

**ST. PAUL WATERWAY AREA REMEDIAL ACTION AND
HABITAT RESTORATION PROJECT
FINAL 1998 MONITORING REPORT**

Prepared for

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1. SUMMARY AND OVERVIEW

1.1 INTRODUCTION

This report describes the 1998 monitoring of the sediment remediation and habitat restoration at the St. Paul Waterway area adjacent to the Tacoma Kraft Mill.

The St. Paul Waterway Area Remedial Action and Habitat Restoration Project (Project), which is the first cleanup at the Commencement Bay Nearshore Tideflats Superfund Site, was initiated in 1987 by Simpson Tacoma Kraft Company and Champion International Corporation, the current and previous owners of the mill, respectively. Project approvals under federal and state Consent Decrees include a long-term monitoring, reporting, and contingency plan (Monitoring Plan) to ensure the effectiveness of the remedy and to provide an annual report on the monitoring results.

The Project is designed to provide: (1) permanent isolation from the environment of chemical contamination found in marine sediments, and (2) restoration of intertidal and shallow water habitat (state and federal Consent Decrees 1987 and 1991; Washington State Department of Ecology (Ecology) 1990; Weiner 1991).

The Project is now in the long-term or confirmational monitoring phase. Project monitoring includes physical, chemical, and biological studies.

Monitoring at the St. Paul Waterway area occurred before, during, and after Project construction. Monitoring before construction helped not only with Project design but also with establishing baseline conditions for evaluating future monitoring results. Monitoring during and immediately after construction ensured pollution control and verified that the remedial work conformed to the remedial design (this monitoring is sometimes referred to as “protection” and “performance” monitoring).

The remedial work was completed and approved by Ecology in September 1988. In January 1991, the U.S. Environmental Protection Agency (EPA) approved the Commencement Bay Nearshore Tideflats Superfund Completion Report for St. Paul Waterway Sediment Remedial Action (Weiner 1991). EPA had previously approved the Commencement Bay Nearshore Tideflats Source Control Completion Report for the St. Paul Waterway (Ecology 1990). Ecology is responsible for administering source control monitoring requirements for the Tacoma Kraft Mill. The St. Paul Waterway Area was delisted from the federal Superfund National Priorities List (NPL) and Washington State Hazardous Sites list.

The Monitoring Plan was revised in conjunction with the December 1991 approval of the federal Consent Decree and an amendment to the 1987 state Consent Decree (both decrees now contain the same monitoring program). As described below, the monitoring protocols have also been revised to incorporate biological indicators and to take into consideration previous monitoring results. These revisions were anticipated by the Consent Decrees, and the Monitoring Plan was updated in 1993 to reflect these changes (i.e., the modifications were filed with the court in August 1993). The 1998

Monitoring Report was prepared in accordance with reporting requirements set forth in the Monitoring Plan.

The fifth year of monitoring was completed in 1993 and a five-year data review was conducted (Parametrix 1993a). The five-year review confirmed that the Project is attaining performance standards and continues to provide a healthy environment for marine organisms (Parametrix 1993a). The Commencement Bay Restoration Plan and Programmatic EIS likewise noted the habitat value of the Project and states that this restoration project will be a significant component of the Trustee's bay-wide restoration plan (USFWS et al., 1997).

Because habitat restoration and re-establishment of healthy biological communities is a fundamental long-term goal of the Project, the Consent Decree and Monitoring Plan anticipated that biological monitoring of benthic communities (marine life living in the sediments) would assume a primary role in the evaluation of Project performance. The main role of chemical and physical monitoring, as well as other biological monitoring, is to assist in interpreting the benthic monitoring results.

As specified in the Monitoring Plan, a biological indicators approach was developed jointly by Simpson, Champion, and EPA in 1994, in consultation with the public and consulted agencies (Parametrix 1994). This approach is used to evaluate the natural habitat at the Project and allows evaluation of biological health and productivity.

Biological indicators are intended to provide early evidence of changes in biological communities at the Project habitat. If statistically significant changes are present, a review process ("second tier analysis") is initiated to evaluate the causes and ecological importance of these changes. The biological indicators approach has been incorporated into the early warning process, which provides early notice of potential problems so that a contingency plan and monitoring can be considered and implemented as necessary. If the second tier analysis shows ecologically important differences are due to human causes (the biological "early warning level"), an early warning notice is sent to EPA, as is the case for the other early warning indicators. As described in the Monitoring Plan, the biological indicators will become the mechanism for the early warning process, compared to the interim chemical early warning levels that were used earlier in the Project (which will continue to be used to assist in evaluating the data).

Consistent with the adaptive management approach to the Project, which includes adjusting the monitoring protocols as appropriate based on actual results, the chemical monitoring program was modified in 1994 and 1998 following review by the consulted agencies and EPA approval (Parametrix 1993b and 1998b). The modifications to monitoring were made because several years of detailed chemical data indicated that the Project is functioning as designed and because the biological indicators approach has been put in place. EPA determined that these modifications are consistent with the objectives of the Monitoring Plan to ensure an appropriate chemical monitoring component to characterize Project performance.

Also consistent with the adaptive management approach to the Project, the biological monitoring program was modified in 1996 following review by the consulted agencies and EPA approval (USEPA 1996a). The primary modification to biological monitoring was the discontinuation of

annual epibenthic monitoring. Review of seven years of epibenthic data indicated that the Project was providing extensive epibenthic habitat as planned and that this habitat was not changing substantially from year to year. Furthermore, epibenthic monitoring is not a part of the biological indicators approach because epibenthic populations tend to be highly variable from year to year, depending on weather and other natural variations. Thus, epibenthic monitoring was neither necessary nor appropriate for determining the proper functioning of the Project habitat through the approved biological indicators approach.

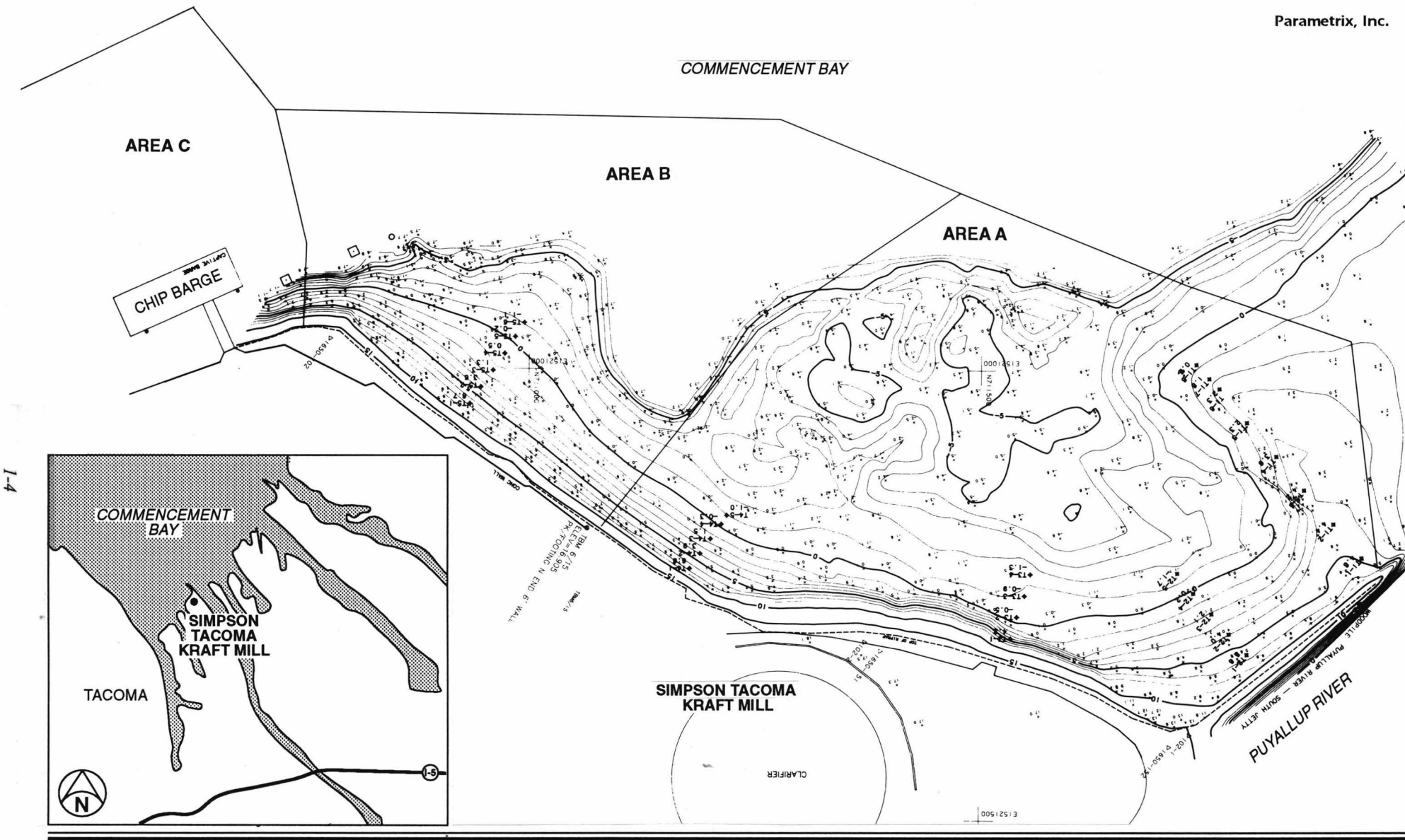
1.2 THE PROJECT

After analyzing many technologies, as well as their effectiveness in—and impact on—marine waters, capping of the contaminated sediments “in place” in the shallow water offshore of the Tacoma Kraft Mill was selected as the environmentally preferred alternative (Weiner 1991). The 17-acre area was capped with clean sediment in July and August of 1988. The cleanup action was integrated with natural resource restoration to produce new intertidal and shallow-water habitat in Commencement Bay, an area that had lost about 90% of such habitat over the last 100 years. More than 6 acres of new intertidal habitat were reconstructed over the portion of the cap along the shoreline. Clean, shallow-water habitat was provided over the remaining 11 acres (Figure 1-1).

To promote biological recovery and enhance the ability of the bay habitat to re-establish itself, sediment from the nearby Puyallup River was used for the cap material (Parametrix 1987). The capping sediments consisted of black sand collected near the mouth of the Puyallup River. Intensive testing of the Puyallup River borrow area showed the sediments to be among the cleanest in Puget Sound. Natural forces normally deposit Puyallup River sediments in the Commencement Bay shallows. These sands were suitable for both physically isolating contaminated sediments and providing a desirable substrate for new marine habitat.

To understand the Monitoring Plan and analyze the results, it is helpful to understand the pre-Project conditions and the variation in cap thickness. The cap ranges from approximately 5 to 20 feet thick, reflecting differences in the sediment contamination over the 17-acre area. Area A, closest to the former mill outfall, had the most chemical contamination (see Figure 1-1). Levels of concern decrease as the distance from the former outfall increases. Area B contained a mixture of chemical and organic woody material, while Area C was largely composed of woodchips on natural sediments.

Most of Area A was to receive a cap of at least 4 feet, plus 4 to 8 feet for habitat enhancement, with the most contaminated area to be filled above the high tide line. Much of Area A actually received 12 feet or more of sediment, while some areas received up to 20 feet. Area B, which was to have at least 4 feet (as a design criteria), received a cap about 12 feet thick. Area C, which did not contain chemical contamination requiring isolation of sediment from marine life, was to receive a cap of 2 feet to provide a new substrate; it received up to 4 feet of clean material. In addition, varied topography was constructed in Areas A and B to allow pools and ridges for diverse habitat, with the expectation that natural forces would continue to redistribute the sediments and shape the areas (Weiner 1991).



1-4

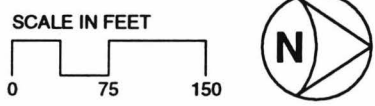


Figure 1-1.
Project Location
and Areas

As part of the Project's adaptive management approach, clean material was placed at Transect 5 in the summer of 1995 as a preventive maintenance measure, after consultation with agencies and the public, and EPA approval (Parametrix 1995b). Irregularly shaped gravelly material was selected both for habitat and armoring value. The material was placed after all 1995 monitoring was completed.

Prior to and following Project construction, natural accretion from deposition of Puyallup River sediments had been and continues to occur on the north side of the Project site. Over time the generally clockwise movement of the currents where the river enters the bay is expected to cause accretion along the entire beach. Although the depth of the cap in Area B has always met performance standards, previous years' monitoring and early warning results showed that some of the middle stations on Transect 5 were 2 to 4 feet lower because of sediment redistribution in the early years of the Project (the 1994-95 monitoring results indicated small changes, actually showing an increase at two of these stations). There was consensus on the desirability of nourishing the beach with additional material along some of the middle stations on Transect 5, to add an additional margin of safety against erosion and allow more time for natural accretion to reach the south end of the beach.

The maintenance construction involved placement of gravel material with some larger cobble to provide protection from wave action in the area of Transect 5. The total area of gravel placed was approximately 0.75 acres in a 300- by 100-ft area between 3 feet mean lower low water (MLLW) and -3 feet MLLW. The maintenance construction took place July 12 through July 16, 1995. The material placement did not effect any monitoring stations. The material is expected to provide substrate that will benefit macrophyte attachment and epibenthic habitat (Parametrix 1995a). Physical monitoring of this area in 1998 indicated that the material was in place, with only minor redistribution since 1995.

1.3 1998 RESULTS AND FIVE/TEN YEAR REVIEW

In general, 1998 monitoring results indicate that the Project and new habitat are both functioning as planned. The Project provides habitat for diverse biological communities of benthic and epibenthic organisms, as well as algae. Shorebirds and salmon use the site for feeding and rearing, and tide pools observed at low tide are abundant with invertebrates. Productive shoreline habitat now exists at the Project site where essentially no productive habitat existed prior to Project construction.

The cap sediment elevations had minimal changes, with only minor redistribution of materials at higher intertidal levels on two transects. Cap thickness surpasses the design criteria of 4 feet over the entire cap and the performance standard of 3 feet, as set forth in the Consent Decree.

Although some biological indicators showed significant differences in Tier One results, (described in Section 1.4.4 and Section 4), further analysis of bay-wide biological conditions around the Project indicates that those changes were caused by conditions unrelated to cap integrity. Thus, no Tier Two analyses were recommended and EPA concurred (USEPA 1998a).

1.3.1 Physical Monitoring

Monitoring data show the cap and habitat are slowly changing because of natural forces and normal processes that were anticipated in the Project design. A land-based survey was conducted to measure Project site elevations in 1998. Intertidal elevations at the Project indicated only minor redistribution of sediments. None of these changes was above early warning levels. No physical survey results above early warning levels (described further in Section 1.4.3) occurred in 1998.

The sediment cores indicated the cap thickness surpasses the design criteria of 4 feet (and the performance criteria of 3 feet) throughout the site. Cap thickness as measured by the cores ranged from 11.0 to 15.9 feet. The cap thickness range observed in the 1998 sediment cores was consistent with previous monitoring results (Parametrix 1990 through 1996).

1.3.2 Chemical Monitoring

The 1998 chemical monitoring included samples of surface sediments and subsurface core sediments. Thirty-one chemicals were monitored at three surface sediment stations, including phenols, phthalates, resin acids, and guaiacol. Six chemicals called “indicator chemicals” (which includes 4-methylphenol, guaiacol, and four chlorinated guaiacols) were monitored at four subsurface sediment core stations. In addition, both surface and subsurface sediments were analyzed for conventional parameters and grain size.

1.3.2.1 Surface Sediments

Chemical monitoring of surface sediments was conducted to determine whether chemicals were present at levels above early warning (see Section 1.4.3.1). Of 93 possible chemical detections, one detection in surface sediments (abietic acid at station SS2) was found to be slightly above the early warning level of 1,000 µg/kg. Many chemicals, including the resin acids, do not have established Lowest Apparent Effects Thresholds (LAETs)(see Section 1.4.2). Therefore, another standard for triggering the early warning process was established, and the level of 1,000 µg/kg was selected because it is well above the detection limit for most of these chemicals. The 1,000 µg/kg early warning level for resin acids is not based on any toxicity testing, and it is unknown whether concentrations over this level are environmentally significant. Because the environmental significance of this level is unknown and the biological community present at the site appears to be healthy (see Section 1.3.3 below), the chemical detection does not appear to indicate any problem with the health or integrity of the Project cap or habitat.

Two of the fourteen phenol compounds that were analyzed were found in the surface sediment samples, but in amounts that were far below early warning levels. One of the six phthalates that was analyzed was found at low levels in the surface sediment samples. Phthalate compounds have no specific early warning level. Guaiacol was not detected in any surface sediment sample.

1.3.2.2 Subsurface Sediments

Four sediment cores were obtained at the Project site to determine cap thickness and to measure chemical concentrations in the cap material. At three of the four stations, all of the indicator chemical results were non-detections. Consistent with past subsurface chemistry monitoring results, 4-methylphenol (200 µg/mg) and guaiacol (2-methoxyphenol) (150 µg/mg) were detected in the C2 sample at the 85-105 cm depth. This sample location is deep within the cap (approximately eight feet deep) near the interface of the underlying surface and the bottom of the cap. This result is below the 536 µg/mg early warning level for 4-methylphenol (guaiacol does not have an established early warning level). Similar detections have occurred in previous years at this location and are believed to be evidence of mixing between cap materials and underlying materials that occurred during Project construction (Parametrix 1993a and 1998a).

1.3.3 Biological Monitoring

In 1998, benthic and macrophyte (marine algae) monitoring were conducted. The monitoring indicated that the habitat has been colonized by numerous organisms and several macrophyte species. Both the benthic and macrophyte communities are similar to other estuarine mudflat communities in Puget Sound.

1.3.3.1 Benthic Monitoring

A two-tiered biological indicators approach is used as specified under the Monitoring Plan. In 1998, Tier One of the biological indicators approach showed that the Project habitat was healthy. Therefore, upon concurrence with EPA, Tier Two analyses were not conducted, consistent with the requirements of the biological indicators approach. Results of Tier One are discussed below.

One aspect of the biological indicators approach is the comparison of the Project site benthic community to background stations (see Section 1.4.4). Comparing the Project site to background stations provides a frame of reference for comparing the new habitat to an established, relatively natural area. Background stations may not contain identical species or communities relative to Project stations, however, comparisons can provide valuable insights or suggest trends caused by natural forces that may help to interpret Project monitoring results.

Two background stations for Commencement Bay were sampled in 1998. Station R1, located on the northeastern side of the Puyallup River Delta near Sitcum Waterway, has been sampled annually since 1993. Station R3, located near R1 at a different water depth, was sampled for the first time in 1996. Benthic community results from both background stations were reviewed to determine whether they were appropriate background stations, prior to making any data comparisons with the Project site. In 1998, EPA determined that both background stations could be used to make comparisons with the Project site (USEPA 1998a).

The ecological indices used to assess the Project area include a set of four tests, three of which evaluate diversity, and one that evaluates the proportional similarities of taxa groupings. As per EPA approval in a July 29, 1997 letter (USEPA 1997), Principal Coordinates (PCOR) analysis is no longer utilized under the biological indicators approach. The PCOR analysis was determined not to

be necessary since the analysis did not appear to provide any information that was not already being provided by the other benthic community indices (with respect to the performance of the cap).

Two types of statistical comparisons were made. One involved pooling the background station data from R1 and R3 and comparing it to the pooled Project data, and the other involved station-specific comparisons (non-pooled data). These two data sets were used both to compare Project to background stations, and to compare 1998 results to 1997. Project abundances and numbers of benthic taxa were also compared to 1997 data. The purpose of the latter was to determine whether large or unusual changes had occurred at the Project stations over time. In many cases, annual changes may reflect normal fluctuations in benthic populations caused by annual variations in weather patterns, currents, sediment deposition, or other natural factors.

Pooled Data Comparisons

The pooled data comparisons of 1998 benthic abundances and diversities indicated that the Project benthic community was statistically indistinguishable from the background stations. The other comparisons indicated that the background stations had greater biomass of molluscs and “other taxa”.

Station-Specific Data Comparisons

The station-specific (non-pooled) comparisons indicated that most Project stations were statistically indistinguishable from background stations, regardless of the indices tested. The two exceptions were for (1) station B1—taxon richness and mollusc biomass were less than either background station; and (2) all project stations—“other taxa” biomass was less than either background station. Although station B1 ranked lower in taxon richness compared to both background stations and the other Project stations, the PSI revealed that station B1 clustered closely to other stations (specifically, near B2 and B6 for log-transformed data).

All three diversity tests (Shannon-Wiener, Simpson’s, and Evenness) showed high diversity at most Project and background stations. Diversity of benthic taxa (equivalent to taxon richness for the purposes of this report) at Project stations B1 and B2 was less than the background stations, determined primarily by the relatively small numbers of taxa found at Project stations B1 and B2.

The Proportional Similarity ecological index calculated the similarities of mean abundances between replicates and stations for log-transformed and untransformed data. Log-transformed data indicated a moderate similarity for abundances between replicates within a station, and for three project stations (B3, B4, and B5) and both background stations. The remaining three Project stations were dissimilar to the background stations for mean abundance.

Comparisons Between 1997 and 1998

In 1998, the pooled Project stations, all individual project stations (except B6), both background stations, and the pooled background stations were statistically indistinguishable from 1997 for total abundance, abundance of numerically dominant (dominant), abundance of non-numerically dominant (non-dominant) taxa, and taxon richness. For station B6, taxon richness and abundance

of non-dominant taxa were indistinguishable between years. Test results for all three diversity indices showed greater or equal diversity (as measured by the number of taxa present) at most stations sampled in 1998, compared to 1997. Background station R1 and Project station B1 displayed a lower diversity for all three tests in 1998 than in 1997. Station B2 also demonstrated a lower diversity in the Shannon-Wiener and Simpson's Index tests in 1998 as did station B5 in the Evenness Index test. The difference between 1997 and 1998 Project benthic populations is attributable to natural variations, as similar differences were observed at the background stations.

Overall, the benthic communities inhabiting the Project and background stations appeared to be normal for the physical conditions found at the sites, compared to similar sites in Puget Sound, where this habitat type has been recognized for many years (MacGinitie and MacGinitie 1968; Kozloff 1983; and Dethier 1990). The results obtained appear to be indicative of natural variation in benthic communities near the Puyallup River and may represent a period of stabilization in abundance and diversity of these communities compared to 1997. Other observations of biological function near the Project (e.g., abundances of juvenile salmon and other fish, discussed in Section 1.3.3.3) confirm that the Project habitat is valuable to other organisms that depend on a healthy benthic community.

1.3.3.2 Macrophytes Monitoring

The macrophyte (large marine algae or "seaweed") community on the Project site was similar to other estuarine mudflat communities found in Puget Sound (Kozloff 1973). While the Project site supported several species, the abundance and diversity of the macrophyte community is limited by substrate conditions and the somewhat brackish nature of the water. The abundance of macrophytes appeared to be directly related to the amount of stable substrate and protection from wave action. In general, most rock surfaces below the riprap were colonized by macrophytes. Similar to other nearby mudflats, areas exposed to wave action were not colonized by macrophytes.

1.3.3.3 Other Biological Observations

Many species have been observed using the site, including gulls, fish, and crabs. Mats of small, tube-building crustaceans, worm tubes, small snails, barnacles, and limpets were also observed at the Project site. Invertebrates collected at the site included sand shrimp, jellyfish, and comb jellies (ctenophores). Numerous birds have been observed at the Project site; the most common species were Canada goose and glaucous-winged gull. Salmon use was documented in the 1997 Monitoring Report (Parametrix 1998a).

1.3.4 Second Five Year Overview and Ten Year Review

Physical, chemical, and biological characteristics of the Project have been monitored consistent with the requirements of the Monitoring Plan for ten years (Parametrix 1990 through this report). The 1993 Annual Monitoring Report provided a five year overview (Parametrix 1994). This section provides a similar overview of the past five years and briefly summarizes the results of the ten years of Project monitoring.

1.3.4.1 Physical Monitoring

Bathymetric surveys were conducted in 1995 and 1998, and transect surveys have been conducted annually for the past five years. (The Monitoring Plan requires transect surveys in 1995 and 1998 (see Appendix 1, Table 1-1); Simpson and Champion elected to perform them annually for the past five years in-part to provide a complete ten-year data set.)

As anticipated, surface features of the Project have changed as cap material has been redistributed over the site. The greatest changes of elevation occurred within two years following Project construction, however, both increases and decreases have continued over time. In general, redistribution of the materials appears to have become less rapid and the magnitude of change has become smaller within the past five-to-eight years (Table 1-1).

A comparison of elevations measured 1994 through 1998 at stations on transects 1 through 4 indicates that the extent of changes within the past five years have been less than six inches at the majority of the stations (Table 1-1). Transect 5 had new material placed as a preventive measure in 1995 (see Section 1.2 of this report). The subsequent three years of monitoring indicate little change in this area at Transect 5 (Table 1-1).

There have been only two physical monitoring results above applicable early warning criteria in the past five years: (1) 1994 for an increase of 2.8 feet over two years at Station 1-4 (which has since gradually returned to the approximate initial cap elevation); and (2) 1995 for a decrease of 1 foot at Station 1-5 (the resulting elevation was 2.2 feet higher than the elevation at the time of the initial cap placement, and is now over 1 foot higher than in 1988).

Since Project construction, eight stations have had net increases, one station is unchanged, and 13 stations have had net decreases (excluding stations on Transect 5) (see Table 1-1). As was found in the first five year review, the redistribution of materials at the site has not affected the integrity or function of the cap in any area measured. Comparison of elevation changes with core thickness (taken for chemical monitoring) has shown that the cap continues to meet performance standards and continues to range from approximately 5 to 20 feet in Areas A and B.

1.3.4.2 Chemical Monitoring

Chemical monitoring over the past five years included sampling of surface and subsurface sediments in 1995 and 1998. The analysis reflected a more focused monitoring program than in the first five years for two reasons: (1) the results from the first five years, which showed few detections or early warning results (Parametrix 1994); and (2) the use of the biological indicators approach required to be developed by the Monitoring Plan (Parametrix and Shimek 1994, Parametrix 1996).

Table 1-1. Elevation changes (ft MLLW) monitored on the Project site at five intertidal transects between 1988 and 1998.

Transect/ Station	12/88	6/89	6/90	6/91	6/92	6/93	6/94	6/95	7/96	6/97	5/98	Elevation Changes 6/94 to 5/98	Elevation Changes 12/88 to 5/98
1-1	5.0	6.1	5.8	5.2	5.2	4.9	4.4	4.8	4.8	4.5	4.5	+0.1	- 0.5
1-2	3.6	4.0	5.1	4.7	4.5	4.5	4.1	4.4	4.5	4.5	4.5	+0.4	+0.9
1-3	2.9	2.9	2.7	3.1	2.7	3.7	3.6	4.2	4.4	3.9	3.0	- 0.6	+0.1
1-4	2.4	2.1	1.5	1.4	1.3	4.0	4.1	3.6	2.8	2.5	2.2	- 1.9	- 0.2
1-5	0.1	0.6	1.0	3.5	3.6	3.7	3.3	2.3	2.1	1.9	1.9	- 1.4	+1.8
1-6	1.8	1.7	2.8	3.4	2.8	2.8	2.4	2.3	2.3	2.2	2.1	- 0.3	+0.3
1-7	0.2	0.5	2.1	2.6	2.1	2.1	1.8	1.8	1.7	1.7	1.4	- 0.4	+1.2
1-8	-0.3	-0.1	1.3	1.5	1.0	0.9	0.9	0.8	0.8	0.8	0.9	+0.0	+1.2
2-1	6.9	6.6	7.0	6.7	6.3	5.8	5.6	5.6	5.3	5.2	4.9	- 0.7	- 2.0
2-2	6.0	5.5	5.1	5.0	4.7	4.3	4.1	4.0	3.6	3.6	3.5	- 0.6	- 2.5
2-3	4.6	4.2	3.4	3.1	2.5	2.5	2.1	2.1	2.0	2.0	2.0	- 0.1	- 2.6
2-4	2.7	1.7	1.0	0.7	0.5	0.4	0.2	0.2	0.3	0.3	0.2	+0.0	- 2.5
2-5	-1.9	-1.8	-1.0	-2.0	-2.1	-1.8	-1.8	-1.7	-1.6	-1.6	-1.6	+0.2	+0.3
3-1	5.7	5.3	4.7	4.7	4.8	4.4	4.3	4.2	4.5	4.5	4.0	- 0.3	- 1.7
3-2	2.9	1.9	0.6	0.1	-0.3	-0.4	-0.6	-0.5	-0.4	-0.2	-0.3	+0.3	- 3.2
3-3	-0.2	-0.4	-0.7	-1.2	-1.4	-1.1	-0.9	-0.9	-0.7	-0.5	-0.6	+0.3	- 0.4
3-4	-1.4	-1.6	-1.6	-1.6	-1.8	-1.5	-1.4	-1.3	-1.4	-1.3	-1.4	+0.0	+0.0
4-1	5.2	7.6	8.4	7.6	7.7	7.0	6.7	6.6	6.7	6.7	6.3	- 0.4	+1.1
4-2	6.2	5.7	5.0	4.8	4.7	4.3	4.0	3.9	3.7	3.7	3.6	- 0.4	- 2.6
4-3	4.4	3.6	2.8	2.5	2.2	2.1	1.9	1.5	1.3	1.3	1.0	- 0.9	- 3.4
4-4	1.4	0.9	0.5	0.5	0.3	0.0	-0.2	-0.3	-0.3	-0.3	0.2	+0.4	- 1.2
4-5	-0.9	-0.8	-0.8	-0.7	-1.0	-1.0	-0.9	-1.0	-1.0	-1.0	-1.0	- 0.1	- 0.1
5-1	5.0	6.5	8.5	7.5	8.0	7.0	6.5	6.7	6.7	7.0	6.8	+0.3	+1.8
5-2	5.8	6.1	5.7	5.4	4.8	4.4	3.8	3.6	3.8	4.0	4.1	+0.3	- 1.7
5-3	5.2	5.4	4.0	2.9	2.2	2.0	1.5	1.3	2.4	3.3	3.2	+1.7	- 2.0
5-4	3.7	3.1	1.7	1.1	0.6	0.5	0.4	0.5	2.8	2.5	2.7	+2.3	- 1.0
5-5	1.5	0.7	0.6	-0.3	-0.4	-0.4	-0.3	-0.2	1.6	1.6	1.2	+1.5	- 0.3
5-6	-0.8	-0.8	-0.7	-1.4	-1.4	-1.3	-0.9	-1.1	0.1	0.2	-0.2	+0.7	+0.6

Although a wide variety of chemicals have been monitored, most of the chemicals have been undetected over the past five year period, and very few of the chemicals monitored have been detected above the early warning criteria (see Table 1-2). Of more than 1,000 possible chemical detections over the past five years, only eight results were above applicable early warning criteria. Seven of the eight early warning results (six in 1995, and one in 1998) were surface sampling results for low levels of resin acids (a surrogate level of 1,000 $\mu\text{g}/\text{kg}$ is used in the absence of apparent effects thresholds).

The other early warning level exceedance was in 1995 at subsurface sediment station C2. The sample location was deep within the cap (approximately eight feet deep) near the interface of the underlying surface and the bottom of the cap. This result, and similar detections in other years at this location, are believed to reflect mixing at depth of berm sediments and contaminated sediments during Project construction. Consistent with the conclusion in the five-year review (Parametrix 1994a), the sediment chemistry does not indicate any chemical migration upward through the cap.

Overall, chemical monitoring over the past ten years indicates: (1) that no substantial levels of chemical from off-site sources are being deposited on the cap; (2) chemicals in the underlying sediments are remaining in-place; and (3) the Project cap is functioning as designed.

1.3.4.3 Biological Monitoring

Benthos and macrophytes have been examined annually at the site over the last five years; epibenthic sampling was conducted in 1994 and 1995. The Monitoring Plan implemented the two-tiered biological indicators approach in 1994 (Section 1.4.4 of the 1994 Annual Monitoring Report, Parametrix 1995c). This approach analyzes benthic communities at six sampling stations as the overall indicator of a healthy ecosystem and Project success. Under Tier One, comparisons are made between the six stations and background stations (located elsewhere in Commencement Bay) for the current year and in comparison to the past year's results. If Tier One analyses identify statistically significant differences that warrant further review, a Tier Two analysis is conducted to analyze ecological interactions at the Project and whether changes are due to natural or human causes. If the latter, an early warning notice is sent to EPA. The biological monitoring has not resulted in either an early warning notice or in the need to conduct a Tier Two analysis in any of the past five years.

Results for the past five years are similar to conclusions from the first five-year review (Parametrix 1994). The silt and sand fractions composing the outer, exposed beaches have fluctuated annually (see Figure 4-4). The inner lagoon area has become typical of a Puget Sound mudflat, with Stations B1 and B6 containing a majority of fines and silty material (also verified by site inspection on the periphery of the lagoon).

The abundance and complexity of biological systems at the site have been relatively similar for at least seven of the past ten years following initial recolonization (see Table 1-3). Throughout the past five years, the number of taxa identified to species at all Project stations ranged from 132 to 167, with variations at individual stations each year (see Table 1-3). Variations in the total number of taxa were also noted for all Project stations. Although total abundances at Project stations have fluctuated over the past five years, the mean total abundance (27,788 organisms) for those years

Table 1-2. Summary of chemical detections over early warning levels in ten years at the Project.

	Sediment Sample Type	Total Number of Parameters	Total Number of Samples**	Total Number of Possible Detections	Total Number of Detections Above Early Warning Levels*
1988	Cores	55	25	1,375	4
1989	Cores	55	19	1,045	1
	Gas Vents	54	3	162	0
1990	Cores	44	13	572	0
1991	Cores	50	36	1,800	31
	Gas Vents	52	8	416	0
	Surface	96	5	480	3
	Seeps	52	4	208	5
1992	Cores	4	36	144	2
	Gas Vents	5	10	50	0
	Surface	153	5	765	0
1993	Cores	6	18	108	0
	Surface	153	5	765	0
	Seeps	49	3	147	0
1995	Cores	6	18	108	1
	Surface	159	5	795	6
1998	Cores	6	4	24	0
	Surface	31	3	93	1
Total		1,030	220	9,057	52

Table 1-3. Abundance of benthic infauna and number of taxa (see Appendix Section 4.4) at Project stations, by year, since 1991. Note: 1994 station B2 abundances based on four replicates .

	Totals							
	1991	1992	1993	1994	1995	1996	1997	1998
A. Abundance								
B1	627	2,693	2,017	3,113	6,117	8,589	2,763	4,414
B2	2,193	3,062	3,341	4,042	3,037	6,268	3,700	3,692
B3	5,275	5,557	5,585	3,806	5,988	8,141	3,768	4,221
B4	3,419	8,303	9,718	4,471	5,247	10,361	2,705	3,129
B5	1,149	2,163	1,172	2,576	1,913	4,911	1,339	2,503
B6	1,262	3,235	2,559	5,703	7,947	3,978	6,681	3,818
Total	13,925	25,013	24,392	23,711	30,249	42,248	20,956	21,777
B. Number of Taxa Identified to Species								
B1	38	56	69	84	74	73	69	67
B2	74	67	69	77	65	68	81	61
B3	85	70	73	87	83	105	99	90
B4	79	82	80	95	96	86	96	89
B5	56	69	60	89	68	86	58	74
B6	59	74	75	79	78	71	68	63
Total	174	216	189	141	148	156	167	132
C. Total Number of Taxa								
B1	56	83	89	104	110	95	86	91
B2	102	101	91	98	99	89	105	87
B3	112	127	120	109	127	140	132	124
B4	111	134	119	112	132	118	120	121
B5	83	94	82	107	94	109	79	106
B6	69	91	79	98	111	111	99	88
Total					211	222	225	190

was higher than the mean total abundance (21,110 organisms) recorded in prior years (see Table 1-3). The variations in abundance over the past five years (e.g., increases in 1995 and 1996; decrease in 1997) appear to reflect bay-wide conditions (Parametrix 1995c, 1996, 1997c, 1998a).

Prior to Project construction, the site was essentially devoid of marine life. The restored intertidal beach and mudflats recolonized rapidly within the first two years (Parametrix 1990, Weiner 1991). Because there has been a change in sampling seasons from summer (in 1989 and 1990) to spring, direct ten-year comparisons of abundance and diversity across all sampling years are not statistically appropriate. However, benthic abundance had increased from essentially zero to between 627 and 5,275 organisms per station by 1991. This increase in abundance from pre-Project conditions has been maintained over the past seven years within a range of 1,172 to 10,361 organisms per station. Abundances ranged from 2,503 to 4,414 organisms per station in 1998.

Over ten years, based on the number of organisms per square meter obtained in the annual monitoring (averaging more than 7,000 organisms per square meter over 69,000 square meters), the

site has changed from an area with no or few benthic communities to intertidal habitat that has annually sustained a diverse population of approximately one-half billion benthic organisms.

The particular species at each station has generally varied from year-to-year, which appears to reflect the dynamic nature of the delta environment near the mouth of the river. Although a few species dominated a particular station in any given year, a variety of species have inhabited most of the areas sampled. The results indicate ongoing colonization and recruitment, biological diversity, and self-sustaining habitat.

As was concluded in the first five year review, substantial epibenthic populations have been found at the Project site, indicating that these organisms are utilizing the site (Parametrix 1994). Because epibenthic populations are generally highly variable, as reflected in Project monitoring, the biological indicators approach developed and adopted under the Monitoring Plan for use in the second five-year period focused on benthic monitoring rather than epibenthic monitoring. Epibenthos are common prey organisms for salmonids. A separate sampling effort conducted last year confirmed use of the site by juvenile salmonids during the spring migration, as reported in a separate study and in Section 1.3.3.3 of the 1997 annual monitoring report (Parametrix 1997b and 1998a).

Macrophyte coverage at the site has increased greatly since construction and has been maintained over the past five years. By 1991 macrophytes were growing on almost every stable hard surface available that was protected from substantial wave action or currents. In 1993, it appeared that macrophyte coverage was near the maximum possible given the physical conditions of the site. As material is redistributed on the site, some previously available surfaces are buried or moving around the site, as was anticipated in Project design.

