry wt.) | Sand (% dry wt.) | Sand (% dry wt. after 550°C) | Silt (% dry wt.) | Clay (% dry wt.) | Fines (% dry wt.) | Fines (% dry wt. after 550 °C) | TVS (% dry wt.) | TOC (% dry wt.) | Ammonia (mg/Kg dry wt.) | Sulfide (mg/Kg dry wt.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | | 23 | 20 | 23 | 18 | 23 | 23 | 23 | 18 | 22 | 23 | 23 | 23 |
| Minimum | | 26.4 | 0.1 | 39.0 | 54.4 | 3.1 | 3.6 | 6.7 | 5.0 | 1.9 | 0.7 | 2.8 | 0.1 |
| 25th %ile | | 34.1 | 0.2 | 51.3 | 62.4 | 8.4 | 6.3 | 15.0 | 9.8 | 2.7 | 1.1 | 7.6 | 13.1 |
| Median | | 59.2 | 3.2 | 63.7 | 80.8 | 11.8 | 8.2 | 20.3 | 18.5 | 8.2 | 2.7 | 8.8 | 67.1 |
| Mean | | 51.9 | 5.7 | 68.3 | 76.5 | 16.9 | 9.8 | 26.7 | 22.9 | 13.0 | 6.6 | 11.9 | 206.5 |
| StdDev | | 17.6 | 7.1 | 18.8 | 15.3 | 10.8 | 4.8 | 15.4 | 14.8 | 10.7 | 7.5 | 6.9 | 289.8 |
| 75th %ile | | 68.7 | 9.6 | 84.8 | 90.2 | 28.4 | 14.5 | 41.5 | 36.3 | 21.7 | 9.2 | 14.2 | 289.0 |
| Maximum | | 74.8 | 22.5 | 93.3 | 95.0 | 33.6 | 18.2 | 51.6 | 45.6 | 33.0 | 23.7 | 33.7 | 951.0 |
| Interquartile range (IQR) | | 34.7 | 9.4 | 33.5 | 27.8 | 20.0 | 8.3 | 26.5 | 26.5 | 19.0 | 8.1 | 6.6 | 275.9 |
| 25th %ile - 1.5*IQR | | -17.9 | -13.8 | 1.0 | 20.8 | -21.6 | -6.1 | -24.8 | -30.0 | -25.8 | -11.1 | -2.2 | -400.8 |
| 75th %ile - 1.5*IQR | | 120.7 | 23.6 | 135.0 | 131.8 | 58.4 | 26.9 | 81.2 | 76.0 | 50.3 | 21.3 | 24.1 | 702.9 |
| Mean - 2.5*StdDev | | 7.8 | -12.0 | 21.4 | 38.3 | -10.1 | -2.3 | -11.8 | -14.2 | -13.8 | -12.0 | -5.3 | -518.1 |

Table C-3. Summary and descriptive statistics for benthic community results for Port Gamble Bay. Results listed represent the mean of three replicates.

| Sampling Location = Station ID | Preliminary stratum | Total abundance | Total richness | Annelida abundance | Annelida richness | Crustacea abundance | Crustacea richness | Mollusca abundance | Mollusca richness | Misc. Taxa abundance | Echino-dermata abundance. | Misc.+ Echino abundance. | SDI | Diversity H' | Evenness J |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AS-01 | M | 2631 | 130 | 1140 | 51 | 452 | 34 | 950 | 32 | 20 | 69 | 89 | 20 | 1.5680 | 0.7418 |
| AS-03 | H | 3416 | 91 | 952 | 31 | 1336 | 21 | 1006 | 21 | 51 | 71 | 122 | 10 | 1.2972 | 0.6622 |
| AS-05 | H | 2768 | 85 | 816 | 32 | 1148 | 26 | 736 | 19 | 8 | 60 | 68 | 8 | 1.2349 | 0.6400 |
| AS-09 | H | 3374 | 124 | 1685 | 52 | 679 | 39 | 960 | 24 | 18 | 32 | 50 | 15 | 1.4795 | 0.7079 |
| AS-13 | M | 1564 | 97 | 757 | 46 | 177 | 24 | 614 | 21 | 13 | 3 | 16 | 13 | 1.4091 | 0.7092 |
| AS-14 | M | 599 | 60 | 334 | 32 | 62 | 8 | 188 | 13 | 13 | 2 | 15 | 13 | 1.3528 | 0.7608 |
| PGSP-103 | H | 1855 | 76 | 1005 | 31 | 692 | 22 | 127 | 16 | 26 | 5 | 31 | 10 | 1.3177 | 0.7006 |
| PGSP-104 | H | 1688 | 88 | 747 | 31 | 704 | 32 | 222 | 18 | 9 | 6 | 15 | 18 | 1.4924 | 0.7675 |
| PGSP-106 | H | 1981 | 105 | 878 | 46 | 209 | 25 | 817 | 22 | 60 | 17 | 77 | 10 | 1.3565 | 0.6712 |
| PGSP-107 | H | 941 | 62 | 664 | 30 | 91 | 20 | 184 | 11 | 2 | 0 | 2 | 11 | 1.2239 | 0.6828 |
| PGSP-108 | H | 754 | 51 | 442 | 20 | 144 | 19 | 163 | 9 | 0 | 5 | 5 | 13 | 1.3645 | 0.7991 |
| PGSP-109 | H | 1109 | 66 | 792 | 27 | 174 | 25 | 135 | 13 | 8 | 0 | 8 | 10 | 1.2379 | 0.6803 |
| PGSP-110 | H | 667 | 60 | 355 | 28 | 88 | 17 | 222 | 14 | 2 | 0 | 2 | 12 | 1.3391 | 0.7531 |
| PGSP-111 | H | 370 | 47 | 215 | 22 | 99 | 15 | 56 | 10 | 0 | 0 | 0 | 8 | 1.2470 | 0.7458 |
| PGSP-116 | M | 1454 | 99 | 515 | 45 | 318 | 25 | 605 | 22 | 8 | 8 | 16 | 18 | 1.5098 | 0.7566 |
| PGSP-118 | M | 1478 | 99 | 595 | 39 | 283 | 30 | 587 | 24 | 6 | 7 | 13 | 19 | 1.5021 | 0.7527 |
| PGSP-119 | L | 1555 | 125 | 726 | 45 | 299 | 35 | 494 | 28 | 29 | 7 | 36 | 18 | 1.4806 | 0.7061 |
| PGSP-120 | L | 858 | 83 | 560 | 47 | 94 | 15 | 185 | 15 | 12 | 7 | 19 | 19 | 1.4605 | 0.7610 |
| PGSP-121 | L | 1060 | 102 | 573 | 47 | 300 | 22 | 162 | 23 | 21 | 4 | 25 | 14 | 1.3313 | 0.6628 |
| PGSP-122 | L | 710 | 76 | 502 | 43 | 76 | 12 | 107 | 13 | 19 | 6 | 25 | 15 | 1.4038 | 0.7464 |
| PGSP-123 | L | 648 | 85 | 460 | 47 | 65 | 14 | 98 | 15 | 24 | 1 | 25 | 17 | 1.4323 | 0.7423 |
| PGSP-129 | L | 1335 | 75 | 1108 | 43 | 178 | 12 | 36 | 15 | 12 | 1 | 13 | 3 | 0.9478 | 0.5055 |
| PGSP-130 | L | 2309 | 79 | 2092 | 38 | 128 | 15 | 73 | 18 | 10 | 6 | 16 | 2 | 0.7146 | 0.3766 |

| Sampling Location = Station ID | Preliminary stratum | Total abundance | Total richness | Annelida abundance | Annelida richness | Crustacea abundance | Crustacea richness | Mollusca abundance | Mollusca richness | Misc. Taxa abundance | Echino-dermata abundance. | Misc.+ Echino abundance. | SDI | Diversity H' | Evenness J |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| Minimum | | 370.0 | 47.0 | 215.0 | 20.0 | 62.0 | 8.0 | 36.0 | 9.0 | 0.0 | 0.0 | 0.0 | 2.0 | 0.7 | 0.4 |
| 25th %ile | | 806.0 | 70.5 | 508.5 | 31.0 | 96.5 | 15.0 | 131.0 | 13.5 | 8.0 | 1.5 | 13.0 | 10.0 | 1.3 | 0.7 |
| Median | | 1454.0 | 85.0 | 726.0 | 39.0 | 178.0 | 22.0 | 188.0 | 18.0 | 12.0 | 6.0 | 16.0 | 13.0 | 1.4 | 0.7 |
| Mean | | 1527.1 | 85.4 | 778.8 | 38.0 | 339.0 | 22.0 | 379.4 | 18.1 | 16.1 | 13.8 | 29.9 | 12.9 | 1.3 | 0.7 |
| StdDev | | 876.4 | 22.8 | 430.4 | 9.5 | 349.2 | 8.1 | 329.3 | 5.9 | 14.9 | 22.1 | 31.2 | 4.9 | 0.2 | 0.1 |
| 75th %ile | | 1918.0 | 99.0 | 915.0 | 46.0 | 385.0 | 25.5 | 609.5 | 22.0 | 20.5 | 7.5 | 33.5 | 17.5 | 1.5 | 0.8 |
| Maximum | | 3416.0 | 130.0 | 2092.0 | 52.0 | 1336.0 | 39.0 | 1006.0 | 32.0 | 60.0 | 71.0 | 122.0 | 20.0 | 1.6 | 0.8 |
| Interquartile range (IQR) | | 1112.0 | 28.5 | 406.5 | 15.0 | 288.5 | 10.5 | 478.5 | 8.5 | 12.5 | 6.0 | 20.5 | 7.5 | 0.2 | 0.1 |
| 25th %ile - 1.5*IQR | | -862.0 | 27.8 | -101.3 | 8.5 | -336.3 | -0.8 | -586.8 | 0.8 | -10.8 | -7.5 | -17.8 | -1.3 | 1.0 | 0.6 |
| 75th %ile - 1.5*IQR | | 3586.0 | 141.8 | 1524.8 | 68.5 | 817.8 | 41.3 | 1327.3 | 34.8 | 39.3 | 16.5 | 64.3 | 28.8 | 1.8 | 0.9 |
| Mean - 2.5*StdDev | | -663.8 | 28.4 | -297.1 | 14.3 | -534.1 | 1.7 | -443.8 | 3.4 | -21.1 | -41.5 | -48.1 | 0.6 | 0.9 | 0.5 |
| Mean + 2.5*StdDev | | 3718.1 | 142.5 | 1854.8 | 61.6 | 1212.1 | 42.4 | 1202.7 | 32.8 | 53.4 | 69.0 | 107.9 | 25.2 | 1.8 | 0.9 |

