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# Marine Sediment Monitoring Program

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# PUGET SOUND AMBIENT MONITORING PROGRAM
# MARINE SEDIMENT MONITORING TASK
# ANNUAL REPORT
# 1990

by

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# ABSTRACT

The 1990 Marine Sediment Monitoring Task was conducted by the Washington State Department of Ecology in conjunction with the Puget Sound Water Quality Authority and other state agencies as a component of the Puget Sound Ambient Monitoring Program. This report includes sediment chemistry and amphipod bioassay data from 50 stations and benthic infauna community data from 35 stations.

The top two centimeters of sediment from three to five grab samples at each station were composited, homogenized, and analyzed for toxicity using amphipod bioassays, and for the presence of metals, semi-volatile and volatile organic compounds, and pesticides/PCBs. Five replicate grab samples were collected at each station for analysis of benthic infaunal communities as well.

Sediments from Stations 34 (Sinclair Inlet) and 35 (Dyes Inlet) exceeded state sediment quality standards for mercury. Concentrations of metals from all other stations were below state standards.

The highest concentrations of volatile organic compounds were found at Station 5 in Samish Bay and Station 38 in East Passage.

Concentrations of low and high molecular weight polycyclic aromatic hydrocarbons (PAHs) were highest at Station 40 at the mouth of City Waterway. When normalized to total organic carbon, the concentration of LPAHs at Station 40 exceeded state standards. Concentrations of beta-coprostanol were highest at Station 41 adjacent to the Tacoma wastewater outfall. One base and two acid extractable compounds were detected above quantitation limits, but no concentrations of these compounds were above state standards. The PCB Aroclor 1254 was detected at Stations 12 (Port Townsend) and 33 (Elliott Bay). With the exception of p,p'-DDE at Station 33, no pesticides were detected.

After factoring in the effect of grain size, sediment from three stations {(Stations 20 (Port Susan), 43 (Carr Inlet), and 105R (Outer Eld Inlet)} in the 1990 survey were characterized as toxic from the results of amphipod bioassay analysis.

Total abundance of benthic infauna (which did not pass through a 1.0mm mesh sieve) ranged from 66.3 at Station 3 (Strait of Georgia) to 2184.3 at Station 41 (Blair/Sitcum Waterways) and the number of taxa ranged from 14 at Station 3 to 92 at Station 47 (Case Inlet). Decreased abundances of pollution tolerant species and increased diversity at Stations 30 (Eagle Harbor), 33 (Elliott Bay), and 40 (City Waterway) may indicate improving conditions for benthic infauna at these stations.

ACKNOWLEDGMENTS

This report was prepared by the Washington State Department of Ecology, Puget Sound Sediment Monitoring Unit. Field sampling, analysis of benthic infauna samples, and all data analyses were performed by Department of Ecology personnel. Analyses of sediment chemistry and sediment toxicity test samples were managed by PTI Environmental Services; chemical analyses were performed by Analytical Resources, Inc. and bioassay analyses were performed by Parametrix, Inc.

Contributors to the 1990 MSMT are listed below.

Department of Ecology

| | |
|---|---|
| Mr. Peter Striplin | Project manager, program design, field sampling chief scientist, benthic infauna rescreening, benthic infauna sorting, QA/QC officer, polychaete, mollusk and misc. phyla taxonomist, technical review, data analysis, report preparation |
| Ms. Pamela Sparks-McConkey | Benthic infauna sorting, arthropod taxonomist, data management and analyses, report preparation |
| Mr. Dale Davis | Field sampling cruise leader, field cruise summary report, benthic infauna rescreening, benthic infauna sorting, trainer of new sorters, polychaete taxonomist, report preparation |
| Ms. Fern Svendsen | Benthic infauna sorting, data entry |
| Ms. Anne Clingman | Field sampling, benthic infauna rescreening, benthic infauna sorting |
| Mr. Richard Cunningham | Technical assistance, report editing, benthic infauna sorting |
| Ms. Carol Janzen | Field sampling |
| Mr. John Tooley | Graphics Preparation |

Bio-Marine Enterprises

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| Mr. Charles Eaton | Skipper of R/V KITTIWAKE |

Marine Taxonomic Services

| | |
|---|---|
| Mr. Howard Jones | Quality control taxonomist |

Chemical and Bioassay Analysis Services

| | |
|---|---|
| PTI Environmental Services | Contract with Department of Ecology to manage chemical and bioassay analyses |
| Analytical Resources, Inc. | Subcontract with PTI to perform sediment chemistry analysis for metals, volatile and semivolatile organic compounds, pesticides and PCBs, TOC, total sulfides, total solids, and grain size |
| Parametrix, Inc. | Subcontract with PTI to perform sediment toxicity tests |

# INTRODUCTION

This report is the second annual report of the Marine Sediment Monitoring Task (MSMT). Marine sediment monitoring in Puget Sound is conducted by the Washington State Department of Ecology (Ecology) Ambient Monitoring Section, and is a major component of the multiagency Puget Sound Ambient Monitoring Program (PSAMP) [Puget Sound Water Quality Authority (PSWQA) 1988].

The PSAMP was developed by an interdisciplinary committee of water quality professionals known as the Monitoring Management Committee (MMC). The PSAMP was designed to be a long-term monitoring program implemented by several state agencies to provide an exhaustive baseline characterization of the condition of Puget Sound. Results from the PSAMP are available for use by any interested party. The PSAMP is coordinated by a steering committee that is composed of representatives of the lead participating agencies.

The Marine Sediment Monitoring Task was designed to identify both natural and man-induced changes in Puget Sound sediments by determining levels of contamination by organic compounds and heavy metals, toxic effects due to contaminants on bioassay organisms, and effects of contaminants on benthic macroinvertebrate communities. The MSMT goals and a list of more specific objectives can be found in the Implementation Plan for the sediment task (Striplin, 1988). The Implementation Plan is an expanded Quality Assurance Project Plan (QAPP) which describes the rationale, methods, QA/QC requirements, and data quality objectives for the sediment task.

Under contract with the Department of Ecology, the 1989 MSMT was performed by Tetra Tech, Inc., of Bellevue, Washington. In 1990, the second year of the MSMT, staff were added within the Ecology Ambient Monitoring Section to manage and carry out the task. Field sampling, benthic infauna sample processing, and all data analysis and report preparation were completed by Ecology personnel. Handling and processing of chemical and bioassay samples were contracted out by Ecology to PTI Environmental Services (PTI) Bellevue, WA. Chemical laboratory services and sediment toxicity tests were subcontracted by PTI to Analytical Resources, Inc. (ARI) of Seattle, Washington and Parametrix, Inc. of Bellevue, Washington, respectively.

The report prepared by Tetra Tech for the 1989 MSMT survey is exhaustive and covers the program in detail. Because the 1990 MSMT was performed in the same manner as the 1989 program, it was determined that another extensive document covering essentially the same material was unnecessary. Consequently, many parts of this report refer to the 1989 MSMT report (Tetra Tech, 1990) and to the implementation plan (Striplin, 1988) for additional detail of sampling and analysis procedures.

For the 1990 MSMT, a total of 50 stations were sampled throughout Puget Sound (Figures 1A and 1B). Of these 50 stations, 31 were sampled in 1989 and will be sampled in all future MSMT surveys. The following adjustments were made to the core network in 1990: Stations 70 (Inner Shelton Harbor) and 71 (Fidalgo Bay), replaced Stations 50 (Shelton) and 6 (Anacortes) respectively, because the PSAMP Steering Committee believed that data from deeper in the embayment would better reflect the ambient conditions of the embayment. Station 69 in Port Madison was added because it is a station established by Dr. Fred Nichols in 1969 and has been sampled continually since then. The continued sampling of this historical station will enable the MSMT to add a considerable amount of data for trend analysis. This brings the total number of core stations to 34. The remaining sixteen (non-core) stations sampled in 1990 are rotating stations located in South Puget Sound. These will be sampled once every three years on a rotating basis with north and central Puget Sound, through the initial five year phase of this Sediment Monitoring Program.

The data used to prepare this report include sediment chemistry and amphipod bioassay data from all 50 stations and benthic macroinvertebrate community data from the 34 core stations. Benthic macroinvertebrate data from the rotating station 46R was used in this analysis because the station was sampled in 1989.

## METHODS

### Field Sampling

Field sampling for the 1990 MSMT was conducted from March 12 to March 30, 1990. Samples were collected from the Research Vessel Kittiwake, owned and operated by Mr. Charles Eaton, of Seattle, Washington.

Station positioning was accomplished using LORAN C, variable radar ranging, water depth, and line-of-sight fixes on land objects (PSEP, 1986a). Latitude and longitude coordinates determined by LORAN C were used to establish positions of new stations. Positioning data were recorded for all stations and are contained in the cruise summary report (Ecology, 1990) which is provided as Appendix A.

On completion of field work, station positions as determined by variable radar ranges were compared to latitude and longitude coordinates on nautical charts. This was done to determine if interference from points, headlands, or radio towers had caused large scale jumps in the LORAN signal which would have led to inaccurate latitude/longitude positions. The final position check was to compare the water depths recorded in the field to those on the nautical charts.

Sediment samples were collected using a double 0.1 $m^2$ stainless steel modified van Veen grab sampler. Sampling procedures followed the Puget Sound Protocols (PSEP, 1986b) and the Marine Sediment Quality Implementation Plan (Striplin, 1988), with the exceptions noted below.

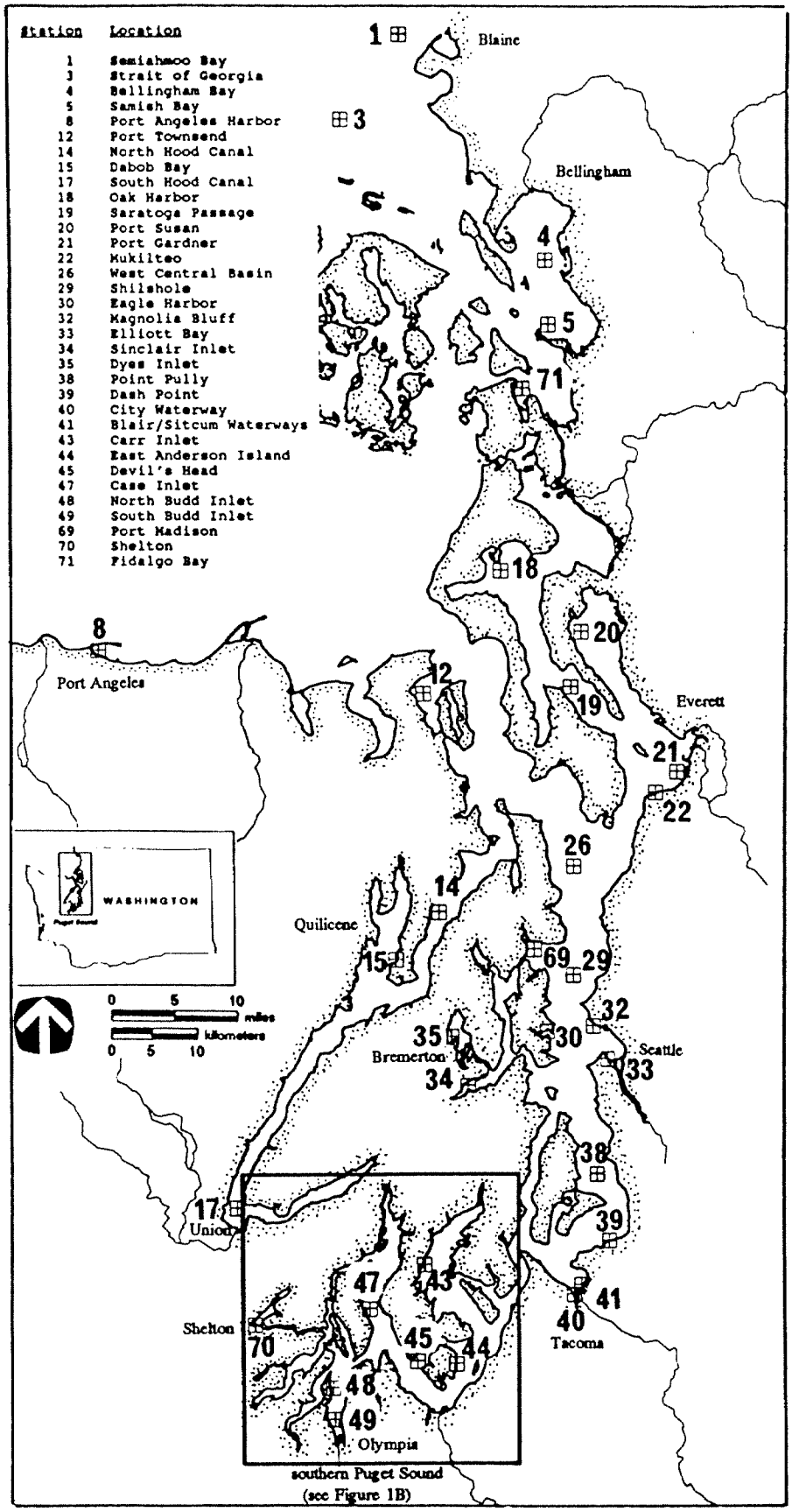



Figure 1A. Locations of the 34 core (fixed) station in Puget Sound for the 1990 marine sediment monitoring task (MSMT).

