PUGET SOUND AMBIENT MONITORING PROGRAM 1989

MARINE SEDIMENT MONITORING

Final Report

January 1990

Prepared for
Washington Department of Ecology
Ambient Monitoring Section

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by

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CONTENTS

FIGURES

TABLES

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UNITS OF MEASUREMENT AND EQUATION ABBREVIATIONS

1-J	Dominance
C	Celcius
cm	Centimeter
DW	Dry weight
E	Estimated value
Enh	Enhancement
g	Gram
h	Hour
H'	Shannon-Weiner index
J	Evenness
kg	Kilogram
m	Meter
m^2	Square-meter
mg	Milligram
min	Minutes
mL	Milliliter
mm	Millimeter
mo	Month
oz	Ounce
P	Probability
ppt	Part per trillion
r	Pearson product-moment correlation coefficient
R	Unusable value
SDI	Swartz dominance index
U	Undetected
ug	Microgram

GLOSSARY OF ABBREVIATIONS

AET	Apparent effects threshold
Ag	Silver
Al	Aluminum
AMS	Ambient Monitoring Section
ANOVA	Analysis of variance
As	Arsenic
AW	Area weighted
Ba	Barium
Be	Beryllium
Ca	Calcium
Cd	Cadmium
CLP	Contract Laboratory Program (U.S. EPA)
Co	Cobalt
Cr	Chromium
Cu	Copper
CV	Coefficient of variation
EAR	Elevation above reference
EC_{50}	Concentration that causes 50 percent decrease in luminescence
Ecology	Washington Department of Ecology
EPA	Environmental Protection Agency
GC/ECD	Gas chromatography/electron capture detection
GC/MS	Gas chromatography/mass spectrometry
GFAA	Graphite furnace atomic absorption
GPC	Gel permeation chromatography
Hg	Mercury
HPAH	High molecular weight polynuclear aromatic hydrocarbons
ICP	Inductively coupled plasma
ITI	Infaunal trophic index
LAET	Lowest AET
LC_{50}	Concentration lethal to 50 percent of test organisms

LPAH	Low molecular weight polynuclear aromatic hydrocarbons
MS	Matrix spike
MSA	Method of standard additions
MSD	Matrix spike duplicate
MSMT	Marine Sediment Monitoring Task
Ni	Nickel
NOAA	National Oceanic and Atmospheric Administration
PAH	Polynuclear aromatic hydrocarbons
Pb	Lead
PCBs	Polychlorinated biphenyls
PCS	Project comparison sample
PSAMP	Puget Sound Ambient Monitoring Program
PSEP	Puget Sound Estuary Program
PSWQA	Puget Sound Water Quality Authority
QA/QC	Quality assurance/quality control
QL	Quantitation limit
RD	Relative differences
RPD	Relative percent difference
Sb	Antimony
SD	Standard deviation
SOW	Statement of work
TCL	Target compound list
TFE	Tetrafluoroethene
TIC	Tentatively identified compounds
TOC	Total organic carbon
VRM	Variable range marker

EXECUTIVE SUMMARY

In 1989, the Marine Sediment Monitoring Task (MSMT) of the Puget Sound Ambient Monitoring Program was implemented. Sediment chemistry, sediment toxicity bioassays, and benthic community structure were evaluated at 50 stations in Puget Sound. Stations were located primarily in non-urban areas at shallow water depths, although some were in deep water. Most stations were positioned away from known anthropogenic sources to document conditions in non-urban areas. This report presents the results of the first year of the MSMT.

Surface (0-2 cm) sediments were sampled at each station. Sediments at shallow (6-15 m) stations were generally sands or sandy silts, whereas sediments at deeper (20 m) stations were generally sands or clayey silts. Sediment compositions varied at the 11 stations deeper than 20 m, and included silty clays, clayey silts, sandy silts, silty sands, and sands.

Some sediments were found to contain contaminants at elevated concentrations. However, except for mercury at two stations, bis(2-ethylhexyl)-phthalate at one station, and phenol at one station, the metal and organic compound concentrations did not exceed the lowest apparent effects threshold (LAET) values for Puget Sound. The concentrations of organic chemicals were generally low in non-urban areas compared with concentrations reported for urban areas.

Some of the lowest contaminant concentrations reported for the MSMT were found in the sandy sediments at stations in north Hood Canal, Dabob Bay, south Sound, and the Straits of Juan de Fuca. Polynuclear aromatic hydrocarbons (PAH) were not found at stations in or near Green Point (Straits of Juan de Fuca), south Hood Canal, west Central Basin, Dash Point, Carr Inlet, and Shelton. Some of the highest contaminant concentrations were found at stations in Port Angeles Harbor, Dyes Inlet, Sinclair Inlet,

Eagle Harbor, Elliott Bay, and Commencement Bay. The presence of chemical contamination at all deep stations with fine-grained sediments in the Central Basin of Puget Sound indicates that contaminants attached to fine particulates settle out of the water column throughout this basin.

PCB-1254 was only detected in 22 percent of the samples, and organochlorine pesticides were only detected in sediments from Elliott Bay. The distribution of beta-coprostanol was found to be a good indicator chemical for areas affected by municipal effluent. Areas with the greatest beta-coprostanol concentrations included outer Bellingham Bay, Port Angeles Harbor, Sinclair Inlet, East Passage off Point Pully, Commencement Bay, and Budd Inlet. Resin acids and guaiacols were analyzed at stations near Lummi Island, Port Angeles Harbor, and Port Gardner. Chlorinated guaiacols were found at each station.

Most sediments sampled in the MSMT lacked significant sediment toxicity. The occurrence of significant toxicity (using the amphipod bioassay) was only observed in sediments from Dyes Inlet, where elevated concentrations of sediment metals and polynuclear aromatic hydrocarbons were also found. There was no observable toxicity (i.e., significant decrease in luminescence) to the Microtox bacterium in any of the samples.

Results of benthic community structure analyses described a variety of different benthic communities throughout Puget Sound, reflecting the wide range of habitats sampled. The benthic community data provides baseline information for the evaluation of temporal trends in the composition of those communities.

Using 1989 MSMT data, the composition of benthic communities was primarily dependent on sediment grain size. Station 41 (Commencement Bay) had the greatest abundance and Station 37 (north Vashon Island) had the highest number of taxa. Ninety percent of the taxa identified were dominant at fewer than five stations, which is further indication of the variety of benthic communities sampled. Station 19 (Saratoga Passage) had an exceptionally depauperate benthic community.

Potential reference stations were identified using MSMT data. The purpose was to identify MSMT stations that were located in potential reference areas (e.g., areas with sediments that have low contaminant concentrations), so that information from those stations would be available to supplement future studies of reference areas. The second objective of that analysis was to provide a benchmark for comparing MSMT data among MSMT stations. Sediment chemistry, toxicity, and benthic infauna data were evaluated, and the 90th percentile values for chemical concentrations were determined and used to identify potential reference areas. The 24 potential reference stations that were identified were located in all areas of Puget Sound. Those stations were located at water depths ranging from 7 to 218 m, with sediments that contained 1.3-93.3 percent fines and 0.06-1.50 percent TOC.

MSMT data were also compared to LAET values, the Washington Department of Ecology's interim performance standards for identifying reference areas (PTI 1989), and the Puget Sound maximum reference values (PTI and Tetra Tech 1988a). Stations with variables that exceeded those sediment quality guidelines were located in Port Angeles Harbor, Port Townsend, south Hood Canal, Port Susan, Saratoga Passage, Port Gardner, east Central Basin, Dyes Inlet, Sinclair Inlet, Eagle Harbor, Elliott Bay, Point Pully, Commencement Bay, and Budd Inlet.

In general, the health of Puget Sound is good based on sediment chemistry, bioassays, and benthic communities at most stations sampled. Variations in sediment quality were related to regional geochemistries (e.g., effects of riverine inputs) and anthropogenic inputs. In future years of the MSMT, factors influencing both spatial and temporal changes in sediment quality will continue to be investigated.

1.0 INTRODUCTION

The Washington Department of Ecology (Ecology) Ambient Monitoring Section is responsible for implementing the Marine Sediment Monitoring Task (MSMT) of the Puget Sound Ambient Monitoring Program (PSAMP). The purpose of the MSMT is to determine baseline ecological conditions and to assess spatial and temporal trends in sediment quality throughout the sound. To meet these objectives, measurements of sediment chemistry, sediment toxicity, and benthic community structure will occur annually during early spring (March-April). This report presents the results of the first year of the monitoring program.

PUGET SOUND AMBIENT MONITORING PROGRAM

The MSMT is a major component of the PSAMP [Puget Sound Water Quality Authority (PSWQA) 1988a], which was designed to support Plan Element M-2 of the *Puget Sound Water Quality Management Plan* (PSWQA 1987, revised 1989). PSAMP provides for long-term comprehensive monitoring of water quality, sediment quality, biological resources, nearshore habitats, and rivers in the Puget Sound basin. The conceptual framework of the program was designed by an interdisciplinary committee, known as the Monitoring Management Committee (MMC), which was appointed by PSWQA in 1986.

In cooperation with the MMC and PSWQA, Ecology developed an implementation plan for the MSMT component of PSAMP, entitled the *Puget Sound Ambient Monitoring Program: Marine Sediment Quality Implementation Plan* (Striplin 1988). That report details field sampling and laboratory analytical methods, quality assurance/quality control (QA/QC) measures, and data management requirements for the program. Tetra Tech (1989b) reviewed Ecology's *Implementation Plan*, recommended improvements to the technical approach of the program, and implemented the 1989 MSMT.

OBJECTIVES OF THE MSMT

The objectives of the MSMT (Striplin 1988) are as follows:

- Provide baseline information on chemical concentrations, toxicity, and benthic communities in the sediments of Puget Sound
- Assist in identifying areas that are uncontaminated and can be used as reference sites, and data that can be used as reference values
- Provide data to be used by researchers concerned with sediment quality
- Identify areas that have been, or are, accumulating toxic contaminants
- Determine physical and chemical factors that influence sediment toxicity and benthic community structure
- Document both natural and anthropogenic changes in sediment quality and evaluate them to determine possible causal factors.

STUDY AREA

Puget Sound is defined by the Puget Sound Water Quality Act as "all salt waters of the state of Washington inside the international boundary line between the state of Washington and the province of British Columbia, lying east of one hundred twenty-three degrees, twenty-four minutes west longitude" (the approximate longitude of the tip of Ediz Hook at Port Angeles). In this report, Puget Sound is subdivided into six general areas: Strait of Georgia, Strait of Juan de Fuca (including Discovery Bay and Port Townsend), Whidbey Basin, Hood Canal, Central Basin, and South Sound.

During the 1989 MSMT, sediment chemistry, sediment toxicity, and benthic community structure analyses were conducted at 50 stations in Puget Sound. The locations of these stations are shown in Figure 1. The rationale for station locations is provided in PSWQA (1988a), Striplin (1988), and Tetra Tech (1989a,b). Based on criteria established by the MMC, stations were selected as follows:

- In nearshore areas, to assess potential integrated effects of multiple sources of contamination
- In the centers of main basins, to assess cumulative, long-term changes in sediment quality and depositional patterns
- In areas at shallow depths (20 m), which tend to be the most biologically productive areas (30 of 50 stations are located at 20 m water depth)
- In areas that were previously sampled, to facilitate comparisons with historical data
- In areas that are not located near major anthropogenic sources of chemical contaminants.

REPORT ORGANIZATION

Descriptions of the field, laboratory, and data management methods for the 1989 MSMT, and the approach for identifying potential MSMT reference stations are provided in Section 2. QA/QC results are presented in Section 3. Results of individual study components are also presented in Section 3, including analyses of 1) sediment contamination, 2) sediment toxicity as measured by the amphipod bioassay using *Rhepoxynius abronius* and the Microtox bioassay using *Photobacterium phosphoreum*, 3) benthic community structure, and 4) potential reference stations. A summary discussion of

results is presented in Section 4. Recommendations for future sediment monitoring programs are presented in Section 5.

Station positioning information and QA memoranda are provided in Appendices A and B, respectively. Sediment conventional and chemical data are provided in Appendices C and D, respectively, and toxicity bioassay and benthic infauna data are provided in Appendices E and F, respectively. Miscellaneous sediment chemistry tables and figures are presented in Appendix G.

2.0 METHODS

Descriptions of the field, laboratory, and data management methods for the 1989 MSMT are provided in the following sections. The approach used to identify potential MSMT reference stations is also described.

STATION POSITIONING

The field survey was conducted between 18 March and 5 April 1989 onboard the R/V KITTIWAKE. Station positions were determined and recorded by the skipper, Mr. Charles Eaton. In the offshore areas of Puget Sound, LORAN C navigational coordinates (and the latitude and longitude coordinates as determined by LORAN C) were recorded for each station. A variable range marker (VRM), which is radar-based, was used to determine distances to shore objects or buoy markers, and in nearshore areas, station locations were also determined using line-of-site fixes on stationary shoreline features. Photographic records of all position alignments were made at most stations, and depth soundings were recorded. By using all positioning methods, Mr. Eaton was able to accurately define locations within a 20-m radius at most stations. Although the research vessel was not anchored during sampling efforts, the station positioning information (e.g., LORAN coordinates, VRM ranges, station depth) was used to ensure that the vessel remained on-station throughout sample collection.

On return from the field, station positions were plotted on nautical charts, using the latitude and longitude coordinates as determined by LORAN C. To identify and correct any positioning errors, the depth and position alignments (e.g., distances from shore objects) of stations plotted on the nautical chart were compared with the depth and VRM ranges obtained in the field (see Tetra Tech 1989a).

Locations of the 50 stations are shown in Figure 1, and positioning data are provided in Table A-1 in Appendix A. Among the 50 stations, water depths ranged from 6.3 to 15 m for 9 stations, from 20 to 24 m for 30 stations, and from 39 to 262 m for 11 stations (corrected to mean lower low water; Appendix A). The sediment samples collected and types of sample analyses conducted at each station are summarized in Table 1. Target analytical variables for chemical analyses are listed in Table 2. Sediment chemistry, sediment toxicity, and benthic community structure were analyzed at all stations. Samples from 3 stations located near pulp and paper mills were also analyzed for resin acids and chloroguaiacols, and samples from 10 stations were analyzed for volatile organic compounds. The selection of stations chosen for analysis of volatile organic compounds is described in Tetra Tech (1989b; pp. 20-21).

SEDIMENT CHEMISTRY

Field Sampling

Sediment samples were collected using a 0.1-m^2 modified single or double stainless steel van Veen grab sampler. The double van Veen grab sampler consists of two single grab samplers joined by a stainless steel bar that allows both samplers to be triggered simultaneously. Field collection procedures followed the recommendations of the Puget Sound protocols (Tetra Tech 1986b) and the *Marine Sediment Quality Implementation Plan* (Striplin 1988), with deviations as noted in the *Review of the Implementation Plan* (Tetra Tech 1989b) and the *Cruise Summary Report* (Tetra Tech 1989a). The following discussion summarizes those procedures and deviations.

Following deployment, the closed grab sampler was retrieved and placed in a sampling tray. The hinged lids of the sampler were opened to inspect the sample. Care was taken to ensure recovery of an intact surface sediment layer, with three major criteria used for rejection of a sample:

TABLE 1. SEDIMENT ANALYSES BY STATION FOR THE 1989 MSMT

Station	Station Description	Semivolatile Organic Compounds[a]	Volatile Organic Compounds[b]	Miscellaneous Organic Acid Compounds[c]	Metals[d]	Conventionals[e]	Amphipod Bioassay	Microtox Bioassay	Benthic Infauna[f]
1	Semiahmoo Bay	X			X	X	X	X	X
2	Cherry Point	X			X	X	X	X	X
3	Strait of Georgia	X	X		X	X	X	X	X
4	Bellingham Bay	X		X	X	X	X	X	X
5 Sample 1[g]	Samish Bay	X	X		X	X	X	X	X
Sample 1R		X	X		X	X			
Sample 2		X	X		X	X			
Sample 3		X	X		X	X			
6	Anacortes	X			X	X	X	X	X
7	Strait of Juan de Fuca	X			X	X	X	X	X
8	Port Angeles Harbor	X		X	X	X	X	X	X
9	Green Point	X			X	X	X	X	X
10	Dungeness Spit	X	X		X	X	X	X	X
11	Discovery Bay	X			X	X	X	X	X
12	Port Townsend	X			X	X	X	X	X
13	North Hood Canal	X			X	X	X	X	X
14	North Hood Canal	X	X		X	X	X	X	X
15	Dabob Bay	X			X	X	X	X	X
16	South Hood Canal	X			X	X	X	X	X
17	South Hood Canal	X	X		X	X	X	X	X
18	Oak Harbor	X			X	X	X	X	X
19	Saratoga Passage	X	X		X	X	X	X	X
20	Port Susan	X		X	X	X	X	X	X
21	Port Gardner	X			X	X	X	X	X
22	Mukilteo	X			X	X	X	X	X
23	East Central Basin	X			X	X	X	X	X
24	East Central Basin	X			X	X	X	X	X
25	West Central Basin	X			X	X	X	X	X
26 Sample 1	West Central Basin	X	X		X	X	X	X	X
Sample 1R		X			X	X			
Sample 2		X			X	X			
Sample 3		X			X	X			
27	Richmond Beach	X			X	X	X	X	X
28	Jefferson Head	X			X	X	X	X	X
29	Shilshole	X	X		X	X	X	X	X
30	Eagle Harbor	X			X	X	X	X	X
31	West Point	X			X	X	X	X	X
32 Sample 1	Magnolia Bluff	X			X	X	X	X	X
Sample 1R		X			X	X			
Sample 2		X			X	X			
Sample 3		X			X	X			

TABLE 1. (Continued)

Station	Station Description	Semivolatile Organic Compounds[a]	Volatile Organic Compounds[b]	Miscellaneous Organic Acid Compounds[c]	Metals[d]	Conventionals[e]	Amphipod Bioassay	Microtox Bioassay	Benthic Infauna[f]
33	Elliott Bay	X			X	X	X	X	X
34	Sinclair Inlet	X			X	X	X	X	X
35	Dyes Inlet	X			X	X	X	X	X
36	Brace Point	X			X	X	X	X	X
37	North Vashon Island	X			X	X	X	X	X
38 Sample 1	Point Pully	X	X		X	X	X	X	X
Sample 1R		X	X		X	X			
Sample 2		X	X		X	X			
Sample 3		X	X		X	X			
39	Dash Point	X			X	X	X	X	X
40	City Waterway	X			X	X	X	X	X
41	Blair/Sitcum Waterways	X			X	X	X	X	X
42	Ruston	X			X	X	X	X	X
43	Carr Inlet	X			X	X	X	X	X
44 Sample 1	East Anderson Island	X			X	X	X	X	X
Sample 1R		X			X	X			
Sample 2		X			X	X			
Sample 3		X			X	X			
45	Devil's Head	X	X		X	X	X	X	X
46	West Nisqually Delta	X			X	X	X	X	X
47	Case Inlet	X			X	X	X	X	X
48	North Budd Inlet	X			X	X	X	X	X
49	South Budd Inlet	X			X	X	X	X	X
50	Shelton	X			X	X	X	X	X

[a] U.S. EPA target compound list variables, including acid/base/neutral organic compounds, PCBs, pesticides, and tentatively identified compounds (TICs). The following indicator chemicals were also analyzed: cholesterol, beta-sitosterol, retene, perylene, caffeine, n-alkanes carbon preference index, and pristane-to-phytane ratio. (See Table 2 for complete list of target chemicals).

[b] U.S. EPA target compound list variables and TICs.

[c] Resin acids and guaiacols (see Table 2).

[d] U.S. EPA target compound list variables.

[e] Total organic carbon, total sulfides, and grain size composition.

[f] Only three of five replicate samples per station were analyzed.

[g] Samples 1 and 1R are analytical replicate samples submitted blind to the laboratory from the field. Samples 2 and 3 are blind field replicate samples.

TABLE 2. TARGET CHEMICALS FOR THE 1989 MSMT

Metals

- Aluminum
- Antimony
- Arsenic
- Barium
- Beryllium
- Cadmium
- Calcium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Magnesium
- Manganese
- Mercury
- Nickel
- Potassium
- Selenium
- Silver
- Sodium
- Thallium
- Vanadium
- Zinc

Semivolatile Organic Compounds

Phenols

- Phenol
- 2-Methylphenol
- 4-Methylphenol
- 2,4-Dimethylphenol

Chlorinated phenols

- 2-Chlorophenol
- 2,4-Dichlorophenol
- 4-Chloro-3-methylphenol
- 2,4,6-Trichlorophenol
- 2,4,5-Trichlorophenol
- Pentachlorophenol

Substituted phenols

- 2-Nitrophenol
- 4-Nitrophenol
- 2,4-Dinitrophenol
- 4,6-Dinitro-o-cresol

Low molecular weight polynuclear aromatic hydrocarbons

- Naphthalene
- Acenaphthylene
- Acenaphthene
- Fluorene
- Phenanthrene
- Anthracene

High molecular weight polynuclear aromatic hydrocarbons

- Fluoranthene
- Pyrene
- Benzo(a)anthracene
- Chrysene
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Benzo(b+k)fluoranthenes
- Benzo(a)pyrene
- Indeno(1,2,3-c,d)pyrene
- Dibenzo(a,h)anthracene
- Benzo(g,h,i)perylene

Chlorinated aromatic hydrocarbons

- 1,2-Dichlorobenzene
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- 1,2,4-Trichlorobenzene
- 2-Chloronaphthalene
- Hexachlorobenzene

Chlorinated aliphatic hydrocarbons

- Hexachloroethene
- Hexachlorobutadiene
- Hexachlorocyclopentadiene

Phthalates

- Dimethyl phthalate
- Diethyl phthalate
- Di-n-butyl phthalate
- Butylbenzyl phthalate
- bis(2-Ethylhexyl)phthalate
- Di-n-octyl phthalate

Miscellaneous extractable compounds

- Isophorone
- Benzyl alcohol
- Benzoic acid
- Dibenzofuran
- beta-Coprostanol
- N-Nitrosodiphenylamine
- 9(H)-Carbazole

TABLE 2. (Continued)

Miscellaneous organic compounds

- beta-Sitosterol
- 4-Bromophenyl-phenylether
- Caffeine
- 4-Chloroaniline
- bis(2-Chloroethoxy)methane
- bis(2-Chloroethyl)ether
- bis(2-Chloroisopropyl)ether
- Cholesterol
- Cymene
- 3,3'-Dichlorobenzidine
- 2,4-Dinitrotoluene
- 2,6-Dinitrotoluene
- 2-Methylnaphthalene
- N-Nitroso-di-n-propylamine
- 2-Nitroaniline
- 3-Nitroaniline
- 4-Nitroaniline
- Nitrobenzene
- Perylene
- Retene
- 4-Chlorophenyl-phenylether
- n-Alkanes carbon preference index
- Pristane-to-phytane ratio

Resin acids/guaiacols (3 stations only)

- Abietic acid
- Chlorodehydroabietic acid
- Dehydroabietic acid
- Dichlorodehydroabietic acid
- 4,5-Dichloroguaiacol
- Isopimaric acid
- 2-Methyoxyphenol (Guaiacol)
- Neoabietic acid
- Palustric acid
- Pimaric acid
- Sandacopimaric acid
- Tetrachloroguaiacol
- 3,4,5(4,5,6)-Trichloroguaiacol

Pesticides/PCBs

- p,p'-DDD
- p,p'-DDE
- p,p'-DDT
- Aldrin
- alpha-BHC
- beta-BHC
- delta-BHC
- gamma-BHC (Lindane)
- alpha-Chlordane
- gamma-Chlordane
- Dieldrin
- Endosulfan I
- Endosulfan II
- Endosulfan sulfate
- Endrin
- Endrin ketone
- Heptachlor
- Heptachlor epoxide
- Methoxychlor
- Toxaphene
- Aroclor 1016/1242
- Aroclor 1248
- Aroclor 1254
- Aroclor 1260

Volatile Organic Compounds

- Acetone
- Benzene
- Bromodichloromethane
- Bromoform
- Bromomethane
- 2-Butanone
- Carbon disulfide
- Carbon tetrachloride
- Chlorobenzene
- Chloroethane
- 2-Chloroethylvinylether
- Chloroform
- Chloromethane
- Dibromochloromethane
- 1,1-Dichloroethane
- 1,2-Dichloroethane
- 1,1-Dichloroethene
- cis-1,2-Dichloroethene
- trans-1,2-Dichloroethene
- 1,2-Dichloropropane
- cis-1,3-Dichloropropene
- trans-1,3-Dichloropropene
- 1,1,2-Trichloro-1,2,2-trifluoroethane
- Ethylbenzene
- 2-Hexanone
- Methylene chloride
- 4-Methyl-2-pentanone
- Styrene
- 1,1,2,2-Tetrachloroethane
- Tetrachloroethene
- Toluene
- 1,1,1-Trichloroethane
- 1,1,2-Trichloroethane
- Trichloroethene
- Vinyl acetate
- Vinyl chloride
- Total xylenes

- Sediments overflowing (i.e., >16-17 cm penetration depth) from the sampler, with sediment touching the rubber flaps or wire mesh of the sampler

- Water leaking from the sides or bottom of the sampler (i.e., indicating that the interstitial water in the sample was being mixed with overlying seawater), or visible scour of the sediment surface near the edges of the sampler

- Turbid water overlying the sediments.

Samples were also rejected if they did not meet the following minimum penetration depths in various sediment types:

- Medium to coarse sand and gravel - 4 to 5 cm

- Fine sand and sandy silt - 7 to 10 cm

- Silt - 10 cm.

Numerous grabs at a single station were sometimes necessary to obtain an acceptable depth of penetration. If an acceptable penetration depth could not be achieved even after numerous attempts, then the station was repositioned to a nearby area.

Once a sample was judged to be acceptable, standardized collection data (i.e., collection date and time, station location, depth, and replicate number) and the following qualitative sediment characteristics were recorded on field logsheets (see Tetra Tech 1989a):

- Penetration depth

- Sediment texture

- Sediment color

- Presence and strength of odors
- Degree of leakage and surface disturbance
- Presence of debris or shell fragments.

After the foregoing observations were recorded, overlying water was carefully drained by manual siphoning techniques. Subsamples for volatile organic compound analyses were taken by removing sediments from the top 2-cm of a single grab sampler (using a stainless steel spoon) and then filling two 4-oz wide-mouth glass jars. Two additional 4-oz glass jars were filled with sediments at each of two stations for matrix spike (MS) and matrix spike duplicate (MSD) analyses. Approximately 5-10 g of sediments for total sulfides analyses were also quickly removed from the sampler by using a stainless steel spoon, placed in a plastic container, and preserved with 5 mL of zinc acetate. The zinc acetate and sediments were thoroughly mixed, and samples were then stored in a cooler on ice.

The remaining subsamples were taken from a homogenized sample. For each station, the upper 2 cm of sediments from a minimum of three separate casts of the grab sampler were carefully removed with a stainless steel spatula, transferred to a stainless steel bowl, and homogenized by stirring with a stainless steel spoon. (In most cases where the double grab sampler was used, sediments for chemical analysis were removed from one of the two grab samplers and sediments for benthic infauna analysis were removed from the other sampler.) Samples were stirred until uniform color and texture were observed. Subsamples from the homogenized sediments were collected as follows:

- 500 mL (16 oz) was transferred to a precleaned glass jar with a tetrafluoroethene (TFE) cap liner for organic, pesticide/PCBs, and total organic carbon (TOC) analyses. (At three stations, these sediments were also used for resin acid and

guaiacol analyses.) An additional 500 mL of sediments was collected at six stations for MS and MSD analyses.

- 125 mL (4 oz) was transferred to an acid-rinsed high density polyethylene container for metal analyses. An additional 125 mL of sediments was collected at six stations for MS and MSD analyses.

- Approximately 125 mL (4 oz) was transferred to double-wrapped Ziploc bags for grain size analysis.

- 250 mL (8 oz) was transferred to a precleaned glass jar with a TFE cap liner for Microtox bioassay analysis.

- 1 L (32 oz) was transferred to a precleaned glass jar with a TFE cap liner for amphipod bioassay analysis.

Sample tracking records (i.e., chain-of-custody and analysis request forms) followed each sample through all stages of sample collection and laboratory processing. Sampling equipment was rinsed with site water and methylene chloride between sampling stations.

For this program, three project comparison samples (PCS) were prepared using homogenized archived sediment from Sequim Bay, which had been prepared as a fortified sample by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service for the U.S. Environmental Protection Agency (EPA) Region X Office of Puget Sound. Dr. Raleigh Farlow, of Jacobs Engineering Group (Seattle, Washington), placed the PCS material in containers that were similar to those being used during the field effort. The containers with the PCS material were transferred to field personnel, who labeled the samples to hide their identity from the laboratory (hence "blind" samples), and those PCS were submitted with other sediment samples to the chemistry laboratory for analysis.

Blind laboratory replicate samples (Samples 1 and 1R in Table 1) and two blind field replicate samples (Samples 2 and 3 in Table 1) were prepared in the field at five stations (i.e., Stations 5, 26, 32, 38, and 44) and were labelled to hide their identity from the laboratory. Blind laboratory replicate and blind field replicate samples for volatile organic compound analyses were collected at two of the five stations (i.e., Stations 5 and 38). The blind laboratory replicate samples were analyzed to measure analytical variability in sediment chemical concentrations. Blind field replicate samples were analyzed to measure within-station variability, which includes an analytical variability component and a within-station variability component.

Blind laboratory replicates for analyses of semivolatile organic compounds, metals, total organic carbon, and grain size were prepared using the top layer (0-2 cm) of sediments from at least six separate casts of the grab sampler. Those sediments were composited and homogenized in the field and split into separate sample containers. Because sediments for volatile organic compounds and total sulfides analyses cannot be homogenized, it is not possible to prepare true blind laboratory replicates. However, it is possible to measure within-grab variability for volatile organic compounds and total sulfides. In the MSMT, nonhomogenized and noncomposited sediments from a single grab sampler were placed in four 4-oz jars for volatile organic compounds and two containers for total sulfides analyses to measure within-grab variability.

To prepare a blind field replicate sample for each type of chemical analysis (except volatile organic compounds and total sulfides), a minimum of three separate casts of the grab sampler were made at a single station. For each blind field replicate sample, the upper 2-cm layer of sediments from each of the casts was homogenized in a bowl, and the homogenized sediments were placed in sample containers. Blind field replicate samples were also prepared for volatile organic compounds and sulfides analyses. Separate casts of the grab sampler were used for each field replicate sample, and nonhomogenized and noncomposited sediments from a single grab sampler were placed in two 4-oz jars for volatile organic compound analyses

and one container for sulfides analyses. If sediments were also to be used for MS/MSD analyses of volatile organic compounds, then it was necessary to place nonhomogenized sediments from a single grab sampler in six 4-oz jars.

Laboratory Analyses

The methods used for analyses of conventional, metal, and organic compound analyses are listed in Table G-4 in Appendix G and briefly described below. As shown in Table G-4, the methods used during the 1989 MSMT are either equivalent or comparable to the Puget Sound protocols (Tetra Tech 1986b).

Conventional Variables--

Sixty-five samples were analyzed for grain size, total solids, TOC, and total sulfides, including 1 sample from each of 50 stations, 5 field-generated laboratory replicate samples (1 from each of 5 stations), and 10 field replicate samples (2 from each of 5 stations). In addition, total solids and TOC analyses were performed on three PCS, and MS and MSD analyses were performed on TOC and total sulfides samples. The grain size and total sulfides analyses were performed by Columbia Analytical Services of Longview, Washington. The TOC and total solids analyses were performed by Analytical Resources, Inc. (ARI) of Seattle, Washington.

Methods used for the analysis of conventional variables are briefly described below:

- Grain size - Sample analyses were conducted according to the Puget Sound protocols (Tetra Tech 1986b). Options in that protocol that were implemented in the MSMT are as follows: 1) to maintain the integrity of the organic or carbonaceous particles, sediments were not treated with hydrogen peroxide, and 2) pipet analyses were repeated if sediments comprised <5 g or >25 g silt and clay (except where the total sample weight of 20-100 g would be violated).

- Total solids - Percent moisture was determined according to the Puget Sound protocols (Tetra Tech 1986b).

- Total organic carbon - Sample analyses were conducted according to the Puget Sound protocols (Tetra Tech 1986b). However, triplicate analyses were not performed on 5 percent of the samples, although this is recommended in the protocols.

- Total sulfides - Samples were analyzed according to the Puget Sound protocols (Tetra Tech 1986b).

Metals--

Sixty-eight sediment samples were analyzed, including 1 sample from each of 50 stations, 5 field-generated laboratory replicate samples (1 from each of 5 stations), 10 field replicate samples (2 from each of 5 stations), and 3 PCS. Samples were analyzed for each of the 23 metals on the U.S. EPA target compound list (TCL) (see Table 2) by ARI. Data were reported in mg/kg dry weight.

Samples were analyzed according to the U.S. EPA Contract Laboratory Program (CLP) Statement of Work (SOW) 788 for inorganics analysis (U.S. EPA 1988c). As a modification to the CLP SOW, antimony, arsenic, cadmium, lead, selenium, silver, and thallium were analyzed by graphite furnace atomic absorption (GFAA), and all furnace analytes were quantitated by the method of standard additions (MSA) for improved detection limits and increased accuracy. Lead concentrations in samples from Stations 32 (Sample 2), 33, 34, and 35 were analyzed by inductively coupled plasma (ICP) atomic emission spectroscopy, and nickel concentrations in samples from Stations 5 (Sample 1R), 32 (Sample 2), and 44 (Sample 3) were analyzed by GFAA. For this program, method quantitation limits were lowered by digesting larger sample sizes and reducing final digestate volumes.

Sediments were prepared for metal analyses by homogenizing each sediment sample, followed by acid digestion of three separate sediment aliquots. Digestions were performed according the U.S. EPA CLP SOW 788. Two of the three aliquots were digested in nitric acid and hydrogen peroxide. One of the digestates was refluxed with nitric acid prior to GFAA analysis of arsenic, cadmium, lead, selenium, silver, and thallium. The second digestate was refluxed with hydrochloric acid for the furnace analysis of antimony, aluminum, barium, beryllium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, nickel, potassium, sodium, vanadium, and zinc. The appropriate digestates were subsequently analyzed by ICP and GFAA using Smith-Heiftje correction. Mercury analyses were conducted using concentrated nitric and sulfuric acid digestions, followed by potassium permanganate and potassium persulfate oxidation. Cold vapor atomic absorption spectrophotometry was used for the instrumental determination of mercury. Steps implemented for QC are described in the CLP SOW and in the data validation memorandum (see Appendix B).

Following data validation, sediment metal concentrations at MSMT stations were compared to available historical sediment data reported in the *Puget Sound Environmental Atlas* (Evans-Hamilton and D.R. Systems 1987). The mercury concentrations reported for MSMT Stations 5 (Sample 3; Samish Bay) and 11 (Discovery Bay) were substantially higher than sediment mercury data reported for Samish and Discovery Bays in the atlas. Mercury concentrations at Stations 5 (Sample 3) and 11 were the highest mercury values found in the MSMT data. Because blind analytical replicate and blind field replicate samples had been collected at Station 5, it was possible to compare analytical results from different samples at Station 5. Mercury concentrations in three of four replicate samples for Station 5 were reported at the quantitation limit (U0.11-U0.13), and the concentration in the fourth replicate (Station 5, Sample 3) was about 18 times higher. Based on those findings, mercury data for Stations 5 (Sample 3) and 11 were suspect. Because archived (frozen) sediment samples were available, two samples from Station 5 and one sample from Station 11 were reanalyzed for mercury. Mercury was not detected in those samples. In subsequent discussions, ARI indicated that their laboratory had analyzed sediment

samples from a different client (which had contained high mercury concentrations) prior to the analysis of MSMT samples. Mercury from those sample analyses may have been carried over to the MSMT samples. ARI recommended that the mercury data initially reported for Stations 5 and 11 should be replaced with the new data from the mercury reanalyses. Mercury data found at other MSMT stations were consistent with or lower than the historical data reported in the *Puget Sound Environmental Atlas*.

Semivolatile Organic Compounds--

Sixty-eight sediment samples were analyzed, including 1 sample from each of 50 stations, 5 field-generated laboratory replicate samples (1 from each of 5 stations), 10 field replicate samples (2 from each of 5 stations), and 3 PCS. Samples were analyzed for each of the semivolatile organic compounds on the U.S. EPA TCL and additional variables as listed in Table 2. Four samples (i.e., Stations 4, 8, 21, and PCS Sample 66) were also analyzed for 13 resin acids and substituted guaiacols (see Table 2). Per CLP requirements, gas chromatography/mass spectrometry (GC/MS) searches for additional organic compounds or compound classes [i.e., tentatively identified compounds (TICs)] were performed on all sediment extracts. All analyses were performed by ARI, and data were reported in ug/kg dry weight.

Samples were analyzed for semivolatile organic compounds by using a method modified from the U.S. EPA CLP SOW for organic compound analyses (U.S. EPA 1988d). The analytical protocol employed options and techniques that are described in the *Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound* (Tetra Tech 1986b). In summary, the method utilizes sediment extraction by methylene chloride/acetone and analysis by GC/MS. To achieve required method quantitation limits, large sample sizes (approximately 100 g wet weight) were analyzed, and nonpolar and polar fractions were analyzed after class fractionation on a solid phase silica gel extraction column.

Sediment samples were extracted using a modified U.S. EPA Method 3550. Two aliquots of sample (approximately 50 g wet weight) were each spiked

with 25-50 ug surrogate standards and extracted three times with methylene chloride/acetone (1:1), using an ultrasonic probe for homogenization. The extracts from the two aliquots were combined and concentrated to 2 mL prior to gel permeation chromatography (GPC) cleanup. GPC cleanup was accomplished on a 25x400 mm column of Bio Beads SX-3, prepared using U.S. EPA CLP protocol and calibrated with corn oil, bis(2-ethylhexyl)phthalate, pentachlorophenol, and elemental sulfur.

Subsequent fractionation into nonpolar and polar classes was accomplished on a solid phase silica gel extraction column following extract exchange into n-hexane. The two eluted fractions (nonpolar and polar) were concentrated to 0.5 mL and analyzed by GC/MS. Additional detail concerning analytical methodology and performance is provided in the data validation QA memorandum in Appendix B.

For analyses of resin acids and substituted guaiacols, an acid fraction was prepared from a split of the extract used for analyses of organic compounds, and the compounds were quantitated by employing a three-point GC/MS calibration curve. Derivatization of resin acids and substituted guaiacols to methyl esters and methyl ethers was performed by reaction of diazomethane with the acid fraction of sample extracts.

Pesticides and PCBs--

Sixty-eight sediment samples were analyzed, including 1 sample from each of 50 stations, 5 field-generated laboratory replicate samples (1 from each of 5 stations), 10 field replicate samples (2 from each of 5 stations), and 3 PCS. Samples were analyzed for PCBs and 20 pesticides on the U.S. EPA TCL (see Table 2) by ARI. Data were reported in ug/kg dry weight.

Samples were analyzed using a method modified from the U.S. EPA CLP SOW for organic compound analyses (U.S. EPA 1988d), using dual column capillary gas chromatography/electron capture detection (GC/ECD). To achieve lower quantitation limits, larger sample sizes were analyzed (approximately 150 g). The full protocol is consistent with the analytical

method options described in the *Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound* (Tetra Tech 1986b). Additional detail concerning analytical methodology and performance is provided in the QA memorandum in Appendix B.

Volatile Organic Compounds--

Eighteen sediment samples were analyzed, including 1 sample from each of 10 stations, 2 field-generated laboratory replicate samples (1 from each of 2 stations), 4 field replicate samples (2 from each of 2 stations), and 2 PCS. Samples were analyzed for 36 volatile organic compounds on the U.S. EPA CLP TCL and 1,1,2-trichloro-1,2,2-trifluoroethane (see Table 2). Per CLP requirements, GC/MS searches for additional TICs were performed on all sediment extracts. Analyses were performed by ARI, and data were reported in ug/kg dry weight.

Samples were analyzed using a method modified from the U.S. EPA CLP SOW for organic analyses (U.S. EPA 1988d). To achieve required quantitation limits, large sample sizes (approximately 100 g wet weight) were analyzed, and specific laboratory setups were modified to increase instrumental sensitivities (e.g., extended purge times and increased multiplier voltage for increased sensitivity). The full protocol is consistent with the analytical method options described in the *Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound* (Tetra Tech 1986b). All QC was in accordance with the requirements of the U.S. EPA CLP SOW. Additional detail concerning analytical methodology and performance is provided in the QA memorandum in Appendix B.

Treatment of Undetected Values and Calculation of Mean Values

Detection limits for chemical variables are generally defined as the lowest measurable concentration reliably detectable by a particular methodology. For the MSMT data, a "U" or "<" was assigned to the value of the chemical that was not detected at the detection or quantitation limit (QL) shown. For example, U15 ug/kg phenol indicates that phenol was not

detected in the sediment sample, and that the phenol concentration in that sample is less than 15 ug/kg (i.e., the concentration may range from 0-15 ug/kg).

In the 1989 MSMT, undetected and detected values were reported. To determine the range of values (i.e., minimum and maximum values) for each chemical variable, both undetected and detected values from all MSMT samples were used (see RESULTS, Sediment Chemistry). Thus, the range of values for most metals, semivolatile organic compounds, pesticides, and PCBs were determined using 65 values (50 station + 15 replicate samples).

Both undetected and detected values were also used to calculate mean values for each chemical variable. However, the undetected values were treated differently than the detected values. In calculating mean values, use of the detection or quantitation limit as a real value would tend to overestimate concentrations of chemicals in any subsequent calculations. The indiscriminate use of "0" as the value of all undetected chemicals would tend to underestimate concentrations of chemicals that may be present at finite but unmeasured concentrations. To minimize the overall biases that would occur as a result of applying either of the first two approaches, undetected values that were used in mean calculations in MSMT analyses were either treated as QL/2 or zero (see Tetra Tech 1989b). Although it would not be appropriate to use this approach if detection/quantitation limits were high, the detection/quantitation limits were low enough in this study to use this treatment (see Tetra Tech 1989b; pp. 22-24). The treatment of undetected values as QL/2 or zero is summarized below:

- QL/2 - All metals (except barium, thallium, cobalt, and vanadium); methylene chloride, 1,1-dichloroethane, 1,1,1-trichloroethane, carbon tetrachloride, 1,1,2-trichloroethane, trichloroethylene, benzene, toluene, ethylbenzene, styrene, total xylenes, chlorobenzene, acetone, carbon disulfide, 2-butanone, and 4-methyl-2-pentanone; all semivolatile organic compounds (except those noted below); p,p'-DDE; PCBs; total sulfides; and TOC.

- Zero - Barium, thallium, cobalt, and vanadium; all volatile organic compounds (except those noted above); the semivolatile organic compounds 2-methylphenol, 4-methylphenol, all chloro- and nitro-substituted phenols, all resin acids and guaiacols, all chloro-aromatics and aliphatics, dimethylphthalate, di-n-octylphthalate, isophorone, all nitro aromatics, and N-nitro-samines; all pesticides (except p,p'-DDE).

The overall mean and 90th percentile values for each chemical variable were calculated using 3 values for resin acids/guaiacols, 10 values for volatile organic compounds, and 50 values for most other analytes, as follows:

- If all replicate values for a given variable were undetected, the mean of the undetected values was calculated and a "U" qualifier was assigned.

- If one or more values for a given variable were detected in a sample, then all of the detected values and detection limits were averaged. The value of the detection limit that was used was the quantitation limit divided by 2 (QL/2) or zero (Tetra Tech 1989b).

In the 1989 MSMT, it was also necessary to calculate a single mean value for each chemical variable at each of the five monitoring variability stations (i.e., stations at which blind field replicates were collected). At those stations, mean values were calculated using results from each of the four separate replicate samples, as follows:

- Metals, semivolatile organic compounds, pesticides and PCBs, total organic carbon, and grain size - Because a combination of analytical and field replicates existed at a single station, the mean of the analytical replicates was calculated and averaged with the values from the field replicates. Thus,

mean values were calculated by first determining the mean of the laboratory analytical replicates [i.e., (Sample 1 + Sample 1R)/2], and then adding Samples 2 and 3, and dividing by 3 [i.e., (((Sample 1 + 1R)/2) + Sample 2 + Sample 3)/3]. The means of the analytical replicates were determined first because those samples were taken from homogenized sediments from a grab, and the field replicates were taken from unhomogenized sediments from different casts of the grab (intuitively, analytical variability should be less than field variability because analytical replicate samples are collected from homogenized sediments).

- Volatile organic compounds and total sulfides - For these compounds, mean values were calculated by a different method [i.e., (Sample 1 + Sample 1R + Sample 2 + Sample 3)/4]. This method was used because the analytical replicates for these compounds were taken as separate samples and not from homogenized sediments.

All mean values were reported to the same number of significant figures as the individual with the fewest significant figures.

SEDIMENT TOXICITY BIOASSAYS

Field Sampling

Sediment samples from 50 stations in Puget Sound were analyzed for toxicity by both the amphipod (*Rhepoxynius abronius*) test and the Microtox bacterium (*Photobacterium phosphoreum*) test. These analyses were performed on a subsample of the homogenized sediment sample collected for chemical analyses. Field collection methods for sediment samples are described above (see SEDIMENT CHEMISTRY, Field Sampling).

The infaunal amphipod *R. abronius* was collected subtidally from West Beach on Whidbey Island, Washington using a bottom dredge. Amphipods were maintained in clean coolers with ice, and were transported to the laboratory within 24 h of collection.

Laboratory Analyses

Amphipod Bioassay--

Amphipod bioassay tests were performed by INVERT*AID of Tacoma, Washington. Amphipod acclimation procedures and holding times followed recommendations of the Puget Sound protocols (Tetra Tech and E.V.S. 1986). The mortality of amphipods exposed for 10 days to fresh (unfrozen) test sediments from Puget Sound and to clean control sediments from West Beach (Whidbey Island) was measured according to the method described in the Puget Sound protocols. Bioassays were conducted on five analytical laboratory replicates of each test sediment and each control sediment. For each analytical replicate, a 2-cm layer of sediment was placed in the bottom of a 1-L glass container and covered with 800 mL of seawater (28 ppt salinity). After resting undisturbed overnight, each beaker was seeded with 20 amphipods and aerated. Test containers were checked daily to establish early trends in mortality and amphipod emergence, and also to gently submerge any amphipods that had become trapped by surface tension at the air/water interface. One of the analytical laboratory replicate containers for each sediment bioassay was also used for daily measurements of water chemistry (i.e., temperature, salinity, dissolved oxygen, and pH).

Reference toxicant (i.e., positive control) bioassays were conducted in parallel with the sediment bioassays described above. In each reference toxicant bioassay, ten amphipods were exposed for 96 h to each of five concentrations (i.e., 0.5, 1.0, 1.5, 2.0, and 3.0 mg/L) of cadmium chloride dissolved in seawater. The numbers of dead organisms were enumerated at the end of the exposure period, and 96-h LC_{50} values (i.e., the concentration of cadmium chloride lethal to 50 percent of the test organisms) were determined for each test series to evaluate sensitivity of the test animals (as per the

Puget Sound protocols). Additional details on the laboratory method are provided in the amphipod bioassay QA memorandum in Appendix B.

Microtox Bioassay--

Sediment toxicity tests using the Microtox procedure on saline extracts of the sediment were performed by Laucks Testing Laboratory of Seattle, Washington. Sediment storage and holding times, the Microtox testing apparatus and test procedures, weight of test sediments, numbers of analytical laboratory replicates, and the duration of bioassays followed recommendations of the Puget Sound protocols (Tetra Tech and E.V.S. 1986) and the *Marine Sediment Quality Implementation Plan* (Striplin 1988). The Microtox bioassay test method is briefly described below, and details are provided in the Microtox bioassay QA memorandum in Appendix B.

Bioassays were conducted on saline extracts of individual sediment samples with two analytical replicates of each concentration of test sediment extract. Sediment samples were prepared by transferring 30 mg of sediments from the 8-oz sample jars to 30-mL glass containers. Those sediments were washed for 24 h in 10 mL of Microtox diluent in the dark at 4^{o} C by gentle agitation on a rotary shaker table. The sediment slurries were then transferred to 30-mL Corex tubes and centrifuged for 15 min. The supernatant was drawn off by pipet, placed in a clean test tube, cooled on ice, and used immediately in preparation of dilutions for the bioassay. Reagent controls were performed with each test sediment sample.

Sediment supernatant dilutions of 100, 50, 25, and 12.5 percent were prepared. After initial luminescence was measured, sediment supernatant was added to the bacterial suspension in a volume equal to the diluent (i.e., 0.5 mL) to make final sediment supernatant dilutions of 50, 25, 12.5, and 6.25 percent. Luminescence was then measured after 5 and 15 min.

Two reference toxicant bioassays were conducted in parallel on each day of the sediment sample bioassays. Bacteria were exposed either to sodium arsenate (101, 50.5, 25.25, and 12.13 mg/L) or to phenol (80, 40, 20, and

10 mg/L) in Microtox diluent, and luminescence was measured at 0, 5, and 15 min. Results of reference toxicant bioassays were used to determine EC_{50} values (i.e., the concentration of phenol or arsenate that causes a 50 percent decrease in luminescence), which were used to assess the day-to-day performance of the bioassay and to determine differences in toxic response among different batches of bacteria.

BENTHIC COMMUNITY STRUCTURE

Field Sampling

Benthic infauna samples were collected at 50 subtidal stations in Puget Sound. Five field replicate grab samples were collected at each station, for a total of 250 samples. All grab samples were collected using a 0.1-m^2 modified single or double van Veen grab sampler. In the field, samples were washed on a sieve with 1.0-mm mesh openings and fixed with a 10 percent solution of buffered formalin. Sample tracking records followed each sample through all stages of sample collection and laboratory processing.

The field sampling methods used to collect benthic infauna samples are detailed in the *Marine Sediment Quality Implementation Plan* (Striplin 1988) and the Puget Sound protocols (Tetra Tech 1986b). Those procedures were briefly described above (see METHODS, Sediment Chemistry), and additional information is provided below.

After a sample was judged acceptable, the sampler was opened and sediments were released into the top section of the sieving stand. If the double van Veen grab sampler was used, sediments in one of the two grab samplers were removed for chemical analyses before sediments in the second grab sampler were released into the top section of the sieving stand. If the sampler contained water, the overlying water was allowed to slowly enter the upper section of the sieving stand before the grab was completely opened. The sediment was then washed from above with a gentle spray of seawater, and the larger masses of sediment were broken apart. Sediment was

rinsed into a sieve box located in the lower level of the sieving stand. The sediment in the sieve box was then completely washed until materials no longer passed through the 1.0-mm mesh screen. That portion retained on the screen was placed in a plastic sample bag having external and internal labels. Samples were fixed in the field with a 10 percent solution of Borax-buffered formalin.

Laboratory Analysis

In the laboratory, benthic infauna samples were washed on a 0.5-mm sieve and transferred to a 70 percent solution of alcohol. The rescreening process was performed by Herrera Environmental Consultants of Seattle, Washington, and QA/QC was conducted by Tetra Tech.

Of the 250 samples scheduled for analysis, 100 samples (i.e., replicates 2 and 4 for each station) were transferred to Mr. Peter Striplin of Ecology for archival. These samples have not been processed. The remaining 150 samples (i.e., replicates 1, 3, and 5 from each station) were sorted and identified by Marine Taxonomic Services of Corvallis, Oregon. (Project personnel are identified in the Acknowledgments.) Organisms were sorted to major taxonomic groups and then identified to the lowest possible taxonomic level. Planktonic organisms that occurred in the samples were not enumerated, and colonial organisms were noted as "present" (and coded with an abundance of 1 in the database) but were not enumerated.

Quality control checks of sample sorting were performed by resorting 20 percent of each sample. If the 20 percent resort indicated a calculated difference of 5.0 percent or greater in total sample abundance for all taxa combined, the entire sample was resorted. Quality control checks of taxonomic identifications were performed by having one taxonomist re-identify 5 percent of another taxonomist's samples. At least one specimen of each genus and species identified in the MSMT survey was placed in a voucher collection (i.e., reference museum) to be archived by Ecology for use in future MSMT programs. Specimens placed in the museum were verified by expert taxonomists. Taxonomic identifications were also compared with

specimens in the Puget Sound voucher collection, which was prepared during Puget Sound Estuary Program studies for the U.S. EPA Region X Office of Puget Sound. Therefore, taxonomic identifications of benthic infauna performed during the 1989 MSMT survey are comparable with taxonomic identifications of benthic infauna performed during the Puget Sound Estuary Program urban embayment studies [i.e., Elliott Bay (PTI and Tetra Tech 1988a), Everett Harbor (PTI and Tetra Tech 1988b)].

DATA MANAGEMENT AND ANALYSES

Data management followed procedures outlined in the *Marine Sediment Quality Implementation Plan* (Striplin 1988). All numerical field data (e.g., navigational coordinates, sampling dates) and laboratory data collected during the 1989 MSMT survey were stored in a dBase III-compatible microcomputer database. The database software allows users to perform a wide variety of retrievals, reports, and analyses. Data can also be transferred to other software (e.g., SAS, Lotus 1-2-3, and Excel) for statistical analyses and graphic displays. A dictionary is incorporated into the database to provide descriptions of data codes and qualifiers. The data have been transferred to Ecology's Ambient Monitoring Section (AMS) database, and Ecology has transferred the data to the PSWQA Puget Sound Ambient Monitoring Program central database. Both data transfers used the PSAMP data transfer formats (PSWQA 1988b).

Data Entry and Quality Control

Quality control of the data was based upon technical evaluation of the data, automated error-checking procedures in the database, and visual verification of all data values. Technical review of the data was carried out before data entry and during analysis and interpretation. All data were documented and linked with a simple numbering system (i.e., reference code) to the raw data sheets from the laboratory. All original data sheets were compiled into three-ring binders by discipline, with the exception of gas chromatographs for volatile and semivolatile organic compound data, which

were collated and paginated in document files and stored in banker boxes. These data sheets will be archived by Ecology.

Data were linked by station and sample numbers so that related kinds of information could be retrieved together for interdisciplinary analyses. During data retrievals, data could be summarized across blind laboratory replicates and field replicates.

Data Analyses

Procedures for summarizing data were programmed into the database, providing consistent treatment and formatting of the data for analysis and interpretation. These procedures included the ability to retrieve all data by station and sample, to perform normalization of chemical data to percent fines and percent total organic carbon, to list only chemical compounds that were detected, to rank chemicals at selected stations, to construct benthic species lists by field replicate or station, to summarize data by major taxonomic group, and to summarize data in formatted tables. Statistical analyses were carried out using SAS, and Lotus 1-2-3 was used for other analyses and data manipulations. A custom SAS program was written to calculate the Infaunal Trophic Index (ITI) values and other benthic indices (e.g., Pielou's equitability). Certain statistical analyses of sediment chemistry data were performed using SYSTAT, a statistics and graphics program from SYSTAT, Inc. (Evanston, Illinois).

Selection of Probability Levels for Statistical Testing--

Statistical tests were applied to sediment chemistry, sediment toxicity, and benthic community data to determine whether certain hypotheses were true. Using statistics, proof of a hypothesis is obtained by showing a lack of support for a null (opposite) hypothesis. For example, if it is desirable to test the hypothesis that species richness is greater in shallow versus deep areas, the null hypothesis tested is that there is no difference in species richness between the two depth intervals. A rejection of the

null hypothesis would indicate that differences in species richness at the two depth intervals probably exists.

True/false hypothesis testing is subject to two types of errors. The null hypothesis may be rejected when it is true (Type I error) or the null hypothesis may be accepted when it is false (Type II error). The occurrence of both Type I and II errors is affected by the number of samples. [In general, when sample size increases, the rate at which both errors occur decreases.] The probability or risk of the occurrence of a Type I error is controlled by the *a priori* selection of a significance level for the statistical test applied. Typically, significance levels of 0.01 and 0.05 are chosen by investigators as acceptable risk levels in evaluating environmental data. For example, a selection of alpha (α) = 0.05 means that investigators are willing to accept the risk of making a Type I error 5 percent of the time. The risk of Type II errors occurring is generally unknown, although it is generally inversely related to the risk of making a Type I error.

In many environmental investigations, measurements are made for multiple conditions (e.g., species richness measured at ten depth intervals). Certain statistical tests can only determine if a difference occurs among all cases, and results do not identify where the difference occurs. It then becomes necessary to perform multiple comparisons among pairs of values to determine which values are different (e.g., mean abundance at Station A vs. mean abundance at Station B). Application of simple two-sample test statistics for performance of multiple comparisons (e.g., mean abundance at Station A vs. mean abundance at Stations B, C, D, and E) increases the risk of a Type I error due to the loss of independence among the pairs of comparisons (Zar 1974). As the number of paired comparisons increases, the risk of making a Type I error approaches 100 percent. One method of controlling this risk when testing multiple pairs of values is to control the comparison-wise error rate by adjusting the significance level based on the number of comparisons to be made. If a significance level of 0.05 was selected for a series of 50 comparisons (i.e., comparing mean abundance at 50 stations with the mean abundance at one reference station), the proba-

bility of correctly identifying all significant differences is $(1-\alpha)^{50}$ or 7.7 percent. By adjusting the significance level to 0.001, the probability of correctly identifying all significant differences is increased to 95 percent. Some statistical tests are designed to make multiple comparisons and minimize the experiment-wise error rate (e.g., Student-Newman-Keuls and Dunnett's tests). Adjustment of the significance level for multiple comparison tests have been used in this study where appropriate.

Sediment Chemistry--

Sediment chemistry data were analyzed to examine the spatial distribution of contaminants in Puget Sound and to provide baseline information for future temporal comparisons. Chemistry data were initially summarized by station and geographic area. Mean values and frequency of detections were determined for metals for each geographic area and for metals and organic compounds for the entire data set.

Comparisons were made between MSMT data and data reported in the *Puget Sound Environmental Atlas* (Evans-Hamilton and D.R. Systems 1987). The Atlas presents sediment chemistry data from 16 field surveys that were conducted throughout Puget Sound from 1980 to 1986. The integrity of Atlas data is high because data were subjected to an extensive QA/QC evaluation before any data were incorporated into the Atlas. Also, the analytical methods used for Atlas data provides data that are comparable to MSMT data. In comparisons between Atlas and MSMT data, the area weighted (AW) mean values presented in the Atlas were used. The AW mean values were calculated based on areal coverage of chemical concentrations and do not represent an average of all available data values. First, ranges of chemical concentrations were used to partition Puget Sound. A relationship between the midpoint of that range and the areal coverage of that range was used to calculate the mean values, such that weighted estimated mean values were obtained for specific geographic areas. This method minimizes the bias presented by the large amount of data that have been collected from urban embayments.

Using only detected values, Pearson's product-moment correlation coefficients were calculated for pairs of chemicals and selected physical variables (e.g., percent fines, percent TOC). Significant correlations were defined at $P>0.01$. Graphical plots were prepared to examine the distribution and relationship of paired variables.

Linear regression analyses using the least squares method of fit were conducted (using both detected and undetected values) for variables that showed a significant ($P<0.01$) correlation with percent fines. The test of significance was chosen at $P<0.01$ to reduce the probability of making Type I errors. Relationships between chemicals and percent fines for which $0.001<P<0.05$ were found only for PCBs ($P = 0.041$; $r = 0.49$), which suggests a fairly weak relationship. The regression results were used to determine percent enhancements of chemical concentrations at MSMT stations relative to fines content, using the following equation:

$$\text{Enh} = \frac{100 \times (\text{Concentration} - \text{Predicted Concentration})}{\text{Predicted Concentration}}$$

Enh = Percent enhancement
Concentration = Measured concentration of variable
Predicted Concentration = Predicted concentration of measured variable relative to percent fines

Percent enhancements were either positive (i.e., enrichments) or negative (i.e., depressions).

Because replicate samples were collected at only five stations during the 1989 survey, no tests of significant differences among stations were performed. Relative differences (RD) between analytical laboratory and blind laboratory replicates were calculated. Univariate statistics, including mean, range, standard deviation, and coefficient of variation (CV) were calculated for field replicates that were collected at five stations. The RD and CV values were used to evaluate analytical and field variabilities.

Elevation above reference (EAR) values are calculated by dividing a chemical concentration at a station by a reference value for that chemical. EAR values are used to characterize concentrations of chemical contaminants in sediments, and to provide information on the magnitude of contamination among different stations. The EAR approach is frequently used in toxic urban embayment studies [e.g., Elliott Bay (PTI and Tetra Tech (1988a)], where contaminant concentrations in sediments are generally elevated, to identify and delineate smaller problem areas or "hotspots" within a larger-sized study area (e.g., the entire urban embayment).

The applicability of the EAR approach to ambient monitoring programs is less relevant. Stations sampled during ambient monitoring programs are generally positioned in a wide geographic area and program objectives do not include the identification and delineation of small problem areas within a single larger-sized area. Also, as in the 1989 MSMT, ambient monitoring stations were not located directly near sources; thus, sediment contaminant concentrations were less elevated than sediment contaminant concentrations in toxic urban bay studies and it was not as necessary to discuss the magnitude of contamination among different stations. Because Striplin (1988) requires the calculation of EAR values for the MSMT program, EAR values were determined for the 1989 MSMT for each chemical value that exceeded an interim performance standard (PTI 1989). EAR values were calculated by dividing the dry-weight concentrations of each chemical by the mean dry-weight concentration of the corresponding MSMT mean reference value (i.e., the 90th percentile values).

Sediment Toxicity--

Analysis of amphipod and Microtox bioassay results followed a step-wise approach. Two response variables, mortality and emergence, were analyzed in the amphipod bioassay. Change in luminescence was evaluated in the Microtox bioassay. Basic descriptive statistics (i.e., mean, range, standard deviation, and 95 percent confidence interval) were calculated for each response variable in the original data. The EAR was also calculated for each

response variable (see RESULTS, Sediment Toxicity Bioassays). For amphipod mortality and emergence data, results of amphipod bioassays conducted using West Beach control sediments were used to define reference values. The objective of the design was to allow investigators to determine whether differences existed among stations or between the reference site and each of the stations sampled. To allow pair-wise comparisons for statistical tests, all reference station data from the amphipod bioassay were pooled ($n = 15$). The mean percent mortality and percent emergence from the pooled reference stations were used to calculate EAR values.