Since 1991, annual variations in coverage by different species have been typical. This annual variation appears to be caused by changes in the availability of hard surfaces for macrophyte attachment, changes in tidal cycles, and weather (sun and growing seasons for each particular year). Some patterns have been observed in the distribution of aquatic macrophytes. A relatively dense kelp bed has formed along the shoal between shallow subtidal and intertidal elevations on the western boundary of the lagoon (where the initial berm was placed for Project construction). This kelp bed provides shelter, food, and detrital biomass for a range of species utilizing the mudflat. Similar functions are provided by beds of kelp and ulva that range in roughly a crescent from the southeastern-to-northeastern shoreline of the lagoon, and a finger of vegetated shallows extending into the center of the lagoon (Parametrix 1994 through 1998a).

The overall habitat results for the past five years, and for the first ten years of the Project, are similar to and consistent with the data and assessment made by EPA and the consulted agencies at the conclusion of the first five years of the Project. As stated in the first five-year review, abundance and diversity observed at the Project site have been generally similar to those found at the various background stations sampled and indicate a community similar to a typical healthy back-bay mudflat in Puget Sound.

1.4 EXPLANATORY NOTES ON THE MONITORING ANALYSIS

The following discussion may help the reader understand the monitoring conducted to date. Throughout this report, whenever the term “significant” is used in referring to numeric variations, it refers to statistically significant rather than environmentally significant variations. In many cases, phrases such as “significantly different from background values” are used. Such phrases indicate that when statistical tests are applied to the data, the Project is statistically different. This does not indicate whether this statistical difference is environmentally important. The statistical result must be evaluated in the context of the entire monitoring approach (particularly the biological indicators approach) to determine whether a result is environmentally important. Although the analytical results generally indicate only statistical differences, the environmental importance is discussed in the same sections.

1.4.1 Monitoring Methods Appendix

Sampling and analysis methods for each type of monitoring are presented in the Monitoring Methods Appendix (Appendix 1) of this document. The appendix contains all of the standard procedures and techniques used to collect samples, as well as those used to generate and analyze data. In most cases, the monitoring followed the methods described in the appendix. Occasionally, however, other methods were used; these deviations are described in the summary methods sections provided at the beginning of each chapter of the monitoring report. In addition, the summary methods sections in some chapters clarify how some results were obtained and describe any special circumstances of the 1998 monitoring. Future monitoring reports will also follow this approach.

The methods for benthic data analysis have also been updated, consistent with the requirements of the Monitoring Plan and the biological indicators approach described in Section 1.4.4.

1.4.2 Apparent Effects Thresholds (AETs)

Project planning and approval, and EPA’s decisions on sediment cleanup in Commencement Bay, were based on using Apparent Effects Thresholds (AETs). AETs are the chemical concentrations in sediments above which statistically significant biological effects are expected. In other words, values above AETs are presumed to cause effects on marine life found in sediments.

An AET level (also called an AET sediment quality value) has been established for each chemical of concern. The AET levels were developed based on biological tests using three types of small bottom-dwelling marine organisms. Amphipod mortality (amphipods are small shrimp-like organisms), oyster larvae abnormality, and benthic infaunal depressions (reduction in populations of tiny, bottom-dwelling organisms) were measured. Therefore, there are three sets of AET levels, one for each type of biological test. These AETs were used for this Monitoring Plan. A fourth biological test, Microtox™, which has established AET values, is not suitable for this type of monitoring and is not used under the Monitoring Plan. For each chemical of concern, the monitoring results are compared to the single biological test with the lowest AET (LAET) value. An LAET is a value considered to be an early indication of potential sediment effects.

Chemical monitoring requirements are explained because they are relevant to years when chemical monitoring occurs. In previous years, during Project sediment monitoring, the chemical concentration measured in sediments was compared to the LAET. This kind of chemical comparison has two main purposes: to serve as an early warning if unexpected conditions develop and to evaluate Project performance. The early warning role, described further below, triggers a contingency planning process if a sediment chemistry sample shows 80% of the LAET for an indicator chemical.

Occurrences of concentrations at early warning levels do not mean that there is a problem or the Project is not working. As discussed in Section 1.4.3.1, the approach is intended to provide sufficient lead time to evaluate whether a cap performance problem really exists or whether the result is an anomaly. The early warning process also helps to anticipate the need for response planning before a serious problem occurs.

AET values have not been established for some of the chemicals monitored over the last several years. The largest group of chemicals tested with no established AETs are commonly known as resin acids. Because these chemicals have no AETs, another standard for triggering the early warning process was established. The relatively arbitrary level of 1,000 ppb is used in this monitoring program as an early warning level. The 1,000 ppb level was chosen because it is well above the detection limits for most of these compounds. This level is used only as a conservative way to trigger the early warning process for chemicals with no established LAET. No existing evidence indicates the relative importance of 1,000 ppb concentrations of these various chemicals. It must be emphasized that it is unknown whether levels in excess of 1,000 ppb of these chemicals are environmentally significant.

The Monitoring Plan was designed so that chemical information would be supplanted by biological information as the primary determinant of the health and integrity of the Project habitat and cap. As discussed earlier, the biological indicators approach is now the primary method of evaluating the Project. Chemical information from parameters such as resin acids, where the environmental significance of chemical concentrations is unknown, is used in support of the biological evaluation.

1.4.3 Performance Standards

Through monitoring, Project effectiveness in isolating contamination from the marine environment and restoring healthy habitat can be evaluated. The federal Consent Decree specifies that physical, chemical, and biological performance standards be met.

- The physical standard requires that a minimum of 3 feet of clean sediment be maintained over Areas A and B.
- The chemical standard was an interim standard that applies until biological tests were established in accordance with the Monitoring Plan. Chemical standards are attained when the concentration of a chemical in a sediment sample, taken from the top 2 cm of the cap, is less than the lowest AET value.

- The biological standard consists of not finding an adverse effect for benthic infaunal abundance (i.e., that mean abundance is less than 50% of the background stations and statistically different); amphipod mortality (i.e., mortality exceeds 25% of the background sample and is statistically different); and bivalve, echinoderm, or larval abnormality (i.e., mean abnormality exceeds 20% of the background sample and is statistically different).

These performance standards are to be used in conjunction with one another to evaluate Project effectiveness. The performance standards are based on sediment quality objectives in the record of decision (ROD), specific human health risk assessments, environmental effects tests, and associated interpretative guidelines, including the Puget Sound Estuary Program protocols.

Monitoring conducted under the Monitoring Plan will provide the information necessary to assess conformance with the performance standards. Performance standards should not be confused with early warning values and indicators, which focus on early identification of potential problems at individual Project stations rather than overall Project performance. As described in Section 1.4.3.1, the Monitoring Plan uses biological, chemical, and physical indicators to initiate an “early warning” process for determining whether a problem might be occurring in terms of the ability of the Project to meet performance standards. For example, a sample that exceeds an LAET or shows substantial ecological differences between Project stations and background stations may trigger a contingency plan and additional biological testing to verify that conditions meet performance standards requirements.

1.4.3.1 Early Warning Approach

The Monitoring Plan’s early warning process identifies potential problems early enough that a rational and deliberate study can be conducted to determine whether there is, in fact, a problem and, if so, how serious it may be.

For example, in various years cap layers are tested to see whether the chemicals are present at early warning levels and whether toxic amounts of chemicals appear to be migrating through the cap. If results are at or above early warning levels, the Monitoring Plan then provides a process for analyzing whether a problem really exists and, if so, how best to respond to avoid recontaminating surface sediments and marine life. The early warning process is also used to ensure physical integrity of the cap. Early warning levels have been established for stations that change 12 inches or more in 1 year or where cap elevation changes an average of more than 10 inches per year over a period of 2 years. In addition, unusual information obtained from the annual visual inspection or post-storm inspections may trigger contingency actions.

In testing for any migration of pollution upward into the environment, the initial approach of the Monitoring Plan was to establish “early warning” levels at 80% of the LAETs for chemicals with LAETs and 1,000 ppb for chemicals without an LAET, as noted above. Now that the biological indicators approach has been developed, these indicators are the focus of the early warning process. As explained in Section 1.4.4, the biological indicators approach has several steps to determine whether the early warning process should be triggered. Initially, statistical analyses of four biological indicators are employed to compare the Project and background stations. These analyses compare the stations with one another, and compare the pooled Project stations with pooled

background, using data from both the current and previous year of benthic monitoring. If the analysis shows statistically significant differences indicative of human-induced changes in the cap's biological communities, EPA is notified that a second tier of analysis will be performed to evaluate the causes and ecological importance of these changes (Tier Two). Three biological indicators are used to assess whether the statistical difference indicates a potential problem regarding the health of the benthic community at each Project station. If this analysis shows ecologically important differences of human cause (the biological "early warning level"), an early warning notice is sent to EPA, as is the case for the other early warning indicators.

1.4.3.2 Contingency Monitoring

The Monitoring Plan provides contingency procedures for areas where monitoring results indicate that potential problems exist and need to be examined. The contingency procedures have four parts: (1) the early warning process (discussed above); (2) a contingency planning process to develop plans for an appropriate response; (3) a contingency response process to carry out the plans; and (4) an expedited review process, which may be initiated by the companies, agencies, or the public. The expedited review would address situations where monitoring results are much higher than early warning levels or where a fast response is needed.

1.4.4 Biological Performance

The introduction to Chapter 4 describes the factors used to evaluate the restored habitat (readers unfamiliar with biological analysis may wish to refer to Section 4.1). The habitat is studied for the numbers, variety, weight, and groupings or communities of species present each year—in biological terms, abundance, diversity, biomass, and benthic assemblages. The results from each sampling station are then compared, both with each other and with background stations.

The results are also evaluated with other factors that can affect the Project's biological communities. For example, different species or communities live at different depths; in different kinds of sediments (such as more sandy or muddy sediments); or in locations affected by other natural forces (such as places with more or less freshwater), predators, or pollution.

These factors and the individual ecology of each site can make evaluating the biological performance of a restored habitat a complex task. In addition, Commencement Bay and Puget Sound have few, if any, nearshore areas that have not been changed or affected by human activities. This makes it difficult to compare new habitat to some "ideal" natural condition. Biological performance is therefore evaluated in two ways: (1) comparison to background stations; and (2) comparison to information known about the ecology of intertidal areas and mudflats.

In the first method, the Project's biological performance is evaluated through a series of statistical comparisons to background stations using various benthic community measures. In the second method, the Project's biological performance is evaluated based on the species and biological communities found in intertidal areas throughout Commencement Bay and Puget Sound. Academic work and biological monitoring for other projects can provide indicators of biological performance for this Project. Although much is still being learned about Puget Sound, there is a sizeable body of

information that allows us to draw conclusions about species or communities typical of Puget Sound intertidal mudflats.

The biological indicators approach was created in 1994 to evaluate the Project benthic community, using primarily the first method with analyses similar to those employed in the first five years of monitoring. The biological indicators approach also uses more general measures of community health, compared to Puget Sound in general. The indicators used in the approach are summarized in the next paragraph. A detailed description of the biological indicators approach can be found in the 1994 Report (Parametrix 1994).

Within Tier One of the biological indicators approach there are two levels of analyses: Tier One, Level One, and Tier One, Level Two. Tier One, Level One assesses the similarity of benthic community structure between the Project stations and background stations using several factors (see Section 4.1 and Table 4-11 for a non-technical explanation of these factors):

- Total abundance of all individuals from each station,
- Total number of taxa for each station (diversity or richness),
- Abundance of numerically dominant taxa,
- Abundance of non-dominant taxa, and
- Standing crop analysis (biomass).

These factors are analyzed using:

- Proportional Similarity Index (PSI), and
- Analysis of Variance (ANOVA).

Tier One, Level Two includes comparisons of benthic data from the most recent year to that of the *previous year* for Project and background stations. Such comparisons help identify and confirm differences and similarities observed over time at the Project, as well as changes occurring at the Project stations as opposed to the background stations.

Tier Two analyses focus on ecological interactions at the Project and assess whether any statistically significant changes are due to natural or anthropogenic causes. The Tier Two indicators compare Project and background abundances of trophic guild taxa, key species, and pollution-sensitive or -tolerant taxa. Tier Two analyses are only conducted if Tier One indicates statistically significant differences that warrant further analysis.

Throughout this report, when statements are made about the general health of the Project, references to studies completed in Puget Sound that have reported similar conditions are provided. Statements on general health are helpful for discussing Project performance where background stations do not address the data or are inappropriate for comparisons.

Based on current knowledge about the Project site and other areas in Puget Sound, it is appropriate to conclude that marine life (particularly benthic organisms) will perpetually colonize the Project site. Animal densities at the Project are within a range considered normal for Puget Sound intertidal unconsolidated sediments (Kozloff 1983). Animal densities at the Project will continue to

naturally fluctuate because of physical changes due to the Project's proximity to the mouth of a major river. Species diversity indicates rapid recruitment into this area. The changing physical conditions at the Project (becoming muddier) also indicate that the Project's benthic community will continue to change. Such dynamic interaction between physical conditions and biological response is expected and commonly occurs in benthic communities.

2. PHYSICAL MONITORING

2.1 CAP ELEVATION MONITORING

Since its construction in 1988, the Project Site has been surveyed annually to monitor anticipated bathymetric changes. The purpose of these annual surveys is to identify any trends in beach erosion or accretion, by comparing year-to-year changes in substrate elevations.

2.1.1 Methods

In 1998, physical monitoring was completed consistent with methods described in the Monitoring Methods Appendix. Although a complete description of the sampling and analysis methods is presented in the appendix, some methods are presented in this section to provide an overview of how the physical monitoring results were obtained.

Two surveys of the Project site—a bathymetric survey and transect survey—were conducted in 1998. The bathymetric survey provided information used to generate elevation contours for the entire Project site, while the transect survey provided information about substrate elevation changes at specific locations (stations) along established transects at the Project site.

Transect surveys provide valuable information on potential redistribution of material on the cap; however, these surveys do not always provide the most accurate assessment of cap thickness because compaction of underlying sediments may have taken place since Project construction. The underlying sediments in many areas are loosely compacted and may be susceptible to compaction from the weight of cap sediments. [This compaction process was discussed in paragraph 4, page 10, of the 1988-1989 Monitoring Report (Parametrix 1990.)]

The overall Monitoring Plan also allows an assessment of cap thickness through the examination of coring profiles. In all the areas tested in 1998, coring profiles indicate that the cap is thicker than the minimum performance criteria (3-foot-thick) established in the Monitoring Plan (see Figure 3-2 in Section 3).

2.1.1.1 Bathymetric Survey

A bathymetric survey of the Project site was conducted during the low tide on May 26, 1998. The mean lower low water (MLLW) on that date was approximately -2.8 feet in Commencement Bay. The low tide allowed an accurate land-based survey to be conducted because elevations as low as approximately -7.0 feet MLLW were accessible to the surveyors. This is the sixth land-based survey of the Project site (in 1989 the survey was done from a vessel). A bathymetric map of the Project site was generated using a computer-aided drafting (CAD) system (Figure 2-1).



Figure 2-1 Project Site Topography and Location of Benchmark Stations

2.1.1.2 Transect Surveys

As in previous years, five elevation transects were surveyed across the surface of the Project site. Each transect consists of four to eight monitoring stations. The same locations established in 1990 are monitored every year (see Figure 2-1). The most recent transect survey was conducted on May 26, 1998.

2.1.2 Results and Discussion

2.1.2.1 Bathymetric Survey

The overall Project bathymetry is similar to results in prior years, with the exception of Transect 5, which had gravel material placed during 1995 as a preventative maintenance measure. As part of the Project's adaptive management approach, clean material was placed at Transect 5 in the summer of 1995, after consultation with agencies and the public, and receiving EPA approval (Parametrix 1995b). Although the depth of the cap in Area B has always met performance standards, previous years monitoring and early warning results showed that some of the middle stations on Transect 5 were two-to-four feet lower because of sediment redistribution in the early years of the Project. There was a consensus that it would be desirable to nourish the beach with additional material along some of the middle stations on Transect 5 to add an additional margin of safety against erosion. Irregularly shaped gravelly material was selected both for habitat and armoring value. Due to gravel content, it is expected to protect the cap from further erosion processes that might occur. This additional material has resulted in a nominal 1- to 2-foot elevation increase over the middle and southern portions of the site around Transect 5.

Since the material was placed after all of the 1995 monitoring was completed, the 1998 bathymetric survey is the first conducted since the material placement. Based on observations of the bathymetric map, best professional judgement, and comparisons to the 1995 map, no erosion that could affect the health or integrity of the cap was observed.

2.1.2.2 Transect Surveys

The transect surveys allow a comparison of annual variations in elevation at specific points on the Project site, as well as overall changes since the first post-cap survey in 1988 (Table 2-1; Figure 2-2). The following comparisons are based on the most recent transect survey conducted in May of 1998. Since project construction in 1988, the greatest changes at individual transect stations occurred at stations 3-2 and 4-3 where the elevations have decreased 3.2 and 3.4 feet, respectively, over the ten year period (see Table 2-1). Since 1990, the net decreases at stations 3-2 and 4-3 have been -0.9 feet and -1.8 feet, respectively. The greatest overall post-construction accretion has occurred at stations 1-5 and 5-1, where the elevations were 1.8 feet higher in 1998 than 1988. Some stations have both increased and decreased at different times since cap construction. The greatest changes in elevation occurred within two years after construction, however, both increases and decreases have continued over time. These results were consistent with redistribution of the cap material which was anticipated in Project planning. Since construction, 13 stations have had net decreases, 8 stations have had net increases, and one station is unchanged (excluding stations on Transect 5 where new material was placed as discussed in Section 1.2 and above).

Table 2-1. Elevation changes (ft MLLW) monitored on the Project site at five intertidal transects between 1988 and 1998.

Transect/ Station	12/88	6/89	6/90	6/91	6/92	6/93	6/94	6/95	7/96	6/97	5/98	Elevation	Elevation
												Changes 6/94 to 5/98	Changes 12/88 to 5/98
1-1	5.0	6.1	5.8	5.2	5.2	4.9	4.4	4.8	4.8	4.5	4.5	+0.1	- 0.5
1-2	3.6	4.0	5.1	4.7	4.5	4.5	4.1	4.4	4.5	4.5	4.5	+0.4	+0.9
1-3	2.9	2.9	2.7	3.1	2.7	3.7	3.6	4.2	4.4	3.9	3.0	- 0.6	+0.1
1-4	2.4	2.1	1.5	1.4	1.3	4.0	4.1	3.6	2.8	2.5	2.2	- 1.9	- 0.2
1-5	0.1	0.6	1.0	3.5	3.6	3.7	3.3	2.3	2.1	1.9	1.9	- 1.4	+1.8
1-6	1.8	1.7	2.8	3.4	2.8	2.8	2.4	2.3	2.3	2.2	2.1	- 0.3	+0.3
1-7	0.2	0.5	2.1	2.6	2.1	2.1	1.8	1.8	1.7	1.7	1.4	- 0.4	+1.2
1-8	-0.3	-0.1	1.3	1.5	1.0	0.9	0.9	0.8	0.8	0.8	0.9	+0.0	+1.2
2-1	6.9	6.6	7.0	6.7	6.3	5.8	5.6	5.6	5.3	5.2	4.9	- 0.7	- 2.0
2-2	6.0	5.5	5.1	5.0	4.7	4.3	4.1	4.0	3.6	3.6	3.5	- 0.6	- 2.5
2-3	4.6	4.2	3.4	3.1	2.5	2.5	2.1	2.1	2.0	2.0	2.0	- 0.1	- 2.6
2-4	2.7	1.7	1.0	0.7	0.5	0.4	0.2	0.2	0.3	0.3	0.2	+0.0	- 2.5
2-5	-1.9	-1.8	-1.0	-2.0	-2.1	-1.8	-1.8	-1.7	-1.6	-1.6	-1.6	+0.2	+0.3
3-1	5.7	5.3	4.7	4.7	4.8	4.4	4.3	4.2	4.5	4.5	4.0	- 0.3	- 1.7
3-2	2.9	1.9	0.6	0.1	-0.3	-0.4	-0.6	-0.5	-0.4	-0.2	-0.3	+0.3	- 3.2
3-3	-0.2	-0.4	-0.7	-1.2	-1.4	-1.1	-0.9	-0.9	-0.7	-0.5	-0.6	+0.3	- 0.4
3-4	-1.4	-1.6	-1.6	-1.6	-1.8	-1.5	-1.4	-1.3	-1.4	-1.3	-1.4	+0.0	+0.0
4-1	5.2	7.6	8.4	7.6	7.7	7.0	6.7	6.6	6.7	6.7	6.3	- 0.4	+1.1
4-2	6.2	5.7	5.0	4.8	4.7	4.3	4.0	3.9	3.7	3.7	3.6	- 0.4	- 2.6
4-3	4.4	3.6	2.8	2.5	2.2	2.1	1.9	1.5	1.3	1.3	1.0	- 0.9	- 3.4
4-4	1.4	0.9	0.5	0.5	0.3	0.0	-0.2	-0.3	-0.3	-0.3	0.2	+0.4	- 1.2
4-5	-0.9	-0.8	-0.8	-0.7	-1.0	-1.0	-0.9	-1.0	-1.0	-1.0	-1.0	- 0.1	- 0.1
5-1	5.0	6.5	8.5	7.5	8.0	7.0	6.5	6.7	6.7	7.0	6.8	+0.3	+1.8
5-2	5.8	6.1	5.7	5.4	4.8	4.4	3.8	3.6	3.8	4.0	4.1	+0.3	- 1.7
5-3	5.2	5.4	4.0	2.9	2.2	2.0	1.5	1.3	2.4	3.3	3.2	+1.7	- 2.0
5-4	3.7	3.1	1.7	1.1	0.6	0.5	0.4	0.5	2.8	2.5	2.7	+2.3	- 1.0
5-5	1.5	0.7	0.6	-0.3	-0.4	-0.4	-0.3	-0.2	1.6	1.6	1.2	+1.5	- 0.3
5-6	-0.8	-0.8	-0.7	-1.4	-1.4	-1.3	-0.9	-1.1	0.1	0.2	-0.2	+0.7	+0.6

Figure 2-2. Project Site Elevation Profiles 1998 Monitoring.

Transect 1 has generally experienced accretion since project construction, as six of the eight stations have had net elevation increases ranging from +0.1 feet to +1.8 feet. Over the past year (June 1997 to May 1998), one station had an elevation increase, three stations were unchanged, and four stations had elevation decreases, including station 1-3, which had an elevation loss of -0.9 feet. The cap thickness at Transect 1 was approximately 11.0 feet at the end of the transect as determined by subsurface coring at station C2 (see Section 3).

Transect 2 has generally had a net decrease in elevation since Project construction, as four of the five stations have had net elevation decreases ranging from -2.0 feet to -2.6 feet. Station 2-5 had a net elevation increase of +0.3 feet since Project construction. Most of the decreases occurred within the first few years after construction. The rate has slowed recently; between 1996 and 1998 the elevation changes at the individual stations were relatively small ranging from 0.0 feet (no change) to -0.4 feet.

Transect 3 has generally had a net decrease in elevation since Project construction, as three of the four stations have had net elevation decreases ranging from -0.4 feet to -3.2 feet. Station 3-4 has had no net elevation change since Project construction. Most of the decreases occurred within the first few years after construction. Between 1996 and 1998 the elevation changes at the individual stations were relatively small ranging from +0.1 feet to -0.5 feet. The estimated cap thickness near the end of Transect 3 is approximately 11.1 feet and 15.9 feet as determined by subsurface coring at nearby stations C1 and C3, respectively.

Transect 4 has generally had a net decrease in elevation since Project construction, as four of the five stations have had net elevation decreases ranging from -0.1 feet to -3.4 feet. Station 4-1 has had a net elevation increase of +1.1 feet since Project construction. Most of the decreases occurred within the first few years after construction. Between 1996 and 1998 the elevation changes at the individual stations were relatively small ranging from +0.5 feet to -0.4 feet.

Elevations at Transect 5 in 1998 were comparable to those surveyed in 1997, 1996, and immediately after placement of new gravelly (cap) material in July 1995. The gravel was placed as part of the Project adaptive management approach (see Section 1.2 and above). As expected, station elevations changed somewhat from immediately after reconstruction in 1995 to 1998; these changes ranged from +0.1 feet to +2.2 feet. Elevation changes between 1996 and 1998 appear to indicate relatively small accretion and erosion since cap maintenance; three stations have had net elevation increases ranging +0.1 feet to +0.8 feet, and three stations have had net elevation decreases ranging -0.1 feet to -0.4 feet.

2.2 AERIAL PHOTOGRAPH AND VISUAL INSPECTION

2.2.1 Methods

Other monitoring tasks provided additional information on the physical condition of the Project site. Similar to previous years, a color aerial photo of the Project site was taken. This year the photograph was taken on July 22, 1998 during a low tide of about -2.1 feet MLLW. A visual inspection occurred on June 24, 1998.

2.2.2 Results and Discussion

The visual inspection and aerial photograph both indicated that the physical integrity of the Project has not substantially changed since 1997 and prior years.

The color and texture of sediments at the Project site are generally uniform. In most areas, the Project sediments are composed of primarily sandy material with a silty top layer in many areas, and occasional boulders. Areas toward the northeastern end of the site (near Transect 1) continue to become siltier at the middle and lower intertidal levels. The silt layer in some low-lying areas has become relatively thick, giving the overall appearance of a mudflat (rather than sand). Generally, sediment color is black or dark brown, with occasional lighter variations and red flecks, typical of Puyallup River sediment.

Many of the benthic organisms described in Section 4, such as barnacles, limpets, shore crabs, and amphipods are associated with the scattered boulders. Bivalve and polychaete worm holes were observed in the silty sand substrate. During a visual inspection, birds (primarily gulls and Canada geese) were observed feeding in the lower intertidal portions of the site. Macrophytes are present on many of the rocks.

In some locations, deposits of organic debris and wood were observed upon or immediately beneath the sediment surface. This material appears to have been deposited by high Puyallup River flows this year. A substantial portion was alder leaves and twigs. A hydrogen sulfide smell was noted on several occasions at different locations. This odor, a common characteristic of tidal areas, is caused by the decay of organic material.

Gravel covers the substrate in the vicinity of Transect 5. This gravel is similar in color (gray) and texture (gravel with some cobble) to the gravel placed over this area in 1995.

3. CHEMICAL MONITORING

3.1 METHODS

Chemical samples were collected and analyzed consistent with methods described in the Monitoring Methods Appendix, except where specified below. In 1998, chemical analyses included surface and subsurface sediment. Three surface sediment samples were analyzed for phenol compounds, resin acid compounds, phthalates, conventional chemicals, and grain size. Four subsurface core samples were analyzed for a shorter list of “indicator chemicals,” conventional chemicals, and grain size. Indicator chemicals consisted of 4-methylphenol, guaiacol (2-methoxyphenol), and chlorinated guaiacols.

This section contains subsections describing the methods used for each type of chemical monitoring and addresses quality control and quality assurance procedures that were performed on all of the chemical analysis results. Complete descriptions of chemical monitoring methods are provided in the Methods Appendix, Section 3.

3.1.1 Surface Sediment

On July 16, 1998, the three surface locations, SS1, SS2, and SS4 (Figure 3-1) were marked with buoys. The station positions were determined through communication with a surveyor located on shore.

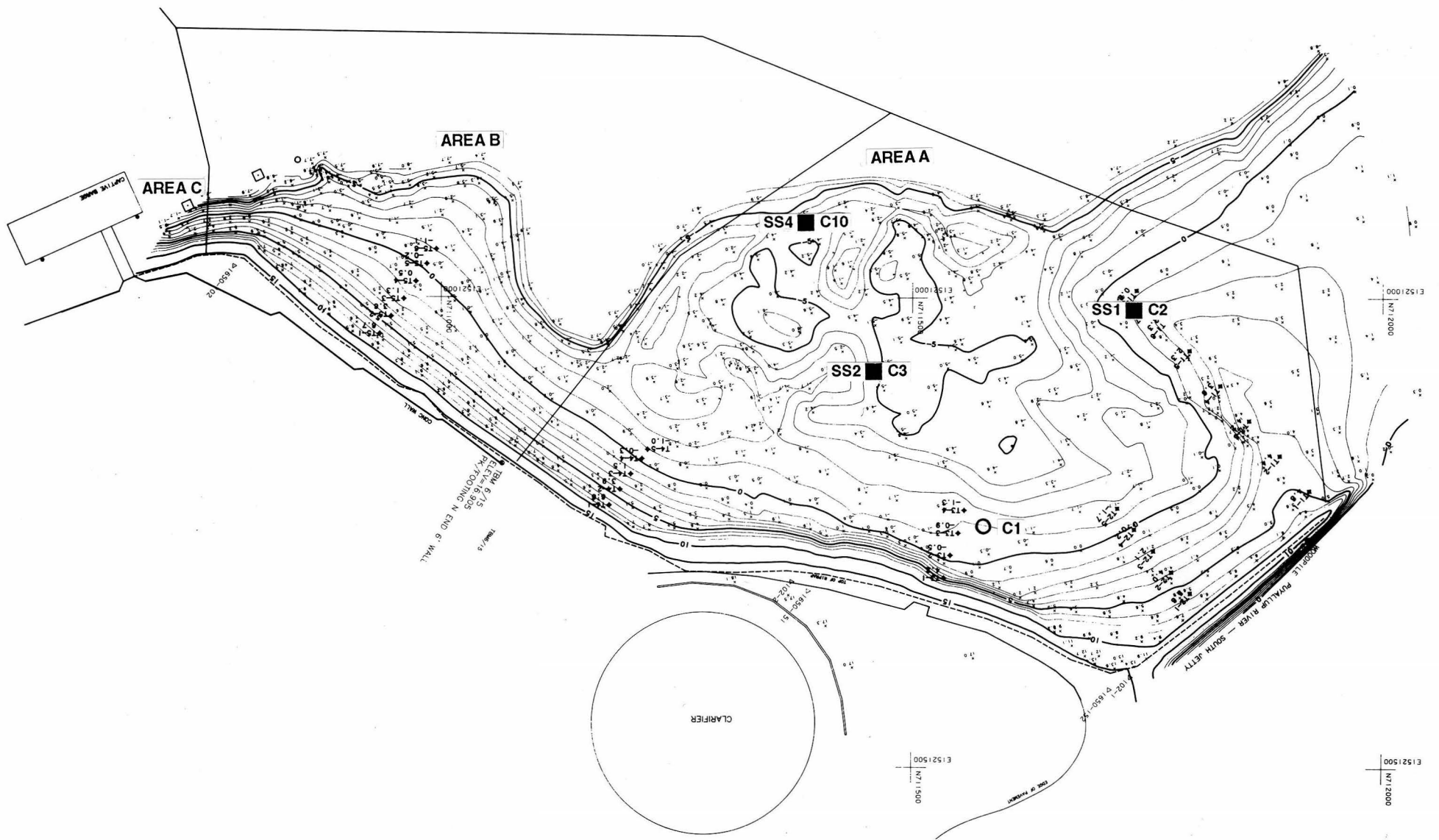
Surface sediment (0 to 2 cm deep in the sediment) was then sampled. A duplicate sample was collected at SS1. The first grab attempt at SS1 was rejected due to obstructions that prevented the grab from closing. The second grab attempt at SS1 was successful.

Surface sediment samples were analyzed for chemicals required by the Final Chemical Monitoring Proposal (Parametrix 1998b). Analytical Resources, Incorporated (Seattle, Washington) performed the laboratory analyses.

3.1.2 Subsurface Sampling

The four coring locations (C1, C2, C3, and C10) were marked with buoys on the morning of July 21, 1998. The station positions were determined through communication with a surveyor located on shore.

Subsurface sediment sampling took place on July 21 and 22, 1998. The field location of subsurface coring stations was based on the locations indicated on Figure 1b of the Monitoring Plan as modified pursuant to changes in the Monitoring Plan (Methods Appendix). The subsurface sampling locations are shown in Figure 3-1.



SCALE IN FEET
 0 75 150



C1 ○ Subsurface Coring
 SS3 ■ C4 Surface and Subsurface Sediments

Figure 3-1.
Surface and Subsurface
(Coring) Sediment Chemical
Sampling Locations

Two sediment cores were rejected at two stations (C1 and C3) and had to be redrilled to obtain the required samples. The lower portion of C1 was rejected due to insufficient core recovery. The second core at C1 was successful. The top portion C3 was also rejected due to insufficient core recovery. The second core at C3 was successful. Figure 3-2 indicates the number of holes started for each station and the approximate depth of each core.

The cores were extruded on July 22 and 23, 1998, at which time the required sampling took place. For coring locations C1, C3, and C10, sediment samples at elevations 25 to 45 cm above the sediment cap/underlying material interface were collected and subsequently submitted for chemical analysis. For coring location C2, a sediment sample at elevations 85 to 105 cm above the sediment cap/underlying material interface was collected and subsequently submitted for chemical analysis (see Figure 3-2). In addition, a field duplicate sample was submitted for C1 25-45.

Subsurface sediment samples were analyzed for chemicals required by the Monitoring Plan. Analytical Resources, Incorporated performed the laboratory analyses.

3.2 RESULTS

This section presents the results of the 1998 chemical monitoring at the Project. Results are discussed for each of the two types of monitoring conducted. Chemical concentrations in excess of the early warning levels are discussed in the following subsections. As explained earlier in Section 1.4, early warning levels do not necessarily indicate a problem, but are used to help evaluate whether a problem may exist by helping interpret the primary biological indicators. Chemical early warning level concentrations are determined by two criteria. First, if the compounds have established Lowest Apparent Effects Thresholds (LAETs; Monitoring Plan), then 80 percent of that LAET is considered an early warning level. Second, for resin acids (which have no established LAETs) concentrations of 1,000 µg/kg (ppb) or above are considered an early warning level. For subsurface samples, any compound not covered by the above early warning levels, but measured in river sediments used for construction of the Project, is assigned an early warning level at five times the original baseline concentration. It has been previously determined by review agencies that these are appropriate levels for distinguishing results for the Project. No early warning levels have been established for chlorinated guaiacols.

Most of the chemicals sampled at all of the stations were either undetected or detected at very low levels. Out of approximately 117 possible chemical detections, only one surface sediment result was above applicable early warning levels. No subsurface sediment results were above early warning levels. The results sections focus on the detected chemicals. Tables 3-1 and 3-2 contain the results for each station and each parameter analyzed at each station, except for complete grain-size results. These are included in the Data Appendix, Section 3.1.

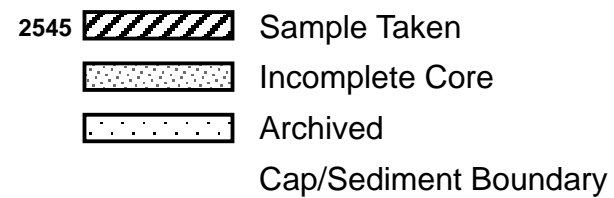
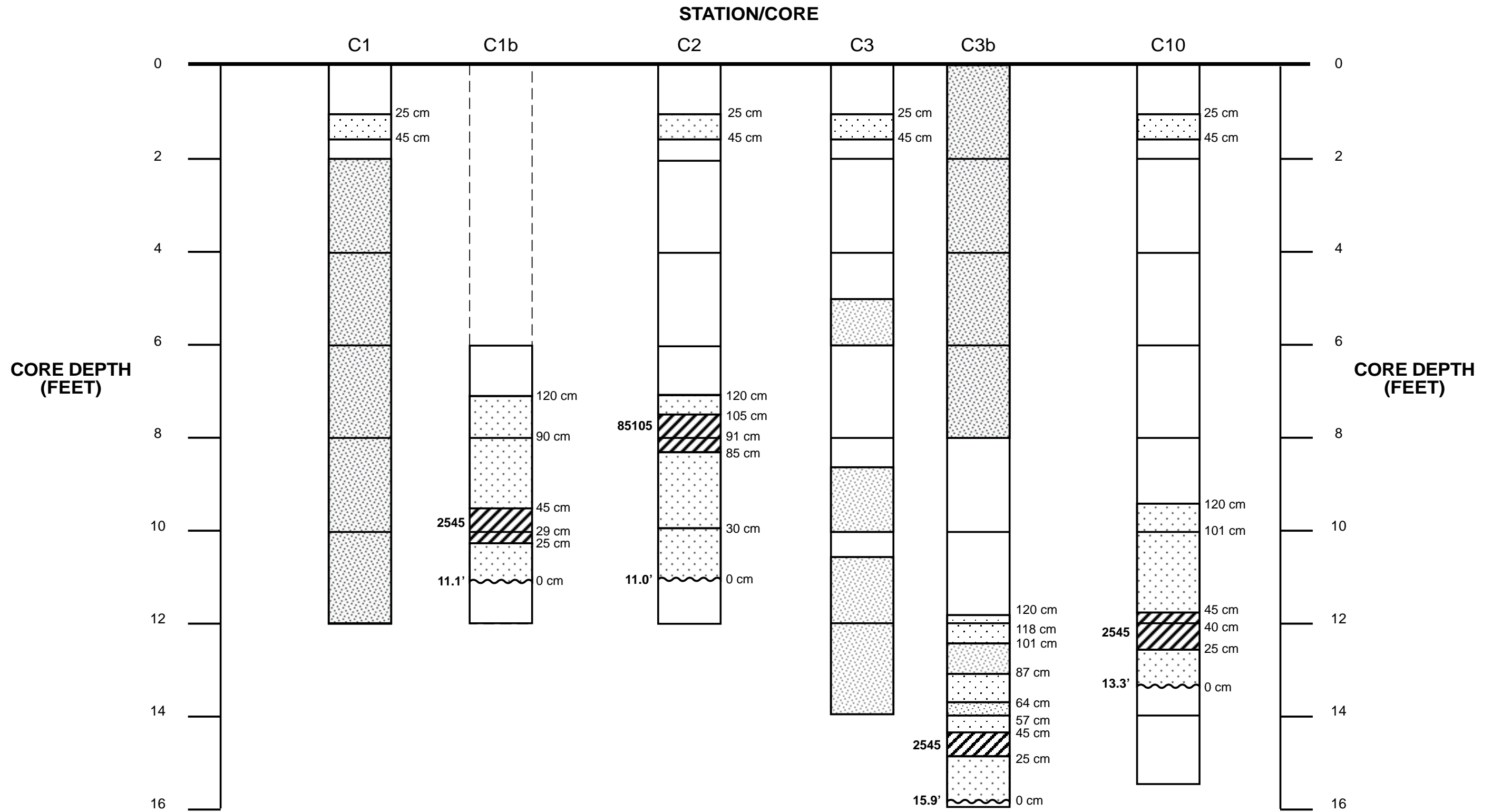


Figure 3-2.
Subsurface Coring Profiles with
Sampling and Archive Sampling Locations

Table 3-1. Chemical results for the Project surface sediment samples, 1998 (on a dry weight basis).