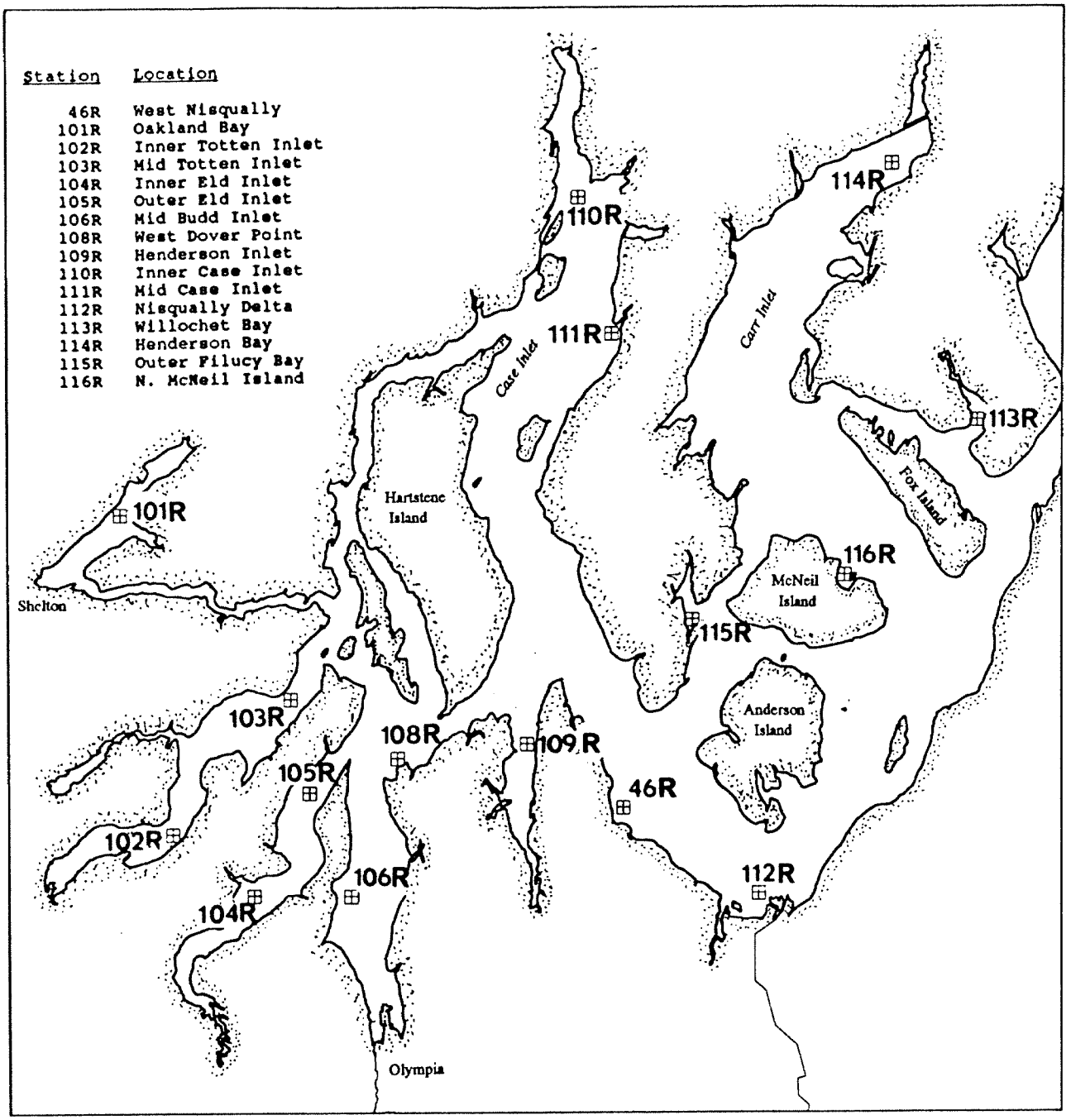



Figure 1B. Locations of the rotating station in southern Puget Sound for the 1990 marine sediment monitoring task (MSMT).

Sampling equipment was decontaminated between stations and between composites at stations where environmental variability was measured. With the exception of utensils used to collect sediment for analysis of volatile organic compounds, decontamination involved the following steps: an Alconox® soap wash of all equipment at the laboratory; in the field, utensils were given a methylene chloride rinse, an acetone rinse (allowed to air dry), and an on-site seawater rinse. The utensils used to take sediment samples for analysis of volatile organic compounds were washed with Alconox®, rinsed with boiling fresh water, and then rinsed with organic free water. The utensils were wrapped with aluminum foil and stored away from both organic solvents, diesel fumes, and the rest of the sample handling equipment.

A list of the types of samples taken at each station are provided in Appendix A.

Sediment samples for sediment chemistry and bioassays were collected at 50 stations. In addition, two types of field generated quality control samples (blind laboratory replicates and blind field replicates) were collected at five stations (Stations 5, 32, 35, 38, and 44). Blind laboratory replicate samples were generated by splitting composited and homogenized sediment from the same group of grab samples; one split was assigned the field station number and the other split was assigned an artificial station number. Blind field replicates were generated by taking two separate sets of composited/homogenized sediment samples and assigning each set an artificial station number.

At each station where replicate sediment samples were collected for chemical analysis, a small quantity of sediment was collected for laboratory matrix spike (MS) and matrix spike duplicate (MSD) analyses. Archived sediment samples from Sequim Bay were obtained from the Environmental Protection Agency's Manchester Laboratory, transferred to MSMT sample containers, and submitted for analysis as Stations 66, 67, and 68. These Project Comparison Samples (PCS) contain known quantities of target chemicals and are used each year to measure the accuracy of the laboratory analyses.

**Laboratory Analysis**

Sediment chemistry samples were analyzed in accordance with the U.S. Environmental Protection Agency (EPA) Contract Laboratory Program (CLP) methods (U.S. EPA, 1986a,b) as modified by the Puget Sound Protocols (PSEP, 1986c,d,e) to obtain lower detection limits. When the routine EPA CLP purge-and-trap protocol for analysis of volatile organic compounds did not detect any volatile compounds, the samples were reanalyzed using a "super VOA method" that uses a larger sample size to provide lower detection limits (Tetra Tech, 1990). This is a departure from the 1989 MSMT when all sediment samples for volatile organic analyses were run using the "super VOA method."

The method used to analyze total sulfides during the 1989 MSMT was erroneously not used during the 1990 MSMT. Total sulfides were found in many samples in 1989 using the spectrometric method specified by Puget Sound Protocols (PSEP, 1986e). The titration method

(involving use of a standardized phenyl arsine oxide solution to titrate and standardize an iodine solution) used for the 1990 MSMT resulted in few samples having detectable sulfide concentrations. Due to the different analytical methods used in 1989 and 1990, the data cannot be compared, thus no analysis has been conducted.

Sixty-five sediment samples (50 field stations, 5 split blind laboratory replicates and 10 blind field replicates) were tested for sediment toxicity using the 10-day amphipod (*Rhepoxynius abronius*) bioassay (PSEP, 1986f).

Due to the number of sediment samples that had to be tested for toxicity, four series of tests were run. Each series consisted of five analytical laboratory replicates of each test sample, a negative control using clean sediments from West Beach (Whidbey Island, Washington) and a positive control. A positive control is a test using a reference toxicant ($CdCl_2$) to evaluate the sensitivity of the test animals (PSEP, 1986f).

Benthic infaunal samples were processed according to the Puget Sound Protocols (PSEP, 1987) and the MSMT implementation plan (Striplin, 1988). All infaunal sample processing and analyses were performed by Ecology Ambient Monitoring staff. In a deviation from the protocol, only three of the five benthic replicates were sorted and identified in the 1990 survey due to staff shortages. Of the 50 stations sampled, only the first three replicates of the 34 core stations and the rotating station 46R have been processed for inclusion in this report. Data from the rotating station 46R is included in this analysis because it was sampled and analyzed during the 1989 MSMT survey. The remaining 15 stations and replicates four and five of all samples will be processed and data reported at a later date.

## RESULTS

### Sediment Chemistry

#### Quality Assurance/Quality Control

Sediment chemistry data were validated according to the *Laboratory Data Validation, Functional Guidelines for Evaluating Inorganics Analyses* (U.S. EPA, 1988a) and *Laboratory Data Validation, Functional Guidelines for Evaluating Organics Analyses* (U.S. EPA, 1988b). A statistical analysis of method blanks was the only deviation from the Functional Guidelines. The quality assurance/quality control (QA/QC) reviews included assessments of sample holding times, initial and continuing instrument calibration checks and tuning, blank results, interference check samples (MS/MSD), accuracy (PCS, MS/MSD, and surrogate recoveries), and precision (using blind laboratory and field replicates). Quality assurance reviews for the conventional variables followed Puget Sound Protocols (PSEP, 1986e).

#### Conventional Variables

A detailed quality assurance review of the conventional parameters is found in the *Puget Sound Ambient Monitoring Program Quality Assurance Reviews of Chemical and Bioassay Analyses*, (Appendix B) (PTI, 1991). The measured parameters included: sediment grain size, total

organic carbon, total sulfides, and total solids. All data with the exception of the total sulfides were acceptable as qualified (Appendix B). The total sulfides data were rejected due to severe holding time violations, analysis of an insufficient sample size, and use of the incorrect analytical method.

Metals

The metals data were acceptable as qualified in the QA memorandum (Appendix B). All but two stations were qualified as rejected for antimony due to poor accuracy based on low recoveries of the matrix spike, matrix spike duplicate and project control samples. All selenium data were also rejected for the same reasons. A detailed quality assurance review can be found in Appendix B (PTI, 1991).

Organic Compounds

**Volatile Organics**-- The data for volatile organic compounds are acceptable as qualified in the quality assurance review. The analytical data for acetone, methylene chloride, and 2-butanone should be used with caution due to possible cross contamination from the cleaning of sampling equipment. Methylene chloride contamination of the double van Veen sampler occurred prior to sampling at Station 29. Therefore, methylene chloride values from this station have the data qualifier "R" (unusable value) and should not be used in any analysis of data. A full review of data quality can be found in Appendix B (PTI, 1991).

**Semivolatile Organics**-- All data from 47 of the 68 samples were qualified as estimates ("E" qualifier) due to holding time violations. An "E" qualifier is given to a data point for a number of reasons. The data are still acceptable and useful for analysis, but not as much confidence can be placed in the data point compared to unqualified data. Holding times were violated because an insufficient amount of sediment was used for analysis (30 grams as opposed to 150 grams). Upon discovery of the error, the analytical laboratory reanalyzed the sediment, however holding times had been greatly exceeded (from 48 to 52 days). A statistical comparison of the results between the 30 gram extracted sample and the 150 gram extracted samples was conducted to determine if there were significant differences in chemical concentrations between the two extractions. If significant differences did occur, it would have indicated that the sample had degraded to the point of being unusable. All data would then be rejected. The results indicated that except for four samples, there was no consistent evidence of positive or negative bias between the 30 gram samples analyzed initially and the 150 gram samples analyzed later. The four samples in which there was evidence of positive bias for the higher molecular weight compounds (e.g., phenanthrene and anthracene), were from Stations 40 (City Waterway), 68 (Project Comparison Sample), 70 (Inner Shelton Harbor), and 102R (Inner Totten Inlet). Therefore, data from these four samples were rejected due to a greater than 50 percent decrease in concentration from the initial analyses, and data from the initial analyses were accepted. A detailed examination of the QA procedure and their results is found in Appendix B (PTI, 1991).

**Pesticides and Polychlorinated Biphenyls--** All pesticide and polychlorinated biphenyl (PCB) data are acceptable as qualified. A detailed examination of the QA procedure is found in Appendix B.

Results

Conventional Variables

**Sediment Grain Size--** Sediment grain size is a physical measurement of the range of sediment particles that make up a given sample. There are two main components: first, large diameter particles or coarse sediment grains (gravel and sands) are measured by shaking a known quantity of the sample through a series of sieves of different sizes, and weighing the resulting fractions; and the second is a measure of the settlement rate of fine grained sediment (silt and clay) using a pipette or hydrometer technique. The rate that silt and clay particles settle in a chamber is directly related to the size of the particle. In the 1990 MSMT survey, the more accurate pipette technique was used. Grain size directly influences the concentration of chemical contaminants in sediments (sediments with smaller grain sizes tend to have greater chemical concentrations) and the structure and function of the associated benthic infaunal communities. The distribution of fined grained sediment (i.e., silt plus clay) at each station is shown in Figure 2A. Stations with higher percentages of silt and clay (i.e., percent fines) were found in small shallow embayments and in the deep basins of the Sound, while the coarser sediments were found along the open shorelines. Percent fines ranged from one percent at Station 112R in the Nisqually Delta to a high of 98 percent at Station 104R in Inner Eld Inlet (Appendix C).

**Total Organic Carbon--** Total organic carbon (TOC) is a measure of the total amount of particulate and non-particulate organic carbon associated with a particular sediment sample. As with grain size, the amount of TOC can have a significant effect on the concentration of chemical contaminants in sediments and on the type of benthic infaunal community at a station. The TOC of MSMT sediment samples ranged from 0.62 to 4.0 percent (Figure 2B and Appendix C). The lowest concentration was found in the Nisqually Delta (Station 112R) and the greatest at the head of Oakland Bay (Station 101R) near Shelton. Typically, low concentrations occurred in exposed areas where fast tidally induced water currents do not allow organic material and fine particulates to settle. The highest TOC concentrations were found in shallow quiet embayments.