Analysis of variance (ANOVA) was proposed as the test for differences among stations. It was necessary to test the data to determine whether or not they met the two basic assumptions of the ANOVA (i.e., normal distribution of data values and homogeneity of variances). The distribution of each response variable was tested for normality using the Kolmogorov-Smirnov D test ($n>50$) or the Shapiro-Wilk test ($n<50$). These tests indicated that the data were not normally distributed. Consequently, the data were converted to proportions and the arcsine square root transformation [$\text{arcsine}(P)^{0.5}$] was applied. These data were then re-evaluated for normality.

The Cochran's C test was used to evaluate homogeneity of variances. This test was used in place of the Fmax test as it exhibits slightly more sensitivity to deviations from homogeneity (Winer 1971). In the case where the null hypothesis was rejected, this test was run again using the transformed data.

Results of the tests for homogeneity of variances and normality of distribution indicated that the bioassay data departed from the assumptions of normality and homogeneity in both the untransformed and transformed data. Distribution-free statistics were then chosen for the remaining analyses. The nonparametric equivalent of the ANOVA (i.e., Kruskal-Wallis) test was used to detect significant ($P<0.05$) differences among all stations. When the null hypothesis that all station means were equal was rejected (i.e., one or more stations differed), the Mann-Whitney U test with a compari-

son-wise error rate of $P<0.001$ was used to determine which stations differed significantly from the pooled reference stations. Repeated comparisons of data from a reference station result in non-independence among the pairwise comparisons (Winer 1971), thus increasing the Type I error. The error rate was adjusted to reduce the probability of incorrectly identifying a significant difference between a mean response variable at a station and a mean response variable at the reference site. If a significance level of $P=0.05$ had been used and data from each of the 50 stations were compared with the pooled reference station, the probability that all the significant differences identified in the comparisons are correct is $(1-\alpha)^{50}$ or 7.7 percent. The adjusted error rate has a 95 percent probability that identified significant differences are correct.

In the positive control test, organisms were exposed to increasing concentrations of known toxicants to test the range of responses. These positive control data were used to calculate the concentration at which 50 percent of the population may show a response during the test. A probit analysis program (Weiner 1988) was used to calculate the LC_{50} (i.e., the concentration that is lethal to 50 percent of the amphipod test population) or EC_{50} (i.e., the concentration that causes a 50 percent decrease in luminescence) value. In addition, the trimmed Spearman-Karber test was used to estimate the LC_{50} (Hamilton et al. 1977) for amphipod mortality. The probit analysis assumes that the response data will approximate a linear relationship when concentration data are log-transformed. A test for heterogeneity of response using the chi-square statistic was used to determine if the straight-line relationship existed. Data from the positive controls, except for the first laboratory replicate control in the amphipod bioassay, met this assumption.

Benthic Community Structure--

Analyses of benthic community structure were conducted to characterize benthic community structure at MSMT stations throughout Puget Sound and to determine whether differences existed among stations based on various community attributes (e.g., species abundance, species richness) or physical

features (e.g., sediment grain size, water depth). These data will provide baseline information for temporal and spatial comparisons of benthic community structure for the MSMT, and will allow identification of potential reference areas.

Three approaches were used to explore patterns in benthic community structure at MSMT stations. First, biological indices were calculated to reduce complex data sets into simple numerical relationships, and relationships between those indices and physical features explored. Second, classification analyses (Bray-Curtis) were used to group stations with similar species compositions. The relationships between the resulting station groups and physical variables were then investigated. Third, potential effects of sediment contaminant concentrations on benthic communities were evaluated by comparing benthic indices and dominant taxa between potential reference and unsuitable reference stations (see RESULTS, Identification of Potential Reference Stations).

The following indices and descriptive statistics were calculated for both replicate and pooled station data:

- Abundance and richness of species and major taxonomic groups (i.e., polychaetes, molluscs, arthropods, echinoderms, and miscellaneous taxa)

- Mean, minimum, and maximum abundance and richness; standard deviation; and variance by station

- Shannon-Weiner diversity (Pielou 1966)

- Pielou's evenness or equitability (Pielou 1966)

- Numerical dominance (complement of evenness) (Pielou 1966)

- Swartz's dominance index (Swartz et al. 1985)

- Infaunal trophic index (Word 1982).

These indices and descriptive statistics are commonly used to describe features of benthic communities. Simple descriptive statistics (i.e., species abundance and richness) are often preferred because they are direct measures of the population. These values are less ambiguous and often as informative as calculated diversity indices (Green 1979; Hurlbert 1971). Richness is the only objective measure of diversity. When the abundance of individuals is considered in the determination of diversity (e.g., Shannon-Weiner index), diversity becomes a function of how the relationship between relative abundance and richness is defined (Poole 1974).

The Shannon-Weiner index (H') is a commonly used diversity index. It is based on information theory, wherein diversity is equated with the uncertainty attached to encountering a given event (i.e., organism) within a set of events (see Washington 1984). It has the advantage of being normally distributed, being reasonably independent of sample size, and being statistically testable (Hutcheson 1970; Odum 1971). Disadvantages of using H' are that it relies on the ordering of individuals among species (Goodman 1975) and it is dependent primarily on the equitability of individuals among the species, and secondarily on species richness. H' may increase under conditions of slight to moderate stress if equitability increases as the number of species decreases (Swartz et al. 1980). Because H' may give "false positives" under conditions of slight or moderate stress, and because low H' values may not be due to anthropogenic stresses, it is necessary to examine other indicators of benthic community structure when interpreting H' values.

Because H' is affected by richness, many investigators prefer to determine the observed diversity in benthic communities as a proportion of the maximum possible diversity for that data set (Zar 1984). The resulting quantity J is termed evenness (Pielou 1966). Evenness values approaching 1.0 indicate a homogeneously distributed population. The reciprocal value

1-J is termed dominance. Higher dominance values (i.e., those that approach 1.0) indicate that few taxa constitute most of the individuals in a community.

Swartz's dominance index (SDI) is the number of taxa that account for 75 percent of the total abundance. Swartz et al. (1985) demonstrated that this index is useful for describing community structure, and that it is statistically testable. Furthermore, it does not assume an underlying distribution of individuals among taxa.

The Infaunal Trophic Index (ITI) is a mathematical index based on the abundances of indicator species (see Word 1982). Although first developed to describe the proportions of various feeding types within benthic communities, it was later used successfully to assess impacts on benthic communities near sewage outfalls in the Southern California Bight.

The application and usefulness of these indices are discussed in the section RESULTS, Benthic Community Structure. Results from these calculated indices are correlated with physical variables such as water depth, total organic carbon content, percent fines, and total sulfides. Correlations among physical variables are also examined.

Relationships among these descriptive statistics and indices were also examined using analysis of variance (ANOVA) methods. Before conducting ANOVA tests, species abundance and richness data were tested for normality using the Kolmogorov-Smirnov D test ($n>50$) or the Shapiro-Wilk test ($N<50$) and for homogeneity of variance using the Cochran's C test. Cochran's C was used in place of the Fmax test as it exhibits slightly more sensitivity to deviations from homogeneity (Winer 1971). Results of these tests indicated that the data departed from the assumptions of normality and homogeneity. Therefore, the data were log transformed [i.e., log $(x+1)$]. Because the log transformed data did approximate a normal distribution with homogeneous variance, all ANOVA tests using abundance and richness data were conducted with log transformed data.

ANOVA tests were conducted to determine whether statistically significant differences existed among various station groupings, including stations grouped by geographic area and stations having the same percent fines grouped by depth. A 0.05 probability level was used in each of these tests because there were no multiple comparison tests using the same station or group of stations.

Community classification (i.e., cluster) analyses were used to group similar stations using species-level data. Classification analysis is a commonly used multivariate statistical approach that enables generation of a visual representation of among-site or among-species relationships. The Bray-Curtis similarity index (Boesch 1977) was selected for development of a similarity matrix on which the classification analysis was conducted. This similarity index is easily understood and widely used in applied studies. However, values of this index are largely determined by taxa present in high abundances, and taxa present in low abundances become relatively unimportant. In some cases cluster groups may be formed due to the abundances of only one or two taxa (Boesch 1977). To reduce the reliance on numerically dominant taxa, and to increase the information residing in less abundant taxa, the abundances of taxa were log transformed prior to calculating the Bray-Curtis index.

Classification analyses were run on total taxa and three major taxonomic groups: polychaeta, mollusca, and arthropoda. In each case, replicate data at each station were pooled. Total taxa clusters provided station groups that could be individual benthic communities or grades of communities. Physical variables (e.g., sediment grain size, water depth) characteristic of each group were used to describe factors potentially responsible for the classification of each group. Classification analyses of the major taxa groups provided information on the response of those taxonomic groups to physical variables including sediment grain size, water depth, and perhaps chemical contamination.

Prior to running the total taxa classification analysis, the data matrix was reduced because its size (i.e., 599 taxa by 50 stations) exceeded

software capabilities. Thus, the matrix was reduced to 377 taxa by 50 stations by excluding observations of taxa with abundances ≤ 2 individuals in any given sample.

After completing the classification analyses, further analysis of the relationships among station groups, sediment toxicity, and chemical contamination could have been investigated using multiple discriminant analysis. However, the overall lack of significant sediment toxicity and observable effects of chemical contamination on benthic community structure suggested that this analysis would not contribute significant results. The multidiscriminant analyses approach would be appropriate in situations when larger ranges of sediment toxicity and chemical contamination occurred.

The final analyses of benthic communities involved comparisons of communities at potential reference and unsuitable reference stations. Differences in certain benthic variables between paired potential reference and unsuitable reference stations were tested using T-tests. The T-tests used a probability level of 0.01 to account for the occasional repetitive testing of certain stations. By using the more conservative 0.01 probability level, the probability of making Type I errors was reduced to acceptable levels.

Selection of Specific Potential Reference Stations for Statistical Testing--The selection of potential reference stations among all MSMT stations was performed so that alterations in benthic community structure could be evaluated. The approach used to identify potential reference stations is described in a subsequent section (see METHODS, Approach for Identifying Potential Reference Stations). This discussion presents the approach used to identify which potential reference stations would be paired with the nonreference stations.

Potential reference stations were paired with other MSMT reference stations having similar physical attributes. Ideally, sediment characteristics and the composition of the benthic infauna in a potential reference area will be the same as that in the potentially degraded area

(minus the effects of chemical contamination or organic loading). Appropriate selection guidelines (e.g., similar water depth, percent fines) used for MSMT benthic data analyses are discussed below (those selection guidelines are applied to MSMT data in the section RESULTS, Benthic Community Structure).

Appropriate potential reference stations are those with comparable sediment characteristics, water depths, geographic locations, and benthic communities as would naturally occur in an unsuitable reference station in the absence of disturbance. Therefore, the comparison between reference and nonreference test stations will only be valid when these variables are held constant, allowing a disturbance (e.g., chemical contamination, organic enrichment, shoreline modification) to modify benthic community structure.

Because Puget Sound is a highly complex estuary, locating suitable reference stations is not a simple task. Development of specific numerical criteria is not possible with available data. The following generalizations were used to select potential reference stations for each unsuitable reference station:

- Grain size: Percent fines at a potential reference station should not differ substantially from that at an unsuitable station.

- Total organic carbon: Total organic carbon at a potential reference station should not differ significantly from that at an unsuitable reference station, unless there is a potential anthropogenic source of organic material.

- Sediment origin: Potential reference stations must contain only sediment that is native to Puget Sound. Stations with sediment that is anthropogenically altered would not be indicative of Puget Sound reference conditions.

- Sediment toxicity: Potential reference stations must not contain toxic sediments as determined using sediment toxicity bioassays.

- Geographic area: Potential reference stations should be located within the same geographic area of Puget Sound as the station it is compared to. MSMT data suggest differences among benthic communities in Hood Canal, Strait of Juan de Fuca, eastern shoreline of northern Puget Sound, Central Basin, and South Sound, even when sediment characteristics are similar.

- Chemical contamination: Potential reference stations must not have metals or organic compounds in elevated concentrations (for the approach used to identify stations with elevated concentrations of chemicals, see below).

In subsequent years of the monitoring program, it may be possible to develop more quantitative standards for defining benthic community structures in reference areas. Three years of benthic data at the same stations would allow for assessments of annual variability. If benthic sampling were conducted during months other than March/April (the current MSMT schedule), resultant data could be used to examine the effects of seasonality on potential standards.

APPROACH FOR IDENTIFYING POTENTIAL REFERENCE STATIONS

One objective of the MSMT is to identify stations that can be used as reference sites (Striplin 1988). Tetra Tech (1986) defined a reference station as a location that is pristine or is considered to have acceptably low levels of contamination and no apparent biological disturbance. Because reference stations must have minimal or low contamination, they are generally located away from urban areas or known contaminant sources. As discussed in Section 1 (INTRODUCTION), most stations sampled in the 1989 MSMT were located away from known contaminant sources (Figure 1). Thus, the

approach developed for identifying potential reference stations in this report was based on the assumption that each of the 50 MSMT stations was a potential reference station, and that those stations with the greatest contamination could be eliminated from the final list of potential reference stations.

In general, reference stations are identified using results of sediment chemistry, sediment toxicity, and benthic infauna analyses. Chemical data are needed to characterize potential contamination, and direct measures of biological variables (e.g., toxicity, benthic community structure) are needed to assess contaminant effects. Major steps in the approach used to identify potential MSMT reference stations are as follows:

- Evaluate sediment toxicity and benthic community structure data
- Evaluate sediment chemistry data, as described below:
  - Evaluate the complete list of MSMT target chemicals, and prepared a subset of that list to be used to evaluate sediment data
  - Calculate 90th percentile values for each chemical
  - Identify initial potential reference stations as those stations with ≤ 2 chemical variables with concentrations that exceeded 90th percentile values
  - Identify chemical variables found in the MSMT data for which only anthropogenic sources have been identified
  - Eliminate from the list of initial potential reference stations those stations at which solely-anthropogenic chemicals were detected.

Additional details are provided below.

Sediment Toxicity and Benthic Community Structure

Sediment toxicity and benthic community structure data were evaluated to identify potential reference stations, using methods described in a previous section (see above, DATA MANAGEMENT, Sediment Toxicity, Benthic Community Structure). In general, the lack of toxicity and the presence of a healthy benthic community at stations were used to identify potential reference stations.

Sediment Chemistry

Sediment data for all target chemicals analyzed in the 1989 MSMT (Table 2), including TOC and total sulfides, were used to identify potential reference stations, with the following exceptions:

- Volatile organic compounds and guaiacol and resin acid compounds were not included because those compounds were analyzed only at select stations

- Pristane-to-phytane ratios and N-alkanes carbon preference indices were not included because those values are ratios

- 3,3-dichlorobenzidine and 4-chloroaniline were not included because concentrations of those compounds were only available for two MSMT stations

- Total benzo(b+k)fluoranthene concentrations were used instead of individual concentrations of benzo(b)fluoranthene and benzo(k)fluoranthene.

For each target chemical, 90th percentile values were calculated using both undetected and detected values for the 50 MSMT stations. [A discussion of undetected values is provided in METHODS, Sediment Chemistry, Treatment of Undetected Values and Calculation of Mean Values.] Undetected values (i.e., data qualified with a "U") were used in the calculations because

those values provide estimates of maximum concentrations that may occur at those stations; hence, use of undetected values provided a conservative estimate of contamination that should not be ignored. The undetected values were treated as quantitation limit/2 or zero, as previously described in this section.

The calculation of 90th percentiles provides a description of the distribution of all measured concentrations for a single chemical. For example, 50 measurements were reported for most target chemicals. Those 50 values were arranged by order of magnitude (i.e., in descending order) using a SAS univariate procedure with a weighted average. The 90th percentile is the value that has 90 percent of the measurements below it and 10 percent of the measurements above it. Thus, 45 stations would occur below the 90th percentile value (50 values x 90 percent = 45 values), and five stations would exceed the 90th percentile value. The 90th percentile value would be a number greater than or equal to the 45th value.

After 90th percentile values were calculated, stations with detected values that exceeded 90th percentile values were summarized. If any of the chemical concentrations that exceeded the 90th percentile value were undetected, then concentrations of that chemical at those stations were not considered to exceed 90th percentile values. For example, the 90th percentile value for butylbenzyl phthalate was 15.5 ug/kg. Because two values that exceeded the 90th percentile value for butylbenzyl phthalate were undetected values (i.e., data were qualified with a "U"), then those two stations were not considered to have exceedances of the 90th percentile value for butylbenzyl phthalate.

Based on discussions with Ecology, stations with 2 or fewer chemical variables that exceeded 90th percentile values were identified as potential reference stations. From that initial list, stations were eliminated if any chemical concentrations were found for which only anthropogenic sources have been identified. The chemical variables that were analyzed in the 1989 MSMT for which only anthropogenic sources have been identified are shown in Table 3.

TABLE 3. CHEMICAL VARIABLES ANALYZED IN THE 1989 MSMT FOR WHICH ONLY ANTHROPOGENIC SOURCES HAVE BEEN IDENTIFIED

Variable
Extractable Halogenated Organic Compounds (Kimbrough 1980)
4-Bromophenyl-phenyl ether
4-Chlorophenyl-phenyl ether
PCBs
Chlorinated pesticides
Chlorinated Resin Acids and Guaiacols (Hutchins 1979)
Chlorodehydroabietic acid
Dichlorodehydroabietic acid
4,5-Dichloroguaiacol
Tetrachloroguaiacol
3,4,5 (4,5,6)-Trichloroguaiacol
Phthalate Esters (Howard 1989)
Dimethyl phthalate
Diethyl phthalate
Di-n-butyl phthalate
Butylbenzyl phthalate
bis(2-Ethylhexyl)phthalate
Di-n-octyl phthalate

These potential reference stations were not proposed to replace existing reference areas identified by the Puget Sound Estuary Program, but this information may be used to supplement their effort. Because the 50 MSMT stations were specifically positioned away from anthropogenic sources, sediments at the stations were not expected to be heavily impacted by chemical contaminants. Thus, the MSMT data may provide baseline data for future reference area studies.

3.0 RESULTS

Results of QA/QC and data interpretation of the sediment chemistry, sediment toxicity, and benthic community structure are summarized in this section. Complete details of QA/QC reviews are provided in the QA memoranda in Appendix B. All sediment chemistry data are provided in Appendices C and D, bioassay data are provided in Appendix E, and benthic data are provided in Appendix F.

SEDIMENT CHEMISTRY

Quality Assurance/Quality Control

Reviews of sediment chemistry data were performed in accordance with U.S. EPA (1988a,b) guidance found in *Laboratory Data Validation, Functional Guidelines for Evaluating Inorganics Analyses* and *Laboratory Data Validation, Functional Guidelines for Evaluating Organics Analyses*. Data validation criteria were identified in those reports and in the *Marine Sediment Quality Implementation Plan* (Striplin 1988). QA/QC reviews of chemistry included assessments of sample holding times, initial and continuing calibration and tuning, blank results, interference check samples, accuracy (using PCS, MS, MSD, and surrogate recoveries, when applicable), and precision (using blind analytical and field replicates).

Conventional Variables--

QA review was performed for the following conventional variables: grain size, TOC, total sulfides, and total solids. All data were acceptable as qualified in the QA memoranda in Appendix B.

Sediment samples were analyzed for grain size distribution within 50 days. The Puget Sound protocols recommend sample analysis within 6 mo.

Because of problems associated with sample containers, some moisture may have been lost from some samples submitted in the first two sample delivery groups [i.e., Stations 28, 30, 31, 32 (Samples 1, 1R, 2, and 3), 33-37, 38 (Samples 1, 1R, 2, and 3), 39-43, 45 (Samples 1, 1R, 2, and 3), and 45-50]. However, data qualifiers were not assigned to any grain size data because the loss of moisture does not effect the dry weight of the grain size fractions that are calculated.

Sediment samples were analyzed for TOC within 19 days. There are no U.S. EPA holding times for TOC, although the Puget Sound protocols recommend analysis of sediments with 6 mo (assuming samples were frozen).

Sediment samples were analyzed for total sulfides within the recommended holding time of 7 days from the time of collection, with the exception of 12 samples that were analyzed within 8 days. Total sulfides data were not qualified.

Percent moisture (i.e., total solids) results are included in the reported dry weight results for total organic carbon, metals, and organic compound analyses.

Results and summary statistics of blind laboratory and field replicate samples (e.g., mean, standard deviation, coefficient of variation, relative percent difference) for those data are presented in the QA memorandum in Appendix B.

Metals--

The metals data were considered acceptable as qualified in the data validation report. All samples were analyzed within required holding times. Samples were analyzed for mercury within 23 days and for other metals within 51 days. The data qualifier "R" (unusable value) was assigned to 40 samples for antimony and 11 samples for selenium because matrix spike recovery acceptance criteria were not met.

Results and summary statistics of blind laboratory and field replicate samples, PCS, and one National Bureau of Standards Buffalo River sediment sample (No. 2405)(e.g., mean, standard deviation, coefficient of variation, relative percent difference) are presented in the metals QA memorandum in Appendix B.

Semivolatile Organic Compounds--

The data were considered acceptable as qualified in the data validation reports. Sediment samples were extracted within 7 days, except for Stations 48, 49, and 50, which were extracted within 9 days. Per requirements of the *Marine Sediment Quality Implementation Plan* (Striplin 1988), sediment samples were analyzed within 40 days of extraction. Bis(2-ethylhexyl)-phthalate was detected in 2 of 10 method blanks. A mean and upper 95 percentile confidence limit was calculated for bis(2-ethylhexyl)phthalate associated with analytical blanks, using concentrations reported for all method blanks, and the value was adjusted to reflect the mean dry sample weight of all samples. In accordance with CLP guidance, the reported quantitation limit for bis(2-ethylhexyl)phthalate in all samples was adjusted by assigning the data qualifier "U" to all data values less than or equal to the 95 percentile value associated with method blanks.

The data qualifier "R" was assigned to a substantial number of samples for three analytes (i.e., benzoic acid, 4-chloroaniline, and 3,3'-dichlorobenzidine) because MS/MSD recoveries did not meet acceptance criteria.

Results and summary statistics of blind laboratory and field replicate samples and PCS (e.g., mean, standard deviation, coefficient of variation, relative percent difference) are presented in the organics QA memorandum in Appendix B.

Pesticides and PCBs--

The data were considered acceptable as qualified in the data validation QA memorandum in Appendix B. Sediment samples were extracted within 7 days,

except for Stations 43, 44 (Samples 1, 1R, and 3), and 45-47, which were extracted within 8 days; Stations 48-50, which were extracted within 9 days; and Station 15, which was extracted within 10 days. All sediment samples were analyzed within 40 days of extraction. Data qualifiers were not assigned to PCB and pesticide data, and target analytes were not detected in method blanks.

Results and summary statistics of blind laboratory and field replicate samples and PCS (e.g., mean, standard deviation, coefficient of variation, relative percent difference) are presented in the QA memorandum in Appendix B.

Volatile Organic Compounds--

The data were considered acceptable as qualified in the data validation report (Appendix B). Sediment samples were analyzed for volatile organic compounds within 7 days, except for Station 38 (Sample 1), which was analyzed in 8 days. Method blanks were analyzed and compounds that were detected are summarized in Table 3 of the volatile organic compounds QA memorandum in Appendix B. A mean and upper 95 percentile confidence limit were calculated for all compounds detected in three or more method blanks, and were adjusted to reflect the mean dry sample weight of all samples. The reported quantitation limit for those compounds was adjusted using the 95 percentile confidence limit by assigning the data qualifier "U" [in accordance with the CLP functional guidelines for data validation (U.S. EPA 1988b)] to all data with reported values less than the 95 percentile value associated with blank results. All reported values associated with the "U" qualifier are analytical quantitation limits with measurable precision and accuracy, and not instrumental or method detection limits.

The data qualifier "R" was assigned to acetone for Stations 38 (Sample 3) and 45 and to 2-butanone for Stations 14 and 17 because the continuing calibration relative response factor did not meet acceptance criteria.

Field replicate samples and PCS were analyzed, in addition to un-homogenized sediments from the same grab sampler that had been placed in separate sample containers. Results from those analytical replicates, which were used to measure within-grab variability, are not a true measure of analytical variability. Analytical variability is determined by repetitive measurements of the same sample (i.e., splits of homogenized samples). Results and summary statistics (e.g., mean, standard deviation, coefficient of variation, relative percent difference) are presented in the volatile organic compounds QA memorandum in Appendix B.

Results

The following section summarizes chemical results for 50 surface (0-2 cm) sediment samples collected in Puget Sound. Samples were analyzed for 3 conventional variables, 23 metals, 75 semivolatile organic compounds, 20 chlorinated pesticides, and PCBs (see Table 2). Samples from three stations located near pulp and paper mills were also analyzed for 13 resin acids and chloroguaiacols. Samples from 10 stations located distant from known point source discharges were also analyzed for 37 volatile organic compounds (Tetra Tech 1989b). Sediment samples were collected at five stations to measure analytical and field variability.

The objectives of the discussion are as follows:

- Review chemical conditions in Puget Sound sediments, including concentration means and ranges, distribution by geographic area, and frequencies of detection

- Compare 1989 MSMT chemical concentrations with values reported in the *Puget Sound Environmental Atlas* (Evans-Hamilton and D.R. Systems 1987) to provide a preliminary evaluation of temporal trends in sediment quality

- Determine relationships between chemistry values and other variables, including water depth and sediment grain size

- Identify stations with enrichments or depressions of chemical concentrations, and determine whether those phenomena can be associated with urbanization or natural processes

- Assess the analytical and field variabilities associated with reported chemical concentrations, and determine their impacts on interpretation of chemical data in urban and nonurban areas.

Sediment chemical concentrations were normalized to account for physical differences among samples. In this report, sediment chemical concentrations are expressed as the weight of the chemical per dry weight of sediments (e.g., ug/kg dry weight or DW). Dry-weight concentrations are better indicators of chemical concentrations in field-collected sediment samples than are wet-weight concentrations because the percent water content can vary considerably among samples. Also, many contaminants have been found to be associated primarily with the sediment-water interface of particles in sediments and suspended solids, and not with the interstitial water (Lee and Jones 1987). Use of dry-weight concentrations precludes the possibility that variations in water content may obscure trends in chemical data.

Chemical concentrations may also be normalized to the fine-grained material (i.e., silt plus clay) and organic carbon content in sediments. Because the surface area available for adsorption of chemicals increases with decreasing grain size and because silt and clay exhibit a high cation exchange capacity, fine-grained sediments tend to accumulate more ionic chemicals than do coarse-grained sediments (Lee 1985). Thus, contaminants (especially metals) may be concentrated in the fine-grained particles of sediments. In addition, metals associated with fine-grained particles are more susceptible to being solubilized during the laboratory acid digestion process used in the MSMT than are metals associated with the refractory mineral and sand matrices. Metals associated with fine-grained material are

thought to be more readily available to biological organisms than are metals incorporated into the refractory mineral and sand matrices (Lee 1985).

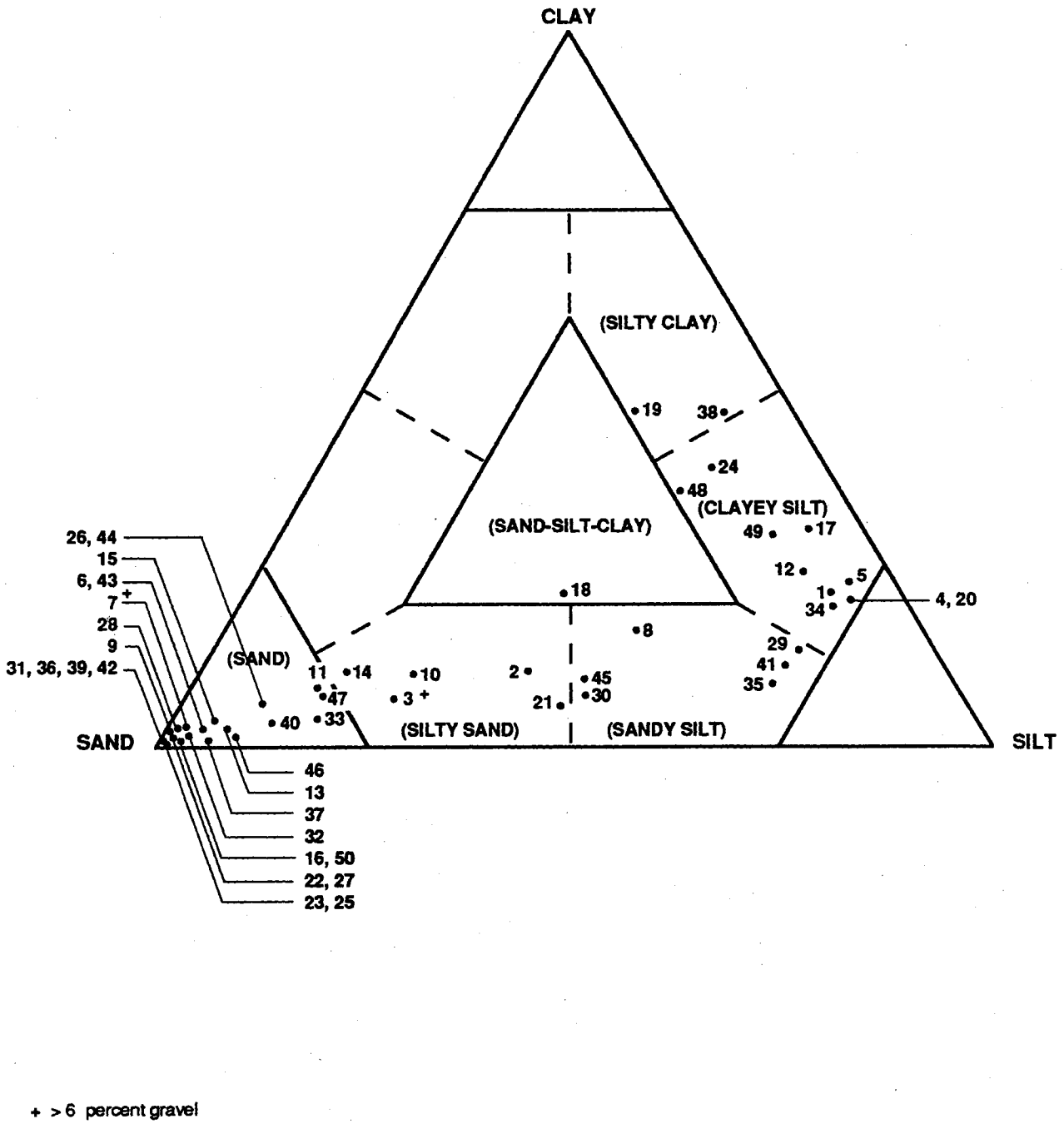
Because fine-grained material content has been shown to covary with total organic carbon content in sediments (Premuzic et al. 1982), normalizing sediment chemistry data to fines content is thought to be equivalent to normalizing to TOC in natural sediments. Although chemical concentrations have been normalized to both fines and TOC content in numerous past studies (e.g., PTI and Tetra Tech 1988a,b), the relationships between those variables and chemical concentrations are evaluated in this report for selected parameters to determine the appropriateness of those normalizations under various environmental conditions.

Conventional Sediment Characteristics

Conventional variables measured in sediments included grain size [as percent gravel, sand (five phi classes), silt, and clay], percent total organic carbon, and sulfides (mg/kg). Complete data are provided in Tables C-1 and C-2 in Appendix C.

Grain Size--

Grain size is a measurement of the size of sediment particles. Particle size influences the fate of the chemicals attached to the particle and the type of benthic communities established in the sediments. Sediment grain size distributions at MSMT stations are plotted in Figure 2. Stations positioned close to one another in this diagram have similar sediment compositions. Because sediments at Stations 3 and 7 contained high percentages of gravel (33.85 and 22.16 percent, respectively), they are not accurately characterized in the diagram. Sediments at all other MSMT stations contained <6 percent gravel, and sediments at 45 stations contained <2 percent gravel. The range of sediment types found during the study included sands (26 stations), silty sands (5 stations), sandy silts (6 stations), clayey silts (10 stations), silty clays (2 stations), and sand-silt-clays (1 station). Spatial trends in grain size distributions among



+ > 6 percent gravel

Figure 2. Sediment grain size characteristics at stations, using the classification scheme developed by Shepard (1954).

regional groups were not apparent, and grain size was not correlated with latitude or longitude. Summary statistics for grain size distribution among all stations are as follows:

	% Gravel	% Sand	% Silt	% Clay	% Fines
Arithmetic Mean	1.64	58.83	27.80	11.67	39.47
Standard Deviation	5.67	36.10	26.89	12.21	36.47
CV (ratio)	3.47	0.61	0.97	1.05	0.92
Minimum	0.0	3.36	0.07	1.01	1.33
Maximum	33.85	98.66	76.11	47.52	96.64

Percent Fine-Grained Material--The percentages of fine-grained materials (i.e., silt plus clay) at each station are shown in Figure 3, and percent fines in sediments are plotted as a function of water depth at stations in Figure 4. Although trends are not readily apparent from Figures 4 and 5, sediments at shallow stations (e.g., 6-15 m water depth) were sands or sandy silts (6 of 9 stations), whereas sediments at 20-m stations were generally sands (19 of 30 stations) or clayey silts (5 of 30 stations). Sediment compositions varied at the 11 stations deeper than 20 m, and included silty clays, clayey silts, sandy silts, silty sands, and sands.

Sedimentary Environments--Three categories of sedimentary environments are identified for shallow ($\leq$50 m), mid-depth (>50-$\leq$150 m), and deep (>150 m) stations in Figure 4. Each sedimentary environment is dictated by sea bottom topography, and the hydrodynamics and particulate loading of the overlying water column.

Depositional environments are characterized by predominantly fine-grained sediments. Flat topography, low current energetics, and high suspended particulate loadings promote the settling and accumulation of silt and clay. For the purposes of this report, sediments with >67 percent fines were herein defined as depositional environments.

Nondepositional/erosional environments are typically characterized by coarse-grained sediments with predominantly gravel and sand textures. Conditions favoring the formation and preservation of erosional environments

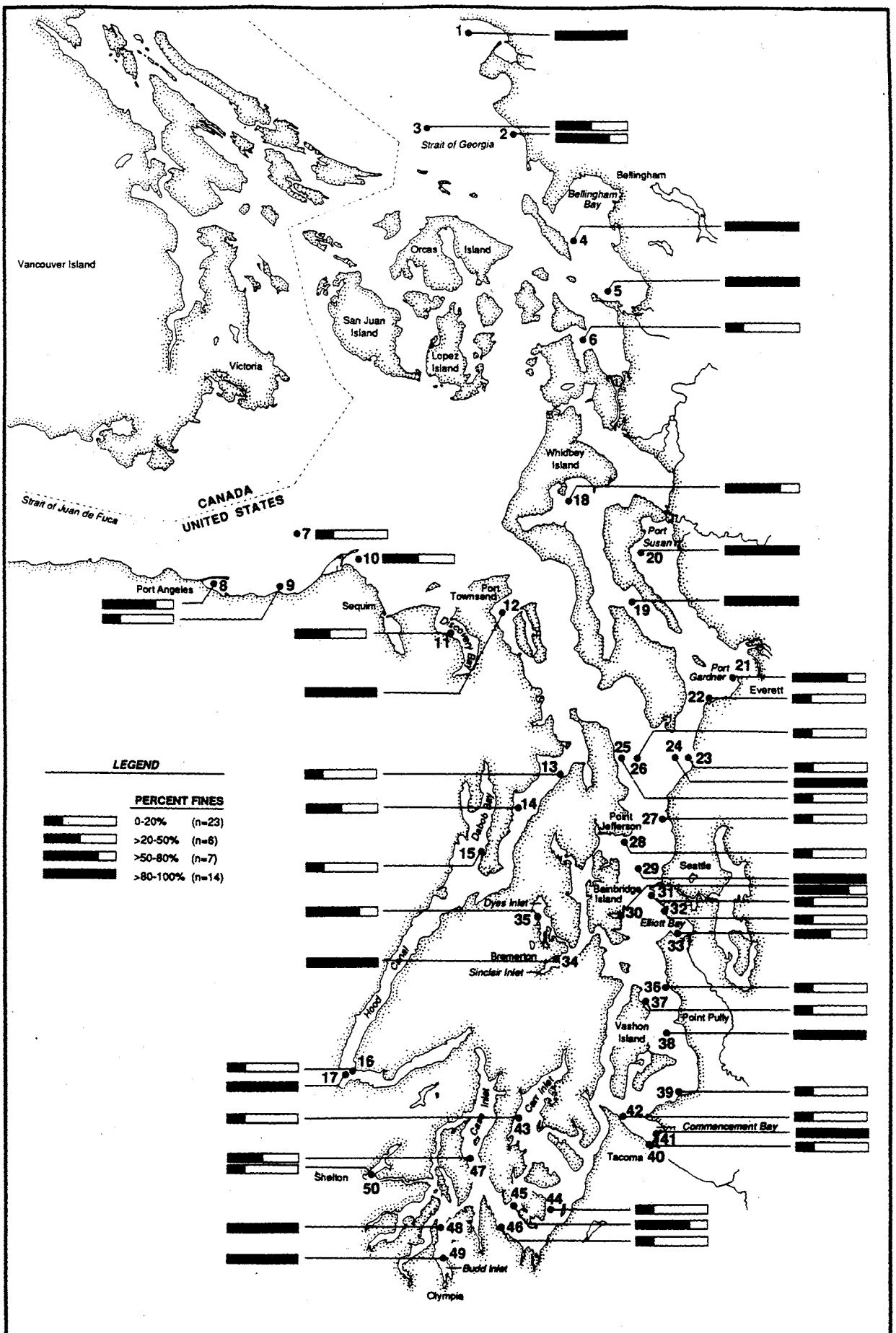


Figure 3. Percent fine-grained material in Puget Sound sediments.

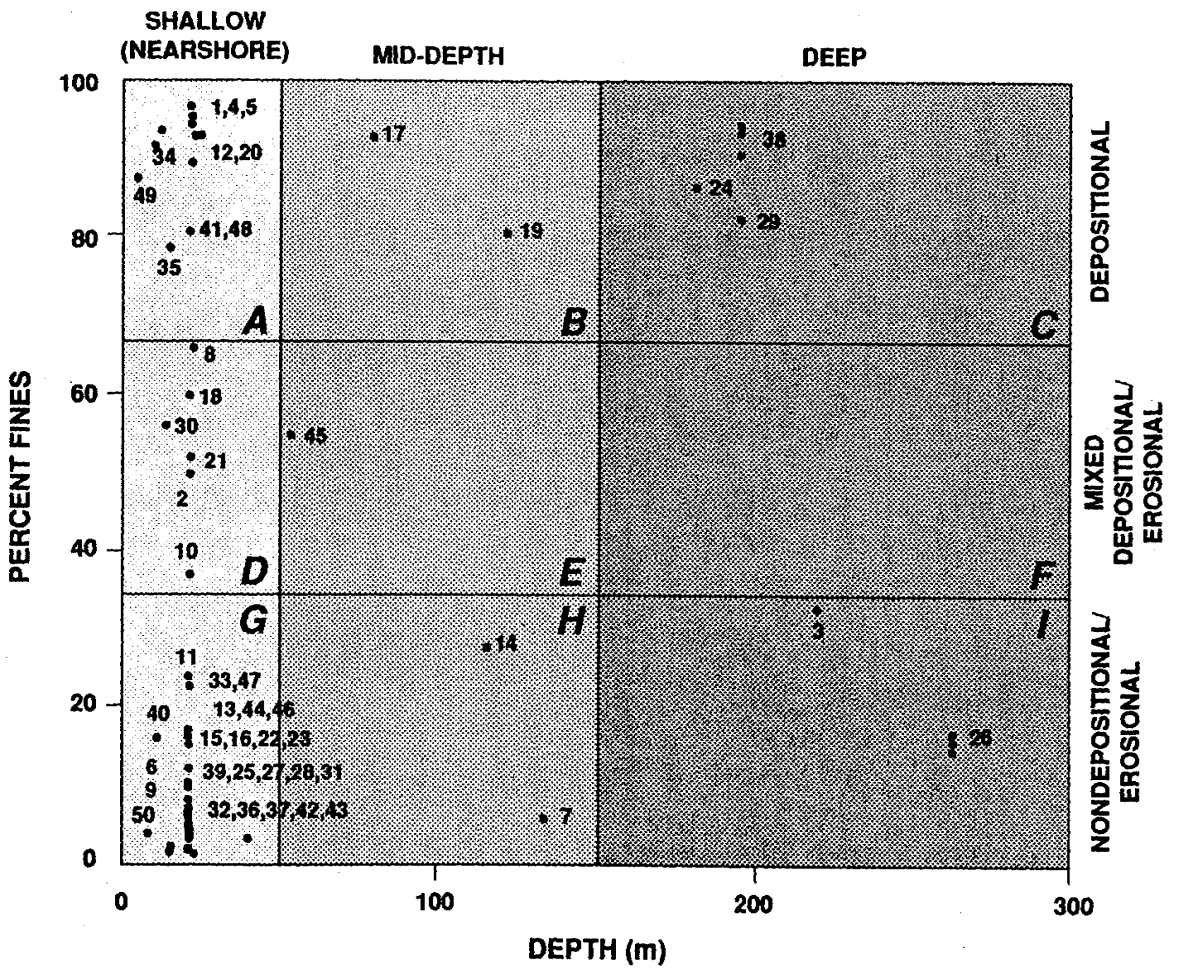


Figure 4. Relationship of percent fines in sediments vs. water depth at MSMT stations.

are high water flow and energetics, low particulate loadings, and steep slopes. For the purposes of this report, sediments containing ≤33 percent fines were herein defined as erosional areas.

Mixed depositional/erosional environments, which are typically transitional areas, were identified for the purposes of this report as those areas with 33 to 67 percent fines. A complete description of stations located in Groups A-I (Figure 4), including physical location, water depth, bottom topography, and reported bottom currents at stations, is presented in Appendix G. Pertinent information is summarized below.

As shown in Figure 4, sediments were sampled in depositional areas at 10 shallow stations (Group A), 2 mid-depth stations (Group B), and 3 deep stations (Group C). Stations in Group A were generally located in level areas within urban embayments or near river mouths where water column particulate loadings are typically expected to be high and bottom current speeds are expected to be low or decreasing with distance from the river mouth. Stations in Group B were located in passages (e.g., Hood Canal, Whidbey Basin) that are expected to have intermediate water column particulate loadings and low bottom current speeds. Stations in Group C occurred at the base of basin slopes, in waters that are expected to have low net current velocities (Evans-Hamilton and D.R. Systems 1987) and significant solids input from fluvial and other terrigenous sources (e.g., Whidbey and Central Basins).

Sediments were sampled in mixed depositional/erosional areas at six shallow stations (Group D) and one mid-depth station (Group E). Stations in Group D were located near the mouths of embayments with level to gently sloping topography, net current speeds are low to intermediate, and suspended solids loadings that are expected to be less than those found within embayments. The single station in Group E occurred west of Anderson Island in Drayton Passage, a level area where medium velocity water is expected to contain intermediate loadings of solids.

Sediments were sampled in nondepositional/erosional areas at 24 shallow stations (Group G), 2 mid-depth stations (Group H), and 2 deep stations (Group I). Stations in Group G were generally found along moderately sloping shorelines located away from sources of settleable solids. Stations located in areas with high net current speeds were also included in Group G. Stations in Group H were located in level areas where current speeds are high, in areas that receive low solids input, or on steep slopes at intermediate depths. Stations in Group I, which were deep stations with low fines content, are located in areas with high current speeds. Station 3 (Strait of Georgia) was located at 218 m, and bottom current speeds are estimated at 4-20 cm/sec (Evans-Hamilton and D.R. Systems 1987). Station 26 (west Central Basin, south of Admiralty Inlet), which was the deepest MSMT station, was located at 262 m, and bottom current speeds are estimated at 8-18 cm/sec (Evans-Hamilton and D.R. Systems 1987). As is shown in Figure 4, the other five deep MSMT stations have high fines content.

Analytical and Field Variability--Sediment samples were collected at five stations (i.e., Stations 5, 26, 32, 38, and 44) to measure analytical and within-station variabilities for grain size determinations. Those stations, which spanned the range of depths sampled in the 1989 MSMT, were located in depositional and erosional environments: clayey silts at one station in Group A, silty clays at one station in Group C, sands at two stations in Group G, and sands at one station in Group I (Figure 4). Grain size distributions for each blind laboratory and field replicate at these stations are plotted in Figures G-1 through G-5 in Appendix G.

Highest analytical and within-station variabilities for grain size were found in the sediment fractions with the lowest percentage contributions, independent of particle size. Analytical variability is measured by the relative difference of samples: RD = (Sample 1 - Sample 2)2/(Sample 1 + Sample 2). Within-station variability is measured by the coefficient of variation of samples: CV = standard deviation/mean. Thus, for sediment fractions constituting <10 percent of a sample, the CV and RD frequently approached 0.50. In general, analytical variability was very similar or equivalent to the within-station variability for the predominant sediment

fractions of samples at all stations. For example, sediments at Station 5 contained a high percentage of silt (mean = 70 percent) and analytical variability for silt content between duplicates (RD = 0.0476) was almost equivalent to within-station variability (CV = 0.0598). The largest variability (CV = 0.547; RD = 0.653) among replicates was associated with the measurement of very coarse sand (mean = 0.12 percent), a minor sediment fraction at Station 5. In conclusion, variability in grain size measurements for this study appears to be primarily due to the natural heterogeneity of sediments.

Total Organic Carbon--

Total organic carbon is a measure of the total amount of organic compounds in particulate, nonvolatile, volatile, and partially volatile forms in sediments. It is measured because organic carbon may affect the bioavailability and toxicity of certain chemicals in sediments, and organic carbon content influences the abundance and composition of the associated infaunal community. TOC concentrations at MSMT stations are shown in Figure 5. Concentrations ranged between 0.06 and 2.0 percent TOC at 44 stations and between >2.0 and 3.9 percent TOC at the remaining 6 stations. The mean TOC concentration (0.9 percent) for all MSMT stations was comparable to the area-weighted mean TOC concentration (1.0 percent) previously reported for all of Puget Sound in the *Puget Sound Environmental Atlas* (Evans-Hamilton and D.R. Systems 1987) (Table 4).

Concentrations that exceeded 2.0 percent TOC were found in Port Angeles Harbor, Dyes Inlet, Sinclair Inlet, Budd Inlet, and near Point Pully. All stations with TOC concentrations >2.0 percent contained >60 percent fine-grained material. TOC concentrations exceeded 3 percent at only one station (3.90 percent TOC at Station 8 in Port Angeles Harbor). This value is greater than the 1.6-2.5 percent TOC concentrations previously found at stations in the inner Port Angeles Harbor (Battelle 1989). It is probably caused by wood and bark inputs to the harbor from local wood products industries. TOC content at Station 4 in Dyes Inlet was measured at 3.0 percent in 1988 (Battelle 1989) and 2.3 percent in 1989.

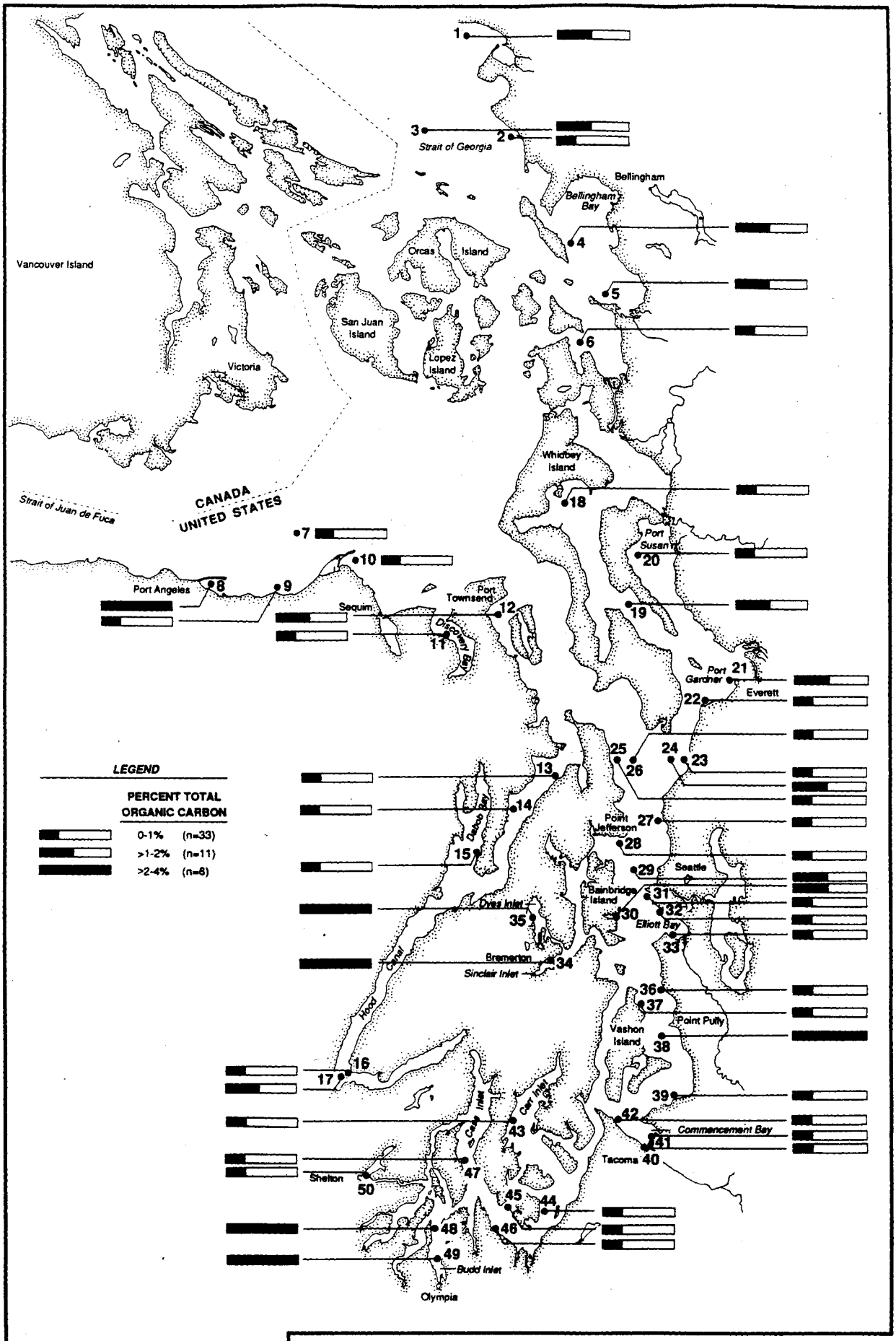


Figure 5. Percent total organic carbon in Puget Sound sediments.

TABLE 4. COMPARISON OF MEAN SEDIMENT CONVENTIONAL AND METALS VALUES AT ALL MSMT STATIONS WITH THOSE REPORTED IN THE *PUGET SOUND ENVIRONMENTAL ATLAS*[a]

	1989 MSMT				Puget Sound Environmental Atlas (1980-1986)		
Variable	Mean QL[b] (n=65)	Frequency of Detections (n=50)	Mean[c] (n=50)	Range[d] (n=65)	N	Mean[e]	Range
TOC	0.01%	100%	0.9%	0.06-3.9%	474	1.0%	0.1-21.0%
Sulfides	0.25	50%	0.34	<0.25-1.15			
Al	5.6	100%	12,200	4,380-31,000			
Sb	0.26	26%[f]	0.26	<0.17-1.3			
As	0.28	100%	4.85	0.74-11.5	529	9.0	0.7-12,200
Ba	0.28	100%	26.2	8.0-59.6			
Be	0.32	4%	0.16	<0.17-<0.66(0.42)			
Cd	0.052	66%	0.26	<0.037-1.80	477	0.30	0.05-184
Ca	2.8	100%	5,490	2,240-22,300			
Cr	1.4	100%	29.0	10.8-104			
Co	0.84	100%	7.0	2.3-19.9			
Cu	0.56	100%	23.6	2.7-129	469	30	3.0-14,300
Fe	1.4	100%	18,800	6,450-48,900			
Pb	0.28	100%	14.3	2.2-94.4	674	10	2-10,635
Mg	6.4	100%	7,710	2,690-18,800			
Mn	0.28	100%	309	105-1,050			
Hg	0.069	24%	0.13	<0.043-0.86	636	0.08	0.001-100
Ni	2.8	100%	27.8	7.9-113			
K	224	100%	1,940	712-4,600			
Se	1.62	0%[f]	<0.8	<0.85-<3.5			
Ag	0.053	62%	0.18	<0.034-1.9			
Na	2.8	100%	10,350	2,700-29,000			
Tl	0.32	2%	0.01	<0.17-<0.69(0.24)			
V	0.56	100%	37.6	13.2-125			
Zn	1.1	100%	52.7	14.7-173	412	50	19-4,700

[a] Values are reported in mg/kg dry weight, with the exception of TOC, which is reported in percent.

[b] QL = Quantitation Limit. The mean QL was calculated using all samples (n=65), including blind analytical and blind field replicates.

[c] Mean values were calculated using QL/2 or zero for undetected values, as described in the text.

[d] The range of values was determined using all samples (n=65), including blind analytical and blind field replicates. Undetected values are shown as they were reported by the analytical laboratory. If the maximum value was undetected, the highest detected value is shown in parentheses.

[e] The mean is area weighted (see text).

[f] N=23 for antimony because data were qualified as unusable at 27 of 50 stations. N=34 for selenium because data were qualified as unusable at 11 of 50 stations.

Summary values of TOC concentrations for each of seven regional basins in Puget Sound are presented in Tables 5-11, as are those previously reported in the *Puget Sound Environmental Atlas*. In each region, mean TOC concentrations for MSMT stations tend to be lower than the area-weighted means reported in the *Puget Sound Environmental Atlas*. This difference may be due to the fact that MSMT stations were generally located away from embayments, and past surveys were generally conducted within embayments that are contaminated due to anthropogenic activities. TOC concentrations reported in the *Puget Sound Environmental Atlas* for individual stations located near MSMT stations are compared to MSMT values in Table G-1 in Appendix G. TOC concentrations at MSMT stations are approximately 21 percent less than those reported in the atlas, which suggests a decrease in sedimentary TOC concentrations between 1980-1986 and 1989. Future monitoring will be used to determine whether this trend is real or an artifact of the sampling design.

Correlation Analyses--A Pearson test of correlation that included detected values from all MSMT stations indicated that TOC and fines contents in sediments are highly correlated ($r = 0.87$) (Table 12). A regression analysis, excluding the outlier Stations 8, 20, 41, and 49, is presented in Figure 6. Outlier stations, which were visually selected, were excluded from the regression analysis to yield a mean regression line centered about the bulk of the data minimizing effects of extreme data. [The correlation coefficient (r) for the regression analysis determined using data from outlier stations is within two significant digits of the correlation coefficient determined without using data from outlier stations.] Sediments at each of the outlier stations exhibited greater than 60 percent fines. In laboratory analyses of TOC concentrations in blind laboratory replicates and field (within-station) replicates at stations with $\geq$80 percent fines, coefficients of variation and relative percent differences were similar (i.e., approximately 5 percent).

A Pearson test of correlation indicates that TOC content is significantly ($P \leq 0.01$) correlated with all metals, except antimony, manganese,

TABLE 5. COMPARISON OF MEAN SEDIMENT CONVENTIONAL AND METALS VALUES AT STRAIT OF GEORGIA MSMT STATIONS WITH THOSE REPORTED IN THE *PUGET SOUND ENVIRONMENTAL ATLAS*[a]

Variable	1989 MSMT[b] Frequency of Detections (n=6)	1989 MSMT[b] Mean[c] (n=6)	1989 MSMT[b] Range[d] (n=9)	Puget Sound Environmental Atlas (1980-1986) N	Puget Sound Environmental Atlas (1980-1986) Mean[e]	Puget Sound Environmental Atlas (1980-1986) Range
TOC	100%	1.24%	0.25-2.00%	18	1.0%	0.5-3.3%
Sulfides	83%	0.36	<0.25-0.56			
Al	100%	14,400	6,610-19,800			
Sb	--[f]	--	--			
As	100%	5.5	3.1-6.7	6	5.0	5.0-15
Ba	100%	38.8	15.6-52.1			
Be	17%	<0.25	<0.23-<0.53(0.29)			
Cd	100%	0.19	0.10-0.25	5	0.15	0.14-0.33
Ca	100%	9,270	5,700-22,300			
Cr	100%	31.2	16.9-47.8			
Co	100%	6.9	4.2-9.5			
Cu	100%	19.9	6.7-32.2	5	30	33-62
Fe	100%	23,300	11,700-31,200			
Pb	100%	9.8	2.7-20.1	41	10	2-23
Mg	100%	9,830	6,180-14,100			
Mn	100%	240	150-296			
Hg	17%	0.06	<0.062-0.14	41	0.06	0.009-4.0
Ni	100%	29.9	16.9-46.4			
K	100%	2,660	896-3,990			
Se	0%	<0.9	<1.2-<2.6			
Ag	67%	0.10	<0.047-0.17			
Na	100%	11,300	4,660-25,500			
Tl	17%	0.04	0.24-<0.53			
V	100%	41.2	23.5-54.3			
Zn	100%	63.3	28.2-87.8	5	30	74-114

[a] Values are reported in mg/kg dry weight, with the exception of TOC, which is reported in percent.

[b] Stations 1-6.

[c] Mean values were calculated using QL/2 or zero for undetected values, as described in the text.

[d] The range of values was determined using all samples (n=9), including blind analytical and blind field replicates. Undetected values are shown as they were reported by the analytical laboratory. If the maximum value was undetected, the highest detected value is shown in parentheses.

[e] The mean is area weighted (see text).

[f] Antimony data were qualified as unusable.

TABLE 6. COMPARISON OF MEAN SEDIMENT CONVENTIONAL AND METALS VALUES AT STRAIT OF JUAN DE FUCA AND DISCOVERY BAY MSMT STATIONS WITH THOSE REPORTED IN THE *PUGET SOUND ENVIRONMENTAL ATLAS*[a]

Variable	1989 MSMT[b] Frequency of Detections (n=5)	1989 MSMT[b] Mean[c] (n=5)	1989 MSMT[b] Range[d] (n=5)	Puget Sound Environmental Atlas (1980-1986) N	Puget Sound Environmental Atlas (1980-1986) Mean[e]	Puget Sound Environmental Atlas (1980-1986) Range
TOC	100%	1.11%	0.06-3.90%	3	0.8%	0.9-4.7%
Sulfides	40%	0.31	<0.25-0.91			
Al	100%	11,300	7,690-15,700			
Sb	0%	<0.14	<0.22-<0.40			
As	100%	3.5	1.1-5.3	8	5.0	3.0-10
Ba	100%	22.7	13.9-35.9			
Be	0%	<0.14	<0.22-<0.40			
Cd	40%	0.13	<0.041-0.48	6	0.16	0.05-1.1
Ca	100%	4,870	3,830-6,580			
Cr	100%	24.6	19.5-29.5			
Co	100%	6.2	4.4-7.3			
Cu	100%	13.6	7.3-27.5	4	30	43-48
Fe	100%	18,500	13,000-24,600			
Pb	100%	8.7	2.6-19.1	21	10	4-15
Mg	100%	7,920	5,900-9,260			
Mn	100%	213	149-307			
Hg	20%	0.08	<0.06-0.26	22	0.05	0.014-0.075
Ni	100%	27.5	17.8-41.2			
K	100%	1,590	895-2,500			
Se	--[f]	--	--			
Ag	20%	0.05	<0.041-0.13			
Na	100%	7,590	3,360-14,700			
Tl	0%	0	<0.21-<0.41			
V	100%	36.4	28.1-47.3			
Zn	100%	46.2	24.5-88.0	4	30	76-88

[a] Values are reported in mg/kg dry weight, with the exception of TOC, which is reported in percent.

[b] Stations 7-11.

[c] Mean values were calculated using QL/2 or zero for undetected values, as described in the text.

[d] The range of values was determined using all samples (n=5), including blind analytical and blind field replicates. Undetected values are shown as they were reported by the analytical laboratory. If the maximum value was undetected, the highest detected value is shown in parentheses.

[e] The mean is area weighted (see text)

[f] Selenium data were qualified as unusable.

TABLE 7. COMPARISON OF MEAN SEDIMENT CONVENTIONAL AND METALS VALUES AT THE PORT TOWNSEND MSMT STATION WITH THOSE REPORTED IN *PUGET SOUND ENVIRONMENTAL ATLAS*[a]

Variable	1989 MSMT[b]		Puget Sound Environmental Atlas (1980-1986)		
	N	Concentration	N	Mean[c]	Range
TOC	1	1.50%	3	0.8%	1.0-1.6%
Sulfides	1	<0.25			
Al	1	16,700			
Sb	1	<0.39			
As	1	6.1	2	5	3-9
Ba	1	41.8			
Be	1	0.42			
Cd	1	0.11	0[d]	0.15 (est.)	
Ca	1	5,490			
Cr	1	34.8			
Co	1	7.6			
Cu	1	28.9	0[d]	30 (est.)	
Fe	1	27,500			
Pb	1	18.0	0[d]	10 (est.)	
Mg	1	10,800			
Mn	1	256			
Hg	1	<0.12	2	0.05	0.009-0.098
Ni	1	31.7			
K	1	3,170			
Se	0[e]	--			
Ag	1	0.12			
Na	1	18,800			
Tl	1	<0.38			
V	1	48.5			
Zn	1	74.9	0[d]	50 (est.)	

[a] Values are reported in mg/kg dry weight, with the exception of TOC, which is reported in percent.

[b] Station 12.

[c] The mean is area weighted (see text).

[d] Where N=0, the area weighted mean concentration is estimated to be equal to that observed at the nearest stations in an adjacent region.

[e] Selenium value was qualified as unusable.