Table C-4. Benthic taxa most frequently making the "top ten" list at 23 sampling locations at the Port Gamble Bay study site.

| Benthic Taxon | Number and % of sampling locations with taxon among top 10 most abundant |
|---|---|
| Rochefortia tumida | 19 (83) |
| Cirratulidae | 17 (74) |
| Alvania compacta | 16 (70) |
| Armandia brevis | 13 (57) |
| Euphilomedes carcharodonta | 12 (52) |
| Oligochaeta | 12 (52) |
| Owenia collaris | 11 (48) |
| Aphelochaeta glandaria | 10 (43) |
| Foxiphalus similis | 10 (43) |
| Prionospio jubata | 10 (43) |

Table C-5. Benthic community taxa comprising 75% of the total number of organisms counted in 23 samples collected in Port Gamble Bay.

| Taxa comprising 75% of Total Abundance<br>Pollution Indicator Category | Count for<br>23 stations |
|---|---|
| *Cirratulidae* (tolerant) | *4,446* |
| <u>Alvania compacta</u> (more tolerant) | 2,700 |
| *Oligochaeta* (probably more tolerant tubificids) | *2,591* |
| <u>Rochefortia tumida</u> (tolerant) | 2,518 |
| *Aphelochaeta glandaria* (tolerant) | *1,653* |
| *Armandia brevis* (more tolerant) | *1,589* |
| Euphilomedes carcharodonta (tolerant) | 1,305 |
| Aoroides spinosus (unknown tolerance) | 1,104 |
| *Owenia collaris* (less tolerant) | *933* |
| Nebalia cf pugettensis (slightly tolerant) | 803 |
| *Prionospio jubata* (slightly tolerant) | *777* |
| Foxiphalus similes (sensitive) | 713 |
| <u>Saxidomus gigantean</u> (unknown tolerance) | 671 |
| <u>Macoma sp</u> (moderately tolerant) | 655 |
| Leptochelia dubia (slightly tolerant) | 584 |
| *Ampharete labrops* (less tolerant) | *564* |
| *Prionospio lighti* (slightly tolerant) | *413* |
| *Neosabellaria cementarium*<br>(sensitive tube dweller on rocks) | *398* |
| Aoroides spp. (unknown tolerance) | 381 |
| <u>Clinocardium nuttalli</u> (slightly tolerant) | 304 |
| *Eumida longicornuta* (slightly tolerant) | *300* |
| <u>Nutricola lordi</u> (slightly tolerant) | 291 |
| *Capitella capitata 'hyperspecies'*<br>(more tolerant, especially of hypoxia) | *268* |
| *Pholoides asperus* (slightly tolerant) | *253* |
| *Glycinde picta* (slightly tolerant) | *251* |
| Count for 75% of Total Abundance | 26,465 |

Annelida taxa are italicized, Crustacea taxa are displayed in normal font, and Mollusca taxa are underlined. Tolerance indicates likely neutral or positive response to organic materials (and usually contaminants) associated with sediment.

Table C-6. Port Gamble Bay benthic community taxa, with percentile total abundance indicated.

| Taxa | Total abundance 23 locations | Total abundance rank | Total abundance cumulative % |
|---|---|---|---|
| Cirratulidae | 4446 | 1 | |
| Alvania compacta | 2700 | 2 | |
| Oligochaeta | 2591 | 3 | |
| Rochefortia tumida | 2518 | 4 | |
| Aphelochaeta glandaria | 1653 | 5 | |
| Armandia brevis | 1589 | 6 | |
| Euphilomedes carcharodonta | 1305 | 7 | |
| Aoroides spinosus | 1104 | 8 | 51% |
| Owenia collaris | 933 | 9 | |
| Nebalia cf pugettensis | 803 | 10 | 56% |
| Prionospio jubata | 777 | 11 | |
| Foxiphalus similis | 713 | 12 | |
| Saxidomus gigantea | 671 | 13 | |
| Macoma sp | 655 | 14 | |
| Leptochelia dubia | 584 | 15 | |
| Ampharete labrops | 564 | 16 | |
| Prionospio lighti | 413 | 17 | |
| Neosabellaria cementarium | 398 | 18 | |
| Aoroides spp. | 381 | 19 | |
| Clinocardium nuttalli | 304 | 20 | |
| Eumida longicornuta | 300 | 21 | |
| Nutricola lordi | 291 | 22 | |
| Capitella capitata 'complex' or 'hyperspecies' | 268 | 23 | |
| Pholoides asperus | 253 | 24 | 75% |
| Glycinde picta | 251 | 25 | 75% |
| Polycirrus sp. complex | 216 | 26 | |
| Mediomastus sp. | 212 | 27 | |
| Harpacticoida | 206 | 28 | |
| Lirularia lirulata | 203 | 29 | |
| Platynereis bicanaliculata | 200 | 30 | |
| Cyclopoida | 199 | 31 | |
| Protothaca staminea | 188 | 32 | |
| Parvilucina tenuisculpta | 184 | 33 | 80% |
| Macoma nasuta | 180 | 34 | |
| Aoroides exilis | 178 | 35 | |
| Pectinaria granulata | 174 | 36 | |
| Pinnixa spp. | 171 | 37 | |
| Cumella vulgaris | 152 | 38 | |
| Cirripedia | 151 | 39 | |
| Leitoscoloplos pugettensis | 147 | 40 | |
| Micrura sp | 147 | 41 | |
| Scoletoma luti | 147 | 42 | |
| Micropodarke dubia | 136 | 43 | |

| Taxa | Total abundance 23 locations | Total abundance rank | Total abundance cumulative % |
|---|---|---|---|
| Scleroplax granulata | 136 | 44 | |
| Photis spp. | 135 | 45 | |
| Euclymene zonalis | 131 | 46 | |
| Prionospio steenstrupi | 123 | 47 | |
| Circeis armoricana | 119 | 48 | |
| Lumbrineris californiensis | 113 | 49 | |
| Axinopsida serricata | 110 | 50 | |
| Protomedeia spp. | 108 | 51 | |
| Cumella cf morion | 107 | 52 | |
| Paleanotus bellis | 104 | 53 | |
| Pinnixa schmitti | 100 | 54 | |
| Podarkeopsis glabrus | 100 | 55 | |
| Euclymeninae | 95 | 56 | |
| Ophiurida | 95 | 57 | |
| Orchomene cf pinquis | 93 | 58 | |
| Ostracoda | 84 | 59 | |
| Desdimelida desdichada | 82 | 60 | |
| Mytilus sp | 76 | 61 | 90% |
| Pododesmus macrochisma | 76 | 62 | 90% |

Table C-7. Benthic community data for Port Gamble Bay, August 2006 (reformatted by Ecology staff from raw data provided by Susan Weeks, OIKOS).

| Location: / Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Achelia echinata | | 2 | | | | | | | | | | | | | | | | | | | | | |
| Aeolidacea | | | | | | | | | | | | | | | | | 2 | | | | | | |
| Alienacanthomysis macropsis | | | | | | | | | | | | 1 | | | | | | | | | | | |
| Alvania compacta | 341 | 170 | 420 | 349 | 133 | 23 | 3 | 11 | 198 | 10 | 19 | 17 | 119 | 14 | 274 | 303 | 183 | 52 | 18 | 6 | 16 | 3 | 18 |
| Americhelidium rectipalmum | 1 | | 1 | 4 | | | 5 | | 2 | | | | | | | | | | | | | | |
| Ampelisca hancocki | | | | | | | | | | | | | | | | | | | | | | | 1 |
| Ampelisca pugetica | 2 | | | | 2 | | 2 | 2 | 1 | 1 | 1 | 2 | 4 | 1 | 2 | 7 | | 1 | 3 | | | | |
| Ampharete acutifrons | 1 | | | | | | | | | | | | | | | | | 2 | | | 1 | | 1 |
| Ampharete labrops | 70 | 4 | | 30 | 28 | 21 | 18 | 47 | 74 | 32 | 31 | 19 | 43 | 2 | 46 | 30 | 36 | 12 | 11 | 3 | 3 | 2 | 2 |
| Ampharetidae | 2 | | | | | | | | | | | | | | | | | | | | | | |
| Amphiodia occidentalis | | 1 | 3 | 4 | | | | 2 | | | | | | | | | | | | | | | |
| Amphiodia sp | | | | | | | | | | | | | | | | | 1 | | | | | | |
| Amphiodia urtica/periercta | 10 | | | | | | 1 | | | | | | | | | | | 6 | | 6 | | 1 | 5 |
| Amphipholis sp | 15 | 6 | 19 | | 2 | | 1 | | 3 | | 2 | | | | 2 | 1 | 1 | | 2 | | | | |
| Amphipholis squamata | 12 | 21 | | | | | | | | | | | | | | | | 1 | | | | | |
| Amphissa | | | 1 | | | | | | | | | | | | | 1 | | | | | | | |
| Amphissa Columbiana | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Amphitrite cirrata | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | | |
| Amphiuridae | 11 | 25 | 11 | 11 | | 1 | | 3 | 7 | | 2 | | | | 2 | | 1 | | | | | | |
| Ampithoe spp. | 1 | | | 2 | | | | | | | | 1 | | | 1 | | 6 | | | | | | |
| Amplisca pugettia | | | | | | | | | | | | | | | | | 3 | | | | | | |
| Anoplarchus insignis | | | | | | | | | | | | | | | 1 | | | | | | | | |
| Anoplodactylus erectus | | | | | | | | | | | | | | | | | 1 | | | | | | |
| Aoroides columbiae | | | | | 2 | | | | | | 1 | 1 | | | | 15 | 3 | | | | | | |
| Aoroides exilis | 17 | 52 | 18 | | | | | 28 | 7 | 6 | | 1 | | 2 | 47 | | | | | | | | |
| Aoroides inermis | 17 | | | 6 | 4 | | | | | | | 3 | | | | 1 | | | | | | | |
| Aoroides intermedius | | | | 8 | | | | | | | | | | | 10 | | 15 | | 4 | | | | |