Chemical	100%	80%*	Station Numbers			
	LAET	LAET	SS1	SS1D	SS2	SS4
Phenols (µg/kg)						
Phenol	420	336	85	66	30	21
2-Chlorophenol	--	--	19 U	19 U	19 U	20 U
2-Methylphenol	63	50	19 U	19 U	19 U	20 U
4-Methylphenol	670	536	28	91	39	20
2-Nitrophenol	--	--	94 U	95 U	95 U	99 U
2,4-Dimethylphenol	29	23	19 U	19 U	19 U	20 U
2,4-Dichlorophenol	--	--	56 U	57 U	57 U	59 U
4-Chloro-3-methylphenol	--	--	37 U	38 U	38 U	40 U
2,4,6-Trichlorophenol	--	--	94 U	95 U	95 U	99 U
2,4,5-Trichlorophenol	--	--	94 U	95 U	95 U	99 U
2,4-Dinitrophenol	--	--	190 U	190 U	190 U	200 U
4-Nitrophenol	--	--	94 U	95 U	95 U	99 U
4,6-Dinitro-2-methylphenol	--	--	190 U	190 U	190 U	200 U
Pentachlorophenol	360	288	94 Uuj	95 Uuj	95 Uuj	99 Uuj
Phthalates (µg/kg)						
Di-n-Butylphthalate	--	--	19 U	19	19 U	20 U
Butylbenzylphthalate	--	--	19 U	19 U	19 U	20 U
bis (2-Ethylhexyl) phthalate	--	--	20 j	19 j	48 j	43 j
Di-n-Octyl phthalate	--	--	19 U	19 U	19 U	20 U
Diethylphthalate	--	--	19 U	19 U	19 U	20 U
Dimethylphthalate	--	--	19 U	19 U	19 U	20 U
Resin Acids and Guaiacol (µg/kg)						
Pimaric Acid	--	--	37 U	38 U	39	40 U
Sandocopimaric Acid	--	--	37 U	38 U	38 U	40 U
Isopimaric Acid	--	--	37 U	38 U	150	110
Palustric Acid	--	--	94 U	95 U	95 U	99 U
Dehydroabietic Acid	--	--	43	60	230	130
Abietic Acid	--	--	280 U	290 U	<u>1100</u>	770
Neoabietic Acid	--	--	94 U	95 U	95 U	99 U
14-Chlorodehydroabietic Acid	--	--	37 U	38 U	38 U	40 U
12-Chlorodehydroabietic Acid	--	--	37 U	38 U	38 U	40 U
Dichlorodehydroabietic Acid	--	--	37 U	38 U	38 U	40 U
Guaiacol	--	--	37 U	38 U	38 U	40 U
Conventionals						
Total Solids (%)	--	--	73.5	72.4	68.2	71.2
Preserved Total Solids (%)	--	--	81.0	79	74.4	75.7
Total Volatile Solids (mg/kg)	--	--	12000	13000	27000	22000
Sulfide (mg/kg)	--	--	4.4 j	11 j	5.9 j	18 j
Total Organic Carbon (%)	--	--	0.60	0.52	0.95	1.1
Total Oil and Grease (mg/kg)	--	--	830	1200	1200	1200
Fines (%)	--	--	0	0	19	9.6

* Represents 80% of the Lowest Apparent Effects Thresholds (LAET) for the most sensitive test organism (Monitoring Plan).

Notes: See text for explanation of data qualifiers.
 Boxed values in the table exceed the 80% LAET criteria.
 Underlined values exceed 1000 µg/kg.

Table 3-2. Chemical results for the Project subsurface sediment samples from corings, 1998 (on a dry weight basis).

Chemical	100% LAET	80%* LAET	Station Numbers				
			C1		C2	C3	C10
			25-45	25-45 Dup.	85-105	25-45	25-45
Organics (µg/kg; ppb)							
4-Methylphenol	670	536	19 U	19 U	200	19 U	19 U
Guaiacol	--	--	38 U	38 U	150	38 U	38 U
4,5-Dichloro-2-methoxyphenol	--	--	96 U	96 U	93 U	96 U	95 U
4,5,6-Trichloroguaiacol	--	--	96 U	96 U	93 U	96 U	95 U
3,4,5-Trichloroguaiacol	--	--	140 U	140 U	140 U	140 U	140 U
Tetrachloroguaiacol	--	--	140 U	140 U	140 U	140 U	140 U
Conventionals							
Total Solids (%)	--	--	80.9	81.0	76.3	82.4	81.0
Preserved Total Solids (%)	--	--	76.6	77.7	76.6	78.1	81.5
Total Volatile Solids (mg/kg)	--	--	1.3	1.3	1.8	1.4	1.3
Sulfide (mg/kg)	--	--	180	110	84	26	57
Total Organic Carbon (%)	--	--	1.0	0.84	1.2	0.37	0.43
Total Oil and Grease (mg/kg)	--	--	360	450	400	640	670
Fines (%)	--	--	4.3	--	0	1.7	0

* Represents 80% of the Lowest Apparent Effects Thresholds (LAET) for the most sensitive test organism (Monitoring Plan).

** Values for oil and grease are blank corrected.

Note: See text for explanation of data qualifiers.

Boxed values in the table exceed the 80% LAET criteria.

3.2.1 Quality Assurance Review

Data qualifiers have been assigned to some analytical results from both the laboratory internal data quality control (QC) reviews and as a result of the Parametrix quality assurance (QA) reviews. Laboratory data qualifiers are indicated by capital letters and have the following definitions:

- B - Indicates possible/probably blank contamination
- J - Indicates an estimated concentration, value is below the calculated reporting limit
- U - Compound was undetected at the reported concentration (same as ND—not detected)

Lower case letters indicates data qualifiers resulting from the QA review. For a given sample result, if a data qualifier was assigned by the laboratory, the data qualifier resulting from the QA review was placed adjacent to the laboratory qualifier. These QA data qualifiers have the following definitions:

- j - Analyte was present, but reported value may not be accurate or precise, and should be considered an estimate
- uj - Analyte was analyzed for but not detected; the reported limit should be considered an estimate
- r - Result is rejected, should be eliminated from statistical or risk evaluations

The QA review was conducted according to the USEPA Contract Laboratory Program (CLP) National Functional Guidelines for Organic and Inorganic Data Review (USEPA 1994a,b). Data for conventionals and grain size were also compared to method information contained in the Puget Sound Estuary Protocols (PSEP) (USEPA 1990). Qualifiers were attached to data based on the results of the data reviews. Any sample data qualified as “estimates” (j or uj) are considered adequate for qualitative purposes such as determining the extent and general level of chemical contamination.

The following sections discuss only deficiencies requiring data qualification based upon the QA review. Memoranda describing the results of the individual QA reviews are included in the Data Appendix. Checklists used during the QA review are also included in the Data Appendix. These checklists describe the data reviews of:

- holding times,
- gas chromatography/mass spectrometry (GC/MS) tuning,
- calibrations,
- laboratory blanks,
- surrogate recoveries,
- matrix spike/matrix spike duplicates (MS/MSD),
- laboratory control samples,
- field duplicates,
- internal standards,
- target compound identification/quantitation, and
- overall assessment of data quality and system performance.

Sections 3.2.1.1 and 3.2.1.2 discuss all QA results for subsurface and surface sediment samples.

3.2.1.1 Conventionals and Grain Size

Surface Sediments

The holding times and conditions and laboratory QA/QC results generally conformed to the applicable PSEP and CLP specifications. The laboratory data package was complete and contained all necessary forms and raw data necessary for data review. Based on the QA review, no data qualifiers were assigned to results for total organic carbon, total solids, total volatile solids, total oil and grease, or grain size. However, due to the low sulfide MS/MSD recoveries (71%, 72%) outside of the applicable control limits (75% - 125%), data qualifiers were assigned to the sulfide results for the subsurface sediment samples. Sulfide results have been qualified as estimates (j) for the following samples: SS-1, SS-1D, SS-2, and SS-4.

Subsurface Sediments

The holding times and conditions and laboratory QA/QC results conformed to the applicable PSEP and CLP specifications. The laboratory data package was complete and contained all necessary forms and raw data necessary for data review. Based on the QA review, no data qualifiers were assigned to any of the conventional or grain size analytical results for these samples.

3.2.1.2 Organics

Surface Sediments

Data reviews were performed for the semivolatile and resin acids analyses performed on the surface sediment samples.

Semivolatile Organic Compounds

Functional guidelines for the CLP were followed when reviewing the semivolatile data. The laboratory data package was complete and contained all necessary forms and raw data necessary for data review.

Based on the QA review, data qualifiers were assigned to pentachlorophenol due to low MS/MSD recoveries (11.7%, 9.9%) below the applicable control limits (15%-157%). Because this compound was not detected in any of the samples, the reporting limits for pentachlorophenol have been qualified as estimates (uj) for the following samples: SS-1, SS-1D, SS-2, and SS-4.

Bis(2-ethylhexyl)phthalate was identified in each of the field samples, but was not found in the laboratory blank for this batch. This compound was found in the laboratory blank analyzed with the subsurface samples, indicating possible sporadic laboratory contamination. Because low-level contamination may cause slightly elevated concentrations of this compound in the surface samples,

the results for bis(2-ethylhexyl)phthalate were qualified as estimates (j) for the following samples: SS-1, SS-1D, SS-2, and SS-4.

Resin Acids

The Project Monitoring Plan inadvertently called for the resin acid analyses to be conducted according to Method 1625c. However, this method has not been used for resin acid analyses in the past and there are no isotopically-labeled analogs for resin acid compounds available. Therefore, resin acids analyses were conducted according to Method 8270.

No specific functional guidelines are available for the analysis of resin acids. However, since resin acids analyses parallel those used for semivolatile compounds (GC/MS), the recommended CLP guidelines for semivolatiles were used to conduct a QA data review.

All data met the minimum criteria outlined in the PSEP and CLP guidelines for semivolatile analyses, except the relative response factor (RRF) for abietic acid was below the CLP guidelines for semivolatile compounds (0.05). However, it was above the contractual minimum RRF criteria of 0.01. The laboratory indicated that abietic acid was calibrated at twice the level of other compounds. Therefore, since the RRF was about half the typical CLP guideline levels and the percent difference between the initial and continuing calibrations were less than 25 percent, no qualifications of the data were deemed necessary.

No data qualifiers were assigned to any of the resin acid results for these samples.

Subsurface Sediments

Data reviews were conducted for the semivolatile analyses of 4-methylphenol and guaiacol compounds performed on the subsurface sediment samples.

Semivolatiles (Guaiacols and 4-Methylphenol)

Functional guidelines for CLP were followed when reviewing the 4-methylphenol and guaiacol data. The laboratory resubmitted the data package to include several compounds not reported in the original data package. The revised laboratory data package was complete and contained all necessary forms and raw data necessary for data review. The compound 2,4-dichloroguaiacol (also called 4,5-dichloro-2-methoxyphenol) was not included in the original calibration curve, and thus, could not be quantified in the same manner as the other compounds. Results were obtained by comparing the gas chromatograph spectra for an injection of the 2,4-dichloroguaiacol standard to spectra previously obtained for the samples. This compound was not detected based on the laboratory review of these data.

Based on the QA review, no data qualifiers were assigned to any of semivolatile results for these samples.

3.2.2 Surface Sediment

3.2.2.1 Field Observations

Surface sediment was typical cap material composed of coarse, angular, dark brown sand with small red flecks, mixed with fine, gray silt. Sediment was generally composed of sand with a low to moderate silt/clay fraction except within the siltier lagoon areas. Silt/clay comprised from 0 to 21 percent of the material. Several sediment grabs contained kelp (*Laminaria* sp.) or sea lettuce (*Ulva* sp.) that was discarded. No odor was detected from any sample.

3.2.2.2 Chemical Results

Most chemical compounds achieved the required detection limits (required by the Monitoring Plan). The exceptions were three resin acids (palustric acid, abietic acid, and neoabietic acid).

All detected chemicals were below the 80 percent LAET values (where established) for all surface sediment samples. The early warning levels for resin acids (1,000 $\mu\text{g}/\text{kg}$) was slightly exceeded for abietic acid at station SS2 (1,100 $\mu\text{g}/\text{kg}$). EPA was notified of this detection as required by the early warning process. EPA, Simpson, and Champion have agreed that no further action was required due to these chemical results. Based on biological information, there appears to be no problem with the health or integrity of the cap or habitat (see Section 4).

Of the fourteen phenol compounds analyzed at the stations, only two, phenol and 4-methylphenol, were detected. Phenol was detected at stations SS1 (85 $\mu\text{g}/\text{kg}$), SS2 (30 $\mu\text{g}/\text{kg}$), and SS4 (21 $\mu\text{g}/\text{kg}$), and 4-methylphenol was detected at stations SS1 (28 $\mu\text{g}/\text{kg}$), SS2 (39 $\mu\text{g}/\text{kg}$), and SS4 (20 $\mu\text{g}/\text{kg}$). These low-level detections were much lower than the respective 80 percent LAETs (phenol-336 $\mu\text{g}/\text{kg}$ and 4-methylphenol-536 $\mu\text{g}/\text{kg}$).

Sediments from the stations were analyzed for ten resin acids. At station SS1, dehydroabietic acid (43 $\mu\text{g}/\text{kg}$) was the only resin acid detected. At station SS2, pimmaric acid (39 $\mu\text{g}/\text{kg}$), isopimaric acid (150 $\mu\text{g}/\text{kg}$), dehydroabietic acid (230 $\mu\text{g}/\text{kg}$), and abietic acid (1,100 $\mu\text{g}/\text{kg}$) were detected. At station SS4, isopimaric acid (110 $\mu\text{g}/\text{kg}$), dehydroabietic acid (130 $\mu\text{g}/\text{kg}$), and abietic acid (770 $\mu\text{g}/\text{kg}$) were detected. With the exception of the one result above early warning levels described earlier, all of these other detections were below the early warning level (1,000 $\mu\text{g}/\text{kg}$).

Sediments from the stations were analyzed for guaiacol (2-methoxyphenol). Guaiacol was not detected in any surface sediment sample for the fifth sampling event in a row (Parametrix 1991 through 1996b).

Sediments from the stations were analyzed for six phthalates. Bis(2-ethylhexyl)phthalate was detected at all three stations at low levels ranging from 20 $\mu\text{g}/\text{kg}$ to 48 $\mu\text{g}/\text{kg}$. Phthalate compounds have no specific LAETs. No other phthalates were detected.

Results for conventional sediment parameters were typical of surface sediment material from this project (Parametrix 1990 through 1996). Grain size analyses ranged from 0 to 19 percent fines. Total solids ranged from 68.2 to 73.5 percent, and total volatile solids (TVS) ranged from 12,000 mg/kg (1.20 percent) to 27,000 mg/kg (2.7 percent). TOC ranged from 6000 mg/kg (0.60 percent) to 11,000 mg/kg (1.1 percent). Oil and grease ranged from 830 mg/kg to 1,200 mg/kg, and sulfides ranged from 4.4 mg/kg to 18 mg/kg.

3.2.3 Subsurface Sediment

3.2.3.1 Field Observations

The samples and the other portions of the subsurface sediment cores were usually made up of typical cap material consisting of coarse angular black, or dark brown, sand with some small red flecks. Occasionally coarser gravelly materials were encountered in the cores. Small cobbles were rare. Underlying sediments (the sediments that were capped) were generally easily distinguished from the overlying cap material while taking and extruding cores, due to the blacker appearance of the underlying sediment. Underlying sediments also smelled strongly of either hydrogen sulfide or hydrocarbons, whereas the cap material typically had no distinctive smell. Frequently, the underlying sediments also contained wood particles or other debris which also served as a distinguishing characteristic.

The core stations varied in depth. The depths shown in Figure 3-2 should be used only as estimates. The distance each shelly tube travels down into the sediment is variable by several inches based on the resistance of the substrate; it is rarely exactly 2 feet as depicted on the figure.

Cores taken at the four locations showed the cap thickness to be between 11.0 and 15.9 feet. The cap thickness range observed in the 1998 sediment corings was consistent with previous monitoring results (Parametrix 1990 through 1996).

3.2.3.2 Chemical Results

At three of the four subsurface locations (C1, C3, and C10), all of the indicator chemical results were non-detections (see Table 3-2). As in the past, 4-methylphenol (200 µg/kg) and guaiacol (2-methoxyphenol) (150 µg/kg) were detected in the C2 85-105 cm sample. The 80 percent LAET level for 4-methylphenol is 536 µg/kg. An LAET has not been established for 2-methoxyphenol. Similar detections have occurred in previous years at the same location and same or similar core depths (25-45 or 85-105 cm). These detections are believed to be evidence of mixing between cap materials and underlying materials that occurred during Project construction (Parametrix 1993, 1998b); this is discussed in further detail in Section 3.3 below). For all other subsurface samples, 4-methylphenol was undetected at a reported detection limit of 19 µg/kg and guaiacol was undetected at a reported detection limit of 38 µg/kg.

The four chlorinated guaiacols (4,5-dichloroguaiacol; 4,5,6-trichloroguaiacol; 3,4,5,-trichloroguaiacol; and tetrachloroguaiacol) were undetected in all subsurface sediment samples.

The reported detection limits ranged from 93 µg/kg to 140 µg/kg. LAETs are not established for the chlorinated guaiacols.

The Monitoring Plan specifies that chemicals in subsurface samples not covered by 80 percent LAET or 1,000 µg/kg (ppb) early warning levels, have early warning levels set at five times baseline concentrations found in cap sediments prior to Project construction. Chlorinated guaiacols and guaiacol (2-methoxyphenol) are the chemicals examined in subsurface sediments that fall into this category. Chlorinated guaiacols and guaiacols were not analyzed in cap sediments prior to construction (Parametrix 1987). Therefore, these compounds cannot be compared to baseline concentrations. However, with the exception of guaiacol in the one sample from C2 discussed above, these compounds were undetected at detection levels ranging from 38 µg/kg to 140 µg/kg in all subsurface sediment samples; the data indicate that chemical migration into the cap has not taken place and there is no evidence that these chemicals affect habitat quality at the Project site.

Of the conventional variables, total solids ranged from 76.3 percent at C2 85-105 to 82.4 percent at C3 25-45. TVS ranged from 13,000 mg/kg (1.3 percent) at C1 25-45 and C10 25-45 to 18,000 mg/kg (1.8 percent) at C2 85-105. TOC ranged from 3700 mg/kg (0.37 percent) at C3 25-45 to 12,000 mg/kg (1.2 percent) at C2 85-105. Oil and grease ranged from 360 mg/kg at C1 25-45 to 670 mg/kg at C10 25-45. Sulfide ranged from 26 mg/kg at C3 25-45 to 180 mg/kg at C1 25-45.

The subsurface sediment samples contained a large percentage of material represented by very fine sand (phi of 4) or larger sized particles. This is expected because deeper sediments do not contain any of the silt that has been deposited on the surface of the Project cap for the last ten years. The subsurface samples contained 96 to 100 percent very fine sand and larger material.

3.3 DISCUSSION

3.3.1 Project Performance

The results indicate that the Project continues to be an effective barrier against recontamination of the area. Most of the chemicals sampled at all of the surface and subsurface stations were either undetected or detected at very low levels. Out of 93 possible chemical detections, only one surface sediment result was above the applicable early warning levels (80 percent LAET or 1,000 µg/kg levels).

The results from the subsurface core samples indicate that no migration of underlying chemicals into the clean cap sediments is occurring. Of the 24 subsurface chemical analyses, 22 were non-detections. The 4-methylphenol and guaiacol detections in C2 85-105 have occurred in previous years as well (Parametrix 1990 through 1996). All detections at station C2 have occurred at middle and lower depth samples within the cores. Station C2 corresponds with the location of the initial berm which was placed around the Project site immediately prior to construction. It appears likely that some mixing of contaminated sediments and berm sediments occurred before the Project construction. It appears likely that some mixing of contaminated sediments and berm sediments occurred before the Project construction was completed. Chemicals have been

detected at the 25-45 or 85-105 sample depths in cores from station C2 in five of the last six subsurface chemical monitoring programs prior to this year. The absence of detections at or near the surface indicates that the chemicals detected are staying in place and are not migrating through the cap. The chemicals detected at C2 are below at least eight feet of clean sediment cap as measured in 1992 (Parametrix 1993c).

In addition, the sediment cores in 1998 showed the cap thickness to be between 11.0 and 15.9 feet in thickness, which greatly exceeds performance criteria of 3 feet.

Surface sediment results indicate that no substantial levels of chemicals from off-site sources are being deposited on the cap surface. All detected chemicals were below the 80 percent LAET values (where established) for all surface sediment samples. The early warning level for resin acids (1,000 µg/kg) was only exceeded for abietic acid at one station. The resin acids do not have established LAETs. EPA was notified of this detection as required by the early warning process. It was agreed that this detection does not indicate a problem with the health or integrity of the project. Based on biological information, there appears to be no problem with the health or integrity of the cap or habitat (see Section 4).

3.3.2 The Effect of Quality Assurance on Results

Several analytes were qualified during the QA reviews described above. However, the vast majority of the data met the requirements of the quality assurance review. Although pentachlorophenol was not detected in any of the four surface samples, the associated reporting limits associated with this compound were qualified as estimates based on the QA review. Bis(2-ethylhexyl)phthalate was detected in all of the surface samples and qualified as estimates; the results may be slightly elevated due to sporadic blank contamination. Sulfide results in the surface samples may be biased low, and were designated as estimates following the QA review. The remaining compounds in the surface and subsurface samples met the QA review requirements. All of the unestimated results for similar parameters (or at nearby stations) indicate the cap is performing as expected.

4. BENTHIC INFAUNA MONITORING

4.1 INTRODUCTION

Benthic infauna are small invertebrates, such as clams and worms, that live in estuarine sediments. These animals are a basic part of many estuarine food webs. The abundance and diversity of benthic invertebrates are often considered a basic measure of the health of soft-sediment ecosystems. This section describes the benthic infauna living in the Project sediments, as well as those from two background stations located on the opposite side of the Puyallup River Delta near Sitcum Waterway. Changes in the benthic community during the tenth full year after Project construction are discussed in this section and data for the 1998 sampling period are presented and compared to data from previous years.

Two types of analyses were used to determine the condition of the Project benthos: (1) physical analyses and (2) biological analyses. Analysis of the Project area's physical characteristics at each sampling location includes sediment type and water depth. The sediment or substrate found at each station was characterized by determining the sediment particle-size distribution in top layer of the sediment. Surface sediments, to a depth of about 15-cm, are the sediments most frequently encountered by benthic organisms that live in the area. Water depth was measured because it also affects invertebrate populations.

Biological health was assessed, based on knowledge of intertidal mudflat ecosystems, especially in Puget Sound. Changes in the Project area community from the previous year were identified. Organisms from six Project stations and two background stations were then identified and counted. Characteristics of the Project benthic community were then evaluated, including:

- **numbers of organisms (abundance),**
- **types of organisms (diversity),**
- **types of communities (benthic assemblages), and**
- **weight of organisms (biomass).**

This information, which has been analyzed annually at each Project station and background station, is compared with:

- **the current year's data for all other stations, including background stations, and**
- **previous years' data for the same station.**

Background stations were evaluated prior to comparison with the Project stations to determine whether these comparisons were appropriate. This year both background stations (R1 and R3), located on the opposite side of the Puyallup River Delta, had abundances and diversity of organisms appropriate for comparison with the Project stations.

The background stations were used to monitor regional changes in infauna. One station (R1) has been sampled annually since 1993. Past data (and this year's data) have shown this station to be adequate for comparisons to background conditions of Commencement Bay. The other station

(R3), located near R1 at a different water depth, was sampled for the first time in 1996. This station was selected in 1996 because other candidate background stations sampled in previous years near the Puyallup River mouth, Vashon Island, and Middle Waterway were all found to be too dissimilar to serve as background stations. Based on station R1 data, the Milwaukee restoration area was considered more appropriate, so a second background station was located in the area at a different water depth.

The purpose of the background stations is to provide information on bay-wide changes in benthic populations for comparison with changes in the Project area. Benthic community changes may occur on an area-wide basis due to biological processes such as predation and competition. These biological processes are generally difficult to identify. Other area-wide changes may also affect benthic community structure, as discussed in this chapter.

Several statistical analyses were used to compare similarities in the biological communities among stations, as well as determine differences. The analyses are summarized in Table 4-1 and in the Monitoring Methods Appendix Section 4. The statistical analyses follow a method (the biological indicators approach) created for this Project (Parametrix 1994), approved by EPA in 1994.

Both the physical and biological results provide information on the general health and condition of the Project habitat. However, it should be remembered that colonization by benthic organisms is a complex process. Although organisms may quickly move into new, clean habitat such as the Project area, ongoing changes in infaunal assemblages are expected. Establishing a relatively stable community depends on several factors:

- Availability of colonists, either by immigration from adjacent communities or recruitment of planktonic larvae;
- Benthic ecology, such as the presence of potential predators and competitors in or near the area in question;
- Physical environment, such as temperature, salinity, turbidity, and substrate; and
- Presence of environmental contamination (Thistle 1980; Zajac and Whitlatch 1982).

Table 4-1. Analyses for the biological indicators. The analyzed data set includes all taxa (identified to the lowest practical taxonomic level) except where otherwise defined. For each statistical test, the general criterion is: No significant difference between the samples tested; $\alpha = 0.05$; $\beta = 0.2$, MDD = the lowest Minimum Detectable Difference possible.

Analysis Type (Project and Background Stations)	Data Analyzed	Statistical Test
Tier One, Level One. Analyses of Present Year Data		
1.1 Analyses of Numerical Abundance	Pooled Project vs. Pooled Background Among stations	
1.1.1 Total Number of Taxa	All taxa	Two-sample test and eight-sample ANOVA
1.1.2 Abundance of Numerically Dominant Taxa	Smallest number of taxa that comprises 75% of total abundance	Two-sample test and eight-sample ANOVA
1.1.3 Abundance of Non-numerically Dominant Taxa	All taxa minus dominant taxa	Two-sample test and eight-sample ANOVA
1.1.4 Abundance of Taxa at Each Station	All taxa	Two-sample test and eight-sample ANOVA
1.2 Analysis of Biomass (Standing Crop)	Defined taxonomic groups Pooled Project vs. Pooled Background Among stations	Two-sample test and eight-sample ANOVA
1.3 Analysis of Station Similarity Using Proportional Similarity Index (PSI)	All station data pooled (all taxa)	PSI
Tier One, Level Two. Comparison to Previous Year Data		
1.5 Analyses of Numerical Abundance	Pooled Project vs. Previous Year's Project Pooled Background vs. Previous Year's Background Between years for each station	Two-sample test
Tier Two. Ecological Analyses of Present Year Data		
2.1 Trophic Guild Analyses	Pooled Project vs. Pooled Background Among stations	
2.1 Trophic Guild Analyses	Total number of individuals in each defined trophic guild	Two-sample test and eight-sample ANOVA
2.2 Key Species Abundance	Total number of individuals in each defined key species	Two-sample test and eight-sample ANOVA
2.3 Pollution Sensitive/Tolerant Species	Total number of individuals in each defined species	Two-sample test and eight-sample ANOVA

4.2 METHODS

4.2.1 General Methods

Sampling and analysis methods are presented in the Monitoring Methods Appendix Section 4 and the biological indicators approach (Parametrix 1994). In 1998, samples at all Project and background stations (Figure 4-1) were collected and analyzed using the methods described in the Monitoring Methods Appendix, except where noted in this section. Organisms from the samples (see Section 4.3.2) were sent to the following taxonomists for identification:

- Polychaeta by Howard Jones, Marine Taxonomic Services; reference collection verified by Eugene Ruff.
- Crustacea by Renee Zane; reference collection verified by Sandy Lipovsky.
- Mollusca by Susan Weeks, Oikos, Inc.; reference collection verified by Allan Fukiyama.
- Miscellaneous Taxa by F. Scott McEuen.

4.2.2 Field and Data Analysis Methods

All field methods were consistent with the Monitoring Methods Appendix. Sampling was conducted on March 10, 11, and 13, 1998.

4.3 RESULTS

The 1998 results are presented in this section, with the physical characteristics described first, followed by the general biological characteristics.

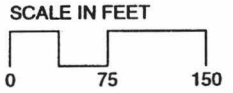
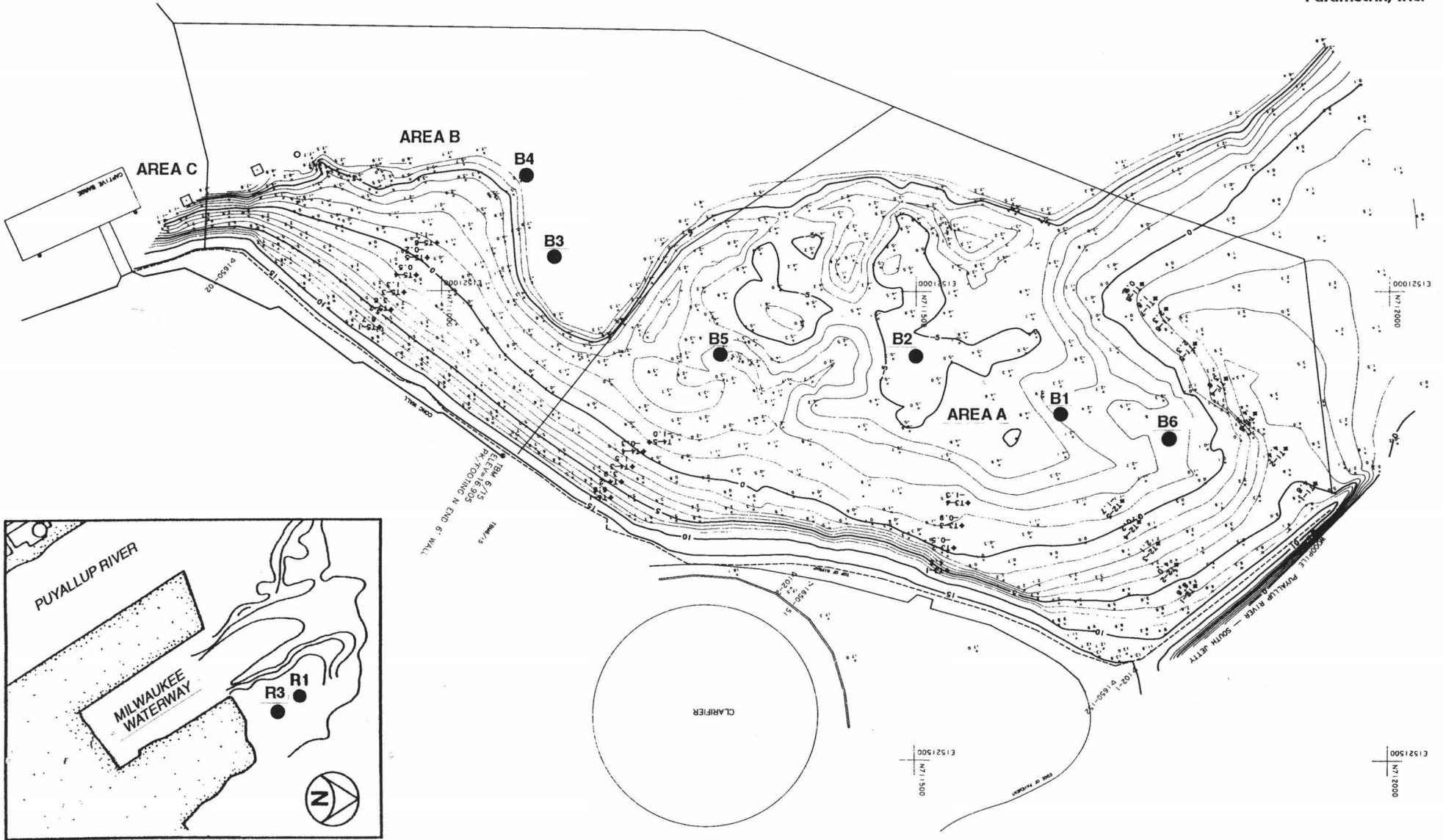
4.3.1 Station Physical Characteristics

The physical characteristics covered in this section include water depth, sediment grain size, and sediment total volatile solids.

4.3.1.1 Water Depth

Sampling depths for the Project station replicates in 1998 ranged from 1.8 to 8.6 feet MLLW (Table 4-2). The mean of the 1998 replicates (± 1 sample standard deviation) varied from 1.9 feet (± 0.1 feet) at station B6 to 7.5 feet (± 0.7 feet) at station B4 (Table 4-3).

4-5



B Stations = Project Area Stations
R Stations = Background Stations

Figure 4-1.
Benthic Infaunal
Sampling Stations

Table 4-2. Sampling depths (ft MLLW) of the 1998 benthic sampling replicates. The water depth was taken from the field logs and adjusted for tidal height. "B" stations are Project stations and "R" stations are background stations.

Station	Replicate				
	A	B	C	D	E
B-1	5.4	5.6	5.1	5.8	5.7
B-2	4.8	4.7	4.9	4.9	4.9
B-3	7.2	7.6	7.3	6.8	7.7
B-4	6.7	7.1	7.6	7.6	8.6
B-5	4.8	5.3	5.3	5.0	5.2
B-6	1.9	1.9	2.1	1.8	1.8
R-1	6.8	6.9	6.5	6.8	6.4
R-3	2.7	3.1	2.9	2.9	2.7

Table 4-3. Mean station depths (± 1 sample standard deviation) (ft MLLW).

Station	Year									
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
B1	2.2 \pm 0.2	3.6 \pm 0.3	1.3 \pm 0.2	3.2 \pm 0.5	3.0 \pm 0.4	4.3 \pm 0.8	3.8 \pm 0.1	3.8 \pm 0.3	3.4 \pm 0.4	5.5 \pm 0.3
B2	5.4 \pm 0.2	6.3 \pm 0.2	5.3 \pm 0.4	5.4 \pm 0.2	5.9 \pm 0.4	4.3 \pm 0.4	6.1 \pm 0.7	3.4 \pm 0.3	4.6 \pm 0.1	4.8 \pm 0.1
B3	9.9 \pm 0.2	10.2 \pm 0.3	10.9 \pm 0.4	11.3 \pm 0.6	11.2 \pm 0.2	10.3 \pm 0.5	11.2 \pm 0.2	11.3 \pm 0.4	9.3 \pm 1.5	7.3 \pm 0.4
B4	3.5 \pm 0.2	7.7 \pm 0.3	9.6 \pm 0.3	6.5 \pm 0.7	7.4 \pm 0.4	4.4 \pm 1.0	7.9 \pm 0.5	6.3 \pm 0.2	7.2 \pm 0.4	7.5 \pm 0.7
B5	Not Sampled	Not Sampled	4.4 \pm 0.4	3.1 \pm 0.4	3.5 \pm 0.6	2.6 \pm 0.4	3.0 \pm 0.3	0.6 \pm 0.3	3.9 \pm 0.7	5.1 \pm 0.2
B6	Not Sampled	Not Sampled	1.4 \pm 0.2	0.1 \pm 0.2	1.1 \pm 0.2	1.4 \pm 0.5	0.9 \pm 0.3	0.9 \pm 0.3	0.3 \pm 0.2	1.9 \pm 0.1
R1	Not Sampled	Not Sampled	Not Sampled	Not Sampled	6.2 \pm 0.9	6.7 \pm 2.1	6.4 \pm 0.6	5.8 \pm 0.2	7.8 \pm 0.4	6.7 \pm 0.2
R21	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	1.9 \pm 0.2	Not Sampled	Not Sampled	Not Sampled	Not Sampled
R2	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	0.6 \pm 0.2	Not Sampled	Not Sampled	Not Sampled
R3	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	0.0 \pm 0.1	2.6 \pm 0.2	2.9 \pm 0.2

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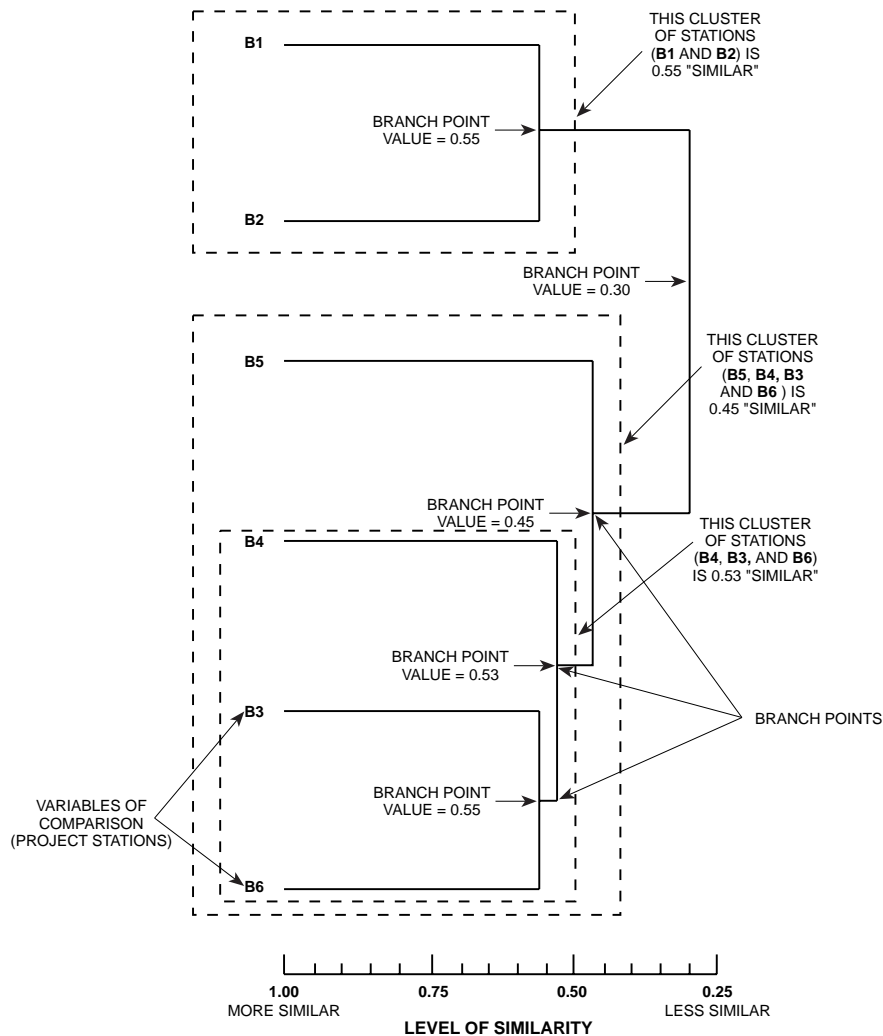
Table 4-4 Sediment grain size distribution at 1998 Project and background benthic infauna stations

Explanation: Dendrograms are one way to graphically present the similarity between groups of stations. Almost any type of station data can be compared this way. In this report dendrograms are used to compare grain size characteristics at the stations as well as biological characteristics such as the total abundances of animals at each station.