There is a fairly good correlation between percent fines and percent TOC ($r^2=0.67$ df=48). However, the relationship appears to be bimodal. The correlation between the two variables is greater for percent fines less than 80 percent ($r^2=0.71$, df=27) while the $r^2$ value at stations with greater than 80 percent fines was 0.04. There was no significant relationship between either percent fines or TOC with water depth.

**Interannual Variability of Grain Size and Total Organic Carbon--** Substantial differences in percent fines and TOC between 1989 and 1990 were seen at 11 of the 50 stations sampled. The relative percent difference (RPD) between the two years is shown in Table 1. The greatest differences in percent fines were found at Stations 46, 47, and 40 in decreasing order. The relative percent difference for TOC shows seven of nine stations with large differences. The greatest occurred at Stations 14, 41, and 33 in decreasing order.

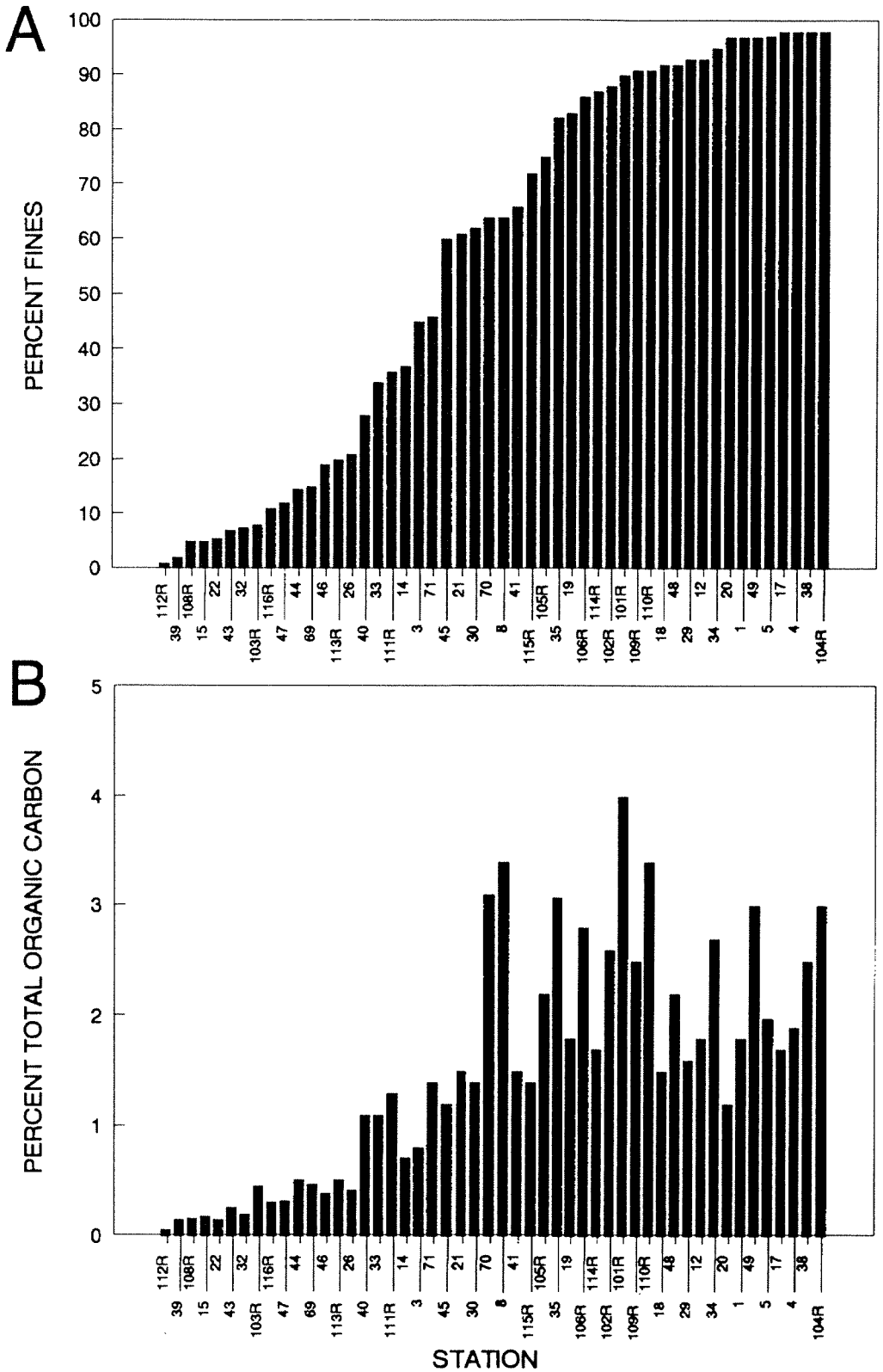



Figure 2. Percent fines (A) and percent total organic carbon (B) in sediments at 1990 MSMT stations.

Table 1. Stations with largest relative percent differences (RPD) for percent fines and TOC between the 1989 and 1990 surveys.

| STATION | 1989 | 1990 | RPD |
|---|---|---|---|
| PERCENT FINES | | | |
| 35 | 78.9 | 82.3 | +4.2 |
| 41 | 81.1 | 66.0 | -20.6 |
| 26 | 15.7 | 21.0 | +29.0 |
| 14 | 27.6 | 37.0 | +29.1 |
| 3 | 32.6 | 45.0 | +31.8 |
| 33 | 24.0 | 34.0 | +34.0 |
| 18 | 60.2 | 92.0 | +41.9 |
| 15 | 8.2 | 5.0 | -48.7 |
| 40 | 15.6 | 28.0 | +56.7 |
| 47 | 23.5 | 12.0 | -64.7 |
| 46 | 9.5 | 19.0 | +66.8 |
| TOTAL ORGANIC CARBON | | | |
| 46 | 0.42 | 0.39 | -7.4 |
| 47 | 0.29 | 0.32 | +9.8 |
| 26 | 0.42 | 0.54 | +25.0 |
| 15 | 0.24 | 0.18 | -28.6 |
| 35 | 2.3 | 3.1 | +28.7 |
| 3 | 1.2 | 0.81 | -38.8 |
| 40 | 0.7 | 1.1 | +44.4 |
| 33 | 0.64 | 1.1 | +52.9 |
| 18 | 0.93 | 1.5 | +46.9 |
| 41 | 0.8 | 1.5 | +60.9 |
| 14 | 0.35 | 0.72 | +69.2 |

Metals

Sediments at all stations were examined for 23 metals (Appendix C). The concentrations of metals at stations located away from known sources of contamination were generally low (Table 2). Of all the metals analyzed for in the survey, only mercury was found at concentrations that exceeded the state sediment quality standards (0.41 mg/kg dry weight). The two stations where the concentration of mercury exceeded the standards were Stations 34 (Sinclair Inlet), and 35 (Dyes Inlet). The greatest concentration (0.87 mg/kg) was found at Station 34, while Station 35 had a concentration of 0.59 mg/kg. Zinc, at a concentration of 147 mg/kg, was also highest at the Sinclair Station. Station 35 in Dyes Inlet had the greatest concentrations of copper and lead at 209 mg/kg and 68.9 mg/kg, respectively. Cadmium was found in 56 of the 65 samples analyzed. The greatest concentration was found at the Inner Carr Inlet Station (114R, 1.67 mg/kg). The highest concentrations of chromium and nickel were found at Station 20 (112 and 127 mg/kg, respectively) in Port Susan. High concentrations of chromium and nickel were also found at Station 20 in 1989. The greatest concentration of arsenic (29.3 mg/kg) was found at Station 17 in South Hood Canal.

**Interannual Variability in Metals--** Five of the more common contaminant metals of concern in Puget Sound are copper, lead, mercury, cadmium, and zinc. Differences in the concentrations of these metals between 1989 and 1990 are displayed in Figures 3-7. With few exceptions the distribution of these metals in 1990 was similar to that in 1989. The concentrations of copper at most stations were similar between 1989 and 1990, but at Station 8 in Port Angeles and at Station 35 in Dyes Inlet the amounts were twice as great in 1990 as in the previous year (Figure 3). The reverse was seen for lead at Stations 34 (Sinclair Inlet) and 48 (North Budd Inlet) where the concentrations in 1990 were 1/3 and 1/2, respectively, of those seen in 1989 (Figure 4). The concentrations of mercury at MSMT stations varied little between 1989 and 1990. The mean concentration at Station 35 in Dyes Inlet ($n=4$) was 0.06 mg/kg dry weight greater in 1990 than in 1989 (Figure 5). Cadmium was found in greater concentrations in Port Angeles (Station 8) and in South Hood Canal (Station 17) in 1990 than in 1989, but was substantially less at Station 33 in Elliott Bay and at Station 48 (North Budd Inlet) (Figure 6). Differences in the concentration of zinc between the two years were not significant (one-way anova) although the concentrations at Stations 34 (Sinclair Inlet) and 35 (Dyes Inlet) were lower in 1990 (Figure 7).

Organic Compounds

**Volatile Organic Compounds--** Nine volatile organic compounds (VOC) were detected at low concentrations during the 1990 MSMT. The concentrations of methylene chloride should be viewed with caution because of the possibility of contamination from the cleaning of sample handling equipment. This contamination did occur at Station 29 when the new grab sampler was decontaminated with methylene chloride. As a result, the methylene chloride data for that station are rejected and not used in this analysis. The highest concentrations ($\mu$g/kg dry weight) of chloroform (0.33), ethylbenzene (0.74), tetrachloroethylene (0.11), acetone (53),

Table 2. Concentrations of detected metals and organic compounds found in the 1990 MSMT sediment survey. Concentrations are in mg/kg dry weight for metals and $\mu$g/kg dry weight for organic compounds.

| | Range | Frequency of Detection | | Station with Highest Concentration |
|---|---|---|---|---|
| Aluminum | 4840-33700 | 65/65 | 17 | S. Hood Canal |
| Arsenic | 1.1-29.3 | 65/65 | 17 | S. Hood Canal |
| Barium | 9.8-59.5 | 65/65 | 4 | Bellingham Bay |
| Beryllium | 0.2-0.8 | 8/65 | 38 | East Passage |
| Cadmium | <.04-1.67 | 56/65 | 114R | Inner Carr Inlet |
| Calcium | 2150-16200 | 65/65 | 3 | Strait of Georgia |
| Chromium | 9.5-112 | 65/65 | 20 | Port Susan |
| Cobalt | 2.6-22.7 | 65/65 | 17 | S. Hood Canal |
| Copper | 3.8-209 | 65/65 | 35 | Dyes Inlet |
| Iron | 6250-52900 | 65/65 | 17 | S. Hood Canal |
| Lead | 1.6-68.9 | 65/65 | 35 | Dyes Inlet |
| Magnesium | 2150-20000 | 65/65 | 20 | Port Susan |
| Manganese | 75.8-864 | 65/65 | 38 | East Passage |
| Mercury | <.04-**0.87** | 18/65 | 34 | Sinclair Inlet |
| Nickel | 6.0-127 | 65/65 | 20 | Port Susan |
| Potassium | 571-4740 | 65/65 | 38 | East Passage |
| Silver | <0.04-1.43 | 61/65 | 34 | Sinclair Inlet |
| Sodium | 3300-32300 | 65/65 | 110R | Inner Case Inlet |
| Thallium | <0.1-0.7 | 13/65 | 104R | Inner Eld Inlet |
| Vanadium | 13.3-136 | 65/65 | 17 | S. Hood Canal |
| Zinc | 15.8-147 | 65/65 | 34 | Sinclair Inlet |
| Acetone | <2.7-53 | 2/16 | 38 | East Passage |
| 2-Hexanone | 4.4 | 1/16 | 38 | East Passage |
| Bromomethane | 0.86 | 1/16 | 38 | East Passage |
| Carbon disulfide | 0.12-1.8 | 10/16 | 38 | East Passage |
| Methylene chloride | 1.9 | 1/15 | 5 | Samish Bay |
| Chloroform | 0.33 | 1/16 | 38 | East Passage |
| Ethylbenzene | 0.74 | 1/16 | 38 | East Passage |
| Tetrachloroethylene | 0.11 | 1/16 | 38 | East Passage |
| Total Xylene | 5.1 | 1/16 | 38 | East Passage |
| 4-Methylphenol | <10-1100 | 5/65 | 35 | Dyes Inlet |
| Diethyl phthalate | <10-79 | 4/65 | 113R | Willochet Bay |
| Di-n-butyl phthalate | 6 | 1/65 | 103R | Outer Totten Inlet |
| Butly benzyl phthalate | <10-21 | 5/65 | 34 | Sinclair Inlet |
| bis(2-Ethylhexyl) phthalate | <7-740 | 15/65 | 38 | East Passage |
| LPAH | 55-**6300** | 53/65 | 40 | City Waterway |
| HPAH | 67-10000 | 59/65 | 40 | City Waterway |
| Benzoic acid | <24-75 | 2/65 | 4 | Bellingham Bay |
| Dibenzofuran | <10-48 | 4/65 | 40 | City Waterway |

Table 2. (Continued).

| | Range | Frequency of Detection | | Station with Highest Concentration |
|---|---|---|---|---|
| b-Coprostanol | <21-660 | 3/65 | 41 | Blair/Sitcum WW |
| 9(H) Carbazole | <10-51 | 2/65 | 30 | Eagle Harbor |
| Aroclor 1254 | <10-28 | 2/65 | 33 | Elliott Bay |
| p,p'-DDE | 22 | 1/65 | 33 | Elliott Bay |
| Abietic acid | <460-630 | 2/3 | 8 | Port Angeles |
| Dehydroabietic acid | <110-730 | 2/3 | 8 | Port Angeles |
| Isopimaric acid | 120-410 | 2/3 | 8 | Port Angeles |
| Neoabietic acid | 150 | 1/3 | 8 | Port Angeles |
| Palustric acid | 130 | 1/3 | 8 | Port Angeles |
| Sandaracopimaric acid | 87 | 1/3 | 8 | Port Angeles |

Bold type indicates that the value exceeded the Washington State Quantitative Standards for Marine Sediments.