| Location: Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aoroides spinosus | 26 | 648 | 259 | 31 | | 1 | | 30 | 1 | 2 | 20 | 40 | 7 | 31 | 8 | | | | | | | | |
| Aoroides spp. | 17 | 130 | 116 | 15 | | | 20 | 24 | 1 | 5 | 9 | 3 | 5 | 3 | 22 | 6 | 4 | | | | | 1 | |
| Aphelochaeta glandaria | 21 | | | 92 | 106 | 44 | 11 | 83 | 1 | 3 | 1 | 6 | | | 5 | 15 | 76 | 38 | 93 | 115 | 49 | 414 | 480 |
| Aphelochaeta monilaris | | | | | | | | | | | | | | | | | | | | | | | 2 |
| Archidistoma sp | | 5 | | | | | | | | | | | | | | | | | | | | | |
| Argissa hamatipes | 2 | | | | 2 | | | 1 | 1 | | | | | | | | | | | | | | |
| Armandia brevis | 64 | 201 | 82 | 94 | 4 | 1 | 282 | 239 | 25 | 48 | 68 | 252 | 52 | 62 | 78 | 33 | 4 | | | | | | |
| Asabellides sibirica | | 4 | | | | | | | | | | | | | | | | | | | | | |
| Astyris gausapata | | | | | | | | | | | | | | | | | 2 | | 3 | 2 | 1 | 1 | 6 |
| Axinopsida serricata | 14 | | | 31 | 6 | 4 | 4 | 1 | 2 | | 2 | | | | 2 | 3 | | 13 | 4 | 5 | 11 | 1 | 7 |
| Axiothella rubrocincta | | | | | 1 | 2 | | | | | | | | | | | 1 | | | 1 | | | |
| Balanus spp. | | | | 2 | | | | | | | | | | 4 | | 6 | | 1 | | | | | 5 |
| Bivalvia | 10 | | | 25 | | | 2 | 6 | 1 | 43 | | 12 | | | 1 | 3 | | | | | | | |
| Boccardia pugettensis | | | | | | | | | | | | | | | | | | | | | | 3 | 3 |
| Bowerbankia sp | | 1 | | | | | | 1 | 1 | | | | | | | | | | | | | | |
| Byblis millsi | | | | | | | | | | | | | | | | | 2 | | | | | | |
| Calanoida | | | | | | | | | | | | | | | 1 | | | | | | | | |
| Callianassa californiensis | | | | | | | | | | | | | | | | | | | | | | | 1 |
| Calliostoma ligatum | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Cancer gracilis | | | | | | | | 1 | | | 1 | | | | | 1 | | 1 | | | 1 | | |
| Cancer productus | | 1 | | | | | | | | | | | | | | | | | | | | | |
| Cancer spp. | 4 | 1 | | | | | | 1 | | | | | | | | 2 | 3 | | 1 | | | | |
| Capitella capitata complex | 50 | 7 | 72 | 9 | 4 | 1 | 11 | 2 | 9 | 15 | 23 | 50 | 2 | 4 | 6 | 5 | 5 | 1 | 1 | | | | |
| Caprella alaskana | 2 | | | | 5 | | | | | | | | | | | | | | | | | | |
| Caprella striata | | | | 4 | 3 | | | | | | 1 | | | 1 | | | 4 | | | | | | |
| Caprellidae | | | | 11 | | | 4 | 6 | | | | | | | | | | | 1 | | | | |
| Carinoma mutabilis | | | | 3 | 1 | 1 | | | 3 | | | | | | | | 2 | | 2 | | 2 | | |
| Caulleriella pacifica | | | | 1 | | | | | | | | | | | | | | | | | | | |
| Celleporella hyalina | | 1 | | | | | | | | | | | | | | | | | | | | | |
| Cerebratulus sp | 2 | | | 2 | 1 | | | | | | | | 1 | | | | 2 | | | | 1 | | |
| Chaetopterus | 2 | | | | | | | | | | | | | | | | | | | | | | |

| Location: Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| variopedatus | | | | | | | | | | | | | | | | | | | | | | | |
| Chaetozone acuta | | 1 | 1 | | | | | | | | | | 1 | 1 | 1 | | | | | | | | |
| Chone duneri | | | | | | | | | | | | | | | | | | 1 | | | | | |
| Circeis armoricana | 29 | | 1 | 29 | 1 | | | | 3 | | | | | | 8 | 1 | 9 | 21 | 6 | 1 | 8 | 2 | |
| Cirratulidae | 105 | | | 290 | 317 | 124 | 54 | | 217 | 25 | 113 | 86 | 10 | 3 | 32 | 86 | 309 | 213 | 265 | 139 | 182 | 490 | 1386 |
| Cirripedia | 1 | | 1 | 26 | 2 | | | 4 | 9 | 2 | | | 1 | 5 | 6 | 4 | | | | | 20 | 25 | 45 |
| Clinocardium nuttalli | 9 | 11 | 4 | 14 | 38 | 11 | 6 | 28 | 6 | 15 | 18 | 28 | 3 | 4 | 16 | 20 | 40 | 13 | 5 | 4 | 5 | 3 | 3 |
| Clinocardium sp | | | | | | | | | | | | | | | 26 | | | | | | | | |
| Clytia sp | | 1 | | | | | | 1 | 1 | | | | | | | | | | | | | | |
| Corophidae | | 1 | | | | | | | 1 | | | | | | | | 3 | | 2 | | | | |
| Crangon alaskensis | 2 | | | | 2 | | 1 | 1 | | 1 | | | | | | 2 | 3 | 1 | | 1 | | | 1 |
| Crangon spp. | | | | | | | | | | | | | | | | 1 | | | | | | | |
| Crepipatella dorsata | 3 | 1 | 3 | | | | | | 2 | | | | 1 | 1 | | 7 | 1 | | | | 1 | | |
| Cryptomya californica | | | | | | | | 1 | | 1 | | 2 | | | | | 6 | | | | | | |
| Cryptonatica affinis | | | | | | | | | | | | | | | | | | | 1 | | | | |
| Cumella californica | | | | | | | | | | | | | 2 | | | | | | | | | | |
| Cumella cf morion | 36 | 4 | | 34 | | | | 32 | | 1 | | | | | | | | | | | | | |
| Cumella vulgaris | | 35 | 7 | 69 | | | 4 | 39 | 10 | 4 | 6 | 2 | 1 | | 17 | 1 | | | | | | | |
| Cyclopoida | | | | 11 | 4 | | 106 | 25 | 5 | 4 | 24 | 3 | | | | | 2 | 2 | 2 | 3 | 3 | 1 | 4 |
| Cylichna attonsa | | | | | | | | | | | | | | | | | 1 | | | 1 | | 1 | 2 |
| Decamastus gracilis | 1 | | | 1 | | | | | 4 | | | | | | | | 1 | 1 | | | 5 | 1 | |
| Decopoda | 3 | 1 | 1 | | 2 | | | | | 1 | 2 | | 1 | 1 | | 5 | 1 | | 1 | 1 | 1 | 2 | |
| Demospongiae | | 1 | | | | | | | | | | | | | | | | | | | | | |
| Desdimelida desdichada | 2 | | 11 | 10 | | | | 28 | 14 | | 2 | | 15 | 1 | 8 | 14 | 1 | | 1 | | 3 | | |
| Deutella californica | | 7 | | | | | | | | | | | | | | | | | | | | | |
| Diastylis quadriplicata | | | | | | | | | | | | | | | | | | | | 1 | | | |
| Diastylis santamariensis | | | | | | | 1 | 2 | 1 | 1 | | | | | 1 | 4 | 1 | | | | | | |
| Diopatra ornata | | | | | | | | | | | | | | | | | | | 1 | | | | |
| Dipolydora caulleryi | 1 | | | 4 | | | | | | | | | | | | | | | | | 1 | 3 | 1 |
| Dipolydora socialis | | | 9 | 2 | 1 | 1 | 2 | 3 | | | | | | 2 | 2 | 1 | | 8 | 3 | 9 | 5 | 2 | 7 |
| Doridoida | | | | | | | | | | | | | | | | | 1 | | | | | | |
| Dorvillea annulata | | 24 | | | | | | | | | | | | | | | | | | | | | |
| Dorvillea rudolphi | 4 | | 14 | | | | 1 | | | 2 | | 1 | 1 | | 2 | 3 | | | | | | | |

| Location: Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dorvilleidae juv | | | | | | | | 1 | | | | | | | | | | | | | | | |
| Dutella californica | | | | | | | | | 1 | | | | | | | | | | | | | | |
| Ericthonius brasiliensis | | | | | | | | | | | | | | | | | 1 | 1 | | | | | |
| Ericthonius spp. | | | | 2 | | | | | | | | | | | | | | 2 | | | | | |
| Eteone longa | | | 4 | | 6 | 6 | | | 1 | | | | | | | | 14 | 7 | 6 | 5 | 1 | 1 | 9 |
| Eualus spp. | | | 1 | | | | | | | | | | | | | | | | | | | | |
| Euchone analis | | | | | | | | | | | | | | | | | 1 | | 1 | 1 | | | |
| Euchone incolor | | | | | 1 | | | | | | | | | | | | | 2 | | | 1 | | |
| Euchone sp | | | | | | | | 1 | | | | | | | | | | | | | | | |
| Euclymene zonalis | | | | 10 | 14 | 7 | | | | | | | | | | | 1 | 21 | 10 | 24 | 30 | 7 | 7 |
| Euclymeninae | 5 | | | 1 | 3 | 7 | 9 | | 9 | | | | | | 2 | 11 | 15 | 10 | | 8 | 4 | 6 | 5 |
| Eudorella pacifica | | | | | | | | | | | | | | | | 2 | | | | | | | |
| Eudorellopsis integra | | | 7 | | | | 2 | | | | | | | | | | | | | | | | |
| Eumida longicornuta | 14 | 13 | 11 | 50 | 23 | 9 | 1 | 19 | 19 | 7 | 3 | | 2 | 1 | 4 | 8 | 17 | 18 | 22 | 16 | 12 | 17 | 14 |
| Euphilomedes carcharodonta | 3 | | 1 | 123 | 114 | 46 | 120 | 179 | 98 | 7 | 4 | 1 | 2 | | 1 | 17 | 167 | 32 | 217 | 20 | 14 | 99 | 40 |
| Euphysa ruthae | | | | | | | | | | | | | | | | 1 | | | | 1 | | | |
| Euphysa sp | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Eupolymnia heterobranchia | | | | | | | | | | | | | | | | | 2 | | | | | | 2 |
| Eusyllis habei | | 1 | 3 | | | | | | | | | | | | 2 | 3 | 1 | | | | | | |
| Eusyllis sp. | | | | | | | | | | | | | | | 3 | | | | | | | | |
| Exogone dwisula | | 64 | | | | | | 2 | | | | | | | | | | | | | | | |
| Exogone lourei | | 27 | 1 | | | | | | | | | | | | | | 1 | | 1 | | | 5 | |
| Exogone naidina | 43 | | | | 1 | | | | | 4 | 5 | | | | 14 | | | | 2 | | | | |
| Flabelligera affinis | | | | | | | | | 1 | | | | | | 1 | | | | | | | | |
| Foxiphalus similis | 88 | 1 | 3 | 102 | 5 | 2 | 115 | 103 | 18 | 22 | 25 | 46 | 36 | 24 | 76 | 38 | 2 | 5 | 2 | | | | |
| Galathowenia oculata | | | | 3 | 8 | 10 | 1 | | 1 | | | | | | | 4 | 10 | 8 | 2 | 2 | 15 | 2 | 1 |
| Gastropoda | 11 | | | 8 | | | | | 1 | | | | | | | 2 | | | | | | | |
| Glycera americana | | 1 | | | | | | 1 | | | | | 2 | | | 1 | 1 | | | | 1 | 1 | |
| Glycera macrobranchia | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Glycera nana | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Glycinde armigera | | | | | | 2 | | | 5 | | 11 | | 2 | | 1 | 1 | 1 | 1 | | 2 | | | |