The dendrograms in this report can be thought of as a kind of family tree turned on its side. In other words, the relatives in the family (stations) which are on close by branches are more closely related to each other than to stations on more distant branches.

The levels of similarity (or relatedness) between groups of stations can be obtained from the graph by looking at the clusters which are formed by the branches of the graph below, the cluster of Stations B1 and B2 indicates that these two stations are somewhat similar. The exact amount of similarity between these two stations can be obtained by looking at where the branches leading to these two stations join and comparing this junction (or branch point) to the scale at the bottom of the graph. If the branch point is located all the way to the left of the graph, the similarity between Stations B1 and B2 would be 1.00 (or completely similar; identical). If the branch point for these stations is all the way to the right of the graph, the similarity would be 0.00 (or completely dissimilar). In the example shown, the branch point is actually somewhat in between these two extremes, or about 0.55 similar (somewhat similar).

The usefulness of this type of graph is apparent when the family tree analogy is used again. Station B1 and B2 are somewhat similar relatives (0.55 similar). Similarly, Stations B4, B3, and B6 at the bottom of the graph form a group of three relatives which are somewhat related (0.53 similar). However, the B1/B2 cluster of relatives is only distantly related to the B4/B3/B5/B6 cluster of relatives (0.30 similar) because their family lines finally come together only at the very right hand side of the graph. Like this example, any cluster of relatives can be compared to any other cluster to determine the degree of relatedness.



**Figure 4-2.
Example Dendrogram**

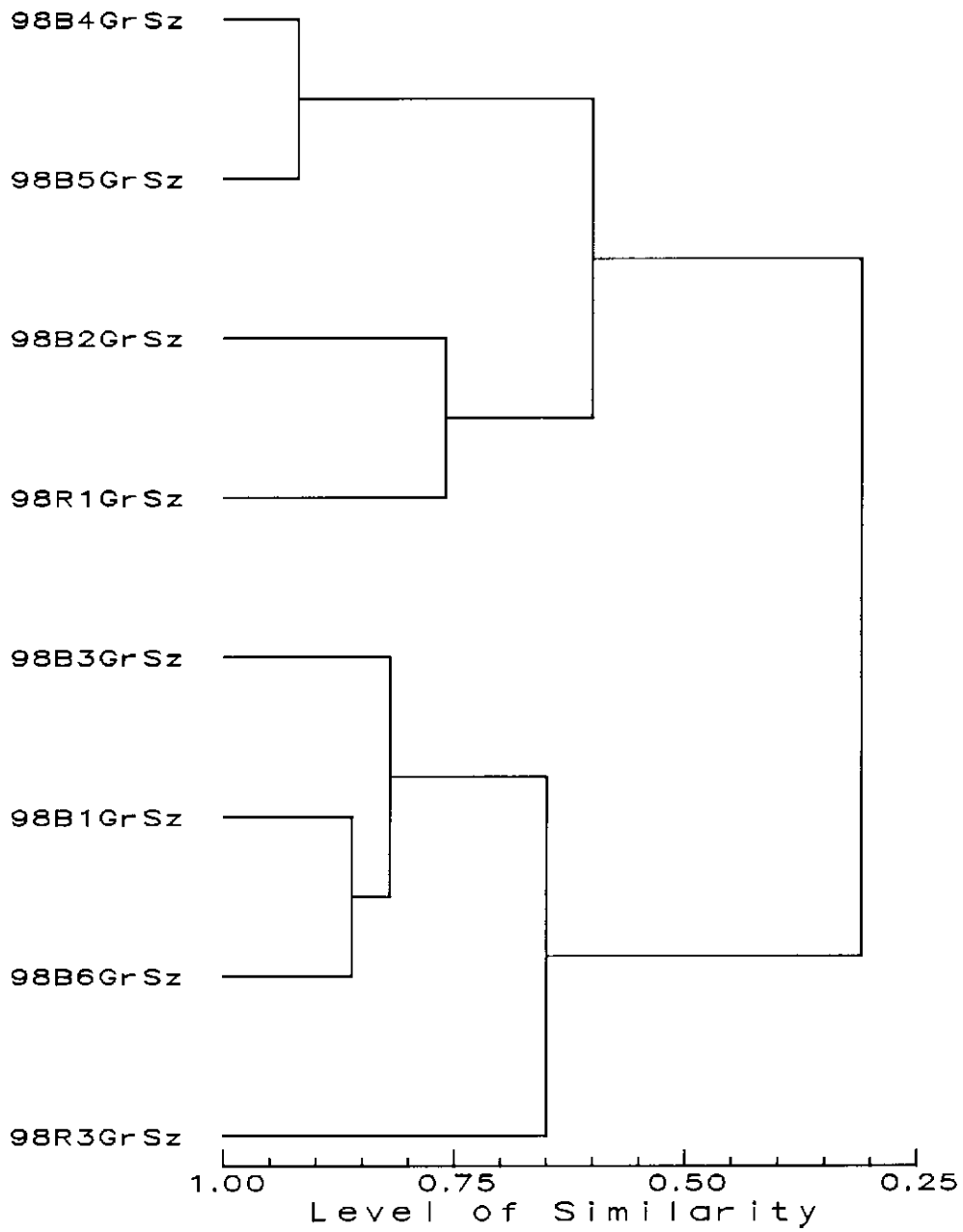


Figure 4-3.
Similarity Dendrogram
for Sediment Grain
Size Distribution

medium to fine sand and/or silt). However, the PSI revealed that all stations, when grouped together, were relatively dissimilar, with a similarity of only 0.31 (see Figure 4-3).

Changes in the particle size distribution of surface sediment have occurred each year at all of the stations (Figure 4-4). These changes probably reflect the overall dynamic state of the unconsolidated substrate in Commencement Bay. Depending on wave action, sediment load in the overlying water, and current velocities, fine sediments will be deposited or eroded from these habitats. Stations B1, B3, B6 and R3 became siltier between 1997 and 1998. Stations B2, B4, B5, and R1 became sandier. The overall range of grain size for all Project and background stations was more varied than in 1997. In 1998, the silt/clay fraction ranged from 13% to 74%, in contrast with a 1997 range of 26% to 79% (see Table 4-4). Generally, stations B1 and B6 within the lagoon have been relatively silty and typical of mudflats, while B4 and B5 have been sandier, typical of intertidal beach (Figure 4-4).

Although a small increase in fines occurred at Station B6, it did not likely result in any significant change in the infauna sampled at this station. Grain size changes at other stations were somewhat more substantial and may have resulted in changes in the infauna. For example, the sand/gravel fraction at Station B5 increased 15% between 1997 and 1998. Station B2 changed from predominantly fines (79%) to predominantly sand (61%) and Station B3 changed from predominantly sand (56%) to predominantly fines (63%) in 1998. Although stations B1 and R3 were predominantly silty in both years, a relatively large increase in fines content (12% and 17%, respectively) occurred at both stations in 1998. The corresponding decrease in the fraction of coarse material (>0.500 mm) present at B1 (17%) was also notable. In addition, a decrease of 12% in coarse material and an increase of 10% in medium to fine sand was observed at station B6.

4.3.1.3 Total Volatile Solids

Total volatile solids (TVS)—a general measure of organic content of sediment—in Commencement Bay surface sediments has been reported to range from 0.3 to 44.7% (n=117) (Tetra Tech 1985). In 1998, TVS from Project stations varied from 1.6% of the sample total dry weight (station B5) to 9.7% (station B3) (Table 4-5). TVS is sometimes related to the amount of fine material in a sample but there did not appear to be a strong relationship between fines and TVS content in these samples (see Table 4-4). For example, although the sediments at stations B1, B3, and B6 contained a majority of fines (70%, 63%, and 60%, respectively) and relatively high TVS values (5.5%, 9.7%, and 7.1%, respectively), the station with the greatest fraction of fines (R3-74%) exhibited a relatively low TVS (3.1%).

Total volatile solids decreased at all Project stations except station B3 between 1997 and 1998 (Figure 4-5; see Table 4-5). The most dramatic reductions in TVS occurred at Project stations B1 (19%) and B6 (11.5%); thereby indicating that the large increases in TVS noted at these stations in 1997 were uncommon and transitory. The organic material that increased in 1997 apparently due to the preceding flood may have been partially consumed or washed from these stations. The TVS at background stations R1 and R3 changed only 0.2% (increase) and 0.1%



Figure 4-4 Percent Fines at Surface Sediment Stations 1989 to 1998

Figure 4-5 Total Volatile Solids as a Percentage of the Total Sediment Dry Weight for Stations Sampled from 1989 through 1998

Table 4-5. Total volatile solids as a percentage of sediment dry weight for all Project and background stations.

Station	Year								
	1989	1990	1991	1992	1993	1995	1996	1997	1998
B1	4.1	3.6	2.4	1.9	2.4 ± 0.09	3.1	3.1	24.5	5.5
B2	2.8	4.0	3.6	3.5	3.7	3.7 ± 0.2	4.2	4.9	3.1
B3	2.2	4.7	3.5	3.9	3.7	4.8	3.2	3.7	9.7
B4	2.1	1.9	3.7	2.0	2.5	1.5	4.2	2.2	2.1
B5	NS	NS	1.8	2.0	2.7	1.4	2.7	2.4	1.6
B6	NS	NS	3.6	2.7	2.2	2.5	4.4	18.6	7.1
R1	NS	NS	NS	NS	1.9	1.4	3.1	2.2	2.4
R3	NS	NS	NS	NS	NS	NS	2.8	3.2	3.1

Note: 1994 data were not collected.
NS = Not Sampled

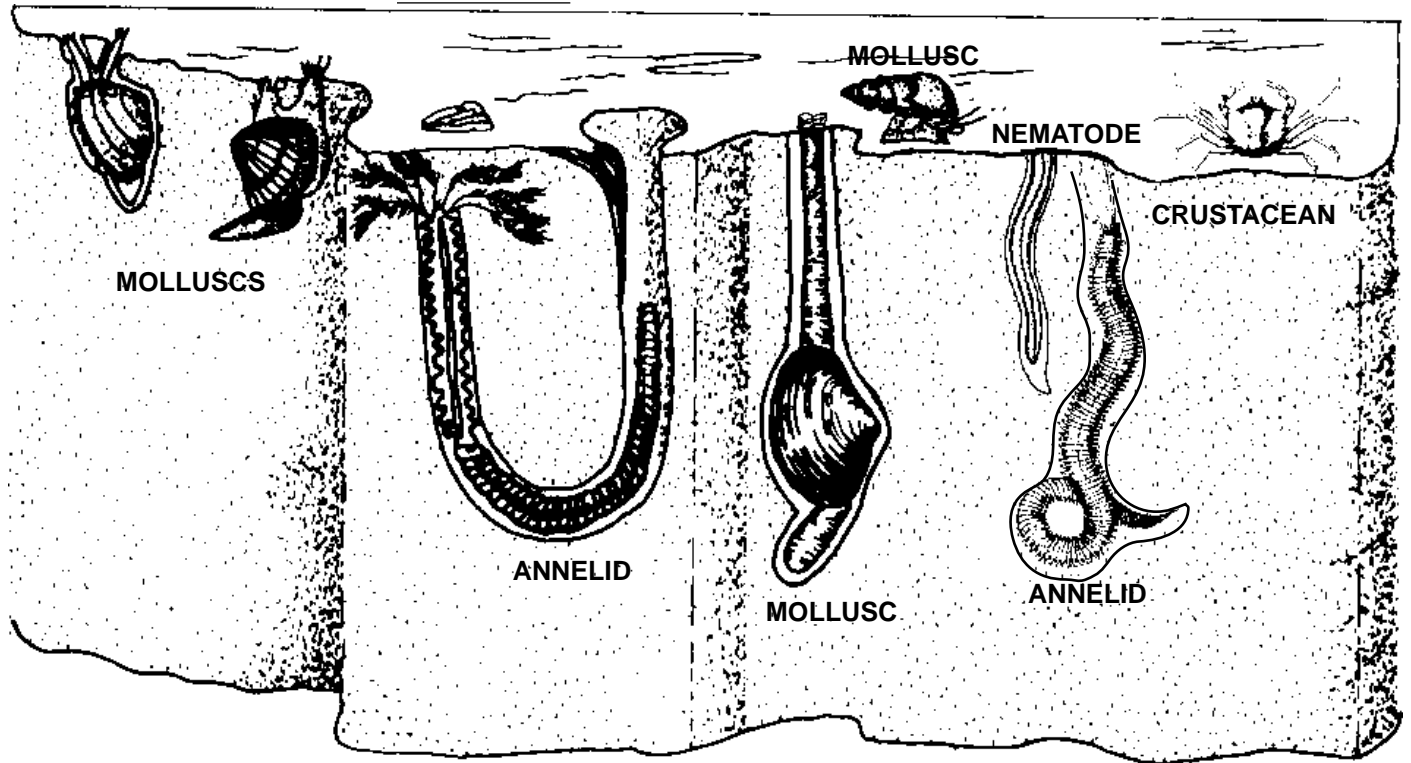
(decrease) between 1997 and 1998. No consistent Project-wide changes were evident from 1989 through 1998. Similarly, none of the individual stations appeared to indicate a clear trend toward either increasing or decreasing TVS.

4.3.2 General Biological Characteristics

The following subsection discusses the more common organisms found in the Project area this year. Common benthic infauna found in the Project area were grouped into the following major taxa or phyla: Annelida, Crustacea, Mollusca, and Echinodermata. Representative organisms from some of these phyla are pictured in Figure 4-6. Other phyla such as Nematoda (round worms) were also found in the Project area, but organisms from these phyla were not as numerous in the samples.

Annelida (Worms)

Polychaete worms of the phylum Annelida are segmented marine worms, related to earthworms. They are relatively advanced animals and many exhibit sophisticated and complex behavioral patterns. Most local polychaetes are small (± 5 cm), although a few can be almost a meter in length. This diverse and successful phylum contains annelids with predatory, herbivorous, scavenging, and/or foraging habits. Over 500 species are found in local shallow-water environments within Puget Sound. Common annelids found this year at the Project site include:



Simpson Mon. '96/55-1650-41(11) 9/96

Source:
Thurman, H.V., Webber, H.H. 1984. Marine Biology.
Charles E. Merrill Publishing Co., Columbus, Ohio.

Figure 4-6.
Typical Benthic Organisms

*Mediomastus sp. Indet.*¹
Prionospio lighti
Prionospio multibranchiata
Lumbrineris californiensis
Pista wui
Platynereis bicanaliculata

Capitella capitata 'hyperspecies'²
Prionospio steenstrupi
Leitoscoloplos pugettensis
Nephtys cornuta
Aphelochaeta sp. N-1
Nephtys ferruginea

Crustacea (Shrimps and Crabs)

The phylum Arthropoda contains the crustaceans; perhaps most well-known are the shrimps, crabs, and barnacles. However, many other ecologically important taxa, such as amphipods, ostracods, tanaids, and isopods, are found in this phylum. Crustaceans have a complicated internal anatomy and are characterized by an external, flexible, skeleton or shell. As they grow, they molt or “shed” their skin. About 2,000 species of crustaceans are found in the Puget Sound region.

A common shrimp (ghost shrimp) in the Project area this year was *Neotrypaea californiensis*. A common crab in the Project area this year was *Pinnixa schmitti*.

Amphipods comprise a large order of familiar crustaceans (for example, the beach hopper or sand flea), with several large suborders. Many amphipods are scavengers or detritus feeders, although some eat algae. As a wide-ranging and diverse group, they may be found locally on silt, sand, algae, or seagrass substrates. The most common Gammarid amphipod found in the Project area this year was *Aoroides sp. Indet.*

Ostracods, or seed-shrimp, are small crustaceans that look like shrimp enclosed in clam shells. Many are detritus feeders, often very common in marine, soft-sediment localities in the Puget Sound region. Those in the Project area this year included *Euphilomedes carcharodonta*.

Tanaids are small crustaceans related to isopods. Most are about 1 to 5 mm long and look like a small praying mantid. An example species at the Project site this year was *Leptocheilia dubia (savignyi)*.

¹ This abbreviation stands for “indeterminate,” meaning that the exact species could not be determined because the animal was too young or damaged to positively identify. Other related abbreviations, such as “sp. A,” “sp. N-1,” or “sp. Juv.,” indicate that the animal was of a particular, but unidentified, species or that the animal was a juvenile.

² Any collection (or sample) of *Capitella capitata* will consist of several “sibling species” that appear to be morphologically identical. The collection is referred to as a ‘hyperspecies’ because the “siblings” cannot be separated on the basis of morphology but differ genetically to the extent they may be classified as separate species (Howard Jones 1998 personal communication).

Mollusca (Snails and Clams)

The phylum Mollusca includes snails, clams, and squids. This phylum contains some of the largest animals found in the Puget Sound region. Over 1,000 molluscan species are described from Puget Sound. A common snail found at the Project site was *Alvania compacta*. Numerous clams were found at the Project site, including:

<i>Rochefortia tumida</i> ³	<i>Tellina sp. Indet.</i>
<i>Parvalucina tenuisculpta</i>	<i>Axinopsida serricata</i>
<i>Macoma nasuta</i>	<i>Tellina modesta</i>
<i>Macoma sp. Indet.</i>	<i>Nutricula lordi</i> ⁴
<i>Macoma inquinata</i>	

Echinodermata (Sea Stars and Urchins)

The phylum Echinodermata contains sea stars, sea urchins, sand dollars, and brittle stars. These are radially symmetrical organisms that often have five major rays or body parts. Two kinds of brittle stars (Ophiuroidea class) were collected at Project stations this year, *Amphiodia urtica* and an indeterminate species of *Amphiodia*, but neither species was particularly abundant. Sea stars and sea urchins were not present in the samples collected this year.

4.3.2.1 Benthos Abundance and Diversity in the Project Area

In 1998, 132 species and 58 supraspecific⁵ taxa were collected at Project stations (Table 4-6). The total number of organisms in 1998 (21,777) was slightly higher than the number collected in 1997. More animals were collected at every station in 1998 than 1997 (see Table 4-6), except at stations B2 and B6. To provide context to the sampled area relative to the entire Project site area, these samples reflect about 7,259 organisms per square meter of habitat and the Project site includes about 69,000 square meters of habitat.

Some sampled taxa cannot be identified to the species level, often because a juvenile life stage can be very difficult to identify. In these cases, the organisms are identified to the lowest level possible. It is likely that some or many of these taxa represent more than one species of organism; however, for the purposes of this report they are treated as if each identified taxa represents one species.

The total number of taxa (those identified to any level of taxonomic precision) increased at stations B1, B4, and B5 and decreased at the other three Project stations between 1997 and 1998. None of

³ Formerly *Mysella tumida* (Howard Jones 1998 personal communication).

⁴ Formerly *Psephidia lordi* (Howard Jones 1998 personal communication).

⁵ "Supraspecific" indicates animals that were not identified to species.

Table 4-6. Abundance of benthic infauna and number of taxa (see Appendix Section 4.4) at Project stations, by year, since 1991. Note: 1994 station B2 abundances based on four replicates.

	Totals								Change Between 1997 and 1998
	1991	1992	1993	1994	1995	1996	1997	1998	
A. Abundance									
B1	627	2,693	2,017	3,113	6,117	8,589	2,763	4,414	1651
B2	2,193	3,062	3,341	4,042	3,037	6,268	3,700	3,692	-8
B3	5,275	5,557	5,585	3,806	5,988	8,141	3,768	4,221	453
B4	3,419	8,303	9,718	4,471	5,247	10,361	2,705	3,129	424
B5	1,149	2,163	1,172	2,576	1,913	4,911	1,339	2,503	1164
B6	1,262	3,235	2,559	5,703	7,947	3,978	6,681	3,818	-2,863
Total	13,925	25,013	24,392	23,711	30,249	42,248	20,956	21,777	821
B. Number of Taxa Identified to Species									
B1	38	56	69	84	74	73	69	67	-2
B2	74	67	69	77	65	68	81	61	-20
B3	85	70	73	87	83	105	99	90	-9
B4	79	82	80	95	96	86	96	89	-7
B5	56	69	60	89	68	86	58	74	16
B6	59	74	75	79	78	71	68	63	-5
Total	174	216	189	141	148	156	167	132	-35
C. Total Number of Taxa									
B1	56	83	89	104	110	95	86	91	5
B2	102	101	91	98	99	89	105	87	-18
B3	112	127	120	109	127	140	132	124	-8
B4	111	134	119	112	132	118	120	121	1
B5	83	94	82	107	94	109	79	106	27
B6	69	91	79	98	111	111	99	88	-11
Total					211	222	225	190	-35

these changes are statistically significant. The total number of taxa at all stations combined decreased from last year (see Table 4-6), but is in a range typical of the Project over the last ten years of sampling.

4.3.2.2 Station Benthic Assemblages and Dominant Taxa

Because all of the Project stations are in close proximity, have similar substrates, and have a relatively small range of depths, the stations contained many of the same species. The total number of taxa common to all six Project stations increased from 34 in 1997 to 46 in 1998, and number of taxa collected from at least three stations similarly increased from 73 in 1997 to 104 in 1998 (Table 4.4-10; Data Appendix Section 4.4).

At the Project stations, the number of numerically dominant taxa (defined as those taxa comprising 75% of a station's abundance) ranged from 7 at station B1 to 20 at station B4 (Table 4-7). As in previous years, the dominant taxa array (or set of dominant taxa) varied between the six Project stations. The dominant taxa arrays of the Project stations included 19 species of annelids, 12 species of molluscs, and 6 species of crustaceans. None of the other (or miscellaneous) taxa were represented in the dominant taxa array of the Project stations.

Polychaetes of the genera *Mediomastus* and *Prionospio* were in the dominant array at all six Project stations. *Mediomastus* sp. Indet. was also one of the three most dominant taxa at all stations, ranging in abundance from 8.0% to 33.0% of the total mean taxa at any given station. At least one *Prionospio* species was in the top three dominant taxa at all stations except B1 and B6. *Mediomastus* sp. Indet. and two *Prionospio* species were the three most dominant taxa at two (B2 and B5) of the six Project stations. The abundance of *Prionospio* spp. varied from 2.5% to 13.9% of the total mean taxa at any given station (see Table 4-7).

The bivalve *Rochefortia tumida* was one of the three most dominant taxa at stations B3 and B6, the fourth most dominant taxa at B5, and present in the dominant array of stations B2 and B4. The abundance of this bivalve varied from 3.0% to 17.3% of the total mean taxa at any given station (see Table 4-7). The leptostracan *Nebalia pugettensis*, and the tanaid *Leptochelia dubia (savignyi)*, were the only crustaceans represented among the three most dominant taxa at any of the Project stations (B1 and B6, respectively). *Leptochelia dubia* was also present in the dominant taxa array of station B3.

In 1998, as in 1997 and 1996, the Project area was dominated by the polychaetes *Mediomastus* sp. Indet. and *Prionospio lighti* and the mollusc *Rochefortia tumida*, as were the background stations. However, other annelids, molluscs, and crustaceans also made up substantial portions of the population at most of the stations. Common (i.e, represented in the dominant arrays of the Project stations) annelids included *Capitella capitata* 'hyperspecies' (very abundant at B1), *Prionospio* spp. other than *P. lighti* (all six stations), and *Leitoscoloplos pugettensis* (except at B1). Common molluscs included the bivalve species *Tellina* spp. (except at B1 and B2), *Macoma* spp. (except at B1), *Parvalucina tenuisculpta* (stations B3, B4, and B5), and *Axinopsida serricata* (stations B3, B4, and B5). Other crustaceans represented in the dominant arrays were *Aoroides* sp. Indet. (station B1), *Pinnixa schmitti* (B2), *Neotrypaea californiensis* (B3, B4, and B5), and *Euphilomedes carcharodonta* (B3 and B4).

The dominant taxa also included all of the more common trophic categories (feeding types). Dominant suspension feeders included *Rochefortia tumida*, *Parvalucina tenuisculpta*, and *Leitoscoloplos pugettensis*, as well as some taxa, such as *Prionospio lighti* and *Axinopsida serricata*, that may be either suspension or deposit feeders. Deposit feeders included members of the *Macoma* genus, *Alvania compacta* and *Mediomastus* sp. Indet. (probably *M. californiensis*). Detritivores were represented in the dominant array by *Euphilomedes carcharodonta* and *Lumbrineris californiensis*. Predators, such as *Leptochelia dubia (savignyi)* and *Nephtys cornuta*, as well as predator/detritivore *Neotrypaea californiensis* and its commensal crab *Pinnixa schmitti*, were also present in the dominant arrays at some stations.

Table 4-7. Faunal abundances (sample replicate mean \pm 1 sample standard deviation) of the numerically dominant taxa for Project and background station in 1998. Normalized to numbers/m². Numerically dominant taxa are those that comprise 75% of a station's abundance. Taxa listed in order of decreasing mean abundance.

Taxon	Numerical Abundance			Percent	
	Mean	\pm	Std. Dev.	Taxon	Cumulative
A. Project Station B1					
<i>Capitella capitata</i> 'hyperspecies'	2696.0	\pm	5425.1	30.5	30.5
<i>Nebalia pugettensis</i>	1212.0	\pm	992.6	13.7	44.3
<i>Mediomastus</i> sp. Indet.	1170.0	\pm	1686.0	13.3	57.5
<i>Prionospio multibranchiata</i>	502.0	\pm	323.0	5.7	63.2
<i>Prionospio lighti</i>	410.0	\pm	261.5	4.6	67.9
<i>Alvania compacta</i>	370.0	\pm	186.0	4.2	72.0
<i>Aoroides</i> sp. Indet.	344.0	\pm	278.2	3.9	75.9
Total Abundance of:					
7 Numerically Dominant Taxa	6704				75.9
84 Other Taxa	2124				24.1
All 91 Taxa	8828				
B. Project Station B2					
<i>Mediomastus</i> sp. Indet.	2434.0	\pm	1423.4	33.0	33.0
<i>Prionospio lighti</i>	1024.0	\pm	275.6	13.9	46.8
<i>Prionospio multibranchiata</i>	464.0	\pm	247.4	6.3	53.1
<i>Capitella capitata</i> 'hyperspecies'	302.0	\pm	147.0	4.1	57.2
<i>Rochefortia tumida</i>	296.0	\pm	166.1	4.0	61.2
<i>Leitoscoloplos pugettensis</i>	204.0	\pm	99.1	2.8	64.0
<i>Platynereis bicanaliculata</i>	190.0	\pm	93.0	2.6	66.5
<i>Macoma</i> sp. Indet.	136.0	\pm	112.6	1.8	68.4
<i>Pinnixa schmitti</i>	128.0	\pm	137.0	1.7	70.1
<i>Lumbrineris californiensis</i>	116.0	\pm	59.0	1.6	71.7
<i>Macoma nasuta</i>	112.0	\pm	35.6	1.5	73.2
<i>Pista wui</i>	110.0	\pm	64.0	1.5	74.7
<i>Armandia brevis</i>	104.0	\pm	65.8	1.4	76.1
Total Abundance of:					
13 Numerically Dominant Taxa	5620				76.1
74 Other Taxa	1764				23.9
All 87 Taxa	7384				
C. Project Station B3					
<i>Mediomastus</i> sp. Indet.	786.0	\pm	158.2	9.3	9.3
<i>Prionospio lighti</i>	594.0	\pm	266.7	7.0	16.3
<i>Rochefortia tumida</i>	530.0	\pm	218.1	6.3	22.6
<i>Tellina</i> sp. Indet.	498.0	\pm	116.5	5.9	28.5
<i>Prionospio steenstrupi</i>	450.0	\pm	90.3	5.3	33.9
<i>Tellina modesta</i>	398.0	\pm	127.9	4.7	38.6
<i>Nephtys cornuta</i>	358.0	\pm	208.4	4.2	42.8
<i>Lumbrineris californiensis</i>	354.0	\pm	196.0	4.2	47.0
<i>Leitoscoloplos pugettensis</i>	324.0	\pm	182.8	3.8	50.8
<i>Leptochelia dubia</i>	280.0	\pm	176.1	3.3	54.2

Table 4-7. Faunal abundances (sample replicate mean \pm 1 sample standard deviation) of the numerically dominant taxa for Project and background station in 1998. Normalized to numbers/m². Numerically dominant taxa are those that comprise 75% of a station's abundance. Taxa listed in order of decreasing mean abundance.

Taxon	Numerical Abundance			Percent	
	Mean	\pm	Std. Dev.	Taxon	Cumulative
<i>Aphelochaeta</i> sp. N-1 (NAMIT)	262.0	\pm 105.7		3.1	57.3
<i>Axinopsida serricata</i>	260.0	\pm 149.3		3.1	60.3
<i>Parvilucina tenuisculpta</i>	242.0	\pm 78.5		2.9	63.2
<i>Neotrypaea californiensis</i>	232.0	\pm 106.2		2.7	66.0
<i>Nutricola lordi</i>	210.0	\pm 158.6		2.5	68.4
<i>Nephtys ferruginea</i>	172.0	\pm 80.1		2.0	70.5
<i>Pista wui</i>	158.0	\pm 77.3		1.9	72.4
<i>Euphilomedes carcharodonta</i>	134.0	\pm 52.2		1.6	73.9
<i>Macoma nasuta</i>	128.0	\pm 56.3		1.5	75.5
Total Abundance of:					
19 Numerically Dominant Taxa	6370				75.5
105 Other Taxa	2072				24.5
All 124 Taxa	8442				
D. Project Station B4					
<i>Mediomastus</i> sp. Indet.	766.0	\pm 312.1		12.2	12.2
<i>Prionospio steenstrupi</i>	584.0	\pm 189.6		9.3	21.6
<i>Parvilucina tenuisculpta</i>	378.0	\pm 183.9		6.0	27.6
<i>Lumbrineris californiensis</i>	342.0	\pm 98.3		5.5	33.1
<i>Axinopsida serricata</i>	338.0	\pm 229.0		5.4	38.5
<i>Euphilomedes carcharodonta</i>	304.0	\pm 207.7		4.9	43.3
<i>Pista wui</i>	264.0	\pm 47.2		4.2	47.6
<i>Leitoscoloplos pugettensis</i>	234.0	\pm 94.8		3.7	51.3
<i>Tellina</i> sp. Indet.	200.0	\pm 30.8		3.2	54.5
<i>Rochefortia tumida</i>	188.0	\pm 72.9		3.0	57.5
<i>Aphelochaeta</i> sp. N-1 (NAMIT)	172.0	\pm 13.0		2.7	60.2
<i>Scoletoma luti</i>	150.0	\pm 58.3		2.4	62.6
<i>Nephtys ferruginea</i>	138.0	\pm 72.9		2.2	64.8
<i>Neotrypaea californiensis</i>	126.0	\pm 104.1		2.0	66.9
<i>Astyris gausapata</i>	102.0	\pm 103.1		1.6	68.5
<i>Nephtys cornuta</i>	92.0	\pm 121.1		1.5	70.0
<i>Macoma obliqua</i>	90.0	\pm 73.8		1.4	71.4
Cirratulidae sp. Indet.	88.0	\pm 50.2		1.4	72.8
<i>Alvania compacta</i>	86.0	\pm 106.9		1.4	74.2
<i>Glycinde polygnatha</i>	80.0	\pm 23.5		1.3	75.5
Total Abundance of:					
20 Numerically Dominant Taxa	4722				75.5
101 Other Taxa	1536				24.5
All 121 Taxa	6258				
E. Project Station B5					
<i>Mediomastus</i> sp. Indet.	876.0	\pm 761.7		17.5	17.5
<i>Prionospio lighti</i>	454.0	\pm 521.6		9.1	26.6

Table 4-7. Faunal abundances (sample replicate mean \pm 1 sample standard deviation) of the numerically dominant taxa for Project and background station in 1998. Normalized to numbers/m². Numerically dominant taxa are those that comprise 75% of a station's abundance. Taxa listed in order of decreasing mean abundance.

Taxon	Numerical Abundance			Percent	
	Mean	\pm	Std. Dev.	Taxon	Cumulative
<i>Prionospio steenstrupi</i>	378.0	\pm 96.3		7.6	34.1
<i>Rochefortia tumida</i>	354.0	\pm 390.0		7.1	41.2
<i>Leitoscoloplos pugettensis</i>	318.0	\pm 174.8		6.4	47.5
<i>Parvilucina tenuisculpta</i>	228.0	\pm 62.2		4.6	52.1
<i>Axinopsida serricata</i>	166.0	\pm 57.3		3.3	55.4
<i>Lumbrineris californiensis</i>	156.0	\pm 106.4		3.1	58.5
<i>Macoma nasuta</i>	144.0	\pm 72.3		2.9	61.4
<i>Tellina modesta</i>	118.0	\pm 49.7		2.4	63.8
<i>Tellina</i> sp. Indet.	114.0	\pm 114.6		2.3	66.0
<i>Alvania compacta</i>	90.0	\pm 94.1		1.8	67.8
<i>Nephtys cornuta</i>	90.0	\pm 100.7		1.8	69.6
<i>Glycera americana</i>	74.0	\pm 40.4		1.5	71.1
<i>Neotrypaea californiensis</i>	74.0	\pm 97.1		1.5	72.6
<i>Nereis procera</i>	70.0	\pm 17.3		1.4	74.0
<i>Pista wui</i>	70.0	\pm 50.5		1.4	75.4
Total Abundance:					
17 Numerically Dominant Taxa	3774				75.4
89 Other Taxa	1232				24.6
All 106 Taxa	5006				
F. Project Station B6					
<i>Rochefortia tumida</i>	1322.0	\pm 349.8		17.3	17.3
<i>Leptochelia dubia</i>	896.0	\pm 1116.5		11.7	29.0
<i>Mediomastus</i> sp. Indet.	612.0	\pm 278.5		8.0	37.1
<i>Prionospio multibranchiata</i>	512.0	\pm 231.3		6.7	43.8
<i>Prionospio lighti</i>	358.0	\pm 125.2		4.7	48.5
<i>Macoma nasuta</i>	312.0	\pm 97.3		4.1	52.5
<i>Leitoscoloplos pugettensis</i>	284.0	\pm 55.0		3.7	56.3
<i>Tellina</i> sp. Indet.	282.0	\pm 94.7		3.7	60.0
<i>Nephtys cornuta</i>	260.0	\pm 92.2		3.4	63.4
<i>Platynereis bicanaliculata</i>	210.0	\pm 89.4		2.8	66.1
<i>Macoma</i> sp. Indet.	202.0	\pm 74.6		2.6	68.8
<i>Prionospio steenstrupi</i>	194.0	\pm 69.9		2.5	71.3
<i>Macoma inquinata</i>	190.0	\pm 70.4		2.5	73.8
<i>Alvania compacta</i>	162.0	\pm 179.2		2.1	75.9
Total Abundance:					
14 Numerically Dominant Taxa	5796				75.9
74 Other Taxa	1840				24.1
All 88 Taxa	7636				
G. Background Station R1					
<i>Aphelochaeta</i> sp. N-1 (NAMIT)	2164.0	\pm 1094.2		24.2	24.2
<i>Rochefortia tumida</i>	952.0	\pm 794.4		10.6	34.9

Table 4-7. Faunal abundances (sample replicate mean \pm 1 sample standard deviation) of the numerically dominant taxa for Project and background station in 1998. Normalized to numbers/m². Numerically dominant taxa are those that comprise 75% of a station's abundance. Taxa listed in order of decreasing mean abundance.