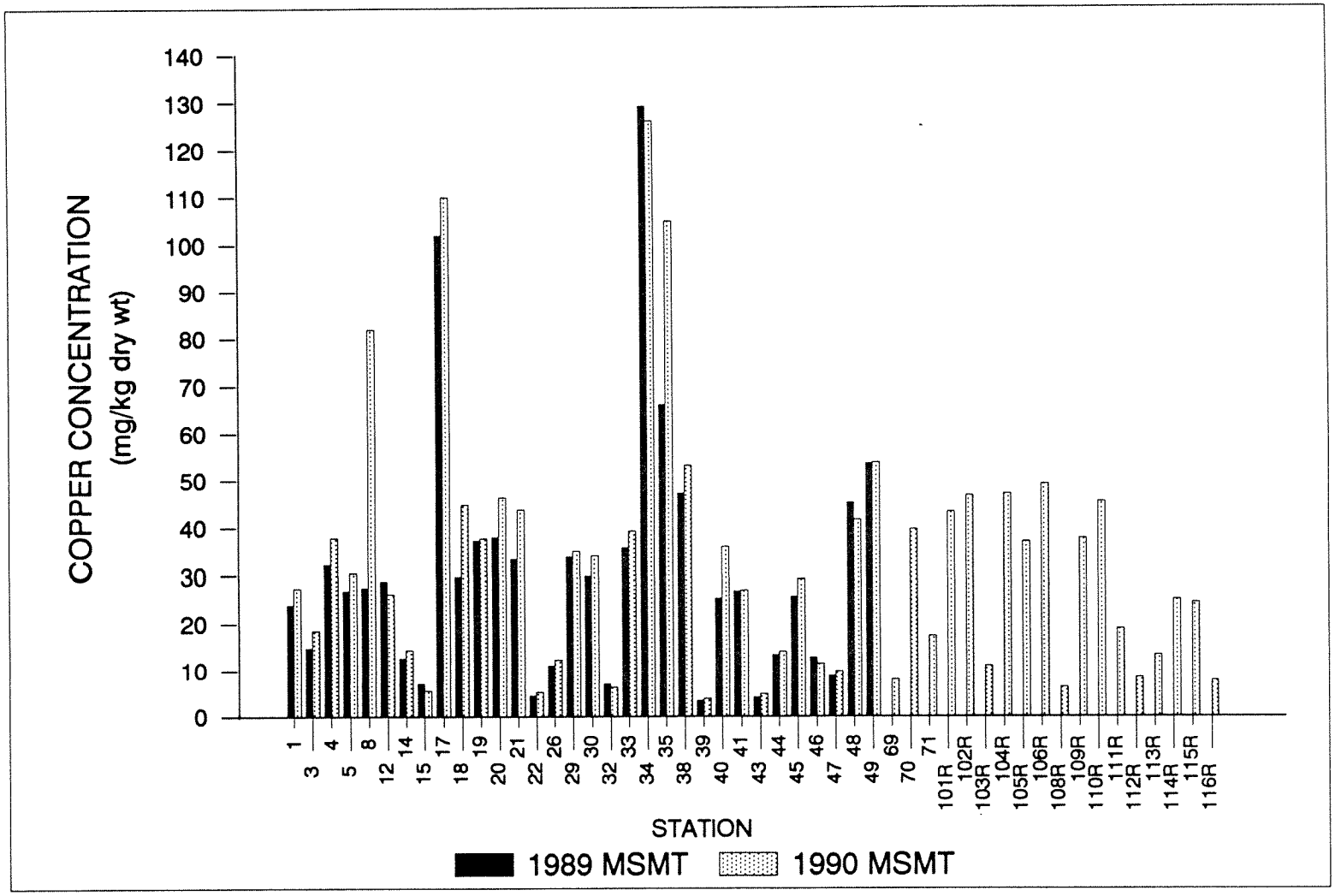



Figure 3. Concentration of copper (mg/kg dry weight) at 1989 and 1990 stations.

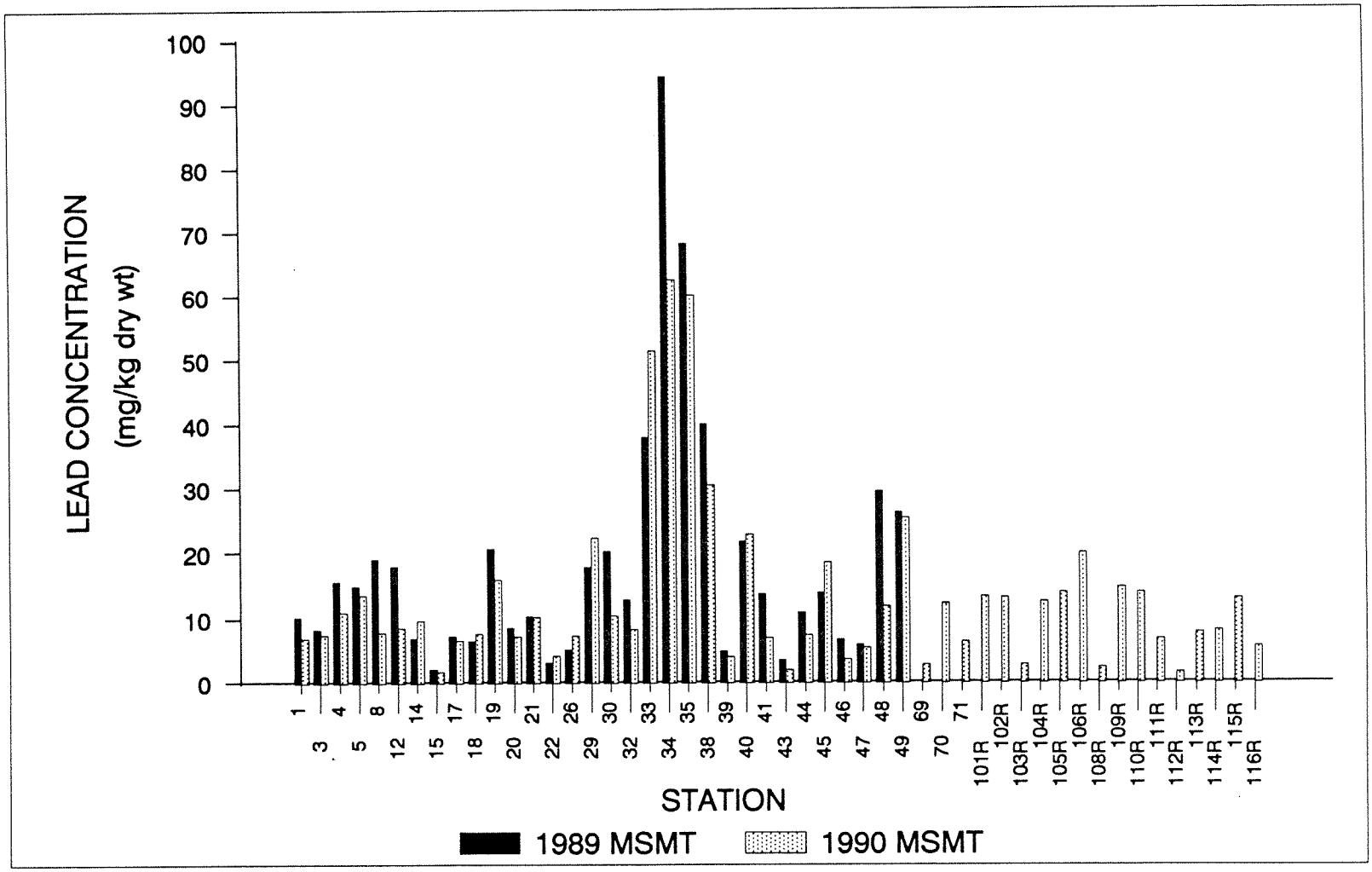



Figure 4. Concentration of lead (mg/kg dry weight) at 1989 and 1990 stations.

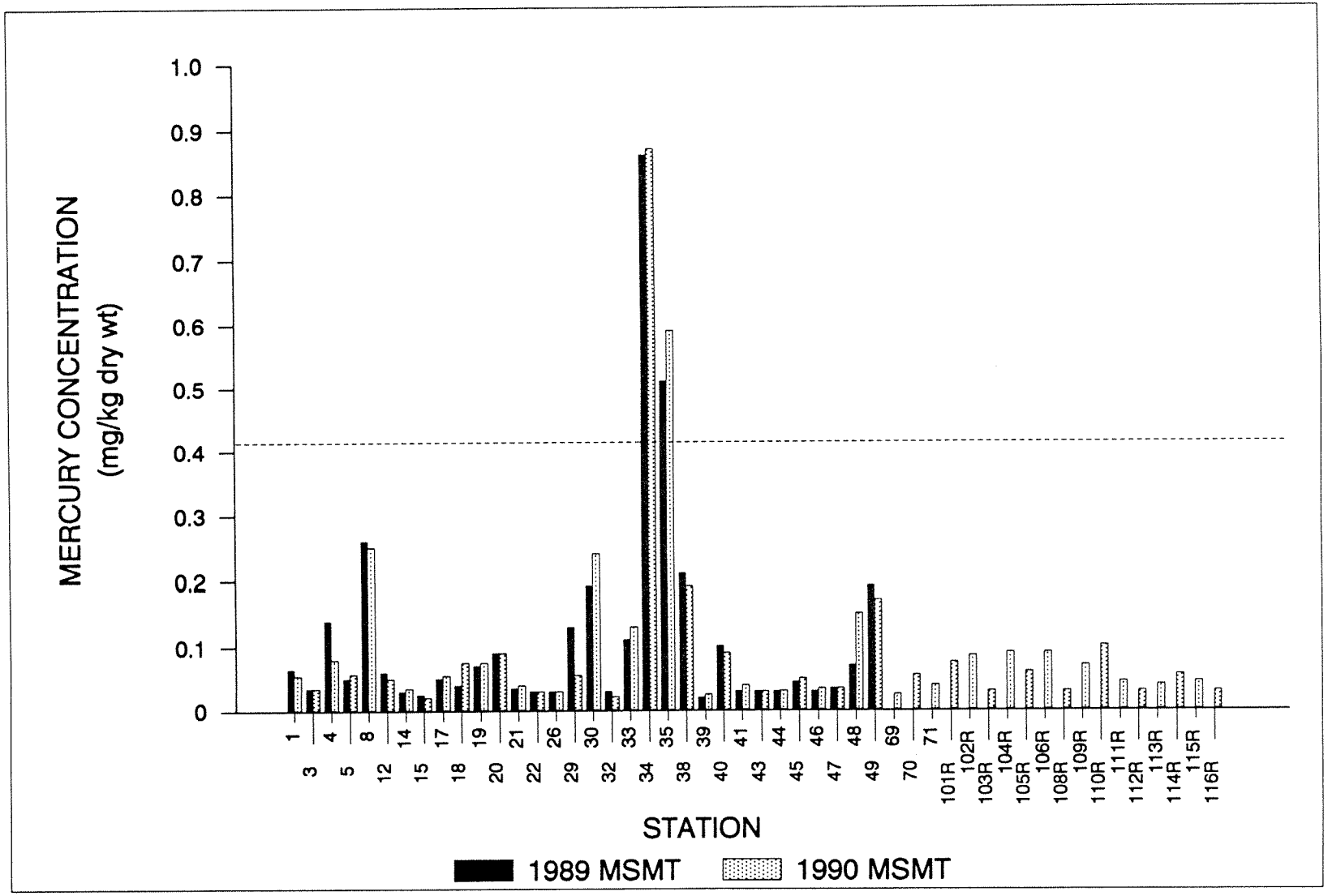



Figure 5. Concentration of mercury (mg/kg dry weight) at 1989 and 1990 stations
Dashed line represents the state sediment standard for mercury (0.41 mg/kg dw).