| Location: / Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Glycinde picta | 17 | 2 | | 12 | 11 | 3 | 16 | 26 | 9 | 21 | 13 | 37 | 9 | 3 | 15 | 25 | 7 | 2 | 9 | 1 | 6 | 6 | 1 |
| Glycinde sp. | 3 | 3 | | | | | 4 | 4 | | 6 | 5 | 1 | 1 | | 2 | 1 | 1 | 1 | | | | 3 | |
| Goniadidae juv | | 5 | | | | | | 4 | | | | | | | | | | | | | | | |
| Gurnea reduncans | 4 | | 1 | 21 | 2 | | | 11 | | 1 | | 1 | | | 1 | | | | | | | | |
| Harmothoe imbricata | 1 | | 6 | | | | | | | | | | | 2 | 1 | 1 | 1 | | | | | | 1 |
| Harpacticoida | 13 | 7 | 16 | 69 | 3 | | 18 | 41 | 5 | 17 | 6 | | | | 5 | 6 | | | | | | | |
| Hemigrapsus oregonensis | | | | | | | | | | | | | | 4 | | | | | | | | | |
| Hemigrapsus spp. | | | | | | | | | | | | | | 1 | | | | | | | | | |
| Heptacarpus brevirostris | 2 | | 12 | | | | | | | | | 2 | | 3 | | 1 | | | | | | | 1 |
| Heptacarpus spp. | | | | | | | | | | | | | | | 2 | 5 | 1 | | 3 | | 2 | | |
| Heptacarpus stimpsoni | | | | 1 | 2 | | | | | | 1 | | 1 | | | 4 | | | | | 3 | | 1 |
| Hesionidae | 1 | | 4 | 8 | | | | | 1 | | | | | | | | | | | | | | |
| Heteromastus filobranchus | | | | | | 1 | | | | | 1 | | | | | | | 2 | | 3 | 3 | 4 | 11 |
| Hiatella arctica | 1 | 1 | 1 | 1 | 1 | | | | | | | 1 | | | 3 | 2 | 2 | | | | | | |
| Hippolytidae | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Hoplonemertea | | | | 1 | | | | | | | | | | | | | | | | | | | |
| Kurtziella plumbea | | | | | | | | | 2 | | | | | | | | | | 1 | | | | |
| Lacuna sp | 4 | 1 | | | | | | | | | | | | | 2 | | 2 | | | | | | |
| Lanassa nordenskioldi | | | | | | | | | | | | | | | | | | 1 | | | | | |
| Lanassa venusta | 1 | | | | | | | | | | | | | | | | | | 1 | | | | |
| Leitoscoloplos pugettensis | 40 | 2 | | 36 | 9 | 7 | 2 | | 12 | | | | | | 1 | 1 | 16 | 1 | 4 | 2 | 7 | 7 | |
| Leptochelia dubia | 120 | 169 | 1 | 6 | 7 | 8 | 155 | 5 | 2 | 4 | | 2 | 4 | | 59 | 21 | 3 | | 8 | 3 | 1 | 6 | |
| Leptosynapta sp | | | | | | | | | | | | | | | | | | | 1 | | | | |
| Leucon magnadentata | | | | | | | | | | 1 | | | | | | | | | | | | | |
| Lima sp | | | | 1 | | | | | | | | | | | | | | | | | | | |
| Limnoria lignorum | | | 15 | | | 1 | | 2 | | | | 8 | 2 | | | | | | | | | | |
| Lineidae | | 1 | 2 | 1 | | | 4 | | | | | | | | | | 4 | | | | | | |
| Lirobittium sp | 3 | | 8 | | | | | | | | | | | | | | | | | | | | |
| Lirularia lirulata | 29 | 18 | 19 | 86 | 17 | 3 | | 5 | 4 | | | | 1 | 1 | 7 | 3 | 9 | | 1 | | | | |
| Lophopanopeus spp. | 6 | | 2 | | | | | | | | | | | | 2 | | | | | | | | |

| Location: / Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lottia sp | 2 | | | | | | | | | | | | | | | | | | | | | | |
| Lucinoma annulatum | 1 | | | | | | | 2 | 1 | | | | | | 2 | | 1 | | 2 | | | | |
| Lumbrineridae | 5 | | | | 2 | 1 | | | 1 | 1 | | | | 2 | 4 | 12 | | 4 | | 4 | 2 | 3 | 11 |
| Lumbrineris californiensis | 5 | | | 1 | 7 | 6 | 2 | 1 | 4 | | | | | | | 15 | 14 | 15 | 10 | 7 | 20 | 6 | |
| Lyonsia californica | 1 | | | 2 | | | 1 | | 3 | | | 1 | | | 1 | 1 | 1 | | 1 | | | 1 | 4 |
| Macoma balthica | | 2 | | | 1 | | | | | | | | | | | | | | | | | | |
| Macoma elimata | | 23 | | | | | | | | | | | | | | | | | | | | | |
| Macoma golikovi | 6 | | | 1 | 2 | | 1 | | 1 | | | | | | | 1 | | | | | 1 | | |
| Macoma inquinata | 13 | 4 | | | 1 | | 1 | | | | | | 5 | | | | | | | | | | |
| Macoma nasuta | 25 | 13 | 17 | 9 | 6 | | 26 | 5 | 1 | | 5 | 2 | 29 | | 13 | 11 | 9 | 2 | 5 | | 1 | | 1 |
| Macoma sp | 57 | 58 | 18 | 27 | 6 | 9 | 2 | 81 | 25 | 65 | 90 | 48 | 15 | 25 | 94 | 25 | | 1 | 1 | 3 | | 1 | 4 |
| Macoma yoldiformis | 2 | | | | | | | | | | | | | | | | 1 | | | | | | |
| Mactridae | | 3 | | | 3 | 2 | 3 | 1 | | | | | | | | | | | | | | | |
| Mactromeris polynyma | | | | | | | | | | | | | | | | | | 1 | 2 | | | | |
| Magelona longicornis | | | | | | | | | | | | | | | | | 1 | 3 | 2 | 5 | 5 | 3 | 1 |
| Maldanidae | 2 | | | 2 | 8 | 6 | | | | | | | | 2 | | | 2 | 11 | 5 | | 1 | 8 | 9 |
| Malmgreniella liei | | | | 4 | 4 | 1 | | | 9 | | | | | | | | 1 | 4 | 1 | 13 | 1 | 7 | 7 |
| Malmgreniella sp juv | | | | | | | | 1 | | | | | | | | | | | | | | | |
| Mayerella banksia | | | | 7 | | | | | 5 | | | | | | | | 1 | | | | | | |
| Mediomastus sp. | 25 | | | 25 | 22 | 8 | 2 | | 16 | 2 | 1 | 1 | | | 1 | 2 | 11 | 28 | 7 | 21 | 9 | 13 | 18 |
| Megalomma splendida | | | | | | | | | | | | | | | | | | 1 | | | | | |
| Megamoera subtener | | 5 | 49 | | | | | | | | 2 | | | 2 | | | 2 | | | | | | |
| Melanochlamys diomedea | | | | | | | | | | | | | | | | | 1 | | | | | | |
| Melinna oculata | | | | | | | | | | | | | | | | | | 2 | | 1 | | | |
| Melita subtener | | | | | | | | | | | | 3 | | | | | | | | | | | |
| Melitidae | | 1 | | | | | | | | | | | | | | | | | | | | | |
| Mesocrangon munitella | | | | | | | | | | | | | | | 1 | | | | | | | | |
| Metacaprella kennerlyi | | | | 6 | | | | | | | | | | | 17 | | 15 | | 10 | | | | |
| Metacrangon spp. | | | | | | | | | | | | | | | | | | | 1 | | | | |
| Metridium senile | | | | | | | | | | | | | | | | | | | | | 1 | | |
| Microjassa cf litotes | | | | 5 | | | | | | | | | | | | | | | | | | | |

| Location: <br><br> Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Micropodarke dubia | 6 | 28 | 6 | 31 | 2 | | 10 | 20 | 1 | 6 | 6 | 4 | 1 | 1 | 11 | 2 | | | 1 | | | | |
| Microporella sp | | 1 | | | | | | | | | | | | | | | | | | | | | |
| Micrura sp | 6 | 24 | 2 | 5 | 11 | 7 | 12 | 6 | 5 | 2 | | | | | 1 | 1 | 13 | 7 | 13 | 7 | 14 | 8 | 3 |
| Modiolus rectus | | | | | | | | | | | | | | | | | | | 1 | | | | |
| Modiolus sp | 1 | 1 | | 1 | | | | | | | | | | | | 1 | | | | | | | |
| Moncorophium spp. | | | | | | | | 2 | | | | | | | | | | | | | | | |
| Monocorophium acherusicum | | | | 4 | | | 4 | 4 | | | | | | | 3 | | 19 | | | | | | |
| Monocorophium spp. | 2 | | | | 2 | | 3 | | | | | | | | | 2 | | | | | | | |
| Monticellina sp | | | | | | | | 3 | | | | | | | | | | | | | | | |
| Monticellina tesselata | | | | | 1 | | | | | | | | | | | | | | | 1 | | | |
| Mopalia phorminx | | | 1 | | | | | | | | | | | | | | | | | | | | |
| Munna cf ubiquita | 2 | | 1 | 62 | 1 | 1 | | 18 | | 2 | | | | | | | 2 | | | | | | |
| Mya arenaria | 3 | | | 2 | | | | | | | | | 1 | | 1 | 1 | 1 | | | | | 1 | |
| Myidae | | | | | | | | | | | 8 | 1 | | | | | | | | | | | |
| Mytilus sp | 6 | 16 | 13 | 8 | 1 | | 1 | 1 | 2 | 1 | | 1 | | | 1 | 10 | 12 | 1 | 2 | | | 1 | |
| Nassarius mendicus | | | | | | | | | | | | | | | | 1 | | | | | | | 2 |
| Nebalia cf pugettensis | 11 | 156 | 604 | 3 | | | | | | | | 8 | 2 | 16 | 2 | | | | 1 | | | | |
| Nematoda | | 6 | | | | | | | 46 | | | | | | | | | | | | | | |
| Nemertea | 5 | | 3 | 4 | | | 1 | | 1 | | | | 1 | | 4 | 4 | 2 | | 2 | 3 | 1 | | 1 |
| Neosabellaria cementarium | 3 | | 351 | 17 | 1 | | | | 3 | | | 2 | 5 | | 1 | | 5 | | | 3 | 5 | 1 | 1 |
| Neotrypaea californiensis | | | | | | | 6 | 1 | | | 2 | 1 | | | | | | | | | | | |
| Neotrypaea spp. | | | | | 1 | | | | | | | 3 | | | | | | | | | | | |
| Nephtys caecoides | 1 | 1 | | | | | 2 | | 1 | 1 | 2 | | 1 | | 1 | | | | 1 | | | | |
| Nephtys cornuta | | | 7 | | 5 | | 1 | 1 | 4 | 10 | | 1 | 2 | 1 | 5 | 15 | | | | | | 1 | |
| Nephtys ferruginea | | | | | | | | | | | | | | | 1 | 1 | | | 1 | 1 | 1 | | 1 |
| Nereidae | | | | 2 | | | | | 1 | | | | | | | | | | | | | | |
| Nereis procera | 2 | | 1 | 1 | 1 | 2 | | | 3 | | | | | | 1 | | 6 | 4 | 2 | 1 | 2 | 2 | |
| Notomastus tenuis | | 12 | | | | | | 3 | | | | | | | | | | | | | | | |
| Nutricola lordi | 1 | | | 14 | 77 | 44 | 6 | | 41 | 2 | | | | | | | 42 | | 48 | 6 | 2 | 3 | 5 |
| Obelia sp | | 1 | | | | | | | | | | | | | | | | | | | | | |