Taxon	Numerical Abundance			Percent	
	Mean	\pm	Std. Dev.	Taxon	Cumulative
<i>Nutricola lordi</i>	690.0	\pm	561.1	7.7	42.6
<i>Mediomastus</i> sp. Indet.	556.0	\pm	311.3	6.2	48.8
<i>Axinopsida serricata</i>	414.0	\pm	297.9	4.6	53.4
<i>Prionospio lighti</i>	360.0	\pm	443.9	4.0	57.4
<i>Prionospio steenstrupi</i>	344.0	\pm	185.6	3.8	61.3
<i>Scoletoma luti</i>	284.0	\pm	174.7	3.2	64.5
<i>Euphilomedes carcharodonta</i>	236.0	\pm	159.0	2.6	67.1
<i>Pista wui</i>	196.0	\pm	111.5	2.2	69.3
<i>Macoma obliqua</i>	176.0	\pm	103.3	2.0	71.3
<i>Nephtys ferruginea</i>	148.0	\pm	104.7	1.7	72.9
<i>Amphiodia</i> sp. Indet.	140.0	\pm	94.9	1.6	74.5
<i>Pholoe</i> sp. N-1	134.0	\pm	65.0	1.5	76.0
Total Abundance:					
14 Numerically Dominant Taxa	6794				76.0
99 Other Taxa	2146				24.0
All 113 Taxa	8940				
H. Background Station R3					
<i>Prionospio lighti</i>	800.0	\pm	582.7	13.8	13.8
<i>Rochefortia tumida</i>	612.0	\pm	508.1	10.6	24.4
<i>Aphelochaeta</i> sp. N-1 (NAMIT)	554.0	\pm	580.4	9.6	34.0
<i>Haminaea vesicula</i>	424.0	\pm	387.9	7.3	41.3
<i>Mediomastus</i> sp. Indet.	412.0	\pm	167.8	7.1	48.5
<i>Neotrypaea californiensis</i>	242.0	\pm	49.7	4.2	52.7
<i>Macoma nasuta</i>	192.0	\pm	28.6	3.3	56.0
<i>Nephtys cornuta</i>	190.0	\pm	178.7	3.3	59.3
<i>Nephtys ferruginea</i>	178.0	\pm	54.5	3.1	62.4
<i>Spiophanes berkeleyorum</i>	172.0	\pm	90.1	3.0	65.3
<i>Prionospio steenstrupi</i>	150.0	\pm	100.0	2.6	67.9
<i>Macoma</i> sp. Indet.	140.0	\pm	117.7	2.4	70.3
<i>Scoletoma luti</i>	118.0	\pm	27.7	2.0	72.4
<i>Pista wui</i>	98.0	\pm	61.4	1.7	74.1
<i>Capitella capitata</i> 'hyperspecies'	90.0	\pm	107.5	1.6	75.6
Total Abundance:					
15 Numerically Dominant Taxa	4372				75.6
84 Other Taxa	1408				24.4
All 99 Taxa	5780				

In 1998, the total dominant array for the Project area (defined as the number of taxa in the dominant array of at least one station) was 36 (Table 4-8). However, because nine of these taxa were not identified to the species level (including members of the families Amphiuroidae, Lumbrineridae, and Cirratulidae; and the class Nemertinea), the dominant array probably contained more than 36 species.

4.3.2.3 Changes in the Dominant Taxa Array

Although the overall array of dominant taxa has remained somewhat similar to last year, the abundances of some taxa showed substantial changes between 1997 and 1998. These changes may indicate the dynamic nature of this community and the Commencement Bay delta. In 1998, the number of dominant taxa was greater or the same at all Project stations except B1, compared to 1997 (Table 4-9).

Mediomastus sp. Indet. was the dominant taxa in 1998, representing 15.3% of the total Project abundance, although it comprised 10.6% as the third most dominant taxa in 1997 (see Table 4-8). *Capitella capitata* 'hyperspecies,' the second most dominant taxa in 1998 (representing 7.1% of the total Project abundance) has been a component of the station dominant taxa arrays since 1995 but previously constituted 1.0% or less of the total Project abundance. *Prionospio lighti*, the third most dominant taxa in 1998 (6.7% of the total Project abundance) had been the second most dominant taxa in 1997 and the dominant taxa in 1995 and 1996 (representing 12.0%, 23.5% and 36.5%, respectively, of the total Project abundance). *Rochefortia tumida* (formerly *Mysella tumida*), the fourth most dominant taxa in 1998 (representing 6.4% of total Project abundance) had been the dominant taxa in 1997 and the third most dominant taxa in 1996 (comprising 22.8% and 7.4% of total Project abundance, respectively). In 1998, *Prionospio steenstrupi* (3.9%), *Prionospio multibranchiata* (3.6%), *Leitoscoloplos pugettensis* (3.2%), and *Leptochelia dubia* (3.1%) were the next most abundant taxa (see Table 4-8).

As noted earlier, the amount of silt measured in the surface sediments was higher this year than in 1997 at three of the six Project stations. As in previous years, many taxa abundances, particularly the continued dominance of the deposit-feeding worms *Prionospio lighti* and *Mediomastus* sp. Indet., were consistent with a silty (muddy) habitat.

In most cases, the changes noted above tend to take place on a site-wide basis. Perhaps most apparent was the increase in abundances for nearly all dominant taxa, especially the deposit-feeding polychaetes and molluscs (except *Rochefortia tumida*, *Parvalucina tenuisculpta*, and *Axinopsida serricata*). Given that the measured silt content in three of six Project samples was greater in 1998, the abundance of the deposit feeders might have been expected to increase. The opposite site-wide pattern occurred in 1997 (i.e., an increase in silty substrate and a decrease in the deposit-feeding organisms). The monitoring data indicate that communities in the Puyallup delta will remain dynamic and are not necessarily correlated to somewhat sandier or siltier substrate. Although the

Table 4-8. Station dominant taxa arrays from 1997 and 1998, expressed as total numerical abundance. (Bold numbers indicate the taxon was in the dominant array for that station.)

Taxa	1997								1998							
	B1	B2	B3	B4	B5	B6	Total	Percent ¹	B1	B2	B3	B4	B5	B6	Total	Percent ¹
<i>Mediomastus</i> sp. Indet.	683	716	310	199	64	246	2218	10.6	585	1217	393	383	438	306	3322	15.3
<i>Capitella capitata</i> 'hyperspecies'	20	54	26	0	1	61	162	--	1348	151	29	0	1	11	1540	7.1
<i>Prionospio lighti</i>	664	942	307	59	38	512	2522	12.0	205	512	297	38	227	179	1458	6.7
<i>Rochefortia</i> (formerly <i>Mysella</i>) <i>tumida</i>	176	347	639	190	270	3155	4777	22.8	41	148	265	94	177	661	1386	6.4
<i>Prionospio steenstrupi</i> (formerly <i>jubata</i>)	57	73	90	65	78	5	368	1.8	4	38	225	292	189	97	845	3.9
<i>Prionospio multibranchiata</i>	94	36	11	1	23	11	176	0.8	251	232	19	2	21	256	781	3.6
<i>Leitoscoloplos pugettensis</i>	62	32	28	88	132	37	379	1.8	17	102	162	117	159	142	699	3.2
<i>Leptochelia dubia</i> (<i>savignyi</i>)	5	1	3	7	0	983	999	4.8	74	8	140	10	2	448	682	3.1
<i>Nebalia pugettensis</i>	11	0	0	0	0	0	11	-	606	0	0	0	0	1	607	2.8
<i>Tellina</i> sp. Indet.	15	10	39	20	36	41	161	0.8	9	14	249	100	57	141	570	2.6
<i>Lumbrineris californiensis</i>	40	8	67	161	95	2	373	1.8	11	58	177	171	78	30	525	2.4
<i>Parvalucina tenuisculpta</i>	3	12	303	220	71	22	631	3.0	1	11	121	189	114	32	468	2.1
<i>Nephtys cornuta</i>	11	146	171	4	21	7	360	1.7	24	38	179	46	45	130	462	2.1
<i>Axinopsida serricata</i>	8	123	108	229	25	2	495	2.4	1	36	130	169	83	14	433	2.0
<i>Alvania compacta</i>	60	45	67	44	0	7	223	1.1	185	37	38	43	45	81	429	2.0
<i>Macoma nasuta</i>	31	58	72	29	54	122	366	1.7	24	56	64	29	72	156	401	1.8
<i>Tellina modesta</i>	0	28	37	29	52	61	207	1.0	2	28	199	32	59	70	390	1.8
<i>Pista wui</i>	12	21	25	13	2	3	76	--	4	55	79	132	35	68	373	1.7
<i>Platynereis bicanaliculata</i>	67	5	43	2	1	10	128	0.6	120	95	15	4	4	105	343	1.6
<i>Nephtys ferruginea</i>	2	41	48	33	13	3	140	0.7	9	33	86	69	28	78	303	1.4
<i>Armandia brevis</i>	25	11	8	0	1	38	83	--	130	52	17	6	15	66	286	1.3
<i>Macoma</i> sp. Indet.	26	24	31	6	26	32	145	0.7	43	68	47	4	21	101	284	1.3
<i>Aphelocheata</i> sp. N-1 (NAMIT)	7	20	10	12	1	2	52	-	4	22	131	86	17	13	273	1.3
<i>Euphilomedes carcharondonta</i>	0	2	29	357	16	0	404	1.9	2	7	67	152	27	12	267	1.2
<i>Neotrypaea californiensis</i>	10	70	18	6	0	8	112	0.5	6	9	116	63	37	1	232	1.1
<i>Scoletoma luti</i>	25	41	75	63	6	0	210	1.0	3	39	64	75	34	8	223	1.0
<i>Micropodarke dubia</i>	24	1	5	0	3	2	35	-	97	9	24	0	1	65	196	0.9
<i>Aoroides</i> sp. Indet.	0	0	0	2	1	0	3	-	172	15	4	0	1	1	193	0.9
<i>Macoma inquinata</i>	10	0	0	0	14	84	108	--	14	42	4	9	11	95	175	0.8
Nemertinea sp. Indet.	2	5	5	2	1	2	17	-	6	34	52	35	16	30	173	--
<i>Glycinde polygnatha</i>	41	55	31	37	23	58	245	1.2	13	10	61	40	26	18	168	0.8
<i>Pinnixa schmitti</i>	17	33	47	8	11	27	143	0.7	33	64	18	7	22	19	163	0.7
<i>Nereis procera</i>	4	7	3	4	10	18	46	-	4	23	35	17	35	25	139	0.6
<i>Nutricola</i> (formerly <i>Psephidia</i>) <i>lordi</i>	0	0	70	49	1	0	120	0.6	0	0	105	18	14	2	139	0.6
<i>Glycera americana</i>	10	11	9	2	5	6	43	--	5	12	23	12	37	40	129	0.6
<i>Macoma obliqua</i>	11	15	30	44	26	18	144	0.7	5	23	15	45	18	23	129	0.6
<i>Macoma yoldiformis</i>	1	2	16	78	13	16	126	0.6	6	24	18	29	33	16	126	--
Cirratulidae sp. Indet.	11	82	40	60	10	1	204	1.0	3	12	35	44	13	5	112	0.5

Table 4-8. Station dominant taxa arrays from 1997 and 1998, expressed as total numerical abundance. (Bold numbers indicate the taxon was in the dominant array for that station.)

Taxa	1997								1998							
	B1	B2	B3	B4	B5	B6	Total	Percent ¹	B1	B2	B3	B4	B5	B6	Total	Percent ¹
<i>Astyris gausapata</i>	1	13	33	101	0	7	155	0.7	6	6	21	51	1	4	89	0.4
<i>Podarke pugettensis</i>	2	0	2	0	0	0	4	-	58	7	6	0	1	0	72	--
Lumbrineridae sp. Indet.	21	17	45	40	17	2	142	0.7	0	0	26	26	0	15	67	--
<i>Amphiodia</i> sp. Indet.	0	13	114	18	4	4	153	0.7	1	6	16	15	8	4	50	--
<i>Cossura</i> sp. Indet.	68	104	70	3	0	0	245	1.2	9	0	13	1	0	0	23	--
<i>Megamoera subtener</i>	53	0	0	0	0	0	53	0.3	11	0	1	0	2	0	14	--
<i>Anisogammarus pugettensis</i>	1	0	0	0	0	423	424	2.0	0	0	4	0	0	0	4	--
Amphiuridae sp. Indet	10	34	70	26	15	7	162	0.8	0	0	1	2	0	0	3	--
<i>Amphiodia (Amphisgina) digitata</i>	2	12	95	8	0	2	119	0.6	0	0	0	0	0	0	0	--
<i>Aoroides spinosus</i>	129	25	3	0	2	0	159	0.8	0	0	0	0	0	0	0	--
<i>Pholoe glabra</i>	23	72	126	16	3	0	240	1.1	0	0	0	0	0	0	0	-
Project Dominant Abundance*	2555	3367	3379	2335	1185	6047	18868		4152	3353	3791	2657	2224	3569	19746	
Total Abundance**	2763	3700	3768	2705	1339	6681	20956		4414	3692	4221	3129	2503	3818	21777	
Station Dominant Abundance***	2113	2788	2849	2047	1013	5073	15883		3352	2810	3185	2361	1887	2898	16493	
Number of Dominant Taxa****	11	12	19	17	15	4	37		7	13	19	20	17	14	36	

¹ Percent of total abundance over all Project stations in that year, of taxa in the dominant array.

* Abundance of all taxa found to be dominant at any Project Station for either year.

** Abundance of all taxa at the station or Project.

*** Abundance of taxa that are members of the dominant array for that station.

**** Number of taxa that are dominant at the station.

--Taxa not in dominant array.

Table 4-9. Abundances and numbers of taxa sampled at Project stations in 1997 and 1998 for dominant, non-dominant, and all taxa.

	Dominant Taxa		Non-Dominant Taxa		All Taxa	
	Abundance	Number	Abundance	Number	Abundance	Number
1997						
B1	2,113	11	650	75	2,763	86
B2	2,788	12	912	93	3,700	105
B3	2,849	19	919	113	3,768	132
B4	2,047	17	658	103	2,705	120
B5	1,013	15	326	64	1,339	79
B6	5,073	4	1,608	95	6,681	99
Total	15,883	37	5,073	188	20,956	225
1998						
B1	3,352	7	1,062	84	4,414	91
B2	2,810	13	882	74	3,692	87
B3	3,185	19	1,036	105	4,221	124
B4	2,361	20	768	101	3,129	121
B5	1,887	17	616	89	2,503	106
B6	2,898	14	920	74	3,818	88
Total	16,493	36	5,284	154	21,777	190

water depths sampled at some stations varied between 1997 and 1998, corresponding differences in taxa diversity and abundances were not apparent. Thus, the changes in abundance did not appear to be an artifact of sampling.

4.3.2.4 Non-Numerically Dominant Taxa

Individuals from the numerically dominant taxa, by definition, constitute most of the individuals collected from any station. However, the numbers and abundances of rarer taxa can also be indicators of environmental health.

In 1998, the overall number of non-dominant taxa (n=154) was less than in 1997 (n=188) for the Project as a whole (see Table 4-9). Compared to 1997, the number of non-dominant taxa was lower in 1998 at all Project stations except B1 and B5. As in previous years, the non-dominant taxa contained representatives of many different taxa. Most of these taxa were present at more than one station.

4.3.2.5 Biomass

Biomass consists of the tissue and fluids found in an organism. To approximate biomass weight, the wet-weight biomass was measured for each of the following at each station: (1) all annelids; (2) all arthropods (essentially, crustaceans); and (3) all molluscs. All other taxa were pooled and their biomass also determined (Table 4-10).

Total biomass (all taxa per station) increased at four Project stations (B2, B3, B4, and B5) and decreased at stations B1 and B6 in 1998. Increases in biomass from 1997 were observed for annelids (all stations), arthropods (stations B2, B3, B4, and B5), "other taxa" (stations B2, B4, and B5), and molluscs (stations B2, B4, and B5). Decreases in biomass occurred for arthropods (stations B1 and B6), "other taxa" (stations B1, B3, and B6), and molluscs (B1, B3, and B5).

4.3.2.6 Ecological Indices

Ecological parameters such as diversity, evenness, and dominance can be measured using standard indices (Pielou 1966a,b, 1975, 1977; Poole 1974; Zar 1984) (Table 4-11). These indices were applied to the entire data set. For these analyses, taxa not identified to species were assumed to represent one species. Simpson's Index was calculated as "S" to express values consistent with the other indices⁶. Like the other indices, higher values indicate higher diversity in the sample (see Table 4-11).

⁶ Simpson's Index can be calculated for either "S" or "C" values. Because the "S" value (1-C) is comparable to other Index values, it was selected for this report.

Table 4-10. Mean replicate wet-weight (g/replicate ± standard deviation) biomass for the "major taxa" from 1991 through 1998.

Site	Year	Pooled Taxa				Total
		Annelid	Mollusk	Arthropod	Other	
B1	1991	0.52 ± 0.40	0.35 ± 0.15	0.04 ± 0.03	0.02 ± 0.01	0.93
	1992	2.96 ± 0.57	1.45 ± 0.32	0.81 ± 0.25	0.04 ± 0.01	5.26
	1993	3.22 ± 1.13	0.73 ± 0.60	1.50 ± 1.50	0.04 ± 0.04	5.49
	1994	6.13 ± 5.75	2.15 ± 2.22	0.50 ± 0.42	0.33 ± 0.46	9.11
	1995	14.30 ± 5.28	8.36 ± 6.21	2.88 ± 1.20	1.56 ± 2.80	27.09
	1996	11.32 ± 1.47	9.94 ± 5.16	1.45 ± 0.52	2.38 ± 3.03	25.09
	1997	3.45 ± 1.81	2.38 ± 2.34	1.79 ± 2.18	1.16 ± 2.57	8.78
	1998	4.51 ± 3.84	1.47 ± 1.35	0.58 ± 0.69	0.35 ± 0.52	6.91
B2	1991	1.70 ± 0.79	1.59 ± 1.13	0.38 ± 0.57	0.03 ± 0.01	3.70
	1992	2.37 ± 0.61	3.68 ± 3.64	0.78 ± 0.54	0.06 ± 0.04	6.89
	1993	5.02 ± 2.24	12.02 ± 3.15	2.82 ± 0.86	2.58 ± 4.54	22.44
	1994	10.53 ± 3.21	14.53 ± 10.71	1.34 ± 0.34	0.21 ± 0.36	26.61
	1995	5.69 ± 2.22	19.70 ± 6.35	2.03 ± 0.41	0.42 ± 0.33	27.85
	1996	8.79 ± 3.34	16.88 ± 22.12	0.61 ± 0.20	0.06 ± 0.07	26.34
	1997	4.25 ± 1.37	5.51 ± 4.49	0.36 ± 0.21	0.23 ± 0.10	10.35
	1998	6.18 ± 2.41	9.20 ± 1.47	0.87 ± 1.66	0.35 ± 0.25	16.60
B3	1991	1.16 ± 0.14	3.88 ± 1.35	0.77 ± 0.23	0.18 ± 0.12	5.99
	1992	2.11 ± 0.48	3.90 ± 1.55	4.14 ± 6.75	0.10 ± 0.06	10.25
	1993	3.12 ± 0.74	16.08 ± 3.39	1.08 ± 0.24	1.00 ± 0.06	21.28
	1994	7.04 ± 2.53	7.73 ± 2.47	0.73 ± 0.24	1.31 ± 1.12	16.80
	1995	8.61 ± 3.74	26.99 ± 9.22	3.59 ± 0.77	2.30 ± 1.07	41.50
	1996	12.86 ± 5.09	17.43 ± 8.85	1.48 ± 0.56	3.18 ± 1.10	34.95
	1997	3.44 ± 1.21	5.47 ± 4.00	0.23 ± 0.17	1.00 ± 1.14	10.14
	1998	4.12 ± 1.42	5.32 ± 1.15	0.91 ± 0.67	0.86 ± 0.31	11.20
B4	1991	2.34 ± 0.85	2.02 ± 0.75	0.26 ± 0.10	0.12 ± 0.15	4.74
	1992	2.33 ± 0.71	1.36 ± 0.41	1.26 ± 0.31	0.26 ± 0.38	5.21
	1993	3.48 ± 0.83	1.59 ± 0.49	1.65 ± 0.39	0.19 ± 0.22	6.91
	1994	7.02 ± 1.81	1.82 ± 0.95	0.90 ± 0.24	0.12 ± 0.07	9.86
	1995	8.15 ± 1.23	3.07 ± 1.24	2.43 ± 0.30	0.51 ± 0.34	14.16
	1996	8.47 ± 1.86	9.63 ± 3.52	1.12 ± 0.24	3.11 ± 1.84	22.33
	1997	2.20 ± 0.53	2.25 ± 1.01	0.26 ± 0.10	0.19 ± 0.14	4.90
	1998	4.73 ± 1.09	2.85 ± 0.65	0.35 ± 0.21	0.44 ± 0.60	8.37
B5	1991	1.85 ± 0.80	1.93 ± 2.46	1.31 ± 2.46	0.03 ± 0.00	5.12
	1992	1.36 ± 0.25	0.45 ± 0.14	28.43 ± 0.26	0.01 ± 0.01	30.25
	1993	2.24 ± 0.73	1.34 ± 2.01	0.27 ± 0.20	0.03 ± 0.03	3.88
	1994	3.60 ± 1.76	1.64 ± 1.72	0.72 ± 1.35	0.02 ± 0.03	5.99
	1995	4.11 ± 0.89	4.63 ± 2.00	3.62 ± 3.80	0.16 ± 0.12	12.52
	1996	8.54 ± 3.05	6.09 ± 2.84	1.14 ± 0.63	0.10 ± 0.15	15.87
	1997	1.95 ± 0.63	1.19 ± 0.62	0.05 ± 0.03	0.01 ± 0.01	3.20
	1998	3.60 ± 1.48	4.19 ± 2.01	0.19 ± 0.13	0.17 ± 0.14	8.15
B6	1991	0.87 ± 0.69	4.20 ± 4.62	1.90 ± 3.61	0.02 ± 0.01	6.99
	1992	2.77 ± 2.02	7.67 ± 4.46	6.59 ± 10.60	0.04 ± 0.04	17.07
	1993	1.75 ± 1.11	8.14 ± 1.38	1.03 ± 0.58	0.08 ± 0.08	11.00
	1994	5.61 ± 4.40	2.84 ± 1.27	0.89 ± 1.06	0.10 ± 0.12	9.44
	1995	9.74 ± 2.56	7.71 ± 4.15	1.56 ± 0.58	0.38 ± 0.25	19.39
	1996	3.94 ± 1.05	5.83 ± 3.04	2.89 ± 5.31	0.35 ± 0.23	13.02
	1997	1.28 ± 0.90	4.92 ± 2.92	1.04 ± 0.43	1.39 ± 2.84	8.64
	1998	3.24 ± 0.91	4.27 ± 1.57	0.33 ± 0.19	0.16 ± 0.09	8.00
R1	1993	1.65 ± 0.29	1.74 ± 0.41	0.28 ± 0.13	0.20 ± 0.18	3.87
	1994	2.67 ± 2.49	1.97 ± 1.03	0.10 ± 0.11	0.50 ± 0.71	5.15

Table 4-11. Ecological indices.

Index	Symbol	Measuring	Range	Meaning of Lower Value	Meaning of Higher Values
Shannon-Wiener	H'	Diversity	0 upward	Less diversity	More diversity
		Whether a specimen in a sample represents a new group (taxa)		Dominated by a few taxa	Less-dominated by a few taxa
				Typical values: less than 2.5	Typical values: greater than 2.75
Simpson's	S	Dominance	0 to 1	Less diversity	More diversity
		Probability that any 2 individuals belong to different species		Dominated by a few taxa	No taxa more numerous than others
				Typical values: less than 0.7	Typical values: greater than 0.9
Evenness	J	Dominance	0 to 1	Less diversity	More diversity
		How evenly the population is divided among species		Dominated by a few species	Approximately equal numbers of species
				Typical values: less than 0.7	Typical values: greater than 0.7
Proportional Similarity (cluster analysis)	PSI	Similarity among stations	Not Applicable	Less similar	More similar
		Groups or clusters of stations with similar species or taxa			

The ecological indices suggest that 1998 conditions at most Project stations were comparable to background stations R1 and R3 (Table 4-12). Except for station B1, and, to some extent station B2, the values were generally indicative of more diverse benthic assemblages in Puget Sound. The Shannon-Wiener results for both background stations were lower than results for B3, B4, and B5 and approximately equal to that of B6 (indicating that these Project stations had communities of equal or greater diversity than the background stations), but higher than results for B1 and B2 (indicating that these Project stations had less diverse communities than the background stations). The Shannon-Wiener value for Project station B1 declined between 1997 ($H' = 2.75$) and 1998 ($H' = 2.38$) and was the lowest of all stations in 1998. The Shannon-Wiener value for background station R1 also declined between 1997 ($H' = 3.53$) and 1998 ($H' = 3.03$).

Table 4-12. Results of ecological indices for all benthic taxa in 1998* . Indices were calculated based on individual replicates. Values shown represent replicate means .

Station	Shannon-Wiener Index (H')		Simpson's Index (S)		Evenness Index (J)	
	1998	1997	1998	1997	1998	1997
B1	2.38	2.75	0.78	0.87	0.62	0.71
B2	2.77	2.87	0.85	0.88	0.69	0.69
B3	3.51	3.37	0.96	0.94	0.81	0.79
B4	3.46	3.33	0.95	0.94	0.81	0.80
B5	3.16	3.04	0.92	0.92	0.77	0.80
B6	3.09	1.84	0.92	0.65	0.77	0.48
R1	3.03	3.53	0.90	0.96	0.72	0.82
R3	3.08	3.03	0.90	0.89	0.75	0.73

* Data for the Shannon-Wiener Index were corrected to a natural log base (\log_e) for 1997 and 1998.

Dominance results, measured by Simpson's Index, indicated that the Project stations were characterized by a moderate to high complexity of taxa (that is, dominated by equal numbers of taxa, rather than just a few taxa). Although station B1 was dominated by seven taxa, its dominance value (0.78) was still in the moderate range ($0.7 < S < 0.9$) for Simpson's Index. Simpson's Index values for the background stations were similar to the five more-diverse Project stations. Evenness Index results indicated that stations B3, B4, B5, and B6 all had relatively high values (and thus, high diversity). Values for stations B3, B4, B5, and B6 were higher than the background stations (see Table 4-12). Stations B1 and B2 had values that were lower than both background stations and slightly less than the lower limit of the moderate range of diversity (see Table 4-11).

Overall, the ecological indices indicate that the diversity at most Project stations was similar to the background stations. Also, diversity at each Project station in 1998 (except B1 and B2) was greater than or equal to 1997. Thus, a benthic community of greater or equal diversity was present at most of the Project stations in 1998.

4.3.3 Statistical Analyses of Benthic Data

The benthic data were statistically analyzed using the biological indicators approach (see Section 1.4.4), which uses a series of statistical (and some non-statistical) analyses on the quantitative benthic data.

The biological indicators approach is intended to detect and quantify:

- differences in the benthic community between the Project and background stations, and
- changes in the benthic community over the last year.

The first set of analyses (Tier One, Level One) consists of statistical comparisons of different benthic components, such as the numerically dominant and numerically non-dominant taxa from each station. The data are compared to each other and to data from the nearby background stations (R1 and R3). The second series of analyses (Tier One, Level Two) consists of statistical comparisons of the benthic data from 1998 to comparable data from 1997. Together, these analyses provide information to determine whether any of the observed changes were of sufficient magnitude to warrant more intensive examination of the data (Tier Two). Tier Two analyses involve a more detailed examination of habitat characteristics and are conducted if Tier One indicates a potential problem with the integrity of the sediment cap or related health of the Project. Tier Two analyses are used to confirm Tier One indicators, if needed. Because Tier One analyses did not indicate problems with the health of the Project (USEPA 1998a), Tier Two analyses were not warranted in 1998.

A summary of the statistical tests is provided (with specific test data, information, and results) in Data Appendix Sections 4.9 and 4.10.

Both parametric and non-parametric two- and eight-sample statistical tests were conducted. Two-sample tests compare the data between two samples, i.e., pooled Project stations versus pooled background stations. Eight-sample tests compare the data between all eight stations, i.e., each Project and background station individually. Normality and homogeneity of variance (HOV) tests were conducted on all log-transformed data to determine whether the assumptions of parametric tests were met. Wherever these assumptions were not met, the results of non-parametric tests were used to evaluate differences in data sets.

4.3.3.1 Power Analysis

Power analyses of statistical tests are conducted to determine what level of difference (minimum detectable difference; MDD) can be accurately discerned by a particular statistical test. Power analyses allow a determination of whether a statistical test has sufficient “power” to discern differences present in the data.

The Monitoring Plan requires that the MDD be less than 50% (percent of pooled reference mean) at 80% power. For the 1998 two-sample Analysis of Variance (ANOVA), only the arthropod taxa biomass test had a MDD greater than 50% (i.e., not meeting the power desired in the Monitoring Plan). For the eight-sample ANOVA, the MDD was less than 50% of the mean at 80% power (i.e., meeting the power desired in the Monitoring Plan) for all analyses except biomass of annelids, arthropods, molluscs, and miscellaneous taxa (Data Appendix Section 4.5). (Insufficient statistical power for biomass analyses was also a problem in 1995, 1996, and 1997. Replicate biomass values tend to be small with a high degree of variability, resulting in low means with high standard deviations. This results in higher MDDs in the power analyses.)

Results of two-sample ANOVAs indicated that differences smaller than about 15.5% of the background station mean were detectable in all tests of abundance and taxa richness. Results of eight-sample ANOVAs indicated that differences smaller than about 20.1% of the background station mean were detectable in all tests of abundance and taxa richness. The biomass power results indicated that only very large changes in biomass are detectable, particularly for eight-sample tests. Consequently, the results of statistical tests on biomass data (except for two-sample analyses of annelid, mollusc, and miscellaneous biomass) should be considered qualitatively, not as true indicators of significant differences in biomass.

4.3.3.2 Tier One, Level One—Comparisons Within the 1998 Data Set

As indicated previously, the Tier One, Level One analyses consist of statistical comparisons between stations.

Two-Sample Tests of 1998 Pooled Background and Pooled Project Station Data (Biological Indicators Analyses 1.1 and 1.2)

Under the biological indicators approach, the 1998 pooled background station data and 1998 pooled Project station data were tested. For the two-sample tests, assumptions of either normality (i.e., a normal distribution around the mean) and/or homogeneity of variance needed for parametric tests were met for all measures except abundance of non-numerically dominant taxa and arthropod biomass (Table 4-13). Results of the parametric two-sample tests were used for evaluating all measures of taxa richness and abundance (except non-numerically dominant taxa) and biomass (except arthropod biomass). The results of the non-parametric Mann-Whitney U test were used for evaluating abundance of non-numerically dominant taxa and arthropod biomass. Results are presented in Table 4-13. All six Project stations were pooled together and compared to pooled background stations (R1 and R3).

For all categories except “other taxa” biomass and mollusc biomass, no significant differences were found between background and Project stations. The background stations were found to have a significantly greater ($p < 0.05$) mollusc biomass and “other taxa” biomass (see Table 4-13).

Table 4-13. Results of two-sample tests of 1998 results comparing the pooled results from the Project stations with the pooled results from the Background stations. $N_{\text{background}} = 10$; $N_{\text{Project}} = 30$. M-W test = Mann-Whitney U test. Probabilities of 0.05 or less are considered to be statistically significant.

Category	Ranking of Means ^a	Probability		Normality ^b	Homogeneity of Variance
		F-test	M-W test		
A. Total Abundance	Background higher	0.4511	0.2509	yes	yes
B. Taxon Richness	Background higher	0.3186	0.4751	yes	yes
C. Abundance of:					
Numerically Dominant Taxa	Background higher	0.4178	0.2712	yes	yes
Non-Numerically Dominant Taxa	Project higher	0.5402	0.6334	no	yes
D. Biomass					
Annelids	Project higher	0.7276	0.6859	yes	yes
Molluscs	Background higher	0.0444	0.0974	yes	yes
Arthropods	Project higher	0.6300	0.6634	no	yes
Other Taxa	Background higher	<0.0001	<0.0001	yes	yes

^a Determined via visual inspection of means of ln-transformed values.

^b "No" indicates that the data set did not meet the noted assumption (i.e., normality or HOV) needed to conduct a parametric test, so use of a non-parametric test is indicated.

ANOVA Tests Comparing 1998 Results for Each Station (Analyses 1.1 and 1.2)

For the eight-sample tests, assumptions of either normality and/or HOV needed for parametric tests were not met for any of the abundance measures nor for mollusc and arthropod biomass (Table 4-14). In these cases, the results of the non-parametric Kruskal-Wallis test were used.

Statistical results for this analysis can be determined using Tables 4-14, 4-15, and 4-16. An example of how to interpret these tables is provided here for the specific case of significantly lower numbers of taxa at B1 compared to the background stations. Table 4-14, Category B, describes the taxon richness test. The "Ranking of Values" column indicates that the number of taxa for R3 was higher than B1, B2, and B6. The normality and HOV columns indicate this data set met assumptions for parametric tests (indicated by "yes" in each column), thus a parametric test result should be used (the ANOVA test column). The ANOVA test column indicates that the probability of differences was less than 0.05 (actually less than 0.001) and, therefore, differences can be considered significant.

The Multiple Range Test summary for the F-test (see Table 4-15) must be used to determine which stations have significantly different values. (If a non-parametric test was called for, Table 4-16 must be used.) For example, the Taxon Richness row in Table 4-15 indicates that B2 is in the same group (Group 2) as R1, R3, B5, and B6, and therefore is not significantly different from them. Note, however, that B1 is not found in any group containing the background stations (i.e., Groups 1, 2, 3, or 4). Therefore, station B1 is significantly different from both background stations and all Project stations except B2 and B6. Refer back to rankings in Table 4-14 to determine whether B1 is significantly higher or lower than the other stations discussed.

The eight-sample comparisons conducted indicated a significant probability of differences for three biological indicator categories: taxon richness, mollusc biomass, and "other taxa" biomass (see Tables 4-14, 4-15, and 4-16). Station B1 was found to be significantly different from background station R3 for all three measures and from R1 for taxon richness and "other taxa" biomass. All Project stations, except B3, had significantly lower "other taxa" biomass than the background stations. Background station R3 was not significantly different from B3. [Recall that the power analysis discussed in Section 4.3.3.1 demonstrated that the biomass data are not powerful enough to discern minimum detectable differences needed to show significance; thus, the data should only be used qualitatively.] Stations B3 and B4 had significantly higher numbers of taxa (taxon richness) than background station R3 and some Project stations. Station B3 was significantly different from all Project stations except B4, and B4 was significantly different than all Project stations except B3 and B5.

Background station R1 ranked higher than R3 in all test categories except mollusc and arthropod biomass, but the difference was never significant. At least one Project station (B1, B2, or B3) ranked higher than background station R1, except for "other taxa" biomass, but the difference was never significant. Among Project stations, the rankings fell into no noticeable pattern except for those previously mentioned for B1.

Table 4-14. Results of ANOVA tests comparing the 1998 results for each category from each station. See Data Appendix for the complete test data. N_{background} = 10; N_{Project} = 30. K-W test = Kruskal-Wallis test. Probabilities of 0.05 or less are considered to be statistically significant.

Category	Ranking of Values ^a	Probability		Normality ^b	Homogeneity of Variance
		F-test	K-W test		
A. Total Abundance	B5<R3<B4<B2<B6<B1<R1<B3	0.2248	0.1944	yes	no
B. Taxon Richness	B1<B6<B2<R3<B5<R1<B4<B3	0.0007	0.0041	yes	yes
C. Abundance of:					
Numerically Dominant Taxa	B5<R3<B4<B2<B1<B6<R1<B3	0.2831	0.2214	yes	no
Non-Numerically Dominant Taxa	B5<R3<B4<B2<B6<R1<B3<B1	0.1499	0.0766	no	yes
D. Biomass					
Annelids	R3<B6<B5<B1<B3<B4<R1<B2	0.2242	0.1887	yes	yes
Molluscs	B1<B4<B5<B6<R1<B3<R3<B2	0.0005	0.0040	yes	no
Arthropods	B5<R1<B6<B4<B1<R3<B2<B3	0.4533	0.0506	no	no
Other Taxa	B6<B5<B1<B2<B4<B3<R3<R1	<0.0001	0.0016	yes	yes

^a Summaries of multiple range tests are shown in Table 4-15 and rankings and groupings for the Kruskal-Wallis tests are shown in Table 4-16.

^b “No” indicates the data set did not meet the noted assumption (i.e., normality or HOV) needed to conduct a parametric test, so use of a non-parametric test is indicated.

Table 4-15 Multiple Range Test (MRT) summary for 1998 ANOVAs (File: ANOMRT98.XLS)

**Table 4-16 Summary of ranks and groupings for 1998 Kruskal-Wallis Multiple Range Tests
($p = 0.05$) (File: KWRT98.XLS)**

Analyses of 1998 Station Similarities (PSI Analysis 1.3)

Proportional Similarity Index (PSI) analysis is used to determine whether replicates from one sample contain similar benthic group assemblages. The PSI was calculated for 1998 replicates and station averages. Figures 4-7 and 4-8 are the similarity dendrograms (untransformed and log-transformed data, respectively) of all sample replicates collected in 1998 from Project and background stations.

Using untransformed replicate data, replicate samples of the same station often grouped together (see Figure 4-7). However, some replicates of a particular station were more similar to replicates of other stations. Station B5 replicates C and D (B5C and B5D) were most similar to the Station B3 replicates (approximately 0.56 level of similarity) as was background Station replicate R1D (0.52 level of similarity). Replicates B5A, B5B, and B5E (0.42 similarity) were most similar to a cluster of replicates including all B4 replicates (one cluster), all B3 replicates (one cluster), and the B5C, B5D, and R1D replicates. In general, stations B3, B4, B6, and the two groups of B5 replicates appeared to group together (0.23 similarity), as did all B2 replicates and the B1B replicate (0.36 similarity). Although the remaining B1 replicates clustered together, their similarity to any other station was very low (approximately 0.05 level of similarity).

Untransformed data revealed that the replicates of both background stations were dissimilar to each other (approximately 0.15 similarity) with the exception of R3D. R3D sorted with station R1 replicates A, B, C, and E (overall 0.41 similarity), forming a group that was more similar (0.23 similarity) to the larger complex of Project stations (including R1D) than to R3 replicates A, B, C, and E. The latter four R3 replicates were more similar to the group containing the B2 replicates and B1B (0.32 similarity).

The use of log-transformed replicate data generally increased the level of similarity at which replicates and groups of replicates formed clusters with other replicates and groups and improved the clustering of some station replicates (see Figure 4-8). The lowest level of similarity observed in the dendrogram of log-transformed data was 0.26 as opposed to 0.05 in the dendrogram of untransformed data. More specifically, all of the station R1 replicates (and R3D) sorted into a larger complex of groups at a higher level of similarity (0.54) than with the untransformed data (0.23). In addition, all of the B1 replicates clustered in another large complex at a similarity of 0.37 as compared to a similarity of 0.29. This second complex also included the station B6 replicates which had clustered with stations B3, B4, B5, R1, and R3D in the dendrogram of untransformed data. Log-transformed data also indicated that the background stations were more similar to each other (0.26 similarity) than suggested by the untransformed data.