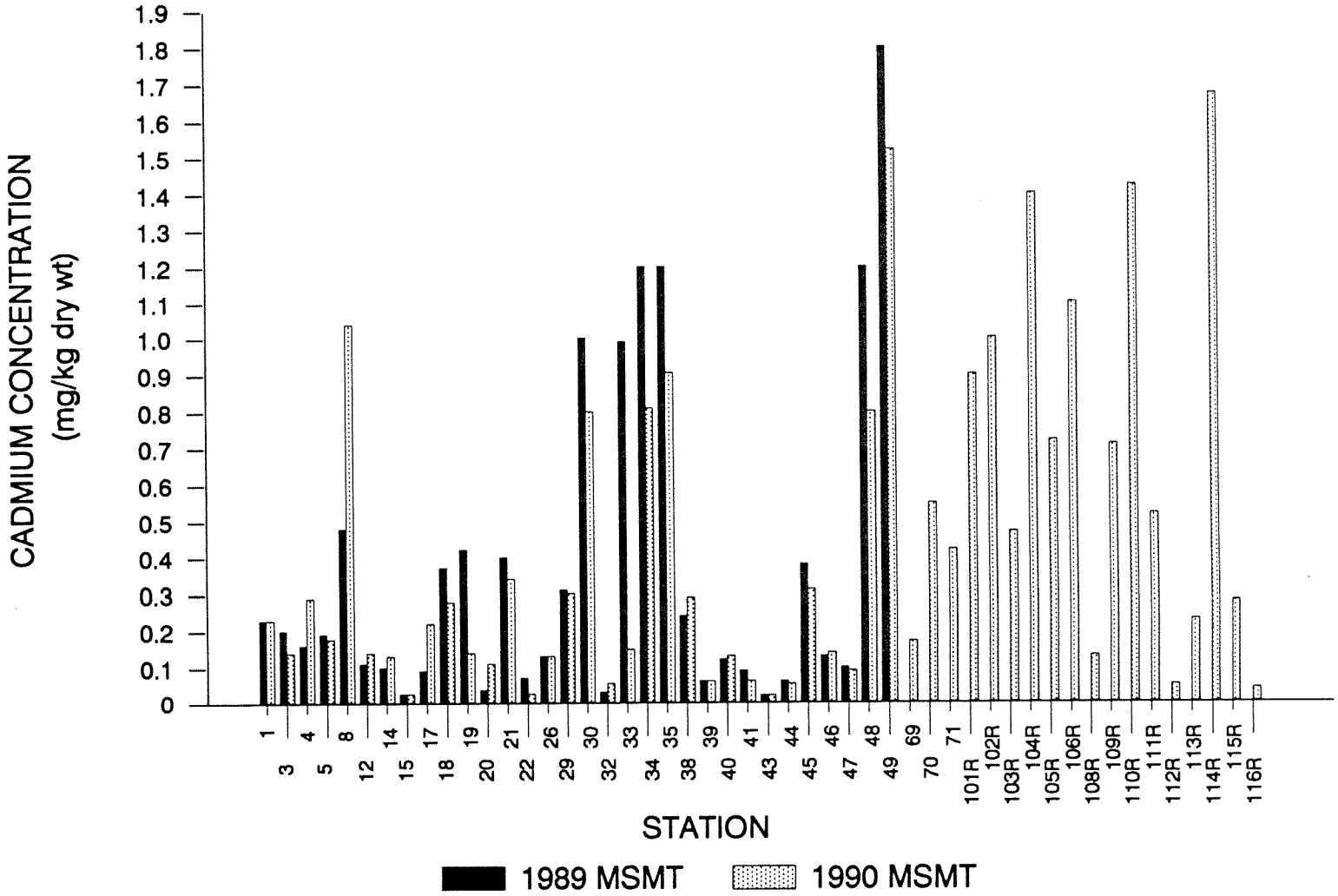



Figure 6. Concentration of cadmium (mg/kg dry weight) at 1989 and 1990 stations.

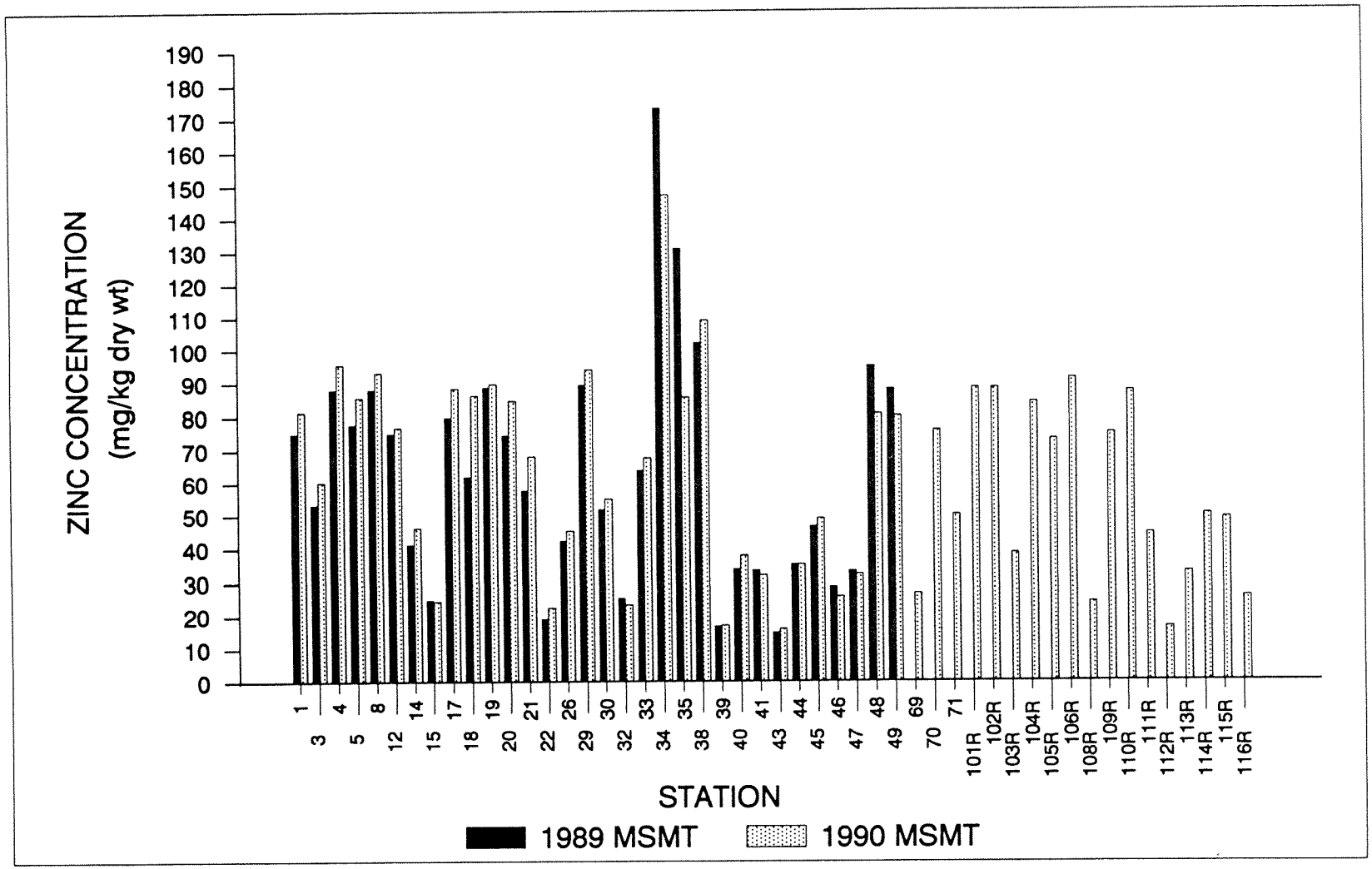



Figure 7. Concentration of zinc (mg/kg dry weight) at 1989 and 1990 stations.

2-hexanone (4.4), bromomethane (0.86), carbon disulfide (1.8), and total xylenes (5.1) were found at Station 38 in the East Passage of Puget Sound (Table 2). The highest concentration of methylene chloride (1.9 $\mu$g/kg dry weight) was found at Station 5 in Samish Bay.

**Semivolatile Organic Compounds--** Most of the semivolatile organic compounds were undetected at low parts per billion detection limits. The most frequently detected neutral extractable compounds were the low (LPAH) and high (HPAH) molecular weight polycyclic aromatic hydrocarbons. LPAH compounds were found in 53 of the 65 samples analyzed. The station with the highest LPAH concentration was at the mouth of City Waterway (Station 40) at a concentration of 6300 $\mu$g/kg dry weight. When the LPAH data are normalized to total organic carbon, only Station 40 (573 mg/kg TOC, Figure 8A) exceeds the state sediment quality standard of 370 mg/kg TOC. HPAH compounds were found in 59 of the 65 samples analyzed. The highest concentrations of HPAH also occurred at Station 40 at 10,000 $\mu$g/kg dry weight (Figure 8B).

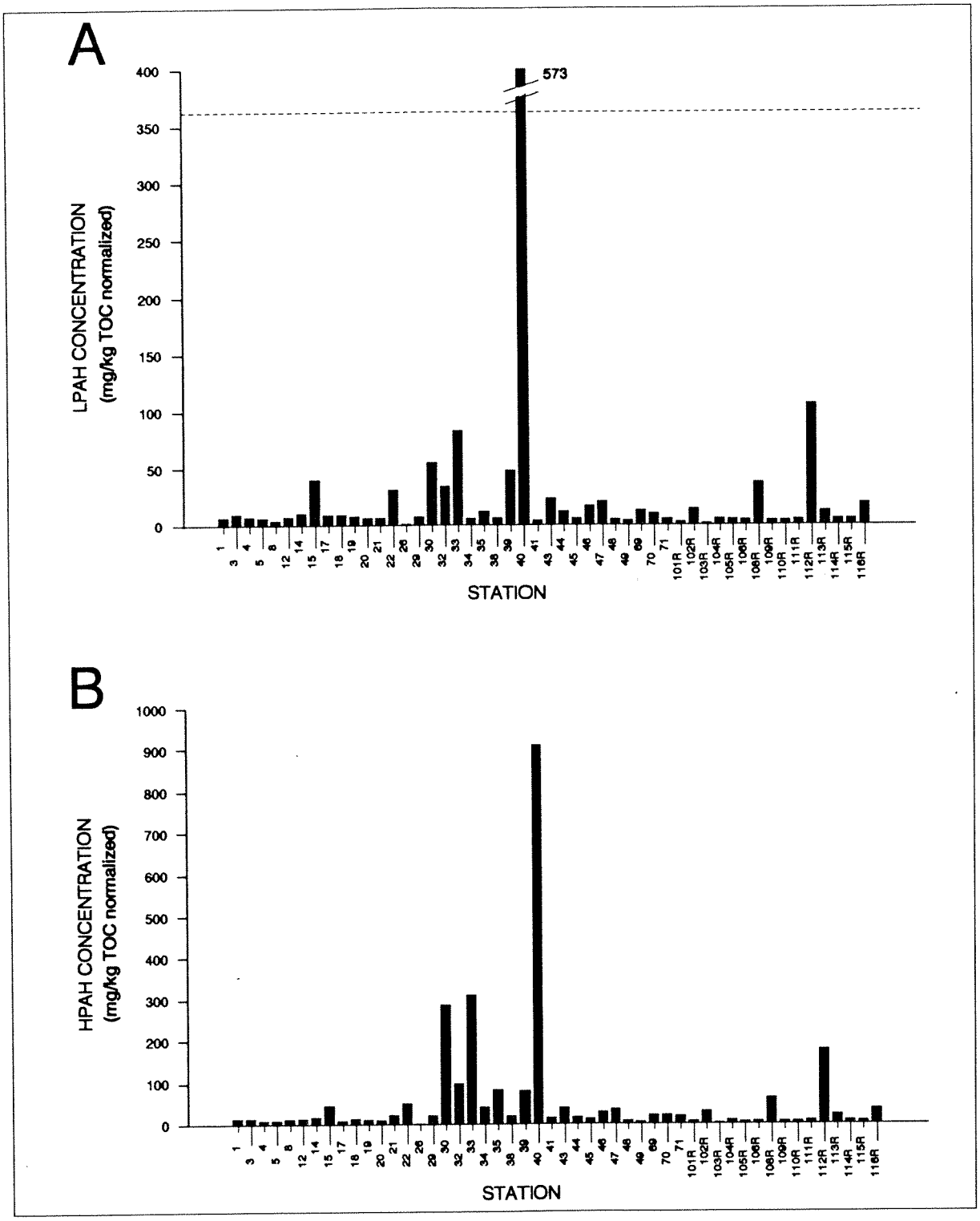
Other neutral extractable compounds detected at MSMT stations included diethyl phthalate (< 10-79 $\mu$g/kg dry weight, highest at Station 113R), di-n-butyl phthalate (6 $\mu$g/kg dry weight, highest at Station 103R), butyl benzyl phthalate (< 10-21 $\mu$g/kg dry weight, highest at Station 34) and bis(2-ethylhexyl phthalate) (< 7-740 $\mu$g/kg dry weight, highest at Station 38).

Concentrations of beta-coprostanol ranged from < 21 to 660 $\mu$g/kg dry weight. This fecal sterol produced by the bacterial breakdown of cholesterol is an excellent marker for sewage effluent. Although beta-coprostanol was detected in 40 of the 50 stations in 1989, it was only found in three samples in 1990. The detection limits achieved by the analytical laboratory were much lower in 1989 than in 1990, and was the reason it was detected at more stations in 1989. The highest concentration was found at Station 41 (660 $\mu$g/kg dry weight) adjacent to the Tacoma wastewater outfall.

The only base extractable found was 9(H)carbazole. It was detected at Station 30 (51 $\mu$g/kg dry weight) in Eagle Harbor, and Station 33 (47 $\mu$g/kg dry weight) in Elliott Bay.

Fifteen acid extractable compounds were analyzed for at all MSMT stations. Two of the fifteen were detected above quantitation limits. The highest concentration of 4-methylphenol occurred in Dyes Inlet at Station 35 (1100 $\mu$g/kg dry weight). The highest concentration of benzoic acid was found in Bellingham Bay at Station 4 (75 $\mu$g/kg, dry weight). Resin acids were detected at the three MSMT stations where they were analyzed. Six of the highest concentrations of resin acid compounds detected were found at Station 8 in Port Angeles Harbor.

The polychlorinated biphenyl (PCB), Aroclor 1254 was detected at two MSMT stations (Stations 33 and 12). The station with the greatest concentration was in Elliott Bay at Station 33 (28 $\mu$g/kg, dry weight). This concentration was less than the greatest concentration seen in the 1989 survey at Station 34 (49 $\mu$g/kg, dry weight). With the exception of 22 $\mu$g/kg p,p'-DDE at Station 33 in Elliott Bay, no pesticides were detected in this survey.