| Location: / Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Odostomia sp | | 1 | | | 2 | | | | | | | | | | 1 | | | 3 | | | 1 | | 2 |
| Oenopota sp | | | | | | | | | | | | | | | | 1 | | | | | | | |
| Oligochaeta | 320 | 420 | 75 | 494 | 20 | 5 | 311 | 66 | 190 | 323 | 50 | 215 | 47 | 9 | 15 | 4 | 8 | 2 | 4 | 2 | 4 | 2 | 5 |
| Onchidorididae | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Onchidoris bilamellata | | | 1 | | | | | | | | | | | | | | | | | | | | |
| Onuphidae | | | | 1 | | | | | | 1 | | | | | | | | | | | | | |
| Onuphis iridescens | | | | | 1 | | | | 1 | | | | | | | | 3 | | 1 | | | | |
| Ophelina acuminata | 1 | | | | | | | | | 1 | | | | | | | | | | | | | |
| Ophiodromus pugettensis | | | | | | | | 1 | | | | | | | | | | | | | | | |
| Ophiurida | 20 | 18 | 23 | 15 | 1 | 1 | 3 | 1 | 7 | | | | | | 4 | | 2 | | | | | | |
| Ophiuridae | | | | | | | | | | | | | | | | 4 | | | | | | | |
| Ophiuroidea sp. | | | 1 | | | | | | | | 1 | | | | | | | | | | | | |
| Orbiniidae | | | | 2 | 1 | | | | | | | | | | | | | | | | | | 1 |
| Orchomene cf pinguis | 2 | | | 3 | | | | | | | | | | | | 93 | | | | | | | |
| Orchomene decipiens | 1 | | | | | | | | | | | | | | | 12 | | | | | | | |
| Ostracoda | 36 | | 7 | 7 | | | | 13 | | | | | | | 14 | 7 | | | | | | | |
| Owenia collaris | 46 | | 14 | 233 | 65 | 39 | 43 | | 138 | 42 | 30 | 1 | 25 | 3 | 30 | 94 | 57 | 13 | 24 | 12 | 16 | 6 | 2 |
| Owenia fusiformis | | 6 | | | | | | 64 | | | | | | | | | | | | | | | |
| Pagurus cf. dalli | | | | | | | | | | | | | | | | | | | | | | | 2 |
| Pagurus spp. | | | | 2 | | | | | 3 | | | | | | | | | | | | 1 | | |
| Paleanotus bellis | 3 | 49 | 9 | 8 | | | | 2 | 2 | 1 | | 1 | | | 6 | 15 | 4 | | 1 | | 1 | | 2 |
| Pandalus danae | | | | | | | | | | | | 2 | | | | | | | | | | | |
| Paranemertes californica | 1 | | | 2 | | | | | | | | | | | | | 1 | | | 1 | | | |
| Paraprionospio pinnata | | | | | | | | | | | | | 1 | | | | | 1 | | 3 | 2 | 1 | 2 |
| Parvilucina tenuisculpta | 17 | 8 | 2 | 1 | 16 | 8 | | 2 | 15 | 3 | | | 4 | 2 | 8 | 16 | 12 | 11 | 14 | 15 | 22 | 4 | 4 |
| Pectinaria californiensis | | | | | | | | | | | | | | | | | | | | | 1 | | |
| Pectinaria granulata | 20 | 7 | 26 | 8 | | 1 | 1 | 12 | 12 | 12 | 3 | 3 | 16 | 2 | 20 | 27 | | 1 | | 2 | | | 1 |
| Pectinaria sp. | 2 | | | | | | | | | 1 | | | | | 1 | 2 | | | | | | | |
| Pentamera lissoplaca | | | 3 | | | | | | | | | | | | | | 1 | | | | | | |
| Pentamera populifera | | | | | | | | | | | | | | | | | 1 | | | | 1 | | 1 |
| Pentamera rigida | | | | | | | | | | | | | | | | | | | 1 | | | | |
| Pentamera sp | 1 | | | 2 | | | | | | | | | | | | 2 | | | | | | | |

| Location: / Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pherusa plumosa | 2 | | | 3 | | | | | | | | | | | | | | | | | | | |
| Pholoe glabra | | 10 | | | | | | 1 | | | | | | | | | | | | | | | |
| Pholoe minuta | | | 4 | 1 | | | | | | | | 1 | | | | | | | | | | | |
| Pholoe sp. | 5 | | | 3 | 2 | | | | | | | 1 | | | | | | | 1 | | 2 | | |
| Pholoe sp. N-1 | 3 | | 3 | | 2 | | 1 | | 4 | | | 1 | 1 | | 2 | | | 5 | | 1 | 4 | 1 | 4 |
| Pholoides asperus | 3 | | 75 | 11 | 2 | | | | 1 | | | 1 | 4 | 71 | 54 | 30 | | | | | 1 | | |
| Phoronida | | | | | | | | | 1 | | | 8 | | | | | 1 | 1 | 1 | 4 | 2 | 1 | 2 |
| Phoronopsis harmeri | | | | | | | | | 1 | | | | | | | | 1 | | | | | | |
| Photis brevipes | 3 | 23 | | 1 | | | | | | | | | | | | | 1 | 2 | 2 | | | | |
| Photis spp. | 10 | 77 | | 5 | 1 | | 8 | 3 | 1 | 4 | 3 | 1 | 2 | | 1 | 3 | 3 | | 11 | | 1 | 1 | |
| Phoxocephalidae | 6 | | | | | | 2 | | | | | | | | | | | | | | | | |
| Phyllochaetopterus prolifica | | | 1 | | | | | | 1 | | | | | | | | | | 20 | | 3 | | 9 |
| Phyllodoce longipes | | 5 | | | | | | | | | | | | | | | | | | | | | |
| Phyllodoce sp. | 1 | | | | | | | | | | | | | | | | | | 1 | | | | |
| Phyllodocida | | | | | | | | | | | | | | | | | | | | | 1 | | |
| Pinnixa schmitti | 2 | | 6 | 6 | 1 | 1 | 34 | 16 | 2 | | | 4 | 2 | | | 1 | | 6 | 1 | 5 | 3 | 4 | 6 |
| Pinnixa spp. | 7 | 13 | 6 | 2 | 2 | 2 | 31 | 55 | 9 | 5 | 7 | 6 | 1 | | | 1 | 3 | 7 | | 4 | 9 | 1 | |
| Platyhelminthes | | | | | | 1 | | | | | | | | | | | | | | 1 | | | |
| Platynereis bicanaliculata | 39 | 29 | 9 | 11 | 4 | | 2 | 7 | 2 | 2 | | 9 | 1 | | 32 | 17 | 26 | 2 | 4 | 2 | 2 | | |
| Podarke pugettensis | 8 | | | 6 | 3 | | 2 | | 3 | | | 4 | | 3 | 4 | | 2 | | | | | 1 | |
| Podarkeopsis glabrus | 5 | 5 | 2 | 6 | 9 | | 14 | 3 | 5 | 1 | 1 | 4 | 17 | | 7 | 8 | 2 | 2 | 2 | 1 | 2 | 3 | 1 |
| Podocerus cristatus | | | | | | | | | | | | | | | | | 3 | | 4 | | | | |
| Pododesmus macrochisma | 8 | | 4 | 2 | 3 | | | 1 | 1 | | | | | | 23 | 1 | 22 | 2 | 5 | | 1 | 1 | 2 |
| Polycirrus sp. complex | | | | 8 | 12 | 7 | | | 22 | | | | | | 1 | | 8 | 40 | 8 | 46 | 11 | 32 | 21 |
| Polycystididae | | | | | | | | | | | | | | | 1 | | | | | | | | |
| Polydora sp. | | | | | | | | | 1 | | | | | | | | | | | | | | |
| Polynoidae | | | 2 | 1 | | | 2 | | | | | 2 | | | | | | | 1 | | | | |
| Polyplacophora sp | | | | | | | | | | | | | | | 1 | | | | | | | | |
| Porcellidium sarsi | | | | | | | | | | | | | | | 11 | | | | | | | | |
| Prionospio jubata | 108 | | 19 | 100 | 19 | 5 | 79 | | 39 | 25 | 29 | 46 | 84 | 36 | 72 | 83 | 19 | 2 | 11 | 1 | | | |