1998 St. Paul Waterway Benthos

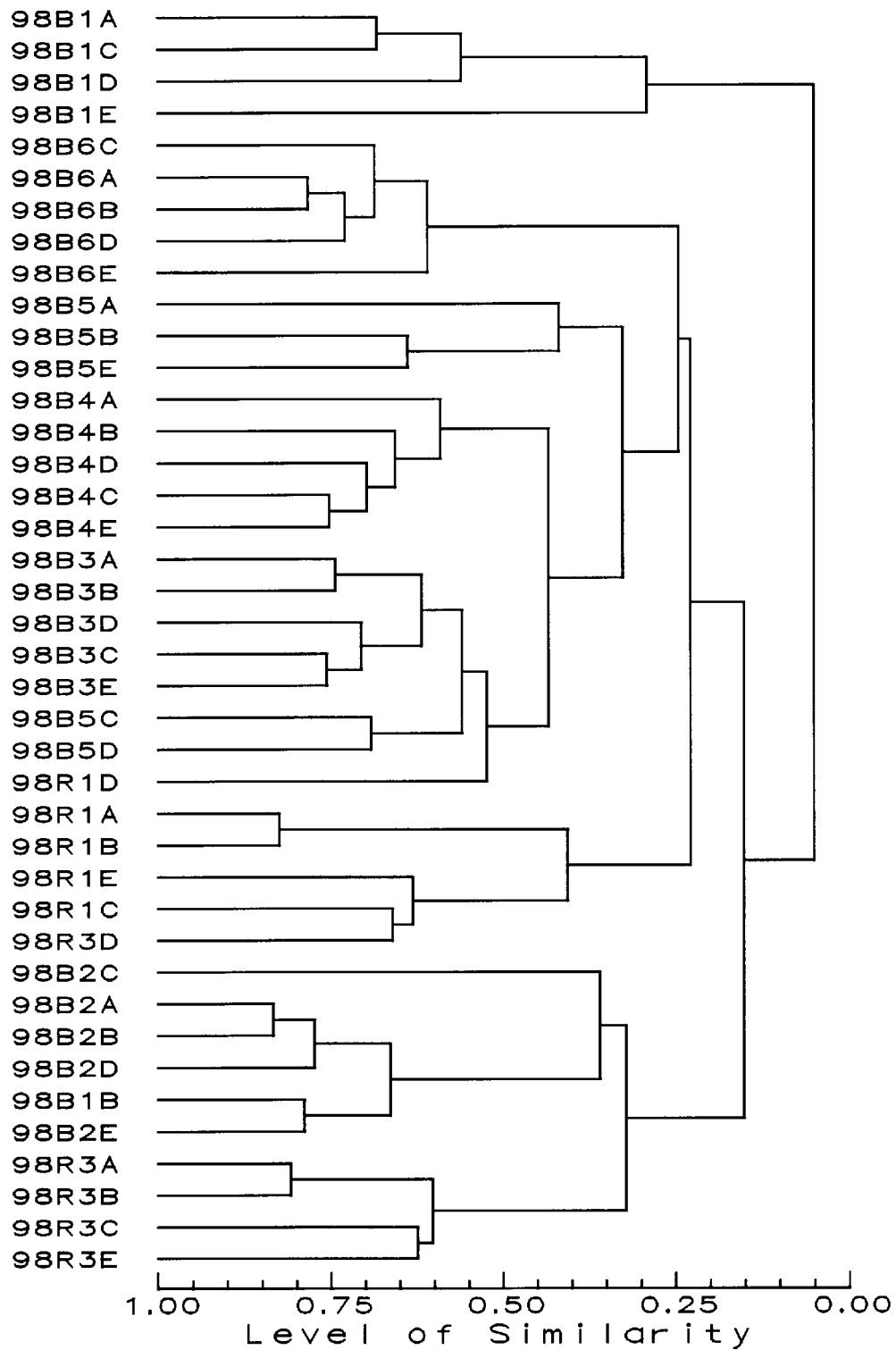


Figure 4-7.
Proportional Similarity Index for
Abundance by Station Replicate

1998 St. Paul Waterway Benthos

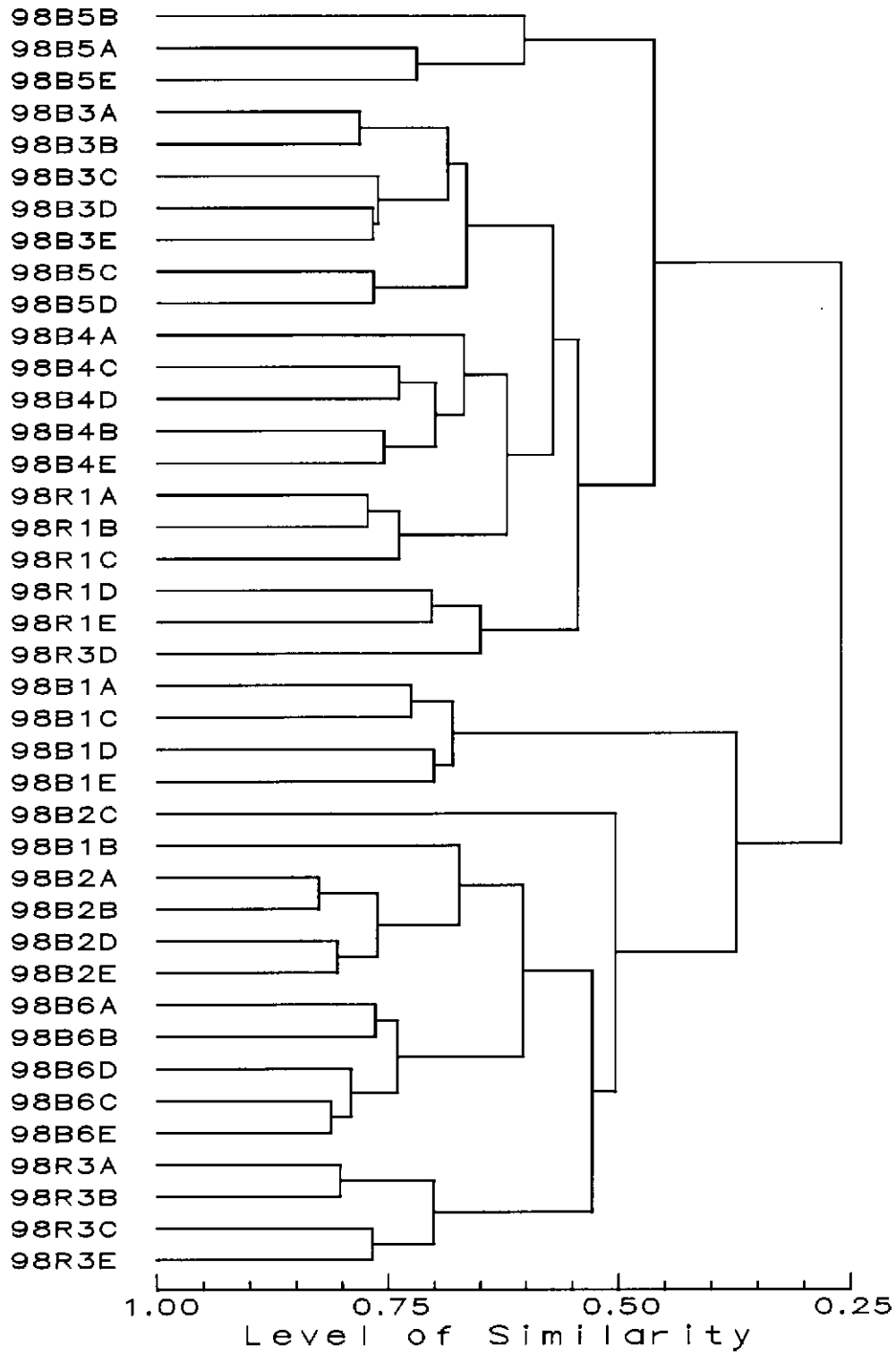


Figure 4-8.
Proportional Similarity Index for
Abundance by Station Replicate
(log-transformed)

Untransformed station data (with the replicates averaged) indicated that there were three core groupings of stations:

- Project stations B3 and B5 (0.69 similarity) with B4 at a similarity of 0.65,
- background stations R1 and R3 together (0.52 similarity), and
- Project stations B2 and B6 (0.50 similarity) with B1 at 0.37 similarity (Figure 4-9).

Project stations B3, B4, and B5 were more similar to the reference stations (0.43 similarity) than the B1, B2, and B6 group which joined the background stations-B3, B4, B5 cluster at 0.19 similarity. The 1998 dendrogram differed from 1997 in that none of the Project stations were remarkably different from all other stations as happened with B6 in 1997. Station B1 was the most dissimilar station in 1998 but still grouped with B2 and B6 at 0.37 similarity. Project Station B1 did resemble B6 by having a low number of dominant taxa ($n=7$) and relatively high abundances (compared to other stations) of two species (see Tables 4-6 and 4-8).

Log-transforming the station data (averaged after log-transformation of replicates) raised overall similarity levels but made little difference in the core groups and order of clustering (Figure 4-10). In particular, only the association of stations B3, B4 and B5 was changed with B3 and B4 being the most similar (0.75 similarity) instead of B3 and B5 (in the untransformed data dendrogram). The other two base groups were the same with background stations grouping at 0.67 similarity and Project stations B2 and B6 (0.70 similarity) grouping with B1 at 0.58 similarity. The background stations were more similar to the B3, B4, B5 complex (0.60 similarity) than the to B1, B2, B6 cluster which joined the background stations-B3, B4, B5 cluster at 0.36 similarity. The 1998 dendrogram of log-transformed data differed from 1997 in that Project stations B2 and B3 did not form a core group separate from any other stations as they did in 1997. In 1998, stations B2 and B3 were more similar to other Project stations than either of the reference stations.

Overall, PSI revealed that although station replicates were similar to each other, Project station similarities were variable within a larger, somewhat dissimilar community. Elements of similarity appear in the dominant array found at the background stations and most Project stations, with the same few dominant taxa comprising most of each station's abundance (see discussion in Section 4.3.2.3). PSI results indicated that within a station, replicates tend to be more similar to each other than to the replicates of other stations. Finally, PSI results suggested that the three Project stations—B3, B4, and B5—were more similar to the background stations than the three remaining Project stations.

1998 St. Paul Waterway Benthos

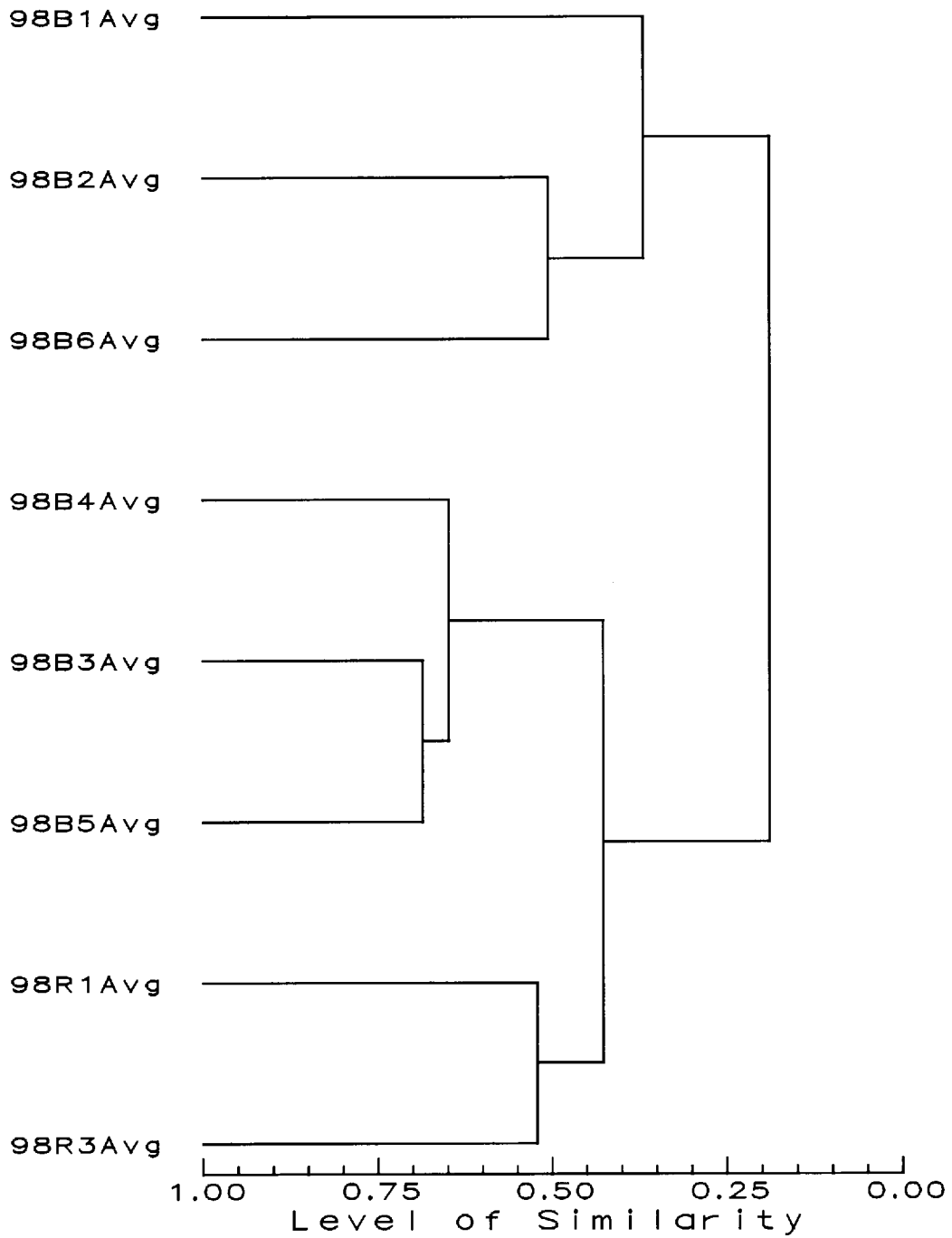


Figure 4-9.
Proportional Similarity Index for
Mean Abundance by Station

1998 St. Paul Waterway Benthos

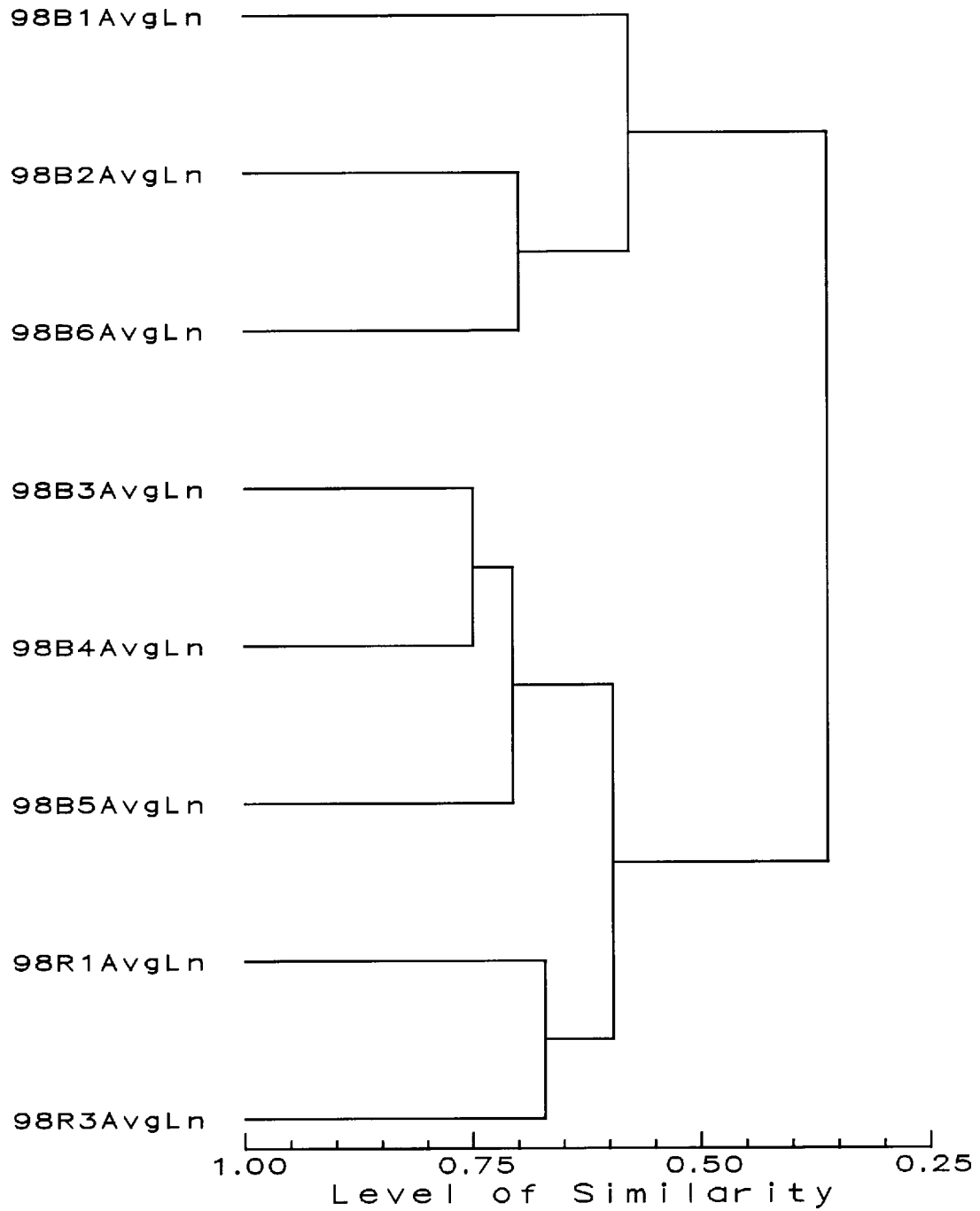


Figure 4-10.
Proportional Similarity Index for
Mean Abundance by Station
(log-transformed)

Principal Coordinates (PCOR) Analysis—Comparison of the 1998 Project and Background Stations (Analysis 1.4)

As approved by EPA in a July 29, 1997 letter, PCOR analysis is no longer utilized as part of the biological indicators approach (USEPA 1997).

4.3.3.3 Tier One, Level Two—Comparisons Between 1997 and 1998 Data

The Tier One, Level Two analyses consist of statistical comparisons between 1997 and 1998 data.

Comparisons of 1997 and 1998 Abundance Data (Analysis 1.5)

After logarithmic transformation, the data for most comparisons met both the normality and HOV assumptions (Table 4-17). Of the 40 data sets compared, only 9 data sets did not meet normality and/or HOV assumptions: total abundance for B1, B2, and B5, taxon richness for B2, numerically dominant taxa for B1 and B2, and non-numerically dominant taxa abundance for B2 and pooled Project stations. In these cases, a non-parametric (Mann-Whitney U) test was used to evaluate differences.

Overall, 1998 results ranked higher than 1997 for most test categories but none of the differences were statistically significant (see Table 4-17). Of the cases (14 of 40) where 1997 results ranked higher than 1998, only total abundance and abundance of non-dominant taxa for station B6 were significantly higher. Although 1998 results were generally higher than 1997 results for total abundance, abundance of numerically dominant, and abundance of non-numerically dominant taxa, half the taxon richness results were higher in 1998 and half were higher in 1997.

For the three measures of abundance, 1998 results ranked higher than 1997 for all test categories, with nine exceptions: total abundance and the abundance of non-numerically dominant taxa at B6 were significantly greater in 1997, the abundance of numerically dominant taxa at B6 was higher in 1997 (but not significantly), and all three abundance measures at R3 and B2 were greater in 1997 (but not significantly). The comparatively low abundances at B6 in 1998 versus 1997 were apparent in the dominant taxa array summaries listed in Table 4-8.

For taxon richness, 1997 results ranked higher than 1998 for pooled background stations, background stations R1 and R3, and Project stations B1 and B2. 1998 results ranked higher than 1997 for pooled Project stations and the remaining individual Project stations. However, none of the differences were statistically significant. Thus, none of the Project or background stations were significantly more diverse in 1998 than in 1997.

Table 4-17. Results of ANOVA tests comparing the 1997 to the 1998 results for each category from each station.
 $N_{\text{background}} = 10$ and $N_{\text{Project}} = 30$. M-W test = Mann-Whitney U test. Probabilities of 0.05 or less are considered to be statistically significant.

Category	Ranking of Values ^a	Probability		Normality ^b	Homogeneity of Variance
		F-test	M-W test		
A. Total Abundance					
Background Pooled	98 Higher	0.629	0.515	yes	yes
R1 Background	98 Higher	0.684	0.662	yes	yes
R3 Background	97 Higher	0.440	0.500	yes	yes
Project Pooled	98 Higher	0.832	0.905	yes	yes
B1	98 Higher	0.905	0.953	no	yes
B2	97 Higher	0.380	0.377	no	yes
B3	98 Higher	0.800	0.735	yes	yes
B4	98 Higher	0.847	0.852	yes	yes
B5	98 Higher	0.960	0.928	yes	no
B6	97 Higher	0.046	0.047	yes	yes
B. Taxon Richness					
Background Pooled	97 Higher	0.058	0.081	yes	yes
R1 Background	97 Higher	0.169	0.202	yes	yes
R3 Background	97 Higher	0.083	0.173	yes	yes
Project Pooled	98 Higher	0.911	0.911	yes	yes
B1	97 Higher	0.288	0.145	yes	yes
B2	97 Higher	0.134	0.122	no	yes
B3	98 Higher	0.631	0.500	yes	yes
B4	98 Higher	0.914	0.875	yes	yes
B5	98 Higher	0.989	0.982	yes	yes
B6	98 Higher	0.974	0.977	yes	yes
C. Abundance of Numerically Dominant Taxa:					
Background Pooled	98 Higher	0.635	0.530	yes	yes
R1 Background	98 Higher	0.687	0.583	yes	yes
R3 Background	97 Higher	0.442	0.500	yes	yes
Project Pooled	98 Higher	0.815	0.868	yes	yes

Table 4-17. Results of ANOVA tests comparing the 1997 to the 1998 results for each category from each station. $N_{\text{background}} = 10$ and $N_{\text{Project}} = 30$. M-W test = Mann-Whitney U test. Probabilities of 0.05 or less are considered to be statistically significant. (continued)

Category	Ranking of Values ^a	Probability		Normality ^b	Homogeneity of Variance
		F-test	M-W test		
B1	98 Higher	0.843	0.895	no	yes
B2	97 Higher	0.415	0.500	no	yes
B3	98 Higher	0.803	0.735	yes	yes
B4	98 Higher	0.841	0.735	yes	yes
B5	98 Higher	0.936	0.895	yes	no
B6	97 Higher	0.052	0.072	yes	yes
Non-Dominant Taxa:					
Background Pooled	98 Higher	0.579	0.515	yes	yes
R1 Background	98 Higher	0.668	0.583	yes	yes
R3 Background	97 Higher	0.417	0.500	yes	yes
Project Pooled	98 Higher	0.865	0.915	no	yes
B1	98 Higher	0.995	0.982	yes	yes
B2	97 Higher	0.333	0.331	no	yes
B3	98 Higher	0.791	0.662	yes	yes
B4	98 Higher	0.839	0.852	yes	yes
B5	98 Higher	0.984	0.977	yes	yes
B6	97 Higher	0.039	0.047	yes	yes

^a Determined via visual inspection of means of ln-transformed values.

^b “No” indicates the data set did not meet the noted assumption (i.e., normality or HOV) needed to conduct a parametric test, so use of a non-parametric test is indicated.

The ANOVA tests indicated that only Project station B6 had a significantly lower total abundance and abundance of non-numerically dominant taxa in 1998 than in 1997. Test results for all other stations, station groupings, and test categories were not statistically significant.

4.3.3.4 Tier Two Analyses

The need for Tier Two analyses was not indicated by the results of the Tier One analyses. Some apparent differences found in Tier One appeared to be related to factors other than the integrity of the sediment cap and the health of the Project community. As described in the biological indicators approach (Section 1.4.4), Tier Two analyses are not conducted if Tier One analyses indicate a naturally active biological community at the Project site. A detailed basis for this conclusion is provided in Section 4.4.

4.4 DISCUSSION

Biological monitoring indicates that numerous types of benthic organisms have colonized the habitat. In 1998, abundance of the pooled Project benthic community was not statistically different from the pooled background community. Compared to 1997 monitoring results, Project and background benthic communities were generally more abundant in 1998. However, abundances at Project and background stations have not returned to 1996 levels with the exception of background station R1 (higher than 1996) and Project station B6 (higher in 1997 than 1996). In 1996, abundances were the highest measured to date for the Project site. The declines noted in 1997 were attributed to bay-wide changes in benthic infauna by Weston (Technical Review of St. Paul Waterway Data, August 27, 1997) and Parametrix (Parametrix, 1998a). Based on the 1998 assessment of the biological indicators, it is likely that differences between 1997 and 1998 benthic populations are also attributable to natural variation.

Several statistically significant differences were found in the Tier One analyses, including:

- 1) Mollusc and “other taxa” biomass at the pooled background stations was significantly higher than the pooled Project stations.
- 2) Taxon richness was significantly higher at Project stations B3 and B4 than at background station R3, and at B3, B4, B5 and each of the background stations than at B1.
- 3) “Other taxa” biomass was significantly higher at background station R1 than all Project stations, and at background station R3 than all Project stations except B3.

All Project stations were statistically indistinguishable from background for taxon richness, except B1, which was significantly lower. The lack of difference between other Project and background stations indicates no overall decline in taxa measurements at the Project.

As in past years, the biological indices indicated that station B1 differed from the other stations by having lower diversity. Although station B1 did not differ significantly from other Project and background stations for abundance measures (dominant, non-dominant, and total abundance), B1 did have significantly fewer numbers of taxa than most other stations. Station B1 also had lower “other taxa” biomass than the background stations and Project stations B2, B3, and B4. These differences were also evident in the dendrograms (untransformed and log-transformed data) for abundance by replicates and abundance by station with station B1 consistently clustering with replicates of other stations, clusters of other stations, and/or other stations at the lowest similarities of all groupings.

Station B1 also had a relatively large increase in abundance and total abundance (highest of Project stations), together with a low diversity, and clustering patterns in 1998 that were similar to station B6 in 1997. The counter clockwise flow of currents around the jetty and sandbar into the Project area creates a quiescent backwater in the area of B1 and B6 that provides deposition of floating and semi-buoyant material such as the deposited organic debris (decaying wood, sticks, and leaf litter) noted in the area in 1997. Finer-grained materials (silt, clay, etc.) suspended in the water (typical of the Puyallup River plume) would also tend to drop out in this area. Organic debris and detritus also tend to accumulate because the prevailing winds are from the southwest and/or south and push material within surface water into the pocket formed by the contour of the Project shoreline and the jetty and sandbar. This area appeared to receive a great deal of organic material from the 1997 flood event. Decomposition of such organic debris often produces hydrogen sulfide and could affect the marine benthos. Decomposition of organic debris appears to at least partially account for a history of relatively lower diversity and higher abundance at stations B1 and B6, which are reflected in the 1997 and 1998 results.

The numbers of organisms sampled at the Project in 1998 were within the range observed during previous monitoring years. The 1998 data strongly implies that changes in abundance and diversity between 1996 and 1997 were relatively short-term at background station R3 and the Project stations. Diversity and abundance of the benthos in the Project area appear to be within the range experienced in past years and, in some cases, increasing. It appears that these differences should be attributed to natural annual variations in bay-wide conditions and physical differences between the Project and background stations as noted in the 1997 Monitoring Report and Weston’s Technical Review of St. Paul Waterway Data (dated August 27, 1997).

In summary, the benthic community at the Project site still appears to be a typical mudflat community of Puget Sound (Kozloff 1983). Abundances were higher than the previous year and diversity of benthic organisms this year was higher for all indices applied. In 1998, abundance and numbers of taxa were within the range of all previous years since 1992. Changes observed in the past year appear to represent normal fluctuations in a healthy, estuarine benthic community.

5. MACROPHYTES

This section describes the macrophyte community (macroscopic algae or “seaweed”) inhabiting the intertidal areas of the Project site (Figure 5-1). Macrophytes help promote establishment of intertidal and nearshore faunal communities by providing shelter and food to other organisms that may be prey for nearshore fishes and shorebirds (Ricketts and Calvin 1969; Simenstad et al. 1979). Assessment of the macrophyte communities at the Project site was completed to further document the ecological value of the habitat to Commencement Bay.

5.1 METHODS

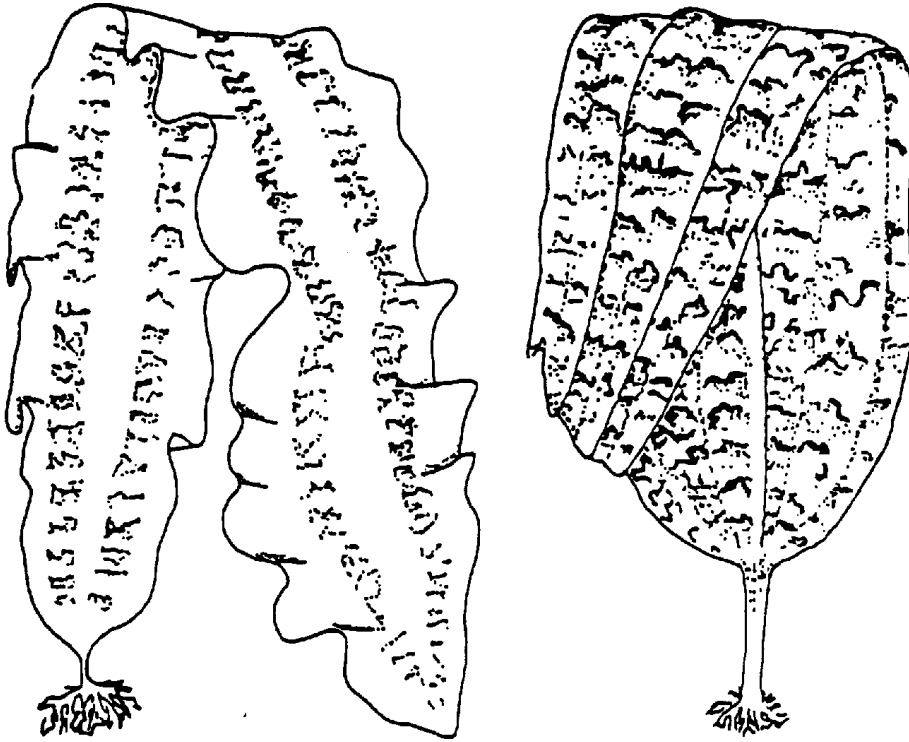
The monitoring methods were agreed to by EPA in 1992 (Cohen 1992 official communication) and are intended to qualitatively determine macrophyte coverage at the Project site, and to inventory macrophyte species using the Project habitat. The macrophyte inventory is not intended to provide quantitative assessment of changes in macrophyte coverage.

To assess the relative abundance of the algae that have colonized the Project site, the intertidal areas were visually assessed to identify algal species and to map locations of significant algal communities. The site was examined on August 7, 1998 between 10:45 a.m. and 12:00 p.m., during low tide (about -1.5 feet MLLW). Algal species were identified using several field guides to marine algae of the region (Scagel 1971; Kozloff 1973; Waaland 1977). Changes in algal coverage from previous monitoring events were approximated based on visual inspections, comparison of photographic records, and examination of the 1998 aerial photographs.

Macrophyte areas were mapped from color aerial photographs taken at 12:29 p.m. on August 8, 1998 at a tidal elevation of approximately -1.6 feet MLLW. The aerial photograph (1:1,000 scale) was magnified up to 20X to assist in mapping.

5.2 RESULTS

The macrophyte community at the Project site contains five species of marine algae (two appear in Figure 5-1). The dominant species found during 1998 were the same as observed during previous years. They occur in four habitat zones: (1) supra-littoral fringe (above 9 feet MLLW), (2) upper mid-littoral (9 to 4 feet MLLW), (3) lower mid-littoral (4.0 to 0.0 feet MLLW), and infra-littoral fringe (0 to -3.5 feet MLLW). The species, their habitat, and distribution are identified as follows:



Laminaria saccharina

Costaria costata

Source: Kozloff 1973.

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Figure 5-1.
Typical Macrophytes

- *Enteromorpha* spp.

Enteromorpha forms bright yellowish-green moss-like tufts about 1 cm tall.⁷ In the Project area, this species was found on riprap in the upper intertidal and supra-littoral fringe. *Enteromorpha* is described by Kozloff (1973, 1983) and Scagel (1971) as occurring in the supralittoral and upper intertidal zones, and often in somewhat brackish water. Distribution of this algae in 1998 was similar to that observed in previous years.

- *Ulva lactuca*

This algae, which has large, thin, green blades (to 30 cm) with ruffled edges, was attached to rocks and coarse gravel in the lower midlittoral and infralittoral zones throughout the Project site. In 1998, densities and coverage of this species were similar to those observed previous years. *Ulva lactuca* was identified using botanical keys, morphological descriptions, photographs, and drawings (Scagel 1971; Kozloff 1973, 1983).

- *Fucus distichus*

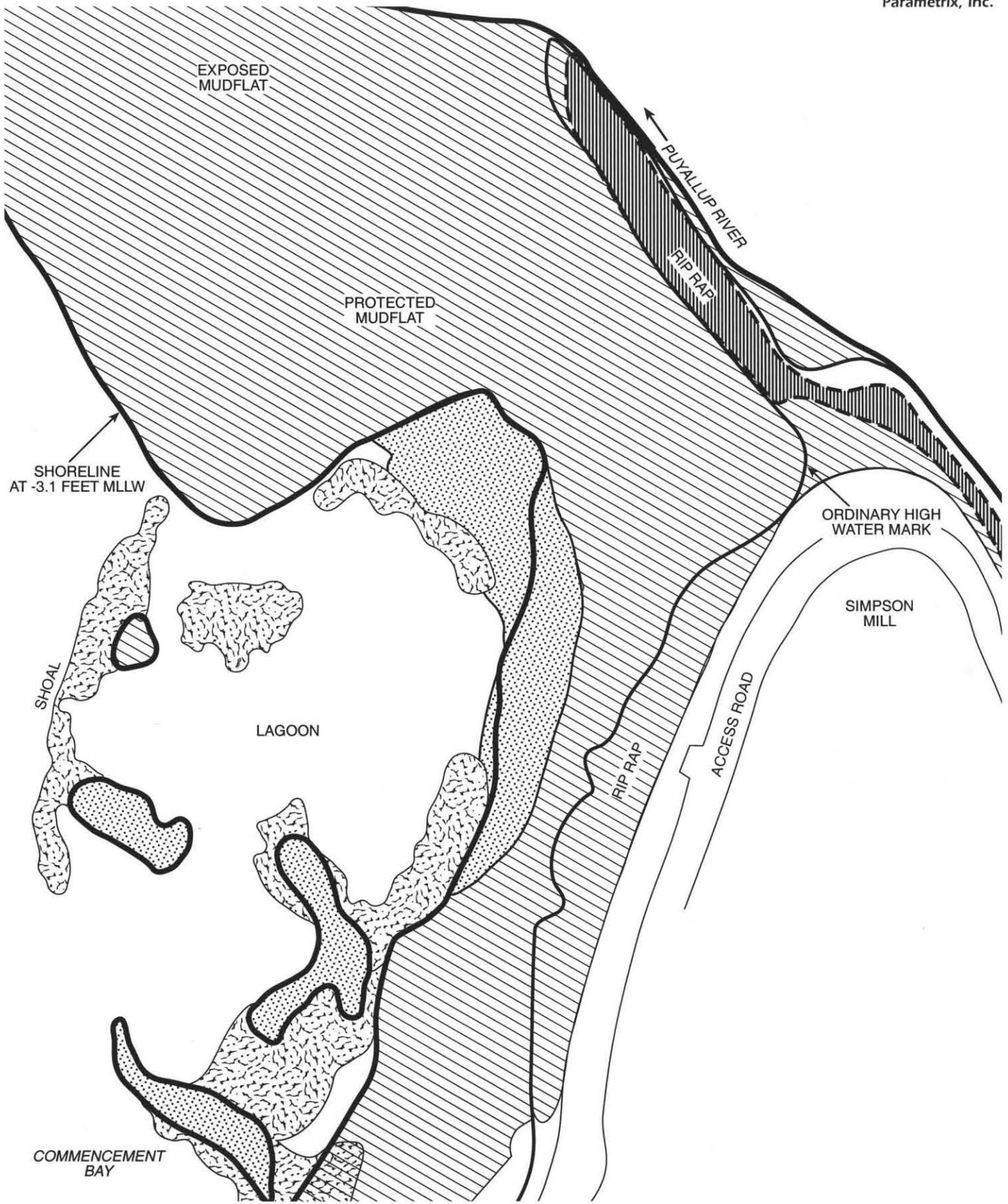
This species, which is an olive-green to yellowish-green, rigid, flattened plant 30-50 cm in size, has branches with swollen tips. *Fucus* was common on the east side of the riprap training wall along the Puyallup River in the upper midlittoral zone. As in previous years, the species was not found on the riprap adjacent to the mill or along the west side of the Puyallup River jetty.

- Kelp: *Costaria costata* and *Laminaria* spp.

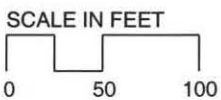
These dark brown algal species have a conspicuous holdfast, blade, and stipe. The blades are greater than 10 cm wide and can reach 3 m in length. The holdfasts are relatively small, greatly branched, root-like structures. These species occurred in the infralittoral zone below about -2 feet MLLW. As in previous years, kelp was common in lower intertidal areas where rocks at least several centimeters in size were available for anchoring.

Macrophytes have colonized several habitats on the Project site, including protected mudflat, a shallow intertidal lagoon, rocky fringe shoals, and the riprap bulkhead and training wall (Figure

⁷ Scagel reports the plant as ranging from 1- to 20-cm in size. While *Prasiola meridionalis* is a similar green algae often present in the supralittoral zone, the species on the Project site was a dirty green color and consisted of a broad, flat blade. Except for its small size, the algae present on the site was similar to *Enteromorpha*, with a yellowish-green color and unbranched, tubular blades (Scagel 1971). Based on color, blade morphology, and other morphological features, the observed algae corresponded best to botanical descriptions of *Enteromorpha* (probably *E. intestinalis*).