TABLE 8. COMPARISON OF MEAN SEDIMENT CONVENTIONAL AND METALS VALUES AT HOOD CANAL MSMT STATIONS WITH THOSE REPORTED IN THE *PUGET SOUND ENVIRONMENTAL ATLAS*[a]

Variable	1989 MSMT[b] Frequency of Detections (n=5)	1989 MSMT[b] Mean[c] (n=5)	1989 MSMT[b] Range[d] (n=5)	Puget Sound Environmental Atlas (1980-1986) N	Puget Sound Environmental Atlas (1980-1986) Mean[e]	Puget Sound Environmental Atlas (1980-1986) Range
TOC	100%	0.49%	0.18-1.50%	6	2.0%	0.4-4.0%
Sulfides	40%	0.28	<0.25-0.55			
Al	100%	13,700	6,620-31,000			
Sb	0%	<0.14	<0.20-<0.41			
As	100%	3.9	1.9-6.0	9	1.0	2.0-17
Ba	100%	15.2	10.6-23.8			
Be	0%	<0.14	<0.20-<0.41			
Cd	20%	0.05	<0.044-<0.18(0.097)	18	0.4	0.1-11.3
Ca	100%	6,100	2,840-13,500			
Cr	100%	30.6	16.0-52.6			
Co	100%	8.8	3.6-19.9			
Cu	100%	29.5	6.3-102	19	30	5.0-135
Fe	100%	23,400	11,000-48,900			
Pb	100%	4.6	2.2-7.4	35	10	2-25
Mg	100%	8,280	4,420-17,600			
Mn	100%	276	148-574			
Hg	0%	<0.033	<0.051-<0.10	36	0.05	0.001-0.12
Ni	100%	27.7	15.4-49.6			
K	100%	1,660	924-3,040			
Se	--[f]	--	--			
Ag	40%	0.03	<0.044-0.14			
Na	100%	8,000	3,850-21,100			
Tl	0%	0	<0.22-<0.45			
V	100%	51.5	20.9-125			
Zn	100%	41.5	24.5-79.7	17	70	20-143

[a] Values are reported in mg/kg dry weight, with the exception of TOC, which is reported in percent.

[b] Stations 13-17.

[c] Mean values were calculated using QL/2 or zero for undetected values, as described in the text.

[d] The range of values was determined using all samples (n=5), including blind analytical and blind field replicates. Undetected values are shown as they were reported by the analytical laboratory. If the maximum value was undetected, the highest detected value is shown in parentheses.

[e] The mean is area weighted (see text).

[f] Selenium data were qualified as unusable.

TABLE 9. COMPARISON OF MEAN SEDIMENT CONVENTIONAL AND METALS VALUES AT WHIDBEY BASIN MSMT STATIONS WITH THOSE REPORTED IN THE *PUGET SOUND ENVIRONMENTAL ATLAS*[a]

Variable	1989 MSMT[b] Frequency of Detections (n=5)	1989 MSMT[b] Mean[c] (n=5)	1989 MSMT[b] Range[d] (n=5)	Puget Sound Environmental Atlas (1980-1986) N	Puget Sound Environmental Atlas (1980-1986) Mean[e]	Puget Sound Environmental Atlas (1980-1986) Range
TOC	100%	1.06%	0.15-1.90%	2	2.0%	0.1-2.8%
Sulfides	0%	<0.25	<0.25			
Al	100%	14,500	5,690-19,100			
Sb	--[f]	--	--			
As	100%	6.5	2.1-8.3	15	10	5.0-46
Ba	100%	35.0	12.1-48.9			
Be	0%	<0.17	<0.25-<0.56			
Cd	80%	0.26	<0.068-0.42	7	0.24	0.05-0.91
Ca	100%	4,420	2,700-5,420			
Cr	100%	54.6	14.1-104			
Co	100%	10.7	3.2-16.6			
Cu	100%	28.5	4.4-37.9	6	20	12-44
Fe	100%	23,200	7,610-33,000			
Pb	100%	9.9	3.2-20.6	23	20	3-70
Mg	100%	11,570	3,440-18,800			
Mn	100%	349	109-598			
Hg	20%	<0.053	<0.057-<0.14(0.088)	22	0.11	0.006-0.145
Ni	100%	53.3	12.1-113			
K	100%	2,110	867-3,730			
Se	0%	<0.9	<1.3-<2.8			
Ag	80%	0.13	<0.050-0.23			
Na	100%	11,700	3,950-25,200			
Tl	0%	0	<0.25-<0.56			
V	100%	44.4	14.6-61.3			
Zn	100%	60.2	18.8-88.6	6	50	40-84

[a] Values are reported in mg/kg dry weight, with the exception of TOC, which is reported in percent.

[b] Stations 18-22.

[c] Mean values were calculated using QL/2 or zero for undetected values, as described in the text.

[d] The range of values was determined using all samples (n=5), including blind analytical and blind field replicates. Undetected values are shown as they were reported by the analytical laboratory. If the maximum value was undetected, the highest detected value is shown in parentheses.

[e] The mean is area weighted (see text).

[f] Antimony data were qualified as unusable.

TABLE 10. COMPARISON OF MEAN SEDIMENT CONVENTIONAL AND METALS VALUES AT CENTRAL BASIN MSMT STATIONS WITH THOSE REPORTED IN THE *PUGET SOUND ENVIRONMENTAL ATLAS*[a]

Variable	1989 MSMT[b] Frequency of Detections (n=20)	1989 MSMT[b] Mean[c] (n=20)	1989 MSMT[b] Range[d] (n=32)	Puget Sound Environmental Atlas (1980-1986) N	Puget Sound Environmental Atlas (1980-1986) Mean[e]	Puget Sound Environmental Atlas (1980-1986) Range
TOC	100%	0.75%	0.07-2.30%	162	1.0%	0.1-3.7%
Sulfide	60%	0.41	<0.25-1.15			
Al	100%	9,810	4,890-22,800			
Sb	45%[f]	0.38	<0.17-1.3			
As	100%	5.0	0.74-11.5	136	10	1-150
Ba	100%	26.3	8.8-59.6			
Be	0%	<0.15	<0.17-<0.66			
Cd	65%	0.30	<0.037-1.2	129	0.33	0.045-6.30
Ca	100%	4,540	2,240-9,600			
Cr	100%	24.9	10.8-59.8			
Co	100%	6.0	2.3-12.2			
Cu	100%	25.1	2.7-129	121	30	3-165
Fe	100%	15,800	6,450-32,600			
Pb	100%	21.0	2.2-94.4	158	20	2-260
Mg	100%	6,500	2,710-13,300			
Mn	100%	309	105-1,050			
Hg	40%	0.13	<0.043-0.86	143	0.11	0.003-1.40
Ni	100%	23.6	7.9-41.7			
K	100%	1,810	735-4,600			
Se	0%	<0.7	<0.85-<3.5			
Ag	65%	0.28	<0.034-1.9			
Na	100%	9,250	2,700-29,100			
Tl	0%	0	<0.17-<0.69			
V	100%	31.9	13.2-66.3			
Zn	100%	53.6	15.3-173	121	80	19-690

[a] Values are reported in mg/kg dry weight, with the exception of TOC, which is reported in percent.

[b] Stations 23-42.

[c] Mean values were calculated using QL/2 or zero for undetected values, as described in the text.

[d] The range of values was determined using all samples (n=32), including blind analytical and blind field replicates. Undetected values are shown as they were reported by the analytical laboratory. If the maximum value was undetected, the highest detected value is shown in parentheses.

[e] The mean is area weighted (see text).

[f] N=11 for antimony because data were qualified as unusable at 9 of 20 stations.

TABLE 11. COMPARISON OF MEAN SEDIMENT CONVENTIONAL AND METALS VALUES AT SOUTH SOUND MSMT STATIONS WITH THOSE REPORTED IN THE *PUGET SOUND ENVIRONMENTAL ATLAS*[a]

Variable	1989 MSMT[b] Frequency of Detections (n=8)	1989 MSMT[b] Mean[c] (n=8)	1989 MSMT[b] Range[d] (n=12)	Puget Sound Environmental Atlas (1980-1986) N	Puget Sound Environmental Atlas (1980-1986) Mean[e]	Puget Sound Environmental Atlas (1980-1986) Range
TOC	100%	0.95%	0.14-2.70%	8	2.0%	0.2-3.1%
Sulfides	50%	0.37	<0.25-1.01			
Al	100%	12,000	4,380-25,600			
Sb	100%[f]	0.33	--			
As	100%	4.2	1.9-8.2	26	10	1-39
Ba	100%	18.3	8.0-36.1			
Be	0%	<0.16	<0.20-<0.49			
Cd	75%	0.46	<0.041-1.8	19	0.66	0.09-7.6
Ca	100%	4,990	2,370-8,830			
Cr	100%	22.7	11.1-39.0			
Co	100%	6.4	2.5-10.1			
Cu	100%	21.6	4.0-53.5	15	40	5-71
Fe	100%	16,100	6,460-28,000			
Pb	100%	12.5	3.2-29.5	33	30	2-42
Mg	100%	5,880	2,690-10,500			
Mn	100%	386	188-605			
Hg	12.5%	<0.056	<0.049-0.19	40	0.12	0.015-0.22
Ni	100%	20.6	9.6-35.0			
K	100%	1,870	712-3,880			
Se	0%	<0.84	<0.91-<3.2			
Ag	75%	0.17	0.038-0.56			
Na	100%	10,800	3,490-26,200			
Tl	0%	0	<0.18-<0.65			
V	100%	35.4	13.9-60.0			
Zn	100%	46.4	14.7-94.9	19	80	15-125

[a] Values are reported in mg/kg dry weight, with the exception of TOC, which is reported in percent.

[b] Stations 43-50.

[c] Mean values were calculated using QL/2 or zero for undetected values, as described in the text.

[d] The range of values was determined using all samples (n=12), including blind analytical and blind field replicates. Undetected values are shown as they were reported by the analytical laboratory. If the maximum value was undetected, the highest detected value is shown in parentheses.

[e] The mean is area weighted (see text).

[f] N=1 for antimony because data were qualified as unusable at 7 of 8 stations.

TABLE 12. RESULTS OF PEARSON CORRELATION ANALYSES FOR METALS AND CONVENTIONAL DATA AT MSMT STATIONS[a]

	Fines	Al	As	Ba	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Hg	Ni	K	Ag	Na	V	Zn
TOC	.87	.83	.72	.79	.54	--	.59	.57	.70	.75	.61	.71	--	--	.43	.86	.50	.88	.70	.87
	Fines	.90	.76	.88	.35	.36	.74	.70	.73	.86	.54	.85	--	.70	.59	.91	.45	.92	.80	.86
		Al	.76	.80	.49	.47	.79	.85	.81	.96	.52	.91	--	--	.65	.91	.47	.90	.94	.87
			As	.79	.47	--	.69	.69	.74	.73	.77	.69	.55	--	.53	.80	.71	.79	.67	.87
				Ba	--	--	.73	.65	.63	.79	.61	.82	--	--	.62	.90	.48	.87	.66	.88
					Cd	--	--	--	.67	--	.61	--	--	--	--	--	.62	--	--	.55
						Ca	--	--	.39	.48	--	.43	--	--	--	.39	--	.40	.48	.40
							Cr	.84	.67	.83	.42	.91	--	--	.94	.69	--	.65	.75	.74
								Co	.68	.90	--	.90	.59	--	.81	.71	--	.69	.91	.68
									Cu	.74	.78	.67	--	.93	.50	.69	.80	.71	.79	.87
										Fe	.41	.96	--	--	.73	.86	--	.84	.95	.82
											Pb	--	--	.90	--	.60	.94	.61	.41	.82
												Mg	--	--	.87	.83	--	.80	.87	.79
													Mn	--	--	--	--	--	.40	--
														Hg	--	--	.95	--	--	.84
															Ni	.53	--	.49	.64	.58
																K	.50	.98	.77	.89
																	Ag	.51	--	.80
																		Na	.78	.88
																			V	.76
																				Zn

[a] Only significant ($P \leq 0.01$) correlations are shown. Correlations were conducted using only detected values ($14 \leq n \leq 65$). Too few detected values were available for antimony, beryllium, selenium, and thallium to allow Pearson correlation tests.

-- = $P > 0.01$.

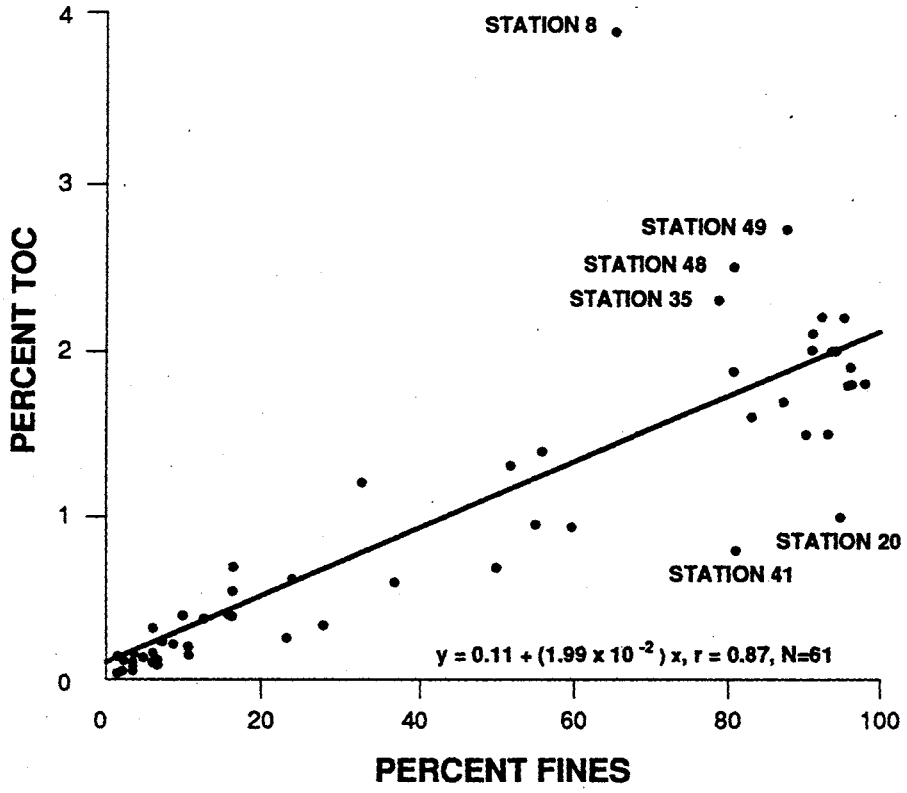


Figure 6. Results of a regression analysis using percent total organic carbon and percent fines in sediments at stations.

selenium, and thallium (Table 12). Those significant correlations probably occur because TOC and fines contents are highly correlated.

TOC content was significantly ($P \leq 0.01$) correlated with only two organic compounds: beta-sitosterol ($r = 0.71$) and retene ($r = 0.57$). TOC content was highly correlated with beta-sitosterol and retene at Stations 8, 21, 35, 38, 40, 41, 48, and 49. Beta-sitosterol is a sterol primarily associated with terrestrial plants, and it was detected at 94 percent of MSMT stations. Retene is a natural oxidation product of abietic acid (a conifer resin acid), and it was detected at 62 percent of MSMT stations. Resin acids (including abietic acid) were measured at Stations 8 and 21, and abietic acid occurred at concentrations of 180 ug/kg at both stations. Dehydroabietic acid occurred at concentrations of 550 ug/kg DW at Station 8 and 520 ug/kg DW at Station 21. These relationships suggest that TOC levels for the MSMT stations were associated with terrestrial plant products and debris, specifically coniferous trees. Sediments at Stations 8 and 40 also contained wood chips, which suggests that there are also anthropogenic (unnatural) sources of plant products at those stations.

Analytical and Field Variability--For TOC measurements, analytical variability (RD = 0.023-0.48) was similar or equivalent to the field or within-station variability (CV = 0.036-0.31). Both analytical and within-station variabilities were a function of the inverse of the absolute TOC value, suggesting that variability was probably a function and limitation of the analytical method for measuring low concentrations of TOC. Station 32 demonstrated the greatest analytical and within-station variabilities (RD = 0.48; CV = 0.31) because TOC content was low (mean = 0.16 percent TOC). At Station 32, TOC content ranged from 0.11 to 0.22 percent, a 67 relative percent difference (RPD). Thus, caution should be exercised when normalizing data to TOC results because low TOC values could introduce high variabilities, as much as a factor of 2, into normalized chemistry data. For example, if TOC concentrations were ≥ 1.0 percent, then an additional 10 percent variability could be introduced into TOC-normalized data. On the other hand, if TOC concentrations were 0.2 percent, then an additional 70 percent variability could be introduced into TOC-normalized data.

Sulfides--

Sulfides in sediments can be toxic to infaunal organisms. Sulfide concentrations may also influence the quantity of metals that bind to the sediment, and toxicity of those metals to biota (Di Toro et al. 1989).

Sulfide concentrations in sediments at MSMT stations ranged from <0.25 mg/kg to 1.15 mg/kg. These concentrations were not considered high. Sulfide concentrations >1.00 mg/kg were only found at Stations 30 (1.07 mg/kg) in Eagle Harbor, 32 (1.15 mg/kg) near Magnolia Bluff at Seattle, 37 (1.04 mg/kg) near north Vashon Island, and 48 (1.01 mg/kg) in north Budd Inlet. Although 1.15 mg/kg sulfides was found in a blind field replicate from Station 32 near Magnolia Bluff at Seattle, sulfides were not detected (U0.25) in a separate aliquot taken from the same grab sampler. Also, >0.25 mg/kg and 0.90 mg/kg sulfides were reported for two field replicates from Station 32. The maximum analytical variability for sulfide analyses (i.e, 50 percent difference among laboratory replicates), suggested that sulfide concentrations among MSMT stations do not differ substantially.

Although previous investigators (e.g., PTI and Tetra Tech 1988a) have shown that sulfide concentrations in urban embayments correlate moderately well with sediment TOC content, the low concentrations of sulfides and TOC found in this study preclude meaningful correlations. No significant ($P \geq 0.10$) correlations were found between total sulfide concentrations and any other measured variables.

Interim performance standards for subtidal sediments were recently developed to define reference conditions in Puget Sound (PTI 1989). The interim performance standard proposed for sulfides is 84 mg/kg dry weight. That value represents the 90th percentile of the distribution of sediment concentration values for potential reference areas that were included in the PTI (1989) study. However, qualitative data (e.g., Everett Harbor data) were used to determine that quantitative standard, and sulfide data included in the study (PTI 1989) were primarily obtained from sediments analyzed by

the water-soluble method, not by the total sulfide method recommended in the Puget Sound protocols (Tetra Tech 1986b). Because water-soluble sulfides are a fraction of total sulfides, water-soluble sulfide values should be less than total sulfide values. However, the water-soluble sulfide method is more difficult to conduct, and analytical results are much more likely to yield erroneously high values (Dailey, J., 23 October 1989, personal communication). Erroneously high values frequently result from having too much sediment in the sampling container in the field (Dailey, J., 23 October 1989, personal communication), which occurred during the Elliott Bay survey (Keeley, K., 24 October 1989, personal communication). As is evidenced by the MSMT study, sulfide concentrations in potential reference areas in Puget Sound (maximum 1.15 mg/kg) are considerably less than 84 mg/kg. Because sulfide concentrations may strongly affect interpretation of sediment chemistry and toxicity data (Di Toro et al. 1989), as well as benthic community structure (Smith and Greene 1976), additional studies should be performed before the proposed standard for sulfides is accepted.

Metals

Most metals listed in Table 2 were detected in all samples, with the exception of antimony, beryllium, cadmium, mercury, selenium, silver, and thallium. The maximum concentration observed for most metals was approximately 10 times the minimum concentration. The greatest ranges in concentrations (expressed as the maximum value divided by the minimum value) were observed for silver (56), cadmium (49), copper (48), lead (43), mercury (20), arsenic (16), and nickel (14). The highest concentrations of arsenic, copper, lead, mercury, silver, and zinc were found at Station 34 in Sinclair Inlet. The highest concentrations of cadmium were found at Station 49 in Budd Inlet, and the highest concentrations of chromium and nickel were found at Station 20 in Port Susan.

Metals of Concern--

Traditionally, contaminants of concern have been identified as those that occur at concentrations exceeding proposed sediment criteria [e.g.,

apparent effects threshold (AET) values (PTI 1988b)] or chemical concentrations in reference areas. The mercury concentrations of 0.86 mg/kg DW at Station 34 and 0.51 mg/kg DW at Station 35 are the only metal concentrations in the MSMT survey that exceeded lowest AET (LAET) values (mercury LAET = 0.41 mg/kg DW) (Table 13).

During the U.S. EPA Puget Sound Estuary Program Urban Bay Action Programs, the range of metal concentrations in reference area sediments were summarized from the following areas: Carr Inlet, Case Inlet, Dabob Bay, Hood Canal, Port Madison, Port Susan, Nisqually Delta, Samish Bay, and Sequim Bay (PTI and Tetra Tech 1988a; p. 74). The range of Puget Sound reference values are shown in Tables 13 and 14. Maximum reference values for antimony, arsenic, cadmium, chromium, nickel, selenium, and silver were not exceeded at MSMT stations. Maximum reference values for copper, lead, mercury, and zinc were exceeded at MSMT station. Maximum reference values were exceeded for copper, lead, mercury, and zinc at Station 34 (Sinclair Inlet); for lead, mercury, and zinc at Station 35 (Dyes Inlet); for lead and zinc at Station 38 (Point Pully); for copper at Station 17 (south Hood Canal); and for lead at Stations 33 (Duwamish Head), 48 (north Budd Inlet), and 49 (south Budd Inlet).

EAR Analysis--EAR values were calculated only for chemicals that exceeded interim performance standards (PTI 1989), using the method previously described (see METHODS, Sediment Chemistry). The magnitude of contamination among stations can be assessed using the EAR values shown in Table 14.

Enhancements--An alternative method for identifying metals of concern is to calculate the enhancements of individual metal concentrations as a function of the fines content in sediments. Based on all detected and undetected values for all MSMT stations, the percent fines content of sediments measured in this study was significantly ($P \leq 0.01$) correlated with all metals analyzed, with the exception of antimony, beryllium, manganese, selenium, and thallium (see Table 12). Too few detected values were available for antimony, beryllium, selenium, and thallium to allow a Pearson

TABLE 13. AET VALUES AND RANGES OF PUGET SOUND REFERENCE AND MSMT VALUES FOR METALS[a]

Metal	Range of Puget Sound Reference Values[b]	Amphipod AET Value	Oyster AET Value	Benthic AET Value	Microtox AET Value	Range of MSMT Values[c]
Antimony	<0.1 - 2.76	200		150		<0.17-1.3
Arsenic	1.9 - 17	93	700	57	700	0.74-11.5
Cadmium	0.047 - 1.9	6.7	9.6	5.1	9.6	<0.037-1.80
Chromium	9.6 - 255	270		260		10.8-104
Copper	5 - 74	1,300	390	530	390	2.7-129
Lead	<0.1 - 24	660	660	450	530	2.2-94.4
Mercury	0.01 - 0.28	2.1	0.59	2.1	0.41	<0.043-0.86
Nickel	4 - 140	>140		>140		7.9-113
Silver	<0.02 - 3.3	6.1	>0.56	>6.1	>0.56	<0.034-1.9
Zinc	15 - 101	960	1,600	410	1,600	14.7-173

[a] Concentrations are reported in mg/kg dry weight.

[b] PTI and Tetra Tech (1988a).

[c] See Footnotes d and f in Table 4.

TABLE 14. SUMMARY OF SEDIMENT QUALITY GUIDELINES FOR SELECTED ORGANIC COMPOUND AND METAL CONCENTRATIONS IN SEDIMENTS AND EAR VALUES FOR SELECTED CONTAMINANTS IN SEDIMENTS AT MSMT STATIONS

	Concentrations[a]															
	TOC	HPAH	LPAH	PCBs	Arsenic	Copper	Cadmium	Chromium	Lead	Mercury	Nickel	Silver	Zinc	Phenol	2-Methyl-naphthalene	Butylbenzyl phthalate
Interim Performance Standards[b]	**3.0**	**1,200**	**240**	**30**	**19**	**58**	**1.4**	**150**	**30**	**0.19**	**65**	**0.78**	**110**	**None**	**None**	**None**
Puget Sound Maximum Reference Values[c]	--	**100**	**71**	**3.1**	**17**	**74**	**1.9**	**255**	**24**	**0.28**	**140**	**3.3**	**101**	**62**	**U22**	**U25**
MSMT[d]																
90th Percentiles (n=50)	2.19	1,160	331	18	8.3	46.9	0.999	52.14	29.17	0.190	45.93	0.424	94.33	28.95	U15.4	U15.5
Mean (n=50)	0.9	602	160	12	4.9	23.6	0.26	29.0	14.3	0.13	27.8	0.18	52.7	27	U8.7	9
Range (n=65)	0.06-3.9	36-11,540	24-3,290	4.0-49	0.74-11.5	2.7-129	U0.037-1.80	10.8-104	2.2-94.4	U0.043-0.86	7.9-113	U0.034-1.9	14.7-173	7-520	3-U68 (45)[e]	U3-U68 (39)[e]
Detection Frequency (n=50)	100%	88%	76%	22%	100%	100%	66%	100%	100%	24%	100%	62%	100%	32%	26%	6%

	Elevations Above IPS Values															
MSMT Stations with Variables Exceeding IPS[b]																
8	E3.90	--	6.7	--	--	--	--	--	--	6.7	--	--	--	--	--	--
17	--	--	--	--	--	6.7	--	--	--	--	--	--	--	--	--	--
20	--	--	--	--	--	--	--	--	--	--	4.6	--	--	--	--	--
21	--	--	--	18	--	--	--	--	--	--	--	--	--	--	--	--
30	--	26	7	--	--	--	--	--	--	--	--	--	--	--	--	--
33	--	14	7	5	--	--	--	--	4.1	--	--	--	--	--	--	--
34	--	--	--	--	--	8.5	--	--	10.2	22.1[f]	--	21	4.0	--	--	4
35	--	22	6	--	--	4.3	--	--	7.4	13.1[f]	--	12	2.9	--	--	--
38	--	--	--	--	--	--	--	--	4.4	5.4	--	--	--	--	--	--
40	--	81	55	--	--	--	--	--	--	--	--	--	--	--	6	5
49	--	--	--	--	--	--	12.9	--	--	--	--	--	--	--	--	--

[a] Values are reported as percent dry weight for total organic carbon (TOC), ug/kg dry weight for organic compounds, and mg/kg dry weight for metals. Data qualifiers: U = undetected; E = estimated. PCBs = Aroclor-1254.

[b] The interim performance standards (IPS) (PTI 1989; p. 62) are the maximum values to be allowed for reference conditions (PSWQA 1987, revised 1988). For each chemical variable, the IPS are equal to the 90th percentile values for frequency distributions of chemical concentrations in potential reference areas.

TABLE 14. Continued

[c] During the Puget Sound Estuary Program, the range and detection frequency of organic compound and metal concentrations in sediments from Puget Sound reference areas were summarized [(Tetra Tech 1988a; pp. 79-82) (PTI and Tetra Tech 1988a; pp. 74, 95-98)].

[d] 90th percentile values for concentrations in sediments only at MSMT stations were calculated as described in the section IDENTIFICATION OF POTENTIAL REFERENCE AREAS.

[e] The maximum detected value.

[f] Chemical concentrations exceed the lowest apparent effects threshold (LAET) value.

correlation test. Because metal concentrations and fines content in sediments were correlated, mean relationships between individual metal concentrations and percent fines could be defined by evaluation of a best fit linear regression based on least squares analysis. For all significant correlations found between metals and fines content (Table 12), a regression analysis was determined using data from all stations except outlier stations. The regression line is intended to represent the mean relationship between fines content and metal concentrations for Puget Sound sediments. Outlier stations were visually selected and excluded from the regression analysis to yield a mean regression line centered about the bulk of the data (minimizing effects of extreme data). As an example, Figure 7 shows a linear regression of percent fines and zinc concentrations at all MSMT stations, excluding outlier Stations 34, 35, and 41. The intercepts and slopes of linear regressions of percent fines and all metals are shown in Table G-2 in Appendix G.

Stations with metal concentrations that deviated from the mean relationship between metals and fines content for all MSMT stations demonstrated either positive enhancements (i.e., enrichments) or negative enhancements (i.e., depressions) in metal concentrations. Relative percent enhancements for individual metals at each station were determined as follows:

$$[\text{variable}]\ \text{Enh} = 100 \times \frac{\text{measured concentration} - \text{predicted concentration relative to fines content}}{\text{predicted concentration relative to fines content}}$$

For example:

$$\text{Zinc, Enh} = 100 \times \frac{[(\text{measured zinc}) - (24 + (0.69 \times \%\ \text{fines})]}{[24 + (0.69 \times \%\ \text{fines})]}$$

Relative percent enrichments (+Enh) and depressions (-Enh) for individual metals at stations are presented in Table 15. For this report, metal enhancements with values $\geq$50 percent were considered substantially high enrichments, and metal depressions $\leq$-50 percent were considered substantially

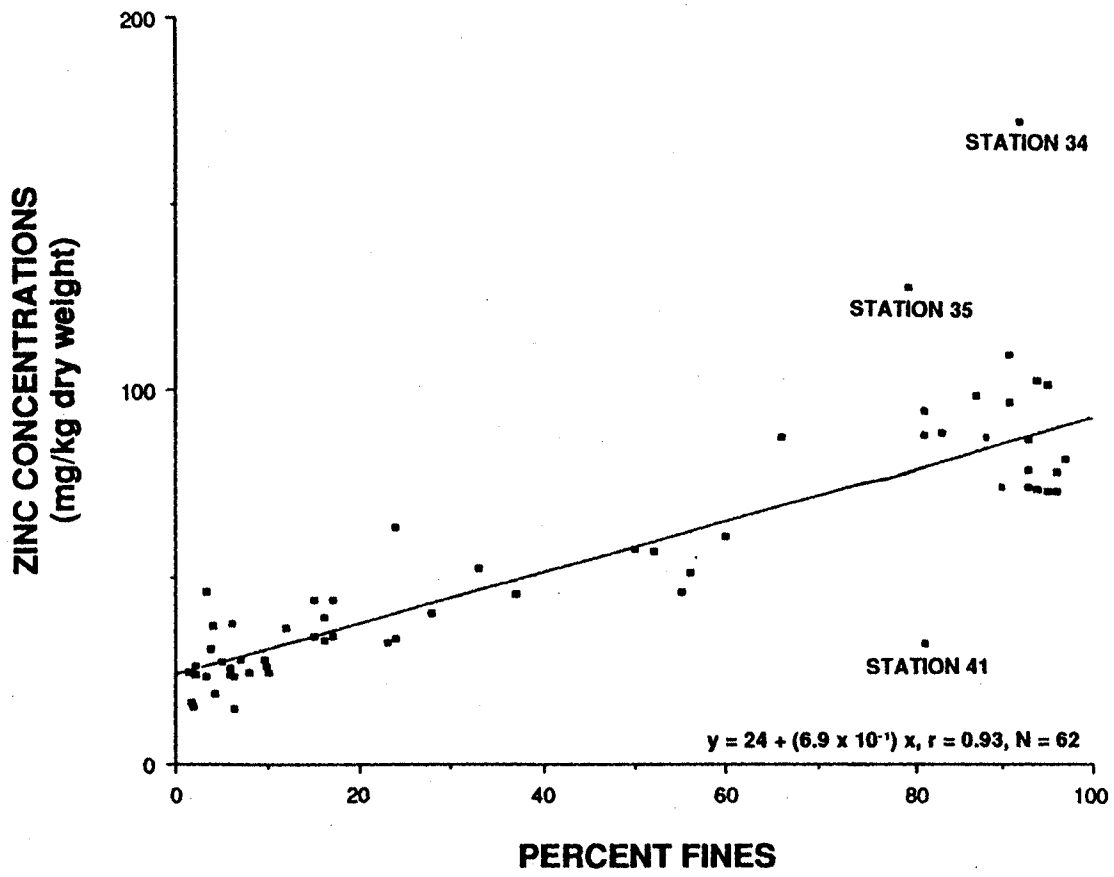


Figure 7. Results of a regression analysis using percent fines and zinc concentrations in sediments at stations.

TABLE 15. RELATIVE PERCENT ENHANCEMENTS FOR METAL CONCENTRATIONS AT ALL STATIONS[a]

Station	Sample	Fines (%)	TOC Enh (%)	Al Enh (%)	As Enh (%)	Ba Enh (%)	Cd Enh (%)	Ca Enh (%)	Cr Enh (%)	Co Enh (%)	Cu Enh (%)	Fe Enh (%)	Pb Enh (%)	Mg Enh (%)
1	1	93	-23.5	-14.0	-14.0	-1.0	15.0	-8.0	-17.0	-25.0	-36.0	-9.0	-38.0	-8.0
2	1	50	-38.5	4.0	-24.0	36.0	**85.0**	27.0	-10.0	-4.0	-36.0	10.0	-43.0	5.0
3	1	33	**56.5**	1.0	38.0	30.0	**83.0**	**395.0**	-16.0	-12.0	-15.0	15.0	-17.0	3.0
4	1	93	2.0	-1.0	-22.0	12.0	-20.0	3.0	11.0	2.0	-14.0	6.0	-5.0	18.0
5	1	96	-10.9	-14.0	-22.0	-3.0	-26.0	0.0	-8.0	-12.0	28.0	-4.0	19.0	-3.0
5	1R	97	-16.7	-19.0	-18.0	-7.0	-22.0	-7.0	-16.0	-19.0	-34.0	-10.0	-21.0	-7.0
5	2	96	-6.0	-20.0	-19.0	-7.0	3.0	-7.0	-14.0	-19.0	-34.0	-9.0	-24.0	-6.0
5	3	95	-10.0	-11.0	-22.0	4.0	9.0	1.0	-7.0	-6.0	-24.0	-2.0	-9.0	-1.0
6	1	7	0.3	-9.0	-5.0	7.0	42.0	**279.0**	-1.0	-17.0	-25.0	2.0	**-63.0**	28.0
7	1	6	43.9	**51.0**	6.0	34.0	1.0	41.0	16.0	46.0	10.0	**85.0**	-34.0	**69.0**
8	1	66	**174.0**	-2.0	-17.0	-1.0	**202.0**	-20.0	-15.0	-16.0	-3.0	3.0	40.0	-5.0
9	1	1.3	**-55.8**	19.0	**-63.0**	11.0	-34.0	6.0	**59.0**	20.0	4.0	27.0	**-61.0**	**89.0**
10	1	37	-27.9	10.0	-22.0	-2.0	-48.0	-7.0	8.0	2.0	-27.0	12.0	-32.0	13.0
11	1	24	8.9	-4.0	-11.0	-7.0	-34.0	**55.0**	-3.0	-25.0	-32.0	-6.0	8.0	-5.0
12	1	90	-21.1	-14.0	-20.0	-8.0	-44.0	-10.0	-17.0	-17.0	-20.0	-5.0	11.0	-8.0
13	1	10	-41.7	-14.0	-15.0	-29.0	-41.0	-26.0	-11.0	-31.0	-36.0	8.0	**-54.0**	-7.0
14	1	28	-47.5	2.0	-22.0	6.0	-5.0	2.0	15.0	30.0	-21.0	21.0	-27.0	11.0
15	1	8	-10.8	-6.0	-43.0	-27.0	-29.0	-14.0	-6.0	-25.0	-25.0	-6.0	**-70.0**	-10.0
16	1	4	-5.1	**94.0**	**67.0**	-21.0	-27.0	**75.0**	**156.0**	**78.0**	**147.0**	**130.0**	**-55.0**	**61.0**
17	1	93	-23.5	**55.0**	-23.0	**-58.0**	-10.0	**118.0**	23.0	**113.0**	**174.0**	**66.0**	**-55.0**	47.0
18	1	6	-28.7	2.0	13.0	3.0	**147.0**	-3.0	**90.0**	19.0	12.0	8.0	-49.0	32.0
19	1	81	10.3	5.0	15.0	17.0	**131.0**	-7.0	**50.0**	**83.0**	12.0	16.0	35.0	34.0
20	1	94	-49.5	-7.0	4.0	2.0	**-66.0**	-17.0	**141.0**	**77.0**	1.0	11.0	-48.0	**56.0**
21	1	52	13.6	-3.0	24.0	1.0	**190.0**	-27.0	9.0	16.0	40.0	-7.0	-14.0	2.0
22	1	4.2	-22.5	-17.0	-33.0	-11.0	6.0	-27.0	-13.0	-35.0	-45.0	-30.0	**-54.0**	-25.0
23	1	2	-19.9	10.0	23.0	23.0	-24.0	-11.0	28.0	8.0	-19.0	16.0	-12.0	24.0
24	1	87	-7.7	20.0	-5.0	35.0	21.0	17.0	17.0	20.0	8.0	15.0	20.0	16.0
25	1	1.9	**-52.6**	-23.0	**-75.0**	-19.0	-40.0	-27.0	-25.0	**-52.0**	**-63.0**	-38.0	**-67.0**	-26.0
26	1	16	30.7	9.0	25.0	31.0	**67.0**	36.0	22.0	25.0	-13.0	26.0	-30.0	34.0
26	1R	16	5.0	20.0	-23.0	40.0	43.0	**57.0**	34.0	36.0	-2.0	36.0	-30.0	43.0
26	2	15	-2.1	14.0	-8.0	23.0	**70.0**	42.0	25.0	28.0	-13.0	29.0	**-50.0**	34.0
26	3	17	-21.9	17.0	13.0	49.0	**52.0**	47.0	26.0	33.0	-4.0	36.0	-32.0	40.0
27	1	3.2	-30.9	-1.0	-19.0	30.0	-32.0	-19.0	-1.0	-22.0	-37.0	-9.0	1.0	-13.0
28	1	4.9	-27.7	7.0	-21.0	-6.0	-29.0	2.0	31.0	-3.0	-39.0	13.0	-16.0	20.0
29	1	83	-9.2	1.0	-8.0	20.0	**68.0**	19.0	1.0	15.0	-1.0	4.0	15.0	5.0
30	1	56	14.3	-30.0	-25.0	-26.0	**594.0**	-16.0	-17.0	-33.0	18.0	-38.0	**61.0**	-32.0
31	1	1.7	4.3	-5.0	-3.0	12.0	-28.0	-21.0	-8.0	-14.0	-34.0	-12.0	17.0	-5.0
32	1	5.8	-20.1	-12.0	6.0	-9.0	-39.0	-13.0	-3.0	-12.0	-25.0	-10.0	**66.0**	-20.0
32	1R	6.3	**-53.3**	-15.0	30.0	-9.0	-28.0	-15.0	-15.0	-18.0	-27.0	-14.0	**70.0**	-23.0
32	2	9.8	-27.9	-15.0	**64.0**	-8.0	-42.0	-15.0	-17.0	-21.0	-20.0	-15.0	**116.0**	-26.0

TABLE 15. (Continued)

Station	Sample	Fines (%)	TOC Enh (%)	Al Enh (%)	As Enh (%)	Ba Enh (%)	Cd Enh (%)	Ca Enh (%)	Cr Enh (%)	Co Enh (%)	Cu Enh (%)	Fe Enh (%)	Pb Enh (%)	Mg Enh (%)
32	3	5.9	-42.8	-14.0	**53.0**	-8.0	-36.0	-16.0	-20.0	-18.0	-25.0	-12.0	44.0	-24.0
33	1	24	8.9	1.0	41.0	**115.0**	**931.0**	-2.0	24.0	-8.0	**146.0**	-4.0	**319.0**	-6.0
34	1	92	13.4	4.0	48.0	17.0	**506.0**	17.0	40.0	-6.0	**249.0**	-1.0	**474.0**	-5.0
35	1	79	36.7	4.0	33.0	3.0	**572.0**	**66.0**	19.0	-10.0	**102.0**	-8.0	**354.0**	-2.0
36	1	2.2	-15.5	3.0	**-50.0**	9.0	-42.0	-15.0	30.0	-17.0	-21.0	-10.0	-30.0	23.0
37	1	5.9	-7.7	-8.0	-10.0	-28.0	21.0	-14.0	16.0	14.0	-27.0	1.0	-2.0	-3.0
38	1	91	4.1	15.0	41.0	27.0	12.0	10.0	8.0	32.0	37.0	12.0	**209.0**	12.0
38	1R	91	9.3	8.0	44.0	19.0	32.0	6.0	3.0	31.0	32.0	6.0	**151.0**	7.0
38	2	95	10.0	-1.0	12.0	8.0	-26.0	-3.0	-4.0	25.0	22.0	-1.0	**112.0**	0.0
38	3	94	1.0	1.0	36.0	20.0	**64.0**	-1.0	-5.0	24.0	21.0	0.0	**135.0**	0.0
39	1	1.7	-37.4	-25.0	-43.0	-30.0	-4.0	-38.0	-30.0	**-52.0**	**-54.0**	-33.0	-25.0	-38.0
40	1	16	**63.4**	-26.0	4.0	-15.0	43.0	-12.0	-45.0	-27.0	**112.0**	-29.0	**164.0**	-47.0
41	1	81	**-53.5**	-43.0	-36.0	-43.0	**-52.0**	-10.0	**-68.0**	-46.0	-20.0	-49.0	-10.0	**-61.0**
42	1	3.2	-48.2	13.0	**223.0**	11.0	-43.0	-12.0	32.0	**67.0**	**83.0**	41.0	**248.0**	17.0
43	1	6.3	-40.5	-39.0	-41.0	-44.0	-41.0	-37.0	-34.0	**-50.0**	**-54.0**	-43.0	**-50.0**	-43.0
44	1	15	5.3	-6.0	-5.0	-15.0	-44.0	-11.0	-16.0	8.0	17.0	-13.0	31.0	-26.0
44	1R	16	2.7	-8.0	23.0	-19.0	-4.0	-14.0	-12.0	9.0	4.0	-13.0	31.0	-26.0
44	2	12	14.7	-5.0	5.0	-18.0	-18.0	-10.0	-16.0	13.0	16.0	-12.0	35.0	-24.0
44	3	17	-4.1	-6.0	5.0	-19.0	-22.0	-9.0	-16.0	17.0	17.0	-12.0	42.0	-26.0
45	1	55	-20.3	-23.0	-9.0	-36.0	**167.0**	-11.0	-43.0	-17.0	3.0	-35.0	11.0	-43.0
46	1	9.5	40.4	2.0	-27.0	-16.0	**75.0**	-1.0	-24.0	-11.0	30.0	-18.0	-10.0	-33.0
47	1	23	-48.9	-15.0	-27.0	-37.0	6.0	-10.0	10.0	4.0	-38.0	19.0	-33.0	-5.0
48	1	81	45.2	19.0	-5.0	-14.0	**561.0**	**51.0**	-3.0	15.0	35.0	-2.0	**93.0**	-4.0
49	1	88	45.1	33.0	8.0	-34.0	**838.0**	13.0	-6.0	-5.0	**50.0**	-2.0	**64.0**	-12.0
50	1	3.8	7.7	35.0	-32.0	-8.0	-38.0	**67.0**	34.0	45.0	26.0	41.0	**-54.0**	17.0
Substantially (≥50%) Enhanced Samples		3	3	4	1	19	9	5	5	8	3	15	4	
Substantially (≤-50%) Depressed Samples		4	0	3	1	2	0	1	3	3	0	11	1	

[a] Values in bold show high enhancement (≥50 percent) or depression (≤-50 percent).

TABLE 15. (Continued)

Station	Sample	Hg Enh (%)	Ni Enh (%)	K Enh (%)	Ag Enh (%)	Na Enh (%)	V Enh (%)	Zn Enh (%)
1	1	-15.0	-16.0	-9.0	**-56.0**	-18.0	-14.0	-15.0
2	1	-27.0	-3.0	-4.0	**-63.0**	-30.0	1.0	-1.0
3	1	-18.0	-32.0	13.0	-2.0	14.0	-5.0	14.0
4	1	-8.0	23.0	8.0	-38.0	12.0	-3.0	0.0
5	1	-29.3	-9.0	-8.0	**-54.0**	-9.0	-7.0	-13.0
5	1R	-23.0	-37.0	-15.0	**-61.0**	-7.0	-14.0	-19.0
5	2	-16.0	-14.0	-15.0	**-57.0**	-4.0	-13.0	-18.0
5	3	**-54.7**	-4.0	-6.0	**-53.0**	-10.0	-3.0	-8.0
6	1	7.0	24.0	-16.0	-18.0	21.0	-1.0	-2.0
7	1	11.0	**51.0**	-2.0	-16.0	-5.0	**69.0**	36.0
8	1	**112.0**	-28.0	-13.0	-37.0	-13.0	4.0	27.0
9	1	17.0	**130.0**	1.0	-5.0	30.0	30.0	-2.0
10	1	-31.0	5.0	-12.0	**-55.0**	-22.0	11.0	-7.0
11	1	**64.2**	-22.0	15.0	-37.0	9.0	-5.0	-16.0
12	1	-19.0	-15.0	-12.0	**-55.0**	-15.0	-10.0	-13.0
13	1	5.0	-9.0	13.0	-32.0	-15.0	-15.0	-21.0
14	1	-31.0	31.0	-6.0	-35.0	-26.0	10.0	-5.0
15	1	-13.0	-20.0	-15.0	-15.0	14.0	-13.0	-17.0
16	1	12.0	33.0	45.0	-4.0	32.0	**147.0**	41.0
17	1	-34.0	31.0	-18.0	-49.0	-7.0	**127.0**	-10.0
18	1	-28.0	**64.0**	-10.0	-26.0	-19.0	16.0	-6.0
19	1	1.0	**65.0**	12.0	-5.0	25.0	21.0	11.0
20	1	-43.0	**197.0**	-46.0	**-68.0**	**-60.0**	2.0	-16.0
21	1	-32.0	15.0	-37.0	-6.0	-43.0	-2.0	-4.0
22	1	4.0	-35.0	-11.0	-1.0	22.0	-36.0	-30.0
23	1	-4.0	**50.0**	16.0	7.0	31.0	9.0	4.0
24	1	-11.0	12.0	16.0	44.0	5.0	16.0	18.0
25	1	25.0	-32.0	-19.0	-15.0	25.0	-40.0	-40.0
26	1	-19.0	41.0	14.0	-12.0	12.0	6.0	14.0
26	1R	-11.0	44.0	21.0	-4.0	13.0	14.0	26.0
26	2	-5.0	40.0	19.0	-15.0	6.0	12.0	15.0
26	3	-8.0	40.0	19.0	-20.0	0.0	12.0	24.0
27	1	-12.0	-30.0	12.0	-8.0	-10.0	-10.0	-10.0
28	1	10.0	16.0	31.0	-8.0	-15.0	-2.0	2.0
29	1	-8.0	6.0	9.0	**74.0**	0.0	-3.0	10.0
30	1	**70.0**	-24.0	-29.0	**94.0**	-34.0	-32.0	-17.0
31	1	-15.0	-13.0	10.0	2.0	46.0	-18.0	-2.0
32	1	14.0	-26.0	17.0	**83.0**	9.0	-12.0	-14.0
32	1R	-2.0	-29.0	7.0	**79.0**	1.0	-15.0	-17.0
32	2	-5.0	-46.0	2.0	**179.0**	-9.0	-16.0	-14.0

TABLE 15. (Continued)

Station	Sample	Hg Enh (%)	Ni Enh (%)	K Enh (%)	Ag Enh (%)	Na Enh (%)	V Enh (%)	Zn Enh (%)
32	3	3.0	-36.0	11.0	**63.0**	9.0	-16.0	-11.0
33	1	44.0	19.0	-17.0	**90.0**	-19.0	-1.0	**57.0**
34	1	**469.0**	11.0	-2.0	**604.0**	-6.0	3.0	**98.0**
35	1	**273.0**	15.0	3.0	**363.0**	15.0	3.0	**63.0**
36	1	-7.0	34.0	-9.0	-19.0	47.0	-10.0	-6.0
37	1	4.0	-11.0	23.0	-21.0	1.0	-8.0	-8.0
38	1	**60.0**	7.0	22.0	**106.0**	30.0	22.0	27.0
38	1R	**60.0**	-4.0	27.0	**98.0**	30.0	11.0	19.0
38	2	23.0	-9.0	14.0	**622.0**	16.0	7.0	14.0
38	3	37.0	-8.0	17.0	**82.0**	26.0	4.0	10.0
39	1	-17.0	**-52.0**	1.0	-23.0	19.0	-32.0	-34.0
40	1	42.0	**-63.0**	-44.0	**87.0**	-15.0	10.0	-4.0
41	1	**-60.0**	**-72.0**	**-64.0**	-13.0	**-61.0**	-26.0	**-59.0**
42	1	-12.0	45.0	23.0	-23.0	26.0	31.0	**79.0**
43	1	4.0	-49.0	-32.0	-26.0	-2.0	-41.0	-48.0
44	1	2.0	-25.0	-14.0	-3.0	8.0	1.0	0.0
44	1R	-28.0	-23.0	-10.0	4.0	-1.0	1.0	-1.0
44	2	-21.0	-21.0	-4.0	6.0	13.0	4.0	4.0
44	3	9.0	-45.0	0.0	2.0	10.0	3.0	4.0
45	1	-23.0	-48.0	-39.0	-4.0	-21.0	-16.0	-25.0
46	1	-2.0	-44.0	4.0	-3.0	45.0	9.0	-7.0
47	1	-14.0	12.0	19.0	**-61.0**	-28.0	5.0	-17.0
48	1	1.0	-1.0	17.0	**53.0**	30.0	18.0	19.0
49	1	29.0	-18.0	5.0	**115.0**	11.0	-3.0	4.0
50	1	-6.0	27.0	-15.0	-17.0	11.0	**65.0**	17.0
Substantially (≥50%) Enhanced Samples		7	6	0	16	0	4	4
Substantially (≤-50%) Depressed Samples	2	3	1	10	2	0	1	

[a] Values in bold show substantial enhancement (≥50 percent) or depression (≤-50 percent).

depressed. Those substantially enriched and depressed metals appear in bold in Table 15.

The following stations exhibited the metal enrichments greater than 50 percent:

Station	Metal
7, 16, 17	Aluminum
16, 32, 42	Arsenic
33	Barium
2, 3, 8, 18, 19, 21, 26, 29, 30, 33, 34, 35, 45, 46, 48, 49	Cadmium
3, 6, 11, 16, 17, 26, 35, 48, 50	Calcium
9, 16, 18, 19, 20	Chromium
16, 17, 19, 20, 42	Cobalt
16, 17, 33, 34, 35, 40, 42, 49	Copper
7, 16, 17	Iron
30, 32, 33, 34, 35, 38, 40, 42, 48, 49	Lead
7, 9, 16, 20	Magnesium
8, 11, 30, 34, 35, 38	Mercury
7, 9, 18, 19, 20, 23	Nickel
29, 30, 32, 33, 34, 35, 38, 40, 48, 49	Silver
7, 16, 17, 50	Vanadium
33, 34, 35, 42	Zinc
16, 17 (South Hood Canal)	Aluminum, calcium, cobalt, copper, iron and vanadium (as a group)
34, 35 (Sinclair and Dyes Inlets)	Cadmium, copper, lead, mercury, silver, and zinc (as a group)

Station	Metal
18, 19, 20 (Whidbey Basin)	Chromium and nickel (as a group)
30, 32, 33, 34, 35, 38, 40, 48, 49	(Central Basin plus Budd Inlet) Lead and silver (as a group)

Chromium and nickel enrichments at Stations 18, 19, and 20 (Whidbey Basin) may result from natural regional effects of sediment discharges from either or both the Skagit and Stillaguamish Rivers. Because the greatest chromium and nickel enrichments were found at Station 20 (Port Susan), the Stillaguamish River is the more likely candidate. Enrichments of aluminum, calcium, cobalt, copper, iron, and vanadium in the lower Hood Canal may be natural constituents of sediment discharged from the Skokomish River. The source of arsenic enrichment at Station 42 (Ruston) was probably the former ASARCO smelter. Cadmium enrichments in Budd Inlet (Stations 48 and 49), which are consistent with results of historical studies that revealed elevated cadmium in Budd Inlet, may be a result of a former metal plating facility in West Bay at Olympia (Tetra Tech 1988a; pp. 46, 105-106). Lead enrichments at Stations 33 (Elliott Bay), 34 (Sinclair Inlet), 35 (Dyes Inlet), 38 (Point Pully), 40 (Commencement Bay-City Waterway) and 42 (Ruston) may be attributable to the effects of urban stormwater runoff, which contains lead-contaminated street dust. Mercury and silver concentrations at Stations 34 (Sinclair Inlet) and 35 (Dyes Inlet) were consistent with historical values and may be due to the proximity of both stations to Navy facilities, including the former ordnance facility in Dyes Inlet.

In urban embayments, enrichments were commonly found for lead, silver, and less frequently for cadmium. Substantial lead and silver enrichments, and slight mercury enrichments, were found at Station 38 (Point Pully), a deep water station. Historical sediment data from Station 38 and other nearby deep water stations show that this area of Puget Sound has accumulated metal and organic contaminants that can be associated with nearby wastewater treatment plant discharges, as well as with Commencement Bay discharges (Farlow 1983). Historical water current studies (Ebbesmeyer et al. 1984) have shown that a portion of the water from the Commencement Bay area flows

north into Colvos Passage (located west of Vashon Island). A portion of the northward flow of water in Colvos Passage moves southward into East Passage (located east of Vashon Island). Thus, it is possible that contaminants from Commencement Bay could be found in sediments in East Passage. Ebbesmeyer et al. (1984) also reported a closed gyre circulating counter clockwise in north Seahurst Bay in East Passage (i.e., north of Station 38), which may affect sediment deposition in that area.

Results of the determination of enhancements relative to average or mean Puget Sound metal concentrations in fine-grained sediments can be used to show enriched or depressed metal concentrations at stations. Those stations exhibiting highest enrichments have sediments that are most affected by those sources of metals different than those that impact average Puget Sound fine sediments. Alternatively, stations exhibiting highest enrichments may simply be impacted by a larger quantity of metals from a source (e.g., urban runoff) that may also be a source of metals contamination to other stations. However, those other stations may have minimally enriched sediments because the source discharges a smaller quantity of metals that impact those stations. Similarly, those stations exhibiting highest depressions have sediments that are least affected by those sources of metals that impact the average Puget Sound sediments. Enhancements are determined relative to the mean Puget Sound sediment composition of metals typically associated with fine-grained sediments. [Enhancements are different than dry-weight normalized metals data, which are calculated by simply dividing the metals concentration at a station by the fines content.] Because limited data on background metal concentrations in Puget Sound is available, and pristine conditions in different areas of Puget Sound may have different metal concentrations, normalization of metal concentrations to the average Puget Sound sediment metals composition (i.e., enhancements) in fine-grained sediments is suggested as one method for categorizing and evaluating the effects of observed metals.

Total metals contributions and enhancements in sediments is presented for each station by summing enrichments for all metals into one category and summing depressions for all metals into a second category. Separate sums

are determined to preserve sign and to prevent cancelling effects by combining opposite signs. A summary of enriched and depressed metals for each station is presented in Figure 8. Individual metals that were responsible for the summed percentages for each station shown in Figure 8 can be found in Table 15. Stations are plotted in increasing order by percent fines to allow comparisons of enrichments and depressions to percent fines for each station.

One can use the enhancement method to identify the least and most contaminated MSMT stations relative to the average Puget Sound fine sediment composition. The following stations with low fines (i.e., <10 percent) content exhibited the most depressed metal concentrations: Stations 39 (Dash Point), 25 (northwest Central Basin), 22 (Mukilteo), 43 (Carr Inlet), 15 (Dabob Bay), and 13 (north Hood Canal). The following stations with high fines content (i.e., >80 percent) exhibited the most depressed and least enriched metal concentrations: Stations 41 (Commencement Bay), 12 (Port Townsend), 1 (Semiahmoo Bay), and 5 (Samish Bay). Stations with depressions and enrichments very close to the zero line represent average MSMT concentrations in Puget Sound, and those stations would be expected to be good candidates for Puget Sound reference areas. Their final selection would be subject to evaluations of organic compound, toxicity, and benthic community data.

The following stations with low fines content exhibited the least depressed and most enriched metal concentrations: Stations 42 (Commencement Bay-Ruston) and 16 (south Hood Canal). A single station with moderate (i.e., 24 percent) fines content exhibited the least depressed and most enriched metal concentrations: Station 33 (Duwamish Head). The following stations with high fines content exhibited the least depressed and most enriched metal concentrations: Stations 35 (Dyes Inlet), 48 and 49 (Budd Inlet), and 34 (Sinclair Inlet). Overall, the greatest enrichments were found in urban embayments. Stations with the greatest enrichments of metals would not be expected to be good reference areas if the enriched metals were contaminant metals (e.g., lead, zinc, cadmium). In reviewing Figure 8, it should be remembered that the figure reflects the sums of all enriched

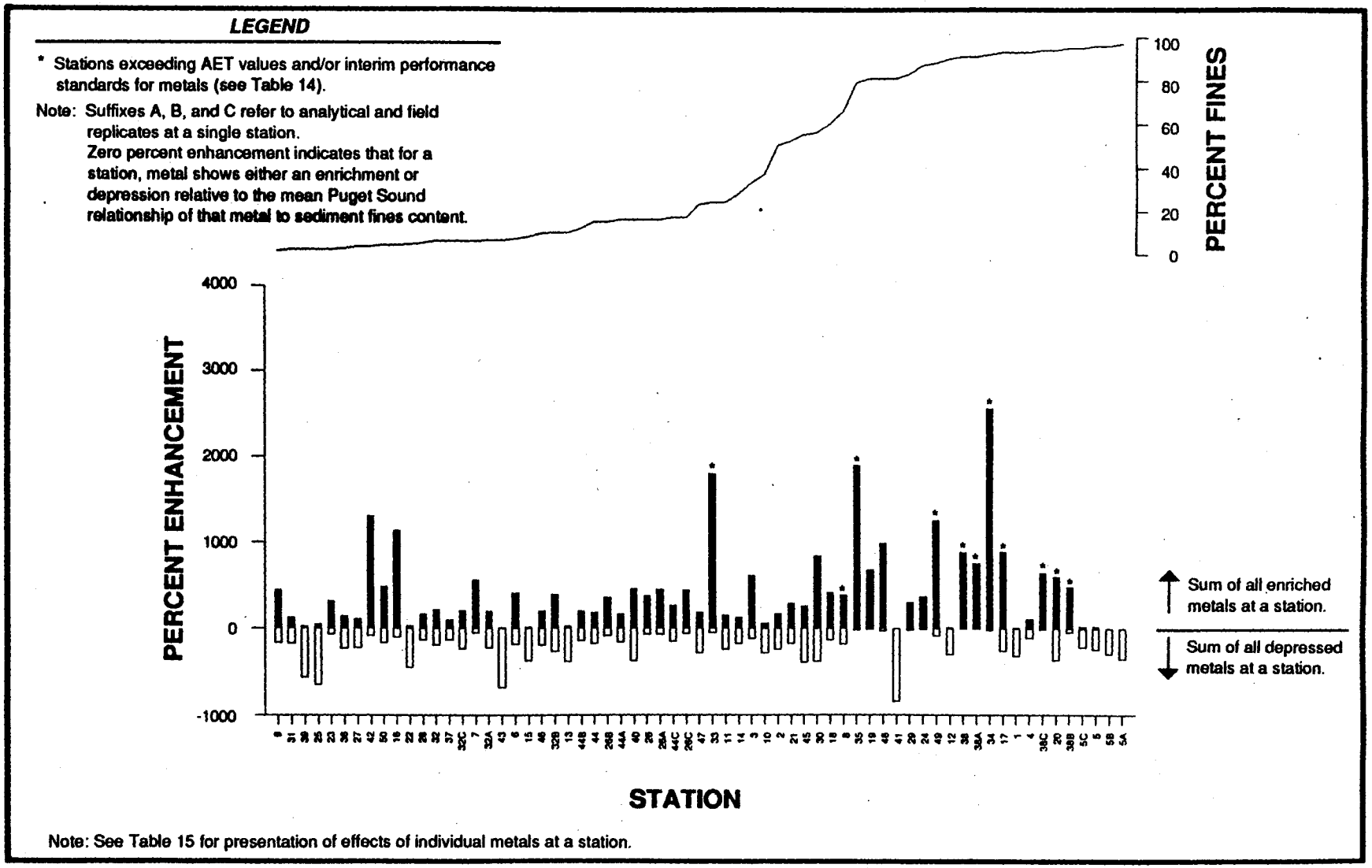


Figure 8. Relative percent enhancements for metal concentrations at all stations.

metals, including both contaminant (e.g., lead, zinc) and noncontaminant (e.g., sodium, vanadium) metals. [Although contaminant and noncontaminant metals were not specifically defined for the MSMT, the *Pollutant of Concern Matrix* (U.S. EPA 1986) identified potential contaminant metals in Table A-1]. Stations where the interim performance standards or Puget Sound maximum reference values presented in Table 14 are exceeded are denoted with an asterisk in Figure 8. At two stations, metal concentrations were >1,000 percent enrichment, but did not exceed standards or maximum reference values due to low absolute concentrations: Stations 16 (south Hood Canal) and 42 (Ruston). Enrichment at Station 16 was primarily due to chromium, copper, iron, and vanadium, and enrichment at Station 42 was primarily due to arsenic and lead.

Individual Metals--

A brief summary of individual metal concentrations is provided below. Metal concentrations are reported by station in Table D-1 in Appendix D.

Aluminum (Al)--Aluminum is not considered a contaminant of concern in Puget Sound (U.S. EPA 1986). Greatest aluminum enrichments were found at Station 7 (Strait of Juan de Fuca) and Stations 16 and 17 (south Hood Canal). Greatest aluminum depressions were found at Stations 41 (near mouth of the Puyallup River) and 43 (Carr Inlet). Aluminum is expected to be primarily a crustal constituent and its concentrations in sediments were highly dependent on fines content ($r = 0.90$). The intercept of the linear regression for aluminum vs. fines content (see Table G-2 in Appendix G) suggests that the average sedimentary aluminum contribution from sand is approximately 6,270 mg aluminum/kg sand.