| Location: / Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prionospio lighti | 31 | 7 | | 12 | 8 | 1 | 114 | 31 | 11 | 65 | 46 | 36 | 22 | 3 | 8 | 12 | 4 | 1 | | | 1 | | |
| Prionospio sp. | | | | 2 | 5 | 2 | | | | 3 | | | | | | | | | 1 | | | 1 | |
| Prionospio steenstrupi | | 6 | | | 1 | | 4 | 93 | 4 | | | | 2 | | | 13 | | | | | | | |
| Proceraea cornuta | | | | 1 | | | | | | | | | | | | | | | | | | | |
| Protodorvillea gracilis | | | | 2 | | | | | | | | | | | | | | | 4 | | | | |
| Protomedeia prudens | | | | | | | | | | | | | | | | | 5 | 2 | 3 | 2 | | 5 | 1 |
| Protomedeia spp. | | | | 1 | 4 | | | | 3 | | | | | | | | 10 | 14 | 18 | 12 | 3 | 31 | 12 |
| Protothaca staminea | 23 | 26 | 2 | | 23 | 8 | | 1 | 6 | | | | 4 | 2 | | 37 | 20 | 24 | 5 | 3 | 3 | | 1 |
| Pseudochitinopoma occidentalis | | | | 2 | | | | | | | | | | | | | | | | | | | |
| Ptilosarcus gurneyi | | | | | | | | | | | | | | | | | | | 1 | | 2 | | |
| Pugettia gracilis | | | 1 | | | | | | | | | | | | | | | | | | | | |
| Pugettia spp. | | | | 1 | | | | | | | | | | | | | | | | | | | |
| Rhepoxynius boreovariatus | | | | | | | | | | | | | | | | | | 17 | | 22 | | 2 | 6 |
| Rochefortia tumida | 244 | 563 | 185 | 318 | 146 | 62 | 63 | 53 | 377 | 37 | 9 | 18 | 26 | 3 | 84 | 90 | 82 | 45 | 23 | 50 | 28 | 9 | 3 |
| Rutiderma lomae | | | | 1 | | | | 1 | | | | | | | | | | | | | | | |
| Sabellidae | | | | 1 | | | | | | | | | | 1 | | | | | | | | 1 | |
| Saxidomus gigantea | 107 | 78 | 36 | 129 | 28 | 9 | 1 | 15 | 121 | 2 | 2 | 1 | 12 | 3 | 38 | 46 | 24 | 11 | 5 | | 3 | | |
| Scleroconcha trituberculata | | | | 3 | | | | | | | | | | | | | | | | | | | |
| Scleroplax granulata | | | 1 | | | | 50 | 25 | 3 | | 27 | 29 | | | | | 1 | | | | | | |
| Scoletoma luti | | | | | 3 | 1 | | | 2 | | | | | | | | 1 | 24 | 1 | 20 | 18 | 23 | 54 |
| Scoloplos acmeceps | | | | | | | | 4 | | | | | | | | | | | | | | | |
| Scoloplos armiger | | | 1 | | | | | | | | | | | | | | | | | | | | |
| Smittina sp | | | | | | | | 1 | | | | | | | | | | | | | | | |
| Solen sicarius | | | | | | 1 | | | | | | | | | | | 2 | 2 | 1 | 1 | | 5 | 1 |
| Sphaerodoropsis minuta | | | | 1 | | | | | | | | | | | | | | | | | | | |
| Sphaerosyllis ranunculus | 4 | | 2 | 10 | 6 | | 2 | | 2 | 2 | | | 1 | | 2 | | | | | | | | |
| Sphaerosyllis sp N1 | | 3 | | | | | | | | | | | | | | | | | | | | | |
| Spio filicornis | | | | | | | | | | | | | | | | | | 1 | | 1 | | 1 | 4 |
| Spiochaetopterus pottsi | 3 | | 1 | 1 | 2 | | 1 | 2 | | | | | | | 6 | 3 | 1 | 14 | 1 | 13 | 6 | | 1 |
| Spionidae | | | | | | | | | | 1 | | | | | | | | | | | | | |

| Location: / Species | AS-01 | AS-03 | AS-05 | AS-09 | AS-13 | AS-14 | PGSP-103 | PGSP-104 | PGSP-106 | PGSP-107 | PGSP-108 | PGSP-109 | PGSP-110 | PGSP-111 | PGSP-116 | PGSP-118 | PGSP-119 | PGSP-120 | PGSP-121 | PGSP-122 | PGSP-123 | PGSP-129 | PGSP-130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spiophanes berkeleyorum | 1 | | | | 1 | | | | 3 | 1 | | | | | | 2 | | 2 | 1 | 4 | 1 | | |
| Stylochidae | | | | | | | | | | | | | | | | | | | 1 | | | 1 | 3 |
| Syllides sp | | 1 | | | | | | | | | | | | | | | | | | | | | |
| Synidotea nebulosa | | | | | | | | | | | | | | | | 1 | 2 | | | | | | |
| Tellina modesta | 2 | 6 | 1 | 4 | 12 | 2 | 6 | 2 | 6 | | | | 1 | 1 | 1 | 1 | 5 | 4 | 9 | 10 | 2 | | 1 |
| Tellina sp | 3 | 2 | | 11 | | | 1 | 6 | 1 | 5 | 10 | 3 | 1 | | 7 | | 9 | | | | | | |
| Tenonia priops | | | | | | 2 | | | 1 | | | | | | | 2 | 1 | 4 | | 2 | | 1 | |
| Terebellidae | 9 | 4 | | 1 | | 1 | | | | | | 7 | | 1 | 3 | 6 | 13 | | 8 | 1 | 2 | | 1 |
| Terebellides californica | | | | | | | | | | | | | | | | | | 1 | | | | | |
| Tetrastemma sp | | | | | | | | | | | | | | | | | | | 1 | | | | |
| Thelepus sp. | | | | | | | | | | | | | | | | | | | | | 1 | 1 | |
| Thysanocardia nigra | | | | | | 4 | 9 | | | | | | | | | | | 1 | | 2 | | 2 | 1 |
| Tubulanus polymorphus | 2 | | | | | | | | 1 | | | | | | | | 1 | 3 | | | 1 | | |
| Tubulanus sp | | 1 | | | | | | | | | | | | | | | | | | | | | |
| Tubulanus sp A | | 2 | | | | | | | | | | | | | | | | | | | | | |
| Turbonilla sp | | | | 2 | 6 | | | | | | | | | | | | 1 | | 5 | 1 | | 1 | 7 |
| Turridae | | | | 2 | | | | | | | | | | | | | | | | | | | |
| Typosyllis elongata | | | | | | | | | | | | | | | | | | | 1 | 1 | | 7 | 3 |
| Typosyllis heterochaeta | | | | | | | | | | | | | | | 1 | | 7 | | 9 | | | 7 | |
| Typosyllis sp. | | | | 1 | | | | | | | | | | | | | | 2 | | | | | |
| Velutina plicatilis | | | 1 | | | | | | | | | | | | | | | | | | | | |
| Westwoodilla caecula | | | | | 4 | | 1 | 1 | 6 | | | | | | | | 3 | | 4 | 2 | | | 2 |
| Zeuxo normani | | 4 | | 3 | | | | | | | | | | | | | 1 | | | | | | |
| Zygonemertes virescens | 3 | 4 | | | | | | | | | | | | | | | 1 | | | | | | |

# Appendix D - Data Preparation and Screening

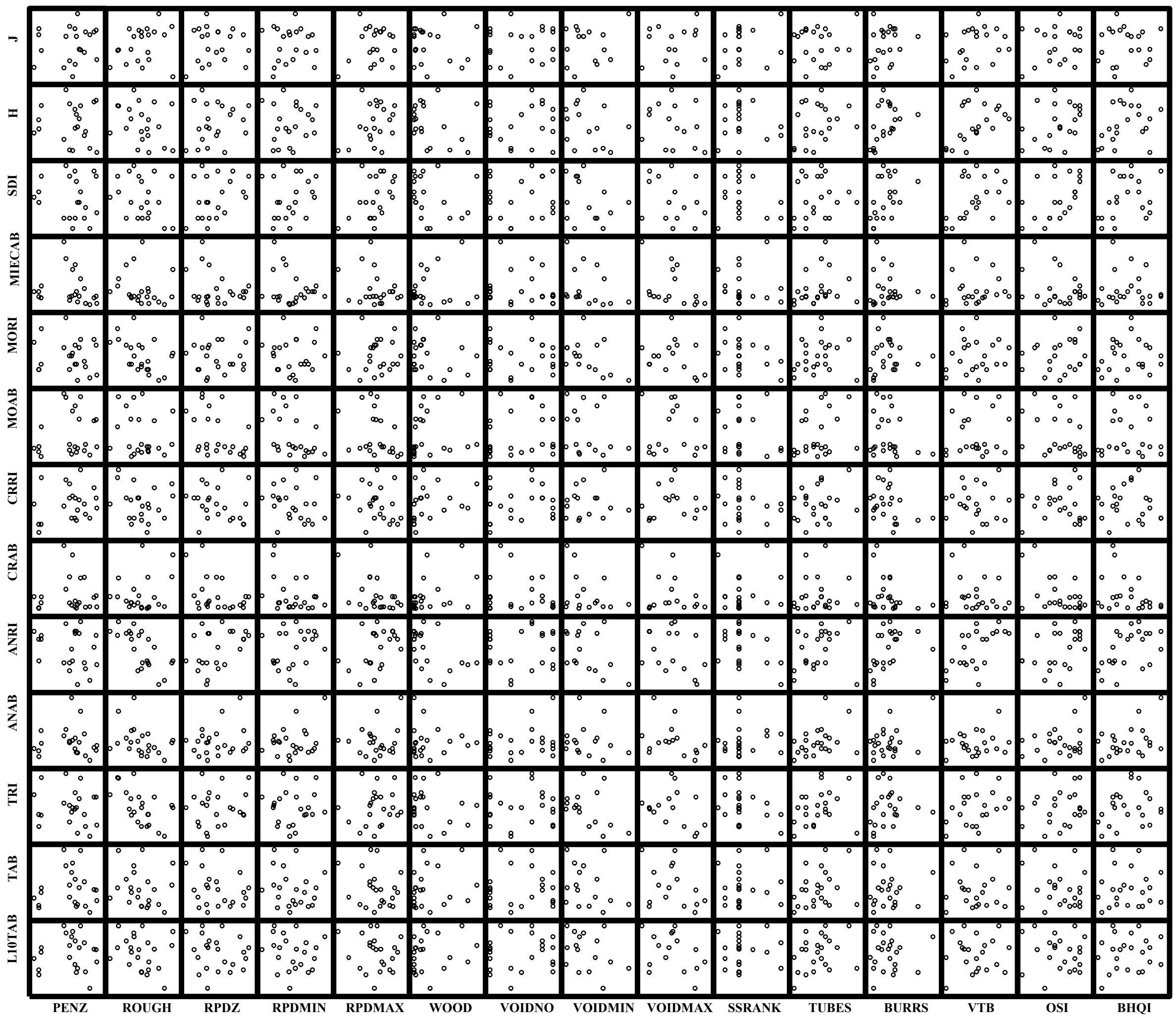


Figure D-1. Example matrix of two-way plots with 15 SPI parameters (as independent variable x) and 13 benthic community metrics (as dependent variable y) for 23 sampling locations in Port Gamble Bay, having removed several potential outlier results.