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


-  No Significant Macrophytes
-  Kelp and/or Ulva
-  *Enteromorpha* and *Fucus*
-  *Ulva* (Sparse to Very Dense Beds)

Figure 5-2.
Distribution of
Aquatic Macrophytes
in 1998

5-2). Though the surf-exposed mudflat (most of which is seaward of the Project site) receives considerable wave energy from Commencement Bay, its configuration is little changed from 1996. The protected mudflat, inshore from the shoals and exposed mudflat, receives less wave energy and thus was subjected to greater silt deposition. The fringe shoals provide shallow habitat with scattered clumps of rock substrate that is exposed to wave action. Riprap along the Puyallup River training wall and the Simpson Mill Road provides stable substrate for algal attachment in a habitat frequently exposed by tides. Algal communities range from sparse on the surf-exposed mudflats and riprap to dense on the fringe shoals and shallows of the lagoon.

Macrophytes covered little area of the exposed mudflats. Ulvoids occurred in sparse patches, with small individuals widely separated. Density and coverage appeared to be lower than was observed in 1997. Since 1989, these communities have fluctuated greatly in density and area colonized. Coverage in this habitat, has always been low and typically limited to areas with gravel and rocks that provide stable substrate.

Mudflat areas within the fringe shoals and lagoon have been sporadically covered by macrophytes. Some areas had dense blankets of Ulvoids, but other areas were devoid of them. Coverage has increased since the initial monitoring study, with a dramatic increase between the 1991 and 1992 evaluations. During 1998, these colonies continued to densely cover portions of the protected mudflats (see Figure 5-2).

Within the lagoon, kelp was visible below the water surface at approximately -2.5 feet MLLW. Kelp coverage was dense wherever substrate of sufficient size was present. One area of mixed Ulvoids and kelp developed on some large rocks on the exposed mudflat area. Kelp was also present, though sparse on the lowest portions of the riprap bulkhead. Kelp density and coverage appeared to have increased since the Project was constructed, but was similar to that observed in previous years.

The fringe shoals supported a dense algal community. Portions exposed during low water were dominated by Ulvoids. Scattered boulders on these shoals are typically covered with dense growths of Ulvoids, while kelp growth is dense in the deeper waters surrounding the shoals. Kelp and Ulvoid coverage in these areas increased somewhat after initial monitoring, but has remained stable for several years.

The riprap along the Puyallup River and Simpson Mill Road had been previously colonized by algal communities dominated by *Fucus*, *Bangia* and *Enteromorpha*. Since 1994, the west side of the riprap has been nearly devoid of these species, while the east side has supported substantial colonies of *Fucus*.

5.3 DISCUSSION

Macrophyte diversity and abundance at the Project is characteristic of other estuarine mudflat communities (Kozloff 1973). Like other such communities in Puget Sound, macrophyte diversity at the Project site is probably limited by the brackish waters, while macrophyte abundance is directly related to the stable substrate available.

The distribution of the algal community at the Project site appears related to the stability of the substrate. More stable substrates (exposed rock and gravel surfaces) were colonized by macrophytes. The less stable sand and silt substrates were generally devoid of substantial macrophyte algal communities, as is common in Puget Sound. Though portions of the mudflat protected from wave action supported a dense growth of Ulvoids, the lack of stable substrate renders these areas susceptible to community alterations resulting from storms and flood events. While macrophyte biomass and distribution could be increased by increasing rock substrate at the Project site, the historical lack of suitable substrate likely limited the establishment of algal communities in similar areas of the Commencement Bay estuary.

Subtidal areas protected from wave action by shoals supported healthy kelp communities (*Laminaria*) and Ulvoids. The distribution and abundance of macrophytes in these areas has remained stable for several years. Here, kelp growth appeared limited to substrate of sufficient mass to anchor large macrophytes in the nearshore and tidal currents.

Ecologically, the macrophyte colonies contribute to the structure and complexity of the Project's biological communities by providing habitat to invertebrates that are prey items for other organisms. Dense macrophyte beds, especially those formed by *Ulva* and kelp, provide protection and moisture to invertebrate animals during low tide. Live macrophytes are consumed by herbivorous organisms, while detrital biomass (dead plant material) accumulates in shallow tidal pools or is transported to nearshore environments, where it is consumed by detritivores. Detritivores, such as gammarid amphipods, are also a food source for nearshore consumers, including fish, shorebirds, and waterfowl (Simenstad et al. 1979); in this way, macrophytes contribute to the biodiversity and productivity of the site.

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APPENDIX 1.

MONITORING METHODS APPENDIX

**ST. PAUL WATERWAY AREA REMEDIAL ACTION
AND HABITAT RESTORATION PROJECT**

FINAL 1998 MONITORING REPORT

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1. INTRODUCTION

Sampling and analysis methods for each type of monitoring are presented in this Monitoring Methods Appendix (Appendix 1 of the Project 1998 Monitoring Report). In addition, this appendix describes the standard procedures and techniques used to collect samples, as well as to generate and analyze data. In most cases, the monitoring followed the methods described here. However, occasionally other methods were used; these deviations are described in the summary methods sections provided at the beginning of each chapter in the main body of the report. In addition, this Methods Appendix describes all monitoring methods used over the course of 10-year monitoring. Some types of monitoring are not required every year but are still described here.

Appendix section numbers correspond to the chapters in the main report. The final section (Section 8) contains the performance standards as they appear in the federal consent decree.

Table 1 of the Monitoring Plan summarizes the sampling to be conducted each year and provides a schedule for monitoring activities; it is revised annually based on any changes to monitoring activities that have been accepted by EPA. Table 1 includes all of the changes to the Monitoring Activities, which were accepted by EPA through 1998.

Table 1-1. Monitoring activities and reporting summary.

Activity	Sample Method	Frequency	Report Due Dates	
			Draft	Final
Visual Inspection	Ground inspections, photos and field notes	Annually, May-June until 1998; thereafter every 5 years as necessary	Oct. 15	Jan. 15
Bathymetry	Ground surveying during extreme low tide	Annually, May-June 1991, 1992, 1993, 1995, 1998; thereafter every 5 years as necessary	Oct. 15	Jan. 15
Intertidal Transects	Ground surveying during extreme low tide	March, May-June, Nov.-Dec. 1991, 1992; May-June 1993, 1995, 1998*; thereafter every 5 years as necessary	Oct. 15	Jan. 15
Sediment Deposition	Measure sediment depth over buried plates	As necessary	Oct. 15	Jan. 15
Intertidal Seeps	Surface sediment, 3 stations	Annually, May-June 1991 and 1993; thereafter as necessary	Oct. 15	Jan. 15
Gas Vents	Core sample sediment, 5 stations	Annually, May-June 1991-1992; thereafter as required	Oct. 15	Jan. 15
Surface Chemistry	Sample surface sediment, 5 stations (3 stations starting in 1998)	Annually, May-June 1991, 1992, 1993, 1995, 1998; thereafter as required	Oct. 15	Jan. 15
Subsurface Chemistry	Core sample 12 stations (6 stations 1993 and 1995, 4 stations starting in 1998), 25-45 cm below surface, 85-105 cm and 25-45 cm above cap-sediment boundary (starting in 1998 25-45 cm above cap-sediment boundary at 3 stations and 85-105 cm at 1 station)	Annually, May-June 1991, 1992, 1993, 1995, 1998; thereafter every 10 years as necessary	Oct. 15	Jan. 15
Benthos	Van Veen grab, 5 replicates at 6 stations at Project and 2 background stations	Annually, March 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998	Oct. 15	Jan. 15
Epibenthos	Suction sampler, 1 cap strata, 1 background strata	Annually, April, May, June 1991, 1992, 1993, 1994, 1995; thereafter as necessary	Oct. 15	Jan. 15
Macrophytes	Ground survey and aerial photography	Annually June-August 1991-1998; thereafter as necessary	Oct. 15	Jan. 15
Table 1 Update (annual monitoring activities)	Not applicable	Annually for duration of monitoring	Jan. 31	Mar. 1

* Although not required, intertidal transects have been conducted annually since 1988.

2. PHYSICAL MONITORING METHODS

2.1 DATA COLLECTION

2.1.1 Cap Elevation Monitoring

To determine possible changes in cap elevation, two types of surveys were conducted. The first type, a bathymetric survey, generated elevation contours for the entire Project site. The second type surveyed transect elevations of known stations on predetermined transects at the Project site. All surveys were conducted using standard land-based theodolite/EDM equipment.

The topographic survey was conducted from land during a spring low tide lower than -2 feet MLLW. Elevations throughout the Project area from +6 to -7 feet MLLW were spot surveyed using a marker stick with a prism device on top. Because surveys are conducted using land-based techniques, some lower elevations were surveyed by having personnel wade into the water and placing the survey rod on the bottom. Areas may have been surveyed this way in up to approximately 3 feet of water.

Five transects across the surface of the Project site were surveyed on three different occasions during the year. The transect survey was conducted at transects and stations established in 1990. Elevations of -4 to +6 feet MLLW were surveyed at each transect station with standard theodolite equipment using a permanent shoreline benchmark. If an earthquake of significance occurred or a storm occurred with winds from the north or southeast with 30-mile-per-hour, or greater, winds which persisted for more than four hours, then additional transect surveys were conducted.

2.1.2 Aerial Photograph and Visual Inspection

Additional information on the physical condition of the Project was collected. A low-altitude color aerial photo of the Project site was taken during a low tide (lower than -1.8 feet MLLW) in July using a standard 9 x 9 inch aerial camera. Kodak 2448 Aerochrome MS film (or an equivalent) was used and altitude was low enough to yield a scale of 1 inch = 100 feet. In addition, visual inspections took place in June, which consisted of walking the Project site while noting and photographing physical and biological features (as defined in the Monitoring Plan).

2.2 QA/QC AND LABORATORY ANALYSIS

No laboratory analysis was conducted as a part of the physical monitoring; therefore, discussion of laboratory analysis methods is not applicable to this section.

2.2.1 Cap Elevation Monitoring

Quality assurance for all cap elevation monitoring consisted of noting all procedures of the survey which deviated from normally accepted practices with standard theodolite/EDM equipment. Estimates on survey accuracy were made based on type and severity of deviations from normal survey procedures. This equipment is normally accurate well within the plus or minus four inches required by the Monitoring Plan.

2.2.2 Aerial Photograph and Visual Inspection

Aerial photo scale of 1 inch = 100 feet and the use of the proper type of color film were verified with the aerial survey crew before and after the photograph was taken.

2.3 DATA ANALYSIS

2.3.1 Cap Elevation Monitoring

Topography and transect profiles were generated from raw elevation data using a computer-aided drafting (CAD) system. Transect data were entered into tables for comparisons to previous years' data and the early warning triggers specified in the Monitoring Plan.

2.3.2 Aerial Photograph and Visual Inspection

The aerial photograph was viewed and any substantial changes in the Project appearance or any unusual features were noted. Notes and photographs from visual inspection were also assessed to determine the most pertinent information for inclusion in the monitoring report. General physical and biological characteristics and any unusual features noted were described and compared to previous years' features.

3. CHEMICAL MONITORING METHODS

3.1 DATA COLLECTION

Chemical sampling for the Project follows the schedule outlined in Table 1 of the Monitoring Plan.

3.1.1 Surface Sediment Samples

A land-based surveyor helped position a boat over the surface sediment stations, and when the exact position of the vessel was determined, using a hand-held prism device on the boat, a buoy marker was dropped at that location. Locations of buoys at the correct location were verified by a final survey shot over the location while holding the buoy line taut directly over the anchor. Location of the grab within plus or minus 2 meters of the buoy anchor was verified by examining the angle of the grab line (correlated with depth in relation to the buoy anchor.)

Surface sediments were collected at the surveyed stations (stations SS1, SS2, and SS4) using a van Veen grab. The grab was cast off the vessel and retrieved. On successful grabs, 2 cm of surface sediment were collected using a stainless steel spatula or spoon. After sediment collection, sampling, mixing, and archiving were completed consistent with the techniques and procedures described in Section 3.5.

3.1.2 Subsurface Sediment Sampling

The state plane coordinates for the subsurface sediment stations were determined and transmitted to the EPA. The locations were fixed in the field through a land-based survey similar to that described for surface sediment sampling. As with surface sampling, locations of buoys were verified with a final survey over the buoy anchor while holding the line taut.

The subsurface corings were collected at the surveyed stations (stations C1, C2, C3 and C10) using a portable (truck type) drill rig placed over a drill hole on a barge. The barge utilized three or more anchors set at various locations around the Project site to hold the barge on station, and anchor winches were used to move the barge around the Project site. This technique allowed for accurate and stable placement over the station. The barge was positioned over the coring station using the anchor winches and the location of the marker buoys as a reference. The angle of the buoy line was used to determine the actual location of the buoy anchor beneath the barge.

The angle of the line was visually correlated with depth at the location and the amount of slack on the buoy line. Although the exact distance was not calculated in the field, the angle and length of line was compared to known distances on the barge. For example, if the distance between the barge drill hole and the edge of the barge was 3 meters, and it was observed that the anchor lies parallel to the barge hole approximately 1 to 2 meters under the barge, it could be inferred that the sampling location was within ± 2 meters of the required site. Sampling at the location proceeded once the barge was stable over the location.

The drill rig used Shelby tubes to recover the sediment core. The previously decontaminated tubes were driven by water pressure into the undisturbed sediment ahead of the tip of the drill bit. The tubes were then retrieved and capped to prevent sediment spillage. Excess water was decanted out

of the tops of the tubes and the tubes were taped with duct tape and labeled. The entire core (in 2-foot sections in the tubes) was then transported on ice to the lab for extrusion and sampling. In some cases, the shelby tube was rejected by rocks or wood pieces in the cap. Standard procedure was to drill past this section and retry the tube lower down. If two full tubes were not obtained before encountering the contaminated sediment, then the core hole was rejected due to an incomplete core. In addition, if the retrieved tubes were only partially filled prior to encountering the contaminated sediment, the core hole was rejected. When core holes were rejected, the barge was moved slightly and the location was resampled.

Once the full shelby tubes were at the laboratory, the cores were extruded using a hand-cranked device which pushes a stainless steel plug down the length of the tube. The core was extruded onto a decontaminated tray. The distance from either the contaminated sediment boundary or the surface of the cap was used to measure the correct distance up or down the core to the sampling location. Samples were taken 25 to 45 cm above the contaminated sediment boundary at stations C1, C3, and C10 (samples were designated by core number and distance such as C1 2545), and 85 to 105 cm above the contaminated sediment boundary at station C2 (example designation, C2 85105). Archives were taken from the core in ten centimeter sections from the contaminated sediment boundary to 120 cm above the boundary and 25 to 45 cm below the surface of the cap. The remainder of each core was discarded.

Once samples were taken from the cores, the sampling and collection procedures were conducted consistent with Section 3.5.

3.1.3 Sample Collection and Transport

Samples were collected in accordance with all applicable Puget Sound Estuary Protocols (U.S. EPA 1990a). Once sediment samples were taken they were placed in a stainless steel bowl and mixed thoroughly with a stainless steel spoon or spatula. All utensils coming in contact with the samples had been previously decontaminated. The mixed samples were then placed in the sample container; they were immediately labeled. For subsurface sulfide analyses, sediment samples were collected from areas all along the extruded core prior to any additional disturbance and placed in a jar with 2 ml of zinc acetate.

For surface samples of sulfides and volatile organics, samples were collected directly from the grab prior to any disturbance of the sediment surface.

Decontamination procedures for all utensils, which were decontaminated in the laboratory prior to sampling, included the following: scrub withalconox in tap water, rinse with deionized water, rinse with 10 percent hydrochloric acid, rinse with methanol, rinse with acetone, rinse with deionized water several times. Next utensils were allowed to air dry and then covered in aluminum foil wrap. Utensils used for the collection of volatile organic samples were not subjected to an acetone rinse. Utensils used for metals samples were not subjected to an acid rinse.

Decontamination procedures for utensils, which were decontaminated in the field, included the following steps: scrub withalconox in deionized or marine water, rinse with deionized water, rinse

with 10 percent hydrochloric acid, rinse with methanol, rinse with acetone, rinse with deionized water several times, and loosely cover in aluminum foil wrap.

Utensils used for volatile organics collection were not subjected to an acetone rinse, and utensils used for metals collection were not subjected to an acid rinse.

When possible, samples were transported to the laboratory on ice on the same day that sampling took place. Chain-of-custody seals were placed on coolers during transport. In some instances, this could not be accomplished and the samples were stored in refrigerators at 4°C (for not more than two days) prior to transport to the laboratory. Chain-of-custody forms were filled out at the end of each day of sampling. Once the samples were transported to the laboratory, the delivery contents were verified and the chain-of-custody forms signed by the laboratory representative.

All sample containers used for sample collection were consistent with the requirements of the Monitoring Plan (Monitoring Plan, Table 4). Sample containers were also cleaned in accordance with Monitoring Plan requirements (Monitoring Plan, Table 4).

3.2 QA/QC AND LABORATORY ANALYSIS

The chemical parameters analyzed in the laboratory vary each year. The chemicals analyzed each year are presented in Table 3-1. The list of parameters to be analyzed is contained in Tables 2 and 3 of the Monitoring Plan. Two other categories of chemicals, indicator chemicals (4-methylphenol and chlorinated guaiacols) and PCDDs and PCDFs (commonly known as dioxins), are monitored in some years. These categories of chemicals are also described in the text of the Monitoring Plan.

Each of the types of parameters tested was analyzed by a specific laboratory method. Table 3-2 contains the different types of parameters within each Monitoring Plan table and the methods that are used to analyze them. The appropriate analysis was used in the laboratory for each type of parameter.

Field quality control consisted of verifying that all sampling stations were sampled within plus or minus 2 meters. Any field procedure which introduced location error was noted and reported.

The quality control and analysis procedures in the laboratory were conducted consistent with the procedures recommended under each specific analysis protocol and the PSEP guidelines (U.S. EPA 1990a). PCBs were evaluated using information from CLP statement of work (U.S. EPA 1991). PSEP guidelines were used where they were more stringent, more specific, or where they address a quality control procedure not specified in an analysis protocol. In addition, detection limits attained in most cases were lower than those specified in analysis protocols or PSEP guidelines for semi-volatiles and PCBs (as specified in the Monitoring Plan). The laboratory provided a CLP data package for all analyses.

The validation of laboratory data was conducted according to U.S. EPA Contract Laboratory Program (CLP) National Functional Guidelines for Organic and Inorganic Data Review (U.S. EPA 1994a,b). These guidelines include quality control limits and specify data qualifiers that were attached to sample results, in addition to qualifiers designated by the laboratory. Additional guidance for data validation came from the PSEP recommended guidelines (U.S. EPA 1990a), the isotope dilution Method 1625C and EPA SW-846 Methods (U.S. EPA 1990b). Parametrix

reviewed all laboratory data for quality using checklists to document quality control checks and to document qualifiers attached to data points. Checklists include the following major categories: holding times, GC\MS tuning, calibration (initial and continuing), blanks, surrogate recovery, matrix spike and matrix spike duplicate, field duplicates, internal standards, TCL compound identification, compound quantification and reported detection limits, tentatively identified compounds, system performance and overall data assessment, ICP interference check samples, reference sample, laboratory duplicate analysis, and furnace AA and ICP controls. (Note that some categories are only applicable to some analyses.) All summary tables generated from laboratory data were checked for transcription errors.

Table 3-1. Analyses requirements at vents (V), intertidal seeps (IS), surface samples (SS), and core samples (C) for the Project.

Year	Table 2 Parameters	Priority Pollutants (Table 3)	Indicator Chemicals	PCDDs and PCDFs
1991	V,IS,SS,C	SS		V,IS,SS,C
1992	SS	SS	C,V	
1993	IS,SS	SS	C	
1994				
1995	SS	SS	C	
1996				
1997				
1998	SS*	SS*	C	
1999				

*Analyses requirements for 1998 surface sediments were revised to include only phenol compounds, phthalate compounds, resin acids, and guaiacol.

Table 3-2. Parameters and analysis methods for the Project.

Parameter	Method
Table 2 Parameters	
Semi-volatiles	EPA SW-846 (1625C)
PCBs	608/8080
Resin Acids	EPA SW-846 (8270)
Chlorinated Guaiacols	EPA SW-846 (1625C)
Metals	EPA SW-846 (as modified by CLP for each applicable metal)
Conventionals	EPA SW-846 (9071) and PSEP Methods for Total Solids, TVS, TOC, Sulfides, and grain size
Table 3 Parameters	
Semi-volatiles	EPA SW-846 (1625C)
Pesticides and PCBs	EPA SW-846 608/8080
Volatile Organics	EPA SW-846 (8240)
Indicator Chemicals	
Semi-volatiles (4-methylphenol)	EPA SW-846 (8270)*
Chlorinated Guaiacols	EPA SW-846 (8270)
PCDDs and PCDFs	EPA SW-846 (8290)

*4-methylphenol was previously measured using method SW-846 (1625C). However, the method shown was used in 1993 and will be used in all subsequent monitoring of indicator chemicals as approved by EPA.

3.3 DATA ANALYSIS

All results were compiled with quality assurance review qualifiers into summary tables. Summary tables also contain 80 percent LAET levels (early warning levels) for each chemical. Any exceedances of 80 percent LAET or 1,000 ppb (early warning level for resin acids) were highlighted in summary tables. The results section also mentions each exceedance of early warning levels or 1,000 ppb as well as any other chemical detections substantially above detection limits. Any detections of non-LAET chemicals in subsurface samples which are five times above baseline values for clean sediment exceed early warning levels detailed in the Monitoring Plan and were also reported in the results section.

Grain-size data is reported for each type of chemical monitoring based on ranges of percentages of particle sizes found. Any apparent correlations between grain-size and chemical results were also noted in the results section. No grain-size plots were generated from the grain-size data, and full grain-size results were reported in a data appendix.

Project performance is evaluated in the discussion section based on the chemical results. Non-statistical correlations of chemical results among types of compound detected, location of detections, and timing of detections is discussed. The effects of data qualifiers on data usefulness are also discussed.

4. BENTHIC MONITORING METHODS

4.1 BENTHIC DATA COLLECTION

4.1.1 Sampling

To monitor the progressive changes in the Project benthic infauna, samples were collected during high tides from six Project sampling stations (four in Region A and two in Region B). Two additional sites to be used as background stations were also sampled.

All stations were sampled using benthic sampling procedures specified in the Puget Sound Estuary Program Protocol (U.S. EPA 1990a). Five sample replicates (A - E) were obtained at each station for benthic community analysis. An additional sample was taken to provide a sample for sediment particle-size distribution and chemical analysis. Benthic sampling stations were determined from shore surveys using standard theodolite/EDM equipment and then marked by buoys. Surveyors on shore verified sampling sites and noted anything which might have affected the required accuracy of plus or minus 2 meters, and the positioning was monitored during all sampling. Offsets of the EDM reflecting board and wire angle were noted to determine the relative error caused by these procedures. Samples were taken subsequent to the determination of all station locations by sampling at the buoy locations.

Before sampling, a file containing the positions of all planned benthic stations was established. In addition, this file contained station designations for all sample sites. This allowed sample labels and containers to be made before field operations. Such prelabeling minimizes sample labeling errors. One team member was responsible for sample tracking and logging. The stations were sampled using benthic sampling procedures specified in the Puget Sound Estuary Program Protocol (U.S. EPA 1990a). Samples were collected using a 0.1 m² van Veen grab. The grab was operated in accordance with the Monitoring Plan. After collection, the grab was measured to determine adequate penetration. Minimum standards for adequate penetration depth, by sediment type, follow:

Sediment Type	Penetration Depth
Cobbles/pebbles	unacceptable sediment type
Coarse sand/gravel	4 cm
Medium sand	7 cm
Fine sand	10 cm
Silty sand, sandy silt	15 cm
Silt	15 cm
Clay	15 cm

To verify that the sample was not disrupted during retrieval, the grab was inspected after each use. Evidence of winnowing, the absence of overlying water, and the presence of materials (rocks, shells, bark, or debris) in the jaws of the grab indicated sample leakage and invalidated a sampling attempt.

Sediment characteristics were observed and recorded according to a five-character sediment-type code. These notations included the following sediment properties:

- Odor
- Color
- Substrate type
- Presence of reducing layer
- Presence of large particles or organisms
- Miscellaneous observations

In addition, a logbook was maintained. Entries detailed all significant events, including the following information:

- Date and time
- Names of all personnel
- Purpose of sampling
- Identification number, location, and depth of sampling site
- Details of sampling effort and deviations from standard procedures
- Observations and measurements

These observations were also entered on printed log sheets for sediment sample characterization.

4.1.2 Sample Tracking

External and internal sample labels accompanied each container. The samples were labeled upon collection. Labels included station identification numbers, date, personnel initials, and the number of containers used. Following the completion of each day's sampling, the team member responsible for tracking and logging prepared a chain-of-custody form that accompanied the samples back to the laboratory.

All samples were logged into the laboratory before further processing and all subsequent processing steps were tracked. If the sample was split (for example, when vials of specimens were sent to different taxonomists), such changes were logged. All transfers of material outside the laboratory were noted on signed chain-of-custody forms.

4.1.3 Sample Sieving and Preservation of the Benthic Samples

After sample collection, the general characteristics of the sample were noted and the sample labeled. The sample was placed in a water-tight, sealed bucket and transferred to a sieving station on the sampling vessel. The samples were initially sieved to retain all materials that would not pass through a 1-mm mesh. The samples were then preserved in 10 percent borax-buffered seawater formalin, stored in labeled containers, and returned to the laboratory.

Grain-size samples were placed in labeled jars which were placed in coolers. The grain size samples were transported to the laboratory where they were maintained at 4°C until analysis.

4.2 BENTHIC QA/QC AND LABORATORY ANALYSIS

4.2.1 Sediment Physical Characteristics

The physical characteristics of the sediment were analyzed using a dry sieve and pipette method (Buchanan 1984). Although sediment particle-size distribution was initially recorded in millimeters, it was converted to the standard Wentworth scale for analysis. According to the Wentworth scale, particle size is indicated in phi (Φ) units, where $\Phi = -\log_2$ of the particle size.

The sieves typically used for sediment analysis have openings that are 2, 1, 0.5, 0.25, 0.125, and 0.063 mm in diameter. The corresponding Φ sizes would be -1, 0, 1, 2, 3, and 4, respectively. Smaller particles are determined by their relative sinking rates in a column of water. Sediment particles from 4 to 0.63 mm in diameter ($-2 < \Phi < 4$) are sands of varying coarseness. Particles between 0.063 and 0.004 mm in diameter are called "silt." Clay particles are smaller than 0.004 mm in diameter.

The amount of organic material was estimated by the percentage of the total volatile solids or the weight of the dried sediment that could be evaporated from the sample by heating at 500°C for 24 hours under controlled conditions.

Station-by-station comparisons of sediments or substrates were done graphically and by using the Proportional Similarity Index, a derivative of the Bray-Curtis (Dis)Similarity Index.

4.2.2 Biotic Characteristics

The samples were preserved for 24 to 48 hours and then rescreened using low-pressure tap water on a 0.5-millimeter sieve to remove the formalin. Formalin is rinsed from the samples to minimize decalcification of mollusks or other taxa with calcareous parts. All containers of a single sample were washed at the same time to ensure consistent handling; all replicates of a single sample were processed by the same individual.

The residual material was returned to the container and covered with denatured 70 percent ethanol. To assist in sorting, sufficient rose bengal stain was added to stain all preserved organisms.

The sample volume was measured, and samples were sorted twice to remove all organisms and organism fragments. A small amount of the sample was placed in a Petri dish and examined under magnification (a minimum of 10X). All organisms observed were transferred to a second Petri dish divided into quadrants labeled for the following four major organism groups: arthropods, mollusks, annelid worms, and miscellaneous. When the dish was full, it was surveyed for misplaced animals, and the organisms were transferred to the appropriate quadrant. The specimens were removed from these quadrants and placed into the appropriate vial (with fresh alcohol) for that taxon. Sediment and other remaining material was saved. All sorted sediments were retained until completion of the entire project.

4.2.2.1 Quality Control Sort-Checks and Quality Assurance Procedures

Quality control (QC) sort-checks were conducted on each sample in accordance with procedures in PSEP guidelines (U.S. EPA 1990a). The post-sorting sample was thoroughly mixed, and a 20

percent aliquot of the sediment removed. This aliquot was sorted by someone other than the initial sorter. If over 1 percent more total organisms than originally counted were found in the QC sort-check (indicating that over 5 percent of the original animals had been missed), the sample failed, and the entire sample was re-sorted. If only one or two organisms were found in the re-sort, and if this number was greater than 5 percent of the total animals sorted, the sample was re-sorted at the discretion of the quality control technician or laboratory supervisor.

The vials of each major taxon were checked when the sample sorting was complete to remove any missorted animals. Any missorted animals were placed into the correct containers. After these vial checks were completed, specimens from each sample were weighed to provide a wet-weight biomass.

Quality assurance (QA) was provided by the laboratory supervisor's routine audits of laboratory procedures. QA forms tracked replicates sorted, initial sorter, QC sorter, passage or failure of the sort, number of organisms found in the initial sort, and the number of organisms found in the QC sort.

4.2.2.2 Wet-Weight Biomass

The wet-weight biomass of each of the major taxa from each sample was determined by pouring the animals from the sorted sample through a preweighed 0.25-mm screen. This screen was placed on absorbent paper and either blotted dry from underneath, or allowed to remain on the paper until no more fluid was removed. The sample was dried for no more than 30 seconds because small animals, polychaetes in particular, will quickly dry out and rupture or tear. The screen and sample were weighed. Finally, the animals were washed back into the vial with 70 percent ethanol, and the wet-weight biomass was determined by subtracting the container weight. Complete biomass data were reported in a data appendix.

4.2.2.3 Traditional Taxonomic Analysis (TTA) Procedures

Verifying that organisms were accurately identified is an important component of the laboratory procedures. Only qualified taxonomic experts were allowed to identify the organisms. The sorters separated the organisms into the major taxonomic groups. Each group was transferred to the appropriate specialist for identification.

Traditional Taxonomic Analysis (TTA) was conducted on the 1-mm fraction from all the samples. The TTA data were summarized by station and site.

4.3 BENTHIC DATA ANALYSIS

4.3.1 Sediment Physical Characteristics

The depth and sediment particle size distribution of each station were analyzed to determine whether any observed changes might simply be due to normal ecological shifts resulting from changes in the substrate. Location-by-location comparisons of sediments or substrates were done graphically and by use of the Proportional Similarity Index (PSI) of which the Bray-Curtis Index is a more general form. Additionally, the quantity of organic material was estimated based on the percentage of total volatile solids.

Physical characteristics of background and Project stations were used qualitatively in the evaluation of all results.

4.3.2 Biotic Characteristics

4.3.2.1 General Descriptions and Ecological Indices

General descriptions of abundances, taxa richness, and assemblages were developed. Three quantitative ecological indices were used to measure diversity and dominance: The Shannon-Wiener (H'), Evenness (J), and Simpson's (S) indices (Poole 1974). From the raw data, mean values and error estimates for each parameter were derived. To be formally correct, all of these indices should be calculated using individuals identified to the same level of taxonomic precision. However, we generally calculated the indices for all taxa.

Shannon-Wiener Index (H')

The Shannon-Wiener index is derived from the mathematical discipline of "Information Theory." It ranges upward from zero and gives a quantitative measure of the relative amount of new information contained in each individual specimen collected. Where the sample is dominated by a few taxa, the amount of new information likely to be gained by enumerating any given specimen is small. Where the sample is diverse, new information is more likely to be gained because each new specimen might be a representative of a previously unsampled taxon. Consequently, the index values are low ($H' < 2.50$) if calculated from areas of relatively few taxa, and high if taxa are numerous.

The following is the formula for the Shannon-Wiener Index:

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

Where: H' = The Shannon-Wiener or information theory index of diversity
 p_i = The proportion of taxon "1" in the sample
 s = The number of all taxa in the sample

Evenness Index (J)

The Evenness Index (J) ranges from 0 to 1 and measures the dominance of the sample by one or a few taxa. It describes the dispersion of all taxa in a sample as a proportion to the maximum possible dispersion. Samples with J values near 0 are dominated by few species, while samples with values near 1 have approximately equal numbers of individuals in each species.

The following is the formula for the Evenness (J) Index:

$$J = \frac{H'}{\ln s}$$

Where: J = The Evenness Index
 H' = The Shannon-Wiener Index
 s = The total number of taxa in the sample

Simpson's Index (S)

Simpson's Index (S) ranges from 0 to 1, and measures the probability of randomly drawing two individuals of any given species from the total sample. This index is a measure of the degree the sample is numerically dominated by one or a few taxa. Values near 1 indicate a diverse array (the probability of drawing two individuals of the same taxon is small), while those near 0 reflect dominance by one taxon (the probability of drawing two individuals of the same species is large). The formula for the Simpson's Index given here is the standard unmodified form (Poole 1974).

$$C = \sum_{i=1}^s \frac{n_i(n_i - 1)}{N(N - 1)}$$

Where: n_i = The number of individuals in species "i"
 N = The total number of individuals in the sample
 s = The number of all taxa in the sample

This form was then expressed and reported as $1 - C$ (or 1-C) so that high diversity would be indicated by high numbers, consistent with the other indices.

4.3.2.2 Power of the Tests

Power analysis is used to determine the statistical validity of field or experimental data for any given analysis. The basic question is one of determining the minimum distance between two sample means that can be distinguished statistically given the variance inherent in the samples being taken, coupled with the number of samples taken.

The two kinds of errors are inherent in statistical analysis: Type I or α error, the error of rejecting a true null hypothesis; and type II or β error, the error of incorrectly specifying the hypotheses. For a given number of sample replicates, the value of α is related inversely to β (Sokal and Rohlf 1981; Zar 1984). Alpha error is commonly set at 0.05. Beta error is often set at 0.1 or 0.2. The "power" of a test is defined as $1 - \beta$, and is commonly referred to as a percentage; thus, a test with $\beta = 0.2$ can be considered to have a power of 80 percent.

The power of the test depends on the error variance of the population being sampled, and this can be estimated by the error mean square of an ANOVA comparing the given taxon across the sampled stations (Zar 1984; C. Hogue, personal communication). This latter value is inversely proportional to the number of samples, consequently the power of a test can be related to the number of replicates. Some of the samples did not pass the tests for homogeneity of variances. To assure consistency in the analyses, all data were $\ln(x+1)$ transformed prior to the analyses of variance.

Power tables were computed using methods presented in Zar (1984) to calculate minimum detectable differences (MDDs). The MDDs were then reported as percent of reference station mean

to determine whether each test can detect a reduction of 50 percent of reference mean with 80 percent of power.

For 1998 benthic samples, the following constants were held constant for the station-by-station comparisons: $k=8$, $v_1=6$, n =harmonic mean of station sample sizes (B1, B2, ..., B6, R1, R3), and $v_2=28$. A series of values for δ , the MDDs, were obtained using formula 11.28 of Zar (1984) given below.

For 1998 benthic two-sample analyses, equation 9.25 in Zar (1984) was used to calculate MDDs (given below). The values for n , α , and t_β differ depending on the sizes of the samples being compared in each statistical test. If the sample sizes are equal, n is equal to that sample size; otherwise, n is the harmonic mean of the sample sizes.

$$\phi = \sqrt{\frac{n\delta^2}{2ks^2}}$$

Where: n = The number of replicates
 δ = The mean detectable difference
 k = The number of samples
 s^2 = The error mean square from a one-way analysis of variance for the given taxon done across all samples from the cap (Zar 1984)

The MDDs can be viewed as the limits on how similar two samples can be and still be discernible, both above and below the sampled mean. Thus, with an α of 0.5, a power of 0.8 implies the hypothesis that two means differing by at least the MDD will be correctly discriminated 95 percent of the time and that 80 percent of the time the difference between the two means can be correctly estimated (Zar 1984).

4.3.2.3 Tier One, Level One Analyses

Analysis 1.1: Analyses of Numerical Abundance

The statistical comparisons between Project and background stations were conducted for several meristic factors. Station mean abundances were statistically compared to determine whether there is no significant difference between the Project and background stations (null hypothesis), or whether there is a significant difference between the Project and background stations (alternative hypothesis).

Comparisons were conducted between the following groups:

- All Project stations (pooled) versus all background stations (pooled)
- Comparisons among all individual stations through an 8-sample ANOVA (or appropriate non-parametric test)

Two null hypotheses were tested: (1) there is no difference in mean abundance between the pooled background stations and the pooled Project stations; and (2) there is no difference in mean abundance between the individual stations (background and Project).

Testing the two null hypotheses provided different levels of information. The two-sample tests were used to compare the mean abundances between the pooled background and pooled Project stations. This test provided a general assessment of Project performance as a whole.

The comparisons between individual stations (among station tests) took into account the existence of different community structures and developing habitats at the Project. If significant station differences were indicated by the ANOVAs (parametric or non-parametric), they were followed by a multiple comparisons technique to identify specific pairwise differences between stations.

These statistical comparisons were conducted at the 0.05 significant level for each of the following analyses:

Analysis 1.1.1	Total number of taxa at each station
Analysis 1.1.2	Number of numerically dominant taxa at each station
Analysis 1.1.3	Number of the non-numerically dominant taxa at each station
Analysis 1.1.4	Total number of individuals at each station

All of these analyses were conducted on station means. Numerically dominant taxa were defined as those taxa which cumulatively comprised 75 percent of the total abundance.

The statistical procedures used are discussed in more detail in the Biological Indicators Approach (Parametrix 1994). Generally, statistical comparisons included a preliminary comparison of the data distributions to a normal distribution and a test of homoscedasticity (homogeneity of variance, or HOV). Both of these tests were necessary to determine whether the assumptions required for parametric statistical tests were met. Prior to testing the data for normality and HOV, the abundance was log-transformed ($\ln[x+1]$), since abundance data commonly included a large number of high values (i.e., the data are skewed). If the assumptions were met, parametric tests were preferred for their greater power. If the assumptions were not met, then non-parametric tests were used. The following tests were used: one-way analysis of variance (parametric) and Kruskal-Wallis Mann-Whitney U-tests (non-parametric). If the assumptions for parametric tests were met for most of the groups examined, then parametric tests were used for the statistical comparisons. Analysis of variance is robust even when the assumptions of normality and homogeneity of variance are not completely met.