Figures 8A and 8B. Concentrations of low and high molecular weight polycyclic aromatic hydrocarbons at 1990 MSMT stations. Data are reported in mg/kg normalized to total organic carbon. Dashed line represents the state standard for LPAH.

Stations with the highest concentrations of detected chemicals from the 1989 and 1990 MSMT surveys are presented in Table 3. The highest concentration of 23 chemicals were found at the same stations in 1989 and 1990. Five chemicals were found at their highest concentration at Station 38 (East Passage). Three chemicals were found at their highest concentration at Stations 20, 34, and 40.

**Sediment Toxicity Tests**

Quality Assurance/Quality Control

Data validation of *Rhepoxynius abronius* bioassay data were performed in accordance with Puget Sound Protocols (PSEP, 1986f) and the Marine Sediment Quality Implementation Plan (Striplin, 1988). The bioassay data were considered acceptable for use as qualified (Appendix B). Numerous problems were identified during the QA review of the bioassay. These included: during the first series of sediment tests a photoperiod (light/dark cycle) was used, interstitial salinity measurements were not carried out on 12 samples (Stations 22, 32, 39, 43, 46R, 56, 57, 69, 103R, 108R, 112R, and 116R), the mortality and emergence of test organisms was highly variable, and the $LC_{50}$ (the concentration of cadmium chloride lethal to 50% of the test organisms) from the positive controls indicated that the test animals were unusually sensitive throughout the testing procedures ($LC_{50}$=0.21-0.39 mg/L). Amphipod mortality at 17 stations was unusually high given the concentration of chemical contaminants found, because of this the 17 stations were retested even though the holding time of 14 days (exceeded by 3-5 weeks) had elapsed. These samples were assigned an E qualifier (estimate).

Mortality in the negative controls from West Beach were within the maximum allowable limit of 10 percent indicating that while the amphipods may have been more sensitive in the test sediments, they survived at acceptable levels in their native sediment. The QA/QC review of the bioassay results indicated that the data may be used to describe conditions found during the 1990 survey, but should not be compared to data of other years.

Results

The mean and range of amphipod mortality for all stations is shown in Table 4. Mean amphipod mortality for the negative sediment controls from West Beach ranged between 0-20 percent with a mean of 5 percent. The core stations had a mean mortality ranging from 7-43 percent (Stations 39 and 20, respectively). The greatest mortality occurred in the following areas: in North Puget Sound at Stations 4 (28 percent), 12 (29 percent), 18 (28 percent), and 20 (43 percent); in Central Puget Sound at Stations 34 (27 percent), 35 (35 percent), and 38 (28 percent); in South Puget Sound and Hood Canal at Stations 48 (26 percent), 49 (31 percent) and 17 (30 percent). The rotating station mean mortalities ranged from 8 to 38 percent with mortalities equaling or exceeding 25 percent at stations 101R, 102R, 104R, 105R, 106R, 109R, 110R, 114R, and 115R. Statistical analysis of data from the replication stations (5, 32, 35, 38, and 44) indicated that there were no significant differences ($P > 0.001$) within the stations.

Table 3. Highest concentrations of detected metals and organic compounds found in the 1989 and 1990 MSMT. Concentrations are in mg/kg dry weight for metals and ug/kg dry weight for organic compounds.

| | 1989 Station (Concentrations) | | 1990 Station (Concentrations) | |
|---|---|---|---|---|
| METALS | | | | |
| Aluminum | 49 | (25600) | 17 | (33700) |
| Arsenic | 34 | (11.5) | 17 | (29.3) |
| Barium | 38 | (57.9) | 4 | (59.5) |
| Beryllium | 12 | (0.42) | 38 | (0.8) |
| Cadmium | 49 | (1.8) | 114R | (1.67) |
| Calcium | 3 | (22300) | 3 | (16200) |
| Chromium | 20 | (104) | 20 | (112) |
| Cobalt | 17 | (19.9) | 17 | (22.7) |
| Copper | 34 | (129) | 35 | (209) |
| Iron | 20 | (33000) | 17 | (52900) |
| Lead | 34 | (94.4) | 35 | (68.9) |
| Magnesium | 20 | (18800) | 20 | (20000) |
| Manganese | 38 | (713) | 38 | (864) |
| Mercury | 34 | **(0.86)** | 34 | **(0.87)** |
| Nickel | 20 | (113) | 20 | (127) |
| Potassium | 38 | (4600) | 38 | (4740) |
| Silver | 34 | (1.9) | 34 | (1.43) |
| Sodium | 38 | (29100) | 110R | (32300) |
| Thallium | 71 | (0.24) | 104R | (0.70) |
| Vanadium | 17 | (125) | 17 | (136) |
| Zinc | 34 | (173) | 34 | (147) |
| VOLATILE | | | | |
| Acetone | 38 | (69) | 38 | (53) |
| Benzene | 38 | (0.17) | ND | (<0.12) |
| 2-Hexanone | ND | (<0.08) | 38 | (4.4) |
| Bromomethane | ND | (<0.08) | 38 | (0.86) |
| 1,1,1,Trichloroethane | 3 | (6.6) | ND | (<0.05) |
| 1,1'Dichloroethane | 3 | (1.1) | ND | (<0.05) |
| Cis-1,2-dichloroethene | 38 | (0.046) | ND | (<0.10) |
| 4-Methyl,2-pentanone | 5 | (0.46) | ND | (<0.24) |
| Carbon disulfide | 26 | (3.7) | 38 | (1.8) |
| Methylene chloride | 38 | (52) | 5 | (1.9) |
| Chloroform | 5 | (0.31) | 38 | (0.33) |
| Ethylbenzene | 5 | (0.08) | 38 | (0.74) |
| Styrene | 5 | (0.11) | ND | (<0.05) |
| Tetrachloroethylene | 38 | (0.17) | 38 | (0.11) |
| Toluene | 5 | (0.25) | ND | (<0.05) |
| Total Xylenes | 38 | (0.32) | 38 | (5.1) |

Table 3. (Continued).

| | 1989 Station (Concentrations) | | 1990 Station (Concentrations) | |
|---|---|---|---|---|
| PHENOL | | | | |
| 4-Methylphenol | ND | (<10) | 35 | (1100) |
| Phenol | 19 | (520) | ND | (<19) |
| PHTHALATE ESTERS | | | | |
| Diethyl phthalate | ND | (<8) | 113R | (79) |
| Di-n-butyl phthalate | 34 | (30) | 103R | (6) |
| Butyl benzyl phthalate | 40 | (39) | 34 | (21) |
| Bis(2-Ethylhexyl) phthalate | 12 | **(8300)** | 38 | (740) |
| POLYCYCLIC AROMATIC HYDROCARBONS | | | | |
| Total LPAH | 40 | **(3290)** | 40 | **(6300)** |
| Total HPAH | 40 | **(11540)** | 40 | (10000) |
| CHLORINATED AROMATIC HYDROCARBONS | | | | |
| 2-Chloronaphthalene | 44 | (4) | ND | (<10) |
| Hexachlorobenzene | 44 | (5) | ND | (<10) |
| POLYCHLORINATED BIPHENYLS | | | | |
| Aroclor 1254 | 34 | (49) | 33 | (28) |
| PESTICIDES | | | | |
| P,P'-DDE | ND | (<0.3) | 33 | (22) |
| Alpha-chlordane | 33 | (0.9) | ND | (<0.8) |
| RESIN ACIDS | | | | |
| Abietic acid | 8 | (180) | 8 | (630) |
| Chlorodehydroabietic | 8 | (90) | ND | (<57) |
| Dehydroabietic acid | 8 | (550) | 8 | (730) |
| Isopimaric acid | 8 | (210) | 8 | (410) |
| Neoabietic acid | 8 | (82) | 8 | (150) |
| Palustric acid | ND | (<230) | 8 | (130) |
| Sandaracopimaric acid | 8 | (49) | 8 | (87) |
| MISCELLANEOUS OXYGENATED | | | | |
| Benzoic acid | ND | (<24) | 4 | (75) |
| Dibenzofuran | 40 | (32) | 40 | (48) |
| b-Coprostanol | 41 | (4700) | 41 | (660) |
| Isophorone | 8 | (69) | ND | (<10) |
| 9(H) Carbazole | 26&40 | (110) | 30 | (51) |

Bold type indicates that the value exceeded the Washington State Quantitative Standards for Marine Sediments.

Table 4. Results of amphipod Toxicity Tests.

| Station | Location | Range of Mortality (Percent) | Mean Mortality (Percent) |
|---|---|---|---|
| 1 | Semiahmoo Bay | 0-35 | 21 |
| 3 | Strait of Georgia | 0-25 | 15 |
| 4 | Bellingham Bay | 5-60 | 28 |
| 5 | Samish Bay | 10-45 | 23 |
| 8 | Port Angeles Harbor | 0-25 | 9 |
| 12 | Port Townsend | 5-45 | 29 |
| 14 | North Hood Canal | 0-35 | 21 |
| 15 | Dabob Bay | 10-25 | 16 |
| 17 | South Hood Canal | 10-55 | 30 |
| 18 | Oak Harbor | 0-60 | 28 |
| 19 | Saratoga Passage | 10-55 | 33 |
| 20 | Port Susan | 35-60 | 43 |
| 21 | Port Gardner | 10-30 | 18 |
| 22 | Mukilteo | 10-20 | 15 |
| 26 | West Central Basin | 10-30 | 18 |
| 29 | Shilshoe | 10-35 | 19 |
| 30 | Eagle Harbor | 10-30 | 20 |
| 32 | Magnolia Bluff | 0-35 | 13 |
| 33 | Elliott Bay | 10-30 | 19 |
| 34 | Sinclair Inlet | 10-40 | 27 |
| 35 | Dyes Inlet | 15-55 | 35 |
| 38 | Point Pully | 10-50 | 28 |
| 39 | Dash Point | 0-20 | 7 |
| 40 | City Waterway | 5-25 | 11 |
| 41 | Blair/Sitcum Waterways | 10-30 | 19 |
| 43 | Carr Inlet | 10-55 | 23 |
| 44 | East Anderson Island | 0-35 | 17 |
| 45 | Devil's Head | 5-45 | 21 |
| 46R | West Nisqually Delta | 0-20 | 10 |
| 47 | Case Inlet | 5-35 | 18 |
| 48 | North Budd Inlet | 10-40 | 26 |
| 49 | South Budd Inlet | 5-65 | 31 |
| 69 | Port Madison | 10-20 | 15 |
| 70 | Shelton | 10-25 | 18 |
| 71 | Fidalgo Bay | 10-30 | 23 |
| 101R | Oakland Bay | 20-45 | 29 |
| 102R | Inner Totten Inlet | 10-75 | 37 |

Table 4. (Continued).

| Station | Location | Range of Mortality (Percent) | Mean Mortality (Percent) |
|---|---|---|---|
| 103R | Mid Totten Inlet | 0-15 | 9 |
| 104R | Inner Eld Inlet | 10-75 | 38 |
| 105R | Outer Eld Inlet | 30-45 | 36 |
| 106R | Mid Budd Inlet | 10-80 | 34 |
| 108R | West Dover Point | 0-20 | 8 |
| 109R | Henderson Inlet | 0-50 | 28 |
| 110R | Inner Case Inlet | 5-60 | 37 |
| 111R | Mid Case Inlet | 15-30 | 24 |
| 112R | Nisqually Delta | 5-25 | 14 |
| 113R | Willochet Bay | 0-20 | 14 |
| 114R | Henderson Bay/Carr Inlet | 25-50 | 33 |
| 115R | Outer Filucy Bay | 20-40 | 28 |
| 116R | North McNeil Island | 0-20 | 11 |
| Control | group 1 | 0-15 | 5 |
| | group 2 | 0-5 | 5 |
| | group 3 | 0-5 | 3 |
| | group 4 | 0-20 | 6 |

DeWitt *et al.* (1988) developed a regression model to differentiate between mortality due to potential toxic effects and mortality due to sediment grain size. The model suggests that a toxic (non-grain size) effect has occurred when the mean number of survivors in a test sediment is less than the 95 percent prediction limit calculated for the regression relationship. The model does not suggest that stations within the 95 percent limit are not toxic, but that grain size may play a role in that toxicity. Using this relationship, sediments at three stations from the 1990 survey showed toxic effects (Figure 9). These stations where toxic effects are suggested include Stations 20 (Port Susan), 43 (Carr Inlet), and 105R (Outer Eld Inlet). It should be noted that each of the three "toxic" stations that exceeded that 95 percent prediction limit did so by less than five percent. Due to the numerous QA/QC problems associated with this data set, the designation of the stations as positively toxic is not possible.

**Benthic Infauna**

Quality Assurance/Quality Control

Quality control of the sorting of the benthic macroinvertebrate samples followed the procedure found in the Puget Sound Protocols (PSEP, 1987). Fifteen of the 105 samples failed the initial quality control check. Corrective action was taken and the samples were resorted. These samples were rechecked and passed the second quality control check.

Five percent of the samples identified were re-identified by other taxonomists. Aside from the use of synonyms for four species of polychaetes, there were no significant differences in taxonomic composition, nor in abundance of organisms when comparing results between taxonomists.