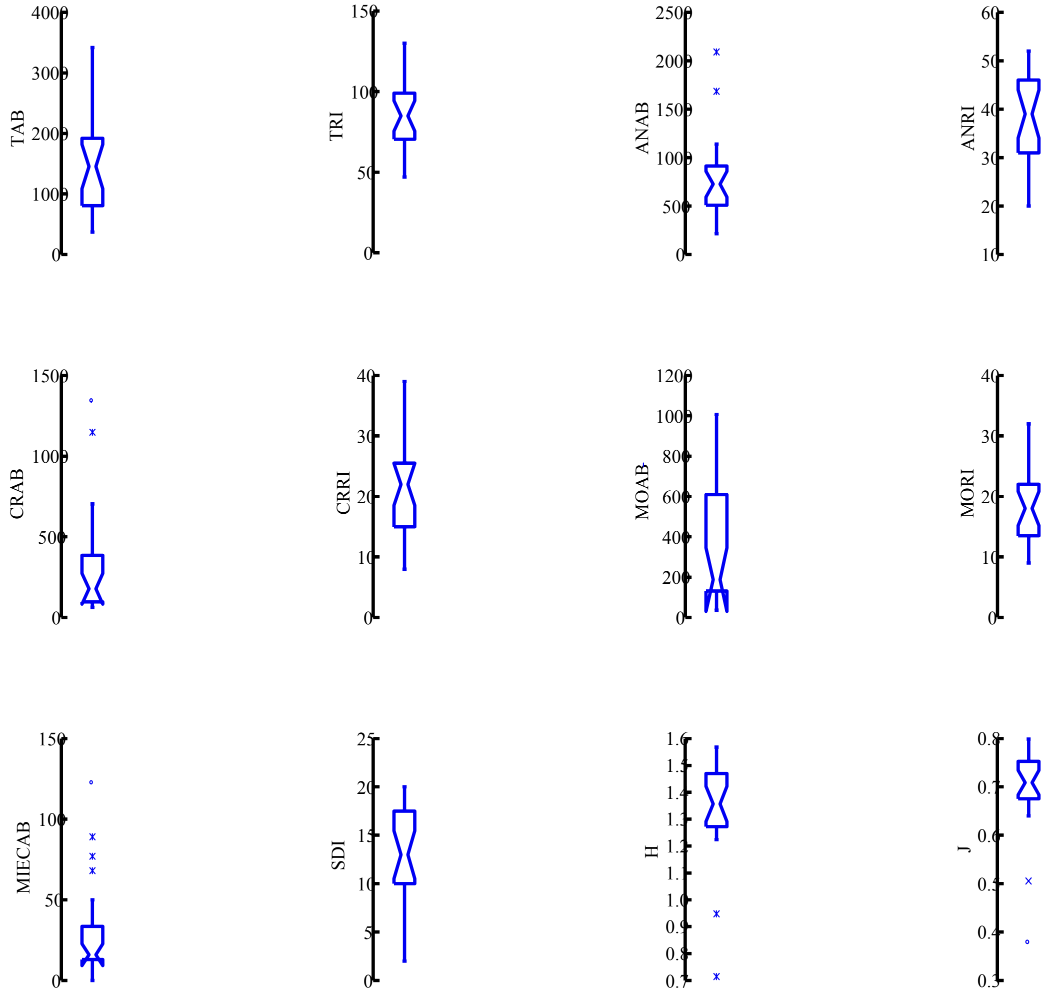


Figure D-2. Example of box-and-whisker plots using 12 benthic community metrics for 23 sampling locations in Port Gamble Bay to identify potential outlier values.

Table D-1. Screening for potential outlier results in SPI, sediment conventionals, and benthic community Port Gamble Bay data sets.

| Parameter | Potential Outlier | Why? | Excluded? | Reason(s) for excluding from some analyses |
|---|---|---|---|---|
| Boundary Roughness | AS-05<br>AS-09<br>PGSP-104<br>PGSP-119<br>PGSP-121 | a | No | Normal distribution but none failed Dixon's test. |
| % Wood | PGSP-103<br>PGSP-104 | a, b, d | No | • Non-normal distribution.<br>• PGSP-103 passed screening but likely outlier. |
| Successional Stage rank | PGSP-109<br>PGSP-111 | b-d | Yes | Successional stage rank not useful metric for analysis of this study site because of limited range of results. |
| Total number small tubes | PGSP-108 | a | No | |
| Burrows | PGSP-130 | b, d | Yes | Improves data distribution. |
| VTB | PGSP-130 | b | Yes | Improves data distribution. |
| % Gravel | AS-03<br>PGSP-108 | b | No | Not used in analyses. |
| % TOC | PGSP-103<br>PGSP-107<br>PGSP-109 | a | No | |
| Ammonia | PGSP-111 | a, b, d | No | |
| Sulfide | PGSP-107<br>PGSP-110 | a, b | No | |
| Annelid Abundance | PGSP-130 | a, b, d | Yes | Geographic considerations. Non-normal distribution. Box plots. |
| Crustacea Abundance | AS-03<br>AS-05 | a-d | AS-03 only | • Geographic considerations.<br>• Non-normal distribution.<br>• Box plot shows > (median value + 3*interquartile range).<br>• Fails Dixon's test too. |
| Misc. Taxa Abundance | AS-03<br>PGSP-106 | a, b, d | AS-03 only | • Geographic considerations.<br>• Non-normal distribution.<br>• Misc. and Echinodermata abundance combined for most analyses. |
| Echinodermata Abundance | AS-01<br>AS-03<br>AS-05<br>AS-09<br>PGSP-106 | a-d | AS-01, AS-03 | • Geographic considerations.<br>• Non-normal distribution.<br>• Misc. and Echinodermata abundance combined for most analyses. |
| Misc. Taxa + Echinoderm. Abundance | AS-01<br>AS-03<br>AS-05<br>PGSP-106 | a-c | AS-01, AS-03 | • Geographic considerations.<br>• Non-normal distribution.<br>• AS-03 identified by box plots. |

| Parameter | Potential Outlier | Why? | Excluded? | Reason(s) for excluding from some analyses |
|---|---|---|---|---|
| H' and J | PGSP-129<br>PGSP-130 | a-d | Yes | • Geographically separate.<br>• Extremely low values for these and SDI. |
| Various benthic metrics | AS-01<br>AS-03 | a-d | Yes | • Geographically separated.<br>• Different hydrodynamic regime.<br>• Evidence of different benthic community. |

a = < 25th percentile value - 1.5*interquartile range or
> $75^{th}$ percentile value + 1.5*interquartile range
b = outside the mean value ± 2.5*standard deviation
c = box plot outlier
d = identified as outlier using Dixon's equations

VTB = Total number of Voids + Small Tubes + Burrows.

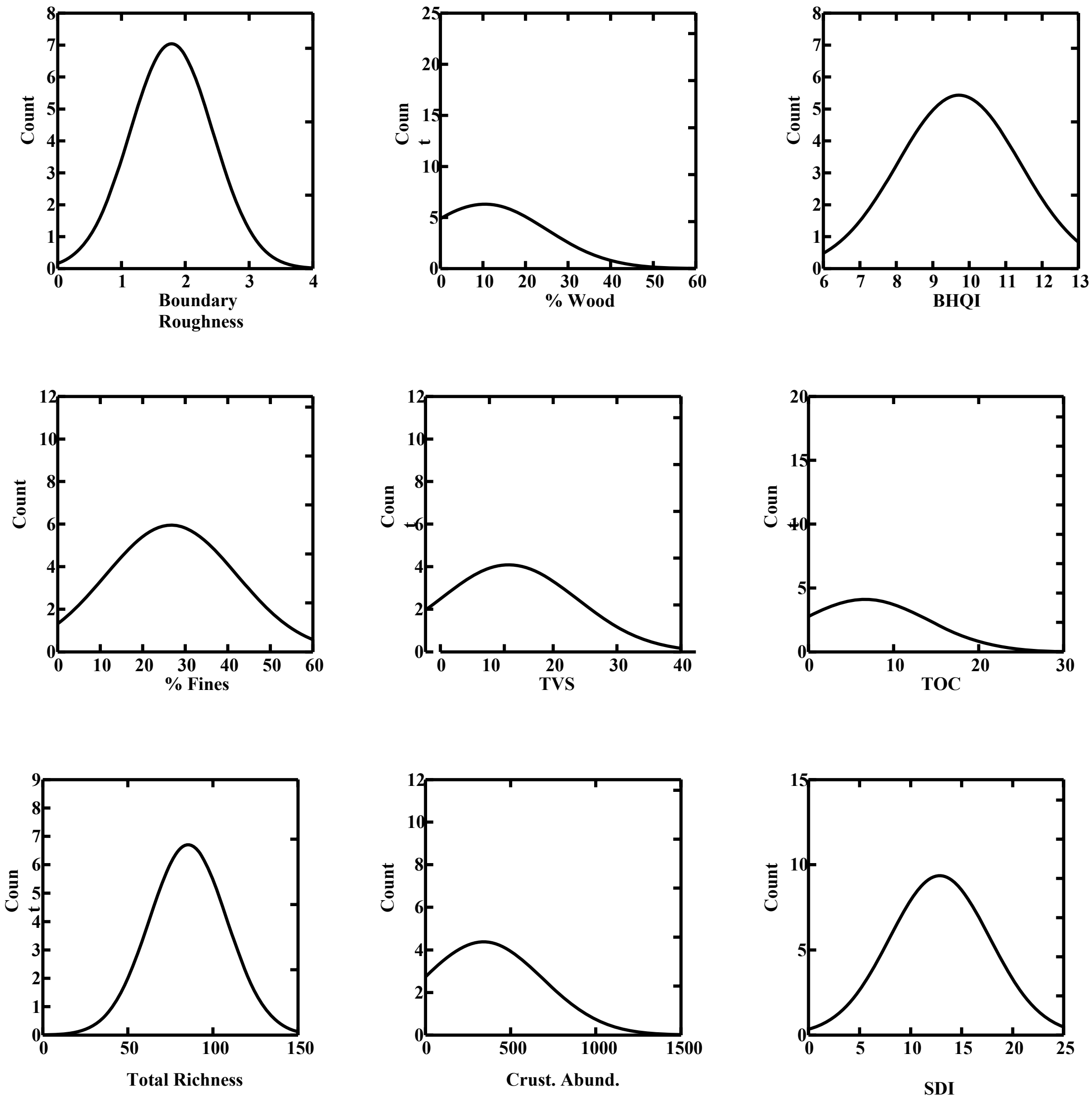


Figure D-3. Examples of smoothed distribution plots of measured SPI, conventional, and benthic community variables.