Aluminum concentrations were significantly ($P \leq 0.01$) correlated with 16 metals (Table 12). Aluminum was most strongly correlated ($r = 0.96$) with iron, indicating the high sorptive capacity of clays (aluminum silicates) for multivalent metals (e.g., iron). Aluminum concentrations in sediments were not strongly correlated with chemical variables that are known constituents of urban discharges, nor did concentrations appear to be

affected by urban activities. These results suggest that aluminum (and associated iron) is a naturally ubiquitous metal in Puget Sound and that its origin is primarily crustal.

Antimony (Sb)--Antimony is a contaminant of potential concern in Puget Sound (U.S. EPA 1986). Antimony was rarely detected in sediments. The mean quantitation limit was 0.26 mg/kg with a minimum of 0.17 mg/kg. Sixty-six percent of the undetected antimony results were qualified as unusable, due to low matrix spike recoveries (see Appendix B). All results greater than the quantitation level were reported and required qualification as estimates. Antimony concentrations at all sites sampled did not exceed AET values or Puget Sound maximum reference values. Greatest concentrations were found near the ASARCO smelter at Ruston (E1.3 mg/kg DW; Station 42) and in Sinclair Inlet (E1.2 mg/kg; Station 34). Results suggest that antimony is not a metal of concern for the MSMT, although caution should be exercised with this interpretation because nondetected results were qualified as unusable due to low recoveries.

Arsenic (As)--Arsenic has been identified as a contaminant of concern in Puget Sound (U.S. EPA 1986). Arsenic was detected at each MSMT station, with a range of 0.74 to 11.5 mg/kg DW. The AET and Puget Sound maximum reference values for arsenic were not exceeded. Highest concentrations were found at Stations 34 (11.5 mg/kg; Enh = 48 percent; Sinclair Inlet), 38 (mean 10.2 mg/kg; Enh = 30 percent; Point Pully), 42 (9.9 mg/kg; Enh = 223 percent; Ruston), and 35 (9.4 mg/kg; Enh = 33 percent; Dyes Inlet). Activities at the former Asarco smelter probably contributed arsenic to sediments at Station 42. A potential source of the arsenic found in sediments at Station 34 may be the Puget Sound Naval Shipyard.

As shown in Table 4, mean Puget Sound arsenic concentrations found in the MSMT are 46 percent less than the mean (area weighted) concentrations reported in the *Puget Sound Environmental Atlas*. However, it should be noted that the range of arsenic concentrations reported in the Atlas is much greater than that found in the MSMT. Sediment arsenic concentrations at 18 individual MSMT stations were an average of approximately 59 percent lower

than those at *Atlas* stations (representing data from 1980 to 1986). Greatest reductions were observed at seven stations in the Central Basin and South Sound regions near ASARCO, a former point source of arsenic. Some of these reductions may be attributed to differences in analytical methods, if total (rather than strong acid) digestion methods were previously used. However, the same methods were used in most cases. Future monitoring results will be available to evaluate the validity of this trend.

Arsenic concentrations were significantly ($P \leq 0.01$) correlated with fines content ($r = 0.76$). The relationship between arsenic and fines content was determined using a scatter plot of MSMT data and a best fit linear regression (Table G-2 in Appendix G). The intercept of the linear regression indicates that the average sedimentary arsenic contribution from sand is approximately 2.9 mg arsenic/kg sand. MSMT stations distant from known sources of arsenic and characterized by a high proportion of gravel and/or medium to coarse sand (e.g., Stations 7 and 23) exhibited arsenic concentrations of 3.4 and 3.7 mg/kg, respectively. Much of the arsenic in Puget Sound sediments that is accounted for by the relationship above is expected to be derived from natural sources in the Puget Sound area. For 22 of the 26 MSMT stations with sediments classified as sand (see Figure 2), arsenic concentrations were less than 4 mg/kg. At the remaining four stations with high sand content, arsenic concentrations exceeded 4 mg/kg [i.e., Stations 16 (south Hood Canal), 32 (Magnolia Bluff), 33 (Duwamish Head), and 42 (Ruston)]. Magnolia Bluff and Duwamish Head stations are expected to be impacted by the Duwamish River and associated urban discharges, and Ruston is known to be impacted by the ASARCO smelter. The Central Basin region exhibited the greatest range in concentrations for arsenic (Table 11), with greatest arsenic enrichments (Table 15) at Stations 42 (220 percent; Ruston), 16 (67 percent; south Hood Canal), and 34 (48 percent; Sinclair Inlet).

Arsenic was also significantly ($P \leq 0.01$) correlated with TOC, 16 metals (see Table 12), beta-sitosterol ($r = 0.43$), and retene ($r = 0.50$), suggesting a natural or nonurban contribution. Correlations between arsenic and other

metals at MSMT stations are probably a result of associations with other natural and background constituents that covary.

Barium (Ba)--Barium has not been identified as a metal of concern in Puget Sound (U.S. EPA 1986). Barium was detected in sediments at each MSMT station, with a range of 8.0 to 59.6 mg/kg DW. Highest concentrations were found at Stations 24 (59.6 mg/kg; northeast Central Basin), 38 (54.5 mg/kg; mid-channel East Passage near Point Pully), 34 (53.9 mg/kg; Sinclair Inlet), 4 (52.1 mg/kg; Lummi Island), and 29 (51.1 mg/kg; northwest of Shilshole).

The relationship between barium and percent fines was determined by a best fit linear regression. The intercept of the linear regression (Table G-2 in Appendix G) indicates that the average sedimentary barium contribution from the outer or acid leachable portion of sand is approximately 12 mg barium/kg sand. Much of the barium in Puget Sound sediments that is accounted for by that relationship is expected to be associated with background and derived from natural sources in the Puget Sound area.

Greatest barium enrichments were found at stations primarily in the Central Basin, particularly Station 33 (115 percent; Duwamish Head). Enriched barium at this station may be due to local source discharges. Industrially uses of barium include glass, paint, rubber, refractories, flares and incendiaries, and automotive lubricants. It is also used as a diesel fuel additive. South Sound stations consistently showed depressed barium concentrations, which suggests a low barium input regionally.

In general, analytical variability was similar or equivalent to the within-station variability for barium at the five monitoring variability stations (0.015-0.098 CV and RD).

Beryllium (Be)--Beryllium is a toxic metal, but it is not a potential contaminant of concern in Puget Sound (U.S. EPA 1986). Beryllium was not detected in sediments at most stations. The mean quantitation limit was 0.32 mg/kg with a minimum of 0.17 mg/kg. Beryllium was detected at three percent of the MSMT stations, and concentrations at each of those stations

were similar to the mean quantitation limit. A Pearson correlation of beryllium and percent fines could not be tested with this small number of data points.

Cadmium (Cd)--Cadmium is a contaminant of concern in Puget Sound (U.S. EPA 1986). Cadmium was detected at 66 percent of the MSMT stations, with a range of <0.037 to 1.80 mg/kg DW (Table 4). Highest concentrations were found within urban embayments at the following stations: 49 (1.8 mg/kg; Enh = 838 percent; south Budd Inlet), 34 (1.2 mg/kg; Enh = 506 percent; Sinclair Inlet), 35 (1.2 mg/kg; Enh = 572 percent; Dyes Inlet), 48 (1.2 mg/kg; Enh = 561 percent; north Budd Inlet), 30 (1.0 mg/kg; Enh = 594 percent; Eagle Harbor), and 33 (0.99 mg/kg; Enh = 931 percent; Duwamish Head-Elliott Bay). The Puget Sound maximum reference (PTI and Tetra Tech 1988a) and AET values for cadmium were not exceeded.

Cadmium concentrations reported for individual MSMT stations were less than those reported in the *Puget Sound Environmental Atlas* for stations at the same locations. In comparison with Atlas data, concentrations were lowest at Stations 40 (City Waterway), 42 (Ruston), and 49 (south Budd Inlet). The concentration of cadmium (0.99 mg/kg DW) at Station 33 in Elliott Bay was slightly higher than the value (0.36 mg/kg DW) reported in the Atlas.

Based on a Pearson test, cadmium was significantly ($P \leq 0.01$) correlated with fines content ($r = 0.35$). Cadmium was also significantly correlated with six metals and TOC (Table 12). Relationships with other variables were not apparent.

The relationship between cadmium and fines content was determined using a best fit linear regression. The intercept of the linear regression (Table G-2 in Appendix G) indicates that the average sedimentary cadmium contribution from sand is approximately 0.06 mg cadmium/kg sand, which is similar to the mean quantitation limit. The maximum cadmium content in Puget Sound sediments attributed to the natural composition of fine-grained sediments, assuming 100 percent fines, is approximately 0.21 mg/kg. Greatest cadmium enrichments were found within urban embayments in the

Central Basin and south Sound at the following stations: 33 (931 percent; Elliott Bay), 49 (838 percent; north Budd Inlet), 30 (594 percent; Eagle Harbor), 35 (572 percent; Dyes Inlet), 48 (561 percent; south Budd Inlet), 34 (506 percent; Sinclair Inlet), and 8 (202 percent; Port Angeles Harbor). TOC and percent fines normalized cadmium data show minimal or no elevations at these stations.

Calcium (Ca)--Calcium was detected at each MSMT station, with a range of 2,240 to 22,300 mg/kg DW. Highest concentrations were found at Stations 3 (22,300 mg/kg; mid-channel Strait of Georgia), 6 (14,300 mg/kg; east of Anacortes), and 17 (13,500 mg/kg; south Hood Canal). Calcium has not been identified as a potential contaminant of concern in Puget Sound (U.S. EPA 1986).

Based on a Pearson test, calcium concentrations were significantly ($P \leq 0.01$) correlated with fines content and eight metals (Table 12), as well as with 1,1,1-trichloroethane. Correlations were very weak, except for trichloroethane ($r = 0.99$). The elevated concentration of trichloroethane (6.60 ug/kg) at Station 3 results in that strong correlation.

The relationship between calcium and fines content was determined using a best fit linear regression. The intercept of the linear regression indicates that the average sedimentary calcium contribution from the outer or acid leachable portion of sand is approximately 3,580 mg calcium/kg sand. Greatest calcium enrichments were found at Stations 3 (395 percent; mid-channel Strait of Georgia) and 6 (279 percent; east of Anacortes). Shell fragments in sediments at Station 3 may account for that enrichment.

Chromium (Cr)--Chromium has been identified as a chemical of concern in Puget Sound (U.S. EPA 1986). Chromium, measured as total chromium, was detected at each MSMT station, with a range of 10.8 to 104 mg/kg DW. Highest concentrations were found at Stations 20 (104 mg/kg; Port Susan), 18 (62.6 mg/kg; Oak Harbor), 34 (59.8 mg/kg; Sinclair Inlet), 19 (58.9 mg/kg; Saratoga Passage), and 17 (52.6 mg/kg; south Hood Canal). Puget Sound

maximum reference values and AET values for chromium were not exceeded at any MSMT station.

Based on a Pearson test, chromium concentrations were significantly ($P \leq 0.01$) correlated with fines, TOC content, and 13 metals (Table 12). The relationship between chromium and fines content was determined using a scatter plot of MSMT data and a best fit linear regression. The intercept of the linear regression (see Table G-2 in Appendix G) indicates that the average sedimentary chromium contribution from sand is approximately 15 mg chromium/kg sand. Greatest chromium enrichments were found at Stations 16 (156 percent; south Hood Canal), 20 (141 percent; Port Susan), 18 (90 percent; Oak Harbor), 9 (59 percent; east of Port Angeles), and 19 (50 percent; Saratoga Passage) (see Table 15). Regional enrichments were similar in the Whidbey Basin, with greatest enrichments in Port Susan, which suggests that the Stillaguamish River may be a source of chromium. Cobalt and nickel concentrations at Whidbey Basin stations covary with chromium, which indicates a probable common source ($r = 0.94$ for nickel vs. chromium; $r = 0.84$ for cobalt vs. chromium). Greatest chromium depressions were found in the Commencement Bay area, especially at Station 41 (-68 percent; Blair/Sitcum Waterways near Puyallup River) and may be a result of sedimentary deposits from the nearby Puyallup River. Sedimentary chromium concentrations in the 1989 MSMT appear to be primarily related to natural regional contributions and not associated with other known contaminants.

For chromium measurements, analytical variability was consistently greater than or equal to within-station variability.

Cobalt (Co)--Cobalt was detected at each MSMT station, with a range of 2.3 to 19.9 mg/kg DW. Highest concentrations were found at Stations 17 (19.9 mg/kg; south Hood Canal), 20 (16.6 mg/kg; Port Susan), and 19 (16.0 mg/kg; Saratoga Passage). Cobalt has not been identified as a potential contaminant of concern in Puget Sound (U.S. EPA 1986).

Based on a Pearson test, cobalt concentrations were significantly ($P \leq 0.01$) correlated with fines content, TOC, and 13 metals (Table 12).

Cobalt was also strongly correlated with phenol ($r = 0.73$), which was due to an extreme value reported for Station 19. Correlations of cobalt with chromium and nickel are primarily driven by stations located in Whidbey Basin, and correlations with iron and vanadium are strongly influenced by stations in south Hood Canal.

The relationship between cobalt and fines content was determined using a best fit linear regression. The intercept of the linear regression (Table G-2 in Appendix G) indicates that the average sedimentary cobalt contribution from sand is approximately 4.7 mg cobalt/kg sand, with some range (3-6 mg/kg) in the observed values at the lowest fines content. Regional enrichments were found at stations in southern Hood Canal and Whidbey Basin, particularly Stations 16 (78 percent; south Hood Canal), 17 (113 percent; south Hood Canal), 19 (83 percent; Saratoga Passage), and 20 (77 percent; Port Susan). These enrichments are probably due to natural regional geochemistries, and to accumulated solids from the Skokomish River at Hood Canal and the Stillaguamish River at Whidbey Basin. Station 42 (Ruston) exhibited 67 percent enrichment, which may be due to former activities at the ASARCO smelter.

Analytical variability for cobalt measurements was similar to within-station variability (CV and RD ranged from 0.008 to 0.087).

Copper (Cu)--Copper is a chemical of concern in Puget Sound (U.S. EPA 1986). Copper was detected at each MSMT station, with a range of 2.7 to 129 mg/kg DW. Highest concentrations were found at Stations 34 (129 mg/kg; Sinclair Inlet), 17 (102 mg/kg; south Hood Canal), 35 (66 mg/kg; Dyes Inlet), and 49 (53.5 mg/kg; lower Budd Inlet). Those stations were located in urban embayments, except for Station 17. The Puget Sound maximum reference value of 74 mg/kg for copper was exceeded at Station 34 in Sinclair Inlet and Station 17 in south Hood Canal (near the Skokomish River discharge). AET values for copper were not exceeded at any MSMT station.

Based on a Pearson test, copper concentrations were significantly ($P \leq 0.01$) correlated with fines content, TOC, and 17 metals (Table 12), weakly

correlated with beta-sitosterol (r = 0.48) and retene (r = 0.52), and more strongly correlated with PCBs (r = 0.77). Correlations of copper with beta-sitosterol and retene, in addition to the elevated copper concentrations and low contaminant organic compounds [e.g., polynuclear aromatic hydrocarbons (PAH)], suggest a primarily natural background contribution of copper at Station 17. A separate anthropogenic component for copper can be identified from its association with PCBs, PAH, lead, and mercury at Stations 33, 34, and 35.

Copper, lead, and zinc are typically associated with urban contamination. Concentrations of those metals were summed (Figure 9), and found to be highest at Stations 17, 24, 34, 35, 38, 48, and 49. With the exception of Stations 17 and 24, elevated copper, lead, and zinc concentrations covaried with organic contaminant concentrations, confirming their association with constituents of urban runoff.

The relationship between copper and fines content was determined using a best fit linear regression. The intercept of the linear regression (Table G-2 in Appendix G) indicates that, on the average, the sedimentary copper contribution from sand is approximately 6.6 mg copper/kg sand. Maximum copper content in Puget Sound sediments attributed to natural mean composition of fine-grained sediments, assuming 100 percent fines, is approximately 40 mg/kg. Greatest copper enrichments were found at Stations 34 (249 percent; Sinclair Inlet), 17 (174 percent; south Hood Canal), 16 (147 percent; south Hood Canal), 33 (146 percent; Elliott Bay), 40 (112 percent; City Waterway), and 35 (102 percent; Dyes Inlet).

As indicated in Table 4, mean copper concentrations in sediments at MSMT stations were approximately 20 percent less, on the average, than historical mean (area weighted) concentrations reported in the *Puget Sound Environmental Atlas*.

Lead (Pb)--Lead is a chemical of concern in Puget Sound sediments (U.S. EPA 1986). Lead was detected at each MSMT station, with a range of 2.2 to 94.4 mg/kg DW. Highest concentrations were found at Stations 34

(94.4 mg/kg; Sinclair Inlet), 35 (68.3 mg/kg; Dyes Inlet), 38 (40.2 mg/kg; East Passage near Point Pully), and 33 (38.1 mg/kg; Duwamish Head). These stations are located in urban embayments, except Station 38. Summed concentrations of copper, lead, and zinc at MSMT stations are shown in Figure 9. Concentrations of these metals covaried, and these metals have been identified as common contaminants in Puget Sound (U.S. EPA 1986).

Based on a Pearson test, lead concentrations were significantly ($P \leq 0.01$) correlated with fines content, TOC, and 13 metals (Table 12). Lead was also weakly correlated with retene ($r = 0.48$). The relationship between lead and fines content was determined using a scatter plot of MSMT data and a best fit linear regression, excluding outlier Stations 33, 34, 35, and 38. The intercept of the linear regression (Table G-2 in Appendix G) indicates that, on the average, the sedimentary lead contribution from sand is approximately 6.5 mg lead/kg sand, with some range (3-12 mg/kg) in the observed values at the lowest fines content. Highest lead concentrations attributed to the natural mean composition of Puget Sound fine-grained sediments, assuming 100 percent fines content, is approximately 17.5 mg/kg.

The greatest (≥50 percent) enrichments in lead concentrations were found at the following 10 stations: Stations 34 (474 percent; Sinclair Inlet), 35 (354 percent; Dyes Inlet), 33 (319 percent; Duwamish Head-Elliott Bay), 42 (248 percent; Ruston), 40 (164 percent; City Waterway), 38 (mean 142 percent; East Passage), 48 (93 percent; Budd Inlet), 32 (mean 76 percent; Magnolia Bluff), 49 (64 percent; Budd Inlet), and 30 (61 percent; Eagle Harbor). All these stations are located in or adjacent to highly urbanized embayments, suggesting that lead enrichments are indicative of urbanization and deposition of lead-contaminated street runoff. Street dust is highly contaminated from past usage of lead additives in motor vehicle fuels. A former secondary lead smelter on Harbor Island in Elliott Bay was also a major source of lead to Puget Sound (PTI and Tetra Tech 1988a).

For lead measurements, variability tended to be greater at higher sediment concentrations. Greatest variability was exhibited by the analysis of a blind laboratory replicate at Station 5 (RD = 0.40, CV = 0.18). The

relatively high RD (compared with CV) suggests that much of the observed within-station variability for lead measurements could be attributed to the analytical method.

Mercury (Hg)--Mercury is a contaminant of concern in Puget Sound (U.S. EPA 1986). Mercury was detected at 11 of 50 MSMT stations, and concentrations ranged from <0.043 to 0.86 mg/kg DW. The highest concentrations were found at Stations 34 (0.86 mg/kg; Enh = 469 percent; Sinclair Inlet), 35 (0.51 mg/kg; Enh = 273 percent; Dyes Inlet), 8 (0.26 mg/kg; Enh = 112 percent; Port Angeles Harbor), and 38 (0.21 mg/kg; Enh = 40 percent; Point Pully). Concentrations found in Dyes and Sinclair Inlets exceeded Puget Sound maximum reference values and LAET values. Concentrations found in Sinclair Inlet were consistent with historical mercury data (0.99 mg/kg DW) reported for that area in the *Puget Sound Environmental Atlas* (Evans-Hamilton and D.R. Systems 1987). Stations with high mercury concentrations were also contaminated with other urban-derived contaminants (e.g., lead and PAH).

Based on a Pearson test of correlation, mercury concentrations were significantly ($P \leq 0.01$) correlated with fines content, copper, lead, silver, and zinc (Table 12). The relationship between mercury and fines content was determined using a scatter plot of MSMT data and a best fit linear regression, excluding outlier Stations 8, 34, and 35. The intercept of the linear regression (Table G-2 in Appendix G) indicates that, on the average, the sedimentary mercury contribution from sand is approximately 0.05 mg/kg (about the QL). Highest mercury concentrations attributed to the natural mean composition of Puget Sound fine-grained sediments, assuming 100 percent fines content, is approximately 0.15 mg/kg. Greatest mercury enrichments were found at Stations 34 (469 percent; Sinclair Inlet), 35 (273 percent; Dyes Inlet), 8 (112 percent; Port Angeles Harbor), and 30 (70 percent; Eagle Harbor).

Mercury was not detected at enough stations to determine where the greatest within-station variability occurs. One station exhibited within-station variability of a CV = 0.11 at 0.23 mg/kg.

Nickel (Ni)--Nickel is a contaminant of concern in Puget Sound (U.S. EPA 1986). Nickel was detected at each MSMT station, with an overall range of 7.9 to 113 mg/kg DW. Highest concentrations were found at Stations 20 (113 mg/kg; Port Susan), 19 (58.2 mg/kg; Saratoga Passage), 18 (50.2 mg/kg; Oak Harbor), and 17 (49.6 mg/kg; south Hood Canal).

Based on a Pearson test, nickel concentrations were significantly ($P \leq 0.01$) correlated with fines content, TOC, and 12 metals (Table 12). Greatest (≥ 50 percent) enrichments in nickel concentrations were found at six stations (Table 15). Because these six stations are not located near urban embayments and there is no correlation with organic contaminant chemicals (e.g., PAH), nickel does not appear to be associated with typical urban runoff in Puget Sound. Its presence and sediment enrichments can be attributed to natural geological processes and regional characteristics (i.e., Whidbey Basin). The intercept of the linear regression (Table G-2 in Appendix G) indicates that, on the average, the sedimentary nickel contribution from sand is approximately 17.6 mg nickel/kg sand.

The analytical variability (as measured by RD) for nickel was generally twice the within-station variability (as measured by CV), which suggests that the variability inherent in the analytical method introduced the largest error in precision (35 percent RD at 33 mg/kg nickel).

Silver (Ag)--Silver is a contaminant of concern in Puget Sound (U.S. EPA 1986). Silver was detected at 69 percent of the MSMT stations. Silver concentrations ranged from <0.034 to 1.90 mg/kg DW. Highest concentrations were found at Stations 34 (1.9 mg/kg; Sinclair Inlet) and 35 (1.1 mg/kg; Dyes Inlet).

Based on a Pearson test, silver concentrations were significantly ($P \leq 0.01$) correlated with fines content, TOC, and 10 metals (Table 12). Greatest correlations were with lead ($r = 0.94$) and mercury ($r = 0.95$) contaminants, both of which are associated with urbanization. The relationship between silver and fines content was determined using a best fit linear

regression, excluding outlier Stations 34 and 35. Greatest enrichments in silver concentrations were found at 10 stations (Table 15). Eight stations (i.e., Stations 29, 30, 32, 33, 34, 35, 38, and 40) are located in the Central Basin, and two stations are located in Budd Inlet. Greatest enrichments occurred at Stations 34 (604 percent; Sinclair Inlet), 35 (363 percent; Dyes Inlet), and 38 (mean 269 percent; East Passage near Point Pully). Silver-enriched stations are located in or adjacent to urban areas. Silver enrichments were found at stations exhibiting lead enrichments, which suggests that urban areas also provide sources of silver to Puget Sound. Silver is typically associated with the metal plating and photographic industries.

Measurement variability for silver ranged from 0.0 (RD) to 0.35 (CV). Within-station variability was generally greater than analytical variability, which suggests some heterogeneity in silver concentrations in sediments.

Zinc (Zn)--Zinc is a chemical of concern in Puget Sound (U.S. EPA 1986). Zinc was detected at each MSMT station, and concentrations ranged from 14.7 to 173 mg/kg DW. Highest zinc concentrations were found at Stations 34 (173 mg/kg; Sinclair Inlet), 35 (128 mg/kg; Dyes Inlet), and 38 (mean 100.2 mg/kg; East Passage near Point Pully). Summed concentrations of copper, lead, and zinc at MSMT stations are shown in Figure 9.

Based on a Pearson test, zinc concentrations were significantly ($P \leq 0.01$) correlated with fines content, TOC, and 17 metals (Table 12). Zinc was also weakly associated with beta-sitosterol ($r = 0.48$). Greatest (≥ 50 percent) enriched zinc concentrations were found at four stations, which were located within urban embayments (i.e., Commencement Bay-Ruston, Elliott Bay, Dyes Inlet, and Sinclair Inlet) (Table 15). A natural zinc contribution is noted in most sediments, as suggested by the association between zinc and beta-sitosterol. The intercept of the linear regression (Table G-2 in Appendix G) indicates that, on the average, the sedimentary zinc contribution from sand is approximately 24 mg zinc/kg sand. Highest zinc concentrations attributed to the natural mean composition of Puget

Sound fine-grained sediments, assuming 100 percent fines content, is approximately 93 mg/kg.

Both analytical and within-station variability (in terms of RD and CV) were less than or equal to 10 percent.

Organic Compounds

Organic compound concentrations in sediments at MSMT stations are provided in Appendix D. Mean quantitation limits, mean values, concentration ranges, and detection frequencies for organic compounds are presented for all stations in Table 16. Concentrations reported in the *Puget Sound Environmental Atlas* (Evans-Hamilton and D.R. Systems 1987) are also shown.

Target semivolatile and volatile organic compounds included the U.S. EPA CLP target compound list variables and the Puget Sound chemicals of concern. Resin acids and guaiacols were analyzed to examine the impacts of wood pulp processing discharges. Retene, a resin acid oxidation product, was analyzed to examine relative impacts of forest and coniferous plant debris. Beta-sitosterol, a land plant sterol, was analyzed to evaluate the presence of organic compounds associated with terrestrial plant products. Pristane-to-phytane ratios were also calculated to assist in the evaluation of anthropogenic impacts due to the presence of weathered petroleum hydrocarbons that are typically associated with urban runoff and storm drain discharges. Elevated pristane-to-phytane ratios are indicative of 1) high planktonic contribution to sediment hydrocarbons and TOC, and 2) the presence of fairly unweathered petroleum hydrocarbons in sediments. This can be useful for a comparative analysis of sediment TOC contributions. Both pristane and phytane are derived from the degradation of the phytol chain in chlorophyll. Pristane predominates in toxic environments and accumulates in phytoplankton and animals that feed heavily on phytoplankton and algae. Enrichments in phytane occur during anoxic deposition of chlorophyll containing plant material and thus found in many petroleum crude and refined oils. Lower pristane-to-phytane ratios indicate enrichments of weathered petroleum hydrocarbons.

TABLE 16. COMPARISON OF MEAN ORGANIC COMPOUND VALUES AT ALL MSMT STATIONS WITH THOSE REPORTED IN THE PUGET SOUND ENVIRONMENTAL ATLAS[a]

Variable	1989 MSMT Mean QL[b] (n=65)	1989 MSMT Frequency of Detections (n=50)	1989 MSMT Mean[c] (n=50)	1989 MSMT Range[d] (n=65)	Puget Sound Environmental Atlas (1980-1986) N	Mean[e]	Range
Acid Extractables							
Phenol	16	32%	27	7-520			
2-Chlorophenol	16	0%	0	<8-<68			
2-Methylphenol	17	0%	0	<8-<68			
4-Methylphenol	17	0%	0	<8-<68			
2-Nitrophenol	84	0%	0	<39-<340			
2,4-Dimethylphenol	50	0%	16.1	<15-<140			
Benzoic acid[f]	173	0%	86	<100-<350			
2,4-Dichlorophenol	50	0%	0	<24-<200			
4-Chloro-3-methylphenol	34	0%	0	<15-<140			
2,4,6-Trichlorophenol	84	0%	0	<39-<340			
2,4,5-Trichlorophenol	84	0%	0	<39-<340			
2,4-Dinitrophenol	169	0%	0	<77-<680			
4-Nitrophenol	84	0%	0	<39-<340			
4,6-Dinitro-2-methylphenol	169	0%	0	<77-<680			
Pentachlorophenol	85	2%	0.06	10-<340	351	<5	<5-860[g]
Resin Acids and Guaiacols (n = 3)							
Abietic acid	58	67%	120	<58-180			
Chlorodehydroabietic acid	120	100%	133	90-210			
Dehydroabietic acid	29	100%	420	190-550			
Dichlorodehydroabietic acid	67	33%	87	<62-150			
4,5-Dichloroguaiacol	88	0%	0	<62-<120			
Isopimaric acid	89	67%	123	<120-210			
2-Methoxyphenol (Guaiacol)	43	0%	0	<31-<58			
Neoabietic acid	144	33%	27	82-<230			
Palustric acid	647	33%	69	120-<1,200			
Pimaric acid	38	33%	8	25-<58			
Sandacopimaric acid	39	33%	16	<31-<58 (49)			
Tetrachloroguaiacol	170	0%	0	<120-<230			
3,4,5(4,5,6)-Trichloroguaiacol	158	0%	0	<120-<230			
Base Extractables							
N-Nitroso-di-n-propylamine	16	0%	0	<8-<68			
2-Nitroaniline	80	0%	0	<39-<340			
3-Nitroaniline	80	0%	0	<39-<340			
4-Nitroaniline	80	0%	0	<39-<340			
N-Nitrosodiphenylamine	16	0%	0	<8-<68			
9(H)-Carbazole	9	6%	12	<8-110			
Neutral Extractables							
bis(2-Chloroethyl)ether	16	0%	8	<8-<68			
1,3-Dichlorobenzene	16	0%	0	<8-<68			
1,4-Dichlorobenzene	16	0%	0	<8-<68			
Benzyl alcohol	80	0%	40	<39-<340			
1,2-Dichlorobenzene	16	2%	<0.06	<8-<68			
bis(2-Chloroisopropyl)ether	16	0%	8	<8-<68			
Hexachloroethane	32	0%	0	<15-<140			
Nitrobenzene	16	0%	0	<8-<68			
Isophorone	17	2%	1	<8-69			
bis(2-Chloroethoxy)methane	16	0%	8	<8-<68			
1,2,4-Trichlorobenzene	16	0%	8.0	<8-<68			
Naphthalene	16	34%	9	2-54			
Hexachlorobutadiene	32	2%	<0.06	<15-<140			
2-Methylnaphthalene	16	26%	8.7	3-<68 (45)			
Hexachlorocyclopentadiene	79	0%	0	<39-<340			
2-Chloronaphthalene	16	2%	0.06	<8-<68			
Dimethylphthalate	16	0%	0	<8-<68			

TABLE 16. (Continued)

Variable	1989 MSMT Mean QL[b] (n=65)	Frequency of Detections (n=50)	Mean[c] (n=50)	Range[d] (n=65)	Puget Sound Environmental Atlas (1980-1986) N	Mean[e]	Range
Acenaphthylene	17	18%	16.1	2-330			
Acenaphthene	16	14%	9.2	4-55			
Dibenzofuran	16	16%	2	5-<68			
2,4-Dinitrotoluene	80	0%	<40	<39-<340			
2,6-Dinitrotoluene	80	0%	<40	<39-<340			
Diethylphthalate	16	0%	8	<8-<68			
4-Chlorophenyl-phenylether	16	2%	7.9	5-<68			
Fluorene	17	24%	14	3-250			
4-Bromophenyl-phenylether	16	2%	7.9	4-<68			
Hexachlorobenzene	16	2%	0.04	5-<68			
Phenanthrene	14	76%	69	3-1,500			
Anthracene	14	42%	43	2-1,100			
Di-n-butylphthalate	16	6%	9	<8-<68			
Fluoranthene	12	88%	95	3-1,700			
Pyrene	12	86%	4	3-1,900			
Butylbenzyl phthalate	16	6%	9	<3-<68 (39)			
Benzo(a)anthracene	13	70%	60	<3-1,300			
bis(2-Ethylhexyl)phthalate	18	44%	207	<11-8,300			
Chrysene	12	74%	82	<4-1,500			
Di-n-octylphthalate	16	0%	0	<8-<68			
Benzo(b+k)fluoranthenes	13	72%	109	6-1,900			
Benzo(a)pyrene	14	60%	66	4-1,400			
Indeno(1,2,3-c,d)pyrene	16	40%	42	5-830			
Dibenzo(a,h)anthracene	16	18%	19	4-340			
Benzo(g,h,i)perylene	16	36%	35	3-670			
Cymene	16	0%	8	<8-<70			
Caffeine	16	0%	8	<8-<68			
Perylene	12	72%	32	4-360			
beta-Coprostanol	29	80%	253	<17-4,700			
Cholesterol	25	98%	1,231	<25-12,000			
beta-Sitosterol	55	94%	977	<42-4,300			
Retene	14	62%	23	5-120			
LPAH	--	76%	160	24-3,290	484	130	<10-47,000
HPAH	--	88%	602	36-11,540	465	420	<10-258,000
Pristane-to-phytane ratio	--	100%	6.8	1.4-21			
N-Alkanes carbon preference index	--	100%	2.2	1.26-3.8			
Pesticides and PCBs							
alpha-BHC	1.0	0%	0	<0.2-<2.0			
beta-BHC	1.0	0%	0	<0.2-<2.0			
delta-BHC	1.0	0%	0	<0.2-<2.0			
gamma-BHC (Lindane)	1.0	0%	0	<0.2-<2.0			
Heptachlor	1.0	0%	0	<0.2-<2.0			
Aldrin	1.0	0%	0	<0.2-<2.0			
Heptachlor epoxide	1.0	0%	0	<0.2-<2.0			
Endosulfan I	1.0	0%	0	<0.2-<2.0			
Dieldrin	1.5	0%	0	<0.3-<3.0			
p,p'-DDE	1.5	0%	0	<0.3-<3.0			
Endrin	1.5	0%	0	<0.3-<3.0			
Endosulfan II	1.5	0%	0	<0.3-<3.0			
p,p'-DDD	3.0	2%	0.052	0.6-<6.0 (2.6)			
Endosulfan sulfate	3.0	0%	0	<0.6-<6.0			
p,p'-DDT	2.0	0%	0	<0.4-<4.0			
Methoxychlor	4.0	0%	0	<0.8-<8.0			
Endrin ketone	1.5	0%	0	<0.3-<2.7			
gamma-Chlordane	1.0	0%	0	<0.2-<2.0			
alpha-Chlordane	1.0	2%	0.018	<0.2-<2.0 (0.9)			
Toxaphene	149	0%	0	<30-<300			
Aroclor 1016/1242	20	0%	10	<4.0-<40			
Aroclor 1248	20	0%	10	<4.0-<40			
Aroclor 1254	20	22%	12	4.0-49	501	20	<10-21,600
Aroclor 1260	20	0%	10	<4.0-<40			

TABLE 16. (Continued)

Variable	1989 MSMT Mean QL[b] (n=16)	1989 MSMT Frequency of Detections (n=10)	1989 MSMT Mean[c] (n=10)	1989 MSMT Range[d] (n=16)	Puget Sound Environmental Atlas (1980-1986) N	Puget Sound Environmental Atlas (1980-1986) Mean[e]	Puget Sound Environmental Atlas (1980-1986) Range
Volatiles							
Chloromethane	0.29	0%	0.13	<0.14-<0.46			
Bromomethane	0.14	0%	0	<0.07-<0.23			
Vinyl chloride	0.29	0%	0	<0.14-<0.46			
Chloroethane	0.29	0%	0	<0.14-<0.46			
Methylene chloride	0.03	40%	4.32	<0.63-52			
Acetone	Approx. 0.10	40%	11.1	<0.10-69			
Carbon disulfide	0.07	100%	1.9	<0.04-3.70			
1,1-Dichloroethene	0.026	0%	0	<0.014-<0.046			
1,1-Dichloroethane	0.029	20%	0.173	<0.014-1.10			
trans-1,2-Dichloroethene	0.057	0%	0	<0.028-<0.092			
cis-1,2-Dichloroethene	0.057	10%	0.001	<0.028-<0.081(0.046)			
Chloroform	0.031	90%	0.085	<0.020-0.310			
1,2-Dichloroethane	0.057	0%	0	<0.028-<0.092			
2-Butanone[h]	0.60	37.5%	2.28	<0.07-13			
1,1,1-Trichloroethane	0.028	70%	0.84	<0.021-6.60			
Carbon tetrachloride	0.028	0%	<0.013	<0.014-<0.046			
Vinyl acetate	0.06	0%	0	<0.03-<0.09			
Bromodichloromethane	0.06	0%	0	<0.028-0.092			
1,2-Dichloropropane	0.119	0%	0	<0.057-<0.180			
cis-1,3-Dichloropropene	0.06	0%	0	<0.028-<0.092			
Trichloroethene	0.029	20%	0.013	0.008-<0.046(0.011)			
Dibromochloromethane	0.030	0%	0	<0.014-<0.046			
1,1,2-Trichloroethane	0.060	0%	<0.026	<0.028-<0.092			
Benzene	0.029	70%	0.071	<0.020-0.170			
trans-1,3-Dichloropropene	0.060	0%	0	<0.028-<0.092			
2-Chloroethylvinylether	0.149	0%	0	<0.07-<0.23			
Bromoform	0.058	30%	0.017	0.020-0.110			
4-Methyl-2-pentanone	0.06	40%	0.064	<0.03-0.46			
2-Hexanone	0.15	0%	0	<0.07-<0.23			
Tetrachloroethene	0.031	80%	0.043	<0.025-0.17			
1,1,2,2-Tetrachloroethane	0.060	0%	0	<0.028-<0.092			
Toluene	0.028	90%	0.14	<0.087-0.250			
Chlorobenzene	0.031	10%	0.016	<0.014-0.050			
Ethylbenzene	0.028	70%	0.042	<0.017-0.081			
Styrene	0.028	10%	0.019	<0.014-0.110			
Total xylenes	0.028	90%	0.18	<0.083-0.320			
1,1,2-Trichloro-1,2,2-trifluoroethane	0.094	0%	0	<0.028-<0.230			

[a] Values are reported in ug/kg dry weight. Most 3,3'-dichlorobenzidine and 4-chloroaniline data were unusable.

[b] QL = Quantitation limit. The mean QL was calculated using all samples, including blind analytical and blind field replicates.

[c] Mean values were calculated using QL/2 or zero for undetected values, as described in the text.

[d] The range of values was determined using all samples, including blind analytical and blind field replicates. Undetected values are shown as they were reported by the analytical laboratory. Most of the maximum undetected values were reported in only a single sample (see mean QL for average of detection limits). If the maximum value was undetected, the highest detected value is shown in parentheses.

[e] The mean is area weighted (see text).

[f] N=36 because benzoic acid data were qualified as unusable at 14 of 50 stations.

[g] Values for pentachlorophenol from the Atlas are the reported chlorophenol values, which were typically 90-98 percent pentachlorophenol.

[h] N=8 because 2-butanone data were qualified as unusable at 2 of 10 stations.

The most frequently detected organic compounds in sediments at all MSMT stations were PAH with three or more benzene rings and sterols (i.e., cholesterol, beta-coprostanol, and beta-sitosterol). In some cases, concentrations of those compounds varied by a factor of 500 among MSMT stations. Low molecular weight PAH (LPAH) compounds, which are typically associated with petroleum fuels and oils, were found at highest concentrations in urban embayments, near Cherry Point, and mid-channel in the Central Basin of Puget Sound. High molecular weight PAH (HPAH), which are a mixture of byproducts of combustion, were found at highest concentrations in similar locations. Results of the 1989 MSMT support previous studies in Puget Sound in which PAH (particularly HPAH) have been identified as indicators of contaminants from urban areas (Battelle 1985; Malins et al. 1980; Malins et al. 1985; Romberg et al. 1984; Tetra Tech 1985; Word et al. 1984; and PTI and Tetra Tech 1988a).

Most semivolatile organic compounds that were detected in sediments at less than 50 percent of the MSMT stations were found at low concentrations, with the exception of bis(2-ethylhexyl)phthalate and anthracene. A high concentration of bis(2-ethylhexyl)phthalate (8,300 ug/kg DW) was found at Station 12, probably due to industrial discharge into the marine environment from Port Townsend. A pulp mill is located in Port Townsend, and some pulp mill processes are reported to use phthalate esters. The primary source has yet to be identified. A concentration of 1,100 ug/kg DW anthracene was found at Station 40 in City Waterway (Commencement Bay). Anthracene is associated with petroleum and combustion PAH found in urban effluents.

Volatile organic compounds were measured at 10 MSMT stations. In this study, special effort was taken to achieve low quantitation levels for these compounds to determine whether their concentrations varied among regional basins in Puget Sound (see volatile organic compound QA memorandum in Appendix B). The highest concentrations of volatile organic compounds and tentatively identified compounds were found at Stations 29 (mid-channel, Central Basin) and 38 (East Passage near Point Pully). Both stations are classified as deep-depositional and appear to be moderately impacted by

urban activities. As shown in Figure 10, greatest concentrations of the sum of acetone, methylene chloride, and total xylenes were also found at Stations 29 and 38. At Station 29, the commercial/industrial solvent chlorobenzene, was tentatively found at 0.05 ug/kg DW. At Station 38, the concentration of cis-1,2-dichloroethane in one sample could easily be a result of microbiological degradation of the relatively high level (0.17 ug/kg DW) of tetrachloroethene (a commercial solvent) found at that station.

The volatile organic compounds that were detected frequently (≥75 percent) at MSMT stations included carbon disulfide, chloroform, benzene, tetrachloroethene, toluene, ethylbenzene, and total xylenes. The alkyl-substituted benzenes e.g., (toluene, xylenes, and ethylbenzene) and carbon disulfide have been observed at low concentrations in pristine forest and marine environments due to natural processes (Farlow 1977).

The compounds that were detected less frequently (13-74 percent) at MSMT stations included 1,1-dichloroethane (1.10 ug/kg DW at Station 3; 0.52 ug/kg DW at Station 29), trichloroethene (0.011 ug/kg at Station 26; 0.008 ug/kg DW at Station 45), and bromoform (0.020 ug/kg DW at Station 3; 0.11 ug/kg DW at Station 10; 0.042 ug/kg DW at Station 26). Although chloroethanes and ethenes may be associated with urban discharges, the significance of concentrations at these levels in sediments remains unknown because limited background concentrations for Puget Sound are available for comparison. Bromoform has been observed as a natural constituent of marine kelp (Farlow 1983).

The presence of chlorinated volatile organic compounds at Station 3 was unexpected and requires verification. Other contaminants also exhibited unexpected elevations at Station 3. The lowest concentrations of volatile organic compounds were found at Stations 14 (north Hood Canal), 17 (south Hood Canal), and 45 (Devil's Head).

The most significant and consistent trend in the measurement of volatile organic compounds was the occurrence and covariation of methylene chloride, acetone, tetrachloroethene, toluene, and total xylenes. Strong correlations were also found between methylene chloride, an industrial/commercial solvent, and beta-coprostanol ($r = 0.95$), and between methylene chloride and HPAH ($r = 0.89$). The fecal sterol beta-coprostanol and combustion PAH are found in wastewater treatment plant effluent, which suggests that methylene chloride concentrations in sediments appears to be primarily associated with wastewater discharges. Although chloroform and beta-sitosterol ($r = 0.84$) were also strongly correlated, the relationship between those compounds is unknown. No correlations between volatile organic compounds and fines content were observed.

Moderate correlations ($r > 0.70$) were found between other volatile organic compounds, including methylpentanone, acetone, methylene chloride, and styrene; and HPAH, LPAH, and beta-coprostanol. This suggests that these materials may have similar origins (e.g., wastewater treatment plant effluent). It is believed that acetone and methylene chloride were not introduced to MSMT samples during field and laboratory handling because these compounds were not found in method blanks and great care was taken in the field to minimize inadvertent contamination of samples. Although methylene chloride was used to rinse some field equipment, acetone was not used. Furthermore, methylene chloride concentrations strongly covaried with four other five volatile organic compounds.

The semivolatile and volatile organic compounds that were detected infrequently (i.e., at less than 10 percent of MSMT stations) are shown in Table 17. Information relevant to Table 17 is presented below.

9H-carbazole was detected only at three stations, two (Stations 30 and 40) of which had the highest LPAH and HPAH concentrations in the MSMT study. Carbazole is associated with high-temperature pyrolyzates containing PAH. At Station 26, a replicate grab sample collected for measurement of within-station variability had a higher concentration of anthracene (an LPAH) and 9H-carbazole than the other samples at that station (anthracene CV = 1.59;

TABLE 17. SEMIVOLATILE AND VOLATILE ORGANIC COMPOUNDS DETECTED AT >0 PERCENT AND ≤10 PERCENT OF MSMT STATIONS[a]

	Station	Concentration[b] (ug/kg DW)	Comment
Pentachlorophenol	32, Magnolia Bluff	E10	Blind analytical replicate measured U39
9(H)-Carbazole	30, Eagle Harbor	53	
	40, City Waterway	110	
	26, mid-channel Central Basin	110	Blind field replicates measured U9 and U10
1,2-Dichlorobenzene	44, Anderson Island	N4	Blind analytical replicate measured U14, and blind field replicates measured U13-U15
Isophorone	8, Port Angeles	69	
Hexachlorobutadiene	44, Anderson Island	N3	Blind analytical and field replicates measured U26-U29
2-Chloronaphthalene	44, Anderson Island	E4	Blind analytical and field replicates measured U13-U15
4-Chlorophenyl-phenylether	44, Anderson Island	E5	Blind analytical and field replicates measured U13-U15
4-Bromophenyl-phenylether	44, Anderson Island	N4	Blind analytical and field replicates measured U13-U15
Hexachlorobenzene	44, Anderson Island	E5	Blind analytical and field replicates measured U13-U15
Di-n-butylphthalate	33, Duwamish Head	E11	
	34, Sinclair Inlet	30	
	35, Dyes Inlet	E16	
Butylbenzyl phthalate	34, Sinclair Inlet	E31	
	35, Dyes Inlet	E18	
	40, City Waterway	39	

TABLE 17. (Continued)

	Station	Concentration[b] (ug/kg DW)	Comment
p,p'-DDD	33, Duwamish Head	2.6	
alpha-Chlordane	33, Duwamish Head	0.9	
cis-1,2-Dichloroethene[a]	38, East Passage near Point Pully	0.046	Blind analytical and field replicates measured U0.075-U0.081
Chlorobenzene[a]	29, mid-channel Central Basin	NO.050	
Styrene[a]	5, Samish Bay	NO.039	Blind analytical and field replicates measured NO.039-0.110

[a] Volatile organic compounds were measured at only 10 stations.

[b] E = Estimated value.

9H-carbazole CV = 1.35; typical RD≤0.10). Thus, variability among field replicates at Station 26 was high, suggesting a patchy distribution of covarying organic contaminants in sediments at that station. This may suggest that the concentrations of anthropogenic contaminants found distant from potential sources exhibit extreme within-station variability. Stations 26 and Station 3 were located at similar depths, and the fines content in sediments was similar between stations. At those stations, total metals enrichment and contaminant concentrations of total volatile organic compounds and beta-coprostanol were similar.

As shown in Table 17, isophorone was detected only at Station 8 in Port Angeles Harbor. High concentrations of beta-sitosterol, retene, and resin acids (e.g., chlorodehydroabietic acid), as well as wood chips, were also found at Station 8. Compounds similar in chemical structure to isophorone have been observed in pulp mill wastewater (Keith 1976). A paper mill is located in Port Angeles Harbor, and the detected chemicals are associated with wood pulp and paper mill effluents. Although various halogenated organic compounds were found at fairly low concentrations at Station 44 near Anderson Island, the importance of those concentrations is unknown and the presence of those compounds should be verified. Di-n-butylphthalate was detected at low concentrations in Elliott Bay, Sinclair Inlet, and Dyes Inlet. Phthalate esters are associated with plasticizers, polymers, and polymer coatings.

Organochlorine pesticides (as defined in Table 2) were detected only at Station 33 near Duwamish Head in Elliott Bay.

Organic Compounds of Concern--

Compounds of concern are identified as those that occur at concentrations exceeding proposed sediment criteria (e.g., AET values) or concentrations in reference areas. AET values and ranges of Puget Sound reference values for selected organic compounds are shown in Table 18. Contaminants of concern may also be identified as those associated with toxicity (e.g., the effects of resin acids and substituted guaiacols on

TABLE 18. AET VALUES AND RANGES OF PUGET SOUND REFERENCE AND MSMT VALUES FOR SELECTED ORGANIC COMPOUNDS[a]

Parameter	Range of Puget Sound Reference Values[b]	Amphipod AET Value[c]	Oyster AET Value[c]	Benthic AET Value[c]	Microtox AET Value[c]	Range of MSMT Values[d]
LPAH	4-≤71	24,000	5,200	13,000	5,200	24-3,290
Naphthalene	<0.5-<40	2,400	2,100	2,700	2,100	2-54
Acenaphthylene	<0.1-<40	1,300	>560	1,300	>560	2-330
Acenaphthene	<0.1-40	2,000	500	730	500	4-55
Fluorene	<0.1-40	3,600	540	1,000	540	3-250
Phenanthrene	4-170	6,900	1,500	5,400	1,500	3-1,500
Anthracene	<0.5-<40	13,000	960	4,400	960	2-1,100
2-Methylnaphthalene	0.3-<22	1,900	670	1,400	670	3-<68(45)
HPAH	34-≤100	69,000	17,000	69,000	12,000	36-11,540
Fluoranthene	5-100	30,000	2,500	24,000	1,700	3-1,700
Pyrene	5-120	16,000	3,300	16,000	2,600	3-1,900
Benzo(a)anthracene	2-<40	5,100	1,600	5,100	1,300	<3-1,300
Chrysene	4-<40	9,200	2,800	9,200	1,400	<4-1,500
Benzo(b+k)fluoranthenes	<5-94	7,800	3,600	9,900	3,200	6-1,900
Benzo(a)pyrene	<0.4-40	3,000	1,600	3,600	1,600	4-1,400
Indeno(1,2,3-c,d)pyrene	<0.4-30	1,800	690	2,600	600	5-830
Dibenzo(a,h)anthracene	<0.4-10	540	230	970	230	4-340
Benzo(g,h,i)perylene	1.2-20	1,400	720	2,600	670	3-670
1,2-Dichlorobenzene		>110	50	50	35	<8-<68
Hexachlorobenzene		130	230	22	70	5-<68
Total PCBs	3.1-<50	3,100	1,100	1,000	130	4-49
Di-n-butyl phthalate		1,400	1,400	>5,100	1,400	<8-<68
bis(2-Ethylhexyl)phthalate		>3,100	1,900	1,300	1,900	<11-8,300
Butylbenzyl phthalate	<0.5-<25	900	>470	900	63	<3-<68(39)
Phenol	<0.5-62	1,200	420	1,200	1,200	7-520
Pentachlorophenol	0.1-<50	360	>140	690	>140	10-<340
Dibenzofuran	>5-14	1,700	540	700	540	5-<68
Hexachlorobutadiene		180	270	11	120	<15-<140
Tetrachloroethene		>210	140	57	140	<0.025-0.17
Ethylbenzene		>50	37	10	33	<0.017-0.081
Total xylenes		>160	120	40	100	<0.083-0.300
p,p'-DDD	<1.9-<10	43	-	16	-	0.6-<6.0(2.6)
Retene	≤130	-	-	-	-	5-120

[a] Concentrations are reported in ug/kg dry weight.

[b] PTI and Tetra Tech (1988a).

[c] PTI (1988b).

[d] The range of values was determined using all samples (n=65), including blind analytical and blind field replicates. Undetected values are shown as they were reported by the analytical laboratory. If the maximum value was undetected, the highest detected value is shown in parentheses. N=23 for antimony because data were qualified as unusable at 27 of 50 stations. N=34 for selenium because data were qualified as unusable at 11 of 50 stations.

salmonids). Selected organic compounds that are typically considered contaminants of concern are discussed below.

Although the EAR approach is more applicable to toxic urban bay studies than to ambient monitoring programs (see METHODS, Sediment Chemistry), EAR values were calculated for organic compounds as required by PSWQA (1988a).. EAR values were calculated only for chemicals that exceeded interim performance standards (PTI 1989), using the method previously described (see METHODS, Sediment Chemistry). The magnitude of contamination among stations can be assessed using the EAR values shown in Table 3.

PAH--According to Pearson correlation analyses, PAH (with the exception of retene) correlated with each other and with LPAH and HPAH groups (Table 19). Retene, an alkyl-substituted phenanthrene, is one of few PAH that is biogenic and derived from the diagenesis of natural materials. As Figure 11 shows, retene is naturally derived from plant resin acids (e.g., abietic and dehydroabietic acids) under ambient conditions in the presence of air, sunlight, and clay minerals. Under natural conditions, retene can be further altered to methylphenanthrene and phenanthrene. Some weak correlation was observed between retene and perylene. Figure 11 also shows the relationship between the porphyrin structure and perylene. Some sediment contribution of perylene may be due to background or diagenesis of porphyrin structures, such as chlorophyll. The best correlation with retene was observed for beta-sitosterol ($r = 0.74$) and the resin acids, indicating that retene is associated primarily with vascular plants and coniferous products. PAH concentrations reflected impacts due to urban drainage and proximity to urban activities.

LPAH and HPAH were not correlated with fines, TOC contents, metal concentrations, or metal enrichments. At many stations with elevated PAH concentrations, cadmium, silver, and lead concentrations were enriched. Metal enrichments in south Hood Canal (e.g., aluminum, cobalt, iron, vanadium) and Whidbey Basin (e.g., nickel, chromium) were not associated with elevated concentrations of organic contaminants, and thus are probably natural geochemical enrichments. Urban organic contaminants (represented by

TABLE 19. RESULTS OF PEARSON CORRELATION ANALYSES AMONG ORGANIC COMPOUNDS AND CONVENTIONAL VARIABLES AT ALL STATIONS

		27	26	25	24	23	22	21	20	19	18	17	16
1	(2-Methylnaphthalene)	0.92	0.93				0.94	0.93	0.94	0.93	0.95	0.94	0.93
2	(Acenaphthene)	0.97	0.98				0.98	0.97	0.98	0.98	0.98	0.99	0.97
3	(Acenaphthylene)	0.98	0.99				0.99	0.97	0.98	0.93	0.99	0.99	0.98
4	(Anthracene)	0.96	0.99				0.96	0.96	0.89	0.93	0.98	0.98	0.95
5	(Benzo(a)anthracene)	1.00	0.98				0.99	0.96	0.93	0.92	0.99	0.97	0.99
6	(Benzo(a)pyrene)	1.00	0.97				1.00	0.96	0.94	0.92	1.00	0.96	0.99
7	(Benzo(b+k)fluoranthene)	0.99	0.95				0.98	0.94	0.93	0.91	0.97	0.94	0.99
8	(Benzo(g,h,i)perylene)	0.99	0.96				0.99	0.95	0.98	0.90	1.00	0.96	0.98
9	(bis(2-Ethylhexyl) phthalate)									0.79	0.84	0.90	
10	(β-Coprostanol)					0.61							
11	(β-Sitosterol)			0.70	0.71	0.74							
12	(Cholesterol)			0.42		0.52							
13	(Chrysene)	0.99	0.95				0.97	0.93	0.92	0.90	0.97	0.93	0.98
14	(Dibenzofuran)	0.96	0.93				0.94	0.93	0.94	0.94			0.96
15	(Dibenzo(a,h)anthracene)	0.99	0.99				0.99	0.97	0.97	0.93	0.99	0.98	0.99
16	(Fluoranthene)	1.00	0.97				1.00	0.97	0.95	0.93	0.99	0.97	
17	(Fluorene)	0.96	1.00				0.97	0.99	0.95	0.97	0.97		
18	(Indeno(1,2,3-c,d)pyrene)	0.99	0.97				1.00	0.96	0.96	0.91			
19	(Naphthalene)	0.92	0.95				0.92	0.96	0.92				
20	(Perylene)	0.94	0.91			0.59	0.94	0.91					
21	(Phenanthrene)	0.96	0.99				0.97						
22	(Pyrene)	1.00	0.98										
23	(Retene)			0.50	0.57								
24	(TOC)			0.87									
25	(Fines)												
26	(LPAH)	0.97											
27	(HPAH)												

		15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	(2-Methylnaphthalene)			0.87					0.96	0.88	0.93	0.92	0.93	0.96	
2	(Acenaphthene)	0.98							0.99	0.94	0.98	0.97	0.98	0.97	
3	(Acenaphthylene)	0.99		0.94				0.92	0.98	0.94	0.98	0.98	0.99		
4	(Anthracene)	1.00	0.92	0.94					0.97	0.94	0.96	0.97			
5	(Benzo(a)anthracene)	1.00	0.96	0.99					0.98	0.99	1.00				
6	(Benzo(a)pyrene)	0.99	0.95	0.98					0.99	0.98					
7	(Benzo(b+k)fluoranthene)	0.98	0.96	1.00					0.96						
8	(Benzo(g,h,i)perylene)	0.98		0.95				0.85							
9	(bis(2-Ethylhexyl) phthalate)	0.93													
10	(β-Coprostanol)				0.93	0.60									
11	(β-Sitosterol)				0.67										
12	(Cholesterol)														
13	(Chrysene)	0.98	0.96												
14	(Dibenzofuran)														
15	(Dibenzo(a,h)anthracene)														
16	(Fluoranthene)														
17	(Fluorene)														
18	(Indeno(1,2,3-c,d)pyrene)														
19	(Naphthalene)														
20	(Perylene)														
21	(Phenanthrene)														
22	(Pyrene)														
23	(Retene)														
24	(TOC)														
25	(Fines)														
26	(LPAH)														
27	(HPAH)														

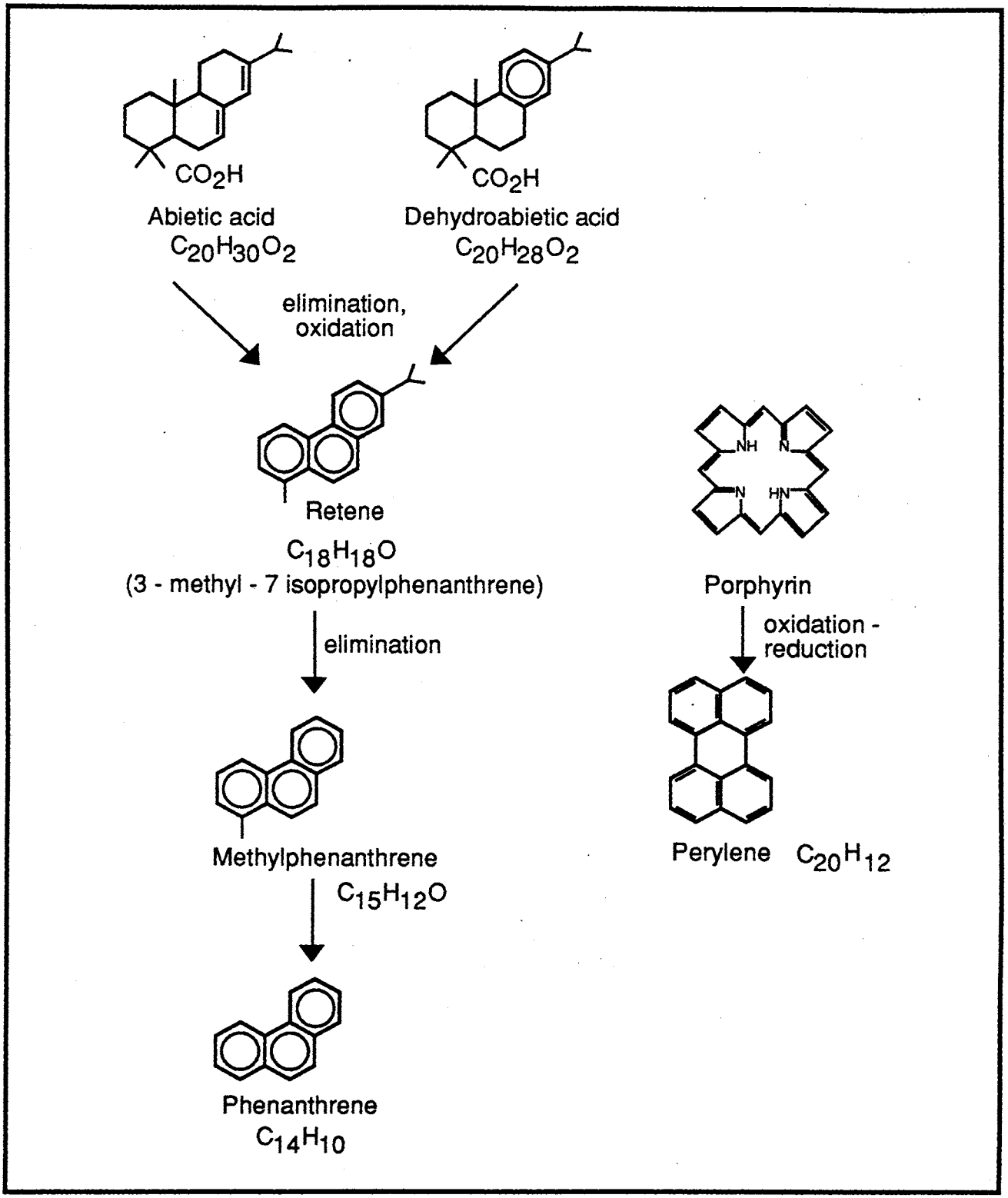
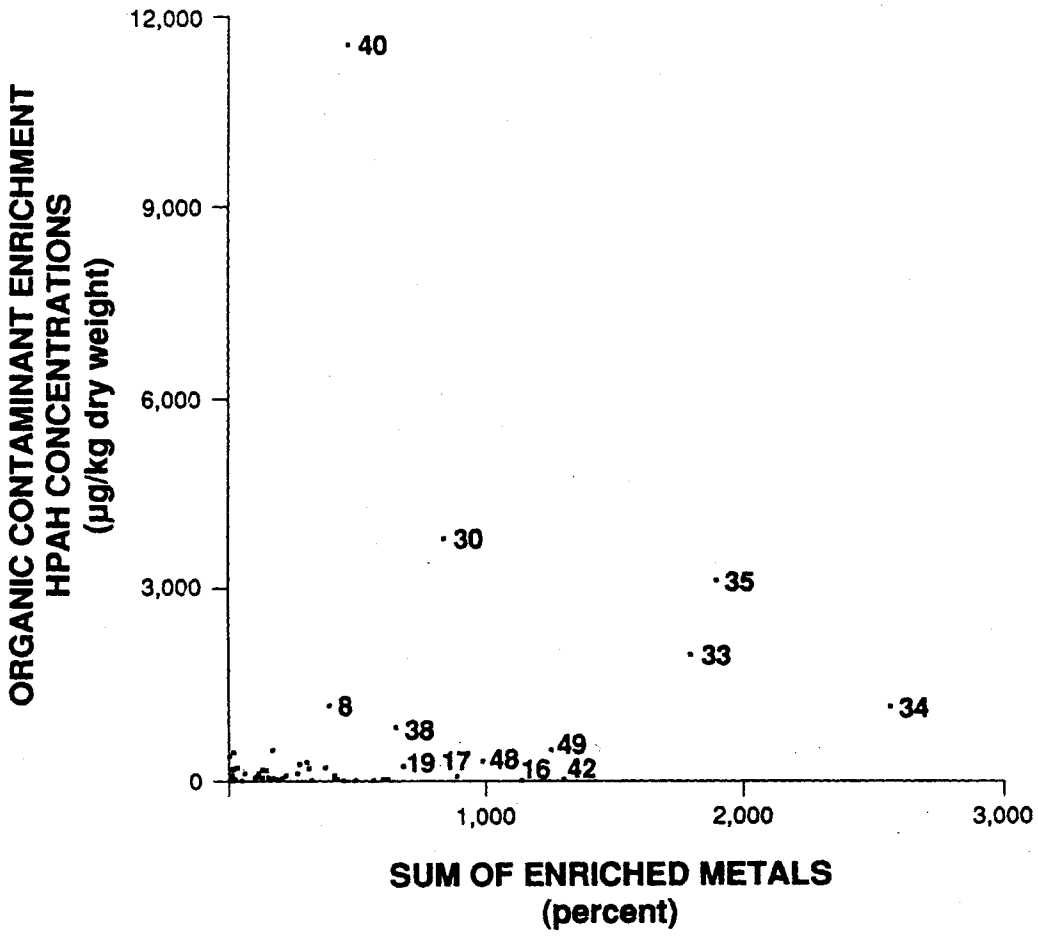


Figure 11. Chemical structure of select resin acids and PAH compounds.