Results

Three replicate samples from the 34 Core stations and from Station 46R were sorted and analyzed to the lowest taxonomic level (generally species). Each species and the abundance of each species are listed in Appendix D by station and replicate. These data are further summarized in Appendix E by the total abundance of each major taxonomic group in each sample. Table 5 lists mean values of total abundance (per $0.1m^2$), number of taxa, diversity (Shannon-weiner H'), evenness (J), and the abundance of arthropods, polychaetes, and mollusks by station.

A total of 50,036 benthic infaunal organisms were found in the 105 samples processed to date. Mean total abundance at each station ranged from 66.3 individuals/$0.1m^2$ at Station 3 to 2184.3 individuals/$0.1m^2$ at Station 41. Mean number of taxa ranged from 14.3 taxa at Station 3 to 92.0 taxa at Station 47. Mean diversity ranged from 0.629 at Station 41 to 1.612 at Station 47.

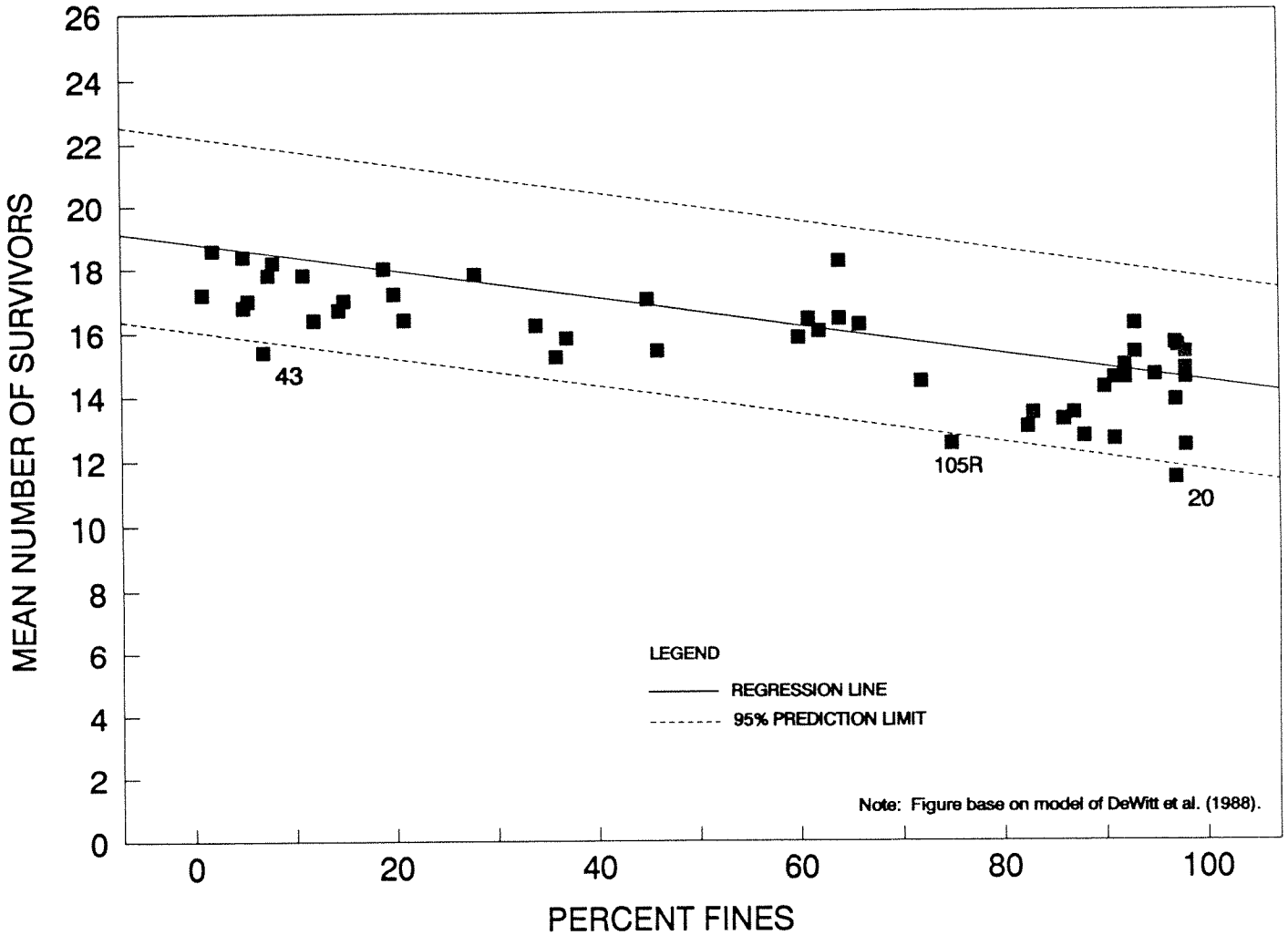



Figure 9. Amphipod survival -vs- percent fine-grained material at MSMT stations.

Table 5. Mean Values of Benthic Infauna Variables per 0.1 $m^2$. Means were calculated using 3 replicates.

| Station | Total Abund. | Number of Taxa | Diver-sity | Even-ness | Arthro-poda | Poly-chaeta | Moll-usca |
|---|---|---|---|---|---|---|---|
| 1 | 750.3 | 29.7 | 0.867 | 0.589 | 169.7 | 144.7 | 82.7 |
| 3 | 66.3 | 14.3 | 0.923 | 0.839 | 13.7 | 33.3 | 19.7 |
| 4 | 521.0 | 53.3 | 1.257 | 0.728 | 107.0 | 231.7 | 125.0 |
| 5 | 505.0 | 46.6 | 1.274 | 0.765 | 119.2 | 168.6 | 150.4 |
| 8 | 377.0 | 66.7 | 1.510 | 0.828 | 55.0 | 243.3 | 71.3 |
| 12 | 496.7 | 51.7 | 1.085 | 0.634 | 64.3 | 105.0 | 140.7 |
| 14 | 275.0 | 68.3 | 1.491 | 0.820 | 58.0 | 125.7 | 72.7 |
| 15 | 313.0 | 71.0 | 1.579 | 0.854 | 32.3 | 175.0 | 89.0 |
| 17 | 213.0 | 25.0 | 0.976 | 0.700 | 24.0 | 110.0 | 78.7 |
| 18 | 254.7 | 30.7 | 0.942 | 0.643 | 17.3 | 67.3 | 165.7 |
| 19 | 67.0 | 21.3 | 0.896 | 0.674 | 5.3 | 52.3 | 6.3 |
| 20 | 386.7 | 39.3 | 1.284 | 0.808 | 77.3 | 240.7 | 68.0 |
| 21 | 762.7 | 47.7 | 1.071 | 0.639 | 237.7 | 151.7 | 371.0 |
| 22 | 404.0 | 43.3 | 1.021 | 0.624 | 191.3 | 53.7 | 159.0 |
| 26 | 263.7 | 65.3 | 1.554 | 0.857 | 83.0 | 116.0 | 60.3 |
| 29 | 286.3 | 36.0 | 0.813 | 0.523 | 51.3 | 35.3 | 197.3 |
| 30 | 478.3 | 52.3 | 1.156 | 0.674 | 106.0 | 309.0 | 60.3 |
| 32 | 481.0 | 58.6 | 1.108 | 0.667 | 107.2 | 517.7 | 45.0 |
| 33 | 448.0 | 74.3 | 1.419 | 0.759 | 118.0 | 203.7 | 118.7 |
| 34 | 448.0 | 48.7 | 1.245 | 0.738 | 108.3 | 302.0 | 33.0 |
| 35 | 600.2 | 28.0 | 0.712 | 0.572 | 271.0 | 454.3 | 49.7 |
| 38 | 86.8 | 23.8 | 1.171 | 0.853 | 47.6 | 29.2 | 8.7 |
| 39 | 229.0 | 44.0 | 1.218 | 0.746 | 85.0 | 85.0 | 55.3 |
| 40 | 353.7 | 55.3 | 1.341 | 0.773 | 102.7 | 182.3 | 61.7 |
| 41 | 2184.3 | 47.7 | 0.629 | 0.375 | 99.0 | 961.0 | 1116.3 |
| 43 | 670.7 | 61.7 | 1.187 | 0.664 | 218.3 | 164.7 | 71.7 |
| 44 | 512.6 | 67.0 | 1.220 | 0.736 | 94.2 | 603.7 | 55.3 |
| 45 | 255.7 | 42.3 | 1.159 | 0.713 | 49.0 | 178.7 | 13.0 |
| 46 | 504.7 | 66.3 | 1.359 | 0.746 | 110.3 | 314.0 | 47.7 |
| 47 | 504.7 | 92.0 | 1.612 | 0.821 | 41.3 | 268.3 | 91.0 |
| 48 | 353.3 | 35.7 | 0.966 | 0.622 | 169.7 | 77.3 | 46.0 |
| 49 | 135.0 | 21.0 | 0.985 | 0.746 | 49.7 | 57.3 | 17.3 |
| 69 | 379.3 | 67.7 | 1.531 | 0.837 | 132.7 | 168.3 | 67.3 |
| 70 | 111.0 | 21.0 | 0.972 | 0.736 | 6.3 | 44.0 | 55.3 |
| 71 | 543.0 | 70.7 | 1.561 | 0.846 | 125.7 | 291.3 | 87.3 |

Values for Arthropoda, Polychaeta, and Mollusca are mean abundances.

The low abundance and number of taxa at Station 3 is probably due to sediment characteristics. Station 3 is in the Strait of Georgia where there are strong bottom currents that scour away most loose fine sediments. Sediment samples from Station 3 are usually composed of compacted clay and shell fragments, which is unsuitable for survival of most infaunal organisms.

In the 1990 survey, Station 41 (Blair/Sitcum Waterways in Commencement Bay) was characterized by having the lowest diversity and the highest total abundance, as was the case in 1989. The high abundance and low diversity was due to high dominance by the polychaete species, *Tharyx multifilis*, and the bivalve *Axinopsida serricata*. The composition of the benthic community at Station 41 is typical of a community influenced by organic enrichment. This may be occurring because the station is located about 50 meters inshore of the City of Tacoma's sewage outfall.

The highest number of taxa and greatest diversity were found at Station 47 in Case Inlet. The exceptionally high number of taxa with no single species being dominant resulted in the high diversity value.

Comparison Between 1989 and 1990 Benthic Infauna Variables

Stations where benthic infauna were sampled in 1989 and 1990 were compared using analysis of variance to test for differences among total abundance, number of taxa, diversity, arthropod abundance, mollusk abundance, and polychaete abundance. Many of the stations tested had significant differences between one or more of the variables.

The abundance of each species and the number of species at each station was compared between years to determine which species were responsible for the differences in the variables tested. Stations 12, 19, and 29 had lower species diversities and higher total abundances in 1990 than 1989, resulting from a few dominant species that were present in high numbers in 1990. Conversely, Stations 20, 30, 33, and 40 had higher species diversity and lower total abundance in 1990 than 1989. At these four stations, the higher diversity resulted from a decrease in the numbers of a few species that were dominant in 1989.

The species that were dominant at Stations 12, 19, 20, and 29 are different for each station. However, Stations 30, 33, and 40 had four dominant species in common: the polychaetes *Tharyx multifilis, Prionospio steenstrupi*, and *Pectinaria granulata*, and the bivalve *Axinopsida serricata*. In addition, the ostracod crustacean *Euphilomedes carcharodonta* was dominant at Station 33. *Tharyx multifilis, Prionospio steenstrupi, Axinopsida serricata*, and *Euphilomedes carcharodonta* are generally considered pollution tolerant indicator species and are often dominant in areas with organic enrichment (Pearson & Rosenberg, 1978). It should be stressed that these species are tolerant to the presence of organic material, and not necessarily to complex mixtures of chemical contaminants.

The abundance at Stations 5, 22, 43, and 44 was significantly higher in 1990 than 1989. At Station 43, enough of the increase in abundance was due to the addition of species that the

number of taxa was also significantly increased. Conversely, lower total abundances at Stations 15 and 26 in 1990 were the result of fewer numbers of several species. Station 15 had significantly fewer taxa, which probably contributed to the decreased total abundance. None of the species that increased or decreased were found at more than two of these stations. *Euphilomedes producta* was found at stations 5 and 26, but it increased in number at Station 5, and decreased at Station 26 in 1990.

The causes for the differences between years are very difficult to determine, but many were almost certainly due to natural variability found in macroinvertebrate communities. It is intriguing to speculate that the differences between years at Stations 30, 33, and 40 may be due to improving conditions. The dominant species present at these stations may be there in high numbers in response to pollution-related community stress, or to changes in grain size (i.e., Stations 33 and 40 had a 10% and 13% increase in percent fines). Whether the reduced numbers of these dominant species are responding to improved benthic conditions or not is again something that can only be answered by future data.

Comparison of Benthic Infaunal Data with Historical Data

Historical data for Station 38 reported by Word *et al.* (1984) and from the 1989 MSMT are compared to 1990 MSMT benthic infauna variables in Table 6. Benthic infauna data were collected at Station 38 by Nichols in 1969-1970 (reported by Word *et al.* (1984) in 1982-1983).

In the past, Station 38 has shown a steady increase in total abundance of the major taxa groups. The 1989 MSMT survey confirmed that trend and reported an increase of 39 individuals from 1982-83 to 1989. However, in 1990 this trend did not continue. Total abundance decreased by 28% between 1989 and 1990. The number of taxa also decreased slightly in 1990. Abundances of the three major taxonomic groups and the four indicator taxa at Station 38 either decreased or remained the same in 1990.