Cataloging of specimens and presentation (graphical or tabular) of data generally included calculations of station mean abundances. Station mean abundances (number of taxa) were used in each of the above tests.

Analysis 1.2: Standing Crop Patterns (Wet-weight Biomass)

Similar analyses were performed using major taxon wet-weight biomass for whole sediment samples as an indication of standing crop. Significant changes in biomass can indicate either the overabundance of one or a few species or significant changes in all species; either of these changes

could be due to substrate contamination or other causes. Biomass patterns are likely to be biased if one or a few large individuals are present. Consequently, in addition to total major taxon wet-weight biomass measurements, a subsequent similar set of measurements were made excluding large organisms. The excluded organisms were subjectively chosen to remove those whose weight was a substantial fraction of the total. The weight and the major taxonomic group of any excluded organisms were also recorded.

Both the total and selective biomass data were analyzed using traditional statistical analyses as described in the previous section. The traditional analysis used ANOVA techniques if the data were sufficiently homogeneous in variance, and if they were normally distributed. The appropriate use of parametric or non-parametric tests was determined using the same methodology as described for Analysis 1.1. If most of the examined groups met the parametric test criteria, all of the tested groups were examined using parametric tests. If the data did not meet the criteria, appropriate non-parametric tests were used to verify the results of the parametric tests.

The statistical comparisons (parametric and/or non-parametric) were conducted between the following groups:

- All Project stations (pooled) versus all background stations (pooled)
- Among all individual stations

Analysis 1.3: Proportional Similarity Index (PSI)

Sample comparisons of taxa abundance were based on taxa-sample matrices from station replicates. Similarity between stations was measured with the PSI, which considers the total number of taxa collected from all the samples. This form of the PSI is generally equivalent to the Bray-Curtis index. This analysis was run on the taxa sample matrices using a nearest-neighbor group clustering algorithm. The data used for these PSIs were the means of the 5 replicates for each station (station means of actual and log-transformed abundances). Results were displayed as optimally rotated dendrograms.

When completed using proportions of abundances, the PSI is independent of the number of taxa in each sample. This sample size independence is desirable when the basis of sampling is different between samples (e.g., when data from different studies are used). When abundances are used in the computations, the resulting quantity is the Bray-Curtis index, an index influenced by sample size. This influence is reduced, however, when log-transformed abundances are used.

The following is the formula used for the PSI:

$$PSI = \frac{2 \sum_{i=1}^s \min(x_{ij}, x_{ik})}{\sum_{i=1}^s (x_{ij} + x_{ik})}$$

Where: x_{ij} = The number of individuals of taxon “i” in sample “j”
 x_{ik} = The number of individuals of taxon “i” in sample “k”
 s = The number of taxa across all samples

Analysis 1.4: Ordination of the Benthic Infaunal Data: Principal Coordinate Analysis (PCOR)

As approved by EPA in a July 29, 1997 letter to Simpson Tacoma Kraft Company (USEPA 1997), PCOR is no longer required as part of the biological indicators approach. The methods used in previous years when PCOR was required follow.

As a part of the Tier One, Level One analysis, the data were tested by the quantitative statistical analyses of ordination (in this case, PCOR) to determine whether the infaunal assemblages sampled annually from each station were significantly different from those collected at background stations. As a part of the Tier One, Level Two analysis, a similar ordination analysis was conducted comparing the present year’s samples to samples collected during the previous year. Ordination analysis projects samples into a multi-dimensional (where each dimension is equivalent to a single taxa) universe, then rotates the axis to maximize information content along a subset of new axes (called Principal Axes). The projections of samples (called Principal Coordinates) onto the new axes are calculated.

Three different and sequential procedures are necessary to complete the PCOR process. The first procedure is classification. The second procedure, ordination, uses principal coordinate analysis to transform the variables and extract the most information from them. These first two procedures are manipulative; that is they change the way of looking at the basic data to assess differences. The third procedure is a statistical test of the results of those data manipulations. These procedures were conducted consistent with the requirements of the Biological Indicators Approach (Parametrix 1994).

4.3.2.4 Tier One, Level Two Analyses

Analysis 1.5: Analyses of Numerical Abundance (Comparison Between Years)

This analysis is similar to Level One analyses of numerical abundance except that comparisons were made between present year data and the previous year’s data. Station mean abundances were statistically compared to determine whether there was no significant difference between present data and the previous year’s data. Comparisons were conducted between the following groups:

- All present year Project stations (pooled) versus all previous year Project stations (pooled)
- Two sample comparisons between individual stations (e.g. B1 1994 vs. B1 1993, B2 1994 vs. B2 1993, etc.)

Hypotheses to be tested and the numerical data to be used for each test were the same as in Analysis 1.1 described above, except that comparisons between years were conducted.

Analysis 1.6: Ordination of the Benthic Infaunal Data (Comparison Between Years)

This analysis is similar to the ordination methods described in Analysis 1.4 to determine whether the infaunal assemblages sampled annually from each station were significantly different from samples collected during the previous year. The procedures and methods followed for Analysis 1.6 were identical to those followed for Analysis 1.4 except the comparisons were made to the previous year's data.

4.3.2.5 Tier Two Tests

Tier Two analyses will be conducted only if the statistical evaluations conducted in Tier One analyses indicate significant differences potentially indicative of a decline in Project health.

The enumeration and quantitative description of the benthic infauna conducted under Tier One (Analyses 1.1 through 1.6) of the biological indicators approach will provide insight as to whether an assemblage is normal, interactive, and productive. However, Tier Two, if conducted, will focus on the ecological interactions occurring at the site. An examination of the collected taxa abundance data for ecological interactions may be able to provide significant information within the framework of previous research. In Tier Two, the attempt will be made to provide a synthesis of such data and a functional interpretation of the biological assemblages sampled at the site. Because it is likely that only one or a few stations will show significant differences in the Tier One indicators, Tier Two analyses described here may only include the station or stations which showed significant differences in Tier One indicators.

Tier Two analyses will examine common infaunal taxa which belong to known feeding guilds or to other ecologically functional groups (Parametrix 1994). As with the Tier One analyses, Tier Two includes qualitative evaluations and statistical tests of these ecological groups. Analyses will be performed using present year data for the Project station compared to the background stations. Tier Two biological indicators will include the following analyses:

- Analysis 2.1** - Examination of trophic guilds including statistical and qualitative comparisons of guild abundances and descriptions of food webs where information is available.
- Analysis 2.2** - Examination of key species including statistical comparisons if abundances are sufficient across the stations to provide valid statistical results.
- Analysis 2.3** - Examination of changes in abundance of pollution-sensitive or -tolerant taxa, including statistical comparisons to background stations if abundances are sufficient across the stations to provide valid statistical results.

Normality and homogeneity of variance will be examined using the same methods described for the Tier One analyses. If most of the groups examined meet the requirements for parametric tests, then parametric tests will be conducted. Although the analysis of variance test is robust, if these requirements are not met for any of the examined groups, then non-parametric tests will also be conducted to verify the results of the parametric tests. The statistical tests used will evaluate the following hypotheses:

Analysis 2.1 - For each trophic guild:

H_0 = the mean abundance at the Project stations is not significantly different from the mean abundance at the background stations.

H_a = the mean abundances are significantly different.

Analysis 2.2 - For each key species:

H_0 = the mean abundance at the Project stations is not significantly different from the mean abundance at the background stations.

H_a = the mean abundances are significantly different.

Analysis 2.3 - For each pollution-sensitive or -tolerant taxa:

H_0 = the mean abundance at the Project stations is not significantly different from the mean abundance at the background stations.

H_a = the mean abundances are significantly different.

The statistical comparisons for each analysis will test two specific null hypotheses: (1) the mean abundance for the pooled Project stations is not different from the mean abundance for the pooled background stations, and (2) the mean abundances for the individual stations, background and Project, are not different. All statistical comparisons will be tested at the 0.05 significance level.

Because these tests focus on a particular group of the benthic community at the site, the abundance of some of these groups may be relatively low. This may result in statistical tests with relatively low power particularly for Analysis 2.3 which involves pollution reactive taxa. The relative power of any test considered will be evaluated so that analyses with wholly insufficient power are not conducted. The power of particular tests will be considered when results of these tests are evaluated. As with other tests, the goal for statistical power will be an MDD of 50 percent of the background mean (see further discussion of power on page A4-7). If lack of power severely limits the interpretation of one or more indicators, the following types of tests will be considered as alternatives:

- Presence-Absence testing using standard non-parametric statistical techniques as presented in Gibbons (1985)
- Presence-Absence testing using the statistical methods of Hendrickson (1978)
- Pairwise statistical comparisons between stations presented by Goodall (1969)

- Coefficient of community (Sorensen's Index) described by Pielou (1977)
- Infaunal Trophic Index described by Word (1990)

4.3.2.6 Other Data Analysis Procedures

Dendrograms

The programs in the Community Analysis System (Bloom 1992) were used to construct all dendrograms as well as to calculate or verify all quantitative indices. All dendrograms were optimally rotated. Dendrograms were based on Proportional Similarity, as described earlier, and constructed using group average sorting.

Statistical Analyses

Since distributions of abundances (counts) tend to be skewed, data were log-transformed ($\ln[x+1]$) prior to evaluating the parametric test assumptions. ANOVA tests for two samples were conducted and the residuals were recorded. The ANOVA residuals were evaluated for homogeneity of variance and normality. Homogeneity of variance was tested using Levene's test in conjunction with box plots of residuals by sample. Other homogeneity of variance tests, such as Cochran's, Bartlett's, or Hartley's were also considered. Normality was evaluated using the Shapiro-Wilk test in conjunction with normal probability plots of residuals (U.S. EPA 1989, 1992).

Based on the results of the homogeneity of variance and normality tests, appropriate statistical tests (parametric or non-parametric) were conducted. For each hypothesis tested, if most of the test groups examined met the requirements for parametric tests, parametric tests were conducted. Although the analysis of variance (ANOVA) test is robust, if these requirements were not met for any of the examined groups, non-parametric tests (Kruskal-Wallis or Mann-Whitney U-tests) were also conducted to verify the results of the parametric tests. These comparisons involving individual stations were followed by a multiple comparisons test if the initial test indicated significant differences.

This basic statistical testing procedure was applied to Analyses 1.1, 1.2, and 1.5. For Analyses 1.1 and 1.5, several types of abundance data (described previously) were examined and each was individually tested as described here. For Analysis 1.2 tested data were wet-weight biomass for major taxonomic groups. The several types of abundance data addressed in Analysis 1.5 were tested individually.

5. EPIBENTHIC MONITORING METHODS

As described in Table 1-1, scheduled epibenthic monitoring was completed in 1995. Therefore, the descriptions of methods in this section only apply to work conducted prior to 1996.

5.1 DATA COLLECTION

5.1.1 Station and Replicate Sample Location

Two sample stations were identified: the Project Epibenthic Station and the Background Station (Figures 5-1 and 5-2 in the Monitoring Report). Transects were set up at each station parallel to the shoreline. The first was established at 0 ft MLLW and the second at -2 ft MLLW. The Project station is referred to as the Project Epibenthic Station (Figure 5-2 in the 1995 Monitoring Report). The background station is the same as the background station called NMR in 1992. The background station is between the Milwaukee Waterway and Sitcum Waterway and is referred to as the Background Epibenthic Station in 1995 (Figure 5-1 in the 1995 Monitoring Report).

Five replicate sample locations (between 0 and -2 ft MLLW) along the transects were established, by a survey crew using standard theodolite/EDM surveying techniques, and surveyed (see Figure 5-2 in the Monitoring Report for state plane coordinates). At the Project station, wooden lath stakes were driven at -2 ft, -1 ft, or 0 ft MLLW. The relative positions of the stakes may change along the transect from year to year depending on the sediment height relative to the tide height. If the surveyor's stake was at 0 ft, another stake was added at -2 ft along the transect line created by the upper stake. One intertidal epibenthic background station was marked, surveyed, and sampled in the same manner as the Project station. A tide gauge placed on a nearby dolphin (pilings lashed together) was used to verify tidal heights. Just before and during slack tide, observations were made on beach substrates between 0 ft and -2 ft MLLW, and stakes were placed just shoreward of the replicate sample location.

5.1.2 Epibenthos

The 0.018 m² epibenthic suction sampler that was used to monitor the Project epibenthos in 1989 and 1990 (Parametrix 1991), 1992, and 1993 was used to monitor epibenthos abundances in 1995. This sampling device and technique are recommended by the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991). The suction sampler, which samples only the benthic boundary layer, has been developed for sampling epibenthic plankters that are important prey to juvenile salmon and other small fish. A sampling cylinder with fine-mesh screened ports was slowly lowered to enclose an area of the bottom and a segment of the benthic boundary layer. Following placement, the pump was switched on and run for 15-30 seconds. The water volume in the sampling cylinder was evacuated with a water pump through a clear plastic hose and all water passing through the screened parts was uncontaminated. If sediment was observed coming through the hose, the pump was switched off to minimize sampling of benthic infauna. About 3 to 5 times the volume of the cylinder was pumped. The pumped water and epibenthos were captured and screened through a 0.25 mm sieve. The pump is attached to a marked plastic pipe which acts as a staff to accurately indicate water depth during sampler placement.

Samples were rinsed from the sieve using seawater in a wash bottle and rinsed into 8-ounce plastic jars that had been prelabelled with the project name and number, station number, replicate number, date, and initials of the persons sampling. The samples from each station were immediately fixed in seawater with a 10 percent borax-buffered formalin solution. The solution was changed to a 70 percent alcohol solution in the laboratory after the samples were rescreened.

In April, May, and June samples were collected at each replicate sample area (total of 30 per transect) along the transect at each station at the same relative tidal height (i.e., rising tide). Because many samples were collected in one narrow tide range, the background stations and the Project stations may have been sampled on consecutive days. The investigator avoided walking seaward of the stake, so as not to disturb the sediment at the exact spot where the epibenthic sample would be taken. To obtain the samples at the same elevation at each station, the sampler was placed to the same depth (with at least 0.5 m of water over the replicate sample area measured on the staff) at 20 cm distances on either side of the stake marking the replicate location. Approximately 10 ft of space was left between replicate sample locations so that taking one sample would not disturb the next.

5.1.3 Sediment Samples

During the first sampling event in April, sediment samples for grain size analysis were collected by hand, during low tide, using a spatula or spoon; stakes were left to mark the replicate location. Five sediment samples from the background station and five samples from the Project station were collected at the five replicate sample areas that had been surveyed. Grain size samples were put into a cooler with ice immediately after collection and transferred to a refrigerator at Parametrix's laboratory when received from the field. Sediment grain size analyses were performed by Soil Technology, Bainbridge Island, Washington. The lab used PSEP protocols for analysis (see Appendix 2, Data Appendix, Section 5.1).

5.1.4 Physical Measurements

Salinity and temperature readings were taken at low tide at the sampling locations before epibenthic samples were collected. The salinity at the Project station was measured with a hand-held refractometer to the nearest part per thousand (ppt), and the temperature was measured with a calibrated laboratory thermometer to the closest 0.5°C.

5.2 LABORATORY ANALYSIS AND QA/QC

All PSEP guidelines applicable to epibenthos monitoring were used for collection, processing, and analysis of epibenthos and grain size samples. The epibenthic samples were checked in and verified at the Parametrix laboratory as soon as they were received from the field. Chain-of-custody forms were completed and the samples, along with chain-of-custody forms, were transferred for sorting and taxonomic identification to J.R. Cordell at the University of Washington Fisheries Research Institute's Trophic Ecology Laboratory.

The samples were washed using fresh water from a low-pressure faucet and rescreened on a sieve or series of stacked sieves with decreasing screen sizes to ensure that specimens collected in the field would be retained. The sample material was then rinsed into a sorting tray. A portion of the sample was placed in a glass petri dish. Epibenthic organisms were sorted, identified, and counted, then

returned to their original sample container with the original label. Sorting was completed using a compound microscope until the entire sample was sorted. Mr. Cordell typically identifies organisms to the lowest possible taxonomic level (usually the species level) as the sample is being sorted. However, if a sample was particularly dense with many organisms or much detritus, the sample was split using a Folsom splitter until 100 of the most dominant taxa were obtained. Samples requiring splitting were either split in half or quarters (i.e., 50 or 25 percent splits). All organisms were identified to the lowest possible taxonomic level and enumerated. Data were recorded onto data sheets and 100 percent of the number of organisms were recorded including the samples that required splitting. The data recorded on the data sheets were also entered into a computer spreadsheet by an assistant of Mr. Cordell. The electronic version, hard copies of the data sheets, the samples for archiving, and voucher collection were returned to Parametrix. Chain-of-custody forms accompanied each transfer. One hundred percent of the electronic data entries were compared to the handwritten entries on the data sheets because the total number of samples collected at both the Project and background stations was relatively low (i.e., 180 entries). Discrepancies were flagged and resolved by coordinating with Mr. Cordell. Corrections were made to both the electronic and handwritten data sheets. The corrections were then initialed and dated.

The Monitoring, Reporting, and Contingency Plan indicates that QC procedures are to be performed on the sorting of epibenthic samples. Basically, the Plan requires that the sediment from each split be re-sorted by another sorter, and that organisms recovered on the sample re-sort be counted and added to the data from the initial sorting. The protocols used in 1995 differ from the Plan in two ways. The first is that a random sample is chosen from the total number of samples to be sent out for re-sorting and taxonomic verification. The second is that the procedures used in 1995 include verification of the taxonomy and counts of organisms within the random samples.

A random sample representing 10 percent of the total number of samples was sent to an independent taxonomist for resorting and verification of the taxonomy. Re-sorting included examining the sample or a sub-sample (split) that had already been sorted and was considered to be free of organisms. Verification of taxonomy included verifying the level of taxonomy and the counts of organisms.

When no more than 10 percent of the organisms in a given sample were missed, the sample sorting efficiency was considered to be 90 percent and was considered acceptable. If the percent error on re-sorting and/or taxonomic verification was exceeded, the entire sample was re-sorted and/or organisms identified and enumerated.

A 10 percent error (i.e., a 90 percent efficiency for re-sorting) is acceptable because of the size of epibenthic organisms and the likelihood of losing and/or crushing some of the epibenthic organisms when they are transferred into vials for the independent taxonomist. Similarly, the taxonomic verification is expected to be accurate for at least 90 percent of the total number of species. It is important to recognize that currently there are no established QA/QC guidelines or protocols for re-sorting and taxonomic verification of epibenthic organisms. This is due, in part, to the level of taxonomic verification that most other taxonomists familiar with Pacific Northwest epibenthic organisms (especially harpacticoids) can attain. It is usually much less (i.e., level of order) than can be obtained by Mr. Cordell. In addition, epibenthic organisms are inherently different with respect to size, habitat requirements, and mobility than benthic infauna, and the guidelines for benthic organisms are not necessarily applicable to epibenthic organisms. Finally, most investigations

associated with epibenthic organisms are interested in those epibenthos known or thought to be important to juvenile salmonids; they do not necessarily focus on the total range of epibenthic organisms or species diversity (Jeff Cordell 1993 personal communication).

One hundred percent of the data entries by the independent sorter/taxonomist were compared to the handwritten entries on the taxonomy data sheets provided by Mr. Cordell because the total number of samples collected at the Project and background stations was relatively low (i.e., 180 entries). If the re-sorting efficiency and taxonomic verification were within the 10 percent error, the QA/QC was considered to be acceptable.

5.3 DATA ANALYSES

5.3.1 General

Following QA checking, the electronic results of all samples analyzed for epibenthos were entered into species lists on a computer spreadsheet. A taxonomic catalog was made and the ecological indices and similarity dendrograms were produced exactly as for the benthos data analysis using the Community Analysis System software. Statistical data were produced using STATGRAPHICS® (STSC 1991). Initial data files included every organism from every sample replicate. Species lists that include all of the organisms collected in the epibenthic sampler were evaluated to determine which organisms are not considered to be endemic to epibenthic communities. Organisms that are not considered part of the “epibenthic community” were not included in the analyses. The primary factor used to determine whether an organism is part of the “epibenthic community” is whether the organism is endemic to the benthic boundary layer. Thus, organisms that are considered endemic to the water column or the benthos were not included. Organisms not considered to be representative of the epibenthic community are excluded for a variety of reasons: (1) life history stage (e.g., nauplii, zoea, copepodites), (2) because the organism is more representative of the water column or benthic infauna communities, or (3) due to the type of organism (e.g., mollusc egg cases). Other organisms, such as *Leptochelia savignyi*, are included as part of the epibenthic community because of their known role as a keystone predator and their influence on community structure. Based on this analysis, tables were generated on a computer spreadsheet that categorized the organisms into two groups: epibenthic taxa and nonepibenthic taxa.

From the revised files, total abundances of each taxon at each station (pooled replicates) were calculated per square meter for each sampling date. The total abundance (i.e., counts) of total epibenthic organisms, harpacticoid copepods, amphipods, and salmonid prey for each station and sampling event were calculated.

5.3.2 Statistical Comparisons

The question asked in 1995 was: “Is the epibenthic community at the Project station comparable to the epibenthic community at the background station?” To answer this question several statistical comparisons were made between the Project and background stations, by month, for several groups of epibenthic taxa: total epibenthos, total harpacticoids, total amphipods, total salmonid prey, and selected abundant taxa (e.g., *Harpacticus uniremis* and *Tisbe* spp.). The selection of the abundant taxa was based on the evaluation of the distribution of counts over all replicates for both stations.

These statistical comparisons were computed using either parametric (Analysis of Variance [ANOVA]) or non-parametric (Mann-Whitney) statistical methods. For the statistical tests, the data were transformed logarithmically [$\ln(x+1)$] to control variances because of the variability of the data. After data transformation, a test for homogeneity of variance (i.e., if boxplots indicate heterogeneity of variance, Levene's test) determined whether parametric or non-parametric statistical tests should be used to compare the Project and background station means for each month. The null hypothesis for each test was that there was no significant difference between the Project and background station means. The alternative hypothesis was that there was a significant difference between the means (i.e., this is a two-sided hypothesis).

5.3.3 Power Analysis

Power analyses were conducted on the log-transformed counts for several epibenthic taxa groups. For each group tested (i.e. comparing between Project and background stations) the data from both the background and Project stations were pooled (via ANOVA) to estimate the variance used to compute each power analysis. Power analyses were performed for the total number of epibenthic organisms, total number of harpacticoid copepods, total number of amphipods, and total salmonid prey taxa, as well as for selected abundant taxa.

Power analyses were used to determine the statistical power of the tests to detect a 50 percent decrease in abundance at the Project station relative to the background station. They were also used to determine the MDDs (minimum detectable differences) between the two sample means in order to construct power curves. This MDD is dependent upon the number of replicates for, and the variance present within, the samples being evaluated. Additional details about power analysis are provided in Zar (1984).

Two kinds of errors are inherent in statistical analysis: Type I or α error, the error of rejecting a true null hypothesis, and Type II or β error, the error of incorrectly accepting the null hypothesis (i.e., the error of not rejecting a false null hypothesis). Beta error is often set at 0.1 or 0.2. The "power" of a test, or the ability to detect a true difference between two population means, is defined as $1 - \beta$, and is commonly reported as a percentage; thus a test with $\beta = 0.2$ is considered to have a power of 80 percent.

The power of a hypothesis test depends on the variance of the population being sampled, and this can be estimated by the error mean square of an ANOVA comparing the given taxon across the two stations being tested (Zar 1984). This latter value is inversely proportional to the number of replicates per station; consequently, the power of a test can be related to the number of replicates. To assure homogeneity of variances and consistency in the analyses, all data were $\ln(x+1)$ transformed prior to computing the ANOVAs. All calculations in the power analyses were made on the transformed scale.

Power curves were generated using the methods of Zar (1984). To calculate the MDD for Project and background stations sampled in April, May, and June, Equation 9.25 was used (Zar 1984). For these power calculations, the following values were held constant, $n = 30$, and $\nu = (2 \text{ times } n - 1) = 58$. Formula 9.25 from Zar (1984) is given below.

$$\delta \geq \sqrt{\frac{2s^2}{n}}(t_{0.05,v} + t_{\beta(1),v})$$

- Where :
- n = Number of replicates per station
 - δ = Minimum detectable difference (MDD)
 - s^2 = Error mean square from a one-way analysis of variance (ANOVA) for the given taxon calculated from both stations
 - $t_{0.05,v}$ = Student's t value for probability = 0.05 and v (one- or two-sided, depending on hypothesis tested)
 - $t_{\beta(1),v}$ = One-sided Student's t value for probability = β and v

For each hypothesis tested, a range of MDD values was determined, and a power curve was constructed. The focus was on whether the hypothesis tests could detect at least a 50 percent decrease from the background station with a power of 80 percent. To determine whether the Project station was providing epibenthic habitat comparable to the background station, the MDDs were calculated using a one-sided $t_{0.05,v}$ -value. Once the MDDs were calculated using Equation 9.25 from Zar (1984), they were divided by the background station means to report them as a percent of the background station mean. This was done for the major taxa groupings that were evaluated, as well as selected abundant taxa, by month.

5.3.4 Ecological Indices

Three quantitative ecological indices were used to measure diversity and dominance: The Shannon-Wiener (H'), Evenness (J), and Simpson's (C) indices (Poole 1974). However, unlike the benthos analysis, epibenthos replicates were pooled for each station, and the diversity indices were calculated from pooled mean abundances using epibenthic taxa identified to genus or species (Blaylock and Houghton 1981; Simenstad et al. 1980; Simenstad and Cordell 1983, 1989).

5.3.4.1 Shannon-Wiener Index (H')

The Shannon-Wiener index is derived from the mathematical discipline of "Information Theory". It ranges upward from zero, and gives a quantitative measurement of the relative amount of new information contained in each individual specimen collected. Where the sample is dominated by a few taxa, the amount of new information likely to be gained by enumerating any given specimen is small. Where the sample is diverse, new information is more likely to be gained because each new specimen might be a representative of a previously unsampled taxon. Consequently, the index values are low ($H' < 2.50$) if calculated from areas of relatively few taxa, and high if taxa are numerous.

The following is the formula for the Shannon-Wiener Index:

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

- Where: H' = The Shannon-Wiener or information theory index of diversity

p_i = The proportion of taxon “i” in the sample
 s = The number of taxa in the sample

5.3.4.2 Evenness Index (J)

The Evenness Index (J) ranges from 0 to 1 and measures the dominance of the sample by one or a few taxa. It describes the dispersion of all taxa in a sample as a proportion to the maximum possible dispersion. Samples with J values near zero are dominated by few species, while samples with values near one have approximately equal numbers of individuals in each species.

The following is the formula for the Evenness (J) Index:

$$J = \frac{H'}{\ln s}$$

Where: J = The Evenness Index
 H' = The Shannon-Wiener Index
 s = The total number of taxa in the sample

5.3.4.3 Simpson’s Index (S)

Simpson’s Index (S) ranges from 0 to 1 and measures the probability of randomly drawing two individuals of any given taxon from the total sample. This index is a measure of the degree to which a sample is numerically dominated by one or a few taxa. Values near 1 indicate a diverse array (the probability of drawing two individuals of the same taxon is small), while those near 0 reflect dominance by one taxon (the probability of drawing two individuals of the same taxon is large). The formula for the Simpson’s Index given here is the standard unmodified form (Poole 1974).

$$C = \sum_{i=1}^s \frac{x_i(x_i - 1)}{N(N - 1)}$$

Where: C = The standard unmodified form of Simpson’s Index
 x_i = The number of individuals in species “i”
 N = The total number of individuals in the sample
 s = The number of all taxa in the sample

5.3.5 Station Similarity

The Proportional Similarity Index (PSI), also known as the Bray-Curtis Index, demonstrates which stations are most similar by measuring the taxonomic proportional abundances between stations. The PSI can be either sample size dependent or sample-size independent, depending on the transformation and/or standardization applied to the data prior to calculating the PSI. A PSI computed using actual abundances is sample-size dependent, but a PSI computed using log-transformed abundances is less so (S. Bloom 1994 personal communication).

Abundance data for the station replicates were pooled, and the PSI was calculated for log-transformed $[\ln(x+1)]$ data. The PSI was calculated using epibenthic taxa identified to genus and species. A dendrogram was generated that shows the similarity/dissimilarity between the Project and background stations for all three sampling events combined. Results of the PSI analysis were presented along with appropriate information that may affect the similarity/dissimilarity between the two stations, including habitat characteristics and features, physical characteristics, and community composition as it relates to dominant taxa.

The following is the formula for the Proportional Similarity form of the Bray-Curtis Index:

$$PS_{jk} = \frac{2x \sum_{i=1}^s \min(x_{ij}, x_{ik})}{\sum_{i=1}^s (x_{ij} + x_{ik})}$$

Where:

PS_{jk}	=	The proportional similarity between samples “j” and “k”
x_{ij}	=	The number of individuals in taxon “i” for sample “j”
x_{ik}	=	The number of individuals in taxon “i” for sample “k”
S	=	The total number of taxa across all samples

Note: x_{ij} and x_{ik} may be transformed $(\ln[x+1])$ or standardized in some way prior to calculating the PSI (Bloom 1990).

6. MACROPHYTE MONITORING METHODS

6.1 DATA COLLECTION

To assess the relative abundance, density, and composition of algae that have colonized the Project site, the intertidal areas were examined by a biologist for macrophytes during a low tide in July. The on-site inspections included notation of extent, density, and general location of all macrophyte beds on the Project. A species list was generated for each macrophyte bed with the aid of several field guides to marine algae of the region (Kozloff 1973; Scagel 1971; Waaland 1977). The presence and general extent of hard substrate within each bed was also noted. Examination of the subtidal areas of the cap were made during the lowest point of the low tide to visually verify the presence or absence of subtidal macrophytes.

A low-altitude color aerial photograph of the Project was taken during a low tide in July. The photograph was taken using a standard 9 x 9 inch aerial camera with true color Kodak 2448 Aerochrome MS film (or an equivalent) from a sufficiently low altitude to yield a scale of 1 inch = 100 feet. The photograph was blown up to approximately 24 x 36 inch size for easier examination. From this photograph, the extent of each macrophyte bed was mapped.

6.2 QA/QC AND LABORATORY ANALYSIS

No laboratory analysis took place as a part of the macrophyte monitoring. QA/QC procedures consisted of independent verification by a second biologist of at least one specimen of each macrophyte species identified at the site. Estimates of macrophyte density and substrate composition were compared to verify that both biologists were noting the same features with similar results. The use of a standard aerial camera and specified color film was verified with the aerial survey crew before and after the aerial photograph was taken.

6.3 DATA ANALYSIS

The general composition, type, and extent of each macrophyte bed recorded was described in the Results section of the Monitoring Report. A map of the macrophyte beds was generated from the aerial photograph with verification from field notes. The composition of macrophytes on the Project was compared to previous years' results, and qualitatively observed trends were reported.

7. MODIFICATIONS TO THE MONITORING PLAN

7.1 CHEMICAL MONITORING

In 1993 and 1998, the Simpson Tacoma Kraft Company and Champion International reviewed the previous years of chemical monitoring data collected at the Project. Following this review Simpson and Champion proposed some changes to the chemical monitoring activities outlined in the Monitoring Plan.

The chemical data review and the proposed Monitoring Plan changes were described in technical proposals submitted to EPA (Parametrix 1993 and 1998). After EPA and the consulted agencies reviewed the proposals—and revisions to the draft document—EPA accepted the proposed changes to the Monitoring Plan.

The chemical data review indicated that the Project is functioning as designed. Every year since Project construction in 1988, all biological and physical components have been monitored annually. In four of the last seven years, surface sediment sampling was performed, and subsurface sediment chemistry was performed seven times since project construction. Gas vent sampling was conducted in 1989, 1991, and 1992, and intertidal seep sampling was conducted in 1991 and 1993.

Over the nine years of the monitoring, of a possible 5,188 chemical detections, only 39 detections above early warning levels have been found in subsurface core samples. Detected chemicals were found deep below the surface of the cap in three of the cores. Subsequent year's data indicated that chemicals found in all three of the cores were staying in place deep below the cap. Over the seven years of surface sediment monitoring, of a possible 2,805 chemical detections, only nine detections above early warning levels were found in surface samples. Similarly, gas vent samples have shown no detections above early warning levels; intertidal seeps have had only 5 detections above early warning levels out of 355 possible chemical detections. In all cases, EPA determined that no further action was necessary and that the Project was functioning as designed.

Following review by EPA, the following modifications were made to the Monitoring Plan during 1993:

- Cores are taken at six stations (instead of twelve).
- Gas vents will not be sampled unless other chemical detections in nearby cores or surface sediment samples indicate that vents may be acting as a chemical pathway.
- Seep sediments (but not water) will be sampled in 1993 and will be sampled thereafter if other sampling indicates seeps may be acting as a chemical pathway.
- Dioxin monitoring will include summaries of effluent dioxin monitoring results from the mill but will no longer be included in Project sampling.

Following review by EPA, the following additional modifications were made to the Monitoring Plan during 1998:

- Cores are taken at four stations.
- Surface sediment samples are taken at three stations.
- Analyses requirements for surface sediments are revised to only include phenol compounds, phthalate compounds, resin acids, and guaiacol.

The modified monitoring will meet all objectives defined in the Monitoring Plan. As described in the introduction to the Monitoring Plan, the following five tasks are performed to ensure cap integrity:

1. Identify any cap erosion and assure adequate cap depth
2. Identify any physical mixing of underlying sediments and cap sediments which might pose a threat to cap integrity
3. Identify any diffusion of chemicals upward through the cap
4. Determine whether vents and seeps are vehicles for surface contamination
5. Determine whether surface contamination is occurring from other sources

A BIOLOGICAL INDICATORS APPROACH

The Monitoring Plan requires that Simpson and Champion establish biological indicators to be used in assessing the health of the Project habitat. The Monitoring Plan also states that after EPA review and approval of the biological indicators, they will be included in future biological monitoring at the Project.

Biological indicators were included in the Monitoring Plan to assure that the Project habitat has been restored to support a productive biological community. Biological indicators are also part of the early warning process and performance monitoring that is required in the Monitoring Plan. The biological indicators were intended to become the primary indicators of change and are now used in the early warning process, if necessary.

As presently described in the Monitoring Plan, the early warning process consists of the physical, chemical, and biological criteria used to identify potential problems associated with cap integrity or biological recovery of the Project habitat. The early warning process was designed to identify potential problems early enough to conduct a rational and deliberate study to determine whether there is, in fact, a problem, and if so, to determine how serious the problem may be. Physical early warning levels include minimum depths of clean cap sediment that must remain in place over the underlying contaminated sediments. Chemical early warning levels include specific chemical concentrations that should not be exceeded in clean cap sediments. Both physical and chemical early warning levels have been used to determine the health and integrity of the Project over the last seven years.

Now that biological indicators are established, sediment chemical monitoring will become a less important factor in the early warning process as chemical monitoring (conducted over the last seven

years) indicates the Project cap is functioning effectively. The emphasis on biological indicators as the primary criteria of the early warning process is reflected in the monitoring schedule for the Project which calls for a reduction in chemical monitoring five years after Project construction.

In order to develop the biological indicators, the advice of many experts was sought, and the previous five years of site-specific benthic infauna data were thoroughly reviewed. Biological indicators were proposed in 1994 because sufficient information on the Project habitat was available. The biological indicators approach may be reviewed and refined in the future. The Monitoring Plan anticipates this need and calls for an adaptive approach to biological indicators.

Several steps were taken to develop biological indicators. First, Parametrix surveyed approximately 60 scientific experts across the United States to identify any previous use of a concept similar to biological indicators. It was found that although the concept of either a biological indicator or a suite of biological indicators is a simple one, in practice such indicators have seldom been used. Because of the diversity of ecosystems and biota, there is no scientific agreement as to which characteristics of biological communities should be considered, or what levels of change in these characteristics should be considered detrimental.

The second step in developing biological indicators was to examine existing data from the Project. This wide variety of past information was used in building a suite of analytical processes using biological data that allow observations of biological change at the Project.

The third step was to examine existing site-specific data to determine whether there were statistical limitations that might be expected in future data analyses. Quantitative analyses of benthic infauna, as well as other ecological systems, are generally statistical in nature. As a result, when developing biological indicators, some of the assumptions, properties, and limits of the applicable statistical analyses have been reviewed to ensure that statistics are properly applied.

Following the above analysis, a two-tiered biological indicators approach was created. Chapter 4 of the Methods Appendix describes analytical and statistical methods that are used in this approach. The statistical tests employed were chosen because they have the statistical power to provide valuable information when considering biological indicators.

Within Tier One of the biological indicators approach, there are two levels of analyses. Tier One, Level One, involves assessing similarity of benthic community structure between the Project stations and background stations using several types of factors:

- Total number of taxa for each station
- Numbers of numerically-dominant taxa
- Numbers of non-dominant taxa
- Total abundance of all individuals from each station
- Standing crop analysis (biomass)

These factors will be analyzed using:

- Proportional similarity index (PSI)
- Principal coordinate analysis (PCOR) and

- Analysis of Variance (ANOVA)

The use of Principal Coordinate (PCOR) analysis was discontinued in 1997 (USEPA 1997).

Tier One, Level Two, includes comparisons of benthic data from the most recent year to that of the previous year for Project and background stations. Such comparisons help confirm differences and similarities observed over time at the Project, and confirm that observed changes are not the result of changes in the background stations as opposed to the Project stations.

If any significant differences are found in any one of the Tier One analyses, EPA will receive a notification letter detailing those differences, and Tier Two biological indicators will be conducted. Tier Two analyses will focus on ecological interactions at the Project, and assess whether any significant changes are due to natural or anthropogenic causes. The Tier Two indicators will compare Project and background abundances of trophic guild taxa, key species, and pollution-sensitive or -tolerant taxa.

If significant changes in the fauna of the Project habitat appear to be due to anthropogenic causes, early warning will be triggered and the contingency planning process will be considered by EPA. If significant changes appear to be due to natural causes, EPA will be notified, but the early warning will not be triggered. As set forth in the Monitoring Plan, investigations or actions under contingency planning will be determined jointly by Champion, Simpson, and EPA.

The biological indicators approach was implemented for the first time in 1994 as required by the Monitoring Plan. Consequently, data analyses in Chapter 4 of the Monitoring Report are somewhat different from previous years' reports.

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