HPAH) were compared to the total inorganic enrichments for each MSMT station. The relationship between HPAH concentrations and the sum of enriched metals is shown in Figure 12. Stations distant from the origin are relatively impacted by either urban contaminants (represented by HPAH) or high metal enrichments due to natural regional processes and geochemical conditions. As such, the following stations should be excluded from consideration as potential Puget Sound reference areas due to extreme organic or inorganic enrichments: 40 (City Waterway), 30 (Eagle Harbor), 33 (Duwamish Head), 34 (Sinclair Inlet), and 35 (Dyes Inlet). Less contaminated stations that should be excluded from consideration are Stations 8 (Port Angeles Harbor), 38 (Point Pully), 19 (Saratoga Passage), 17 (south Hood Canal), 48 and 49 (Budd Inlet), and 42 (Ruston). (As defined in a subsequent section, IDENTIFICATION OF POTENTIAL MSMT REFERENCE STATIONS, none of these stations are potential reference stations.)

Relationships between individual PAH and total LPAH or HPAH at all MSMT stations are shown in Table 20. HPAH accounted for approximately 83 percent of total PAH concentrations. The primary constituents of HPAH were fluoranthene, pyrene, chrysene, benzofluoranthenes, and benzo(a)pyrene. The primary constituents of LPAH were phenanthrene and anthracene. The highest variabilities for PAH concentrations were associated with the PAH detected least often.

Concentrations of LPAH and HPAH for each MSMT station are shown in Figures 13 and 14, respectively, and Table 21. In general, PAH concentrations at MSMT stations were about 50 percent greater than those concentrations reported in the *Puget Sound Environmental Atlas* for similarly located stations (relative to the total area weighted mean). LPAH concentrations at 11 of 50 MSMT stations exceeded the Puget Sound maximum reference area value of 71 ug/kg (Figure 13). HPAH concentrations at 25 of the stations exceeded the Puget Sound maximum reference area value of 100 ug/kg (Figure 14). The majority of these stations are found in the Central Basin. Results of analyses of the PCS demonstrated that the method and laboratory performance



Note: Only positive values are shown (see Figure 8)

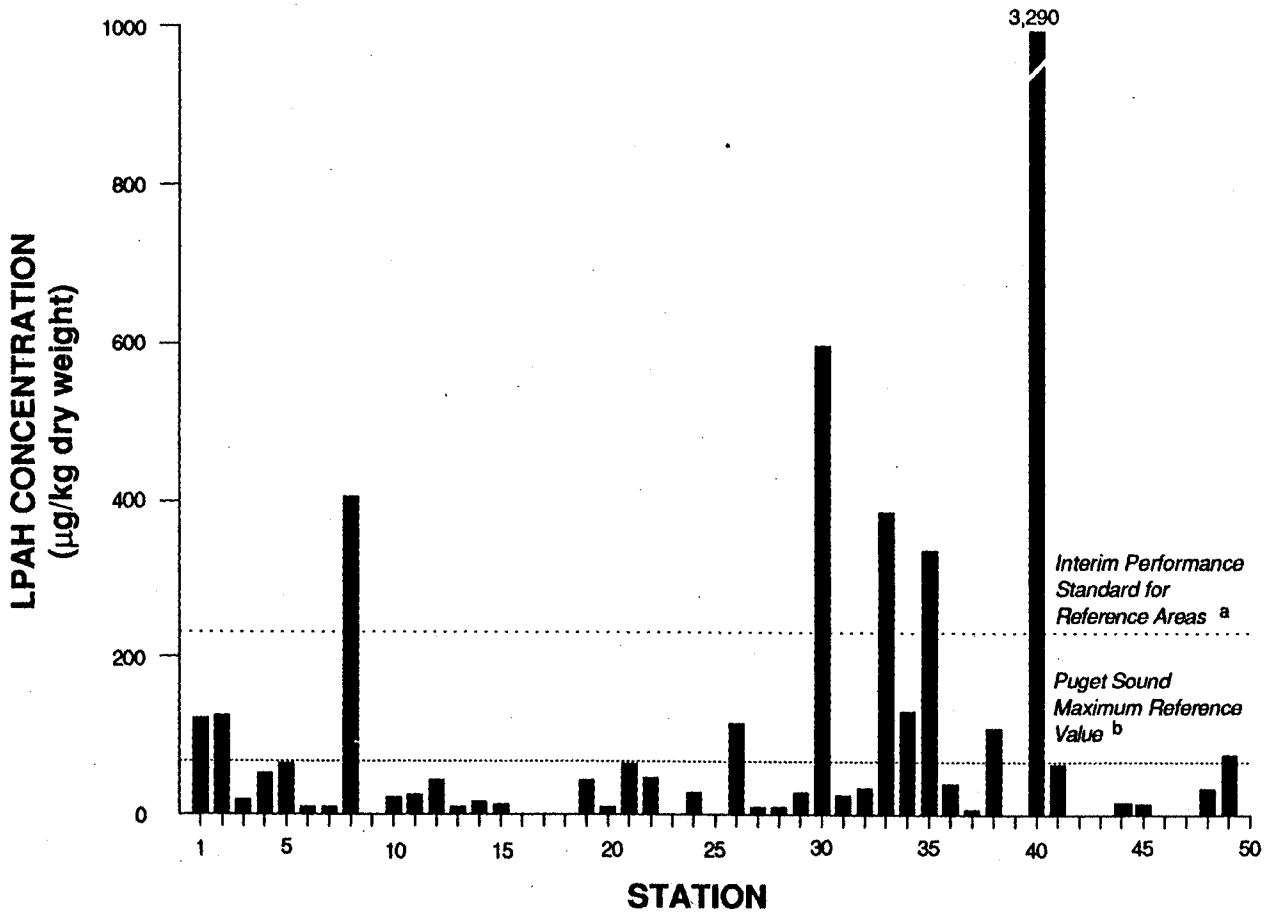
Figure 12. Relationship of HPAH concentrations to the sum of enhanced metals at all stations.

TABLE 20. RELATIONSHIPS BETWEEN INDIVIDUAL PAH AND TOTAL LPAH OR HPAH AT MSMT STATIONS

Variable A/Variable B	Ratio of Mean Values[a]	Coefficient of Variation
HPAH/Total PAH[b]	0.83	15%
Naphthalene/LPAH	0.10	89%
Acenaphthylene/LPAH	0.077	59%
Acenaphthene/LPAH	0.067	110%
Fluorene/LPAH	0.065	34%
Phenanthrene/LPAH	0.79	28%
Anthracene/LPAH	0.25	61%
Fluoranthene/HPAH	0.24	50%
Pyrene/HPAH	0.20	47%
Benzo(a)anthracene/HPAH	0.094	30%
Chrysene/HPAH	0.16	52%
Benzo(b+k)fluoranthenes/HPAH	0.22	26%
Benzo(a)pyrene/HPAH	0.11	54%
Indeno(1,2,3-c,d)pyrene/HPAH	0.077	32%
Dibenzo(a,h)anthracene/HPAH	0.026	31%
Benzo(g,h,i)perylene/HPAH	0.068	34%

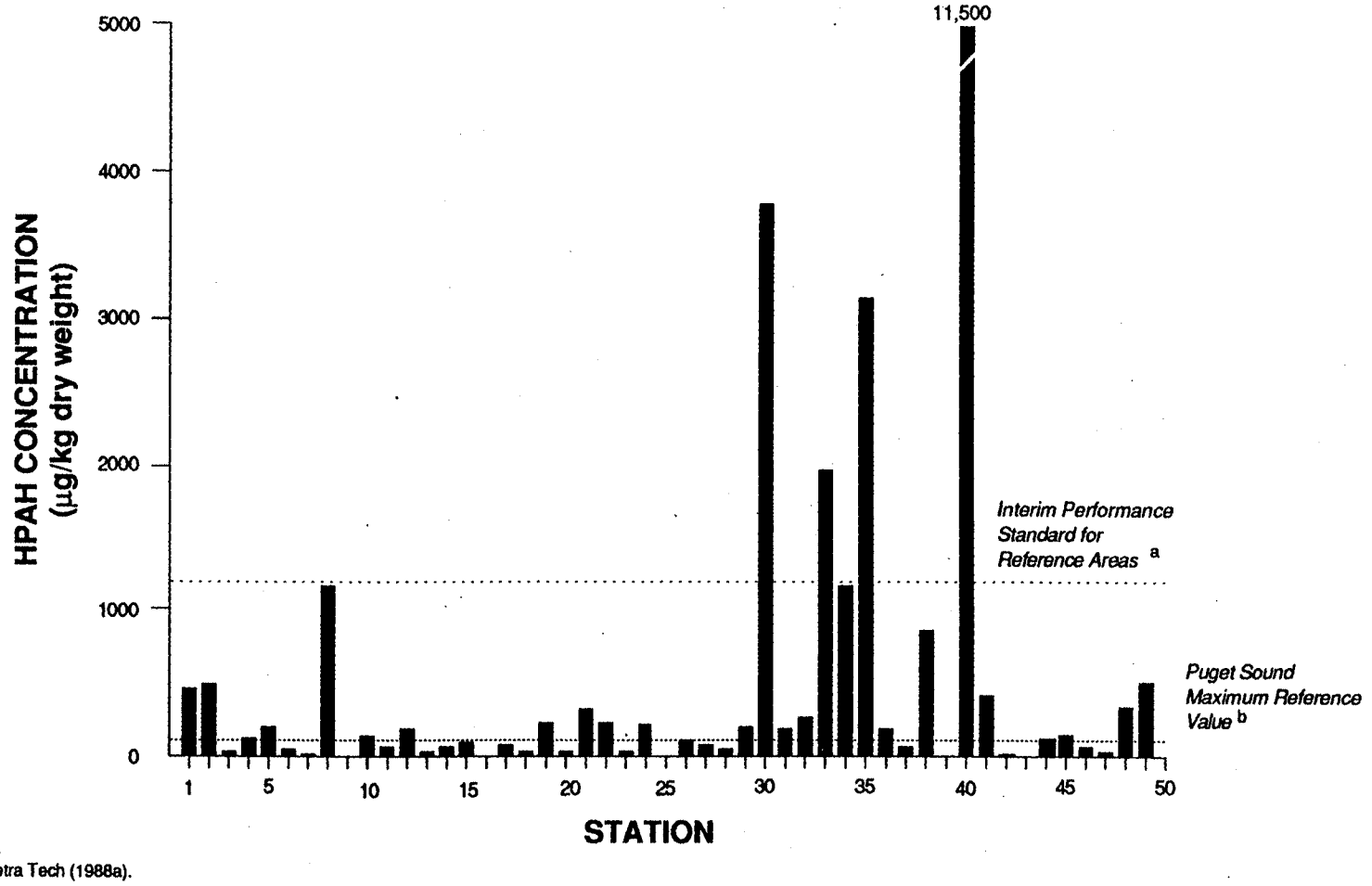
[a] Ratio was determined as the mean of detected values for Variable A divided by the mean of detected values for Variable B.

[b] By using only detected values, the mean value of total PAH at MSMT stations was 684 ug/kg DW and the CV was 297 percent.



a PTI (1989).
b PTI and Tetra Tech (1988a).

Figure 13. Concentrations of LPAH at MSMT stations.



a PTI (1989).
b PTI and Tetra Tech (1988a).

Figure 14. Concentrations of HPAH at MSMT stations.

TABLE 21. LPAH AND HPAH CONCENTRATIONS AT MSMT STATIONS

Station	LPAH[a]	HPAH[a]	Station	LPAH	HPAH
1	175.0	480.0	26	136.0	100.0
2	138.0	490.0	27	28.0	69.0
3	53.5	68.5	28	28.0	45.0
4	108.0	171.0	29	73.0	212.0
5	111.5	233.5	30	600.0	3,780.0
6	28.0	58.5	31	48.0	178.5
7	33.0	50.0	32	47.5	258.0
8	404.0	1,162.0	33	387.0	1,951.0
9	36.0	60.0	34	131.0	1,146.0
10	57.5	134.0	35	348.5	3,118.0
11	59.5	78.5	36	52.0	158.0
12	89.0	208.5	37	31.0	62.0
13	38.0	51.0	38	165.0	849.0
14	48.0	70.0	39	36.0	54.0
15	41.5	98.5	40	3,289.0	11,540.0
16	39.0	58.5	41	90.5	390.5
17	75.0	109.0	42	33.0	49.5
18	60.0	87.0	43	36.0	54.0
19	117.5	265.5	44	42.0	95.0
20	47.0	70.0	45	48.0	126.5
21	81.0	313.5	46	39.0	63.0
22	64.0	213.5	47	42.0	60.5
23	27.0	38.5	48	98.0	323.5
24	70.5	233.5	49	132.0	501.5
25	24.0	36.0	50	39.0	58.5

[a] Values are reported in ug/kg dry weight. LPAH and HPAH concentrations were calculated using QL/2 or zero for undetected values, as described in the text. PAH were not detected at Stations 9, 16, 25, 39, 43, and 50.

for PAH analyses was average relative to the other methods and laboratories that generated PAH data used in the Atlas.

Ecology's proposed interim performance standards (PTI 1989) for LPAH and HPAH concentrations are 240 ug/kg and 1,200 ug/kg, respectively (see IDENTIFICATION OF POTENTIAL REFERENCE AREAS). Sediments at five MSMT stations exceeded the proposed standard for LPAH (i.e., Stations 8, 30, 33, 35, and 40). At six other MSMT stations, LPAH concentrations ranged between the Puget Sound maximum reference value (PTI and Tetra Tech 1988a) of 71 ug/kg and the proposed standard [i.e., Stations 34 (131 ug/kg), 2 (123 ug/kg), 1 (120 ug/kg), 26 (117 ug/kg), 38 (113 ug/kg), and 49 (78 ug/kg). Note: to be consistent with the method used to calculate interim performance standards, only detected compounds were included in these sums].

At four of the five stations where the proposed LPAH standard was exceeded, the proposed HPAH standard was also exceeded (i.e., Stations 30, 33, 35, and 40). At 21 other MSMT stations, HPAH concentrations ranged between the Puget Sound maximum reference value of 100 ug/kg DW and the proposed standard: (in descending order of HPAH concentrations) Stations 8, 34, 38, 49, 2, 1, 41, 48, 21, 32, 19, 22, 24, 5, 29, 31, 12, 36, 10, 45, and 4.

The highest concentration of LPAH was found at Station 40 (City Waterway in Commencement Bay). High concentrations of 9H-carbazole were found at Station 40, and TOC, silver, copper, and lead were enriched. The high concentrations of organic contaminants, wood chips, gravel, and low fines content at this station suggests that high flows containing organic contaminants and metals probably occurs during episodic events when stormwater flows occur in the area. Mean net water currents in this area during non-storm conditions are reported at 1-4 cm/sec (Norton, D., 8 November 1989, personal communication), which are not considered extreme. Extreme stormwater discharges occur in the area due to large storm system discharges at the head of City Waterway.

PAH were not detected at Stations 9 (Green Point), 16 (south Hood Canal), 25 (west Central Basin), 39 (Dash Point), 43 (Carr Inlet), and 50 (Shelton).

Phenol--Phenol concentrations exceeded the Puget Sound maximum reference area value (i.e., 62 ug/kg DW) at Stations 41 (240 ug/kg DW; Blair/Sitcum Waterways) and 19 (520 ug/kg DW; Saratoga Passage). The phenol concentration at Station 19 also exceeded the LAET value of 420 ug/kg DW.

A hydrolysis product of plant lignins, phenol is generally formed by the aerobic decomposition of organic plant and animal wastes. Phenol is frequently found in wastewater treatment plant effluent, and can be used as an indicator chemical of such discharges. For example, phenol, beta-coprostanol, and fecal matter were all found in sediments at Station 41. The latter constituents are clearly related to the nearby discharge from the Tacoma wastewater treatment plant, and the phenol probably is, too.

Results of a Pearson correlation analysis revealed that phenol concentrations were significantly ($P \leq 0.01$) correlated with cobalt ($r = 0.73$), sodium ($r = 0.78$), vanadium ($r = 0.66$), and percent fines ($r = 0.69$). No other metal or organic contaminants were correlated with phenol concentrations. The concentration of phenol at Station 19 was not correlated with any other contaminant organic compounds, and thus cannot be associated with identifiable anthropogenic activities. The importance of phenol at Station 19 is unknown, and its presence requires verification.

Analyses of the PCS (see METHODS, Sediment Chemistry) resulted in a CV of 0.13 for phenol. Surrogate recoveries for phenol were in range of 40 to 47 percent in samples from Stations 19 and 41, well within the U.S. EPA criteria for acceptable phenol results.

Butylbenzyl phthalate--Butylbenzyl phthalate was detected at Stations 40 (City Waterway; 39 ug/kg DW), 34 (Sinclair Inlet; 31 ug/kg), and 35 (Dyes Inlet; 18 ug/kg). Concentrations found in City Waterway and Sinclair Inlet exceeded the Puget Sound maximum reference value of 25 ug/kg. AET values

were not exceeded. Butylbenzyl phthalate is a component of plasticizers and polymer coatings, primarily those containing polyvinylchloride (PVC). It is a common constituent of urban and point source discharges that contact PVC.

Guaiacols and Resin Acids--Chloroguaiacols and resin acids were measured at Stations 4 (Bellingham Bay), 8 (Port Angeles Harbor), and 21 (Everett Harbor) to determine impacts of nearby pulp and paper processing effluents on marine sediments. Resin acids are constituents of higher plant resins and supportive plant tissue, particularly in conifers. While unchlorinated resin acids occur naturally, they are concentrated by pulping processes. Also, chlorine bleaching processes used by the pulp industry have been demonstrated to result in the release of chlorinated resin acids (e.g., chlorodehydroabietic and dichlorodehydroabietic acids) and chlorinated guaiacols in bleached sulfite and kraft effluents. Chlorinated resin acids have only been reported to be produced in chlorine bleaching processes during pulping. Guaiacols were not detected at quantitation limits of 70 ug/kg. However, if analytical methods improve in the future, guaiacols may be detected in sediments at lower concentrations. Chlorinated resin acids were found at each station. Chlorodehydroabietic acid measured 90 ug/kg at Station 8 (Port Angeles Harbor) and it was tentatively identified at Stations 4 (Bellingham Bay) and 21 (Port Gardner). Dichlorodehydroabietic acid was measured at 150 ug/kg at Station 4. Concentrations of abietic (180 ug/kg), dehydroabietic (520-550 ug/kg), and isopimaric (160-210 ug/kg) acids were similar in Port Angeles and Everett Harbors. Lower concentrations of resin acids were found at Station 4, which is located at a much greater distance from a pulp and paper mill than is either Station 8 or 21.

Retene and beta-sitosterol both covaried with resin acids at Stations 4, 8, and 21. This suggests that retene, beta-sitosterol, and resin acids are all associated with vascular plant and coniferous products.

PCBs--The only PCB detected at MSMT stations was Aroclor 1254. Aroclor 1254 was detected in 28 percent of the samples. Highest Aroclor 1254 concentrations were found at Stations 34 (49 ug/kg DW; Sinclair Inlet), 33 (40 ug/kg DW; Duwamish Head-Elliott Bay), and 21 (30 ug/kg DW; Everett

Harbor), but at concentrations considerably lower than those reported for the same areas in the *Puget Sound Environmental Atlas* (Evans-Hamilton and D.R. Systems 1987). Although data from MSMT stations represent only a single point in time, PCB concentrations at MSMT stations were less than Atlas data by about 40 percent in Sinclair Inlet, 60 percent in Elliott Bay, and 80 percent in Everett Harbor. Given the high quality of PCB data for this study, the observed reductions may be due to a decrease in PCB-contaminated discharges. Comparisons between MSMT data and PCB concentrations found at similar stations in 1981 (Romberg et al. 1984; two stations) and 1985 (PTI and Tetra Tech 1988a; two stations) suggests an approximate decrease of 10 percent in the East Waterway of the Duwamish River and 60 percent in the West Waterway of the Duwamish River.

Organochlorine Pesticides--Organochlorine pesticides (i.e., DDD, alpha-chlordane) were detected at only Station 33 near Duwamish Head in Elliott Bay (see Table 17). This low frequency of detections is not surprising because few of the organochlorine pesticides analyzed in the 1989 MSMT are manufactured or used by the agricultural industry (Tetra Tech 1988b).

Pristane-to-Phytane Ratios and Sterols--Pristane-to-phytane ratios and sterol measurements were used to interpret environmental processes in Puget Sound. Pristane-to-phytane ratios for each MSMT station are shown in Figure 15. The highest pristane-to-phytane ratios occurred in South Sound, indicating relatively high inputs of either plankton-derived hydrocarbons or relatively unweathered petroleum hydrocarbons. Low concentrations of LPAH (which are components of petroleum) were found in the South Sound. The high inputs of planktonic detritus, which explain the high pristane-to-phytane ratios, probably contribute relatively more to sedimentary TOC in the South Sound than in other MSMT station locations.

Beta-coprostanol is a fecal sterol produced by microbiological reduction of cholesterol in the gut of ruminants and humans. Figure 16 presents a diagram showing the reduction of cholesterol, a major plant and animal sterol, to beta-coprostanol. The chemical structure and formula for beta-sitosterol, the third sterol analyzed in the MSMT, is also shown for

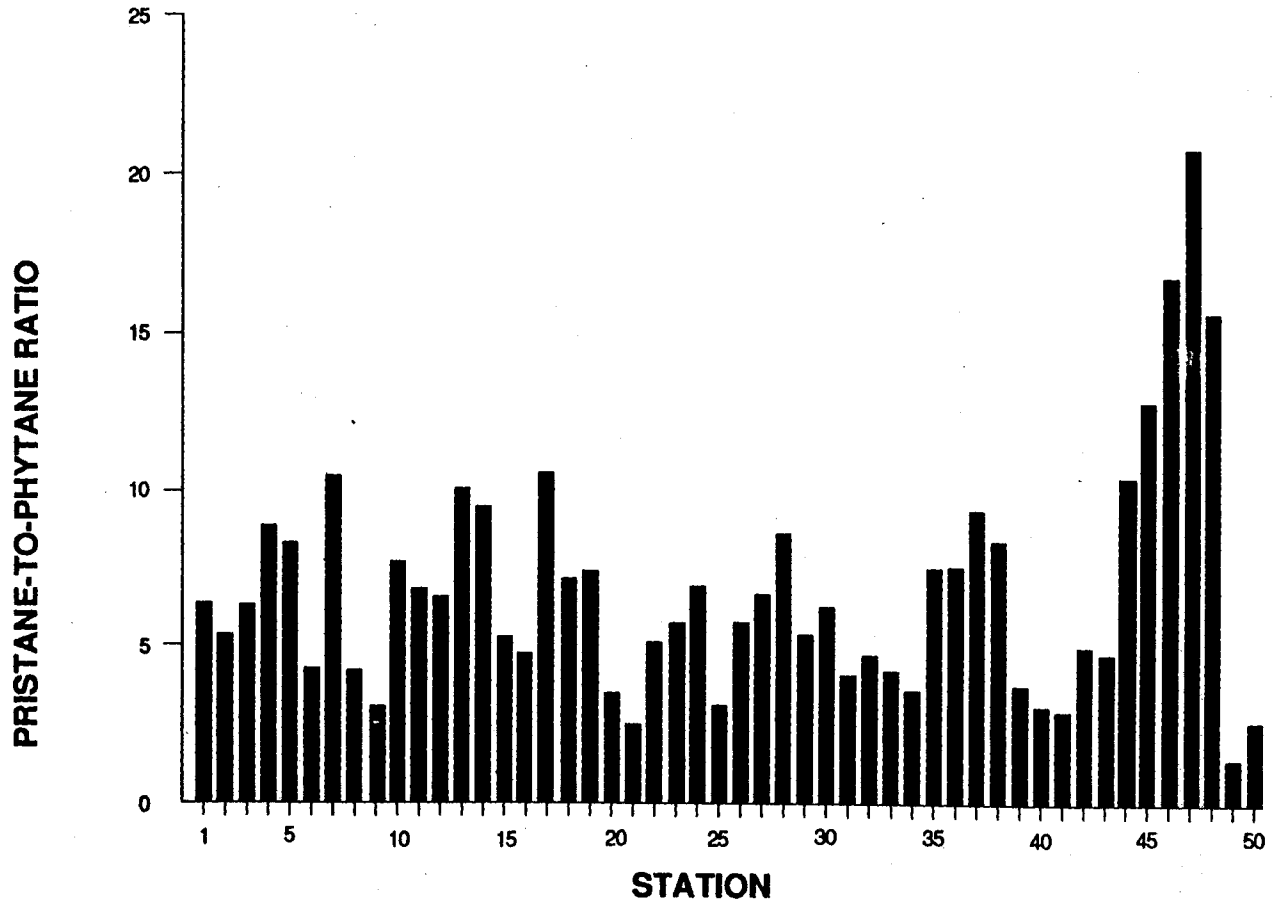
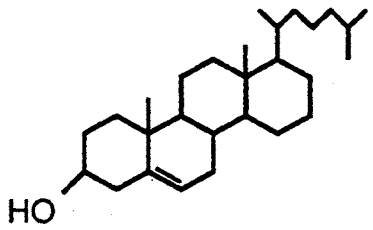
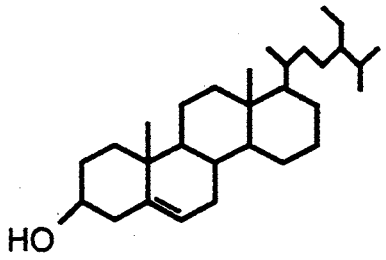


Figure 15. Pristane-to-phytane ratios at MSMT stations.



Cholesterol

$C_{27}H_{46}O$

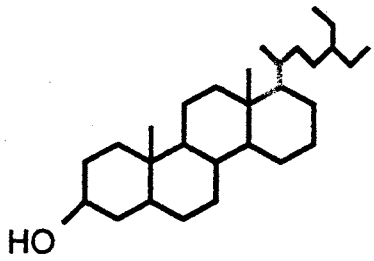


beta - Sitosterol

$C_{29}H_{50}O$

(primary sterol of vascular plants)

microbiological reduction in guts of ruminants and mammals



beta - Coprostanol

$C_{27}H_{48}O$

Figure 16. Chemical structure of cholesterol, beta-coprostanol, and beta-sitosterol.

comparison. Beta-coprostanol can be present in municipal wastewater treatment effluent, combined sewer overflows, and nonpoint source runoff (e.g., from residential septic systems and animal husbandry). The accumulation of beta-coprostanol in sediments reflects an equilibrium between inputs and environmental degradation of beta-coprostanol. The degradation period for beta-coprostanol in Puget Sound is not known. Although beta-coprostanol is not a toxic contaminant, its presence can be used as an indicator of anthropogenic source inputs.

As shown in Figure 17, beta-coprostanol concentrations at MSMT stations ranged from <17 to 4,700 ug/kg DW. Highest concentrations were found in the Central Basin, particularly in nearshore embayments. Highest concentrations were found at Stations 41 (4,700 ug/kg) and 40 (1,000 ug/kg) in Commencement Bay, suggesting relatively high local inputs of fecal material. Tacoma's wastewater treatment plant outfall, which is located directly north of Station 41, is a potential source of beta-coprostanol. A high concentration (588 ug/kg) was also found at Station 38, a deep-water station that appears to be receiving contaminants from nearby urban centers. Residential wastewater treatment plant outfalls are located in the vicinity of Station 38, including the Miller Creek outfall (about 3.5 MGD) south of Point Pully and the Salmon Creek outfall north of Point Pully (Schy, J., 20 December 1989, personal communication). The fourth highest concentration (570 ug/kg) was found near Station 34, located near the discharge from the Bremerton wastewater treatment plant. The fifth and sixth highest concentrations were found in Budd Inlet. Station 48 (560 ug/kg) is located near two outfalls that discharge from residential wastewater treatment plants. Station 49 is located north of the Lacey, Olympia, Tumwater, Thurston County (LOTT) wastewater treatment plant. Microbial contamination in Budd Inlet has been previously reported by Tetra Tech (1988a) and URS (1986).

Excluding data from Station 41, beta-sitosterol, retene, cholesterol, and TOC are highly correlated. This correlation suggests that, in general, sediment TOC in Puget Sound is primarily derived from natural sources associated with higher plants and detritus from relatively unimpacted areas

(as compared with typical urban sources) or induced by high flows containing plant detritus (e.g., pulp mill effluents).

Tentatively Identified Compounds--

Additional analyses were conducted to determine the presence of other nontarget organic compounds (known as tentatively identified compounds) at MSMT stations. Data on semivolatile and volatile tentatively identified compounds (TICs) are summarized in Table 8 of the semivolatile organics QA memorandum and Table 6 of the volatile organics QA memorandum in Appendix B. Most identifiable compounds were hydrocarbon-like in character or fatty acids. The greatest number of TICs at highest concentrations were found in Commencement Bay at Station 41, and lowest mean concentrations were found at Stations 27 and 28. No correlations were found between the number (or mean concentrations) of TICs and the presence of contaminant organic compounds. These TICs could be either naturally occurring or anthropogenically derived. Little additional information was provided by the limited TIC analyses conducted for the MSMT. Future work could be more productive in identifying TICs if resources were available for the laboratory to perform additional workup of those sediment samples that are located near known, identifiable contaminant sources.

Summary

This section presents a summary of chemical characteristics in sediments at stations sampled during the 1989 MSMT. Because chemical concentrations were previously presented by individual chemicals, this section will present sediment chemistry results by geographic region from north to south.

Stations 1 (Semiahmoo Bay) and 2 (Cherry Point) were located at similar depths in the Straits of Georgia. Sediments at Station 1 contained more fine-grained material than sediments at Station 2, although they both exhibited similar chemical characteristics. Concentrations of HPAH and LPAH were only slightly elevated at these stations, suggesting some minor impact

from combustion particulates, which are typically associated with urban drainage.

Station 3 was the deepest station located in the Strait of Georgia. Fecal sterol concentrations at Station 3 were higher than concentrations at either Stations 1 or 2, suggesting some effects from urban wastewater discharges.

Sediments at Stations 4 (Bellingham Bay) and 5 (Samish Bay) had LPAH concentrations that were below Puget Sound maximum reference values, and HPAH concentrations that exceeded Puget Sound maximum reference values. Metal concentrations at these stations were not elevated, and silver concentrations were depressed relative to the Puget Sound mean for composition of fine-grained sediments. Station 4 exhibited moderately elevated concentrations of beta-coprostanol and chlorinated resin acids, which indicates that sediments were impacted by fecal-derived material and bleached pulp processes. Sediments at Station 5 showed moderate concentrations of volatile organic compounds and beta-coprostanol, suggesting some effects from urban wastewater discharges.

Station 6 was located east of Anacortes, in a shallow area that experiences generally high net water current speeds. The fines content was very low at Station 6, and chemical concentrations were not elevated.

Stations 7 (Strait of Juan de Fuca), 9 (Green Point), 10, and 11 (Discovery Bay) did not appear to be impacted by anthropogenic contamination. Metal concentrations in sediments at Station 7 were slightly enriched for aluminum, iron, magnesium, nickel, and vanadium. These appear to be natural metal enrichments in the Strait of Juan de Fuca. Minimal concentrations of beta-coprostanol were found at the shallow, nearshore stations (i.e., Stations 9 and 11), and PAH concentrations were not found at Station 9. HPAH concentrations in sediments at Station 10 exceeded the Puget Sound maximum reference value for HPAH.

Station 8 (Port Angeles) exhibited sediment characteristics typically found in urban embayments. Metal concentrations were enriched for cadmium, mercury, and lead, and the highest concentration of TOC (3.90 mg/kg) found in the MSMT was observed at Station 8. The presence of chlorodehydroabietic acid and moderately high concentrations of beta-sitosterol and retene are indicative of impacts from nearby pulp mill discharges. Beta-coprostanol concentrations suggest some influence of fecal-derived material in Port Angeles Harbor.

The bis(2-ethylhexyl)phthalate concentration at Station 12 (8,300 ug/kg DW; Port Townsend) exceeded the LAET of 1,300 ug/kg DW. At Station 12, the beta-coprostanol concentration was low to moderate, and the HPAH concentration exceeded the Puget Sound maximum reference value.

Some of the lowest contaminant concentrations reported for the MSMT were found in the sandy sediments at Stations 13, 14, and 15 in North Hood Canal and Dabob Bay.

At Stations 16 and 17 in South Hood Canal, concentrations of aluminum, calcium, cobalt, copper, iron, magnesium, and vanadium were enriched relative to the mean Puget Sound composition in fine sediments. However, organic compounds that are normally associated with anthropogenic activities were not found at Stations 16 or 17. PAH were not detected at Station 16, although some alkyl-substituted benzenes, which could be associated with natural diagenetic processes, were found at low concentrations in South Hood Canal. Therefore, those enrichments are not likely the result of anthropogenic activities, and are probably due to natural regional geochemistry and the proximity of those stations to the Skokomish River mouth. However, historical data have not shown elevated particulate metal concentrations in the Skokomish River (Paulson, T., 19 January 1990, personal communication). Because historical data have shown that the Great Bend in Hood Canal (i.e., the area in which Stations 16 and 17 are located) is a reducing environment, this may explain the enriched concentrations of metals (e.g., cobalt, iron, magnesium, vanadium) found at Stations 16 and 17 (Paulson, T., 19 January 1990, personal communication). In a reducing environment, low oxygen

concentrations in the water column lead to higher hydrogen sulfide concentrations, which causes certain metals (e.g., cobalt) to precipitate from the water column to the sediments. This process may be a seasonal occurrence. Arsenic and chromium were enriched only at the shallower station (Station 16). Lead concentrations were depressed relative to the mean Puget Sound composition for fine-grained sediments, which may reflect the lack of urban stormwater street runoff in the area.

The Whidbey Basin Stations 18, 19, and 20 exhibited enrichments of chromium and nickel. The highest concentrations of chromium and nickel reported in the MSMT were found at Station 20 in Port Susan. High particulate and dissolved nickel concentrations have been observed in the Stillaguamish River (Paulson, T., 19 January 1990, personal communication). Because other contaminants that are associated with anthropogenic sources (e.g., PAH, lead, and silver) were not found at these stations, the metal enrichments in the Whidbey Basin may reflect the effects of natural regional geochemical processes that could be associated with local riverine discharges. Station 20 showed the highest enrichments, which may be related to the proximity of that station to the mouth of the Stillaguamish River. At Station 19, HPAH concentrations were slightly greater than the Puget Sound maximum reference value for HPAH, phenol concentrations were elevated, and chlorinated solvents were found at moderate concentrations. Those chemical concentrations suggest that wastewater discharges may be impacting sediments at Station 19. At Station 19, the phenol concentration (520 ug/kg DW) exceeded the Puget Sound maximum reference value, and the LAET value of 420 ug/kg DW.

Station 21 (Port Gardner) exhibited sediment characteristics that are typical of urban embayments. The HPAH concentration exceeded the Puget Sound maximum reference value for HPAH, beta-coprostanol and PCBs were detected at moderate concentrations, and cadmium was enriched. Concentrations of resin acids and chlorinated resin acids were indicative of effects from bleach pulp mill discharges.

In Possession Sound, Stations 22 (Mukilteo), 23 (East Central Basin), and 24 (East Central Basin) showed low concentrations of beta-coprostanol and HPAH concentrations at some stations exceeded the Puget Sound maximum reference value for HPAH. Metal concentrations were unremarkable.

In the north Central Basin, Stations 25 (West Central Basin), 26 (West Central Basin), 27 (Richmond Beach), and 28 (Jefferson Head), exhibited lower concentrations of organic contaminants than other MSMT stations, except for the deepwater Station 26 which had a LPAH concentration that exceeded the Puget Sound maximum reference value and a 9(H)-carbazole concentration that was elevated. At Station 26, the low concentration of chlorinated solvents indicates that sediments may be impacted by wastewater treatment plant or industrial effluents. Cadmium was also enriched at Station 26 relative to the mean Puget Sound composition of fine-grained sediments. PAH were not detected at Station 25.

Sediment characteristics at Station 26, a deepwater Central Basin station, were similar to those at Station 3, a deepwater station in the Strait of Georgia. Cadmium enrichment, moderate beta-coprostanol concentrations, and volatile organic compounds were found at both stations. The low percent fines content (with moderate contaminant concentrations) at these stations suggests that water current speeds are high at both stations, and that the overlying water column contains moderately contaminated solids. Concentrations of beta-coprostanol and volatile organic compounds at Station 3 were slightly higher than concentrations at Station 26, which suggests that materials typically associated with municipal wastewater treatment plant effluents may impact Station 3 more than Station 26.

In the Central Basin region, Stations 29 (Shilshole), 30 (Eagle Harbor), 31 (West Point), 32 (Magnolia Bluff), 33 (Elliott Bay), 34 (Sinclair Inlet), and 35 (Dyes Inlet) exhibited similar sediment characteristics. Those stations exhibited moderate concentrations of beta-coprostanol and enrichments of lead and silver relative to the mean Puget Sound lead concentrations in fine-grained sediments. PCBs were also detected in sediments at each station, and HPAH and LPAH concentrations exceeded Puget

Sound maximum reference values. At Station 29, high concentrations of volatile organic compounds were found, and at Station 34, concentrations of butylbenzyl phthalate exceeded the Puget Sound maximum reference value. The only organochlorine pesticides (i.e., DDD, alpha-chlordane) that were detected in the MSMT were both found at Station 33, and the only detected value for pentachlorophenol was reported at Station 32.

At Stations 33, 34, and 35, cadmium, copper, mercury, and zinc were also enriched. The highest concentrations of arsenic, copper, lead, mercury, silver, and zinc were found at Station 34 in Sinclair Inlet. The mercury concentrations of 0.86 mg/kg DW at Station 34 and 0.51 mg/kg DW at Station 35 are the only metal concentrations in the MSMT survey that exceeded LAET values.

Chemical concentrations at Stations 36 (Brace Point) and 37 (North Vashon Island) were lower than at other MSMT stations. Concentrations of HPAH, LPAH, and beta-coprostanol were higher at Station 36 than at Station 37.

Station 38, located mid-channel in East Passage at 195 m, exhibited a high concentration of beta-coprostanol and enrichments of lead and silver. PCBs were detected at this station, and both HPAH and LPAH concentrations exceeded the Puget Sound maximum reference values. Station 38 appears to be a deepwater Central Basin station that is impacted by urban runoff and discharges.

Chemical concentrations at Stations 39 (Dash Point) and 42 (Ruston) were not generally distinctive. PAH were not detected at Station 39. At Station 42, the enrichments of arsenic, cobalt, copper, lead, and zinc that were found may be related to the former activities conducted at the Asarco smelter.

In Commencement Bay, sediments at Stations 40 (City Waterway) and 41 (Blair/Sitcum Waterways) appeared to be im ed by anthropogenic activities. The highest concentration of LPAH repor n the MSMT was found at Sta-

tion 40. High concentrations of 9(H)-carbazole were also found at Station 40, and TOC, silver, copper, and lead were enriched. Puget Sound maximum reference values were exceeded for 2-methylnaphthalene and butylbenzyl phthalate at Station 40, and for phenol at Station 41. The high concentrations of organic contaminants, wood chips, gravel, and low fines content at this station suggest that high flows containing organic contaminants and metals probably occurs during episodic events when stormwater flows occur in the area. The depressed metal concentrations found at Station 41 could not be easily explained. The source of high concentrations of beta-coprostanol at Stations 40 and 41 may be the Tacoma wastewater treatment effluent.

In South Sound, sediment characteristics were similar at Stations 43 (Carr Inlet), 44 (East Anderson Island), 45 (Devil's Head), 46 (West Nisqually Delta), 47 (Case Inlet), and 50 (Shelton). Beta-coprostanol, PCBs, and volatile organic compounds were undetected or detected at low concentrations. PAH were not detected at Stations 43 and 50, but were detected at the other stations. Low concentrations of phenol and halogenated extractable organic compounds were found at Station 44.

In Budd Inlet, sediment characteristics at Stations 48 and 49 were typical of urban environments. Elevated beta-coprostanol concentrations suggest that municipal wastewater discharges impact sediments in the inlet, and elevated PAH concentrations indicate effects from urban discharges. At both stations, PCBs were detected, and cadmium, lead, and silver enrichments were observed. The highest concentrations of cadmium were found at Station 49, and cadmium concentrations found in Budd Inlet were consistent with concentrations reported in historical studies.

SEDIMENT TOXICITY BIOASSAYS

Quality Assurance/Quality Control

Data validation of amphipod and Microtox bioassay data were performed in accordance with Puget Sound protocols (Tetra Tech 1986b) and the *Marine Sediment Quality Implementation Plan* (Striplin 1988). QA memoranda, which are provided in Appendix B, are summarized below.

Amphipod Bioassay--

Bioassay data were considered acceptable with the following qualification for data from Station 28. Low interstitial salinity (25 ppt) was measured in Station 28, although it was within the acceptable range for toxicity testing. However, Station 28 bioassay data were considered estimates because fresh water may have entered the sample container during transport from the field to the laboratory, and porewater dilution may result in underestimation of sediment toxicity.

The data generated in the reference toxicant bioassays were acceptable, but were qualified as estimates because a negative control was not conducted with the reference toxicant bioassay tests, and because only 10 amphipods were exposed to each concentration of the reference toxicant. According to the Puget Sound protocols (Tetra Tech and E.V.S. 1986), a minimum of 20 organisms should be exposed to each toxicant concentration, and a negative control, which consists of exposure of amphipods to seawater that does not contain the reference toxicant, should be conducted (see amphipod bioassay QA memorandum in Appendix B). Nevertheless, the reference toxicant bioassays showed a dose-response relationship which resulted in EC_{50} values that agreed with those generated by the testing laboratory in past Puget Sound studies.

Microtox Bioassay--

The Microtox data for test sediments were considered acceptable without qualification. The reference toxicant (i.e., positive control) bioassays gave acceptable EC_{50} values as compared with Williams et al. (1986) and Beckman (1981), except for a single sodium arsenate bioassay performed on 29 March 1989. For that bioassay, sediment supernatant blanks were not appropriately calculated, which resulted in inaccurate determination of luminescence values. Although this discrepancy was correctable, it was not considered worthwhile because it was only a single anomaly among many reference toxicant tests that were conducted. Each of the other reference toxicant bioassays indicated that the bacterial response was within the tolerances established for this method. Consequently, the overall quality

and interpretation of the sediment toxicity tests were not affected by the results of the sodium arsenate reference toxicant test that was conducted on 29 March 1989.

Results

Results of sediment toxicity tests using the amphipod *Rhepoxynius abronius* and the Microtox bacterium *Photobacterium phosphoreum* are presented in this section. First, the results of the amphipod bioassay are presented and discussed. Both mortality and emergence behavior of the amphipod are measured as indicators of sediment toxicity. Because the amphipod *Rhepoxynius abronius* normally burrows into sediments, the frequency of emergence from sediments provides an indication of potential subtle and irritating toxic effects that can occur well in advance of grosser toxic symptoms such as mortality. Second, the results of the Microtox bioassay are presented and discussed. The Microtox bioassay measures changes in luminescence, which is a sensitive indicator of cellular processes that govern respiration, and which are susceptible to chemical toxicity. Finally, the possible relationship between observed sediment chemical toxicity and sediment contaminant concentrations is discussed.

Amphipod Bioassays--

Amphipod mortality and amphipod emergence results for each station are presented and compared statistically with results for the control area (i.e., native sediments from West Beach, Whidbey Island). Further evaluation of the amphipod bioassay data is then provided by comparisons with sediment quality guidelines (Mearns et al. 1986; DeWitt et al. 1988; U.S. Army Corps of Engineers et al. 1989) established for the amphipod bioassay, and by comparisons with results for similar or identical stations from past studies. These additional comparisons are needed to distinguish between amphipod mortality that can be attributed to chemical toxicity and amphipod mortality that can be explained by other factors that are not directly related to chemical toxicity.

Mortality--The mean and range of amphipod mortality for all stations is shown in Table 22. Mean amphipod mortality for the West Beach control sediments was 0.7 percent, and ranged from 0-10 percent. Amphipod mortality for all MSMT stations ranged from <1 percent at a number of sites to 44 percent at Station 35 in Dyes Inlet. Elevations of amphipod mortality values above reference (i.e., West Beach control) values are also presented in Table 22. These EAR values ranged from 0 for several of MSMT stations to 66 for Station 35 in Dyes Inlet.

Amphipod mortality at the following four stations was significantly ($P<0.001$) different than the control (West Beach) values:

- Station 6 (East of Anacortes) -- 13 percent mortality
- Station 11 (Discovery Bay) -- 14 percent mortality
- Station 14 (North Hood Canal) -- 13 percent mortality
- Station 35 (Dyes Inlet) -- 44 percent mortality.

Although mean amphipod mortality exceeded 20 percent at Stations 20 (27 percent), 24 (38 percent), and 38 (24 percent), none of these stations were significantly ($P>0.001$) different from the control primarily because of the high degree of variability among individual replicates. Individual replicates at these stations included at least one value of zero percent mortality and one or two values that were greater than 50 percent mortality. For example, at Station 24 the mean mortality was 38 percent and the range of mortality in the analytical replicates was 0-80 percent. Although a wide variety of factors (e.g., sediment contaminant heterogeneity) may contribute to the variability observed for these samples, none could be identified from review of the testing laboratory procedures nor from review of replicate sediment chemistry data. Variability in the results of replicate amphipod bioassay tests has been found in past Puget Sound studies.

TABLE 22. RESULTS OF AMPHIPOD BIOASSAY ANALYSES

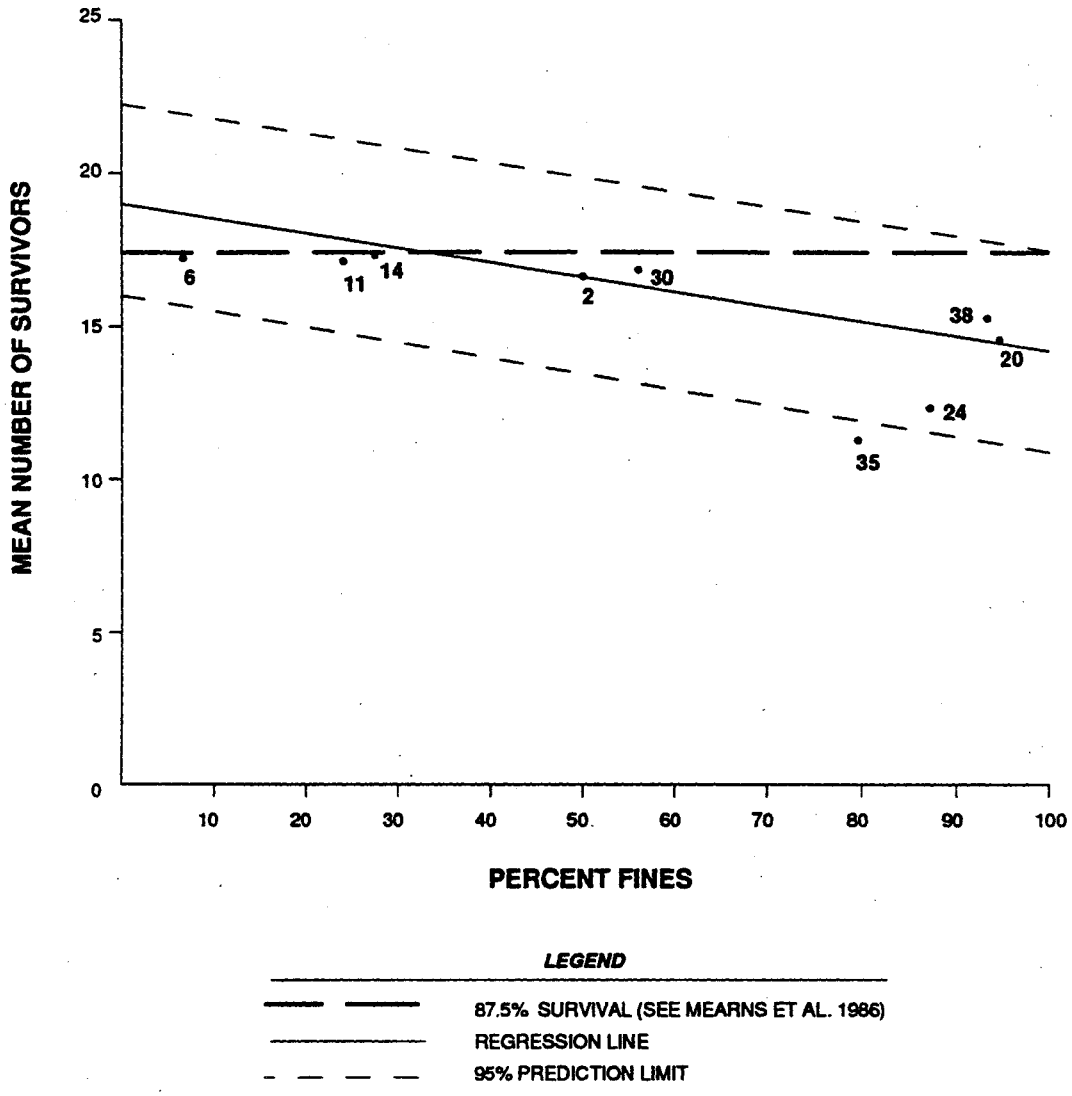
Station	Location	Range of Mortality (Percent)	Mean Mortality (Percent)	EAR[a]	Mean Emergence (Percent)	EAR
1	Semiahmoo Bay	0-5	3	4.5	0	0
2	Cherry Point	0-25	17	25.5	0	0
3	Strait of Georgia	0-30	12	18.0	1.4	1.4
4	Bellingham Bay	0-20	5	7.5	0	0
5	Samish Bay	0-5	4	6.0	1.0	1.0
6	Anacortes	5-20	13	19.5	0	0
7	Strait of Juan de Fuca	0-15	9	13.5	1.0	1.0
8	Port Angeles Harbor	0-15	10	15.0	0.6	0.6
9	Green Point	0-0	0	0	0	0
10	Dungeness Spit	0-15	8	12.0	0.4	0.4
11	Discovery Bay	10-20	14	21.0	0.1	0.1
12	Port Townsend	0-15	7	10.5	0.1	0.1
13	North Hood Canal	0-15	7	10.5	0	0
14	North Hood Canal	5-30	13	19.5	0	0
15	Dabob Bay	0-15	8	12.0	0.7	0.7
16	South Hood Canal	0-0	0	0	0	0
17	South Hood Canal	0-10	3	4.5	0	0
18	Oak Harbor	0-5	2	3.0	0	0
19	Saratoga Passage	0-10	5	7.5	0.4	0.4
20	Port Susan	0-85	27	40.5	0.3	0.3
21	Port Gardner	0-15	6	9.0	2.2	2.2
22	Mukilteo	0-5	2	3.0	0.2	0.2
23	East Central Basin	0-10	3	4.5	0	0
24	East Central Basin	0-80	38	57.0	0.4	0.4
25	West Central Basin	0-10	4	6.0	0	0
26	West Central Basin	0-20	8	12.0	0	0
27	Richmond Beach	0-10	3	4.5	0	0
28	Jefferson Head	0-10	5	7.5	0	0
29	Shilshole	0-20	8	12.0	0	0
30	Eagle Harbor	0-50	16	24.0	8.9	8.9
31	West Point	0-15	6	9.0	1.0	1.0
32	Magnolia Bluff	0-10	2	3.0	0	0
33	Elliott Bay	0-10	8	12.0	3.3	3.3
34	Sinclair Inlet	0-20	11	16.5	0	0
35	Dyes Inlet	10-90	44	66.0	0	0
36	Brace Point	0-10	4	6.0	0	0
37	North Vashon Island	0-0	0	0	0	0
38	Point Pully	0-65	24	36.0	0	0
39	Dash Point	0-5	2	3.0	0	0
40	City Waterway	0-10	6	9.0	0	0
41	Blair/Sitcum Waterways	0-10	7	10.5	0	0
42	Ruston	0-5	2	3.0	0	0
43	Carr Inlet	0-10	2	3.0	0.3	0.3
44	East Anderson Island	0-15	10	15.0	0	0
45	Devil's Head	0-10	6	9.0	1.0	1.0
46	West Nisqually Delta	0-10	3	4.5	0	0
47	Case Inlet	0-5	2	3.0	1.0	1.0
48	North Budd Inlet	0-10	4	6.0	0	0
49	South Budd Inlet	0-15	5	7.5	0.1	0.1
50	Shelton	0-10	4	6.0	0	0
CONTROL		0-5	0	1.0	0	0

[a] EAR = Elevation above reference (control).

Comparisons with Guidelines--Based on guidelines presented by Mearns et al. (1986), sediments at MSMT stations may be considered nontoxic (i.e., ≤12.5 percent mortality) at 41 stations, marginally toxic (i.e., 12.5 to <24.5 percent mortality) at 6 stations, and clearly toxic (i.e., ≥24.5 percent mortality) at 3 stations (see Table 22). The nine stations considered marginally toxic or clearly toxic by Mearns et al. (1986) guidelines are located in both the shallow waters of urban and nonurban bays and the deeper waters of the Central Basin and Hood Canal (Figure 18).

Results of the Mearns et al. (1986) classification of sediment toxicity were further evaluated by considering the potential effects of sediment grain size on amphipod mortality. DeWitt et al. (1988) demonstrated that elevated mortality in the amphipod bioassay can result solely from exposure of the organisms to fine-grained sediments. That relationship was summarized by linear regression of amphipod survival on the percent fines fraction of reference sediments (Figure 19). According to that relationship, if the mean number of survivors observed for a test sediment is less than the lower 95 percent prediction limit calculated for the regression relationship, then the observed mortality is probably due to factors other than percent fines (i.e., a contaminant effect would be indicated). The nine MSMT stations considered marginally toxic or clearly toxic by Mearns et al. (1986) guidelines were plotted on the DeWitt et al. (1988) model in Figure 19. Using the lower 95 percent prediction limit of the DeWitt et al. (1988) model, amphipod mortalities at only one station (Station 35; Dyes Inlet) can be attributed to non-grain size effects. It should be noted that the DeWitt et al. (1988) model allows for accepting relatively high amphipod mortality in fine-grained sediments as "no hit." This approach does not imply that sediments whose contamination falls within the predicted range are uncontaminated.

Additional comparisons were made with the PSDDA Phase II guidelines for the evaluation of dredged materials (U.S. Army Corps of Engineers et al. 1989). According to these guidelines, decisions concerning disposal of dredged material may be made on the basis of biological tests, which include



Note: Figure based on model of DeWitt et al. (1988).

Figure 19. Amphipod survival vs. percent fine-grained material in sediments at nine stations.

amphipod sediment toxicity tests. For the amphipod bioassay, the single-test criteria for determining suitability of dredged material for disposal are as follows:

- The mean bioassay response must be statistically significant in comparison with the control

- The mean bioassay response must exceed that for the control by 20 percent (e.g., a control value of 5 percent mortality would result in a criterion value of 25 percent mortality)

- The mean bioassay response must exceed that for the reference location by 30 percent for disposal at a non-dispersive site or by 10 percent for disposal at dispersive site (e.g., a reference value of 12 percent mortality would result in a criterion value of 42 percent for non-dispersive disposal or a criterion value of 22 percent for dispersive disposal).

If each of these conditions are met, sediments at the proposed dredging site may not be suitable for disposal because of their toxicological characteristics. Based on results of the MSMT amphipod bioassays, Station 35 in Dyes Inlet is the only station where sediments would not be suitable for dredged material disposal at either dispersive or non-dispersive sites. Hence, application of the PSDDA decision-making framework for identification of areas of concern is consistent with the evaluation based on grain-size effects as described above.

Comparison of Mortality Results with Historical Data--Historical amphipod bioassay mortality data are available for four of the nine MSMT stations that exhibited >12.5 percent mortality. Comparative data for stations in Port Susan (Station 20), Eagle Harbor (Station 30), Dyes Inlet (Station 35), and the Central Basin (Station 38) are shown in Figure 20. Data indicate that sediment toxicity measured at stations in 1989 is equal to or greater than toxicity measured in previous years. However, meaningful interpretation of these differences is precluded by the wide ranges of

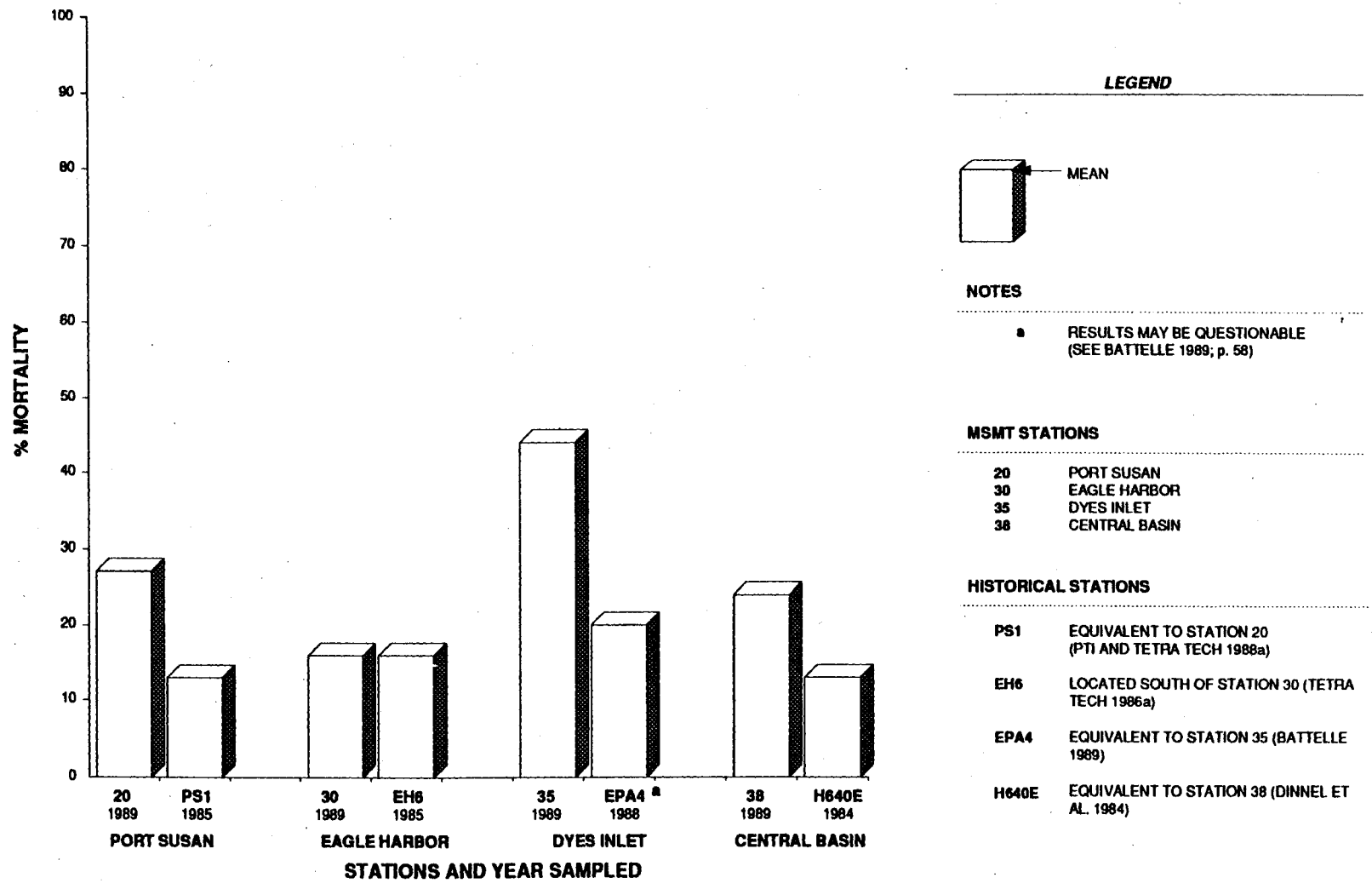


Figure 20. Comparison of mean amphipod bioassay responses at selected MSMT stations with historical data from past studies at the same stations.

mortality observed in the 1989 analytical laboratory replicates. The mean amphipod mortality (27 percent) found in Port Susan in 1989 is twice the value found at that precise location in 1986, but is similar to mortality (29 percent) found at a different station sampled in Port Susan in 1986 (PTI and Tetra Tech 1988b).