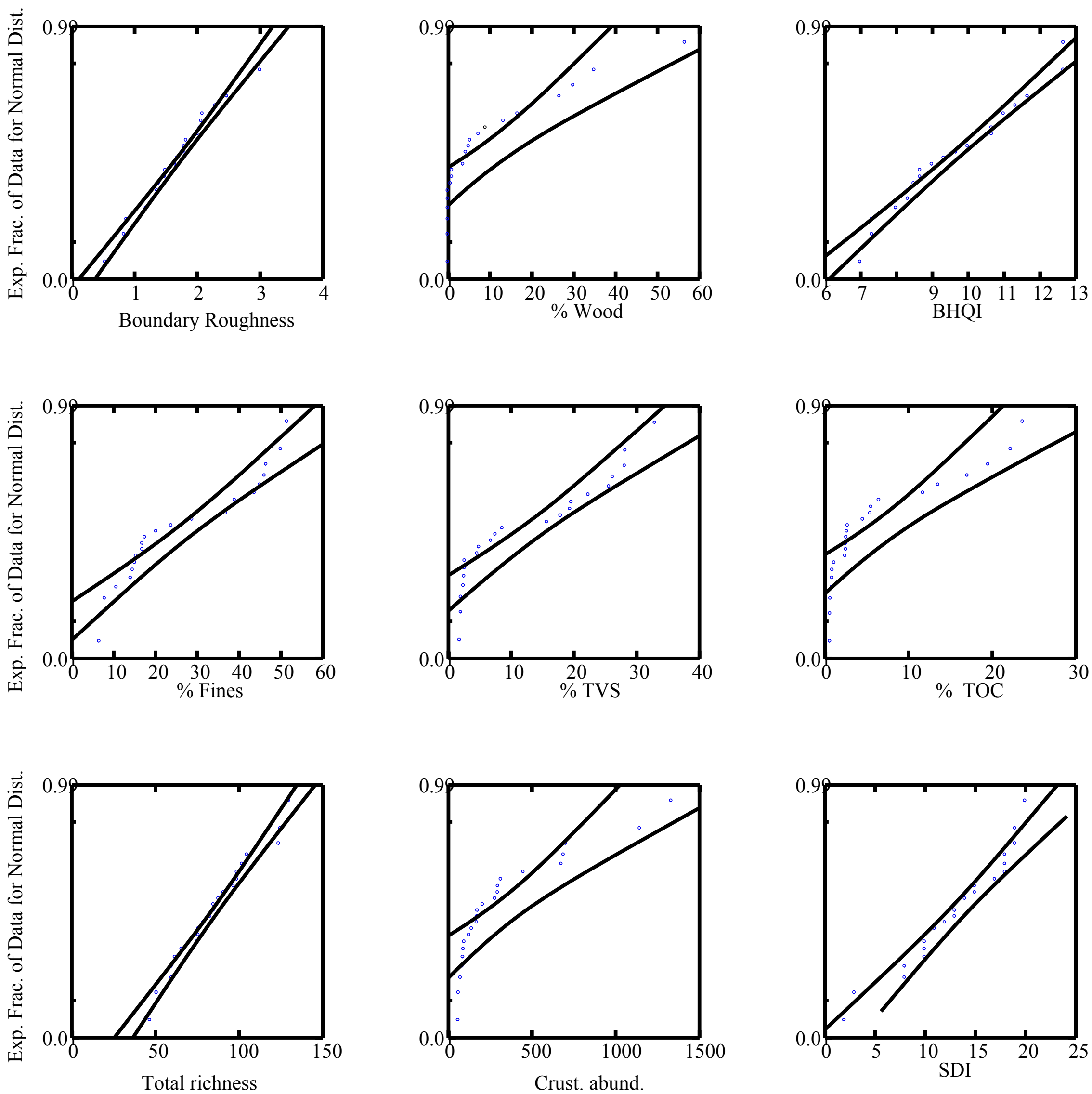


Figure D-4.  Normal probability plots of the same SPI, conventional, and benthic community variables, showing 95% confidence intervals.

Table D-2. Distributional analysis of results for 19 sampling locations in Port Gamble Bay.

| SPI Variable | Normal? (SW) | Conventionals Variable | Normal? (SW) | Benthic Community Variable | Normal? (K-S) |
|---|---|---|---|---|---|
| Penetration Depth | X | Total Solids | X | Total Abundance | √ |
| Boundary Roughness | √ | % Sand | X | $log_{10}$ Total Abundance | √ |
| RPD Depth (mean) | √ | % Silt | X | Total Richness | √ |
| RPD Depth (min) | √ | % Clay | X | $log_{10}$ Total Richness | √ |
| RPD Depth (max) | √ | % Fines | X | Annelid Abundance | √ |
| Wood (% Vol) | X | % TVS | X | Annelid Richness | X |
| Total Voids | X | % TOC | X | $log_{10}$ Annelid Richness | √ |
| Voids (Min. Depth) | √ | Ammonia | √ | Crustacea Abundance | X |
| Voids (Max. Depth) | √ | Sulfide | X | Crustacea Richness | √ |
| Successional stage | X | | | Mollusca Abundance | X |
| Small Tubes (Total Number) | √ | | | Mollusca Richness | √ |
| Burrows (Total No.) | √ | | | Misc. taxa Abundance | √ |
| VTB = Total Number Voids + Small Tubes + Burrows | √ | | | Echinodermata Abundance | X |
| OSI | √ | | | Miscellaneous + Echinoderm. Abundance | X |
| BHQI | √ | | | SDI | √ |
| | | | | H' | √ |
| | | | | J | √ |

SW = Shapiro and Wilk test (1965).
X = normal distribution.
√ = normal distribution.

Table D-3. Example matrix of Spearman rank correlation coefficients involving SPI and benthic community results.

Correlations between parameters or variables within a single data type are enclosed in a dark box. Significant correlations between pairs of parameters or variables (p<.05) are shaded. N = 19 except for void depths (N = 13). Ellipses indicate potential to predict certain benthic community metrics using certain SPI metrics or sediment conventionals independent variables. Values with an absolute value that has been rounded up to 0.5 are not shaded.

| | PENET | BROUGH | RPD | RPDZMN | RPDZMX | WOOD | TVOID | VOIDMN | VOIDMX | TUBES | BURRS | VTB | OSI | BHQI | TS | SAND | SILT | CLAY | FINES | TVS | TOC | AMMON | SULF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAB | 0.0 | -0.2 | -0.1 | -0.2 | -0.2 | 0.2 | 0.1 | -0.2 | -0.1 | 0.3 | -0.1 | 0.0 | -0.1 | 0.1 | -0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | -0.2 |
| TOTRI | -0.2 | -0.6 | 0.3 | 0.2 | 0.4 | -0.3 | -0.1 | -0.3 | -0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.4 | 0.5 | -0.5 | -0.4 | -0.5 | -0.5 | -0.5 | -0.5 | -0.3 |
| ANAB | 0.0 | -0.2 | 0.0 | -0.1 | -0.2 | 0.2 | 0.1 | -0.1 | -0.3 | 0.2 | -0.1 | 0.0 | 0.0 | 0.1 | -0.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | -0.2 |
| ANRI | -0.2 | -0.7 | 0.5 | 0.3 | 0.6 | -0.7 | 0.0 | -0.4 | -0.5 | 0.4 | 0.7 | 0.6 | 0.5 | 0.5 | 0.7 | 0.7 | -0.7 | -0.6 | -0.7 | -0.8 | -0.8 | -0.8 | -0.5 |
| CRAB | 0.0 | 0.0 | -0.2 | -0.2 | -0.3 | 0.3 | -0.1 | -0.2 | 0.0 | 0.1 | -0.3 | -0.2 | -0.2 | -0.2 | -0.3 | -0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.0 |
| CRRI | 0.1 | -0.2 | -0.1 | -0.2 | -0.1 | 0.4 | 0.0 | 0.0 | 0.0 | 0.1 | -0.3 | -0.2 | 0.0 | 0.0 | -0.2 | 0.0 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.0 |
| MOAB | 0.1 | -0.2 | -0.2 | -0.4 | -0.2 | 0.1 | 0.3 | -0.2 | 0.0 | 0.4 | 0.1 | 0.2 | -0.1 | 0.4 | 0.0 | 0.1 | -0.2 | 0.0 | -0.1 | -0.1 | -0.1 | -0.2 | -0.1 |
| MORI | -0.1 | -0.5 | 0.2 | 0.2 | 0.3 | -0.3 | -0.1 | -0.4 | -0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.3 | 0.4 | -0.4 | -0.3 | -0.4 | -0.4 | -0.4 | -0.4 | -0.3 |
| MIAB | -0.5 | -0.6 | 0.5 | 0.4 | 0.4 | -0.7 | -0.3 | -0.4 | -0.6 | 0.3 | 0.6 | 0.4 | 0.4 | 0.2 | 0.5 | 0.8 | -0.6 | -0.7 | -0.7 | -0.5 | -0.6 | -0.6 | -0.6 |
| ECAB | -0.1 | -0.1 | 0.0 | 0.0 | 0.0 | -0.2 | -0.1 | -0.3 | -0.1 | 0.4 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 | 0.2 | -0.3 | -0.1 | -0.3 | -0.3 | -0.3 | -0.3 | -0.2 |
| MIECAB | -0.4 | -0.4 | 0.2 | 0.2 | 0.2 | -0.5 | -0.2 | -0.4 | -0.5 | 0.3 | 0.4 | 0.3 | 0.2 | 0.2 | 0.4 | 0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.6 |
| SDI | -0.1 | -0.2 | 0.4 | 0.3 | 0.6 | -0.4 | 0.0 | -0.4 | -0.4 | 0.2 | 0.5 | 0.4 | 0.6 | 0.3 | 0.4 | 0.4 | -0.5 | -0.4 | -0.5 | -0.4 | -0.5 | -0.3 | -0.1 |
| H | 0.0 | -0.2 | 0.2 | 0.1 | 0.4 | -0.3 | 0.0 | -0.3 | -0.3 | 0.3 | 0.4 | 0.5 | 0.4 | 0.3 | 0.3 | 0.3 | -0.4 | -0.3 | -0.4 | -0.3 | -0.4 | -0.3 | 0.0 |
| J | 0.1 | 0.3 | -0.2 | -0.1 | -0.1 | 0.0 | 0.1 | -0.1 | 0.0 | 0.1 | 0.2 | 0.3 | 0.0 | 0.0 | 0.0 | -0.1 | -0.1 | 0.0 | -0.1 | 0.2 | 0.1 | 0.0 | 0.2 |