Station 29, located just to the North of West Point has also been sampled by Dr. Fred Nichols since 1969 (Station 2; Nichols, 1985). Four infaunal species have historically been dominant at Station 29. These species are listed in Table 7 and their abundances are compared between 1989 and 1990. Nichols (1985) reported that the total abundance of these four species increased at Station 29 between 1963 and 1983, and observed that there were frequent, large-scale changes in the relative abundances of these species between 1978 and 1983. The combined abundance of the four species dropped from 180 reported by Nichols in 1985, to 63 in 1989, and then rebounded in 1990 to 184.

The higher total abundance at station 29 in 1990 is due to the very high abundance of *Macoma carlottensis*. The number of taxa did not increase between years and the other three species either decreased in abundance or increased only slightly, so the dominance of *M. carlottensis* resulted in a significantly lower diversity in 1990.

Table 6. Comparison of Benthic Infauna Data at Station 38 with Historical Data

| | 1969-1970 | 1982-1983 | 1989 | 1990 |
|---|---|---|---|---|
| Total abundance | 50.3 | 89.0 | 128.0 | 86.8 |
| Number of taxa | 21.0 | 26.0 | 26.3 | 23.8 |
| Polychaete abundance | 23.0 | 38.6 | 31.7 | 29.3 |
| *Pectinaria californiensis* | 12.0 | 2.0 | 11.3 | 1.3 |
| *Ampharete acutifrons* | 0 | 5.0 | 0 | 0.7 |
| Mollusk abundance | 3.3 | 30.4 | 12.7 | 8.7 |
| *Macoma carlottensis* | 0.3 | 3.8 | 7.7 | 4.7 |
| *Axinopsida serricata* | 0 | 17.6 | 1.3 | 0.7 |
| Arthropod abundance | 16.7 | 17.0 | 79.0 | 47.6 |

Number of taxa and abundance are reported as mean number/0.1m$^2$

Table 7. Comparison of Selected Benthic Infauna Data at Station 29 between the 1989 and 1990 MSMT.

| | 1989 | 1990 |
|---|---|---|
| *Macoma carlottensis* | 32 | 171 |
| *Axinopsida serricata* | 2 | 5 |
| *Pectinaria californiensis* | 25 | 1 |
| *Ampharete acutifrons* | 4 | 7 |
| Total | 63 | 184 |
| Total abundance | 155 | 286 |
| Number of taxa | 35 | 36 |
| Diversity | 1.16 | 0.81 |

Number of taxa and abundance are reported as mean number/0.1m$^2$

The 1989 MSMT report suggests that the lower abundance at Station 29 may have been due to seasonal sampling differences. The high abundance at Station 29 in 1990 is at a level similar to that found in 1985. This contradicts the above idea and suggests that the differences between years are merely a consequence of natural variability.

The 1989 MSMT report also postulated that there was a trend of increasing overall abundance of benthic infauna at Stations 29 and 38. While the abundance at Station 29 did increase in 1990, the higher abundance was due almost entirely to *Macoma carlottensis* which has been shown to vary annually, (Nichols, 1988). High dominance by one species in a single year does not constitute a trend of increasing overall abundance. The significant decrease in abundance at Station 38 also appears to cast doubt on a trend of increasing abundance.

Natural variability undoubtedly plays a major role in structuring the benthic community. However, the 1989 MSMT report demonstrated the differences in community structure that have taken place at Station 38 since 1969 and proposed that these changes may be due to increasing anthropogenic input. In 1990, mercury, lead, and zinc concentrations at Station 38 were at, or exceeded interim performance standards for reference areas (PTI, 1989). In addition, eight volatile organic compounds were highest at Station 38 (Table 2). The implications of these contaminants and their effects on benthic community structure are unknown, but the possibility certainly exists that the organisms are being affected by chemical contaminants. Additional data from future monitoring is needed to understand what is happening at Stations 29 and 38.

Pollution Indicator Species

To identify potential reference stations in 1989, a list of pollution sensitive and pollution tolerant species found in Puget Sound was compiled from benthic literature (Tetra Tech, 1990, Table F-3 in Appendix F). Proposed qualitative performance standards for benthic communities in reference areas (PTI, 1989) suggest that sensitive species should be present and tolerant species should be rare or absent.

The abundance of tolerant or sensitive species at each station in 1989 was compared between non-reference stations and potential reference stations to test the proposed standards. Only four pollution sensitive species were found during the 1989 survey, and the data showed that stations with the highest percentage of sensitive species were stations with elevated contaminant concentrations. Abundances of tolerant species were not different between reference and non-reference stations. These results suggested that identification of reference stations using the present list of sensitive and tolerant species is not appropriate.

The polychaete *Terebellides stroemi* was the only "sensitive" species found in the 1990 MSMT survey. *T. stroemi* was not abundant at any station and was often present at stations where tolerant species were abundant.

Many of the pollution tolerant species from the 1989 list were found in 1990, and at least one tolerant species was found at all 35 core stations. Only four stations had less than 10% tolerant species (Table 8), (tolerant species present in abundances greater than 10% should not be considered rare). These results support the conclusion reached in 1989 that reference stations cannot be identified using the present list of pollution sensitive and tolerant species.

These results also suggest that the performance standards for reference areas need to be reevaluated. Many tolerant species may be responding to natural stresses or disturbances rather than contaminated sediments. These species are generally opportunistic and are only present in high abundances when conditions are unfavorable for competing species. Unfavorable conditions may include scouring bottom currents such as at Station 3 in the Strait of Georgia or the black, poorly oxygenated mud of Station 70 near Shelton, caused by poor water circulation. Even with a carefully selected list of pollution tolerant species from Puget Sound, it may be impossible to determine if the organisms are present in high abundances due to natural stress or anthropogenic contamination.

## SUMMARY

### Sediment Chemistry

Data from 68 samples from 50 stations were analyzed for the presence of 103 chemical compounds. An additional 37 volatile organic compounds were analyzed for at 10 stations and 13 resin acids and guaiacols were analyzed for at three of the 50 stations.

Data validation of the results indicated that data for total sulfides, antimony, and selenium be rejected due to low recoveries of matrix spike/matrix spike duplicates and holding time exceedances. Validation also indicated that results for acetone, 2-butanone, and methylene chloride be used with caution because cross contamination may have occurred during field collection of samples. Forty-seven of the 68 samples analyzed for semivolatile organic compounds were qualified as estimates because an insufficient amount of sediment was used in the analysis, samples were held at the wrong temperature between extractions, and holding times were greatly exceeded between the first and second extractions. Statistical comparisons done on the results of the two extractions to determine if samples had degraded between extractions indicated that except for certain HPAH compounds at four stations, no significant degradation occurred.

Analytical results of conventional parameters showed a good correlation between total organic carbon (TOC) and percent fine grained sediment. The TOC ranged from 0.62 to 4.0 percent with the lowest value at Station 112R in the Nisqually Delta and the highest value at Station 101R in Oakland Bay. The distribution of fine grained sediment (percent silt plus clay) at the 1990 stations was typical of what was seen in other studies in Puget Sound. High percent fines are found in small, shallow embayments and in deep basins; and coarser sediments are found along the open shorelines.

Table 8. Pollution tolerant species at each station.

| Station | Total Abundance | Abundance of Tolerant Spp. | Percent Tolerant Spp. |
|---|---|---|---|
| 1 | 760 | 9 | 1.2 |
| 3 | 66 | 23 | 34.3 |
| 4 | 521 | 99 | 18.9 |
| 5 | 504 | 102 | 20.2 |
| 8 | 378 | 72 | 19.1 |
| 12 | 487 | 23 | 4.7 |
| 14 | 273 | 50 | 18.4 |
| 15 | 312 | 56 | 18.1 |
| 17 | 212 | 85 | 40.0 |
| 18 | 287 | 173 | 60.1 |
| 19 | 67 | 4 | 6.0 |
| 20 | 387 | 61 | 15.8 |
| 21 | 765 | 468 | 61.2 |
| 22 | 405 | 189 | 46.8 |
| 26 | 264 | 70 | 26.4 |
| 29 | 286 | 35 | 12.3 |
| 30 | 479 | 230 | 48.0 |
| 32 | 482 | 93 | 19.3 |
| 33 | 447 | 257 | 57.5 |
| 34 | 448 | 154 | 34.3 |
| 35 | 600 | 140 | 23.3 |
| 38 | 87 | 15 | 17.3 |
| 39 | 229 | 106 | 46.4 |
| 40 | 353 | 211 | 59.8 |
| 41 | 2185 | 1974 | 90.3 |
| 43 | 673 | 137 | 20.4 |
| 44 | 511 | 61 | 11.9 |
| 45 | 258 | 52 | 20.3 |
| 46 | 515 | 126 | 24.4 |
| 47 | 549 | 87 | 15.9 |
| 48 | 355 | 26 | 7.3 |
| 49 | 136 | 16 | 11.8 |
| 69 | 379 | 137 | 36.2 |
| 70 | 111 | 37 | 33.0 |
| 71 | 550 | 93 | 16.9 |

Abundances are mean values for each station.

Some heavy metals were found at all 50 stations with higher concentrations in the urban embayments. With the exception of mercury, no metal exceeded the state sediment quality standards. The standard for mercury was exceeded at Station 34 in Sinclair Inlet and at Station 35 in Dyes Inlet. With few exceptions, the concentrations of other pollutant metals were similar between the 1989 and 1990 MSMT surveys. Copper concentrations at two stations (8 and 35 in Port Angeles and Dyes Inlet) while still low, were twice as great in 1990 as in 1989. The concentration of lead at Stations 34 (Sinclair Inlet) and 48 (outer Budd Inlet) were less in 1990 than 1989.

Nine volatile organic compounds were detected at low concentrations at MSMT stations. The highest concentrations of eight of these were found at Station 38 in East Passage. These compounds included: acetone, bromomethane, carbon disulfide, chloroform, 2-hexanone, ethyl benzene, tetrachloroethylene, and total xylenes. Acetone, tetrachloroethylene, and total xylenes were also found at their highest concentrations in the 1989 MSMT at Station 38. The highest concentration of methylene chloride was found at Station 5 in Samish Bay.

Results of analyses for semivolatile organic compounds indicated that the compounds detected most frequently were the low and high molecular weight polycyclic aromatic hydrocarbons (LPAH and HPAH, respectively). The highest concentrations of both were found at Station 40 located at the mouth of the City Waterway. The concentration of LPAHs at Station 40 exceeded the state sediment standards. One base and two acid extractable compounds were detected above quantitation limits. No concentrations of any of these compounds were found above the state standards. The PCB Aroclor 1254 was detected at low concentrations at Station 12 in Port Townsend and at Station 33 in Elliott Bay. Also found at Station 33 was a small amount of p,p'-DDE, a breakdown product of the pesticide DDT. This was the only pesticide detected at any station in the 1990 MSMT survey.

Sediment Toxicity Tests

The amphipod bioassay using *Rhepoxynius abronius* was conducted on 65 samples from 50 stations. Data validation of the results indicated that the amphipods were unusually sensitive to the reference toxicant as seen in the positive controls. Mortality in the negative controls ranged from 2.5-6.0 percent, suggesting that the test organisms were suitably healthy for survival in control sediments. The validation report concluded that the data may be used to describe trends within the 1990 MSMT survey, but should not be compared to other bioassay studies.

Amphipod mortality within the 1990 MSMT survey ranged from 7 to 43 percent. The highest mortality occurred at Station 20 in Port Susan and the lowest at Station 39 off Dash Point. Twenty stations had mortalities greater that 25 percent, which is the maximum value observed in Puget Sound reference areas. The mortality values at these 20 stations were plotted against the Dewitt model to differentiate between toxic and grain size effects. This analysis indicated that three of the 20 stations may have had mortality related to toxicity in the sediment. These stations are located in Carr Inlet, Outer Eld Inlet, and in Port Susan. The mortality at these

three stations exceeded the 95% prediction limit by less than five percent, thus their characterization as being toxic is uncertain.

**Benthic Infauna**

Data from a total of 105 samples (35 stations, 3 replicates per station) are reported. Total abundance ranged from 66.3 at Station 3 to 2184.3 at Station 41. Number of taxa ranged from 14 at Station 3 to 92 at Station 47. Station 41 had the highest abundance and the lowest diversity due to high dominance by two species. This dominance may be attributed to organic enrichment due to the location of the station (adjacent to the City of Tacoma wastewater outfall).

Comparison between 1989 and 1990 infauna data revealed significant differences between 16 of the 32 stations tested. Many of the differences may be attributed to natural variability, but decreased abundances of pollution tolerant indicator species and increased diversity at Stations 30, 33, and 40 may be due to improving conditions for benthic infauna at these stations.

Comparison of infauna data for 1990 at Stations 29 and 38 with historical data appears to contradict the hypothesis presented by Tetra Tech (1989) that abundances of benthic infauna in the Puget Sound basin are increasing. Abundances at Station 29 were high in 1990, but the high abundances were due to one dominant species. Abundances for Station 38 had decreased to levels similar to abundances reported in 1982-1983, rather than increasing as predicted. Changes in benthic community structure at Station 38 may be linked to chemical contamination.

Pollution tolerant species were present at all 35 core stations and are not recommended for use in identification of reference stations. Reevaluation of performance standards for reference areas is recommended due to the unpredictable response of indicator species to stress.

Despite the presence of chemical contaminants at many non-urban stations, most of the benthic macroinvertebrate communities were healthy. This was the case even at stations where the concentration of a chemical exceeded the state sediment standard. The abundance and species richness of the benthic communities varied greatly throughout the Sound, primarily in relation to sediment particle size.

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