Emergence Behavior--The effect of sediments on amphipod behavior was assessed by monitoring amphipod emergence from the sediments during the 10-day mortality bioassay. Amphipod emergence results are provided in Table 22. For the 50 samples, mean amphipod emergence ranged from 0 to 8.9 percent, with maximum emergence value occurring in sediments from Station 30. Emergence in sediments from the West Beach control was 0 percent. No significant ($P>0.001$) differences were observed between emergence data at monitoring and control (i.e., West Beach) stations.

Microtox Bioassays--

Changes in bacterial luminescence as measured in the Microtox bioassay are presented and discussed qualitatively. Discussion of the Microtox results is limited to qualitative aspects of the data because none of the test sediments indicated toxic effects as measured by this method.

Results of the Microtox saline extract bioassay are presented in Table E-1 of Appendix E. There was no observable toxicity (i.e., significant decrease in luminescence) to the Microtox bacterium in any of the samples. Sediments were tested at a concentration of 50 percent sediment extract, which is the maximum concentration tested under the Puget Sound protocol (Tetra Tech 1986b). In general, bacterial luminescence increased slightly with increasing concentrations of sediment extract. Increased bacterial luminescence has been observed previously in the Microtox bioassay using nontoxic extracts (Beckman 1982), and is most likely due to slight stimulatory effects of unknown sediment components on the bacteria.

Microtox bioassay analyses have been conducted as part of other studies in Puget Sound. Results of those studies show that no observable

toxicity in Microtox samples is not unusual in Puget Sound samples. During the baseline survey of Phase I disposal sites for the Puget Sound Dredged Disposal Analysis program (PTI 1988a), the Microtox bioassay revealed no effect for any of the samples (n = 16) that were collected at stations in Commencement Bay, Elliott Bay, Port Gardner, Carr Inlet, Port Susan, and West Beach.

Relationship Between Bioassay Results and Contaminant Concentrations--

Potential relationships between sediment toxicity and sediment chemical concentrations were examined. Amphipod bioassay results indicated that sediments were toxic at Station 35. Although sediment chemical concentrations found at Station 35 did not exceed LAET values, concentrations of semivolatile organic compounds and certain metals (e.g., copper, lead, and zinc) at Station 35 were higher than concentrations found at other MSMT stations (see Figure 26, RESULTS, Identification of Potential Reference Stations).

Sediment characteristics at Station 35 (Dyes Inlet) were compared to those at Station 34 (Sinclair Inlet) to evaluate factors that may have been responsible for toxicity at Station 35. Stations 35 and 34 are located at similar depths in the same geographic area of Puget Sound, and sediments at both stations exhibited similar fines and TOC content. Moreover, the chemicals and concentrations present were similar at Stations 35 and 34, except that PAH concentrations were much higher at Station 35. The LPAH concentration at Station 34 was 131 ug/kg and that at Station 35 was 348 ug/kg. The HPAH concentration at Station 34 was 1,146 ug/kg and that at Station 35 was 3,118 ug/kg. These results suggest a relationship between PAH concentrations and sediment toxicity at Station 35 in Dyes Inlet. HPAH concentrations at Station 30 in Eagle Harbor (3,780 ug/kg) and Station 40 in City Waterway (11,540 ug/kg) were higher than HPAH concentrations in Dyes Inlet, but elevated amphipod mortality was not observed at those stations. Synergistic effects of contaminants on amphipod mortality have not been thoroughly studied, and may be responsible for the mortality observed at Station 35. Mortality may also have resulted from chemicals that were

present in sediments but for which analyses were not conducted in the 1989 MSMT (e.g., contemporary pesticides, ordnance compounds).

For the nine stations where mean amphipod mortalities exceeded 12.5 percent (see Figure 18), sediment chemical concentrations exceeded LAET values only at Station 35 for mercury. Although sediment chemical concentrations were less than the corresponding LAET values, semivolatile organic compound concentrations were higher at Station 30 than at other MSMT stations, and metal concentrations at Stations 20, 24, and 38 were higher than those at other MSMT stations (see RESULTS, Sediment Chemistry). However, based on studies conducted by DeWitt et al. (1988), mortality observed at these stations could be explained by fine-grained particles in the sediments. DeWitt et al. (1988) demonstrated that elevated mortality in the amphipod bioassay can result solely from exposure of the organisms to fine-grained sediments. Using the lower 95 percent prediction limit of the DeWitt et al. (1988) model, amphipod mortalities at only one station (Station 35; Dyes Inlet) can be definitely ascribed to non-grain size effects.

BENTHIC COMMUNITY STRUCTURE

Benthic community structure at the 50 MSMT stations is discussed in this section. Because most MSMT stations are located in relatively unimpacted areas of Puget Sound, the benthic infauna data are suitable for investigations of natural, abiotic factors that regulate benthic community structure. Although many other benthic investigators have discussed the effects of natural variables on benthic community structure in Puget Sound (e.g., Lie 1968; Nichols 1985; Word et al. 1984; PTI and Tetra Tech 1988a,b; Parametrix 1989), the MSMT data provide a greater range of geographic areas and sediment characteristics over which these effects can be investigated.

Quality Assurance/Quality Control

QA/QC procedures resulted in an acceptable data set without qualification. However, Mollusca data were missing for Stations 11 (Replicate 1),

30 (Replicate 5), and 35 (Replicate 3) because the sample vials were broken. Therefore, Stations 11, 30, and 35 include mollusca data from two rather than three replicates.

Results

The following discussion is organized into several major topics. First, descriptive statistics and indices that represent benthic community structure are discussed relative to various geographic areas and station water depths. Data for individual taxa are then used to characterize groups of similar stations, and abiotic variables that may influence the formation of those station groups are described. Third, numerically dominant taxa are discussed. Fourth, differences between benthic communities at potential reference and nonreference MSMT stations are described. Finally, data collected at Stations 29 and 38 are compared to historical data (Nichols 1985, 1988) collected at the same stations.

All reported abundance and richness (i.e., number of taxa) values were averaged using data from three field replicates at each station in order to express a single mean value for those variables. The mean abundance was then multiplied by a factor of 10 to report the number of individuals per 1.0 m^2. This approach allows for comparison of MSMT data with most other Puget Sound investigations (e.g., PTI and Tetra Tech 1988 a,b; Word et al. 1984). Mean richness values were not converted to 1.0 m^2 because one cannot estimate the number of new taxa that could occur in an area greater than that which was sampled.

Benthic data are presented by station and replicate in Appendix F. The complete benthic species list for 1989 is provided in Table F-5 in Appendix F.

Characteristics of Benthic Communities--

A total of 69,962 benthic organisms belonging to 598 taxa were identified at the 50 stations (three field replicates per station). Mean total

abundance at stations in Puget Sound ranged from 467 individuals/m^2 at Station 19 (Saratoga Passage) to 20,403 individuals/m^2 at Station 41 (Blair/Sitcum Waterways). The mean number of taxa at stations ranged from 21.7 taxa/0.1 m^2 at Station 19 to 98.7 taxa/0.1 m^2 at Station 37 (north Vashon Island). The following abiotic variables may have been responsible for this wide range of total abundances and numbers of taxa: sediment grain size, sediment organic carbon content, water depth, water currents, and proximity of stations to urban embayments and to freshwater sources.

Descriptive Indices--Total abundances and numbers of taxa were summarized, and benthic indices were calculated on pooled species-level data. Index values were determined for Shannon-Weiner diversity (H'), Swartz's dominance index (SDI), evenness (J), dominance (1-J), and the Infaunal Trophic Index (ITI) (see METHODS, Benthic Community Structure). Results are listed by station and by geographic area in Table 23. Values of the Shannon-Weiner diversity index ranged between 0.627 and 1.599, while those for Swartz's dominance ranged between 1.954 and 24.583. Evenness and dominance had low values of 0.395 and 0.082, respectively, and high values of 0.918 and 0.605, respectively. Finally, the ITI ranged from 60.48 to 89.88. Taxa included in calculation of ITI values are shown in Table 24.

Each of these indices should be interpreted cautiously. It is most appropriate to interpret the values at a single station relative to the range of values reported within the data set. For example, it is useful to identify that the benthic community is more diverse at Station A than at Station B. It may also be useful to monitor the change in diversity or dominance (1-J) values at Station A over time. However, because temporal trends in benthic index values at a station may be affected by any number of environmental occurrences (e.g., seasonality, predation, storm conditions), it is inadvisable to use temporal changes in benthic indices to determine whether a stressed benthic community exists at a station.

Swartz's dominance index values are simple to interpret because those values are equal to the number of taxa that account for 75 percent of the total abundance at a station. High SDI values indicate a community with few

TABLE 23. VALUES OF BENTHIC INFAUNA VARIABLES AT STATIONS WITHIN THE MAJOR GEOGRAPHIC AREAS OF PUGET SOUND

Geographic Area	Station		Total Abundance (per 1.0 m^2)	Number of Taxa (per 0.1 m^2)	Shannon-Weiner Diversity (H')	Swartz's Dominance (SDI)	Evenness (J)	Dominance (1-J)	Infaunal Trophic Index
Strait of Georgia	1		4,193	29.0	1.104	6.864	0.757	0.243	80.86
	2		4,060	58.7	1.320	12.390	0.753	0.247	73.85
	3		2,540	27.0	0.960	5.197	0.674	0.326	68.30
	4		3,037	46.7	1.338	13.177	0.802	0.198	71.04
	5		2,300	37.7	1.242	9.452	0.789	0.211	73.40
	6		2,850	50.3	1.432	15.708	0.844	0.156	60.48
		Mean	**3,163**	**41.6**	**1.233**	**10.465**	**0.770**	**0.230**	**71.32**
		SD[a]	789	12.5	0.173	4.007	0.058	0.058	6.76
Strait of Juan de Fuca, Discovery Bay, Port Townsend	7		4,090	60.7	1.022	9.722	0.574	0.426	70.81
	8		3,880	66.3	1.460	15.800	0.803	0.197	80.41
	9		4,820	50.7	1.143	7.038	0.671	0.329	89.13
	10		6,460	67.0	1.232	9.141	0.676	0.324	85.11
	11		9,810	91.0	1.341	12.703	0.685	0.315	89.88
	12		3,500	45.7	1.226	9.928	0.739	0.261	80.43
		Mean	**5,427**	**63.6**	**1.237**	**10.722**	**0.691**	**0.309**	**82.63**
		SD[a]	2,389	15.9	0.152	3.079	0.076	0.076	7.08
Hood Canal	13		15,580	71.3	0.801	3.257	0.433	0.567	67.06
	14		2,573	56.7	1.294	12.708	0.738	0.262	64.59
	15		4,380	84.7	1.599	24.583	0.830	0.170	69.01
	16		2,447	59.0	1.552	20.590	0.877	0.123	70.67
	17		1,310	22.0	0.887	4.800	0.659	0.341	66.93
		Mean	**5,258**	**58.7**	**1.227**	**13.188**	**0.707**	**0.293**	**67.65**
		SD[a]	5,874	23.4	0.369	9.405	0.175	0.175	2.30
Oak Harbor, Saratoga Passage, Port Susan, Port Gardner	18		3,673	34.0	1.001	6.019	0.659	0.341	66.21
	19		467	21.7	1.226	10.417	0.918	0.082	73.29
	20		4,433	39.3	1.187	7.366	0.746	0.254	76.57
	21		9,580	54.0	1.012	3.940	0.584	0.416	61.15
	22		3,067	37.3	1.038	4.627	0.661	0.339	68.24
		Mean	**4,244**	**37.3**	**1.093**	**6.474**	**0.714**	**0.286**	**69.09**
		SD[a]	3,335	11.6	0.106	2.568	0.128	0.128	6.03

TABLE 23. (Continued)

Geographic Area	Station		Total Abundance (per 1.0 m^2)	Number of Taxa (per 0.1 m^2)	Shannon-Weiner Diversity (H')	Swartz's Dominance (SDI)	Evenness (J)	Dominance (1-J)	Infaunal Trophic Index
Central Basin	23		4,590	58.7	1.245	9.222	0.704	0.296	72.08
	24		1,080	40.0	1.462	17.625	0.913	0.087	74.62
	25		3,247	41.3	1.028	5.114	0.637	0.363	70.38
	26		3,673	66.3	1.463	17.303	0.804	0.196	65.46
	27		6,243	91.3	1.335	17.972	0.681	0.319	74.51
	28		5,817	93.0	1.402	18.654	0.712	0.288	85.85
	29		1,547	35.0	1.158	9.014	0.757	0.243	62.47
	30		7,093	46.0	0.889	3.886	0.536	0.464	67.02
	31		4,047	82.0	1.519	22.683	0.794	0.206	76.80
	32		7,103	96.0	1.355	15.147	0.683	0.317	85.08
	33		6,397	66.3	1.261	9.639	0.692	0.308	66.96
	34		4,897	48.0	1.225	8.252	0.729	0.271	72.49
	35		6,453	38.0	1.000	5.449	0.633	0.367	81.54
	36		4,067	56.7	1.282	11.944	0.732	0.268	66.82
	37		5,337	98.7	1.504	23.950	0.754	0.246	82.11
	38		1,280	26.3	1.113	7.213	0.785	0.215	70.83
	39		2,487	42.3	1.191	8.327	0.734	0.266	67.77
	40		6,543	51.7	1.132	7.407	0.662	0.338	67.28
	41		20,403	39.0	0.627	1.954	0.395	0.605	66.92
	42		890	31.3	1.152	11.083	0.773	0.227	76.37
		Mean	**5,160**	**57.4**	**1.217**	**11.592**	**0.706**	**0.294**	**72.67**
		SD[a]	4,139	23.3	0.222	6.303	0.107	0.107	6.81
South Sound	43		5,423	51.3	1.219	8.836	0.714	0.286	82.85
	44		4,663	83.7	1.488	19.846	0.781	0.219	78.13
	45		2,967	50.0	1.179	9.380	0.694	0.306	70.59
	46		4,297	67.0	1.486	17.641	0.816	0.184	76.81
	47		4,507	67.0	1.403	15.954	0.770	0.230	80.27
	48		2,853	29.7	0.859	3.684	0.583	0.417	64.55
	49		1,357	22.0	1.044	6.381	0.778	0.222	68.87
	50		4,907	58.0	1.419	13.060	0.805	0.195	68.30
		Mean	**3,872**	**53.6**	**1.262**	**11.848**	**0.743**	**0.257**	**73.80**
		SD[a]	1,356	20.3	0.228	5.702	0.077	0.077	6.57
	All	Mean	**4,664**	**53.7**	**1.217**	**11.041**	**0.718**	**0.282**	**73.02**
		SD[a]	3,447	20.8	0.214	5.771	0.103	0.103	7.33

[a] SD = Standard deviation.

TABLE 24. FOUR CATEGORIES OF INFAUNAL TROPHIC INDEX FEEDING STRATEGIES[a]

Group I - Suspended Detrital Feeders

Passive	Normal	Active
Ampharetidae	*Ampelisca* sp. I	*Ampelisca* sp. II
Maldanidae	*Amphiodia* sp.	*Byblis* sp.
Onuphidae	*Amphipholis* sp.	*Crenella* sp.
Phyllochaetopterus spp.	Caprellida	*Cucumaria* sp.
Terebellidae	*Owenia* sp.	*Nemocardium* sp.
	Phoronis sp.	Phoxocephalidae
	Sabellidae	*Sthenelanella* sp.
	Serpulidae	

Group II - Surface Detritus Feeders

Stationary	Mobile	Specialized
Axinopsida sp.	Cumacea	*Pectinaria californiensis*
Calyptogena sp.	*Decamastus* sp.	
Cirratulidae	*Euphilomedes* sp.	
Magelonidae	*Glycera* sp.	
Myriochele sp.	*Goniada* sp.	
Mysella sp.	Lumbrineridae	
Photis sp.	*Mediomastus* sp.	
Psephedia sp.	*Nephtys* sp.	
Spionidae	Orbiniidae	
	Tanaid	

Group III - Surface Deposit Feeders

Stationary	Mobile
Macoma carlottensis	*Bittium* sp.
Nucula sp.	*Mitrella permodesta*
Nuculana sp.	*Nassarius* sp.
Parvilucina tenuisculpta	*Nereis* sp.
Yoldia sp.	*Travisia* sp.

Group IV - Subsurface Deposit Feeders

Armandia bioculata	*Ophelina acuminata*
Capitella capitata	*Solemya* sp.
Dorvilleidae	Stenothoidae
Oligochaeta	

[a] Reference: Word (1982) and Word (15 October 1989, personal communication).

numerically dominant taxa, whereas low values suggest a community composed of a few relatively abundant taxa. Because stressed benthic communities tend to be dominated by one or two opportunistic taxa, they generally have very low SDI values.

ITI values for benthic communities in Puget Sound are difficult to interpret. There are no existing data sets, for which ITI values were calculated, that include both severely impacted and unimpacted sites. That kind of data set is needed to understand the range of ITI values obtained in this study. Although Bascom et al. (1978) defined normal, changed, and degraded benthic communities based on ITI values in southern California, those definitions are not applied herein because of the differences in oceanographic properties between Puget Sound and southern California. In general, Bascom et al. (1978) showed that lower ITI values corresponded to changed or degraded benthic communities. The ITI was included in the MSMT analysis because it represents a functional measure of the benthic community (trophic structure). It will provide data for temporal trend analysis in future MSMT surveys.

Station 19 (Saratoga Passage) was characterized by the lowest total abundance, lowest number of taxa, highest evenness, and lowest dominance. The scores of these indices suggest the presence of a homogeneous sedimentary environment at Station 19 in which few species exist. Station 41 (Blair/ Sitcum Waterways) had the highest total abundance and a substantially lower number of taxa compared to all other stations. This station also had the lowest diversity, lowest SDI, lowest evenness, and highest dominance, indicating the presence of an impacted benthic community. Station 37 (north Vashon Island) contained the greatest number of taxa, while Station 15 (Dabob Bay) exhibited the greatest diversity and greatest SDI. Both of these stations are likely located in heterogeneous sedimentary environments that support a large variety of taxa.

Although stressed or impacted marine benthic communities are rarely identified using benthic indices, Poole (1974) noted that in general, H' values that fall between 0 and 2 typically indicate a stressed benthic

community while those greater than 3 indicate a well-balanced community. The highest H' in this survey was 1.599 at Station 15 (Dabob Bay). The low H' values observed throughout the MSMT data may occur because MSMT benthic samples were collected prior to annual recruitment (i.e., when the numbers of taxa and abundances are presumed to be the lowest).

The ITI (Word 1978, 1980, 1982) was also calculated for each station and summarized by geographic area (Table 23). The ITI was lowest at Station 6 (60.5; Anacortes) and highest at Station 11 (89.9; Discovery Bay). Although decreasing ITI scores suggest a degraded benthic community, there is insufficient information to determine whether values in the low 60s are indicative of benthic degradation.

Geographic Variability in Benthic Indices--Geographic variability in benthic community structure was assessed by statistically comparing mean values of benthic indices for stations in different geographic areas of Puget Sound (see Table 23). Analysis of variance indicated that benthic indices values did not differ statistically ($P<0.05$) among geographic areas. As shown in Table 23, similar ranges of benthic indices occurred in each geographic area, which suggests similar ranges of habitats (i.e., sediment grain size, total organic carbon, water depth) for stations located within each geographic area. In addition, statistical analyses showed that within-station variability (using three field replicates) was high, so the ability to discern significant differences among stations (and thus geographic areas) for the 1989 MSMT was limited. If data were available from five field replicates, within-station variability may have been lower, and it may have been possible to discern significant differences among geographic areas.

Although statistically significant differences were not observed, general trends among geographic areas were apparent. The greatest mean total abundance and number of taxa were found in the Strait of Juan de Fuca, including Discovery Bay and Port Townsend (5,427 individuals/m^2 and 63.6 taxa/0.1 m^2, respectively). This area also exhibited the lowest evenness and highest dominance. South Sound had the lowest mean abundance (3,872 individuals/m^2) but the highest mean diversity (1.262). Oak Harbor,

Saratoga Passage, Port Susan, and Port Gardner collectively had the lowest number of taxa (37.3 taxa/0.1 m^2), lowest diversity (1.093), and lowest SDI (6.474). Stations in Hood Canal possessed the highest SDI (13.188), while stations in the Strait of Georgia possessed the highest evenness (0.770) and lowest dominance (0.230).

Geographic variability in benthic community structure was further examined at stations located at water depths between 6-24 m (Table 25). Among these shallow stations, the Hood Canal stations contained the lowest fines and total organic carbon contents (7.3 and 0.20 percent, respectively), and greatest abundance (2,490 individuals/m^2), number of taxa (71.7 taxa/0.1 m^2), and diversity (1.32). This suggests that these shallow stations in Hood Canal are heterogeneous sandy environments that support enriched benthic communities. Stations in the Strait of Georgia contained the greatest percent fines (67.9 percent) and lowest abundance (1,095 individuals/m^2). Stations in the Strait of Juan de Fuca, Discovery Bay, and Port Townsend contained the highest total organic carbon content (1.34 percent), while stations in Oak Harbor, Saratoga Passage, Port Susan, and Port Gardner had the lowest number of taxa and diversity (41.2 taxa/0.1 m^2 and 1.06, respectively). The ITI was highest in the Strait of Juan de Fuca/Discovery Bay/Port Townsend group of stations (85.0) and lowest in Hood Canal (68.9).

Variability in Benthic Indices Related to Grain Size and Water Depth--In this section, the effects of grain size and water depth on benthic community structure are examined. The relative grain size distribution at a station often results from water currents (i.e., tidal currents and net currents) in the area. Coarse sediments indicate rapid water currents that both remove fine-grained sediments and prevent those sediments from settling. Conversely, areas with little water movement frequently have fine-grained sediments because low water current speeds are not capable of transporting coarser particles, and fine-grained particles tend to settle from slow moving water. The grain size distribution at a station reflects an integration of water currents through time.

TABLE 25. MEAN VALUES OF CONVENTIONAL SEDIMENT VARIABLES AND SELECTED BENTHIC INFAUNA VARIABLES AT SHALLOW (6-24 M) STATIONS STRATIFIED BY GEOGRAPHIC AREA

Geographic Area	Number of Stations	Depth[a] (m)	Fines[a] (Percent)	Total Organic Carbon[a] (Percent)	Total Abundance[a] (per 1.0 m^2)	Number of Taxa[a] (per 0.1 m^2)	Shannon-Weiner Diversity[a]	Infaunal Trophic Index[a]
Strait of Georgia	5	21.2 (1.8)	67.9 (39.0)	1.25 (0.8)	1,095 (271)	44.5 (11.5)	1.29 (0.12)	71.9 (7.4)
Strait of Juan de Fuca, Discovery Bay, Port Townsend	5	20.45 (0.5)	43.8 (34.9)	1.34 (1.52)	1,898 (856)	64.1 (17.7)	1.28 (0.12)	85.0 (4.6)
Hood Canal	3	20 (0)	7.3 (3.0)	0.20 (0.03)	2,490 (2,363)	71.7 (12.8)	1.32 (0.45)	68.9 (1.8)
Oak Harbor, Saratoga Passage, Port Susan, Port Gardner	4	17.8 (4.8)	52.7 (37.1)	0.84 (0.49)	1,729 (994)	41.2 (8.8)	1.06 (0.09)	68.0 (6.4)
Central Basin	15	17.5 (4.3)	25.2 (33.6)	0.62 (0.76)	2,117 (1,432)	63.3 (22.7)	1.20 (0.24)	73.6 (7.0)
South Sound	7	16.5 (6.8)	32.4 (36.3)	0.95 (1.13)	1,334 (470)	54.1 (21.8)	1.27 (0.24)	74.3 (7.0)

[a] Values shown in parentheses are the standard deviation.

Water currents are influenced by water depth. In general, water current speeds decrease as depth increases. Tidal currents, which may affect many of the shallow MSMT stations, tend to be greater than net currents (i.e., currents vector-averaged over time). For the most part, sediment grain size decreases as water depth increases due to the reduction in water current speeds. However, as noted previously (see RESULTS, Sediment Chemistry, Conventional Variables) some deep stations have relatively coarse-grained sediment. For example, relatively strong bottom currents at Station 26 move southward from Admiralty Inlet, influencing sediment grain size composition. Although the following discussion focuses on the effects of grain size and water depth on benthic variables at a station, remember that these variables are surrogates for water currents, which may be the single most important factor influencing benthic community structure.

The importance of grain size and water depth in structuring benthic communities was evaluated by using a Pearson test of correlation that included mean values for sediment and benthic variables from all MSMT stations. A matrix of the Pearson correlation coefficients is presented in Table 26. Number of taxa and total abundance were both highly correlated with percent fines ($r = -0.84$ and -0.81, respectively). These benthic variables also correlated with total organic carbon content, although at lower correlation coefficients (-0.50 and -0.74, respectively). Thus, the number of taxa and total abundance would be expected to decrease as percent fines (or TOC) increases. In both instances, the number of taxa correlated more closely with sediment variables than did abundance. Water depth and both sediment and benthic variables were not highly correlated, although an r value of 0.50 was obtained for the correlation between water depth and diversity. Poor correlation between water depth and sediment and benthic variables is not surprising considering the range of sediment types found at shallow and deep MSMT stations.

To evaluate the effects of water depth on benthic community structure, stations were sorted into four depth categories (i.e., shallow: 6-24 m; shallow to mid-depth: 39-53 m; mid-depth: 78-133 m; and deep: 180-262 m).

TABLE 26. MATRIX OF PEARSON CORRELATION COEFFICIENTS USING SEDIMENT VARIABLES AND BENTHIC VARIABLES

	Water Depth	Percent Fines	Total Organic Carbon	Total Abundance	Number of Taxa	Diversity	Infanal Trophic Index
Water Depth	1.00						
Percent Fines	0.29	1.00					
Total Organic Carbon	0.27	0.82	1.00				
Total Abundance	0.01	-0.81	-0.74	1.00			
Number of Taxa	0.12	-0.84	-0.50	0.79	1.00		
Diversity	0.50	-0.30	0.01	0.04	0.58	1.00	
Infanal Trophic Index	0.23	0.11	0.63	-0.06	0.33	0.35	1.00

The 39 stations in the shallow category were subdivided into six groups according to sediment fines content, because benth community structure is affected by sediment grain size. The percent fin ategories for shallow stations were <10 percent, 10-29 percent, 30-49 cent, 50-69 percent, 70-89 percent, and >89-100 percent. These catego are similar to those used in the *Puget Sound Environmental Atlas* (Evans- lton and D.R. Systems 1987). There were too few stations in the other depth categories to allow sorting by percent fines.

Mean values of conventional sediment variables and selected benthic indices were then calculated for each group of stations (Table 27). General trends in the relationships between percent fines and total abundance, diversity, and ITI were not observed. As percent fines increased, however, number of taxa decreased and total organic carbon content increased.

Depth-related trends in benthic indices were assessed among stations with similar percent fines (i.e., 51.9-62.4 percent fines) but located in different depth categories. Total abundance and number of taxa were significantly ($P<0.05$) less at the mid-depth (78-133 m) stations than at the shallow (6-24 m) stations. Total abundance and number of taxa did not differ statistically ($P>0.05$) between shallow and deep stations, nor between mid-depth and deep stations. Diversity and the ITI did not follow depth-related trends.

Classification Analyses--

Classification analyses were performed on total taxa and three major taxa groups (i.e., polychaetes, molluscs, and arthropods). All taxa present with an abundance greater than 2 at a station were included in the total taxa cluster analysis. All taxa within each group were included in cluster analyses for the major taxa groups. Abundances were log(x+1) transformed prior to calculating the similarity indices.

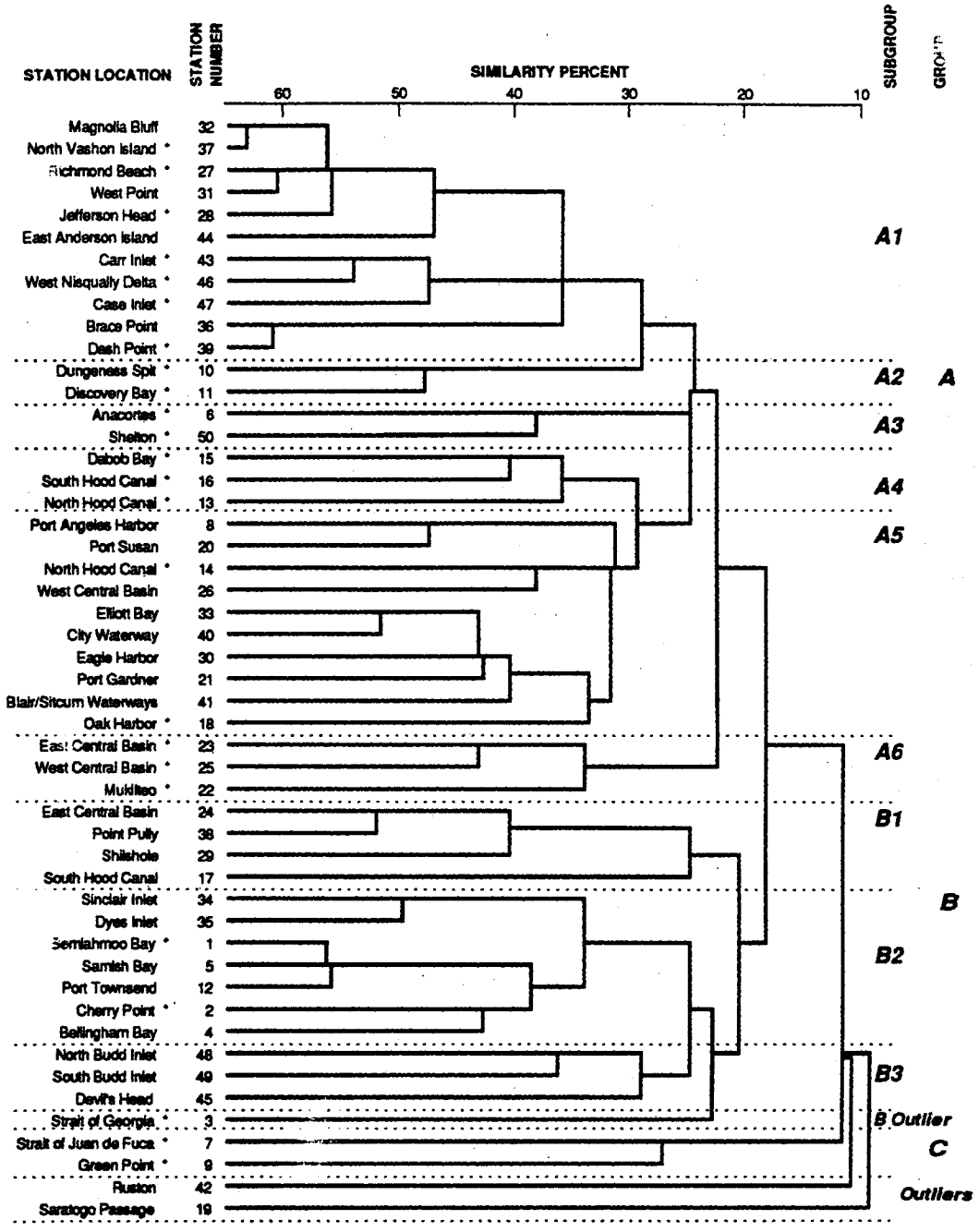
Total Taxa--Similarities between station pairs and groups of stations bas on the Bray-Curtis similarity index and normal classification analysis are shown in Figure 21. Three major groups and two outlier stations were

TABLE 27. MEAN VALUES OF CONVENTIONAL SEDIMENT VARIABLES AND SELECTED BENTHIC INFAUNA VARIABLES STRATIFIED BY DEPTH

Station Depths	Number of Stations	Depth (m)[a]	Fines (Percent)[a,b]	Total Organic Carbon (Percent)[a]	Total Abundance (per 1.0 m^2)[a]	Number of Taxa (per 0.1 m^2)[a]	Shannon-Weiner Diversity[a]	Infaunal Trophic Index[a]
Shallow (6-24 m)	18	19.0 (3.6)	4.7 (2.8)	0.17 (0.08)	1,679 (977)	66.1 (20.2)	1.31 (0.21)	74.1 (8.0)
	5	18.0 (4.6)	20.4 (4.8)	0.54 (0.17)	2,128 (712)	71.9 (15.6)	1.32 (0.14)	76.5 (9.6)
	1	20.0	37.2	0.61	2,153	67	1.23	85.1
	5	18.8 (3.3)	56.8 (6.3)	1.64 (1.29)	1,885 (868)	51.8 (12.4)	1.14 (0.24)	69.7 (7.5)
	4	15.1 (6.6)	82.4 (4.0)	2.08 (0.87)	2,589 (2,897)	32.2 (8.0)	0.88 (0.19)	70.5 (7.6)
	6	17.5 (6.4)	93.0 (1.9)	1.67 (0.43)	1,242 (322)	41.1 (7.2)	1.22 (0.08)	75.6 (4.2)
Shallow to mid-depth (39-53 m)	2	46.0 (9.9)	29.3 (36.8)	0.53 (0.62)	643 (489)	40.7 (13.2)	1.16 (0.02)	73.5 (4.1)
Mid-depth (78-133 m)	4	111.9 (23.5)	51.9 (41.6)	1.02 (0.80)	703 (526)	40.3 (21.3)	1.11 (0.18)	68.9 (3.9)
Deep (180-262 m)	5	209.9 (32.1)	62.4 (35.6)	1.40 (0.63)	674 (360)	38.9 (16.3)	1.23 (0.22)	68.3 (4.7)

[a] Values shown in parentheses are the standard deviation.

[b] At shallow stations, percent fines were calculated for five ranges: 0-<10, 10-29, 30-49, 50-69, 70-89, and >89-100.



Note: Because of matrix size limitations, only species with an abundance >2 were included in analysis.
* = Potential reference station.

Figure 21. Dendrogram resulting from a Bray-Curtis classification analysis of benthic infauna data.

defined at a similarity of 20 percent. Within the three major groups, nine subgroups and one subgroup outlier were identified. Characteristics of each cluster group are shown in Table 28 and variables responsible for defining the subgroups are summarized in Table 29.

Stations within Groups A, B, and C were similar to one another based on sediment grain size, water depth, or geographic area. However, sediment grain size and water depth in Groups A and B were not significantly different ($P<0.05$). Mean percent fines was 21.8 percent in Group A and 80.4 percent in Group B. All but one station in Group A were located at water depths less than 25 m while the mean water depth of Group B stations was 71.6 m. Group C comprised Stations 7 (Strait of Juan de Fuca) and 9 (Green Point). Although water depth was substantially greater at Station 7 than Station 9, percent fines was similar (mean = 3.7 percent). Because water depths and percent fines at these stations were similar to many stations in Groups A and B, Group C stations appear to be unique because of the degree of exposure to wave action or geographic factors that influence species composition. In summary, percent fines appeared to be the most important physical variable in defining station groups.

Subgroup A1 was composed of Stations 27 (Richmond Beach), 28 (Jefferson Head), 31 (West Point), 32 (Magnolia Bluff), 36 (Brace Point), 37 (north Vashon Island), 39 (Dash Point), 43 (Carr Inlet), 44 (east Anderson Island), 46 (west Nisqually Delta), and 47 (Case Inlet). All stations were located in shallow sandy areas with low sediment total organic carbon contents. Dominant taxa included the crustacean *Euphilomedes carcharodonta*, and the polychaetes *Phyllochaetopterus prolifica* and *Prionospio steenstrupi*. Defining characteristics of Subgroup A1 included shallow stations with sand, and a benthic community dominated by *E. carcharodonta* and *P. prolifica*.

Subgroup A2 included Stations 10 (Dungeness Spit) and 11 (Discovery Bay). These stations were geographically close together and were located at 20 m water depth. Sediment composition was either sand or silty sand, and *Phyllochaetopterus prolifica* numerically dominated the infauna. The high abundances of *P. prolifica* characterized this group.

TABLE 28. CHARACTERISTICS OF STATION GROUPS DEFINED BY CLUSTER ANALYSIS

Cluster Group[a]	Stations in Group	Mean Water Depth[b] (m)	Mean Percent Fines[b]	Mean Percent TOC[b]	Numerically Dominant Taxa of Subgroups	Mean Total Abundance[b] (per 1.0 m^2)	Frequency of Occurrence
A	6, 8, 10, 11, 13, 14, 15, 16, 18, 20, 21, 22, 23, 25, 26, 27, 28, 30, 31, 32, 33, 36, 37, 39, 40, 41, 43, 44, 46, 47, 50	29.4 (46.7)	21.8 (25.6)	0.53 (0.72)			
A1	27, 28, 31, 32, 36, 37, 39, 43, 44, 46, 47	19.4 (2.5)	7.3 (6.6)	0.21 (0.12)	Euphilomedes carcharodonta Phyllochaetopterus prolifica Prionospio steenstrupi	829 (640) 746 (788) 302 (226)	11/11 11/11 11/11
A2	10, 11	20 (0)	30.7 (9.2)	0.63 (0.02)	Phyllochaetopterus prolifica	1,947 (354)	2/2
A3	6, 50	13.5 (9.2)	5.4 (2.3)	0.23 (0.04)	Mysella tumida Psephidia lordi	407 (42) 268 (177)	2/2 2/2
A4	13, 15, 16	20 (0)	7.3 (3.0)	0.20 (0.03)	Psephidia lordi Axinopsida serricata	3,244 (5,565) 254 (302)	3/3 3/3
A5	8, 14, 18, 20, 21, 26, 30, 33, 40, 41	51.1 (80.4)	49.2 (27.6)	1.14 (1.03)	Axinopsida serricata Tharyx multifilis Euphilomedes carcharodonta Euphilomedes producta	1,676 (2,696) 1,446 (2,749) 376 (542) 302 (378)	10/10 9/10 6/10 10/10
A6	22, 23, 25	20.2 (0.3)	2.7 (1.3)	0.11 (0.04)	Euphilomedes carcharodonta Psephidia lordi	793 (166) 304 (13)	3/3 3/3
B	1, 2, 3, 4, 5, 12, 17, 24, 29, 34, 35, 38, 45, 48, 49	71.6 (80.6)	80.4 (19.0)	1.75 (0.56)			
B1	17, 24, 29, 38	162.1 (56.2)	89.0 (4.8)	1.72 (0.25)	Axinopsida serricata Euphilomedes producta Pectinaria californiensis Eudorella pacifica	167 (280) 127 (102) 103 (106) 82 (63)	4/4 3/4 3/4 4/4
B2	1, 2, 4, 5, 12, 34, 35	18.3 (5.4)	84.7 (16.3)	1.71 (0.55)	Eudorella pacifica Pinnixa spp. Amphiodia urtica/ periercta complex	455 (337) 389 (717) 304 (401)	7/7 5/7 7/7
B3	45, 48, 49	26.6 (24.0)	74.9 (17.3)	2.05 (0.95)	Spiophanes berkeleyorum Sigambra bassi	128 (126) 107 (22)	3/3 3/3

TABLE 28. (Continued)

Cluster Group[a]	Stations in Group	Mean Water Depth[b] (m)	Mean Percent Fines[b]	Mean Percent TOC[b]	Numerically Dominant Taxa of Subgroups	Mean Total Abundance[b] (per 1.0 m^2)	Frequency of Occurrence
B Outlier	3	217.7	32.6	1.20	Prionospio steenstrupi	533	1/1
					Prionospio lighti	307	1/1
					Cossura longocirrata	250	1/1
C	7, 9	77.0 (79.0)	3.7 (3.4)	0.195 (0.19)	Ampelisca spp.	811 (1,035)	3/3
					Mediomastus californiensis	72 (7)	3/3
					Polycirrus californicus	57 (24)	3/3
Outlier	19	121	81.3	1.90	Pectinaria californiensis	63	1/1
					Chaetodermatida	60	1/1
					Onuphis iridescens	33	1/1
Outlier	42	39	3.2	0.09	Prionospio steenstrupi	300	1/1
					Olivella baetica	97	1/1
					Rhepoxynius daboius	60	1/1

[a] Cluster groups are shown in Figure 21.

[b] Values shown in parentheses are the standard deviation.

TABLE 29. CHARACTERISTICS THAT DEFINE SMALL CLUSTER GROUPS

Cluster Group[a]	Station	Station Location	Water Depth[b]	Sediment Type	Characteristics that Define Cluster Groups
A1	27	Richmond Beach	Shallow	Medium sand	Shallow; medium and fine sand; Euphilomedes carcharodonta, Phyllochaetopterus prolifica, Prionospio steenstrupi
	28	Jefferson Head	Shallow	Medium-fine sand	
	31	West Point	Shallow	Fine sand	
	32	Magnolia Bluff	Shallow	Fine sand	
	36	Brace Point	Shallow	Fine sand	
	37	North Vashon Island	Shallow	Medium-fine sand	
	39	Dash Point	Shallow	Fine sand	
	43	Carr Inlet	Shallow	Fine sand	
	44	East Anderson Island	Shallow	Fine sand	
	46	West Nisqually Delta	Shallow	Fine sand	
	47	Case Inlet	Shallow	Very fine sand	
A2	10	Dungeness Spit	Shallow	Silty sand	Shallow, protected, Strait of Juan de Fuca; Phyllochaetopterus prolifica
	11	Discovery Bay	Shallow	Fine sand	
A3	6	Anacortes	Shallow	Fine sand	Shallow, protected, fine sand; Mysella tumida, Psephidia lordi
	50	Shelton	Shallow	Fine sand	
A4	13	North Hood Canal	Shallow	Medium sand	Shallow; medium and fine sand, Hood Canal; Psephidia lordi
	15	Dabob Bay	Shallow	Fine sand	
	16	South Hood Canal	Shallow	Fine sand	
A5	8	Port Angeles Harbor	Shallow	Sandy silt	Axinopsida serricata, Tharyx multifilis, Euphilomedes carchardonta, Euphilomedes producta
	14	North Hood Canal	Mid-depth	Silty sand	
	18	Oak Harbor	Shallow	Sand-silt-clay	
	20	Port Susan	Shallow	Clayey silt	
	21	Port Gardner	Shallow	Sandy silt	
	26	West Central Basin	Deep	Fine sand	
	30	Eagle Harbor	Shallow	Sandy silt	
	33	Elliott Bay	Shallow	Very fine sand	
	40	City Waterway	Shallow	Fine sand	
	41	Blair/Sitcum Waterways	Shallow	Silt	
A6	22	Mukilteo	Shallow	Fine sand	Shallow; medium and fine sand, northern Central Basin; Euphilomedes carcharodonta, Psephidia lordi
	23	East Central Basin	Shallow	Medium-fine sand	
	25	West Central Basin	Shallow	Medium-fine sand	
B1	17	South Hood Canal	Mid-depth	Clayey silt	Deep silt; Axinopsida serricata, Euphilomedes producta, Pectinaria californiensis
	24	East Central Basin	Deep	Clayey silt	
	29	Shilshole	Deep	Clayey silt	
	38	Point Pully	Deep	Silty clay	

TABLE 29. (Continued)

Cluster Group[a]	Station	Station Location	Water Depth[b]	Sediment Type	Characteristics that Define Cluster Groups
B2	1	Semiahmoo Bay	Shallow	Clayey silt	Shallow, silt; Eudorella pacifica, Pinnixa spp., Amphiodia urtica/periercta complex
	2	Cherry Point	Shallow	Silty sand	
	4	Lummi Island	Shallow	Clayey silt	
	5	Samish Bay	Shallow	Clayey silt	
	12	Port Townsend	Shallow	Clayey silt	
	34	Sinclair Inlet	Shallow	Clayey silt	
	35	Dyes Inlet	Shallow	Sandy silt	
B3	45	Devil's Head	Shallow/Mid-depth	Sandy silt	Shallow, silt, South Sound; Spiophanes berkeleyorum, Sigambra bassi
	48	North Budd Inlet	Shallow	Clayey silt	
	49	South Budd Inlet	Shallow	Clayey silt	
B Outlier	3	Strait of Georgia	Deep	Silty sand, gravel	Prionospio steenstrupi, Prionospio lighti; 34% gravel consisting primarily of mollusc shells
C	7	Strait of Juan de Fuca	Mid-depth	Sand, gravel	Exposed Strait of Juan de Fuca; Ampelisca spp.
	9	Green Point	Shallow	Medium sand	
Outlier Stations	19	Saratoga Passage	Mid-depth	Silty clay	Pectinaria californiensis, Chaetodermatida, Prionospio steenstrupi
	42	Ruston	Mid-depth	Medium-fine sand	

[a] Cluster groups are shown in Figure 21.

[b] Shallow = 6-24 m; shallow to mid-depth = 39-53 m; mid-depth = 78-133 m; deep = 180-262 m.

[c] Sediment types are shown in Figure 2.

Subgroup A3 was composed of Stations 6 (Anacortes) and 50 (Shelton). These stations were located in shallow sandy areas, with benthic communities dominated by the molluscs *Mysella tumida* and *Psephidia lordi*. These taxa represented the defining characteristics of the cluster group.

Subgroup A4 included three stations in Hood Canal: Stations 13 (north Hood Canal), 15 (Dabob Bay), and 16 (south Hood Canal). Each station was located in a shallow sandy area. The molluscs *Psephidia lordi* and *Axinopsida serricata* dominated the infauna. Although water depth, fines content, and total organic carbon content were the same as those in Subgroup A1, the dominant taxa belonged to different major taxonomic groups. The numerical dominance of *P. lordi* and *A. serricata* characterized this cluster group.

Subgroup A5 included Stations 8 (Port Angeles Harbor), 14 (north Hood Canal), 18 (Oak Harbor), 20 (Port Susan), 21 (Port Gardner), 26 (west Central Basin), 30 (Eagle Harbor), 33 (Elliott Bay), 40 (City Waterway), and 41 (Blair/Sitcum Waterways). Most stations within this subgroup were located in shallow areas, although Station 14 was a mid-depth station and Station 26 was a deep station in an area with high bottom water current speeds. Sediment grain size composition ranged from sand to clayey silt, and there was considerable variation in the abundances of dominant taxa (Table 28). *Axinopsida serricata* and *Euphilomedes products* were present at all stations, while the polychaete *Tharyx multifilis* and the crustacean *Euphilomedes carcharodonta* were present at 9 and 6 of the 10 stations, respectively. *A. serricata, E. products,* and *T. multifilis* are indicative of organically enriched sediment. Many stations in Subgroup A5 were located near sources of freshwater and near urban embayments or shoreline population centers with municipal effluent discharges, which may have resulted in organic enrichment of the sediment.

Subgroup A6 was composed of stations in the northern Central Basin of Puget Sound including Stations 22 (Mukilteo), 23 (east Central Basin), and 25 (west Central Basin). Stations in this subgroup were located in shallow areas with sandy sediment. Dominant taxa included *Euphilomedes carcharodonta*

and *Psephidia lordi*. Although several other station groups were also located in shallow water with sandy sediment, the combination of numerically dominant taxa in Subgroup A6 differed from that in Subgroups A1, A3, and A4. Because Stations 22, 23, and 25 were located in a relatively small geographic area, their proximity to one another may have the effect of reducing variability associated with geographic area. Proximity in location appears to be responsible for the formation of this subgroup.

Subgroup B1 comprised Stations 17 (south Hood Canal), 24 (east Central Basin), 29 (Shilshole), and 38 (Point Pully). Each of these stations was located in relatively deep depositional areas of Puget Sound. The sediment composition was mostly silt and clay, with a relatively high percentage of total organic carbon. Dominant taxa at these stations were characteristic of organically enriched fine-grained sediments: *Axinopsida serricata, Euphilomedes products*, the polychaete *Pectinaria californiensis*, and the crustacean *Eudorella pacifica*. Abundances of these taxa were low compared with those of stations in Subgroup A5, which were located in shallow areas with sandy, organically enriched sediment. Sediment characteristics and relatively low abundances of the dominant taxa characterized this group.

Subgroup B2 included Stations 1 (Semiahmoo Bay), 2 (Cherry Point), 4 (Bellingham Bay), 5 (Samish Bay), 12 (Port Townsend), 34 (Sinclair Inlet), and 35 (Dyes Inlet). All stations were located in shallow water, with high percent fines and high total organic carbon content. Dominant taxa included *Eudorella pacifica*, the crustacean *Pinnixa* spp., and the ophiuroid *complex Amphiodia urtica/periercta*. This group of stations was subdivided into two groups. Stations 1, 2, 4, 5, and 12 were more similar to one another than to Stations 34 and 35. Stations 1, 2, 4, 5, and 12 were located in the northern portion of the sound in areas that should be well flushed. Stations 34 and 35 were located in enclosed inlets. Additionally, sediment concentrations of chemical contaminants were elevated at Stations 34 and 35. Dominant taxa at Stations 1, 2, 4, 5, and 12 included *E. pacifica, A. urtica/periercta* complex, and the polychaete *Levinsenia gracilis*. In addition to *E. pacifica* and *Pinnixa* spp., dominant taxa at Stations 34 and 35 included *Tharyx multifilis* and *Phyllochaetopterus prolifica*. *E. pacifica*

and *Pinnixa* spp. were the taxa that characterized Subgroup B2, although other taxa resulted in the formation of two smaller groups within Subgroup B2.

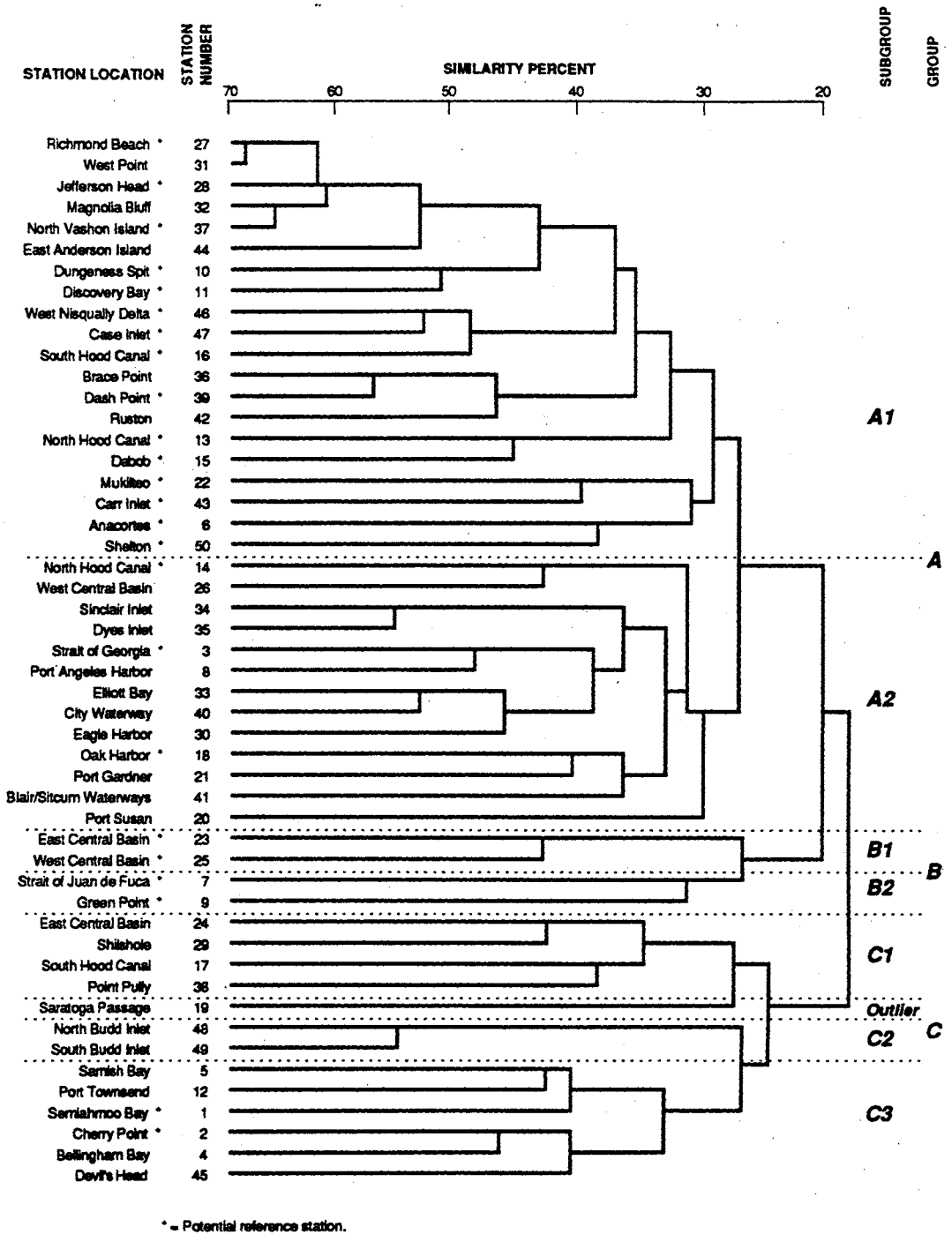
Subgroup B3 comprised Stations 45 (Devil's Head), 48 (northern Budd Inlet), and 49 (southern Budd Inlet). Each station was located silty sediments in South Sound. Water depths were shallow to mid-depth (i.e., <75 m). Numerically dominant taxa included the polychaetes *Spiophanes berkeleyorum* and *Sigambra bassi*.

Station 3 (Strait of Georgia) was an outlier in Group B. Station 3 was a deep station with sediment composed of silty sand and 34 percent gravel, which was primarily mollusc shells. The polychaetes *Prionospio steenstrupi* and *Prionospio lighti* numerically dominated the infauna.

Group C was composed of Stations 7 (Strait of Juan de Fuca) and 9 (Green Point). Both stations were located close together in exposed areas and sediments were primarily sand or sand and gravel. The crustacean *Ampelisca* spp. was the dominant taxon.

Stations 19 (Saratoga Passage) and 42 (Ruston) were outliers to Groups A, B, and C. Station 19 was a mid-depth station containing silty clay sediment. *Pectinaria californiensis* and Chaetodermatida dominated the infauna. Station 42 was a mid-depth station located off the ASARCO smelter in Commencement Bay. Sediment grain size was sand, probably due to the slag generated by the smelting process. Benthic community structure at this general location has previously been reported (Parametrix 1989) as anomalous for Puget Sound.

Polychaetes--Three groups of similar stations were identified based on the composition of polychaete taxa (Figure 22). Groups A, B, and C were distinguished by depth, grain size, total organic carbon content, mean abundance, and dominant taxa (Table 30). Stations in Group A were relatively shallow with intermediate amounts of silt and total organic carbon (Table 30). These stations also had high mean polychaete abundances and were characterized by numerical dominance of *Tharyx multifilis* and



* = Potential reference station.

Figure 22. Dendrogram resulting from a Bray-Curtis classification analysis of polychaete species abundance data.

TABLE 30. CHARACTERISTICS OF STATION GROUPS DEFINED BY CLUSTER ANALYSIS OF POLYCHAETE TAXA

Cluster Group[a]	Stations in Group	Mean Water Depth (m)[b]	Mean Percent Fines[b]	Mean Percent TOC[b]	Mean Polychaete Abundance[b] (per 1.0 m^2)	Numerically Dominant Taxa	Mean Abundance[b] (per 1.0 m^2)	Frequency of Occurrence
A	3, 6, 8, 10, 11, 13, 14, 15, 16, 18, 20, 21, 22, 26, 27, 28, 30, 31, 32, 33, 34, 35, 36, 37, 39, 40, 41, 42, 43, 44, 46, 47, 50	34.9 (56.0)	26.6 (28.9)	0.67 (0.81)	2,556 (1,887)	Tharyx multifilis	481 (1,599)	26/33
						Phyllochaetopterus prolifica	438 (722)	20/33
						Prionospio steenstrupi	240 (288)	31/33
						Lumbrineris luti	98 (173)	25/33
						Mediomastus californiensis	67 (152)	25/33
						Euclymene zonalis	57 (111)	25/33
A1	6, 10, 11, 13, 15, 16, 22, 27, 28, 31, 32, 36, 37, 39, 42, 43, 44, 46, 47, 50	20.0 (5.6)	9.1 (9.2)	0.24 (0.16)	2,244 (447)	Phyllochaetopterus prolifica	617 (810)	16/20
						Prionospio steenstrupi	247 (199)	20/20
						Mediomastus californiensis	84 (183)	16/20
A2	3, 8, 14, 18, 20, 21, 26, 30, 33, 34, 35, 40, 41	57.8 (85.9)	76.6 (81.7)	1.32 (0.98)	3,033 (2,358)	Tharyx multifilis	1,193 (2,431)	12/13
						Prionospio steenstrupi	230 (398)	11/13
						Lumbrineris luti	207 (236)	13/13
						Euclymene zonalis	101 (151)	10/13
B	7, 9, 23, 25	48.5 (56.3)	2.8 (2.2)	0.15 (0.13)	1,515 (1,137)	Spiophanes bombyx	762 (985)	3/4
						Polycirrus californicus	53 (22)	4/4
						Mediomastus californiensis	39 (38)	3/4
						Prionospio steenstrupi	27 (32)	3/4
B1	23, 25	20.0 (0)	2.0 (0.2)	0.10 (0.04)	910 (280)	Spiophanes bombyx	445 (427)	2/2
						Prionospio steenstrupi	52 (26)	2/2
						Polycirrus californicus	50 (28)	2/2
B2	7, 9	77.0 (79.2)	3.7 (3.4)	0.20 (0.19)	2,125 (1,520)	Spiophanes bombyx	1,078 (1,525)	1/2
						Mediomastus californiensis	72 (7)	2/2
						Polycirrus californicus	57 (24)	2/2
C	1, 2, 4, 5, 12, 17, 19, 24, 29, 38, 45, 48, 49	73.5 (73.4)	83.4 (14.5)	1.73 (0.55)	963 (804)	Levinsenia gracilis	221 (358)	12/13
						Prionospio lighti	57 (131)	12/13
						Paraprionospio pinnata	43 (79)	10/13
						Spiophanes berkeleyorum	39 (74)	10/13
C1	17, 24, 29, 38	162.1 (56.2)	89.0 (4.8)	1.72 (0.25)	468 (129)	Pectinaria californica	103 (106)	3/4
						Levinsenia gracilis	35 (8)	4/4
C2	48, 49	13.3 (10.0)	84.7 (4.8)	2.60 (0.14)	756 (12)	Spiophanes berkelyorum	177 (132)	2/2
						Paraprionospio pinnata	162 (191)	2/2
						Sigambra bassi	105 (31)	2/2
						Nephtys cornuta franciscana	90 (9)	2/2

TABLE 30. (Continued)

Cluster Group[a]	Stations in Group	Mean Water Depth (m)[b]	Mean Percent Fines[b]	Mean Percent TOC[b]	Mean Polychaete Abundance[b] (per 1.0 m^2)	Numerically Dominant Taxa	Mean Abundance[b] (per 1.0 m^2)	Frequency of Occurrence
C3	1, 2, 4, 5, 12, 45	26.5 (13.1)	79.7 (21.1)	1.41 (0.50)	1,482 (951)	Levinsenia gracilis	451 (436)	6/6
						Prionospio lighti	112 (185)	6/6
						Pholoe minuta	85 (104)	5/6
						Paraprionospio pinnata	32 (24)	5/6
Outlier	19	121.0	81.3	1.9	258	Pectinaria californiensis	63	1/1
						Spiophanes berkeleyorum	20	1/1

[a] Cluster groups are shown in Figure 22.

[b] Values shown in parentheses are the standard deviation.

Phyllochaetopterus prolifica. Group B stations were intermediate in depth and sediment composition was sandy with low total organic carbon content. Mean polychaete abundance was moderate, and *Spiophanes bombyx* was the dominant taxon among Group B stations. Stations in Group C were generally deep with high silt and total organic carbon contents. Mean polychaete abundance was relatively low and *Levinsenia gracilis* was the dominant taxon among the stations. In general, the polychaete cluster groups corresponded closely with clusters identified using total taxa (see above).

Group A included two subgroups. Subgroup A1 was composed of 20 stations (i.e., Stations 6, 10, 11, 13, 15, 16, 22, 27, 28, 31, 32, 36, 37, 39, 42, 43, 44, 46, 47, and 50). These stations were located in shallow areas with low fines and total organic carbon contents. *Phyllochaetopterus prolifica*, *Prionospio steenstrupi*, and *Mediomastus californiensis* were the numerically dominant taxa. The composition of Subgroup A1 was similar to that of total taxa cluster Subgroups A1-A4 except for Station 42 (Ruston), which was present in the polychaete group but not the total taxa groups.

Subgroup A2 was composed of 13 stations (i.e., Stations 3, 8, 14, 18, 20, 21, 26, 30, 33, 34, 35, 40, and 41). The composition of this subgroup closely resembled that of total taxa Subgroup A5. The subgroup contained both shallow and deep stations (8.5-262 m) with sediment grain sizes ranging from sand to clayey silt. Mean polychaete abundances were relatively high compared with other polychaete cluster groups. *Tharyx multifilis*, *Prionospio steenstrupi*, and *Lumbrineris luti* were the dominant taxa. *T. multifilis* and *P. steenstrupi* are considered pollution tolerant taxa.

Group B was divided into two subgroups. Stations 23 and 25 constituted Subgroup B1. This cluster was similar to Subgroup A6 of the total taxa, which was identified as shallow sandy stations in Puget Sound's northern Central Basin. *Spiophanes bombyx* was the dominant taxa among these stations. Subgroup B2 was the same as Group C of the total taxa cluster, consisting of Stations 7 and 9. Both stations were located in exposed areas in the Strait of Juan de Fuca and had low percent fines and total organic carbon. *Spiophanes bombyx* was the dominant taxon at these stations.

Three subgroups constitute Group C. Subgroup C1 was composed of Stations 17, 24, 29, and 38, which were the same as Subgroup B1 of the total taxa cluster. All were mid-depth to deep stations containing high percent fines. Mean polychaete abundance was relatively low compared with other cluster groups. *Pectinaria californiensis* was the dominant taxon among these stations. Subgroup C2 was composed of Stations 48 and 49 from Budd Inlet. The subgroup was similar to Subgroup B3 of the total taxa cluster. Both stations were located in protected shallow water with silty sediments and high total organic carbon content. Subgroup C3 was composed of six stations (i.e., Stations 1, 2, 4, 5, 12, and 45). Five of these six stations were also grouped together in the total taxa cluster Subgroup B2. This group was located in shallow water with silty sediments and moderately high percent total organic carbon. *Levinsenia gracilis* was the dominant polychaete. Station 19 was an outlier within Group C. The station was characterized by low polychaete and total abundances. It was also an outlier in the total taxa, mollusc, and arthropod cluster analyses.

Molluscs--Six groups and five outlier stations were identified by classifying the mollusc taxa (Figure 23). Major groups are distinguished by percent fines, mean mollusc abundance, and dominant taxa (Table 31). There was less concordance between the total taxa station groups and mollusc station groups than between the total taxa and polychaete station groups. Classification of polychaete taxa would be expected to resemble more closely that of the total taxa more than would classification of mollusc taxa because polychaetes were the numerically dominant major taxa group in the MSMT. Because the Bray-Curtis similarity index relies primarily on numerical abundance, those taxa with the highest abundances (i.e., polychaetes) have a greater effect on the resulting clusters than do taxa present at lower abundances (i.e., molluscs).

Group A was composed of Stations 1, 4, 5, and 34. Group A was most similar to Subgroup B2 of the total taxa cluster (all four stations are included within total taxa Subgroup B2) and Subgroup C3 of the polychaete cluster (three stations are similar). Stations in Group A were located in

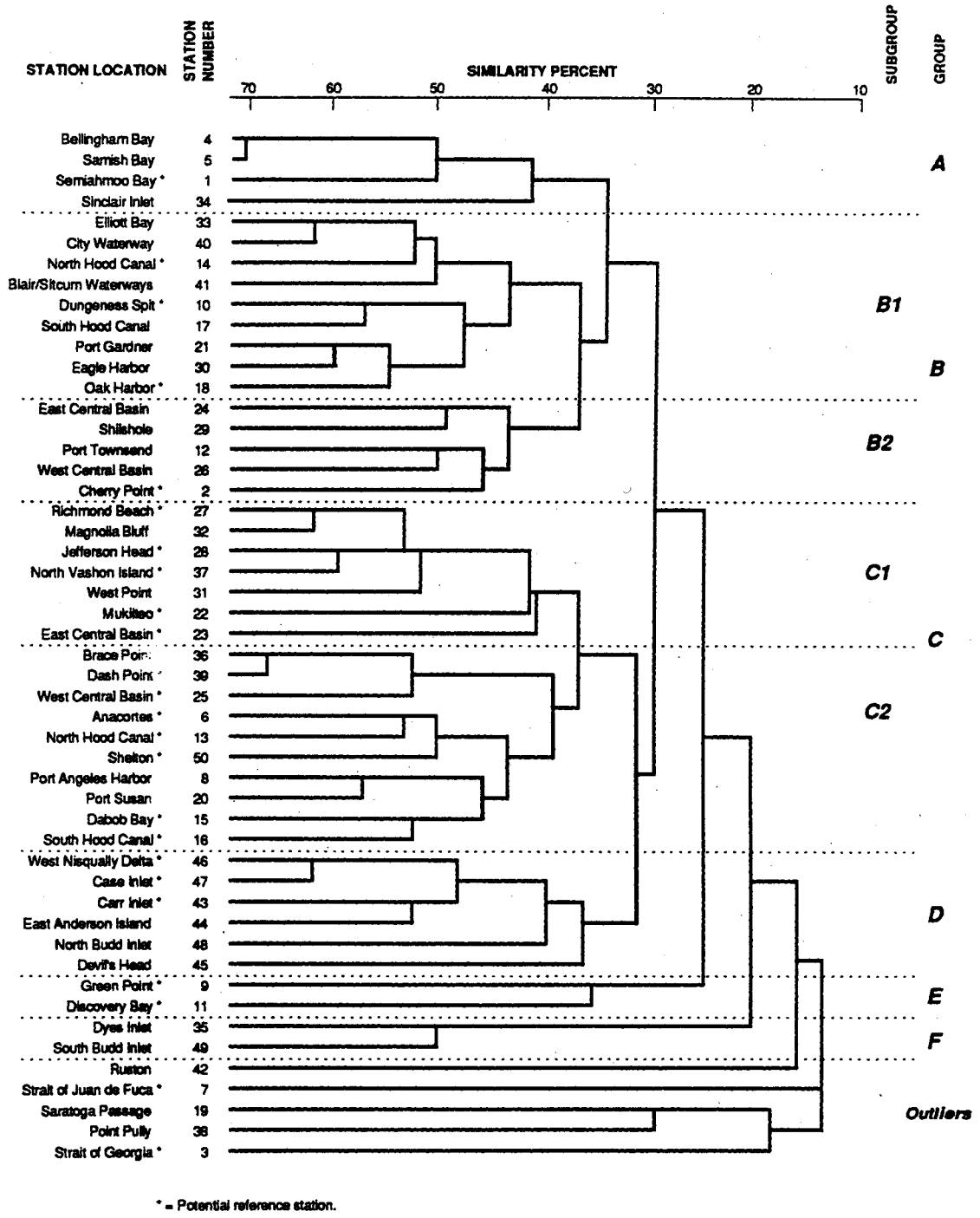


Figure 23. Dendrogram resulting from a Bray-Curtis classification analysis of mollusc species abundance data.

TABLE 31. CHARACTERISTICS OF STATION GROUPS DEFINED BY CLUSTER ANALYSIS OF MOLLUSC TAXA

Cluster Group[a]	Stations in Group	Mean Water Depth (m)[b]	Mean Percent Fines[b]	Mean Percent TOC[b]	Mean Mollusc Abundance[b] (per 1.0 m^2)	Numerically Dominant Taxa	Mean Abundance[b] (per 1.0 m^2)	Frequency of Occurrence
A	1, 4, 5, 34	18.6 (6.9)	93.5 (1.7)	1.88 (0.30)	550 (144)	Axinopsida serricata	133 (146)	4/4
						Acila castrensis	126 (44)	4/4
						Odostomia sp. A	72 (86)	4/4
B	2, 10, 12, 14, 17, 18, 21, 24, 26, 29, 30[c], 33, 40, 41	71.0 (83.7)	55.2 (28.2)	1.01 (0.47)	1,962 (2,499)	Axinopsida serricata	1,267 (2,347)	14/14
						Macoma carlottensis	270 (557)	13/14
B1	10, 14, 17, 18, 21, 30[c], 33, 40, 41	35.1 (36.3)	49.6 (26.1)	0.91 (0.40)	2,667 (2,922)	Axinopsida serricata	1,949 (2,736)	9/9
						Macoma carlottensis	314 (693)	8/9
B2	2, 12, 24, 26, 29	135.4 (109.8)	65.2 (32.1)	1.18 (0.59)	693 (348)	Macoma carlottensis	191 (194)	5/5
						Turbonilla sp. B	40 (37)	5/5
						Axinopsida serricata	40 (12)	5/5
C	6, 8, 13, 15, 16, 20, 22, 23, 25, 27, 28, 31, 32, 36, 37, 39, 50	18.2 (4.1)	13.4 (25.7)	0.43 (0.92)	1,809 (2,610)	Psephidia lordi	714 (2,312)	17/17
						Axinopsida serricata	145 (230)	17/17
						Mysella tumida	105 (135)	17/17
C1	22, 23, 27, 28, 31, 32, 37	20.4 (0.7)	4.2 (2.0)	0.15 (0.03)	1,158 (879)	Turbonilla sp. B	194 (266)	6/7
						Axinopsida serricata	170 (302)	7/7
						Psephiaia lordi	144 (136)	7/7
C2	6, 8, 13, 15, 16, 20, 25, 36, 39, 50	16.7 (4.9)	19.8 (32.5)	0.62 (1.18)	2,262 (3,321)	Psephidia lordi	1,096 (3,016)	10/10
						Mysella tumida	166 (149)	10/10
						Tellina modesta	100 (110)	6/10
D	43, 44, 45, 46, 47, 48	25.9 (13.3)	31.6 (30.0)	0.79 (0.88)	408 (135)	Macoma yoldiformis	66 (62)	5/6
						Parvilucina tenuisculpta	58 (45)	6/6
E	9, 11[c]	20.5 (0.7)	12.8 (16.2)	0.35 (0.41)	820 (311)	Psephidia lordi	75 (82)	2/2
						Mysella tumida	67 (42)	2/2
						Mya arenaria	30 (14)	2/2
F	35[c], 49	9.9 (5.1)	83.5 (6.5)	2.50 (0.28)	85 (7)	Odostomia sp. A	25 (2)	2/2
						Mitrella tuberosa	10 (5)	2/2
Outliers	3	217.7	32.7	1.20	300	Macoma calcarea	117	1/1
	7	133.0	6.1	0.33	200	Nuculana minuta	97	1/1
	19	121.0	81.3	1.90	100	Chaetodermatida	60	1/1
	38	195.0	93.3	2.08	130	Macoma spp.	77	1/1
	42	39.0	3.2	0.09	160	Olivella baetica	97	1/1

[a] Cluster groups are shown in Figure 23.
[b] Values shown in parentheses are the standard deviation.
[c] Only two replicates were available for Stations 11, 30, and 35.

shallow water with high percent fines and percent total organic carbon. *Axinopsida serricata, Acila castrensis*, and *Odostomia* sp. A were the dominant taxa at these stations. Mean mollusc abundance was low for this group compared with other cluster groups.

Group B was divided into two subgroups. Subgroup B1 was composed of nine stations (i.e., Stations 10, 14, 17, 18, 21, 30, 33, 40, and 41). Seven of these stations appeared in Subgroup A5 of the total taxa cluster. Subgroup B1 was also similar to Group A2 of the polychaete cluster. This subgroup contained both shallow and mid-depth stations with sediment grain sizes ranging from sand to sandy silt. *Axinopsida serricata* and *Macoma carlottensis* were the dominant molluscs among all stations. Mean mollusc abundance was high compared with that for other mollusc cluster groups.

Subgroup B2 was composed of Stations 2, 12, 24, 26, and 29, and does not resemble any of the total taxa groups. Station depth and geographic area were variable, with two shallow stations (northern Puget Sound and Port Townsend) and three deep Central Basin stations. All stations had moderately high percent fines and total organic carbon. *Macoma carlottensis, Turbonilla* sp. B, and *A. serricata* were the dominant taxa. Sediment grain size at stations in this group had relatively more influence on the composition of molluscs than did depth.

Group C was composed of two subgroups. Subgroup C1 contained seven stations (i.e., Stations 22, 23, 27, 28, 31, 32, and 37, all in the Central Basin of Puget Sound) and was similar to total taxa Subgroups A1 and A6. Stations in this group were located in shallow sandy areas with low percent total organic carbon. *Turbonilla* sp. B, *Axinopsida serricata*, and *Psephidia lordi* were the dominant taxa. Subgroup C2 was composed of Stations 6, 8, 13, 15, 16, 20, 25, 36, 39, and 50. All stations were located in shallow areas. Sediment composition at Stations 8 and 20 was silt while that at the other stations was sandy sediment. *Psephidia lordi, Mysella tumida*, and *Tellina modesta* were the dominant taxa. Subgroup C2 was similar to total taxa Subgroups A3 and A4. Mean mollusc abundances were relatively high compared with the other mollusc cluster groups.

Group D was composed of Stations 43, 44, 45, 46, 47, and 48. Each station was located in south Puget Sound in a shallow or mid-depth location. Sediments at Stations 43, 44, 46, and 47 were sandy while those at Stations 45 and 48 contained >50 percent silt. *Macoma yoldiformis* and *Parvilucina tenuisculpta* were the dominant molluscs at these stations.

Group E comprised Stations 9 and 11. Both stations were located in shallow water with sandy sediment, although Station 9 was exposed (off Green Point) while Station 11 was protected (Discovery Bay). *Psephidia lordi, Mysella tumida,* and *Mya arenaria* were the dominant molluscs at these stations.

Group F was composed of Stations 35 and 49. These stations were both located in very shallow water (<20 m) with high percent fines and total organic carbon. *Odostomia* sp. A and *Mitrella tuberosa* were the dominant molluscs. Mean mollusc abundance was very low compared with other mollusc clusters.

Stations 3, 7, 19, 38, and 42 were outlier stations. The abundances of molluscs was low at each of these stations. Stations 3, 19, and 42 were also outliers in the total taxa cluster.

Arthropods--Classification analysis of the arthropods resulted in the formation of five groups of similar stations and three outlier stations (Figure 24). The major distinguishing features among the major groups were grain size, mean arthropod abundance, geographic area, and dominant species (Table 32). Of the major taxa groups, the arthropods were the least similar to the total taxa cluster groups.

Group A was composed of 20 stations. Most were shallow sandy stations dominated by *Euphilomedes carcharodonta* and *E. products*. Subgroup A1 had five shallow stations (i.e., Stations 13, 21, 33, 40, and 41) with grain sizes ranging from sand to silt. This subgroup was similar to total taxa Subgroup A5. Stations 21, 33, 40, and 41 were non-reference stations because

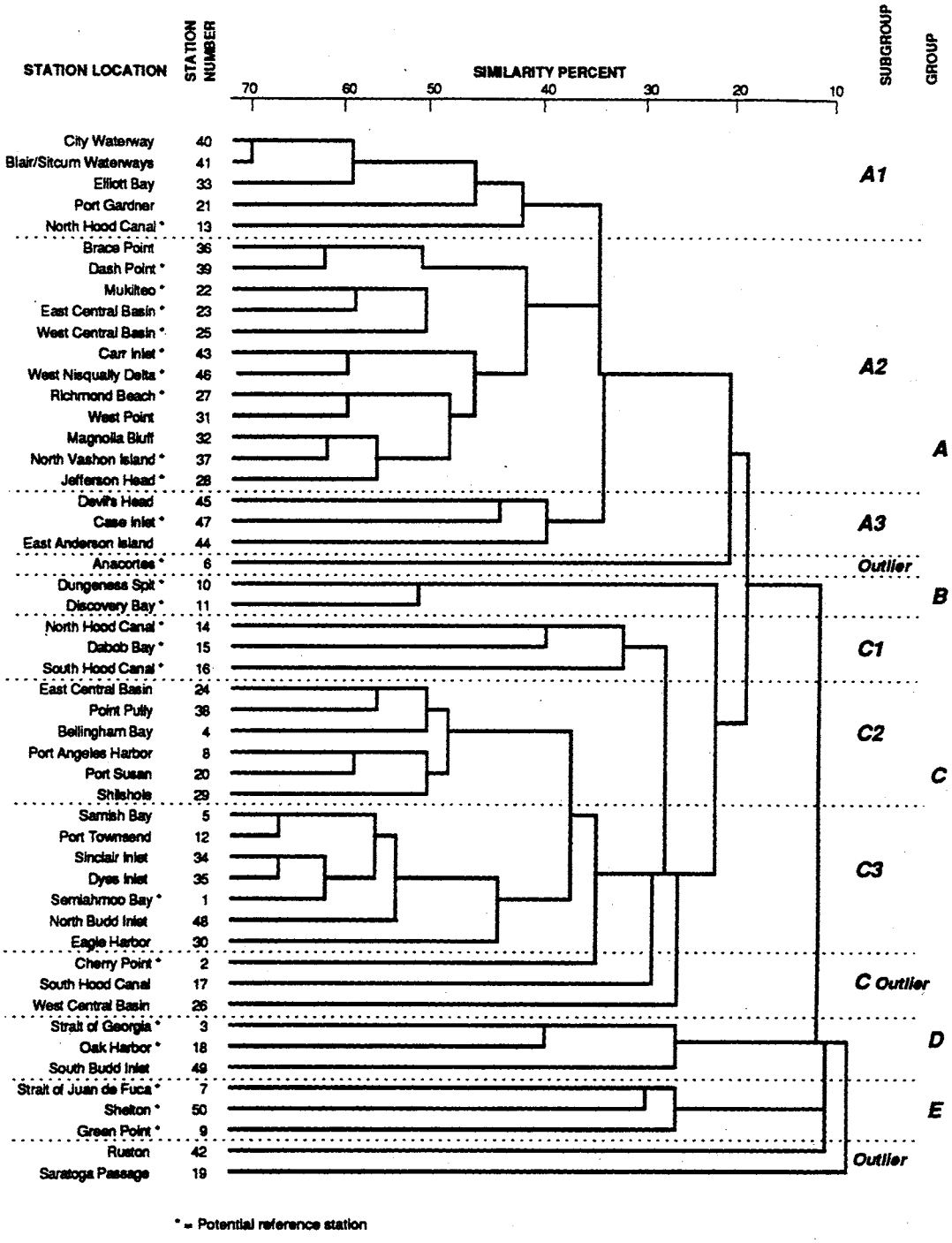


Figure 24. Dendrogram resulting from a Bray-Curtis classification analysis of arthropod species abundance data.

TABLE 32. CHARACTERISTICS OF STATION GROUPS DEFINED BY CLUSTER ANALYSIS OF ARTHROPOD TAXA

Cluster Group[a]	Stations in Group	Mean Water Depth (m)[b]	Mean Percent Fines[b]	Mean Percent TOC[b]	Mean Arthropod Abundance[b] (per 1.0 m^2)	Numerically Dominant Taxa	Mean Abundance[b] (per 1.0 m^2)	Frequency of Occurrence
A	13, 21, 22, 23, 25, 27, 28, 31, 32, 33, 36, 37, 39, 40, 41, 43, 44, 45, 46, 47	20.8 (8.1)	16.3 (21.7)	0.36 (0.34)	1,341 (663)	Euphilomedes carcharodonta Euphilomedes producta Rhepoxynius abronius Pinnixa spp.	811 (535) 92 (274) 71 (84) 53 (70)	20/20 9/20 11/20 17/20
A1	13, 21, 33, 40, 41	18.0 (4.6)	36.5 (29.8)	0.72 (0.40)	1,524 (861)	Euphilomedes carcharodonta Euphilomedes producta Pinnixa spp.	870 (522) 361 (190) 61 (38)	5/5 5/5 4/5
A2	22, 23, 25, 27, 28, 31, 32, 36, 37, 39, 43, 46	19.5 (2.4)	4.2 (2.6)	0.16 (0.09)	1,401 (576)	Euphilomedes carcharodonta Rhepoxynius abronius Byblis millsi	936 (524) 118 (79) 39 (33)	12/12 11/12 11/12
A3	44, 45, 46	31.0 (19.0)	31.2 (21.3)	0.56 (0.36)	783 (552)	Euphilomedes carcharodonta Pinnixa spp. Heterophoxux oculatus	214 (176) 56 (82) 43 (9)	3/3 3/3 3/3
B	10, 11	20.0 (0)	30.7 (9.2)	0.63 (0.02)	2,373 (1,947)	Heterophoxus oculatus Foxiphalus similis/cognatus	262 (42) 117 (16)	2/2 2/2
C	1, 4, 5, 8, 12, 14, 15, 16, 20, 24, 29, 30, 34, 35, 38, 48	56.1 (70.9)	71.5 (31.2)	1.64 (0.94)	921 (660)	Eudorella pacifica Heterophoxus oculatus Euphilomedes producta	346 (432) 128 (138) 98 (152)	14/16 16/16 13/16
C1	14, 15, 16	51.7 (54.8)	13.2 (12.6)	0.26 (0.09)	231 (114)	Euphilomedes producta Heterophoxus oculatus Westwoodilla caecula	74 (33) 27 (22) 16 (15)	3/3 3/3 3/3
C2	4, 8, 20, 24, 29, 38	104.3 (94.2)	86.1 (10.9)	2.05 (0.98)	690 (270)	Euphilomedes producta Heterophoxus oculatus Eudorella pacifica	207 (210) 194 (188) 93 (34)	6/6 6/6 6/6
C3	1, 5, 12, 30, 34, 35, 48	16.8 (5.1)	83.9 (13.8)	1.89 (0.44)	1,410 (675)	Eudorella pacifica Pinnixa spp. Heterophoxus oculatus	710 (433) 443 (814) 115 (91)	7/7 7/7 7/7
C Outliers	2	20.0	50.0	0.68	380	Eudorella pacifica	87	1/1
	17	78.5	92.5	1.50	100	Eudorella pacifica	67	1/1
	26	262.0	15.7	0.42	1,200	Euphilomedes producta	467	1/1

TABLE 32. (Continued)

Cluster Group[a]	Stations in Group	Mean Water Depth (m)[b]	Mean Percent Fines[b]	Mean Percent TOC[b]	Mean Arthropod Abundance (per 1.0 m^2)	Numerically Dominant Taxa	Mean Abundance (per 1.0 m^2)[b]	Frequency of Occurrence
D	3, 18, 49	81.3 (118.3)	60.3 (27.7)	1.61 (0.95)	144 (198)	Pinnixa spp.	126 (189)	3/3
E	7, 9, 50	53.7 (69.1)	3.7 (2.4)	0.20 (0.14)	1,521 (1,080)	Ampelisca spp. Photis brevipes	567 (846) 150 (202)	3/3 3/3
Outliers	6	20.0	7.1	0.25	99	Euphilomedes carcharodonta	15	1/1
	19	121.0	81.3	1.90	60	Paraphoxus oculatus	6	1/1
	42	39.0	3.2	0.09	153	Rhepoxynius daboius	18	1/1

[a] Cluster groups are shown in Figure 24.

[b] Values shown in parentheses are the standard deviation.

of chemical contamination. Very low abundances of amphipods were observed at these stations. Subgroup A2 consisted of Stations 22, 23, 25, 27, 28, 31, 32, 36, 37, 39, 43, and 46. All stations were located in shallow water with sandy sediments. In contrast to Subgroup A1, three amphipod taxa were numerically dominant at these stations. The composition of this subgroup was similar to that of total taxa Subgroups A1 and A6. Subgroup A2 was also similar to mollusc Subgroup C1 and polychaete Subgroup A1. Subgroup A3 is composed of Stations 44, 45, and 46 which were located in south Puget Sound. Station depths varied from shallow to mid-depth and grain size varied from sand to silty sand. This subgroup was most similar to mollusc Group D.

Stations 10 and 11 constituted Group B. These same stations constituted total taxa Subgroup A2. These stations were located in shallow protected areas that contained silty sand in the Strait of Juan de Fuca. Mean arthropod abundance was high relative to other arthropod station groups. Among the arthropods, the stations were dominated by amphipods.

Group C was composed of 19 stations that can be further divided into three subgroups and three station outliers. Subgroup C1 was composed of Stations 14, 15, and 16 which were located in Hood Canal. Station depth varied among stations, but the sediment at each station was sand. All three stations had low arthropod abundances. Subgroup C2 was composed of Stations 4, 8, 20, 24, 29, and 38, all of which were characterized by fine-grained sediment. Both shallow and deep stations were included in the group, indicating that grain size was more important than depth for determining the composition of arthropods. *Euphilomedes products*, *Eudorella pacifica*, and *Heterophoxus oculatus* were the dominant arthropods. Subgroup C3 was composed of Stations 1, 5, 12, 30, 34, 35, and 48, and was similar to total taxa Subgroup B2. The stations were located in shallow areas with high percentages of silt and total organic carbon. *E. pacifica*, *Pinnixa* spp., and *H. oculatus* were the dominant taxa among these stations. In addition to the three subgroups, Stations 2, 17, and 26 belong to Group C. Each was considered an outlier. Arthropod abundances were low at Stations 2 and 17. Abundance was high at Station 26, which was located at a water depth of 262 m

and contained only 15.7 percent silt plus clay. No other deep stations had such coarse-grained sediment.

Group D was composed of Stations 3, 18, and 49. Station depths ranged from very shallow to deep and grain size varied from silty sand to clayey silt. The stations grouped together because they all had very low arthropod abundances and very few taxa. *Pinnixa* spp. was present at all three stations.

Group E consisted of Stations 7, 9, and 50 and was similar to total taxa Group C. Stations 7 and 9 were located in exposed areas of the Strait of Juan de Fuca, while Station 50 was located in a protected area near Shelton. Although water depth ranged from very shallow to mid-depth, all stations had sandy sediments, low percent total organic carbon, many amphipod taxa, and high amphipod abundances. The amphipods *Ampelisca* spp. and *Photis brevipes* were the numerically dominant arthropods in this group.

Stations 6, 19, and 42 were outlier stations for the arthropod cluster analysis. All three stations had very low arthropod abundances. Stations 19 and 42 were also identified as outliers in the total taxa and mollusc cluster analyses, and Station 19 was identified as an outlier in the polychaete analysis.

Polychaete station groups corresponded closely with station groups identified using the total taxa list. The mollusc station groups resembled the total taxa station groups less so than do the polychaete groups. Of the major taxa groups, the arthropod station groups were the least similar to the total taxa station groups. Because the Bray-Curtis similarity index weights the most abundant taxa most heavily, similarity between total taxa and polychaete station groups is clearly a function of the numerical dominance of polychaetes throughout the MSMT data.

Summary--The following trends were evident from the Bray-Curtis classification analyses:

- Within the three major taxa groups and the total taxa analyses, there were clusters of shallow sandy stations, shallow silty stations, and deep silty stations.

- Most clusters were defined by one or more of the following variables: grain size, water depth, percent total organic carbon, geographic area, mean abundance, and dominant taxa.

- Stations 10 and 11 were similar, and Stations 7 and 9 were similar for total taxa, polychaete, and arthropod cluster groups but not for mollusc cluster groups. Benthic community structure evidently differed between protected and exposed areas of the Strait of Juan de Fuca.

- Stations 19 and 42 were outliers for total taxa, mollusc, and arthropod cluster groups. Station 19 was also an outlier for polychaete clusters. Station 19 (Saratoga Passage) had very low abundances of all taxa, and Station 42 (Ruston) was located in an area with sediments that contain slag.

- Based on all taxa at MSMT stations, there were four geographic areas with one or more unique benthic communities: Hood Canal, Strait of Juan de Fuca, Central Basin, and South Sound.

- Based on the composition of polychaetes at stations, there were three geographic areas with one or more unique benthic communities: Central Basin, Strait of Juan de Fuca, and Budd Inlet. Many of the polychaete cluster groups included stations from several geographic areas within Puget Sound. Polychaete assemblages did not appear to be affected by geographic location to the same extent as mollusc and arthropod assemblages.

- Based on the composition of molluscs at stations, there were three geographic areas with one or more unique benthic communities: Central Basin, South Sound, and Strait of Juan de Fuca.

- Based on the composition of arthropods at stations, there were three geographic areas with one or more unique benthic communities based on the composition of arthropods: Hood Canal, Strait of Juan de Fuca, and South Sound.

- Sediment grain size was strongly correlated with many of the station cluster groups and appeared to be considerably more important than water depth or geographic location in defining arthropod station groups.

Numerically Dominant Taxa--

The benthic analyses described earlier in this section relied upon specific attributes of benthic communities (e.g., abundance, diversity) or on species composition (e.g., classification analysis). Benthic community structure can also be analyzed by examining the taxa that are most successful at inhabiting an area, and thus dominate the benthic community. In this section, the numerically dominant taxa (i.e., the five most abundant taxa at each station) and the characteristics of the physical environment (i.e., grain size and water depth) at each MSMT station are discussed.

Eighty-seven taxa were numerically dominant at one or more MSMT stations. Forty-eight of these taxa (i.e., 55 percent) were numerically dominant at one station, while another 13 taxa (i.e., 15 percent) were numerically dominant at two stations. Ninety percent of the taxa were dominant at fewer than five stations. Natural variability in benthic communities, as well as the wide range of sediment grain sizes, water depths, and geographic areas sampled in the MSMT, probably accounted for the lack of many taxa that were dominant at many stations.

Taxa that were numerically dominant at more than five stations included polychaete, mollusc, and arthropod species. The ostracod *Euphilomedes carcharodonta* was dominant at 19 stations. These stations had less than 70 percent fines and water depths shallower than 53 m. The polychaete *Prionospio steenstrupi* was a dominant taxon at 14 stations that were located in shallow (i.e., <25 m) to deep (i.e., >180 m) areas with less than 50 percent fines. The mollusc *Axinopsida serricata* was a dominant taxon at 12 stations located shallower than 133 m and having both fine and coarse sediments. The 11 stations dominated by the cumacean *Eudorella pacifica* were located at all water depths and had more than 50 percent fines. Eleven stations were also dominated by the polychaete *Phyllochaetopterus prolifica*. These stations were located at less than 25 m water depth with sediment ranging from <10 percent fines to >90 percent fines. The nine stations with benthic communities that were numerically dominated by the mollusc *Psephidia lordi* were also located in shallow water with different sediment types. *Euphilomedes products* was a dominant at eight stations. Unlike its congener, *E. products* was a dominant taxon at stations with more than 10 percent fines and located at all water depths. The polychaete *Tharyx multifilis* was a numerically dominant taxon at seven stations as was the polychaete *Pectinaria californiensis*. The stations dominated by *T. multifilis* were shallow with sediment ranging from <10 to >90 percent fines. *P. californiensis* was a dominant at stations located at all water depths. These stations had more than 10 percent fines.

As additional data become available during successive years of the MSMT, the composition of numerically dominant taxa in Puget Sound benthic communities may change as a result of natural variability or other factors. Monitoring the numerically dominant taxa will provide a quick overview of the taxonomic similarity of benthic communities at stations over time.

The numerically dominant taxa discussed above also provide an indication of the abundant taxa one might expect at stations with certain physical characteristics. As this knowledge base increases with successive years of the MSMT program, it may become easier to identify degraded benthic communities by comparing numerically dominant taxa in those communities with

taxa that are known to be numerically dominant at non-degraded stations having similar physical characteristics.

Differences in Benthic Community Structure at Potential and Unsuitable Reference Stations--

In the following discussion, MSMT benthic data are examined to determine whether benthic community structure differs between potential and unsuitable reference stations. Although results of the approach that was used to identify potential MSMT reference stations are described in a subsequent section (see RESULTS, Identification of Potential Reference Stations), it is necessary to use those results in this evaluation. In general, potential reference stations were lacking chemical contamination, and nonreference stations were those MSMT stations that contained the highest concentrations of chemical contaminants. It is important to recognize that the contaminant concentrations at nonreference stations are substantially less than those in many Puget Sound urban embayments (see Tetra Tech, 1985, 1986a; Evans-Hamilton and D.R. Systems 1987; PTI and Tetra Tech 1988a, 1988b).

Variables describing benthic community structure were compared statistically between the 24 potential and 26 unsuitable reference stations to identify characteristics of benthic communities at reference and nonreference stations. Additionally, the distribution of nonreference stations was examined in the cluster groups that were defined using the Bray-Curtis classification analysis.

Descriptive Indices at Potential and Unsuitable Reference Stations--
Benthic variables at potential and unsuitable reference stations were compared to assess whether benthic communities at stations with higher chemical contaminants were altered relative to stations with minimal or no chemical contamination. Based on Student t-tests, the mean total abundance, mean number of taxa, and mean abundance of molluscs at all potential reference stations were significantly ($P<0.01$) different than the means of those variables at all nonreference stations. Mean total abundance at

potential reference stations was 4,283 individuals/1.0 m^2 and was 3,177 individuals/1.0 m^2 at nonreference stations. Richness was also depressed at nonreference stations (i.e., 57.4 taxa/0.1 m^2 at potential reference stations vs. 44.9 taxa/0.1 m^2 at nonreference stations). The mean abundance of molluscs followed this trend, with fewer individuals (i.e., 553 individuals/1.0 m^2) at nonreference stations than at potential reference stations (i.e., 874 individuals/1.0 m^2). Average values of other benthic variables (i.e., mean abundance of polychaetes, mean abundance of arthropods, diversity, SDI, and ITI) were not significantly ($P>0.01$) different between potential and unsuitable reference stations.

Although differences between some benthic variables were observed at potential and unsuitable reference stations, results suggest that sediment grain size is probably at least as important as chemical contaminant concentrations in structuring benthic communities. Percent fines, total organic carbon, and water depth were also tested using a Student's t-test between potential and unsuitable reference stations. Percent fines and total organic carbon content were both significantly ($P<0.0001$) different between station groups. Potential MSMT reference stations were located in coarse-grained sediment (mean = 17.8 percent fines) with low total organic carbon content (mean = 0.38 percent), while nonreference stations had fine-grained sediment (mean = 59.4 percent fines) with a higher organic carbon content (mean = 1.38 percent). Water depth was not significantly ($P<0.05$) different between station groups, although potential reference stations were located in shallower water than were nonreference stations (mean water depths of 17.8 and 59.4 m, respectively). These results are in agreement with results of correlations presented earlier, which showed that percent fines and total organic carbon were found to be negatively and most strongly correlated with abundance and number of taxa.

Potential effects of chemical contamination on benthic community structure were also investigated using a method that has been frequently employed in Puget Sound urban embayment studies. Each nonreference station was paired with a potential reference station using the method previously described (see METHODS, Data Management and Analysis, Benthic Community

Structure). Differences between benthic variables at those stations were statistically tested. Of those benthic variables tested, grain size and water depth were considered to be the most important factors, based on results presented earlier in this section.

Suitable reference stations could not be identified for 6 of 26 nonreference stations (i.e., Stations 17, 19, 24, 29, 38, and 45). With the exception of Station 45, these stations were located in relatively deep water (i.e., >75 m) and had fine-grained sediment (i.e., >80 percent fines). No potential reference stations were located in fine-grained sediment and relatively deep water. Station 45 was located at 53 m water depth and had 55 percent fines. The only potential reference stations with between 40 and 70 percent fines were located at 20 m water depth, which was considered too shallow for a valid comparison with Station 45.

Station pairs were tested statistically using a Student's t-test to determine whether there were differences in total abundance; number of taxa; abundance of polychaetes, molluscs, or arthropods; diversity; SDI; or ITI. Because some potential reference stations were used in more than one comparison, a significance level of 0.01 was used to reduce the probability of a Type I error to acceptable levels. Results are shown in Table 33.

No significant differences in benthic variables were observed in 11 of 20 station pairs. Differences in eight of the remaining nine pairs (i.e., pairs with the following nonreference stations: 4, 20, 21, 32, 33, 42, 44, and 49) could have resulted from many factors, including natural variability and chemical contamination. The comparison of Stations 8 and 18 provided useful information concerning the presumed effects of organic enrichment (i.e., enhanced number of taxa, diversity, SDI, and ITI).

Distribution of Unsuitable Reference Stations Within Cluster Groups--In this section, the distribution of unsuitable reference stations is examined in the cluster groups that were defined using the Bray-Curtis classification analysis. This evaluation, which complements the previous discussion on benthic indices, relies on the distribution of taxa among stations. If

TABLE 33. SIGNIFICANT DIFFERENCES (P<0.01) BETWEEN BENTHIC VARIABLES AT UNSUITABLE REFERENCE AND POTENTIAL REFERENCE STATIONS[a,b,c]

Station Pair	Status of Station[d]	Water Depth (m)	Percent Fines	Percent TOC	Benthic Variables (Total abundance; number of taxa; abundances of polychaetes, molluscs, arthropods; Shannon-Weiner diversity; SDI; ITI)
4	UR	24	93.3	2.00	Enhanced diversity
1	PR	22	93.3	1.50	
5	UR	20	95.7	1.82	--
1	PR	22	93.3	1.50	
8	UR	21	65.8	3.90	Enhanced number of taxa, diversity, SDI, ITI
18	PR	20	60.2	0.93	
12	UR	20	90.3	1.50	--
1	PR	22	93.3	1.50	
20	UR	10	94.1	1.00	Enhanced ITI
18	PR	20	60.2	0.93	
21	UR	20	52.2	1.30	Depressed ITI
18	PR	20	60.2	0.93	
26	UR	262	15.7	0.42	--
14	PR	115	27.6	0.35	
30	UR	13	56.0	1.40	--
18	PR	18	60.2	0.93	
31	UR	22	1.73	0.15	--
27	PR	20	3.2	0.12	
32	UR	20	7.2	0.16	Enhanced ITI
27	PR	20	3.2	0.12	
33	UR	20	24.0	0.64	Depressed SDI
47	PR	20	23.5	0.29	
34	UR	8	91.6	2.20	--
1	PR	22	93.3	1.50	
35	UR	13	78.9	2.30	--
1	PR	22	93.3	1.50	
36	UR	15	2.2	0.13	--
39	PR	14	1.7	0.09	
40	UR	10	15.6	0.70	--
47	PR	20	23.5	0.29	

TABLE 33. (Continued)

Station Pair	Status of Station[d]	Water Depth (m)	Percent Fines	Percent TOC	Benthic Variables (Total abundance; number of taxa; abundances of polychaetes, molluscs, arthropods; Shannon-Weiner diversity; SDI; ITI)
41	UR	20	81.1	0.80	--
18	PR	20	60.1	0.93	
42	UR	39	3.2	0.09	Depressed total abundance, depressed abundances of molluscs and arthropods
39	PR	14	1.7	0.09	
44	UR	20	14.7	0.42	Depressed arthropod abundance, enhanced SDI
43	PR	20	6.3	0.14	
48	UR	20	81.3	2.50	--
1	PR	22	93.3	1.50	
49	UR	6	88.1	2.70	Depressed arthropod abundance, depressed ITI
1	PR	22	93.3	1.50	

[a] Student's t-tests were used to test for significant differences.

[b] Unsuitable reference stations for which no appropriate potential reference station could be found included Stations 17, 19, 24, 29, 38, and 45.

[c] Enhanced = Value at the unsuitable reference station was significantly greater ($P \leq 0.01$) than at the potential reference station.
Depressed = Value at the unsuitable reference station was significantly less ($P \leq 0.01$) than at the potential reference station.

[d] UR = Unsuitable reference station; PR = Potential reference station.

cluster groups only contain unsuitable reference stations, it may suggest that chemical contaminants have affected the structure of the benthic communities at those stations in a similar manner. Alternatively, other sediment or unmeasured variables may have influenced the benthic community structure.

Nonreference stations did not consistently group together in any of the total taxa, polychaete, mollusc, or arthropod classification analyses (see Figures 20, 21, 22, and 23). The nonreference stations were generally spread among most station groups. In reviewing Figures 20-23, it appears that the nonreference stations grouped together most frequently in the total taxa cluster, followed by the polychaete and arthropod clusters. Nonreference stations grouped together least frequently in the mollusc cluster analysis.

In the MSMT data set, the distribution of nonreference stations among all station cluster groups suggests that physical variables, such as sediment grain size, are more important in regulating benthic community structure than are the relatively low concentrations of chemical contaminants that were observed at MSMT stations. If the MSMT survey design had included stations located in areas generally recognized as containing high concentrations of chemical contaminants (e.g., some urban embayments), this evaluation may have shown contaminant-related effects at the community level.

Comparison of Benthic Community Structure with Recent Historical Data--

Historic benthic infauna data for MSMT Stations 29 (Shilshole) and 38 (Point Pully) were reported by Lie (1968, 1974), Lie and Evans (1973), Word et al. (1984), and Nichols (1985, 1988). Station 29 is equivalent to Nichols' Station 2, and Station 38 is equivalent to Nichols' Station 4 (Nichols 1975) and Word et al.'s Station H-640. Stations 29 and 38 had silty sediments and were located at 195 m water depth in the Central Basin of Puget Sound (see Figure 1).

Station 29--Between 1963 and 1988, Nichols (1985, 1988) studied the abundances of four species that were found in this study to numerically

dominate the benthic community at MSMT Station 29 (see Table F-2 in Appendix F). Those four species included the molluscs *Macoma carlottensis* and *Axinopsida serricata*, and the polychaetes *Ampharete acutifrons* and *Pectinaria californiensis*. Nichols (1985) reported that total abundance of the four indicator taxa increased at Station 29 between 1963 and 1983. A regression analysis of abundance over time supported this conclusion [$r = 0.73$; slope significantly different ($P<0.05$) than zero]. Nichols (1988) also observed that there were frequent, large-scale changes in the relative abundances of these indicator taxa between 1978 and 1983. *P. californiensis* was rare or absent between 1978 and 1983 but increased between 1983 and 1985, and *M. carlottensis* and *A. acutifrons* alternated as the dominant taxa. Abundances of *A. serricata*, which had been low for a number of years, increased in 1982 and 1983 and then returned to previously low abundances by 1985.

In 1989, *M. carlottensis* was numerically dominant at Station 29, although its abundance was lower than abundances reported by Nichols for 1985 (32/0.1 m^2 grab and 80/0.1 m^2, respectively). Similarly, abundances of *P. californiensis* were lower in 1989 (25 individuals/0.1 m^2) than in 1985 (50 individuals/0.1m^2). Neither *A. acutifrons* nor *A. serricata* was abundant in 1989 (i.e., less than 3 individuals/0.1 m^2). The total abundance of the four indicator taxa was 63 individuals/0.1 m^2 in 1989, which is considerably lower than the approximately 180 individuals/0.1 m^2 found in 1985 [because tabulated quantitative data are lacking in Nichols (1985, 1988), abundances were estimated from plots of abundance vs. year in Nichols (1985, 1988)]. The decrease in abundances between 1989 and 1985 may reflect seasonal sampling differences: 1989 data were collected in March where 1985 data were collected twice yearly [seasons were not identified in Nichols (1985, 1988)]. However, examination of benthic data collected in January-March by Lie (1968, 1974) and Lie and Evans (1973) suggests that total abundances of benthic organisms in Puget Sound have followed a trend similar to that observed by Nichols (i.e., a long-term trend of increasing abundance). Additional data are needed to determine whether the decrease in abundance between 1985 and 1989 reflects a reversal in the long-term trend. These data will be provided in future MSMT surveys. No temporal trends were

observed for species richness at Station 29, indicating that numbers of taxa have been relatively constant since 1963.

Station 38--At the location of MSMT Station 38, benthic infauna data were collected in previous surveys by Nichols in 1969-1970 and by Word et al. (1984) in 1982-1983. Although Nichols' numerical data for Station 38 were not available for this study, Word et al. (1984) presented those data in the Seahurst baseline study. [Word et al. (1984) obtained Nichols' samples, re-sorted and re-identified the samples, and presented results of data analyses.] Historical and MSMT data for Station 38 are summarized in Table 34. To reduce the effects of seasonality on benthic community structure (see Tetra Tech 1987), only data from samples collected during February or March are included in Table 34.

Word et al. (1984) compared 1969-1970 winter data from Nichols to 1982-1983 winter data from the Seahurst baseline survey and reported the following trends:

- Polychaete abundance was greater in 1982-1983, primarily due to the abundance of *Spiophanes* spp. *P. californiensis* was numerically dominant in 1969-1970 but not in 1982-1983.

- Mollusc abundance was greater in 1982-1983, primarily due to the abundance of *A. serricata* (the numerically dominant taxon).

- *A. serricata* replaced *P. californiensis* as the dominant taxon during 1982-1983.

- Abundance of indicator taxa and total taxa increased from 1969-1970 to 1982-1983.

Based on the 1989 MSMT data, abundances of *P. californiensis*, which were low in 1982-83, have returned to the levels observed by Nichols in 1969-1970. Abundances of *M. carlottensis* are higher than those reported

TABLE 34. COMPARISON OF BENTHIC INFAUNA DATA AT STATION 38 WITH HISTORICAL DATA

	1969-1970[a]	1982-1983[b]	1989[c]
Total abundance[d]	50.3	89.0	128.0
Total richness[e]	21.0	26.0	26.3
Polychaete abundance	23.0	38.6	31.7
P. californiensis	12.0	2.0	11.3
A. acutifrons	0	5.0	0
Mollusc abundance	3.3	30.4	12.7
M. carlottensis	0.3	3.8	7.7
A. sericata	0	17.6	1.3
Arthropod abundance	16.7	17.0	79.0

[a] Samples collected by Dr. F. Nichols and processed and reported by Word et al. (1984).

[b] From Word et al. (1984), based on samples collected in February and March.

[c] From 1989 MSMT data.

[d] Abundance is reported as the mean number of individuals per 0.1 m^2.

[e] Richness is reported as the number of taxa per 0.1 m^2.

previously, and that species has replaced *A. serricata* as the dominant mollusc at Station 38. *A. serricata* abundances in 1989 were similar to abundances in 1969-1970. *A. acutifrons*, which was absent in 1969-1970 and dominant in 1982-1983, was absent again in 1989.

Total abundance of the four indicator taxa decreased from >28 individuals/0.1 m^2 in 1982-1983 to 20 individuals/0.1 m^2 in 1989. However, overall total abundance increased at MSMT Station 38 since 1982-1983. That increase is primarily due to the presence of arthropods, which were numerically dominant at this station in 1989.

Summary--Long-term benthic data at MSMT Stations 29 and 38 indicate an overall increase in the abundances of benthic invertebrates. A number of hypotheses have been proposed to explain this trend. Most recently, Nichols (1988) summarized these explanations in the form of the following two hypotheses:

- "Physical processes, such as water circulation and mixing that affect survival and recruitment of larvae and juveniles, have changed

- The waters of the Puget Sound basin have become more productive, and thus support higher abundances of benthic invertebrates."

Clearly, additional monitoring data is needed to test these hypotheses. Because species may undergo dramatic fluctuations in their abundances, reliance on intermittent sampling does not yield the data necessary to understand the reasons for increases in benthic abundance in the central basin of Puget Sound.

Lie (1974) found that benthic community structure at Stations 29 and 38 was similar in 1969. Although relative abundance at the stations was different, six of the seven dominant taxa were common to both stations. In 1989, the community structure at each station was very different (Table 35)

TABLE 35. ABUNDANCES OF DOMINANT TAXA AT MSMT STATIONS 29 AND 38 IN 1989

Station 29	Abundance[a]	Station 38	Abundance[a]
Macoma carlottensis	32.3	*Eudorellopsis integra*	23.3
Pectinaria californiensis	24.7	*Euphilomedes producta*	20.7
Euphilomedes producta	21.3	*Eudorella pacifica*	12.7
Eudorella pacifica	13.7	*Heterophoxus occulatus*	12.0
Paraphoxus occulatus	5.3	*Pectinaria californiensis*	11.3
Levinsenia gracilis	4.3	*Macoma carlottensis*	7.7
Ampharete acutifrons	3.7	*Protomedeia prudens*	6.7
		Levinsenia gracilis	3.0
Mean Abundance	154.7	Mean Abundance	128.0
Mean Richness	35.0	Mean Richness	26.3

[a] Mean number of individuals per 0.1 m^2.

and total abundance and richness were slightly higher at Station 29 than at Station 38. Although sediment contaminant concentrations at Stations 29 and 38 are not available for historical data sets, higher chemical concentrations were found in 1989 at Station 38 than at Station 29. It is possible that chemical contamination may have influenced total abundance at Station 38. However, other biotic and abiotic factors also may have resulted in the lower abundance at Station 38. Neither Station 29 nor Station 38 are potential MSMT reference stations. At Station 29, chemical concentrations did not exceed interim performance standards or Puget Sound maximum reference values. At Station 38, however, concentrations of lead and mercury exceeded interim performance standards (see RESULTS, Identification of Potential Reference Stations), and the concentration of zinc exceeded the Puget Sound maximum reference value.

Summary--

The design of the MSMT permitted an exhaustive examination of benthic community structure at 50 stations in Puget Sound. Because the majority of the stations were located in shallow areas (i.e., <25 m), it allowed for the investigation of variables that influence benthic communities in shallow water. However, because few stations were located at depths below 25 m, a thorough analysis of variables that affect communities at deep stations was not possible. The large distances between most stations made it difficult to identify location-specific factors (e.g., contaminant sources, salinity gradients) that could affect benthic community structure.

The composition of benthic communities at MSMT stations varied widely, and was primarily dependent on sediment grain size followed by water depth. The importance of water depth on benthic community structure was most evident when examining stations with similar grain size. Total organic carbon, which was strongly correlated ($r = 0.82$) with fines content, also influenced species composition. There were no statistically significant ($P<0.05$) differences in benthic communities among geographic areas of Puget Sound due to the wide range of physical environments that were sampled in each part of the sound. Using data from all MSMT stations, both total

abundance and number of taxa decreased as percent fines increased (r = -0.81 and -0.84, respectively).

Station 19 (Saratoga Passage) had an exceptionally depauperate benthic community. On average, this station contained only 21.7 taxa/0.1 m^2 and 467 individuals/1.0 m^2. In comparison, the mean number of taxa at all MSMT stations was 53.7 taxa/0.1 m^2 and the mean abundance was 4,664 individuals/1.0 m^2. Station 37 (north Vashon Island) contained the highest number of taxa (i.e., 98.7 taxa/0.1 m^2) and Station 41 (Blair/Sitcum Waterways) had the greatest abundance (i.e., 20,403 individuals/1.0 m^2).

Classification analysis was used to identify similar stations based on the composition of benthic infauna. This analysis provided the most useful information for identifying the variables that regulated benthic community structure. Classification analyses using all taxonomic groups and those using one taxonomic group (e.g., polychaetes, arthropods, or molluscs) revealed similar trends. In the analysis using total taxa, several groups of shallow sandy stations were identified. Each group was dominated by different taxa, and some groups contained stations from the same geographic area (e.g., stations in Hood Canal were grouped together, as were stations in the Strait of Juan de Fuca and stations off the southern end of Whidbey Basin). In that analysis, stations located in shallow silty areas were grouped separately from those located in deep silty areas.

In the classification analyses, several stations were identified as outliers. Station 19 (Saratoga Passage) was an outlier in each of the four analyses. Station 42 (Ruston) was an outlier in the total taxa, mollusc, and arthropod analyses. Stations 3 (Strait of Georgia), 7 (Strait of Juan de Fuca), and 38 (Point Pully) were outliers in the mollusc classification analysis. Finally, Station 6 (Anacortes) was an outlier in the arthropod analysis.

Eighty-seven taxa were numerically dominant (i.e., one of the five most abundant taxa) at one or more stations. Ninety percent of these taxa were dominant at fewer than five stations, which is a further indication of the

variety of benthic communities sampled in the MSMT. The ostracod *Euphilomedes carcharodonta* was a numerically dominant taxon at 19 stations, which were located at water depths less than 53 m, and had sediments with less than 70 percent fines. The second most frequent numerically dominant taxon, the polychaete *Prionospio steenstrupi*, was numerically dominant at 14 stations, which were located in shallow to deep water and had sediments with less than 50 percent fines. The analysis of dominant taxa in future MSMT surveys will provide a quick tool by which temporal trends can be evaluated.

Benthic community structure was compared between unsuitable reference stations and potential reference stations. Although potential reference stations had significantly ($P<0.05$) greater total abundance, mollusc abundance, and number of taxa, it is doubtful that the relatively low concentrations of chemical contaminants present at the nonreference stations affected the resident benthic community. Instead, sediment grain size, which was also significantly different between these two groups of stations, was probably the more important factor affecting benthic community structure.

Analysis of MSMT data at two stations with recent historical data (i.e., Stations 29 and 38) clearly supports Nichols' (1988) arguments regarding the importance of long-term monitoring data. Comparisons of benthic community structure between two years may suggest trends opposite of those indicated by long-term data due to the effects of natural variability in benthic community structure. For example, the abundance of benthic infauna at MSMT Station 29 decreased in 1989 relative to data collected in the early 1980's (Nichols 1988). However, total abundance at that station has shown an overall increase between 1963 and 1985. Additional monitoring is needed to determine whether the recent decrease reflects a reversal in the long-term trend.

IDENTIFICATION OF POTENTIAL REFERENCE STATIONS

In accordance with the approach described in Section 2 (see METHODS, Approach for Identifying Reference Stations), potential reference stations

were identified using the results of the sediment chemistry, sediment toxicity, and benthic infauna analyses at MSMT stations. Reference stations were identified to expand knowledge of reference conditions in Puget Sound, as well as to propose promising new reference areas for use in future environmental investigations (including future studies of reference areas). Potential reference stations were also identified to enable comparisons between those stations and the most contaminated MSMT stations. Existing information concerning the identification of reference areas [i.e., *Puget Sound Interim Performance Standards* (PTI 1989)] was not used to identify potential MSMT reference stations because that information was developed using data from stations with higher concentrations of chemical contaminants than those reported at most MSMT stations. Also, interim performance standards have only been developed for three organic compounds and nine metals.

Results of sediment bioassay tests showed that only 1 station (Station 35; Dyes Inlet) was definitely unsuitable as a reference station (see RESULTS, Sediment Toxicity Bioassays). Results of benthic community structure analyses were inconclusive in identifying any stations as unsuitable reference stations (see RESULTS, Benthic Community Structure). Thus, the identification of potential reference stations is essentially based on an evaluation of sediment chemistry data.

As described in Section 2, 90th percentile values were calculated using both undetected and detected values for each target chemical analyzed at the 50 MSMT stations. The 90th percentile values for each chemical are presented in Table 36. The 90th percentile values that were undetected values are identified, and the number of stations with detected values that exceeded the 90th percentile values are listed.

All chemicals that were detected at concentrations above 90th percentile values are summarized by station in Table 37. The total number of exceedances for each station are also shown. Those stations with 2 or fewer chemical variables with concentrations that exceeded 90th percentile values were initially identified as potential reference stations. (The 32 stations with ≤ 2 exceedances are marked with an asterisk in Table 37.) However, 8 of

TABLE 36. THE 90th PERCENTILE VALUES FOR TARGET CHEMICALS FOR THE 1989 MSMT

	90th Percentile Value[a]	90th Percentiles That Were Reported at the Quantitation Limit	Number of Stations With Detected Values Exceeding the 90th Percentile Value[a]
Metals			
Aluminum	20,780		5
Antimony	0.928		2
Arsenic	8.29		5
Barium	50.88		5
Beryllium	0.265	X	0
Cadmium	0.999		5
Calcium	8,666		5
Chromium	52.14		5
Cobalt	10.83		5
Copper	46.9		5
Iron	31,120		5
Lead	29.17		5
Magnesium	13,210		5
Manganese	523.7		5
Mercury	0.190		4
Nickel	45.93		5
Potassium	3,729		5
Selenium	1.35	X	0
Silver	0.424		5
Sodium	23,950		5
Thallium	0	X	1
Vanadium	59.68		5
Zinc	94.33		5
Semivolatile Organic Compounds			
Phenol	28.95		5
2-Methylphenol	0	X	0
4-Methylphenol	0	X	0
2,4-Dimethylphenol	26.4	X	0
2-Chlorophenol	0	X	0
2,4-Dichlorophenol	0	X	0
4-Chloro-3-methylphenol	0	X	0
2,4,6-Trichlorophenol	0	X	0
2,4,5-Trichlorophenol	0	X	0
Pentachlorophenol	0	X	0
2-Nitrophenol	0	X	0
4-Nitrophenol	0	X	0
2,4-Dinitrophenol	0	X	0
4,6-Dinitro-o-cresol	0	X	0
Naphthalene	15.95		5
Acenaphthylene	15.5	X	2
Acenaphthene	15.4	X	4
Fluorene	15.5	X	4
Phenanthrene	120		4
Anthracene	80.1		5
Fluoranthene	263		5
Pyrene	190		4
Benzo(a)anthracene	93.5		5
Chrysene	175		5
Benzo(b+k)fluoranthenes	265		5
Benzo(a)pyrene	116.4		5
Indeno(1,2,3-c,d)pyrene	91.8		5
Dibenzo(a,h)anthracene	33.5		5
Benzo(g,h,i)perylene	83.3		5
1,2-Dichlorobenzene	0	X	1
1,3-Dichlorobenzene	0	X	0

TABLE 36. (Continued)

	90th Percentile Value[a]	90th Percentiles That Were Reported at the Quantitation Limit	Number of Stations With Detected Values Exceeding the 90th Percentile Value[a]
Semivolatile Organic Compounds (Cont.)			
1,4-Dichlorobenzene	0	X	0
1,2,4-Trichlorobenzene	13.4	X	0
2-Chloronaphthalene	0	X	1
Hexachlorobenzene	0	X	1
Hexachloroethene	0	X	0
Hexachlorobutadiene	0	X	1
Hexachlorocyclopentadiene	0	X	0
Dimethyl phthalate	0	X	0
Diethyl phthalate	13.45	X	0
Di-n-butyl phthalate	15.4	X	2
Butylbenzyl phthalate	15.5	X	3
bis(2-Ethylhexyl)phthalate	118		5
Di-n-octyl phthalate	0	X	0
Isophorone	0	X	1
Benzyl alcohol	65	X	0
Benzoic acid	146.5	X	0
Dibenzofuran	9.3		5
beta-Coprostanol	552		5
N-Nitrosodiphenylamine	0	X	0
9(H)-Carbazole	15.5	X	3
beta-Sitosterol	2,570		5
4-Bromophenyl-phenylether	13.4	X	0
Caffeine	13.4	X	0
bis(2-Chloroethoxy)methane	13.5	X	0
bis(2-Chloroethyl)ether	13.5	X	0
bis(2-Chloroisopropyl)ether	13.5	X	0
Cholesterol	2,370		5
Cymene	14.4	X	0
2,4-Dinitrotoluene	65	X	0
2,6-Dinitrotoluene	65	X	0
2-Methylnaphthalene	15.4	X	2
N-Nitroso-di-n-propylamine	0	X	0
2-Nitroaniline	0	X	0
3-Nitroaniline	0	X	0
4-Nitroaniline	0	X	0
Nitrobenzene	0	X	0
Perylene	71.8		5
Retene	75.8		5
4-Chlorophenyl-phenylether	13.4	X	0
LPAH[b]	331		5
HPAH[c]	1,160		5
Pesticides/PCBs			
p,p'-DDD	0	X	0
p,p'-DDE	1.34	X	0
p,p'-DDT	0	X	0
Aldrin	0	X	0
alpha-BHC	0	X	0
beta-BHC	0	X	0
delta-BHC	0	X	0
gamma-BHC (Lindane)	0	X	0
alpha-Chlordane	0	X	1
gamma-Chlordane	0	X	0
Dieldrin	0	X	0

TABLE 36. (Continued)

	90th Percentile Value[a]	90th Percentiles That Were Reported at the Quantitation Limit	Number of Stations With Detected Values Exceeding the 90th Percentile Value[a]
Pesticides/PCBs (Cont.)			
Endosulfan I	0	X	0
Endosulfan II	0	X	0
Endosulfan sulfate	0	X	0
Endrin	0	X	0
Endrin ketone	0	X	0
Heptachlor	0	X	0
Heptachlor epoxide	0	X	0
Methoxychlor	0	X	0
Toxaphene	0	X	0
Aroclor 1016/1242	17.25	X	0
Aroclor 1248	17.25	X	0
Aroclor 1254	18		4
Aroclor 1260	17.25	X	0
Conventionals			
Total sulfides	0.893		5
Total organic carbon	2.19		5

[a] N=50 for all chemicals, except n=23 for antimony, n=29 for selenium, and n=36 for benzoic acid.

[b] LPAH = Sum of acenaphthene, acenaphthylene, anthracene, naphthalene, phenanthrene, and fluorene.

[c] HPAH = Sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, benzo(b+k)fluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-c,d)pyrene, and pyrene.

TABLE 37. CHEMICALS AT MSMT STATIONS THAT EXCEEDED MSMT 90TH PERCENTILE VALUES[a]

Station[b]	Total Number of Exceedances	Chemicals Exceeding 90th Percentile Values		
		Metals	Organics	Conventionals
*1 - Semiahmoo Bay	1		Cholesterol	
*2 - Cherry Point	1	Be		
*3 - Strait of Georgia	1	Ca		
4 - Bellingham Bay	6	Ba, Fe, Mg K, Na, Ni		
*5 - Samish Bay	0	Ca, Th		
*6 - Anacortes	2	Ca, Th		
*7 - Strait of Juan de Fuca	0			
8 - Port Angeles Harbor	12	Hg	Beta-sitosterol, benzo(a)anthracene, benzo(b+k)fluoranthenes, chrysene, dibenzofuran, fluoranthene, fluorene, isophorone, naphthalene, phenanthrene [LPAH and HPAH were also exceeded]	
*9 - Green Point	0			
*10 - Dungeness Spit	0			
*11 - Discovery Bay	2		Phenol	Sulfides
*12 - Port Townsend	2	Be	Bis(2-ethylhexyl)phthalate	
*13 - North Hood Canal	0			
*14 - North Hood Canal	0			
*15 - Dabob Bay	0			
*16 - South Hood Canal	0			
17 - South Hood Canal	11	Al, Ca, Cr, Co, Cu, Fe, Mg, Mn, Ni, V	Beta-sitosterol	
*18 - Oak Harbor	2	Cr, Ni		

TABLE 37. (Continued)

Station[b]	Total Number of Exceedances	Chemicals Exceeding 90th Percentile Values		
		Metals	Organics	Conventionals
19 - Saratoga Passage	11	As, Cr, Co, Fe, Mg, Mn, Na, Ni, K, V	Phenol	
20 - Port Susan	5	Co, Cr, Fe, Ni, Mg		
*21 - Port Gardner	2		Aroclor-1254, retene	
*22 - Mukilteo	0			
*23 - East Central Basin	0			
24 - East Central Basin	8	Al, Ba, Co, Fe, Mg, K, V, Zn		
*25 - West Central Basin	0			
*26 - West Central Basin	2		Anthracene, 9(H)-Carbazole	
*27 - Richmond Beach	0			
*28 - Jefferson Head	0			
29 - Shilshole	3	Ag, Ba		Sulfides
30 - Eagle Harbor	19	Cd	9(H)-Carbazole, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b+k)fluoranthenes, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, dibenzofuran, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, perylene, phenanthrene, pyrene [LPAH and HPAH were also exceeded]	
*31 - West Point	0			
*32 - Magnolia Bluff	0			

TABLE 37. (Continued)

Station[b]	Total Number of Exceedances	Chemicals Exceeding 90th Percentile Values		
		Metals	Organics	Conventionals
33 - Elliott Bay	20	Pb	Aroclor-1254, acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b+k)fluoranthene, benzo(g,h,i)perylene, chrysene, p,p'-DDD, dibenzo(a,h)anthracene, dibenzofuran, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, perylene, phenanthrene, phenol, pyrene [LPAH and HPAH were also exceeded]	
34 - Sinclair Inlet	20	Ag, As, Ba, Cd Cr, Cu Hg, Pb Sb, Zn	Aroclor-1254, beta-coprostanol, bis(2-ethylhexyl) phthalate, benzo(a)pyrene, butylbenzyl phthalate, cholesterol, dibenzo(a,h)anthracene, di-n-butyl phthalate, indeno(1,2,3-c,d)pyrene	TOC
35 - Dyes Inlet	25	Ag, As, Ca, Cd, Cu, Hg, Pb, Zn	2-methylnaphthalene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b+k)-fluoranthenes, benzo(g,h,i)perylene, bis(2-ethyl-hexyl)phthalate, butylbenzyl phthalate, chrysene, dibenzo(a,h)anthracene, di-n-butyl phthalate, fluoranthene, indeno(1,2,3-c,d)pyrene, perylene, pyrene [LPAH and HPAH were also exceeded]	TOC
*36 - Brace Point	1		Dibenzofuran	
*37 - North Vashon Island	1			Sulfides
38 - Point Pully	18	Ag, Al, As, Ba, Co, Cu, Hg, K, Mn, Na, Pb, V, Zn	Acenaphthylene, benzo(g,h,i)perylene, beta-coprostanol, naphthalene, perylene	
*39 - Dash Point	0			
40 - City Waterway	23		2-methylnaphthalene, 9(H)-carbazole, acenaphthene, acenaphthylene, anthracene, beta-coprostanol, bis(2-ethylhexyl)phthalate, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, butylbenzyl phthalate, chrysene, dibenzo(a,h)anthracene, dibenzofuran, benzo(b+k)fluoranthenes, indeno(1,2,3-c,d)pyrene, fluorene, fluoranthene, naphthalene, perylene, phenanthrene, pyrene, retene [LPAH and HPAH were also exceeded]	

TABLE 37. (Continued)

Station[b]	Total Number of Exceedances	Chemicals Exceeding 90th Percentile Values		
		Metals	Organics	Conventionals
41 - Blair/Sitcum Waterways	6		Beta-coprostanol, beta-sitosterol, bis(2-ethylhexyl)-phthalate, cholesterol, phenol, retene	
42 - Ruston	3	As, Mn, Sb		
*43 - Carr Inlet	0			
44 - East Anderson Island	4	Mn	2-Chloronaphthalene, hexachlorobenzene, hexachlorobutadiene	
*45 - Devil's Head	0			
*46 - West Nisqually Delta	0			
*47 - Case Inlet	1		Phenol	
48 - North Budd Inlet	14	Al, Ca, Cd, K, Na, Pb, V, Zn	Beta-coprostanol, beta-sitosterol, cholesterol, retene	TOC, sulfides
49 - South Budd Inlet	10	Ag, Al, Cd, Cu, Na	Aroclor-1254, beta-sitosterol, cholesterol, retene	TOC
*50 - Shelton	0			

[a] 90th percentile values are presented in Table 36.

[b] Stations with an "*" have $\leq$ 2 exceedances.

those 32 stations are unsuitable reference stations because they exhibited concentrations of chemicals for which only anthropogenic sources have been identified (see Table 3), as follows:

- Stations 5, 12, 26, 36, 45 - Bis(2-ethylhexyl)phthalate
- Station 21 - Aroclor-1254, chlorodehydroabietic, bis(2-ethylhexyl)phthalate
- Station 31 - Aroclor-1254
- Station 32 - Aroclor-1254, bis(2-ethylhexyl)phthalate.

The 24 potential reference stations for the 1989 MSMT are shown in Figure 25. It should be noted, however, that chemicals for which analyses were not conducted may be present in sediments. For example, the concentrations of many pesticides in Puget Sound sediments have not been evaluated, and pesticides may affect sediment toxicity or benthic community structure. Chlorinated guaiacols (which may be discharged from pulp mills) and certain volatile organic compounds may also affect biological variables.

Sediment characteristics at MSMT reference stations are shown in Table 38. These stations are located throughout Puget Sound at water depths ranging from 7 to 218 m, with sediments that contain 1.3-93.3 percent fines and 0.06-1.50 percent TOC. Because these stations occur over a large range of water depths and grain sizes, they provide a range of reference conditions for future investigations in Puget Sound.

COMPARISON OF MSMT DATA TO PROPOSED PUGET SOUND SEDIMENT QUALITY GUIDELINES

This section presents the results of comparisons between MSMT data and the following Puget Sound sediment quality guidelines:

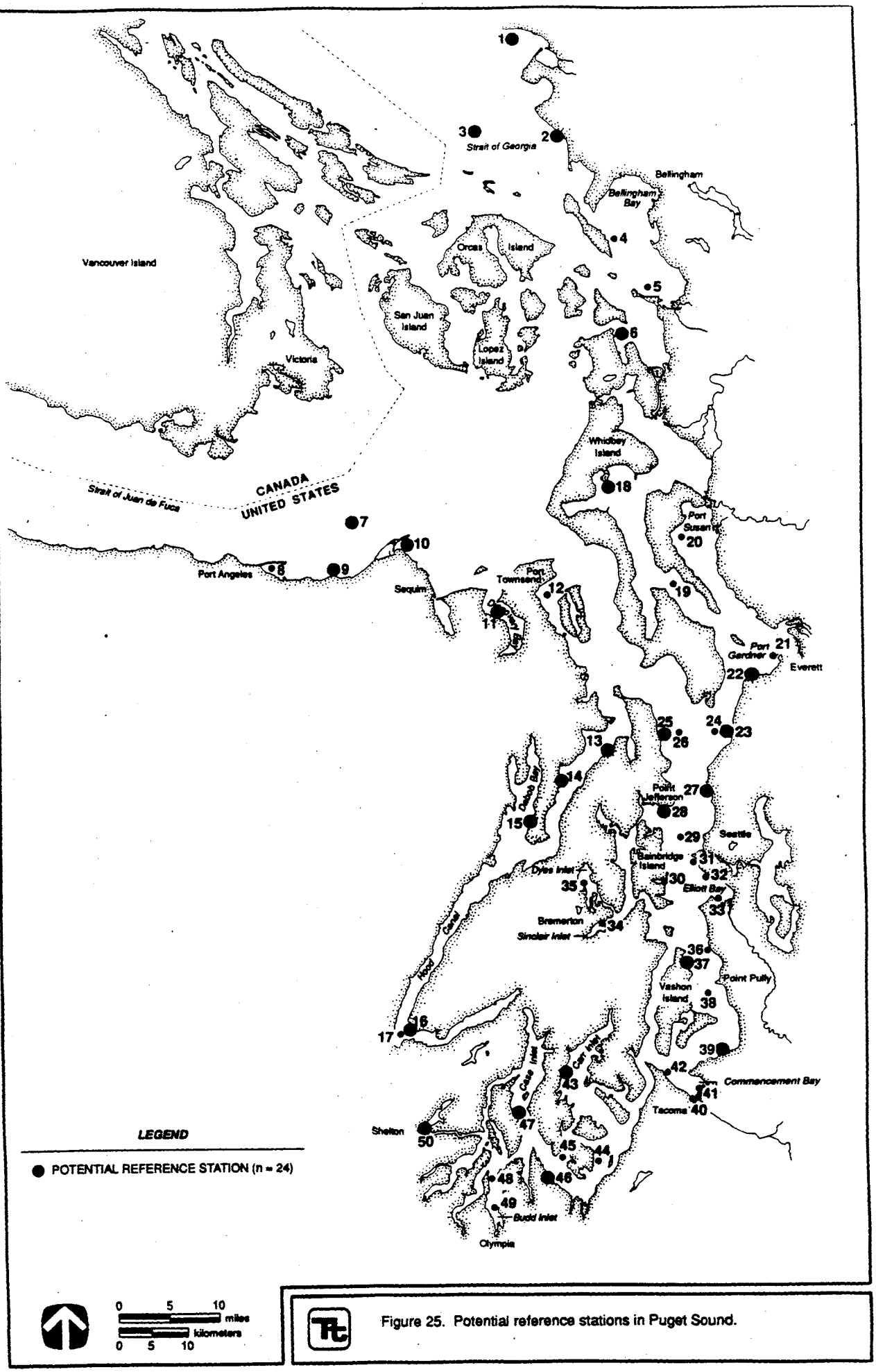


Figure 25. Potential reference stations in Puget Sound.

TABLE 38. SEDIMENT CHARACTERISTICS AT POTENTIAL MSMT REFERENCE STATIONS

Station	Depth (m)	Percent Fines	Percent TOC
1	22	93.3	1.50
2	20	50.0	0.68
3	218	32.7	1.20
6	20	7.0	0.25
7	133	6.1	0.33
9	21	1.3	0.06
10	20	37.2	0.61
11	20	24.2	0.64
13	20	9.7	0.18
14	115	27.6	0.35
15	20	8.2	0.24
16	20	3.9	0.18
18	20	60.2	0.93
22	20	4.2	0.15
23	20	2.1	0.12
25	20	1.8	0.07
27	20	3.2	0.12
28	20	4.9	0.15
37	20	5.9	0.21
39	14	1.7	0.09
43	20	6.3	0.14
46	22	9.5	0.42
47	20	23.5	0.29
50	7	3.8	0.20

- AET values (PTI 1988b)
- Ecology interim performance standards (PTI 1989)
- Puget Sound maximum sediment chemistry reference values (PTI and Tetra Tech 1988a).

Comparison with AET Values

AET values have currently been developed for 10 metals and 45 organic compounds, including total LPAH and HPAH (PTI 1988b). AET values represent concentrations above which harmful biological effects are always expected. If sediment concentrations of any one chemical at a station exceeds its corresponding AET value, it is reasonably certain that biological harm is occurring at that site. Thus, stations with sediment chemical concentrations that exceed LAET values are not suitable reference stations.

Concentrations of one metal and two organic compounds in sediments at four MSMT stations exceeded LAET values. Mercury concentrations at Stations 34 (E0.81 mg/kg DW; Sinclair Inlet) and 35 (E0.51 mg/kg DW; Dyes Inlet) exceeded the LAET value of 0.41 mg/kg DW. The phenol concentration at Station 19 (520 ug/kg DW; Saratoga Passage) exceeded the LAET value of 420 ug/kg DW, and the bis(2-ethylhexyl)phthalate concentration at Station 12 (8,300 ug/kg DW; Port Townsend) exceeded the LAET of 1,300 ug/kg DW. As shown in Figure 25, those stations were not identified as potential reference stations in the 1989 MSMT.

Comparison with Interim Performance Standards and Maximum Reference Values

In support of the 1987 and 1989 *Puget Sound Water Quality Management Plan* (PSWQA 1987, revised 1988), interim performance standards for subtidal sediments were recently developed to define reference conditions in Puget Sound (PTI 1989). Interim performance standards are proposed as the maximum values that may exist at a reference area. Performance standards have been established for amphipod bioassays and for 13 chemical variables:

3 organic compounds (i.e., LPAH, HPAH, PCBs), 9 metals, and total organic carbon (Table 14). (For reasons discussed in a subsequent section, the proposed interim performance standard for sulfides is not used in this discussion.) The interim performance standards represent the 90th percentile values for frequency distributions of chemical concentrations in potential reference areas. The 90th percentile values were calculated using only detected chemical concentrations from 21 surveys and 31 study areas in Puget Sound, excluding stations with more than one chemical that exceeded LAET values. Because available quantitative data are limited, only qualitative performance standards for benthic community structure have been described (PTI 1989). Interim performance standards were applied to MSMT data, and the adequacy of those standards in identifying reference areas is assessed below.

As discussed above, interim performance standards have been developed for certain chemicals only. Because standards have not been proposed for other chemicals that may degrade sediment quality (e.g., phenol, resin acids, pesticides), reference area conditions cannot be defined using only those standards. MSMT data for other chemicals were compared to Puget Sound maximum reference values to identify stations where chemical concentrations may be elevated (and thus unsuitable as reference stations). The ranges of chemical concentrations for Puget Sound reference areas were summarized in reports produced for the U.S. EPA PSEP by Tetra Tech (1988a; pp. 79-82) and PTI and Tetra Tech (1988a; pp. 74, 95-98). Those Puget Sound reference values were determined using data from 13 studies that were conducted in the following nine areas: Carr Inlet, Case Inlet, Dabob Bay, Hood Canal, Nisqually Delta, Port Madison, Port Susan, Samish Bay, and Sequim Bay. For those chemicals for which an interim performance standard has not been proposed, the Puget Sound maximum reference value for a chemical was compared with concentrations of the same chemical at MSMT stations.

The interim performance standards (PTI 1989) were determined using more surveys and study areas than were used to determine the Puget Sound reference values (PTI and Tetra Tech 1988a). However, chemical concentrations were elevated at several of the reference areas that were used by PTI

(1989). For example, although Dyes Inlet is not herein considered a suitable reference area, chemical concentrations from Dyes Inlet (which are elevated) were used to calculate the interim performance standards. This may be one factor that explains the fact that interim performance standards are generally higher than PTI and Tetra Tech (1988a) Puget Sound maximum reference values, and higher than mean reference values calculated using MSMT data (Table 14). Furthermore, data were accepted from stations which had up to one chemical that exceeded and LAET. PTI (1989) suggests that elevated chemical concentrations (from unsuitable reference areas) are excluded by using the 90th percentile values of chemical concentrations. A second factor is that only detected values were used in calculating the interim performance standards. If undetected values were used, the interim performance standards would be lower values. Thus, the interim performance standards cannot be used to identify pristine reference conditions in Puget Sound.

Sediment Chemistry--

Using only the proposed interim performance standards for chemical variables, 11 of 50 MSMT stations are unsuitable potential reference stations. Stations that are unsuitable as reference stations are Stations 8 (Port Angeles Harbor), 17 (south Hood Canal), 20 (Port Susan), 21 (Port Gardner), 30 (Eagle Harbor), 33 (Duwamish Head-Elliott Bay), 34 (Sinclair Inlet), 35 (Dyes Inlet), 38 (East Passage near Point Pully), 40 (City Waterway-Commencement Bay), and 49 (south Budd Inlet). The interim performance standards that were exceeded at each of these 11 non-reference stations are presented in Table 14. As shown in Figure 25, those stations were not identified as potential reference stations in the 1989 MSMT.

In the MSMT data (excluding chemicals for which interim performance standards exist), only three chemicals were reported at concentrations higher than PTI and Tetra Tech (1988a) Puget Sound maximum reference values. Puget Sound maximum reference values were exceeded for 2-methylnaphthalene and butylbenzyl phthalate at Station 40 (City Waterway), for butylbenzyl phthalate at Station 34 (Sinclair Inlet), and for phenol at Stations 19

(Saratoga Passage) and 41 (Blair/Sitcum Waterways) (see Table 14). Puget Sound maximum reference values for those chemicals are shown in Table 14. As shown in Figure 25, those stations were not identified as potential reference stations in the 1989 MSMT.

Sediment Toxicity--

The interim performance standard for the amphipod bioassay, which is based on studies by Mearns et al. (1986), requires that the mean mortality for a reference sample be less than 25 percent. Stations unsuitable as potential reference stations include Stations 20 (Port Susan), 24 (northeast Central Basin), and 35 (Dyes Inlet). An alternative standard could be defined by the 95 percent prediction limit for amphipod mortality derived from the model of DeWitt et al. (1988) for the relationship of amphipod mortality to grain size [the DeWitt et al. (1988) model is further described in RESULTS, Sediment Toxicity Bioassays]. On the basis of that alternative standard, the observed mortality at Stations 20 and 24 may have resulted from grain size effects rather than toxic chemical exposure. Therefore, all MSMT stations could be potential reference stations for sediment toxicity, except for Station 35.

Benthic Community Structure--

The qualitative performance standards that have been proposed for benthic communities in reference areas (PTI 1989; p. 63) are as follows:

- The taxonomic richness of benthic macroinvertebrates and the abundances of higher taxonomic groups should reflect seasonality and natural physical/chemical conditions in a reference area (e.g., grain size composition and salinity of sediments, water depth) and should not be obviously depressed as a result of chemical toxicity

- Normally abundant species that are known to be sensitive to chemical contaminants should be present

- Normally rare species that are known to become abundant only under chemically disturbed conditions should be rare or absent

- The abundance of normally rare species that control community structure through physical modification of the sediment (e.g., large tube-dwelling worms, geoducks, or sea pens) should be similar to those observed at the potentially impacted site.

Although PTI (1989) hypothesized that these qualitative standards would be appropriate, the standards were not tested using benthic data sets from potential reference areas (PTI 1989). Prior to the 1989 MSMT, most existing benthic data had been collected within urban embayments and the central basin of Puget Sound, and relatively few potential reference stations had been sampled. [Although benthic infaunal samples were collected in the 1988 reconnaissance survey in 13 Puget Sound locations (Battelle 1989), those samples were not analyzed.] MSMT benthic infauna data provide an opportunity to evaluate the appropriateness of those standards, and to direct the future development of reference area standards for benthic communities.

The first qualitative benthic infauna standard proposed by PTI (1989) concerns the effects of seasonality, abiotic factors (e.g., sediment grain size, total organic carbon), and chemical toxicity on benthic community structure. There is wide agreement that benthic community structure should be compared only within seasons; however, seasonality could not be evaluated within the MSMT because data were collected during the same season. MSMT data demonstrated that physical/chemical conditions control benthic community structure (see RESULTS, Benthic Community Structure). Therefore, reference area sediments should have the same physical/chemical conditions as stations that are compared to them. Finally, benthic community structure at reference stations must not be altered (i.e., significant change in total abundance, number of taxa, or composition of numerically dominant taxa) as a result of chemical toxicity or organic enrichment because the benthic community would not be representative of unimpacted conditions.

The second qualitative standard proposed that normally abundant species that are known to be sensitive to chemical contaminants should be present at reference stations. Generally, the identities of such species are currently unknown, and their identification would require an intensive evaluation of benthic data from contaminated and uncontaminated areas. Data generated by the MSMT would be appropriate as data from uncontaminated areas. As part of the MSMT, an attempt was made to assess whether species considered pollution sensitive could be used with this qualitative standard. Refereed journals and local Puget Sound documents were examined to identify pollution sensitive species that have been reported either in benthic literature or in local Puget Sound studies (Keeley, K., 6 June 1989, personal communication). As a result of that review, only four pollution sensitive species that live in Puget Sound were identified (Table F-3 in Appendix F): *Archaeomysis grebnitzkii, Grandifoxus grandis, Aphrodita aculeata,* and *Terebellides stroemi.* The abundance of the four sensitive species at each MSMT station was summed (see Table F-2 in Appendix F), and abundances were evaluated to identify whether sensitive species were only found at uncontaminated stations. These species were located at 9 of 24 (37.5 percent) potential MSMT reference stations and 14 of 26 (53.8 percent) of the unsuitable reference stations, with abundances ranging from 3 to 82 individuals/m^2. Stations with at least 40 individuals of sensitive species/m^2 included Stations 8 (Port Angeles Harbor), 20 (Port Susan), 34 (Sinclair Inlet), and 35 (Dyes Inlet). These stations were unsuitable as reference stations because elevated contaminant concentrations were found in sediments at each station. Additionally, sediment toxicity (as measured by amphipod mortality) was found at Station 35 (Dyes Inlet). The MSMT data showed that the greatest abundances of sensitive species occurred at chemically contaminated or toxic stations; therefore, these four species were inappropriate for testing this qualitative standard. Based on this examination, additional research is necessary to expand the list of pollution sensitive species in Puget Sound and to identify those that are normally abundant in areas lacking chemical contamination.

The third qualitative standard proposed that normally rare species that are known to become abundant only under chemically disturbed conditions should be rare or absent at reference stations. For this report, pollution tolerant species (as reported in the literature) were used to evaluate this standard because a list of Puget Sound species that are normally rare in areas lacking chemical contamination and only abundant under chemically disturbed conditions was not available. Pollution tolerant species are capable of existing in polluted areas, but may or may not be present in areas lacking chemical contamination. Pollution tolerant taxa that have been reported in benthic literature and are found in Puget Sound were identified (Table F-3 in Appendix F), and their abundances were summed for each MSMT station (Table F-2 in Appendix F). Species that have been characterized as being pollution tolerant were present at all 50 MSMT stations. These species accounted for between 1.2 percent [i.e., Station 1 (Semiahmoo Bay)] and 67.2 percent [i.e., Station 30 (Eagle Harbor)] of the total abundance at all stations. Of the 69,962 organisms collected during the 1989 MSMT, 24.8 percent were pollution tolerant species.

Abundances of pollution tolerant species at 26 nonreference stations were compared with abundances at 24 potential reference stations. At those 26 non-reference stations, pollution tolerant taxa accounted for a mean of 25.2 percent (standard deviation = 17.4 percent) of the total abundance. Although the 24 potential reference stations contained fewer pollution tolerant species (mean = 19.8 percent, standard deviation = 14.1 percent), the difference between abundances of pollution tolerant species at reference and non-reference stations was not statistically significant ($P \geq 0.05$).

Because pollution tolerant species were widely distributed at MSMT stations, the abundance of these species (as listed in Table F-3 of Appendix F) was not used to select reference areas.

The final recommendation proposed by PTI (1989) for selecting reference areas concerned the presence of organisms that may regulate benthic community structure through physical modification of the sediment. Although several large infauna species were present at MSMT stations (i.e., *Pachycerianthus*

fimbriatus, *Echiurus* spp., *Molpadia intermedia*, *Brisaster latifrons*, *Stylatula elongata*), relationships between the presence of these species and the abundances of other taxa were not evident. If large infauna are abundant at an impacted study area, it would be most suitable to choose a reference area that had similar abundances of large infauna.

Although qualitative standards for benthic community structure were proposed in PTI (1989) to define reference area conditions, these standards were not useful in defining which of the 50 MSMT stations were appropriate reference stations. Adequate information is not available on pollution sensitive species that occur in Puget Sound, and MSMT data analyses indicate that standards based on the abundance of currently-recognized pollution tolerant species or the occurrence of large organisms are not useful. A more detailed analysis of MSMT benthic community structure data with PSEP urban bay studies [e.g., Elliott Bay (PTI and Tetra Tech 1988a), Everett Harbor (PTI and Tetra Tech 1988b)] may yield more appropriate guidelines or criteria for identifying reference areas.

Summary

Application of AET values and the proposed interim performance standards (PTI 1989) for chemical variables and for bioassays (the alternative Dewitt et al. 1989 standard was used) to MSMT data, and comparison of MSMT data with Puget Sound maximum reference values (PTI and Tetra Tech 1988a), indicated that 36 of 50 stations could be potential reference stations (Figure 26). Four of those stations had chemical concentrations that exceeded LAET, 11 stations had chemical concentrations and sediment toxicity that exceeded IPS, and 4 stations had chemical concentrations that exceeded Puget Sound maximum reference values. Some stations [e.g., Station 34 (Sinclair Inlet)] exceeded more than one sediment quality guideline. Of the 14 stations that would be unsuitable reference stations (per LAET, IPS, and Puget Sound maximum reference guidelines), each station was identified as an unsuitable reference station using the MSMT approach (see section above).

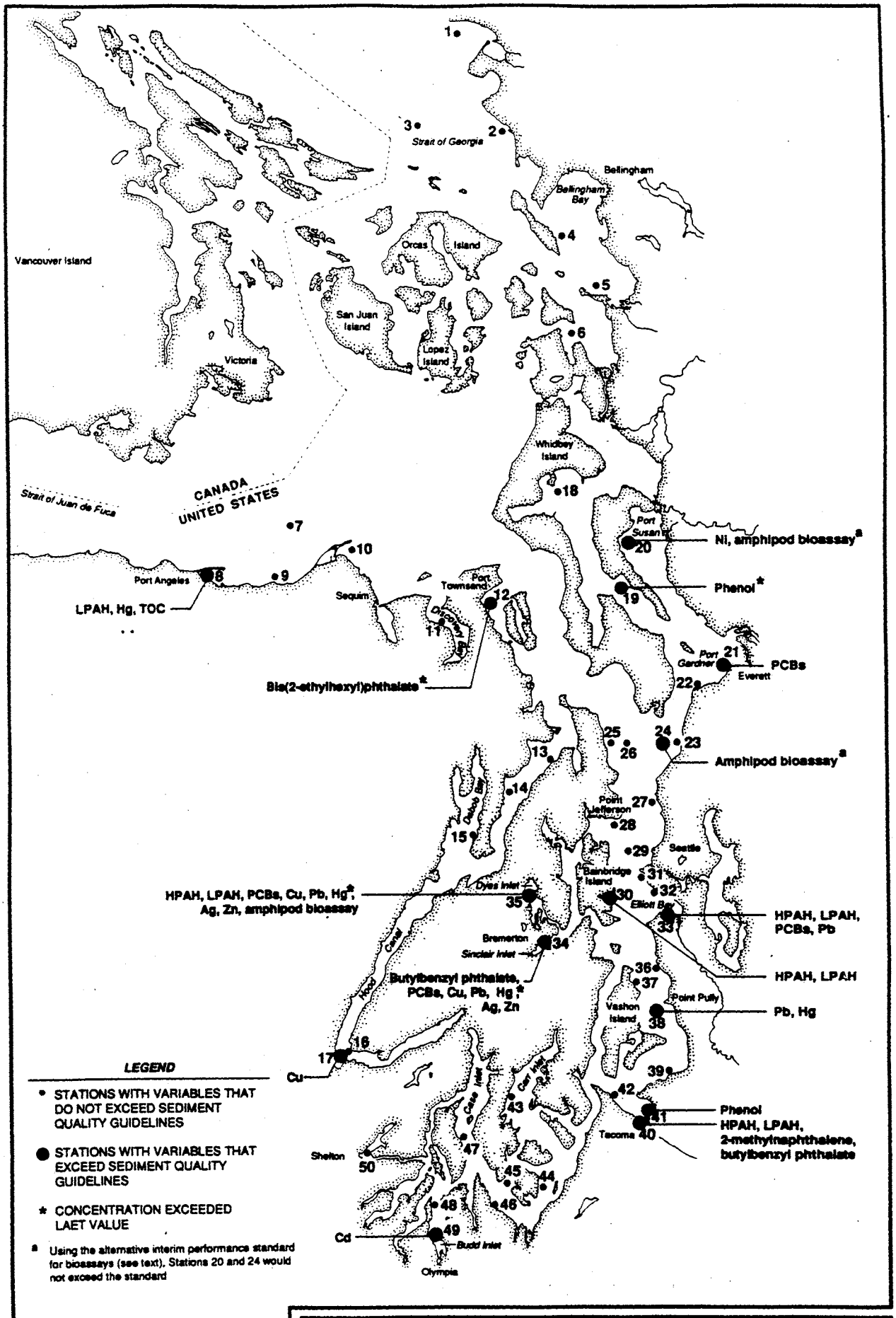


Figure 26. Stations with variables that exceed LAET values, Ecology's interim performance standards for reference areas, or selected Puget Sound maximum reference values.

4.0 SUMMARY AND DISCUSSION

The 1989 MSMT met program objectives (Striplin 1988; see INTRODUCTION) through the implementation of a successful field effort, and the generation and interpretation of a high quality sediment chemistry, toxicity, and benthic community data set. As data of similar quality are generated during successive years of the MSMT, we will achieve an increased understanding of sediment quality trends in Puget Sound. In this section, results of the first year of the MSMT are discussed relative to MSMT program objectives.

GENERATION OF BASELINE INFORMATION

Baseline information on chemical concentrations, toxicity, and benthic communities in the sediments of Puget Sound has been provided for 50 MSMT stations. Because rigorous collection, analytical, and QA/QC procedures were followed, data from those stations allow for quantitative comparisons among stations to identify temporal and spatial trends in sediment quality. The baseline conditions described herein provide a common frame of reference for comparisons with existing historical data, and will be available for comparisons with future investigations to evaluate changes in sediment quality. The value and usefulness of this baseline information will become increasingly important as our knowledge of temporal trends in sediment quality are enhanced with data from future MSMT surveys. Furthermore, approximately one half of the MSMT stations were located in previously unsampled areas, and first-time information for those areas increases our understanding of the diverse environments in Puget Sound.

Sediment grain size characteristics at stations are shown in Figure 2. The range of sediment types found during the study included sands (26 stations), silty sands (5 stations), sandy silts (6 stations), clayey silts (10 stations), silty clays (2 stations), and sand-silt-clays (1 station). Percent fine-grained material in Puget Sound sediments are shown in Figure 3,

and the relationship of percent fines vs. water depth at stations is shown in Figure 4. Although trends are not readily apparent from Figures 3 and 4, sediments at shallow stations (e.g., 6-15 m water depth) were sands or sandy silts (6 of 9 stations), whereas sediments at 20-m stations were generally sands (19 of 30 stations) or clayey silts (5 of 30 stations). Sediment compositions varied at the 11 stations deeper than 20 m, and included silty clays, clayey silts, sandy silts, silty sands, and sands.

MSMT sediment chemistry data represent a significant advancement in our understanding of sediment chemical concentrations in Puget Sound. By requiring U.S. EPA CLP protocols for metal and organic chemical analyses and data validation, and by working closely with the analytical laboratories, the quantitation limits obtained for the MSMT generally met or were less than the lowest previously reported for Puget Sound sediments (particularly for volatile organic compound analyses). These low detection limits increased the accuracy of data obtained from non-urban areas of Puget Sound, where sources of chemical contaminants are generally lacking, and allowed for better estimates of background chemical concentrations in Puget Sound. Sediment contaminant concentrations in both urban and non-urban areas are baseline data that can be used in comparisons with data from other geographic areas and with future data collected at the same locations to determine temporal changes. Also, sediment chemistry data from the 1989 MSMT has provided information on concentrations of numerous chemicals [see Table 2 (e.g., beta-coprostanol, retene) that have not previously been analyzed at a large number of stations in Puget Sound. Mean values, frequency of detections, range of values, and mean quantitation limits were reported for sediment conventionals and metals data using all MSMT data (see Tables 5-11) and for organic compounds (see Table 16). Mean sediment conventional, metals, and organic compounds data were also compared to *Puget Sound Environmental Atlas* (Evans-Hamilton and D.R. Systems 1987) data.

Using 1989 MSMT data, a unique approach was developed to identify stations with enriched or depressed concentrations of sediment metal concentrations. That approach provided a different measure of baseline metal concentrations in Puget Sound sediments than has been previously

reported. After showing that metal concentrations increased as percent fines (i.e., percent silt plus clay) increased, a linear regression analysis permitted the estimation of the contribution of individual metals by the various sediment grain size fractions. Metal enrichments and depressions were determined relative to the mean Puget Sound relationship between metal concentrations and sediment grain size. This approach has allowed the identification of areas that exhibit relative enrichments of metals as a function of sediment grain size. For certain applications, the mean Puget Sound relationship may be useful as an estimate of baseline sediment concentrations.

Most sediments sampled in the MSMT lacked significant sediment toxicity. The occurrence of significant toxicity (using the amphipod Rhepoxynius abronius bioassay test) was only observed in sediments from Dyes Inlet, where elevated concentrations of sediment metal and PAH were also found. Sediment toxicity data at MSMT stations can be used as baseline data to assess changes in sediment toxicity over time.

Results of benthic community structure analyses were used to identify and describe a variety of different benthic communities throughout Puget Sound, reflecting the wide range of habitats sampled. Benthic community data provides baseline information for the evaluation of temporal trends in the composition of those communities.

IDENTIFICATION OF REFERENCE AREAS

One objective of the 1989 MSMT was to develop a method to identify reference areas for comparison with MSMT stations containing elevated concentrations of chemical contaminants, as well as for comparison with data generated by future investigators. Existing information concerning the identification of reference areas [i.e., *Puget Sound Interim Performance Standards* (PTI 1989)] was not used to identify potential MSMT reference stations because that information was developed using data from stations with higher concentrations of chemical contaminants than those reported at most MSMT stations. By working within the MSMT data set, a set of reference

stations was identified using 90th percentile values of the frequency distribution of chemical concentrations. That approach allowed for the calculation of conservative reference values. These stations were termed potential reference stations, as investigators will need to determine the appropriateness of the application of these stations on a case-by-case basis. Results of sediment toxicity and benthic community structure analyses were also evaluated.

Potential reference stations were located in all areas of Puget Sound, from Station 1 (Semiahmoo Bay) to Station 50 (Shelton) (see Figure 25). The majority of potential reference stations were located in shallow sandy areas. Sediment characteristics at potential MSMT reference stations are shown in Table 38. Station 1 was the only shallow potential reference station having silty sediment (i.e., >61 percent fines). No deep stations with silty sediments were identified as potential reference stations. Although potential reference Stations 3 (Strait of Georgia), 7 (Strait of Juan de Fuca), and 14 (north Hood Canal) were located at water depths exceeding 100 m, sediments at these stations had less than 35 percent fines. The presence of chemical contamination at all deep stations with fine-grained sediments in the Central Basin of Puget Sound indicates that contaminants attached to fine particulates settle out of the water column throughout this basin. Chemicals at MSMT stations that exceeded MSMT 90th percentile values are shown in Tables 36 and 37.

MSMT data were compared to LAET values, Ecology's interim performance standards (PTI 1989), and Puget Sound maximum reference values (PTI and Tetra Tech 1988a). Stations with variables that exceeded those sediment quality guidelines were located in Port Angeles Harbor, Port Townsend, south Hood Canal, Port Susan, Saratoga Passage, Port Gardner, east Central Basin, Dyes Inlet, Sinclair Inlet, Eagle Harbor, Elliott Bay, Point Pully, Commencement Bay, and Budd Inlet (see Figure 26). Each of those stations had been identified as unsuitable reference stations using the aforementioned MSMT approach.

GENERATION OF DATA FOR USE BY RESEARCHERS

Another objective of the MSMT was to provide data for use by researchers concerned with sediment quality. Based on results of a thorough QA/QC review, all data are of the highest quality and are well-suited for quantitative analyses. All collection and analytical methods used for the MSMT, and all data generated for the 1989 MSMT (including QA memoranda and station positions) are available in this report and appendices. The data will also be available in electronic format from the Ambient Monitoring Section of the Washington Department of Ecology.

IDENTIFICATION OF AREAS WITH TOXIC CONTAMINANTS

The major emphasis of this report was to describe trends in sediment quality at MSMT stations, which are generally located away from sources of contaminants. Sediment contaminant concentrations at many stations were attributed to anthropogenic sources including municipal and industrial discharges and urban runoff. The sources of contamination at some stations [e.g., Station 8 (Port Angeles Harbor), 12 (Port Townsend), 21 (Port Gardner), 30 (Eagle Harbor), 33 (Elliott Bay), 40 (City Waterway), 41 (Blair/Sitcum Waterways), and 48 and 49 (Budd Inlet)] were clearly related to the proximity of those stations to known sources. Deep stations in the Central Basin had the greatest concentrations of volatile organic compounds, suggesting the influence of municipal and industrial discharges throughout the basin (see Figure 10).

Identification of potential contaminant sources for other stations was not as straightforward. For example, Station 19 (Saratoga Passage) had a high phenol concentration and chlorinated solvents were found at moderate concentrations, but contaminant sources were not easily identifiable. Benthic community structure at Station 19 was also substantially different, having the lowest number of taxa and lowest total abundance. At Station 3 (Strait of Georgia), concentrations of fecal sterols and volatile organic compounds suggested the influence of municipal effluent.

Concentrations of one metal and two organic compounds in sediments at four MSMT stations exceeded LAET values. Mercury concentrations at stations in Sinclair Inlet and Dyes Inlet exceeded the LAET value. The phenol concentration in Saratoga Passage (Station 19) and the bis(2-ethylhexyl)-phthalate concentration near Port Townsend (Station 12) exceeded the LAET values for those compounds. No other chemical concentrations exceeded LAET values.

The distribution of beta-coprostanol provided a good indication of areas affected by municipal effluent (see Figure 17). Areas with the greatest beta-coprostanol concentrations (i.e., >400 ug/kg DW) included outer Bellingham Bay, Port Angeles Harbor, Sinclair Inlet, East Passage off Point Pully, Commencement Bay, and Budd Inlet. Other areas with substantial concentrations (i.e., 301-400 ug/kg DW) included Port Gardner, off Shilshole, Eagle Harbor, Dyes Inlet, and East Passage at Brace Point. Stations lacking measurable concentrations of beta-coprostanol included stations in the Strait of Georgia, Dungeness Spit, north and south Hood Canal, Case Inlet, Carr Inlet, and Oak Harbor.

Resin acids and guaiacols were analyzed at stations near Lummi Island in Bellingham Bay, Port Angeles Harbor, and Port Gardner. Chlorinated guaiacols were found at each station. An anomalously high value of bis(2-ethylhexyl)phthalate was found in sediments near Port Townsend. The organochlorine pesticides were detected only at Station 33 near Duwamish Head in Elliott Bay. DDD and alpha-chlordane were detected at low concentrations. This low frequency of detections is not surprising because few of the organochlorine pesticides analyzed in the 1989 MSMT are manufactured or used by the agricultural industry (Tetra Tech 1988b).

The only PCB detected at MSMT stations was Aroclor 1254. Aroclor 1254 was detected in 28 percent of the samples. Highest Aroclor 1254 concentrations were found at stations in Sinclair Inlet, Duwamish Head-Elliott Bay, and Everett Harbor, but at concentrations considerably lower than those reported for the same areas in the *Puget Sound Environmental Atlas* (Evans-Hamilton and D.R. Systems 1987).

In several cases, the measured chemicals were ones not associated with anthropogenic inputs. For example, the metals aluminum, calcium, cobalt, copper, iron, magnesium, and vanadium, and some alkyl-substituted benzenes were measured at elevated concentrations (relative to most of the remaining MSMT data) in southern Hood Canal (i.e., Stations 16 and 17). The presence of those metals was attributed to regional geochemistry and the proximity of those stations to the Skokomish River. The Great Bend area of Hood Canal has also been identified as a reducing environment. Under low oxygen and high hydrogen sulfide conditions, certain metals may precipitate from the water column to sediments. Natural diagenetic processes may have formed the alkyl-substituted benzenes.

Significant sediment toxicity was observed only at Station 35 (Dyes Inlet). Sediments at this station had elevated concentrations of several metals and PAH but those concentrations were not substantially different than concentrations at some other MSMT stations, including Station 34 (Sinclair Inlet). Although mercury concentrations at Stations 34 (i.e., 0.86 mg/kg DW) and 35 (i.e., 0.51 ug/kg DW) exceeded an LAET value, the amphipod toxicity bioassay AET value (i.e., 2.1 ug/kg DW) was not exceeded at those stations.

Benthic community structure at MSMT stations did not appear to be influenced by the chemical contaminants found at the stations. As noted above, the benthic community at Station 19 was depauperate, perhaps in response to concentrations of phenol and volatile organic compounds. However, other unmeasured variables may also have affected benthic community structure at this station. Total abundance at Station 41 (Blair/Sitcum Waterways) was exceedingly high (i.e., 20,403 individuals/1.0 m^2). Although organic enrichment can lead to increased abundances, total organic carbon content was not substantially elevated (i.e., 0.80 percent) at this station in comparison with other MSMT stations. Chemical contaminants at Station 41 did not exhibit particularly high concentrations.

Variables describing benthic community structure were compared at potential and unsuitable reference stations. Although total abundance, number of taxa, and abundance of molluscs were significantly ($P<0.05$) depressed at nonreference stations, sediment grain size was probably responsible for the depressions. Sediments at nonreference stations had significantly greater ($P<0.05$) percentages of fines than did sediments at potential reference stations, and percent fines was negatively correlated with total abundance and number of taxa.

IDENTIFICATION OF FACTORS INFLUENCING SEDIMENT TOXICITY AND BENTHIC COMMUNITY STRUCTURE

As noted above, significant sediment toxicity was observed only at Station 35 (Dyes Inlet). Factors responsible for the observed toxicity were not identified. Concentrations of metals at Station 35 were similar to those at Station 34 (Sinclair Inlet). Although PAH concentrations at Station 35 were higher than at Station 34, they were considerably less than at some other stations that lacked toxic sediments. Sediment toxicity at Station 35 is probably influenced by a combination of measured and unmeasured chemical variables.

The primary factor influencing benthic community structure was sediment grain size. Percent fines were highly correlated with total abundance and number of taxa. Although total organic carbon also correlated with percent fines, the correlation coefficients were lower. Across all MSMT stations, water depth had little impact on benthic community structure because sediments with high and low percent fines were found in both shallow and deep water. However, within one grain size class (i.e., silt), benthic variables at shallow stations differed from those at deeper stations.

Classification analyses confirmed the relative importance of sediment grain size and water depth in the structuring of benthic communities (see Tables 28-32 and Figures 21-24). Stations located in shallow sandy areas grouped together as did stations from shallow silty areas. Benthic communities at deep silty stations were considerably more similar to one

another than to shallow silty stations, demonstrating that water depth is an important variable when sediment grain size is held constant.

IDENTIFICATION OF CHANGES IN SEDIMENT QUALITY

The 1989 MSMT identified spatial variation in sediment quality throughout many parts of Puget Sound. In general, the health of Puget Sound is good based on sediment chemistry, bioassays, and benthic communities at most stations sampled. Variations in sediment quality were related to regional geochemistries (i.e., rivers) and anthropogenic inputs (e.g., municipal and industrial effluents, urban runoff). In future years of the MSMT, factors influencing both spatial and temporal changes in sediment quality will be investigated.

Long-term monitoring at many MSMT stations will allow for the observation of changes influenced by the continued discharge of municipal and industrial wastes and urban runoff. Reductions in waste loads may also be reflected in improvements in sediment quality. The continued investigation of sediment quality at many stations will indicate whether there are natural temporal trends in sediment contaminant concentrations and sediment toxicity, and will supplement the long-term data on benthic community structure in the Central Basin collected by Nichols (1985, 1988).

5.0 RECOMMENDATIONS FOR FUTURE SEDIMENT MONITORING PROGRAMS

Recommendations for future sediment monitoring programs are discussed below, including the selection of proposed fixed, rotating, and new stations. Recommendations are proposed for the sediment chemistry, sediment toxicity, and benthic infauna phases of the program. In all cases, it will be important that collection and analytical methods are comparable to those of the 1989 MSMT. Final decisions concerning locations of future monitoring stations will be determined by Ecology and the Puget Sound Ambient Monitoring Program Steering and Management Committees.

STATION LOCATIONS

Future monitoring events will occur at fixed stations to be sampled each year, and at rotating stations to be sampled on an alternating schedule. Some stations sampled in the 1989 MSMT may be dropped, and new stations will be identified. Results of sediment analyses at the new stations will determine whether they will be fixed or rotating. Because a primary objective of the MSMT is to perform long-term monitoring of sediment quality in Puget Sound, most of the 1989 MSMT stations should remain fixed for the duration of the ambient sediment monitoring task. Annual sampling of these fixed stations will allow identification of temporal changes in sediment quality within Puget Sound. The proposed locations of fixed, rotating, and new stations are shown in Figure 27.

Fixed Stations

Thirty-one fixed stations are recommended:

- Stations 5, 26, 32, 38, and 44 - Sediments at these five stations were measured for analytical and field variabilities in 1989. Four sediment samples from each station were

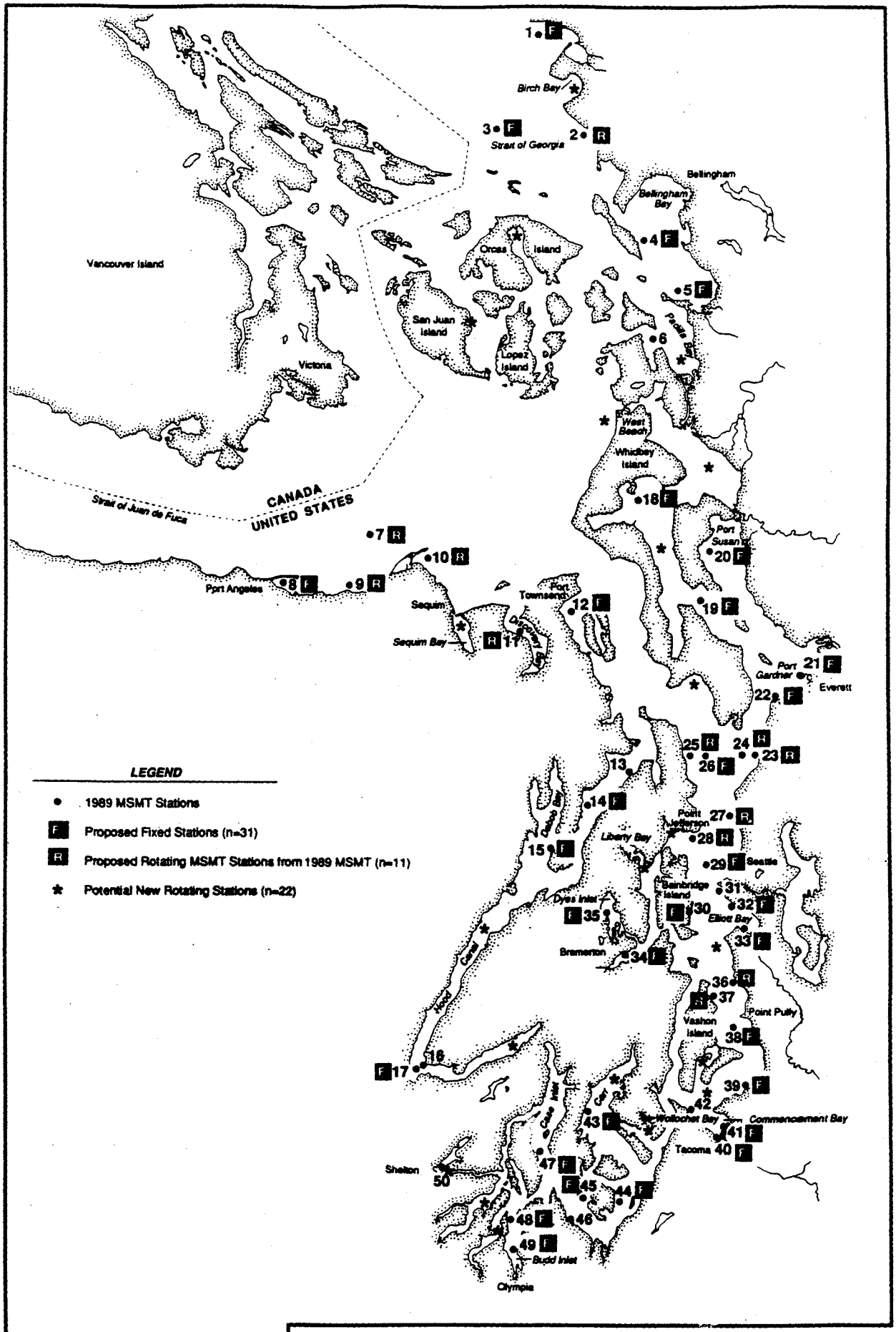


Figure 27. Recommendations for future MSMT station locations.

analyzed for all conventional variables, metals, and organic compounds. Four sediment samples from Station 38 were also analyzed for volatile organic compounds. Variability should continue to be measured at these stations, allowing differences between and among stations to be tested and temporal trends in sediment quality in Puget Sound to be identified. In addition, historical benthic data (see RESULTS, Benthic Community Structure) are available for Station 38, which was located in a depositional area that appears to be accumulating contaminants.

- Stations 30, 33, 34, 35, and 49 - Sediment contamination was identified at these stations in 1989 (see RESULTS). Cleanup or action programs have been implemented in each of these urban embayments (i.e., Eagle Harbor, Elliott Bay, Sinclair Inlet, Dyes Inlet, Budd Inlet). Continued sampling will provide data by which to monitor sediment quality changes from those programs.

- Stations 4, 8, and 21 - Resin acid analyses were conducted at these stations, and chlorinated guaiacols were found at each station.

- Station 1 - Station 1 is the only potential reference station at shallow depth with sediments containing >62 percent fines. Metals in sediments were not enhanced. LPAH concentrations were 175 ug/kg and HPAH concentrations were 480 ug/kg.

- Station 3 - Anomalous values for beta-coprostanol and volatile organic compounds were found at this station. The presence of those chemicals suggests that sediments in that area may be impacted by anthropogenic sources, although possible anthropogenic sources to that area are not obvious.

- Station 12 - The high concentration of bis(2-ethylhexyl)-phthalate (8,300 ug/kg) suggests that future monitoring should occur at this station. Because phthalate esters are used in some pulp processes, sediments should also be analyzed for resin acids/guaiacols.

- Station 14 - Station 14 is a potential mid-depth reference station with low fines content in Hood Canal. Percent fines content at Station 14 was higher than percent fines at nearby Station 13, which is recommended to be dropped. Volatile organic compounds should be analyzed again at Station 14 to monitor temporal changes in sediment concentrations.

- Station 15 - Station 15 was a shallow, sandy station located in Dabob Bay, a potential reference area. Metals were not enhanced at Station 15, and low PAH concentrations were found in sediments (41 ug/kg LPAH and 99 ug/kg HPAH). The benthic population was diverse, indicating a healthy community.

- Station 17 - Several metal concentrations (e.g., cobalt, copper, iron, vanadium) were elevated at Station 17. However, their concentrations were not correlated with organic contaminants that are associated with anthropogenic sources, which suggests a natural source of metals at Station 17. Volatile organic compounds were analyzed at Station 17 and should be analyzed in future years. Resin acids should also be analyzed at this station to gain an understanding of natural contributions from wood products.

- Station 18 - Station 18 is a potential reference station in shallow waters, with sediments that contained about 60 percent fines. Metals were only slightly enhanced at this station, and PAH concentrations were not elevated (60 ug/kg LPAH and 87 ug/kg HPAH).

- Station 19 - Anomalous chemistry values and benthic community structure were found at Station 19. The phenol concentration at Station 19 was not correlated with other contaminant organic compounds, and thus cannot be associated with identifiable anthropogenic activities. The significance of phenol at Station 19 is unknown, and its presence requires verification. Volatiles should be analyzed again at Station 19. The benthic community at Station 19 was depauperate, and total abundance and number of taxa were lower than at any other station.

- Station 20 - Extensive historical sediment chemistry, sediment toxicity, and benthic infaunal data are available for Station 20.

- Station 22 - Sediments at this potential reference station were sandy, and the station was located in shallow water. Metals were not enhanced, and PAH concentrations were not elevated (64 LPAH ug/kg and 214 HPAH ug/kg).

- Station 29 - Historical benthic infaunal data are available for Station 29 (see RESULTS, Benthic Community Structure). Volatiles should be analyzed again at Station 29.

- Station 39 - Although Station 39 is a potential reference station, a new wastewater treatment plant will soon begin discharging via an outfall located in this vicinity.

- Station 40 - Contaminated sediments were identified at Station 40 in the 1989 MSMT. Results of continued sampling at this station can be used to monitor the effects of remedial actions (e.g., institutional controls) that are being implemented in City Waterway. The mouth of City Waterway is the only problem area in the Commencement Bay Nearshore/Tide-

flats Superfund site that is predicted to recover without active remediation (i.e., dredging or capping).

- Station 41 - The phenol concentration at Station 41 was elevated above the Puget Sound maximum reference value (PTI and Tetra Tech 1988a). The presence of phenol and beta-coprostanol at this station suggests that effluent from the nearby Tacoma wastewater treatment plant may be impacting this area. The benthic community was strongly dominated by two pollution tolerant species: the mollusc *Axinopsida serricata* and the polychaete *Tharyx multifilis*.

- Station 45 - The water depth at Station 45 was 53 m, and sediments were sandy silts (55 percent fines). Few MSMT stations at this depth had 55 percent fines. Very low concentrations of volatile organic compounds were found at this station, and monitoring of volatiles should continue here.

- Stations 43 and 47 - At Station 43, PAH were not detected and metal concentrations were not enhanced. At Station 47, metal concentrations were not enhanced, LPAH were not detected, and HPAH were detected at low concentrations. Both stations are potential reference stations.

- Station 49 - Certain metals appeared slightly elevated at this station, and the concentration of beta-coprostanol was elevated (which suggests anthropogenic inputs at this station).

Rotating and New Stations

Thirty rotating stations will be identified by the MMC for the MSMT. Ten stations will be located in North Sound, ten stations in Central Sound, and ten stations in South Sound (Striplin 1988). Eleven of the 50 MSMT

stations sampled in 1989 and 22 new stations are herein recommended for rotating stations, as follows:

North Sound (13 stations)--

- Station 2 - Sediments at Station 2 appeared to be only slightly impacted by PAH. Concentrations of LPAH exceeded the Puget Sound maximum reference value (PTI and Tetra Tech 1988a), but did not exceed the interim performance standard (PTI 1989a). Station 2 is a potential reference station.

- Stations 7, 9, and 10 - Metals were only slightly enhanced at these stations, and PAH concentrations were undetected or low. All stations had <50 percent fines. The benthic communities at Stations 7 and 9 are indicative of exposed sites in the Strait of Juan de Fuca. Station 10 is a protected site in the Strait of Juan de Fuca. All stations are potential reference stations.

- Station 11 - Sandy sediments at this shallow station were not contaminated and the station is a potential reference station.

- Mouth of the Skagit River - Enhanced metal concentrations were identified in the Whidbey Basin, and metals data from near the mouth of the river may assist in assessing the natural input of metals from the Skagit River.

- Between Stations 18 and 19 - Enhanced metal concentrations were found in the Whidbey Basin, and anomalous chemical concentrations (e.g., volatile organic compounds, phenol) were found at Station 19. Data from an additional station in Saratoga Passage may help explain those data.

- West Beach - Because organisms used in the amphipod bioassay toxicity test are collected at West Beach, it is recommended that chemical monitoring occur at this station.

- Other potential stations - Birch Bay, Padilla Bay, and Sequim Bay. Stations could also be sampled in the San Juan Islands in Friday Harbor on San Juan Island and East Sound on Orcas Island.

Central Sound (11 stations)--

- Stations 23, 24, 25, 27, and 28 - Stations 23, 25, 27, and 28 are potential reference stations. Contaminated sediments were not identified at these stations, except for Station 24. At Station 24, concentrations of HPAH exceeded the Puget Sound maximum reference value (PTI and Tetra Tech 1988a), but did not exceed the interim performance standard, and concentrations of zinc were similar to concentrations found in urban embayments. A new station is proposed to be located west of Station 28 in Port Madison. That new station would be positioned at the precise location sampled by Nichols (1985).

- Alki Point - Historical benthic infaunal data are available for this station (Nichols 1985). Effluents discharged from the West Point, Renton Treatment Plant (Duwamish Head), and Alki Point outfalls may impact this area.

- Hood Canal/Belfair - In lieu of sampling Stations 13 and 16, it is recommended that new stations be positioned east of Station 17 towards Belfair, and between Stations 17 and 15 in mid-Hood Canal.

- Other potential stations--Useless Bay and Liberty Bay, which may have silty sediments.

South Sound (10 stations)--

- Stations 36, and 37 - These Central Basin shallow stations had sandy sediments, and metals and organic compounds were not elevated. Station 37 is a potential reference station and Station 36 is not.

- South Vashon Island - A station located in the depositional area south of Maury Island and east of the southern tip of Vashon Island may assist in determining the impacts of contaminants from the Central Basin and Commencement Bay on the area between Vashon Island and the Tacoma Narrows. Station CBVIII-H540, which is located in this area, was sampled during the Phase I depositional analysis of the Puget Sound Dredged Disposal Analysis (Striplin et al. 1986). According to that study, silty sediments occur in that area.

- Shelton - Major NPDES-permitted discharges occur in Oakland Bay, and a lumber mill is located in Shelton. Because chemicals were not elevated in the sandy sediments that were found at Station 50, it is recommended that a new station be located in this area in silty sediments.

- Other potential sites - Yukon Harbor, Quartermaster Harbor, Eld and Totten Inlets, north Carr Inlet, and Wollochet Bay may have silty sediments and could be potential reference stations.

Results of sediment analyses at new stations will determine whether new stations become rotating or fixed stations. In successive MSMT surveys, an attempt should be made to sample new stations with silty sediments. In 1989, only two potential reference station (Stations 1 and 18) had sediments with >60 percent fines.

Dropped Stations

The following seven stations are recommended to be dropped from the MSMT:

- Station 6 - This station was located at a shallow depth in an erosional environment (7 percent fines) with high current speeds. The accumulation of contaminants in such environments is less likely than in depositional environments. Because contaminants were not elevated at this station, future sampling is not recommended. An alternative station located in a depositional area (e.g., Padilla Bay) is proposed.

- Stations 13 and 16 - Contaminant concentrations were not elevated at these stations. Because Stations 13 and 16 are located in an erosional environment (sediments were very sandy), contaminants are less likely to accumulate there. Other stations in Hood Canal (i.e., Stations 14, 15, and 17) are proposed as rotating stations.

- Station 31 - This Central Basin shallow station had sandy sediments, and metals and organic compounds were not elevated. Sampling should be conducted in depositional rather than erosional areas in the Central Sound.

- Station 42 - Although arsenic and lead enhancements were identified in sediments at this station, the slag component of the sediments makes this station an unsuitable station for continued monitoring. Because conditions are not expected to change and monitoring will occur as part of the Asarco cleanup effort, it is not recommended to continue monitoring here.

- Station 46 - This shallow, sandy station had very low metals and PAH concentrations (39 ug/kg LPAH and 63 ug/kg HPAH).

Because Station 46 is located in an erosional environment where chemical contaminants would not normally accumulate, it is recommended that this station not be monitored in the future.

- Station 50 - Sediment chemistry values at this station were very low, and sediments were sandy. Because major NPDES-permitted discharges occur in Shelton, it is recommended that this station be repositioned (see above).

SEDIMENT CHEMISTRY

In general, the target variables for the 1989 MSMT (see Table 2) should be analyzed in future years, with the exceptions noted below.

As was the case in 1989, resin acids and guaiacols should be analyzed at Stations 4, 8, and 21. Future analyses for these compounds should be conducted on sediments at Station 12, which is located near a pulp mill in Port Townsend. Resin acids should also be analyzed at Station 17. Although anthropogenic sources of resin acids are not located near Station 17, sediments contained a high concentration of retene, which indicates a natural input of forest and coniferous plant debris. Analyses of resin acids at Station 17 could provide information on background concentrations of resin acids (from forest inputs) in Puget Sound sediments. Analytical detection limits for resin acids and guaiacols should not exceed 70 ug/kg.

Organochlorine pesticides (see Table 2) were included in the 1989 MSMT, but pesticides were detected at only one station (Station 33). Those pesticides should not be included as analytes in future years, unless new MSMT stations are located directly near the mouths of rivers that receive runoff from agricultural lands. However, contemporary pesticides that are currently used in the Puget Sound basin should be included as analytes for the same areas (e.g., Whidbey Basin, Samish Bay) in future MSMT surveys. Contemporary pesticides which occur in the Puget Sound basin (and for which analytical methods currently exist) are listed below:

- Organophosphate pesticides - Chlorpyrifos, diazinon, parathion, phorate, disulfoton, methyl parathion, azinphos-methyl

- Chlorinated pesticides and herbicides - Trifluralin, dichlobenil, lindane, dicamba, 2,4-D

- Carbamates and urea pesticides - Tebuthiuron, diuron, pronamide

- Miscellaneous pesticides - Fenvalerate, benfluralin, prometon, simazine.

Analyses for volatile organic compounds should occur at 10 stations each year of the MSMT.

In addition to analyses of marine sediments in Puget Sound, Sequim Bay reference material samples were analyzed for all variables in the 1989 MSMT. It is necessary to continue analyses of these reference material samples in future years to assess the variability associated with different analytical or laboratory procedures. The Sequim Bay reference material sediments should be acquired and maintained by Ecology.

In consideration of recent work performed by Di Toro et al. (1989), useful data may result from the analysis of acid volatile sulfides at selected stations. Normalization to acid volatile sulfides content (on a molar basis) enables cadmium toxicity to be predicted. Di Toro et al. (1989) postulate similar relationships for nickel, zinc, lead, copper, and mercury. Because acid volatile sulfide forms when sediments are not totally oxidized, it is recommended that such analyses be conducted only at stations where total organic carbon content is $\geq$0.5 percent.

SEDIMENT TOXICITY BIOASSAYS

Future monitoring events should include sediment toxicity testing using the amphipod *Rhepoxynius abronius* bioassay. The Microtox bioassay is not

recommended because toxic effects were not observed at any MSMT station in 1989, even where amphipod bioassay results indicated that toxics were present. It is recommended that the saline extract Microtox test be replaced by either the organic extract Microtox test, or by another sediment bioassay (e.g., bivalve or echinoderm larvae test, *Neanthes* sp. test), to identify potential toxic effects in Puget Sound sediments.

BENTHIC COMMUNITY STRUCTURE

Results of the 1989 MSMT indicate that three benthic replicates per station may not accurately characterize benthic community structure. Statistical analysis revealed that within-station variability (using three replicates) was high, which limits the ability to discern significant differences among stations for the 1989 MSMT and may also limit the ability to identify temporal trends in future programs. If the remaining two replicates (i.e., replicates 2 and 4) for the stations sampled in 1989 are analyzed, the ability to detect spatial and temporal trends in benthic community structure in Puget Sound would be improved. In future programs, five replicates per station should be analyzed.

Because pollution tolerant species were widely distributed at MSMT stations, the abundance of these species (as listed in Table F-3 of Appendix F) is not recommended as a standard for use in selecting reference areas. In future studies, it might be more appropriate to identify a subset of those species that respond more predictably to chemical contamination in Puget Sound sediments. Additionally, existing information on pollution sensitive species in Puget Sound is very limited. Research on the identification of pollution sensitive species may allow for better interpretation of the effects of chemical contamination on benthic community structure.

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